Report No. FHWA-NJ-2007-001

Safety Audit of Fatalities and Injuries Involving Guide Rail

Final Report
December 2006

Submitted by

H. Clay Gabler, Ph.D.
Douglas J. Gabauer

Virginia Tech
Department of Mechanical Engineering
Blacksburg, VA

NJDOT Research Project Manager
W. Lad Szalaj

In cooperation with

New Jersey
Department of Transportation
Bureau of Research
And
U. S. Department of Transportation
Federal Highway Administration

DISCLAIMER STATEMENT

Technical Report Documentation Page

1. Report No. FHWA-NJ-2007-001	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Safety Audit of Fatalities and Injuries Involving Guide Rail		5. Report Date December 2006
		6. Performing Organization Code
7. Author(s) H. Clay Gabler, and Douglas Gabauer		8. Performing Organization Report No.
9. Performing Organization Name and Address Virginia Tech Department of Mechanical Engineering Blacksburg, VA 24061		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 99ROW1-8
12. Sponsoring Agency Name and Address New Jersey Department of Transportation P.O. Box 600 Trenton, NJ 08625-0600	Federal Highway Administration U.S. Department of Transportation Washington, D.C.	13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes Project Manager: W. Lad Szalaj, NJDOT		

16. Abstract

The goal of this study is to evaluate fatal and injury-causing guide rail accidents in New Jersey. The project has investigated this issue through the combination of a comprehensive literature survey, interviews with roadside safety researchers on ongoing research, examination of U.S. and state accident databases, and field investigation of guide rail crash sites which result in either fatal or serious occupant injury. The research program has evaluated the characteristics of fatal guide rail accidents which occurred in New Jersey during the contract period, and also conducted site investigations of a subset of guide rail crashes.

17. Key Word Highway Crash Guide Rail Crash Injury and Fatality	18. Distribution Statement		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

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

Acknowledgments

The authors wish to acknowledge the New Jersey Department of Transportation for their support of this research effort. Specifically, we would like to thank David Bizuga, Peter Therkelsen, Kevin Conover, Nazhat Aboobaker, Ed Kondrath and Nick Vitillo of the New Jersey Department of Transportation, and Karen Yunk of the Federal Highway Administration. Our special thanks to Sgt. David Beaver, Sgt. Carsten Boethig, Lt. Steven Cozzi, and Sgt. Scott Wishart, of the New Jersey State Police for their crucial role in providing the research team with prompt notification of guide rail crashes.

We wish to acknowledge Rowan University faculty members Dr. John Chen, Dr. Jennifer Kadlowec, and Dr. Yusuf Mehta of the Rowan University College of Engineering for their assistance in making this project a success. The authors are deeply indebted to the following Rowan University and Virginia Tech engineering students for their assistance in conducting the field investigations or performing analyses for this project: David Bowen, Aaron Bryan, Alana DeSimone, James DiMarco, Jennifer Lake, Peter Niehoff, Casey Oware, Kimberly Swanseen, Craig Weinschenk and Clinton Yard. We also wish to thank Carolyn Hampton and Craig Thor, Virginia Tech graduate research assistants, for their expert assistance in the analysis of national crash databases conducted for this project.

Table of Contents

List of Abbreviations

AASHTO – American Association of State Highway and Transportation Officials
AIS – Abbreviated Injury Scale
CAT – Conneticut Attenuating Terminal
CDS – Crashworthiness Data System (part of NASS)
CSS – Continuous Sampling System (older version of CDS)
GES – General Estimates System (part of NASS)
FARS – Fatality Analysis Reporting System
HSIS – Highway Safety Information System
KABCO – Police Injury Rating System; K = Killed, A = Incapacitated, B = Non-Incapacitated, C = Possible Injury, and O = Property Damage Only
LBSS – Longitudinal Barrier Special Study
LON – Length of Need (non-end terminal portion of guide rail)
LTV – Light Trucks and Vans
MAIS – Maximum Abbreviated Injury Score
MELT – Modified Eccentric Loader Terminal
MP – Milepost
MY – Model Year
NASS – National Automotive Sampling System (crash database)
NB – Northbound
NCHRP – National Cooperative Highway Research Project
NHTSA – National Highway Traffic Safety Administration
NJCRASH – New Jersey Crash Record System
NJDOT – New Jersey Department of Transportation
NJSP – New Jersey State Police
PAR – Police Accident Report
SB – Southbound
SRT – Slotted Rail Terminal
SUV – Sport Utility Vehicle
TL-(x) – NCHRP Report 350 Test Level Designation ("x" can be any integer 1-6)

List of Figures

List of Tables

Executive Summary

Guide Rail is designed to protect vehicle occupants from from overhead sign supports, traffic signals and luminaire supports of non-breakaway design, concrete pedestals extending more than 4 inches above the ground, bridge piers, abutments and ends of parapets and railings, wood poles or posts with cross sectional area greater than 50 square inches, drainage structures and other hazards they may encounter in run-off road accidents. Unfortunately, a guide rail is not always a forgiving object to strike. In 2005, there were 1189 fatal crashes and 35,000 injurious crashes into guide rail in the United States. The goal of this study was to investigate the crash performance of guide rail in New Jersey.

Findings

Based on New Jersey Crash Records from 2003-2005 and FARS 2000-2005, following is a summary of the characteristics of guide rail collisions in New Jersey:

1. Each year in New Jersey, approximately 10,000 vehicle occupants are exposed to crashes involving a guide rail impact. In crashes in which the guide rail was the most harmful object struck approximately 10-12 persons were fatally injured and 100 persons received incapacitating injuries. Approximately 40 fatal crashes involved a guide rail impact of some nature.

2. In general, guide rail in New Jersey perform well in crashes. Guide rail crashes fortunately result in only a small fraction (1.5%) of New Jersey highway deaths. Three-fourths of all occupants exposed to guide rail crashes suffer no injuries.

3. State highways are overrepresented in serious guide rail collisions. State highways account for 23% of all guide rail crashes, but 30% of all fatal and incapacitating guide rail crashes.

4. The State of New Jersey does not have an unusually high percentage of guide rail fatalities. New Jersey ranks only 20th among the states in terms of guide rail fatalities as a percentage of all traffic fatalities

Identified Issues in Guide Rail Crash Performance

Although guide rail exhibit admirable crash performance, there remain several unresolved issues in guide rail crash safety. Each issue is summarized below:

1. <u>Secondary Impacts.</u> Over half of all fatal guide rail collisions involved a secondary event – either a second impact or a rollover. Many of these secondary events, e.g. trees, poles, and rollovers, typically carry a much higher fatality risk than a guide rail impact.

2. Guide Rail as a Potential Rollover Hazard. In New Jersey, 14% of all fatal guide rail collisions result in a rollover. Although all vehicles can overturn, light trucks having a high center of gravity may be especially at risk. When light trucks collide with guide rail there is a significantly greater chance of guide rail "vaulting" and roll-over.

3. Motorcycles. Motorcycle riders account for over one-fourth of all New Jersey guide rail crash fatalities – a surprisingly high fraction. Nationally, motorcycle riders now account for more fatalities than the passengers of any other vehicle type involved in a guide rail collision.

4. Side Impacts. Frontal impacts are the most common type of guide rail impact, but side impacts are the most lethal crash mode. Side impacts are only 16% of all crashes, but result in 27% of all fatal guide rail crashes. Particularly dangerous are side impacts into guide rail end treatments.

Actions to Remedy Identified Problems

The following solutions have been proposed and implemented to reduce secondary impacts and fatal guide rail collisions involving a rollover.
NJDOT is revising their Standard Construction Detail CD-609-9.1 entitled: Recovery Area at Flared and Tangent Terminals and Standard Construction Detail CD-609-9.2 entitled: Grading Treatment at Flared and Tangent Terminals. These details require design specific information to be added and included in the contract plans regarding the size and grading of the recovery area at each guide rail terminal. This will enable the designer to make sure that the recovery area is free of fixed objects, the proper grading treatment is applied and the proper notes are placed on the construction plans. Design guidance on how to fill out the detail is to be included in the NJDOT Roadway Design Manual. The success of these solutions should be evaluated in a future guide rail crash performance project.

Introduction and Background

Guide Rail is designed to protect vehicle occupants from from overhead sign supports, traffic signals and luminaire supports of non-breakaway design, concrete pedestals extending more than 4 inches above the ground, bridge piers, abutments and ends of parapets and railings, wood poles or posts with cross sectional area greater than 50 square inches, drainage structures and other hazards they may encounter in run-off road accidents. Unfortunately, a guide rail is not always a forgiving object to strike. In 2005, there were 1189 fatal crashes and 35,000 injurious crashes into guide rail in the United States [NHTSA, 2006].

Figure 1. Collisions with Guide rail are not always forgiving. [NASS/CDS Case 2001-81-036 - Fatal Side Impact of 1999 VW Passat into Guide Rail End Treatment]

The reasons why guide rail impacts sometimes lead to fatality or injury are complex and not completely understood. Guide rail problems include, but are not limited to, many of the following issues (1) improper installation, (2) impacts with end treatments, (3) unfavorable roadside conditions, e.g. soft soil or excessive side slope (4) side impact, (5) improper redirection after a crash, (6) wheel snagging, and (7) secondary impacts with fixed objects. Guide rail performance can be affected not only by barrier design, but also by vehicle design. Poor guide rail performance may result from (1) light trucks overturning on impact with guide rail, (2) cars “submarining” under the rail, (3) airbag-induced injuries, and (4) incompatibility with heavy trucks.

The objective of this project is to investigate the factors which can result in injury to occupants of a vehicle involved in a crash with a guide rail.

Objective

The goal of this study is to evaluate fatal and injury-causing guide rail accidents in New Jersey. The specific objectives are to:

1. Locate and assemble documented information on fatal and injurious guide rail impacts.

2. Identify all ongoing research involving guide rail accidents.

3. Determine unsolved guide rail collision problems.

4. Evaluate fatal and injury-causing impacts with guide rail in New Jersey, and recommend actions for improvements in guide rail safety performance.

Injury and Fatality in Guide Rail Collisions: Literature Review

This chapter reviews the findings of research into guide rail performance and unresolved problems.

Methodology

The propensity for occupant injury in guide rail collisions is first examined based on published results of full-scale crash tests. These tests are intended to examine barrier function at practical worst-case impact scenarios. Since they are staged events, detailed engineering data is collected to allow for a thorough analysis of barrier performance. Although actual occupant injury cannot be obtained in these tests, surrogate measures based primarily on vehicle motion are used to assess occupant injury potential. These metrics can be used to compare the performance of different guide rail configurations as well as guide rail performance relative to other longitudinal barriers. In addition, the crash test results are used to identify other potential barrier performance problems.

Secondly, injury mechanisms in guide rail collisions can be obtained from longitudinal barrier in-service evaluations and accident studies. As in-service evaluations focus on the field performance of only one type of implemented device, they can be used to identify specific barrier performance problems. Alternatively, accident studies generally analyze data in aggregate and for various longitudinal barrier types. These studies can be used to establish the extent of identified barrier performance problems. Unlike full-scale crash tests, the injury consequences are known in both in-service evaluations and accident studies. Another advantage of these investigation types is the ability to account for a much wider distribution of impact conditions and barrier installation variations than addressed with full-scale crash testing. These studies, however, typically lack the detailed vehicle and occupant trajectory information available in full-scale crash tests. When available, both types of studies will be utilized to characterize longitudinal barrier performance problems.

Full-Scale Crash Testing

All roadside hardware, including guide rail, must meet a minimum set of criteria based on full-scale crash testing prior to actual field installation. Currently, NCHRP Report 350 [*2*] provides the framework for the evaluation of these roadside safety devices. The NCHRP 350 guidelines provide specifications for the test configuration (e.g. device installation), impact conditions (e.g. vehicle speed, approach angle, and impact point on the device), standardized test vehicles, data collection procedures, and evaluation procedures.

Identified Problems

According to NCHRP Report 350, unacceptable barrier performance consists one or more of the following:

- Barrier penetration by impacting vehicle (not applicable to some terminal tests)
- Barrier underride by impacting vehicle
- Barrier override by impacting vehicle
- Penetration of barrier debris into the vehicle occupant compartment
- Large deformations of the vehicle occupant compartment
- Vehicle rollover
- Occupant risk values greater than the established thresholds
- Vehicle intruding into adjacent traffic lanes after barrier impact

Based on the results of full-scale crash tests, anecdotal evidence is presented regarding problems with longitudinal barrier and end terminal performance.

Heavy Vehicle Performance

Heavy vehicles, including tractor-trailer vehicles, are critical in terms of barrier penetration. Also, these vehicles are more prone to rollover due to the higher vehicle center of gravity. The propensity for rollover is even evident in the test procedures, as NCHRP 350 only "prefers" that heavy vehicles remain upright as opposed to the requirement for passenger vehicles [*2*]. Other than select rigid concrete barriers, however, longitudinal barriers are typically designed to NCHRP 350 test level 3 (TL-3) and not intended to redirect heavy vehicles. Nevertheless, the performance of these barriers in heavy vehicle impacts is valuable, as these collisions cannot always be avoided.

With respect to w-beam guide rail, Ivey et al. [*5*] tested the upper performance limits of the strong post w-beam barrier under the previous NCHRP 230 crash test procedures. The strong steel post w-beam failed to redirect a 20,000 lb utility bus impacting at 59.7 mph and an angle of 15 degrees, ultimately resulting in vehicle rollover. No NCHRP 350 tests involving heavy vehicles have been found.

Despite being designed to enable improved performance with heavy vehicles, the strong steel post thrie beam barrier failed to redirect a 20,000 lb utility bus impacting at 55.9 mph and an angle of 13.5 degrees and ultimately resulted in vehicle rollover [*5*]. The modified thrie beam barrier, however, is tested to TL-4 based on a successful redirection of a single-unit truck impacting at 51 mph and 15 degrees [*6*]. Previous heavy vehicle testing with the modified strong steel post thrie beam barrier also produced satisfactory results. The barrier successfully redirected both the 20,000 lb utility bus (55.8 mph and 15 degrees) and the 40,000 lb intercity bus (59.6 mph and 14 degrees) [*5*]. Buth et al. [*3*], however, encountered unsuspected results testing the dual-faced median barrier version of the modified thrie beam with an intercity bus (40,000 lb) impacting at 59.6 mph and 14.5 degrees. A splice failure in the barrier permitted the bus to penetrate the barrier. The result of this test corroborates that barrier performance can be sensitive to seemingly minor installation details. Note that the median barrier version of the modified thrie beam barrier has been tested to NCHRP 350 TL-4 [*7*].

Light Truck Incompatibility

Despite the poor performance with heavy vehicles, the strong post w-beam has traditionally had acceptable performance with passenger vehicles under NCHRP 230 test procedures. A testament to this is the widespread use of the barrier across the United States. The adoption of the NCHRP 350 procedures, however, raised questions regarding the performance of these barriers due to the replacement of the 4500S (4500 lb sedan vehicle) with the 2000P (¾ ton pickup truck).

Bligh [*8*] expressed concerns that the higher center of gravity, higher front bumper, and shorter front overhang of the 2000P test vehicle will degrade the performance of the w-beam barriers. Specifically, the higher center of gravity may increase the tendency for the test vehicle to roll on or over the barrier and vaulting may be amplified since higher bumpers increase the likelihood of the bumper overriding the rail element. Also, the reduced front overhang of the 2000P results in greater interaction between the vehicle front tire and the barrier components, which may increase the propensity for wheel snagging. A review of early crash tests provided some insight to the performance of light trucks with w-beam barriers. Adverse vehicle behavior was observed in a strong-post w-beam barrier (12.5 foot post spacing) test with a 4410 lb (2000 kg) pickup impacting at 45 mph and 25 degrees. The bumper of the truck overrode the rail, pocketing occurred at the first post downstream of the impact point, and the vehicle vaulted the barrier. In another test with a ½ ton Ford F-150 pickup impacting a strong steel-post w-beam barrier at 57 mph and 23.5 degrees, the front wheel of the test vehicle snagged severely on the second post (downstream of the impact point) and the vehicle attained a maximum roll angle of 35 degrees prior to redirection. Two other tests with a ¾ ton pickup impacting a G4(1S) system (strong steel post, steel blockout w-beam) at 60 mph and 20 degrees proved successful. In the first, the barrier was installed on a 6:1 down slope; the vehicle was redirected with a maximum roll of 15 degrees. In the second, the barrier was a curved configuration with radius 1192 feet.

Despite the early concerns, the strong wood post w-beam barrier has been adequately tested according to NCHRP 350 TL-3 [*7*]. The barrier successfully redirected the 2000P pickup impacting at 62.6 mph and 24.3 degrees despite the presence of wheel snagging. A similar test with the strong steel post version (with steel blockouts), however, failed to satisfy the TL-3 requirements [*7*].

Impacting at 63 mph and an angle of 26.1 degrees, the front right wheel assembly of the 2000P test vehicle snagged on the posts causing the vehicle to rollover. This result is surprising since these two barrier variations have long been considered equivalent in terms of performance. More recent crash testing, however, has shown that two modified steel strong post w-beam barriers pass TL-3 requirements. One modification is the use of timber blockouts in lieu of steel blockouts [9] while the other uses recycled polyethylene blockouts [*10*]. Nevertheless, the discrepancy between the results of these crash tests reinforces barrier performance sensitivity to relatively minor barrier details.

Although these blockout modifications did result in satisfactory crash test performance, researchers still caution that these systems may not have sufficient reserve capacity to redirect higher center-of-gravity vehicles in high speed, high angle collisions [*11*]. As a result, several new guardrail systems have been developed including the Midwest Guardrail System [*12*] and the T-31 W-Beam Barrier [*13*].

Adverse Roadside Conditions

Typically, crash tests involving roadside barriers involve “standardized” impact and barrier installation conditions. This precludes analysis of barrier performance in situations that deviate from the “standardized” conditions. For instance, barriers are typically installed on sloping ground or in a curved configuration rather than on flat ground and in a straight configuration, as prescribed by NCHRP 350. Some non-standard full-scale crash tests, though, have been performed to investigate potential performance problems of barriers.

Bligh [*8*] highlights two tests involving strong steel post w-beam barrier installed behind either 6 inch or 8 inch curbing. With an 8-inch curb in front, a ¾ ton pickup impacting at 60 mph and 20 degrees vaulted the barrier after the front bumper overrode the rail element. The same barrier system with a 6-inch curb in front failed to redirect a ½ ton pickup impacting at 45 mph and 25 degrees.

Ross and Smith [*14*] investigated barrier performance on the common 6:1 slope at different offset distances from the roadway shoulder. A series of NCHRP 230-based crash tests were utilized to evaluate the functionality of the three-strand cable barrier as well as the strong post steel w-beam barrier. Based on the crash test results, the w-beam barrier does not meet the evaluation criteria for offsets through 12 feet. In the 6-foot offset barrier test, the 4500S vehicle impacting at 62.8 mph and 25 degrees vaulted over the barrier. In the 12-foot offset test (same impact conditions), the 4500S began to redirect, however, the impact forces fractured the rail element and the vehicle penetrated the barrier. Conversely, the cable barrier system displayed satisfactory NCHRP 230 performance at a 6-foot offset.

Field Experience

Due to the high costs involved, full-scale roadside hardware crash tests cannot be utilized to investigate all permutations of vehicle impact conditions and barrier installation configurations. Thus, documented experience with barriers installed on roadways is utilized to evaluate barrier performance in impact conditions and barrier configurations other than those prescribed in the crash test procedures. In addition, documented experience provides known occupant injury consequences rather than surrogate measures based on measured vehicle motion.

Typically, documented barrier field experience falls into one of two categories: (1) in-service evaluations, or (2) accident studies. An in-service evaluation is a study to evaluate the field performance of a particular roadside safety device. An accident study, alternatively, utilizes crash data (not necessarily from the same device) to investigate the performance or relative performance of one or several roadside devices. When available, both types of studies will be utilized to characterize longitudinal barrier performance in terms of occupant injury and potential operational problems.

Comparison of Occupant Risk

Despite being precise in relation to the vehicle motion, the occupant risk criteria is limited by the small number of crash configurations and barrier installation configurations set by the test procedures. Also, there has been little research investigating the relation of these criteria to actual occupant injury. Thus, accident studies are crucial to ensuring that barriers installed in the field are performing properly.

New York State completed a number of investigations on the performance of longitudinal barriers and associated end terminals. Although these older studies tended to focus on the functionality of the weak-post barriers, useful information can be gleaned regarding guide rail performance. In 1977, Van Zweden and Bryden [*15*] evaluated the field performance of the older strong-post barriers and newly developed weak-post barriers based on New York State accident data. NYDOT maintenance personnel collected the data utilized in this study from state highway accidents between November 1967 and October 1969. For the statistical analyses, the authors compared the performance of the investigated barriers based on the resulting occupant injury, reaction of the vehicle, and the maintenance required after impact. There were a total of 4213 guide rail accidents from the statewide portion of the study (3496 strong-post, 717 weak–post), which generated a number of conclusions. Although there was no significant difference in fatality rates between strong and weak-post barriers, the weak-post barriers exhibited a combined fatality/serious injury rate significantly lower than that found for all strong-post barriers. As evident in the occupant risk values observed in the full-scale crash tests, occupant injury appears linked to barrier stiffness. With respect to barrier penetration, the weak-post barriers demonstrated a lower penetration rate than the strong-post barriers (with the exception of the w-beam). Note that this most likely due to the lack of consistency between early strong-post barrier designs; according to the authors, there were 22 combinations of rail, post type and post spacing identified between 1950 and 1965. Compared to cases where the barrier contains the vehicle, serious occupant injury is more likely in cases where the barrier is penetrated (this trend is evident for both weak and strong-post barriers). Barrier end terminals (includes first or last 50 feet of barrier) are observed to have higher penetration rates than their midsection counterparts and also resulted in higher serious injury rates.

Carlson, Allison and Bryden [*16*] utilized New York State accident and maintenance data over a 5-year period to evaluate the performance of light-post roadside and median barrier, impact attenuation devices, slip-base sign supports, and frangible base luminaire supports. With respect to barrier performance, the objective was to document the performance at the higher rail mounting height (27" to center of rail). The study included five longitudinal barrier types: w-beam barrier, cable barrier, box-beam barrier, w-beam median barrier, and box-beam median barrier. Similar to the Van Zweden study, the observed roadside and median barriers are evaluated based on the resulting occupant injury severity, containment of the vehicle, and performance of the end terminal (if applicable). Considering all collected barrier accident data, there were no fatalities, 2% of the collisions involved severe injuries, and approximately 10 percent involved minor injuries. Thus, from an overall prospective, the barriers performed well. Because of the low number of injury cases, the study was not able to discern differences between injury rates for most of the individual barrier types. The only statistically significant difference (95% confidence level) in injury rate found was between the w-beam (higher injury rate) and box-beam (lower injury rate) median barriers. In terms of barrier penetration, all penetration rates (with the exception of the cable barrier) were lower than those in the previous Van Zweden study. Of the total of 15 length-of-need barrier penetrations, only two involved occupant injury (one minor and one severe). A total of 29 end terminal accidents were present in the data set; only one resulted in minor occupant injury suggesting satisfactory performance.

More recently, Erinle et al. [*17*] utilized the Longitudinal Barrier Special Study (LBSS) to determine the performance of longitudinal barriers in real-world crash situations. The LBSS is a specialized accident database within the National Highway Traffic Safety Administration's (NHTSA) National Automotive Sampling System (NASS) system that has detailed information on collisions involving traffic barriers that occurred between 1982 and 1986. Much of the analysis is based on 665 single vehicle impacts (450 barrier length of need impacts and 215 end terminal impacts) that involved only impact with a single barrier. Unfortunately, the number of cases available for analysis prevented conclusions between specific barrier systems; instead, the authors grouped barriers with similar stiffness characteristics. For barrier length of need hits, significant differences among the studied barriers are found for driver injury versus no injury, however, non-significant differences for MAIS ≥ 2. This conclusion appears consistent with the studies done by Van Zweden and Bryden [*15*] in New York. Strong post barrier systems (median and roadside barrier) and concrete median barrier are found to present a significantly greater risk of occupant injury. For driver injury versus no injury, there was no statistically significant difference found between adverse barrier performance (snagged, overrode, vaulted, penetrated) and correct barrier performance (vehicle redirected).

Michie and Bronstad [*18*] revisited previous longitudinal barrier and end terminal research to provide a new assessment on the effectiveness of these highway safety devices. If barrier effectiveness is based solely on reported accidents, as in many studies, then approximately 50 to 60 percent of guide rail accidents involve occupant injury or fatality. Using previous studies to provide an estimate of the proportion of unreported barrier collisions (this value is approximately 90 percent), the authors assert that only 6 percent of barrier impacts result in severe occupant injury or fatality. Also, according to the estimates of the authors, the ideal barrier collision produces fatal injury in approximately 0.5 percent of collisions and incapacitating injuries in 7.3 percent of collisions (excluding end terminal impacts).

Viner [*19*] utilizes 1985 data from the Continuous Sampling System (CSS) of the National Accident Sampling System (NASS) in conjunction with comprehensive crash costs (in 1988 dollars) to investigate the nature of the roadside safety problem. The types of roadside crashes are ranked based on the percentage of loss incurred with the top five greatest losses attributed to overturns, trees, utility poles, embankments, and guide rail. According to the analysis, approximately 4 percent of the total crash losses can be attributed to longitudinal barriers.

Elvik [*20*] utilizes a statistical approach to analyze conglomeration of previous studies on the safety effects of median barriers, roadside guide rail, and crash cushions. The objective is to determine how the installations of these devices affect the probability of an accident occurrence as well as the severity of a given collision. From the 32 analyzed studies, there were 232 numerical estimates of the safety effects of these devices, where each estimate constitutes a unit of analysis. Based on the available data, median barriers are found to increase the accident rate (by approximately 30%) but to decrease the severity (20% reduction of probability of fatal injury), given that a collision occurs. For longitudinal barriers situated at the roadway edge, the data indicates a reduction in both the accident rate and accident severity (45% reduction of probability of fatal injury). The random variation in the number of accidents for a given study is found to be the most significant contributor to variation in the study results (on the whole).

Identified Problems

Based on the documents assessing the field performance of longitudinal barriers, anecdotal evidence is presented regarding problems with longitudinal barrier and end terminal performance.

Improper Installation

As evident in the full-scale crash tests with roadside hardware, barrier performance can be sensitive to seemingly minor changes in barrier details. Different contractors may install longitudinal barriers across a particular state making quality control difficult. Often times, the result is a barrier installed in the field that does not match the detailed specifications of the crashworthy design. For instance, the rail element in the end terminal (shown in Figure 2) is not properly aligned in the extruder terminal. In the event of a head-on impact with this system, the misalignment will not allow the rail to be deformed as originally intended and may result in adverse performance.

Figure 2. Improper Rail Installation for an Extruder End Terminal

While investigating longitudinal barriers in New York State, Van Zweden and Bryden [*15*] noted a lack of consistency between early strong-post barrier designs; they reported 22 combinations of rail, post type and post spacing identified between 1950 and 1965. In an attempt to evaluate the effect of the increased barrier height standards, Carlson, Allison and Bryden [*16*] found a large variation in the barrier heights even after the implementation of the revised barrier height specification.

Although no figures are provided, Michie [*21*] stresses the problem of improperly installed guide rail and associated end terminals. Common problems are longitudinal barriers that fall short of adequately shielding the hazardous roadside objects, end terminals shielding bridge rails that fail to properly shield the associated embankment, and breakaway cable terminals installed without the 4-foot offset and proper parabolic flare.

Rollover

Vehicle rollover has been evident in full-scale crash testing, especially with respect to the NCHRP 350 test procedures, which require testing with the 2000P test vehicle. Viner [*22*] used Illinois Highway Safety Information System (HSIS) data (over 100,000 cases with over 16,000 rollovers) to examine vehicle rollovers. Major findings indicated that the principal cause of rollover was slopes and ditches, the rollover problem is dominant in the rural environment, and the rollover rate is strongly dependent on the vehicle type and vehicle speed prior to the event. Although this study reinforces the likelihood of light trucks to rollover, it suggests that slopes and ditches may have a larger contribution to rollover than guide rail.

Secondary Collisions

Traditionally, roadside hardware has been designed using the following assumptions: (1) the propensity for occupant injury is highest during the initial collision, as vehicle energy and speed is greatest, and (2) occupant injury is directly related to the severity of the vehicle decelerations. Research done in conjunction with the review of the NCHRP Report 230 procedures and the development of the NCHRP Report 350 procedures, however, challenges this longstanding philosophy. Ray et al. [*23,24*] found that severe longitudinal barrier impact conditions alone does not typically produce severely injured occupants and that vehicle trajectory and stability subsequent to the collision are major factors in the cause of occupant injury. Likewise, the authors suggest that smooth redirection of an impacting vehicle is a more effective means of reducing occupant injury than attempting to limit vehicle accelerations.

In the same study sponsored by the FHWA, Ray et al. investigated the scope of the secondary collision problem using state accident data [*25,26*]. The available barrier collisions were limited to those collisions where a longitudinal barrier was the first object struck, only passenger vehicles were involved, midsection impacts only, oblique impact angle and the vehicle was tracking prior to impact (non-skidding). Analyzing a total of 2332 cases from New York State and 103 cases from North Carolina, the authors used a fault tree analysis to characterize occupant severe injury and fatality for different barrier performance modes. For both state data sets, longitudinal barrier impacts with a secondary collision were 3 times more likely to produce fatality or severe injury than if there was no second impact. Post impact vehicle trajectory can be as important as shielding the vehicle from a roadside hazard.

Although much more limited, Erinle et al. [*17*] present a more recent analysis utilizing the LBSS. An analysis of impacts subsequent to a barrier impact indicates that rollover rate for concrete median barrier is double the overall rate for all barriers. Also, where rollover is the subsequent event, injury rates are found to be highest. Note that the difference in injury rates is not found to be statistically significant.

End Terminal Performance

An end terminal is utilized to ensure a safe termination of a longitudinal barrier without adverse consequences. These include but are not limited to vehicle rollover, severe accelerations, and vehicle spearing (shown in Figure 3). Several studies have addressed the propensity of occupant injury in collisions with guide rail end terminals.

Figure 3. Poor End Terminal Performance: Vehicle Spearing

A large portion of the LBSS study [*17*] was aimed at comparing injury severity between length-of-need (LON) and end terminal impacts. Although the study lacks exposure data, impacts with end terminals are found to be more likely to cause occupant injury than if the LON portion of the barrier is struck. Also, end terminal hits are found to be both more likely to induce vehicle rollover and, in the event that the vehicle does not rollover, produce more serious injuries than LON impacts. Viner [*19*] also notes a disproportionately higher crash risk for guide rail end treatments in comparison to the LON as well as the increased severity of the end crashes in comparison to crashes within the LON.

Light Truck Incompatibility

Crash testing has uncovered performance problems between light trucks and the current hardware in place on the nation's roadways, specifically the steel strong post w-beam barrier with steel blockouts. From 1980 to 1994, the light truck portion of the vehicle fleet has increased from 20 percent to approximately 40 percent of the entire vehicle fleet [*27*]. In light of this, the field performance of light trucks interacting with guide rail is of interest.

Viner et al. [*28*] investigated the relative safety of crashes with roadside safety hardware by vehicle body type. For this investigation, the authors utilized accident data from North Carolina and Michigan (from HSIS) as well as FARS data, GES data and Polk vehicle registration data. Although there were some discrepancies between the state and national data, the study found that if the measure of safety is K+A (fatal plus incapacitating) injuries, there is no significant difference between cars and sport utility vehicles. On the other hand, if fatalities only are used to gauge safety, drivers of pickups were found to be at a higher risk. The authors suggest that this higher fatality rate could be due to a higher propensity for occupant ejection during rollovers

References

1. NHTSA, Traffic Safety Facts 2005, National Traffic Safety Administration, US Department of Transportation, Washington, DC, December 2006.
2. Ross, H.E., Sicking, D. L., Zimmer, R.A., and J.D. Michie. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. NCHRP Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.
3. Buth, C.E., Campise, W.L., Griffith, L.I., Lowe, M.L., and D.L. Sicking. *Performance Limits of Longitudinal Barriers*. FHWA-RD-86-154, Federal Highway Administration, Washington, D.C., 1986.
4. Bronstad, M.E., Michie, Jarvis D., and J.D. Mayer. *NCHRP Report 289: Performance of Longitudinal Traffic Barriers.* Transportation Research Board, Washington, D.C., June 1987.
5. Ivey, D.L., Robertson, R.R., and C.E. Smith. Test Evaluation of W-Beam and Thrie Beam Guardrails. FHWA/RD-82/071, Federal Highway Administration, Washington, D.C., March 1986.
6. Buth, C. Eugene and Wanda L. Menges. *NCHRP Report 350 Test 4-12 of the Modified Thrie Beam Guardrail*. Report FHWA-RD-99-065, US Department of Transportation, Federal Highway Administration, December 1999.
7. Ray, Malcolm H. and Richard G. McGinnis. *Synthesis of Highway Practice 244: Guardrail and Median Barrier Crashworthiness*. Transportation Research Board, National Research Council, Washington, D.C., 1997.
8. Bligh, Roger. Performance of Current Safety Hardware for NCHRP 350 Vehicles. *Transportation Research Circular 440*, Transportation Research Board, National Research Council, April 1995, pp. 29-34.
9. Bullard, D.L., Menges, W.L., and Alberson, D.C. *NCHRP Report 350 Compliance Test 3-11 of the Modified G4(1S) Guardrail with Timber Blockouts*, Report FHWA-RD-96-175, Texas Transportation Institute, Federal Highway Administration, September 1996.
10. Bligh, R.P. and Menges, W.L. *Testing and Evaluation of a Modified Steel Post W-Beam Guardrail System with Recycled Polyethylene Blockouts*, Report 400001-MPT, Texas Transportation Institute, February 1997.
11. Faller, R.K., Sicking, D.L., Bielenberg, R.W., Rohde, J.R., Polivka, K.A., and Reid, J.D. Performance of Steel Post, W-Beam Guardrail Systems,

Paper 07-2642, *Proceedings of the 86th Annual Meeting of the Transportation Research Board*, January 21-25, 2007, Washington, DC.

12. Sicking, D.L., Reid, J.D., and Rohde, J.R. Development of the Midwest Guardrail System. *Transportation Research Record 1797*, Transportation Research Board, Washington, D.C., 2002.
13. Baxter, John R. [Letter for T-31 W-Beam Guardrail TL-3 acceptance]. HSA-10/B-140, November 3, 2005. Located at: http://safety.fhwa.dot.gov/roadway_dept/road_hardware/barriers/pdf/b140.htm
14. Ross, H.E., and D.G. Smith. Impact Behavior of Barriers on Nonlevel Terrain. *ASCE Journal of Transportation Engineering*, Volume 107, Issue 1, American Society of Civil Engineers, New York, NY, pp 69-79, January 1981.
15. Zweden, John Van and James E. Bryden. *In-service Performance of Highway Barriers*. Report No. NYSDOT-ERD-77-RR51 New York State Department of Transportation, Albany, NY, July 1977.
16. Carlson, Robert D., Joseph R. Allison and James E. Bryden. *Performance of Highway Safety Devices*. Report FHWA-NY-77-RR 57, New York State Department of Transportation, Albany, NY, December 1977.
17. Erinle, O., Hunter, W., Bronstad, M., Council, F., and J. Richard Stewart. *An Analysis of Guardrail and Median Barrier Accidents Using the Longitudinal Barrier Special Studies (LBSS) File, Volume I: Final Report*. Report FHWA-RD-92-098, Scientex Corporation/Federal Highway Administration, February 1994.
18. Michie, Jarvis D., and Maurice E. Bronstad. Highway Guardrails: Safety Feature or Roadside Hazard? *Transportation Research Record 1468*, Transportation Research Board, Washington, D.C., December 1994, pp 1-9.
19. Viner, John G. The Roadside Safety Problem. Transportation Research Circular # 435, TRB, National Research Council, January 1995, pp. 17-29.
20. Elvik, R. "The Safety Value of Guardrails and Crash Cushions: A Meta-Analysis of Evidence From Evaluation Studies," *Accident Analysis and Prevention*, Volume 27, Issue 4, August 1995, pp 523-549.
21. Michie, J.D. Roadside Safety: Future Areas of Focus. Transportation Research Circular 453, Transportation Research Board, February, 1996, pp 30-37.
22. Viner, John G. Risk of Rollover in Ran-Off-Road Crashes. *Transportation Research Record 1500,* National Research Council, Washington, D.C., July, 1995, pp 112-118.
23. Ray, M. H., Michie, J.D., and M. Hargrave. Events That Produce Occupant Injury in Longitudinal Barrier Accidents*. Transportation Research Record 1065,* TRB, National Research Council, Washington, D.C., 1986, pp. 70-75.
24. Ray, M. H., Michie, Jarvis D., Hunter, W.W. and J. Stutts. *Evaluation of Design Analysis Procedures and Acceptance Criteria for Roadside Hardware, Volume IV: The Importance of the Occupant Risk Criteria.* FHWA RD-87/099, U.S. Department of Transportation, Washington, D.C., 1987.

25. Ray, Malcolm H., Michie, Jarvis D., Hunter, W.W., and J. Stutts. *Evaluation of Design Analysis Procedures and Acceptance Criteria for Roadside Hardware, Volume V: Hazards of the Redirected Car*. FHWA RD-87/100, U.S. Department of Transportation, Washington, D.C., 1987.
26. Ray, Malcolm H., Michie, J. D., Hunter, William, and J. Stutts. Analysis of the Risk of Occupant Injury in Second Collisions. *Transportation Research Record 1133*, TRB, National Research Council, 1987, p 17-22.
27. Ross, H.E. Implications of Increased Light Truck Usage on Roadside Safety. Transportation Research Circular 453, Transportation Research Board, February 1996, pp 4-15.
28. Viner, John G., Council, Forest M., and Stewart, J. Richard. Frequency and Severity of Crashes Involving Roadside Safety Hardware by Vehicle Type. *Transportation Research Record 1468*, National Research Council, Washington, D.C., December, 1994, pp 10-18.

Summary of New and Ongoing Guide Rail Research

The National Cooperative Research Program (NCHRP) of the Transportation Research Board has several research programs either underway or recently completed which are relevant to understanding the crash performance of guide rail. For each current research project related to guide rail safety, a brief description of progress and results to date is provided.

NCHRP Project 22-17: Recommended Guidelines for Curbs and Curb-Barrier Combinations

The objective of this research was to develop design guidelines for implementing curbs and curb-barrier combinations on roads with operating speeds greater than 37 mph (60 km/hr). The project has been completed. The American Association of State Highway and Transportation Officials (AASHTO) Technical Committee for Roadside Safety is planning to issue an update of the Roadside Design Guide in 2008. The NCHRP 22-17 recommendations will most likely be included in that update. Recommendations include the following:

1. For roadway operating speeds up to 53 mph (85 km/hr), any combination of sloping-faced curb at or below a height of 6 inches (150 mm) with a strong post guide rail can be used at a zero lateral offset (rail face is flush with curb).

2. Cases where the guide rail must be placed behind the curb (6 inches or smaller), a lateral distance of 8 feet (2.5 meters) is recommended for operating speeds up to 43.5 mph (70 km/hr). For operating speeds between 43.5 and 53 mph (71 and 85 km/hr), the lateral distance is increased to 13 feet (4 meters) and the curb is recommended to be 4 inches (100 mm) or smaller in height.

3. Above operating speeds of 53 mph (85 km/hr), guide rail should only be used with 4 inches (100 mm) or smaller curbing placed flush with the face of the rail (zero offset). An additional stipulation for operating speeds in excess of 56 mph (90 km/hr) recommends the slope of the curb be 1:3 or flatter.

4. For roads with operating speeds in excess of 53 mph (85 km/hr), guide rail should not be located behind curb (other than the zero offset case mentioned above).

For the instances where the guide rail is placed behind the curb at a non-zero lateral offset, the basis of the guidelines is to prevent vehicle vaulting of the barrier.

NCHRP Project 22-14(02): Improved Procedures for Safety-Performance Evaluation of Roadside Features

The objectives of this research are to prepare the update to the procedures for the safety-performance evaluation of roadside features and to identify research needs for future improvements. Currently, NCHRP Report 350 provides the framework for the evaluation of roadside safety devices by providing specifications for the test configuration (e.g. device installation), impact conditions (e.g. vehicle speed, approach angle, and impact point on the device), standardized test vehicles, data collection procedures, and evaluation procedures. As all guide rail must be crash tested to the specifications in NCHRP Report 350, revisions to this document will have a direct and major effect on guide rail safety.

The final report for NCHRP 22-14(02) is in preparation. Prior to review by AASHTO, TRB will conduct extensive crash testing under a new project NCHRP 22-14(03) for which contract negotiations are currently underway. It should be emphasized that none of these changes has been approved by AASHTO until after extensive review and comment. The major topics presented included test impact condition revisions and test vehicle selection revisions; a brief description of each is provided below:

- Heavier Test Vehicles. Roadside safety hardware must perform adequately for a range of vehicle types, especially the wide variety of passenger vehicles. Currently, NCHRP Report 350 specifies the 820C test vehicle, equivalent to a Geo Metro, and the 2000P test vehicle, equivalent to a Chevrolet 2500 pickup. With the changing vehicle fleet, the suitability of these test vehicles, which were chosen in the early 1990's, is a point of serious debate. The researchers propose replacing the 820C small passenger car test vehicle with the 2425 lb (1100 kg) small passenger car (equivalent to a Kia Rio). For the large test vehicle, the team proposes the use of a 5000 lb (2270 kg) pickup truck. Tests have been conducted with a Dodge Ram Quad Cab.

- More Severe Impact Angle. The recommendation is that the impact angle in all redirection tests should be 25 degrees. This may have a dramatic effect in tests of guide rail terminals and crash cushions, and may require redesign.

- Impact Speed. No change has been proposed in impact speed.

- Side Impact. Side impact tests will only be optional.

NCHRP Project 17-22: Identification of Vehicular Impact Conditions Associated with Serious Ran-Off-Road Crashes

The objective of this project is to identify the vehicle types, impact conditions, and site characteristics associated with serious injury and fatal crashes involving roadside features and hardware and to create a database of these crashes for future research. All progress to date has focused on previous literature and development of a data collection plan for the database. Note that the same research team is preparing the update to NCHRP Report 350 and much of the research under this project has been used in the proposed revisions to the impact conditions. Project 17-22 is still underway. Completion is expected in spring 2007.

NCHRP Project 22-13(2): Expansion and Analysis of In-Service Barrier Performance Data and Planning for Establishment of a Database

The purpose of this research was to extend the current in-service performance evaluation database, develop insights on hardware effectiveness based on an analysis of gathered data, and establish means to access, maintain, supplement, and disseminate data on in-service performance. Compiling previous in-service data, providing a more detailed framework for future in-service data collection, and establishing a national repository is expected to increase the availability and usefulness of in-service data.

The project is completed and the results have been published in *NCHRP Report 490: In-Service Performance of Traffic Barriers*. A large portion of the data collection procedures from this report have been adopted by the research team to investigate guide rail collisions in New Jersey.

NCHRP Project 22-16: Development of an Improved Roadside Barrier System

The intent of this research was to develop an improved roadside barrier capable of meeting NCHRP 350 requirements while being more cost effective than the common strong post w-beam barrier. Specific objectives included investigating the feasibility of candidate barrier design concepts, evaluate the most promising design(s), and develop a plan for development and testing for those designs. A survey of the State DOT's was conducted to determine the perceived strengths and weaknesses of the current strong post w-beam barrier, which aided in the determination of the characteristics required of an improved barrier system. Five concepts for a new or improved guide rail system were developed including an improved strong post w-beam system, a popout post guide rail system, the z-post guide rail system, the leaf-spring post guide rail system, and the honeycomb fiber-reinforced polymer (HFRP) post guide rail system.

Phase I of the project has been completed and the final report is available. However, there are no plans to implement Phase II of the project.

NCHRP Project 22-23: Restoration of Longitudinal Barrier

State highway agencies expend significant resources to ensure that all longitudinal barriers meet the safety performance guidelines to which they were constructed. Barrier systems are damaged by a wide variety of activities and factors, including minor crashes, snow plowing, mowing operations, and deterioration due to environmental conditions. Such damage may or may not be repaired by maintenance forces. For example, snowplows often bend W-beam guide rail and sometimes bend or break the posts. Even seemingly insignificant barrier damage or deterioration may compromise a barrier's safety performance.

With limited maintenance budgets, state highway agencies often have large backlogs of needed safety-feature repairs. These agencies cannot afford to repair damage that does not alter a barrier's safety performance, but significant barrier damage must be repaired to provide adequate protection for the motoring public. Unfortunately, in the absence of objective criteria for determining when repair is not required, highway agencies may be held to the unachievable standard of maintaining all safety features in as-built condition to avoid tort liability. Therefore, there is a need for objective, quantitative criteria in the form of guidelines for assessing damage and deterioration and determining when a longitudinal barrier requires repair or can remain in service.

The objective of this new project is to develop guidelines to assist maintenance personnel in identifying the levels of damage and deterioration to longitudinal barriers that require repairs to restore operational performance.

Analysis of Guide Rail Crashes in New Jersey: 2003-2005

Introduction

This chapter analyzes New Jersey Crash Records and U.S. fatal accident records to (1) determine the characteristics of guide rail crashes in New Jersey, and (2) to identify the unsolved problems in guide rail crashes.

Approach

The analysis will be based upon the 2003-2005 New Jersey Crash Record System (NJCRASH) and the 2000-2005 Fatality Analysis Reporting System (FARS).

The New Jersey Crash Record system contains summary records of over 300,000 police-reported accidents each year. The information for each accident is extracted from the NJTR-1 New Jersey Police Accident Report. Injury severity for each person is rated using the KABCO scale. K = killed, A = incapacitating injury, B = moderate injury, C = complaint of pain, O = property damage only. Analysis of state accident data will allow investigation of the frequency and severity of all guide rail impacts which occur in the state.

FARS is a comprehensive census of all traffic related fatalities in the U.S. By Federal mandate, all states including New Jersey must collect and provide the National Highway Traffic Safety Administration (NHTSA) with records of all traffic related fatalities on their highways. FARS will be used to characterize the nature of the fatal guide rail impact problem in New Jersey based upon accident data.

Results

Figure 4 presents the number of fatal crashes and fatalities involving collisions with guide rail which occurred in New Jersey during the period from 2000-2005. On average during this period, there were approximately 10-12 fatalities which resulted from collisions with guide rail. Because some crashes resulted in multiple fatalities, the annual number of fatalities is slightly higher than the number of fatal crashes each year. This analysis was based upon cases from FARS for which the most harmful event was an impact with a guide rail.

In terms of fatalities, guide rail crashes fortunately result in only a small fraction of New Jersey highway deaths. Figure 5 presents a rank ordering of all New Jersey motor vehicle fatalities by most harmful object struck for the period of 2000-2005. During this six year period, only 55 deaths occurred as a result of a guide rail crashes. This count accounts for 1.5% of all motor vehicle fatalities and less than 5% of all fatalities resulting from collisions with fixed objects. By contrast, collisions with trees and utility poles accounted for over 25% of all traffic deaths and over 70% of all fatalities resulting from collisions with fixed objects.

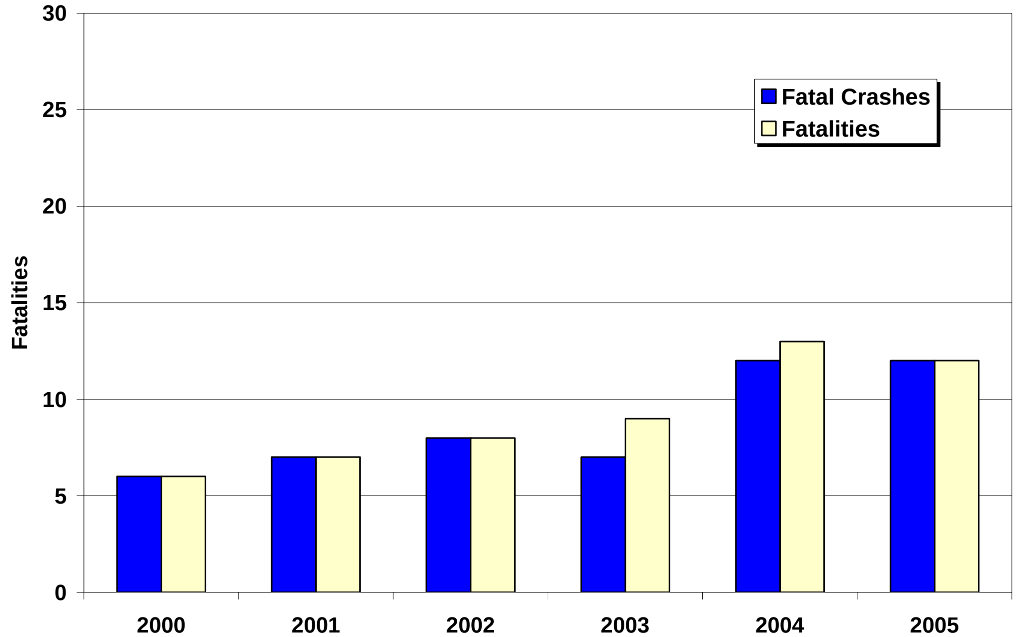


Figure 4. Fatal Guide Rail Crashes in New Jersey (FARS 2000-2005)

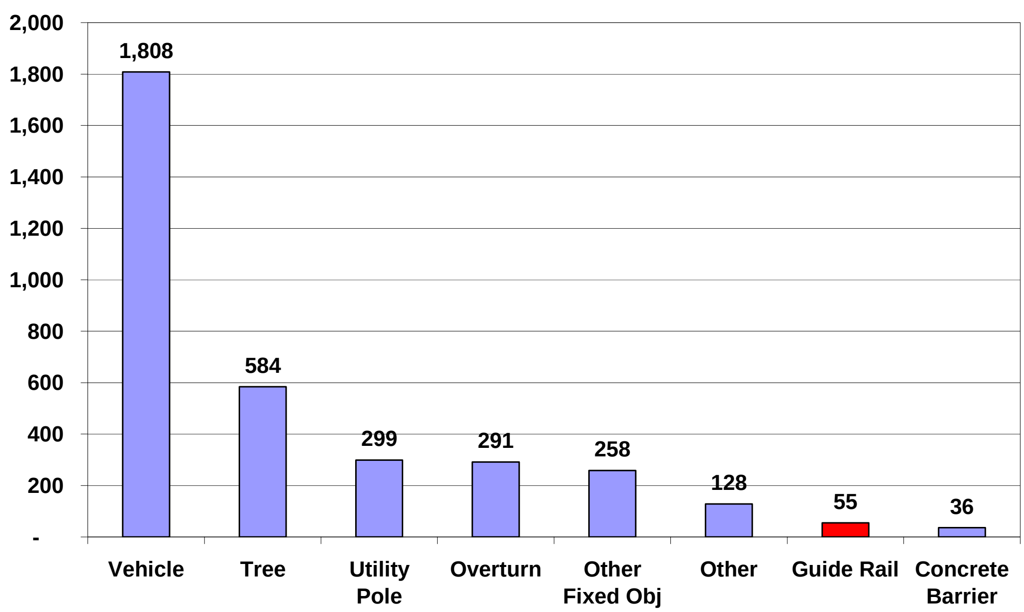


Figure 5. Distribution of New Jersey Motor Vehicle Fatalities by Most Harmful Object Struck (FARS 2000-2005)

Table 1 presents the distribution of all occupants exposed to guide rail crashes by injury severity. The analysis was based upon cases from NJCRASH 2003-

2005 in which a guide rail impact was one of the events in a crash. Each year, approximately 10,000 vehicle occupants in New Jersey are exposed to crashes involving at least one guide rail impact. Of these occupants approximately 40 persons were fatally injured and 100 persons were incapacitated in guide rail crashes.

Table 1. Guide Rail Crash Injury Severity in New Jersey (NJCRASH 2003-2005)

Occupant Injury Severity	**2003**	**2004**	**2005**
Killed	26	41	40
Incapacitated	99	107	93
Moderate Injury	865	862	709
Complaint of Pain	1,777	1,640	1,568
No Injury	7,935	7,616	7,371
Severity Not Coded	37	24	25
Total	10,739	10,290	9,806

Note that the NJ Crash Records reported a larger number of occupants were fatally injured in guide rail crashes than does FARS. FARS and NJCRASH differ for two reasons.

1) Unlike FARS, the NJCRASH does not code the most harmful event. The NJTR-1 allows a police officer to code up to four accident sequences or events that occurred during a crash. For example in a two event crash, the first event might be a sideswipe of a guide rail followed by a head-on collision with a utility pole. Table 1 is simply a tabulation of those accidents which had any guide rail involvement whether minor or severe. Because the guide rail-car interaction may not have been the most harmful event, the number of fatalities involving guide rail impacts recorded in the NJCRASH will be higher than the number of guide rail-related fatalities reported by FARS.

2) Our analysis used the NJCRASH accident sequence code for guide rail (23). While this should be correct in theory, the research team has observed during our visits to crash sites that police accident reports sometimes coded collisions with concrete barrier as guide rail. Hence, the counts in Table 1 refer primarily, but not exclusively, to guide rail impacts.

The State of New Jersey does not have an unusually high percentage of guide rail fatalities. As shown in the figure which follows, New Jersey ranks only 20th among the states in terms of guide rail fatalities as a percentage of all traffic fatalities

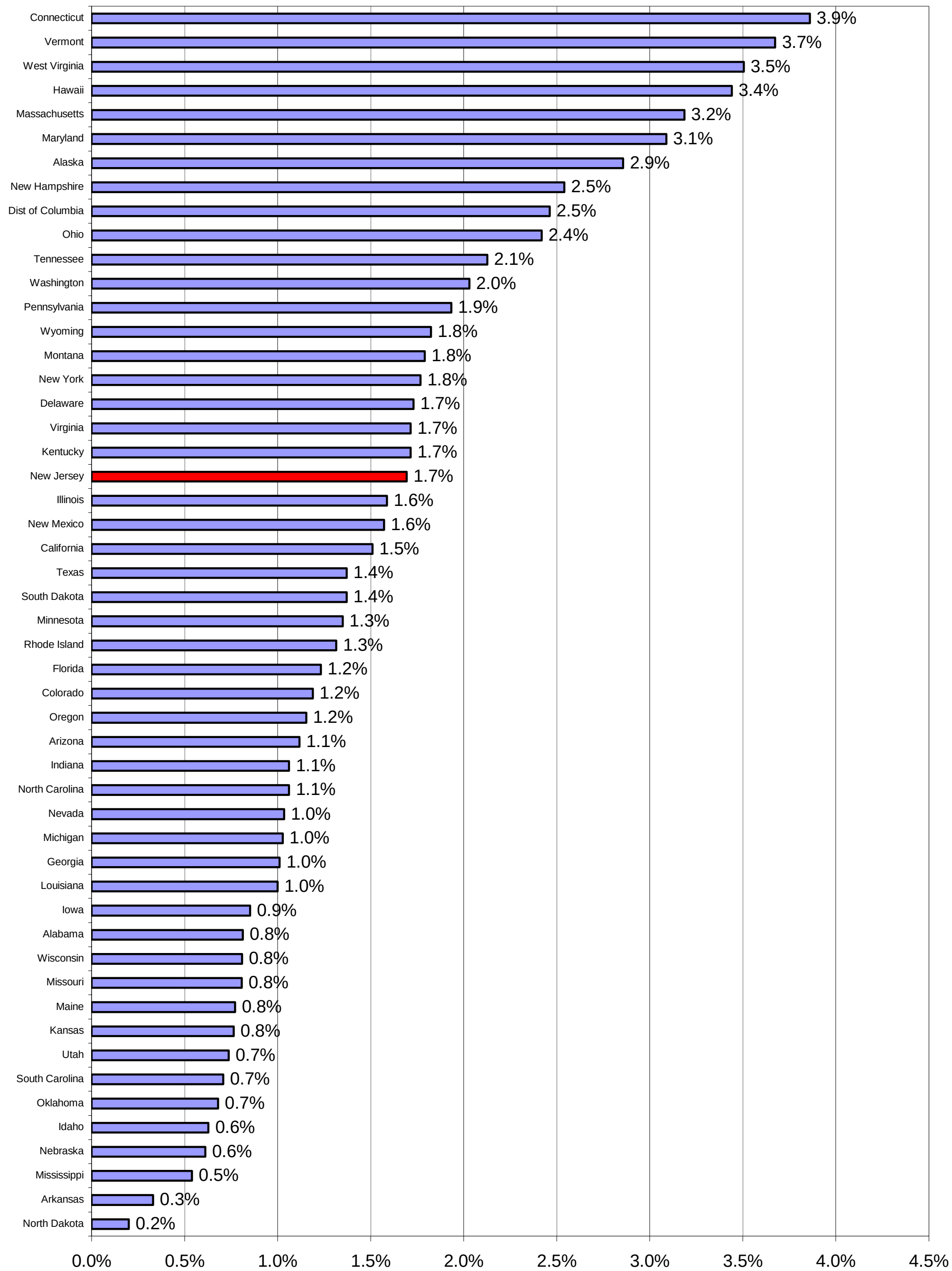


Figure 6. New Jersey ranks 20th among all states in Guide Rail Fatalities as a Percentage of All Traffic Fatalities (FARS 2000-2005)

Figure 7 shows the injury severity distribution of police-reported guide rail crashes in NJ. This figure suggests that guide rail perform well in collisions. Nearly three-fourths of all occupants involved in a guide rail crash suffered no injuries. The remaining 25% of occupants exposed to guide rail crashes suffered some level of injury ranging from complaint of pain to death. Fortunately, fatal and incapacitating injuries were rare. Annually, 1.3% of occupants exposed to guide rail crashes received either a fatal or incapacitating injury.

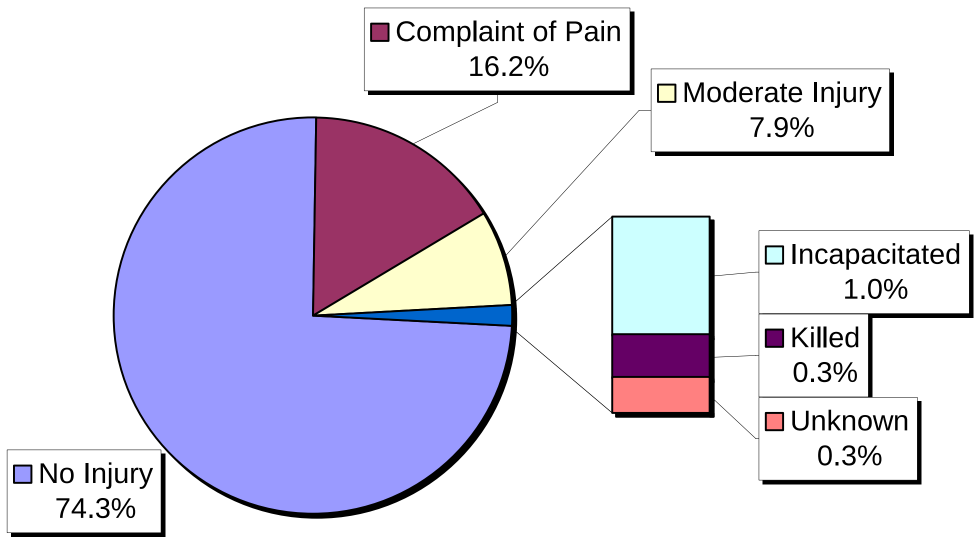


Figure 7. Distribution of Injury Severity in Guide Rail Crashes (NJCRASH 2003-2005)

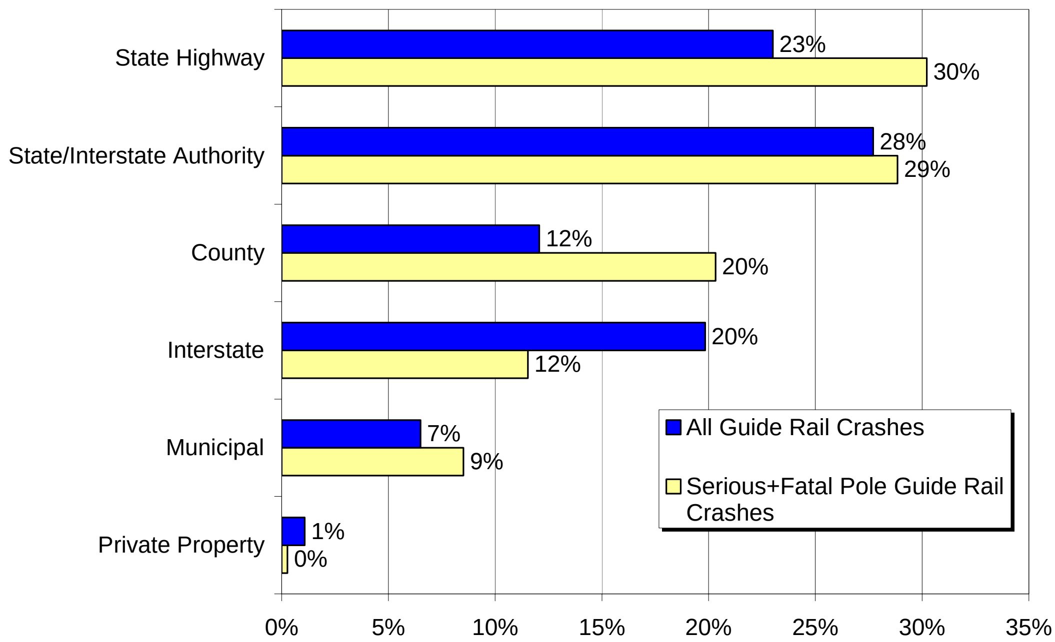


Figure 8. Fatal and Incapacitating Guide Rail Crashes by Road System (NJCRASH 2003-2005)

Figure 8 presents the distribution of serious guide rail crashes by road system. For this analysis, serious crashes are defined to be those collisions which resulted in fatal or incapacitating injury. State highways and state/interstate highways (e.g. the NJ Parkway) each account for approximately 30% of all serious guide rail crashes. State highways, however, are overrepresented in serious guide rail collisions. State highways account for 23% of all guide rail crashes, but 30% of all fatal and incapacitating guide rail crashes.

Unresolved Problems in Guide Rail Crashes

Secondary Events

Traffic collisions are frequently composed of several impact events. For example, in the hypothetical scenario shown in Figure 9, a car first collides with a guide rail (event 1), is redirected back onto the roadway as guide rail are designed to do, collides with an oncoming car (event 2), exits the opposite of the road, and collides with a group of trees (event 3).

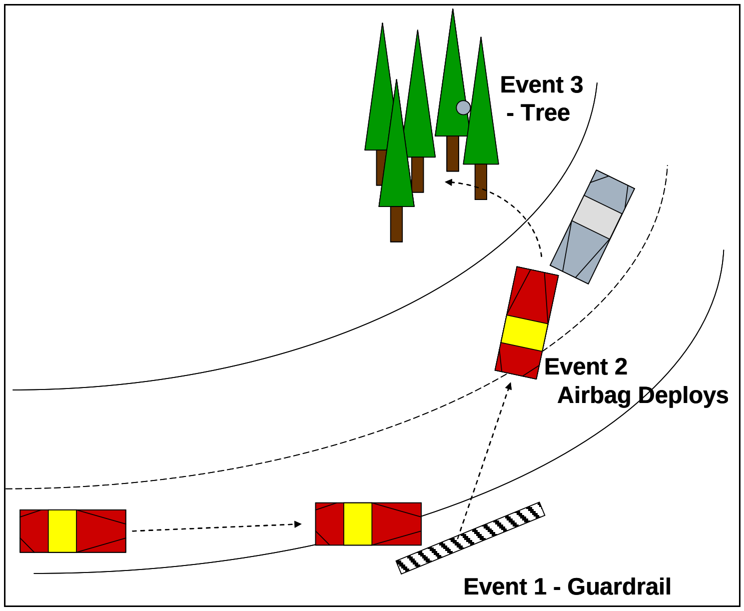


Figure 9. Traffic crashes are frequently composed of several events.

In fatal NJ guide rail crashes, Figure 10 presents what happened after the guide rail was impacted. Over half of all fatal guide rail collisions involved a secondary event – either a second impact or a rollover. Many of these secondary events, e.g. trees, poles, and rollovers, typically carry a much higher fatality risk than a guide rail impact.

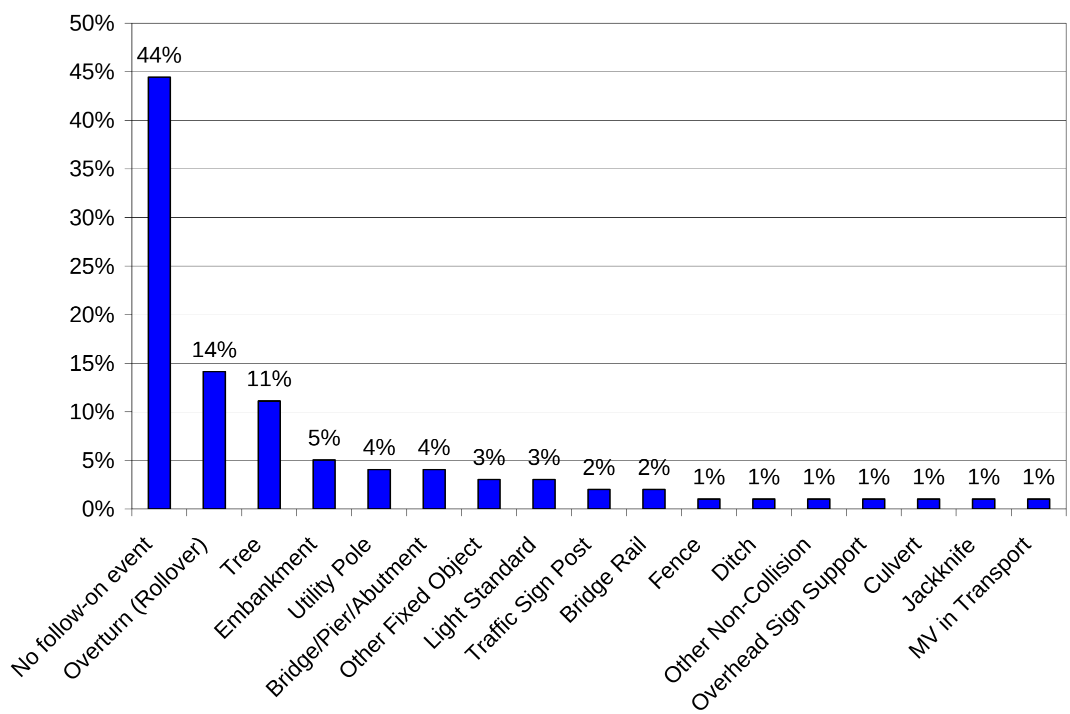


Figure 10. Event occurring after the first guide rail impact (NJCRASH 2003-2005)

Guide Rail as a Potential Rollover Hazard

Figure 10 shows that 14% of all fatal guide rail collisions result in a rollover. One concern raised in the national literature is the possibility that a guide rail could act as a rollover trip hazard. In today's fleet, many light trucks have a center of gravity which is higher than the guide rail. When light trucks collide with guide rail there is a significantly greater chance of guide rail "vaulting" and roll-over [Stephens, 1996; Eskandarian, 2003]. Figure 11 presents an example of a sport utility vehicle (SUV) which vaulted over a guide-rail and then overturned.

Figure 11. Higher Center-of-Gravity SUVs can "vault" a guide rail system. In this 2001 case, a 1992 GMC Suburban became airborne on impact with a W-beam guide rail, overturned, and injured the driver. (Ref: NASS/CDS 2001-75-001)

Motorcycle Rider Fatalities

Motorcycle riders compose a surprisingly high fraction of guide rail fatalities as shown in Figure 12. In New Jersey, motorcycle riders account for over one-fourth of all guide rail crash fatalities. Cars are the most common vehicle involved in fatal guide rail crashes, accounting for approximately half of all fatal guide rail crashes. The light trucks and van (LTV) category, which includes SUVs, pickup trucks and vans, has fewer fatalities than either cars or motorcycle riders.

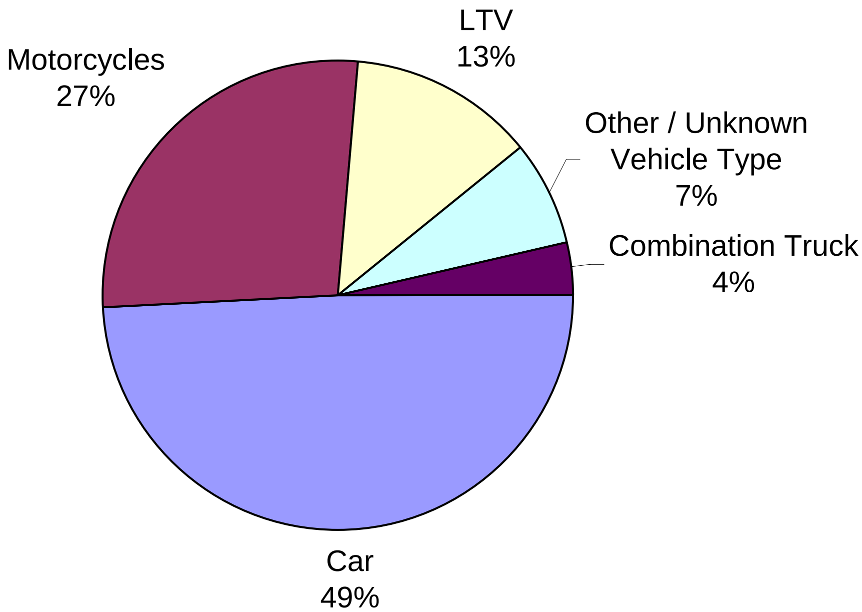


Figure 12. Distribution of NJ Guide Rail Fatal Crashes by Vehicle Type (FARS 2000-2005)

The motorcycle-guide rail crash fatality problem is not unique to New Jersey. Figure 13 presents the distribution of U.S. fatalities by vehicle body type in collisions in which a guide rail impact was the most harmful event. The distribution of fatalities and vehicle registrations are for the 2005 calendar year (NHTSA, 2006).

Nationally, motorcycle riders now account for more fatalities than the passengers of any other vehicle type involved in a guide rail collision. As shown in Figure 13, motorcycle riders accounted for 42% of all fatalities resulting for a guide rail collision in 2005. Following motorcycle riders were car occupants with 32% of all fatalities in this crash mode. This was a particularly surprising finding as cars compose over half of the vehicle fleet (56%) while motorcycles comprise only 3% of the registered vehicles. The occupants of light trucks and vans (LTVs), a category which includes pickup trucks, sport utility vehicles, minivans, and full sized vans, trailed car occupants with 22% of the guide rail crash fatalities and 30% of the registered vehicles in 2005. In terms of fatalities per registered vehicle, motorcycle riders are dramatically overrepresented in number of fatalities resulting from guide rail impacts.

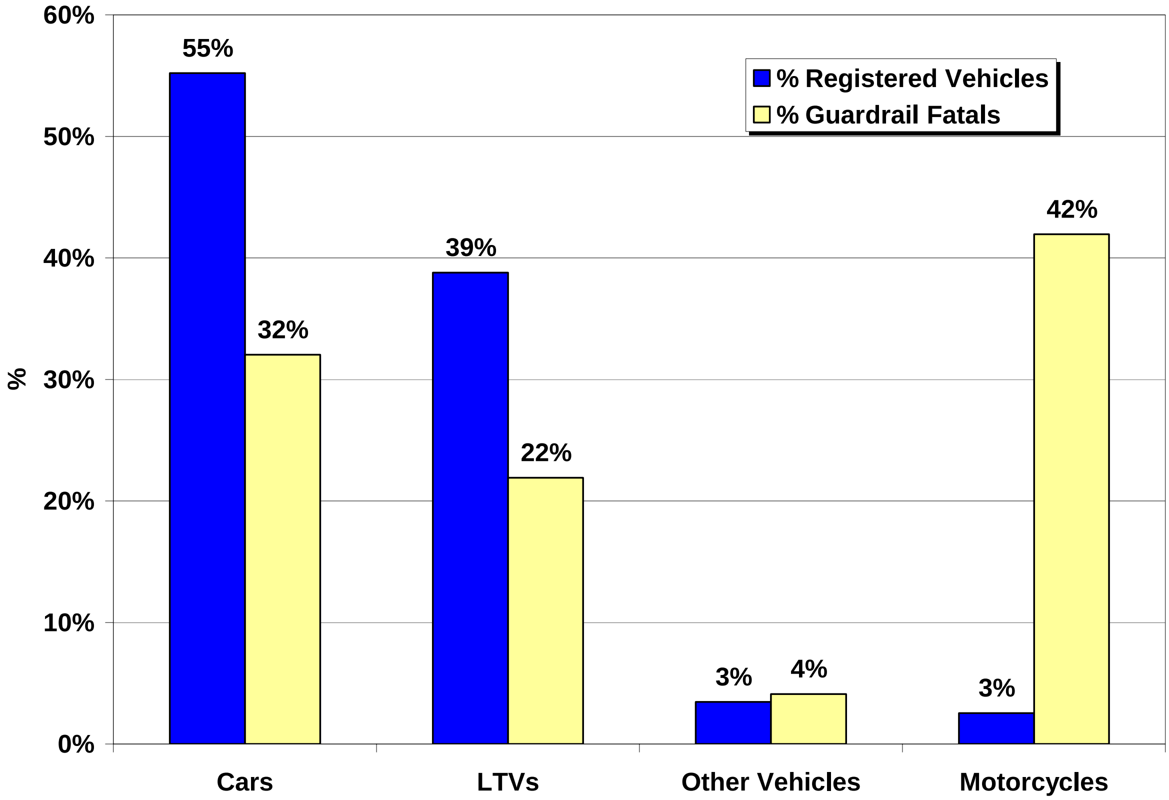


Figure 13. Guide rail Crash Fatalities vs. Registrations by Vehicle Body Type (FARS 2005; NHTSA, 2006)

<u>Side Impacts</u>

Frontal impacts are the most common type of guide rail impact, but side impacts are the most lethal crash mode. Figure 14 presents the distribution of guide rail crashes by crash mode. Frontal impacts account for 65% while side impacts account for 16% of all guide rail crashes regardless of injury severity. For fatal crashes, however, frontal impacts account for 68% while side impacts account for 27% of all fatal guide rail crashes.

Side impacts are overrepresented in terms of fatality risk. Side impacts are only 16% of all crashes, but result in 27% of all fatal guide rail crashes. One would expect that most guide rail would be struck by the front of a car. However, if a vehicle loses control and begins to spin, a non-tracking vehicle may actually strike the guide rail in the side or rear. Particularly dangerous is a side impact to the end treatment of a guide rail. Guide rail end treatments are designed to breakaway under the loads which are typical of a frontal impact. Because the side of a vehicle, unlike the front, has so little structure to protect an occupant, side impacts to a guide rail end treatment can be especially dangerous.

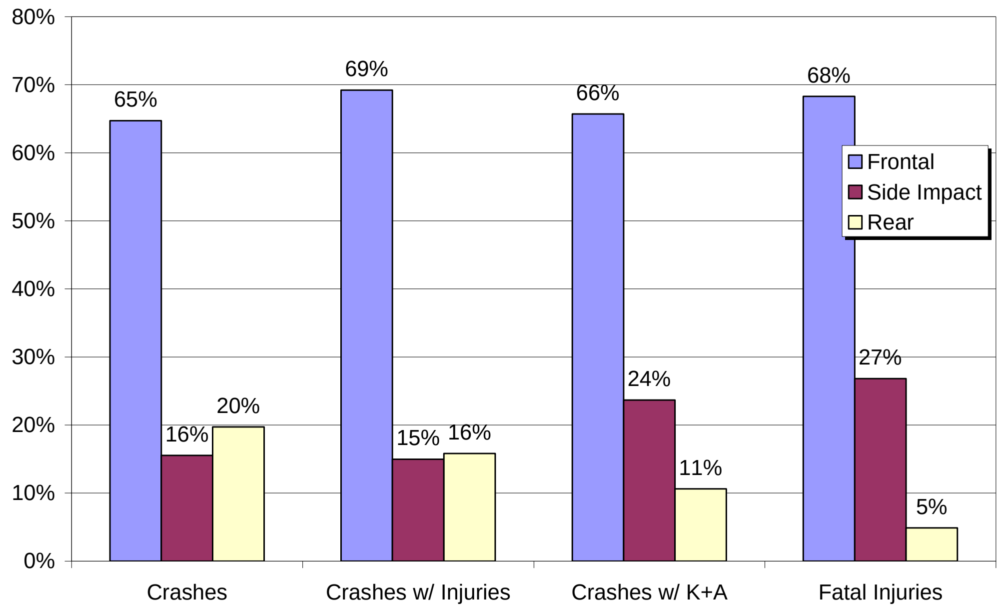


Figure 14. Distribution of Guide Rail Crashes by Crash Mode (NJDOT 2003-2005)

Figure 15 shows the outcome of a side impact of a car into a guide rail end treatment. In this case, extracted from the NHTSA National Automotive Sampling System / Crash Data System (NASS/CDS), a w-beam barrier end treatment speared through the passenger door of a 1999 VW Passat. The right front passenger was seriously injured but survived. The driver was fatally injured.

Figure 15. Guide Rail End treatments are not designed for Side Impact [NASS/CDS Case 2001-81-036]

Conclusions

This analysis has investigated New Jersey crash experience in guide rail collisions. The analysis was based on New Jersey Crash Records from 2003-2005 and FARS 2000-2005.

1. Each year in New Jersey, approximately 10,000 vehicle occupants are exposed to crashes involving a guide rail impact. In crashes in which the guide rail was the most harmful object struck approximately 10-12 persons were fatally injured and 100 persons received incapacitating injuries. Approximately 40 fatal crashes involved a guide rail impact of some nature.

2. In general, guide rail in New Jersey perform well in crashes. Guide rail crashes fortunately result in only a small fraction (1.5%) of New Jersey highway deaths. Three-fourths of all occupants exposed to guide rail crashes suffer no injuries.

3. State highways are overrepresented in serious guide rail collisions. State highways account for 23% of all guide rail crashes, but 30% of all fatal and incapacitating guide rail crashes.

Despite their admirable crash performance, there remain several unresolved issues in guide rail crash safety. Each issue is summarized below:

1. <u>Secondary Impacts.</u> Over half of all fatal guide rail collisions involved a secondary event – either a second impact or a rollover. Many of these secondary events, e.g. trees, poles, and rollovers, typically carry a much higher fatality risk than a guide rail impact.

2. <u>Guide Rail as a Potential Rollover Hazard</u>. In New Jersey, 14% of all fatal guide rail collisions result in a rollover. Although all vehicles can overturn, light trucks having a high center of gravity may be especially at risk. When light trucks collide with guide rail there is a significantly greater chance of guide rail "vaulting" and roll-over.

3. <u>Motorcycles.</u> Motorcycle riders account for over one-fourth of all New Jersey guide rail crash fatalities – a surprisingly high fraction. Nationally, motorcycle riders now account for more fatalities than the passengers of any other vehicle type involved in a guide rail collision.

4. <u>Side Impacts</u>. Frontal impacts are the most common type of guide rail impact, but side impacts are the most lethal crash mode. Side impacts are only 16% of all crashes, but result in 27% of all fatal guide rail crashes. Particularly dangerous are side impacts into guide rail end treatments.

In-Depth Crash Investigations of New Jersey Guide Rail Accidents

INTRODUCTION

This chapter will scrutinize the results of in-depth crash investigations conducted in New Jersey by NHTSA for the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS). NASS/CDS provides a detailed record of a national sample of 4,000 - 5,000 crashes investigated each year by NHTSA at 27 locations throughout the United States. One of the NASS/CDS investigation teams is located in Ocean County, New Jersey.

NASS/CDS provides an unusually in-depth investigation of each crash in the database. Each investigation is documented with over 450 data elements including complete photographic coverage, injury data, vehicle deformation data, and accident scene documentation. The analysis which follows will examine these NASS cases to better understand the crash performance of guide rail in New Jersey.

METHODOLOGY

The analysis was based upon crash records extracted from NASS/CDS 2000-2005. In several of the crashes, the research team was able to extract additional information on the crash site by linking NASS/CDS records with New Jersey Police Accident Reports from the NJDOT Crash Records database. To be included in the study, the crash had to occur in New Jersey and involve at least one guide rail impact. In NASS/CDS, guide rail are classified under Object Contacted as “Other Barrier” to differentiate these objects from “Concrete Barriers”.

The severity of each injury suffered by an occupant is coded in NASS/CDS using the Abbreviated Injury Scale (AIS). AIS ranks the severity of an injury on a 6-level scale in terms of threat to life. The AIS scale varies from a score of 0 for no injury to a score of 6 for a fatal injury. Because an occupant may suffer multiple injuries, It is possible for die from AIS injuries less than 6. Developed by trauma physicians, the AIS scale is widely regarded to be superior to the more KABCO scale for scoring injury severity.

A total of 13 cases met these criteria for inclusion in the analysis. Although not a sufficiently large sample for a statistical analysis, examination of these cases on a case-by-case basis yields important insights into the mechanics and outcomes of guide rail crashes.

RESULTS

Summary of All Cases

Between 2000 and 2005, NASS/CDS investigated a total of 13 guide rail collisions in New Jersey. Table 2 provides a summary of the investigated cases. Half of the vehicles involved were late model vehicles (model year 1999 or newer), while the remainder ranged from model year (MY) 1976 to MY 1993. Five of the vehicles were light trucks, e.g., pickup trucks or SUVs.

Table 2 NJ NASS/CDS Cases Involving Guide Rail

Case	Model Year	Make	Model	Most Harmful Object Contacted	Number Guide Rail Impacts	Max Injury Level (AIS)
NASS-1	2002	Mercury	Sable	Guide Rail	1	0
NASS-2	1993	Toyota	Corolla	Guide Rail	1	1
NASS-3	2000	Toyota	Tacoma	Large Pole	1	0
NASS-4	1993	Ford	Tempo	Other Vehicle	1	5 (Fatal)
NASS-5	2002	Dodge	Dakota	Guide Rail	1	3
NASS-6	2000	Ford	Taurus	Other Vehicle	1	Unknown
NASS-7	1999	GMC	Sierra	Other Vehicle	1	1
NASS-8	1999	Mazda	626	Guide Rail	2	2
NASS-9	1992	Subaru	Legacy	Not specified	1	4 (Fatal)
NASS-10	1999	Hyundai	Elantra	Guide Rail	2	1
NASS-11	1987	Chevrolet	Suburban	Not specified	1	Unknown
NASS-12	1976	Toyota	Land Cruiser	Other Vehicle	1	0
NASS-13	1980	Ford	Fairmont	Concrete Barrier	2	1

Injury. Consistent with the earlier analysis of New Jersey crash records, most cases (9 of the 13 collisions) resulted either in no injury (AIS = 1), only minor injury (AIS = 1) or no injury reported. One driver suffered a moderate injury (an AIS=2 concussion). Another driver suffered an open upper arm fracture (AIS=3). There were two fatal crashes resulting in three fatalities.

Fatalities. In the first of the fatal crashes, the most harmful event was an impact to another car followed by a very minor impact to a guide rail. The driver was 79 years old. In the second of the fatal crashes, an elderly couple (80 and 83) vaulted a non-standard guide rail on a county road and died on impact with a culvert. The advanced age of all three occupants was likely a contributing factor in the fatal outcome of these crashes.

Most Harmful Object. In less than half of the cases (5 of 13), investigators concluded that the guide rail was the most harmful object contacted. In three of the cases, the most harmful object contacted was not specified. In these cases, either the vehicle was not inspected or the most harmful event could not be determined.

Case by Case Analysis

A brief synopsis of each case is presented below. Because NASS/CDS is primarily a vehicle safety database, each case has copious detail on occupant injury and vehicle damage, but little information regarding the barrier struck. Our approach to determine the specific barrier type was to examine the scene photographs. Based on the photographs, all collisions involved strong post w-beam barrier. Three instances of an end treatment impacts were noted and there were four instances where no block outs were present or their presence was unknown.

<u>Case NASS-1</u>: A 2002 Mercury Sable was eastbound on New Jersey State Highway 70 in Brick Township, New Jersey proceeding straight through an intersection. The vehicle drifted toward the median as it was exiting the intersection. The front left of the vehicle struck a w-beam (steel block-outs) guide rail end treatment in the median. The guide rail end treatment redirected the vehicle to continue in the eastbound direction. There was subsequent sideswipe damage to the vehicle on the driver's side. Neither the driver, a 78 year old male, nor the passenger, a 74 year old female had reported injuries. Both occupants were restrained with lap and shoulder belts and there was no airbag deployment. Figure 8 provides images of the vehicle damage and guide rail.

Damaged Barrier

Damage to 2002 Mercury Sable

Figure 8. Barrier and Vehicle Damage in 2002 Mercury Sable – End Treatment Collision

<u>Case NASS-2</u>: A 1993 Toyota Corolla was traveling southbound on Route 549, a county road running through Lakewood Township, New Jersey. The vehicle drifted to the right, exiting the roadway and striking the end treatment of a w-beam guide rail (steel block outs). The vehicle did not continue on past the end treatment. The driver, a 19 year old female, was restrained by both the lap and shoulder belts. The driver's airbag deployed. The occupant suffered only an upper extremity abrasion (AIS 1) attributed to the contact with the airbag. The guide rail is assumed to have performed properly by limiting the amount of injury to the occupant. The guide rail end treatment and damaged guide rail were

replaced before NASS investigators reached the crash site. Figure 9 provides the images of the vehicle and the replacement guide rail end treatment.

Barrier With New End Treatment.

Damage to 1993 Toyota Corolla

Figure 9. Replaced Guide Rail End Treatment and Damage to 1993 Toyota Corolla

<u>Case NASS-3</u>: A 2000 Toyota Tacoma was traveling on Ocean County Road 636, a county road in Jackson Township, New Jersey. The vehicle exited the two-lane roadway to the right as it was negotiating a left curve. The vehicle contacted the w-beam guide rail (no block outs) then began following a path along the guide rail. The vehicle also struck a mailbox and continued on its path to climb a curb and strike a utility pole just off the roadway. The vehicle came to rest against the pole. The driver, a 21 year old male, had no reported injuries. He was restrained by the lap and shoulder belts as well as the deployed airbag. The pole was determined to be the most harmful event. The guide rail had succeeded in returning the vehicle to the roadway, but the driver was unable to negotiate the vehicle away from the roadside following the guide rail contact resulting in the subsequent collisions. Figure 10 provides the images of the barrier and the vehicle damage.

(1) Initial Barrier Contact. (2) Pole Contact

Damage to 2000 Toyota Tacoma

Figure 10. Barrier Damage and Utility Pole Contact (left) and Damage to Vehicle (right).

Case NASS-4: A 1994 Honda Civic was sitting at a red light on State Highway 37 in Dover Township, New Jersey, waiting to continue straight through the intersection. A 1993 Ford Tempo struck the Civic in the rear and both vehicles were forced into the intersection. The Honda Civic came to rest in the center of the intersection and the Tempo continued on through the intersection and exiting to the right side where the vehicle came to rest against a w-beam guide rail (steel block outs). The driver of the Tempo, a 79 year old male, sustained massive injuries to the chest resulting in 3 rib fractures on each side as well as hemothorax and pneumothorax (AIS 5). The driver of the Tempo passed away two days after the crash as a result of his injuries. A determination of which event caused the fatal injuries was not reported. The photographs taken from the scene show no damage to the guide rail at the point of contact and only show minimal paint transfer. We conclude that the injuries were the result of the initial impact with the Honda Civic, and not the guide rail. The guide rail was able to prevent the vehicle from continuing on down the embankment. Figure 11 shows the contact point on the guide rail for the Tempo. No photographs were available for the Ford Tempo.

Figure 11. Barrier which contained 1993 Ford Tempo after striking another vehicle.

Case NASS-5: A 2002 Dodge Dakota was traveling on US 9, a State Highway in Lacey Township, New Jersey. The Dakota was negotiating a left curve and drifted off the roadway to the right. The vehicle struck a w-beam guide rail (wood block-outs) and began to rotate clockwise. The vehicle climbed the guide rail and began to rollover, leading with its left side. The vehicle completed one full rotation and landed on its wheels in a water hazard of approximately four feet in depth. It was not noted whether the driver, a 44 year old male was wearing a seat belt or if the air bags deployed. The driver suffered an open humerus fracture (AIS 3). The guide rail was determined to be the most harmful object. It was determined that the guide rail was unable to contain the vehicle and resulted in the vehicle vaulting the guide rail and causing the vehicle to rollover. Figure 12 shows the guide rail damage and the vehicle damage.

	
Barrier Damage.	Resulting Vehicle Damage to 2002 Dodge Dakota.

Figure 12. Barrier and Vehicle Damage in 2002 Dodge Dakota – Guide Rail Collision

<u>Case NASS-6</u>: A 2000 Ford Taurus was passing through an intersection controlled by a traffic light on Ocean County Road 638 in Jackson Township, New Jersey. A 2004 Toyota Corolla was traveling in the opposite direction and made a left turn at the intersection striking the Taurus in the driver's side. The Corolla struck the Taurus in the left front quarter panel. The Corolla came to rest at the site of impact.

	
Point of Contact with Guide Rail.	Damage to 2000 Ford Taurus on Right Front Corner.

Figure 13. Barrier and Vehicle Damage in 2000 Ford Taurus – Guide Rail Collision

The Taurus continued on, coming to rest after impacting a w-beam guide rail (unknown block-outs) off to the right side, in the original direction of travel. The guide rail produced only minimal damage to the vehicle. The driver of the Taurus, a 43 year old female, and the passenger, a 14 year old male, were restrained by the lap and shoulder belts but no airbags were deployed. The injuries of all occupants were not reported but it was known that they were transported to medical facilities. Judging from the small amount of damage to the vehicle and the guide rail, it is unlikely that the guide rail collision resulted in any injuries that may have occurred. Figure 13 shows the guide contact point and the vehicle damage.

Case NASS-7: A 1999 GMC Sierra was struck by a 1992 Honda Civic which lost control while entering a curve on a two-lane roadway. As a result, the Sierra spun counterclockwise coming to a stop after hitting the strong post w-beam guide rail (steel block outs) on the east side of the road. The belted driver of the Sierra sustained only a minor leg injury (AIS 1). Note that the barrier prevented the vehicle from traversing a steep slope despite being impacted at a splice location. Figure 16 provides images of the vehicle and barrier damage.

	
Damaged Strong Post W-Beam with system	Damaged 1999 GMC Sierra

Figure 16. Barrier and Vehicle Damage in 1999 GMC Sierra – Guide Rail Collision

Case NASS-8: A 1999 Mazda 626 vaulted the median curb and the vehicle front engaged the guide rail located behind the curbing. The guide rail redirected the vehicle across three eastbound lanes of traffic and the vehicle became wedged under the guide rail off the right shoulder of the road. Belted but not subjected to an airbag deployment, the 55 year old driver sustained a concussion (AIS 2). It appears that some conditions may have been pre-existing as the driver blacked out just prior to the crash. Note that both guide rail prevented penetration but the post-impact vehicle trajectory from the first impact was not desirable. Figure 17 provides images of the initially impacted barrier and the resulting vehicle damage.

Median Barrier Damaged in first impact

Damage to 1999 Mazda 626

Damaged Barrier at Final Impact and Rest.

Figure 17. Barrier and Vehicle Damage in 1999 Mazda 626 – Guide Rail Collision

Case NASS-9: The driver of a 1992 Subaru Legacy failed to negotiate a 90-degree right hand curve on a two-lane road. Exiting the road to the left, the vehicle impacted and overrode the guide rail ultimately coming to rest suspended over a spillway of a nearby lake. No airbag was available in the vehicle and investigators could not determine belt usage by either occupant. The 83 year-old male driver suffered AIS 2 level injuries to the face while the 80 year-old female passenger suffered major head trauma (AIS 4). The combination of injuries resulted in fatality for both occupants. Note that there were no block outs present in the guide rail. Figure 18 provides images of the impacted guide rail and final resting place of the vehicle. There were no photos of the vehicle as the vehicle was not inspected.

	
Damaged Guide Rail	Final Resting Place of Vehicle

Figure 18. Guide Rail at the Crash Location of 1992 Subaru Legacy

Case NASS-10: A 1999 Hyundai Elantra lost control while negotiating a U-turn exit. Leaving the roadway to the left, the Hyundai spun and the right side of the vehicle impacted a strong post w-beam median barrier (steel block outs). The 18 year-old belted female driver sustained minor injuries to the head (AIS 1) and minor cuts to the upper and lower extremities. Note that the airbag did not deploy in this collision and that the barrier properly contained the vehicle. Figure 19 provides images of the barrier and vehicle damage.

	
Damaged Median Barrier	Damaged 1999 Hyundai Elantra

Figure 19. Barrier and Vehicle Damage in 1999 Hyundai Elantra – Median Barrier Collision

Case NASS-11: A 1987 Chevrolet Suburban lost control, skidded across an intersection, and struck the right front of a 1993 Buick Skylark traveling in the opposite direction. The Suburban then spun clockwise, and its left side impacted a guide rail end treatment situated on the roadway shoulder. The Suburban was not the subject vehicle and was not inspected by investigators. No information was collected regarding the Suburban or injuries to its occupants. The SRT 350 end terminal performed satisfactorily even though the impacting vehicle most likely was struck on the side. Figure 20 shows the damaged end terminal.

Figure 20. Barrier End Treatment Damage after collision with 1987 Chevrolet Suburban

<ins>Case NASS-12</ins>: A 1976 Toyota Land Cruiser struck the rear of a stopped 2001 Volkswagen Jetta near an intersection. The Land Cruiser then departed the north side of the roadway impacting a strong post w-beam guide rail (no block outs) installed behind a curb. Both occupants of the Land Cruiser were belted (no airbag available) and no injuries were reported. Note that the barrier successfully contained the vehicle. Figure 21 provides images of the vehicle and damaged barrier.

Damaged Barrier	Damage to 1976 Toyota Land Cruiser

Figure 21. Barrier and Vehicle Damage in 1976 Toyota Land Cruiser – Guide Rail Collision

<ins>Case NASS-13</ins>: A 1980 Ford Fairmont station wagon attempted to pass a 1985 Chrysler New Yorker on a two-lane road but clipped the New Yorker on the side in the process. The Fairmont subsequently struck strong post w-beam guide rail (steel block outs) on the right side of the roadway. After redirection, the Fairmont impacted a concrete barrier on the opposite side of the road and came to rest. The unbelted driver of the Fairmont sustained minor injuries (AIS 1) to the face

and a minor abrasion to the arm. Although the guide rail produced an undesirable post-impact vehicle trajectory, the vehicle was successfully contained. Figure 22 provides images of the vehicle damage and guide rail.

Damaged Barrier

Damage to 1980 Ford Fairmont (primarily from concrete barrier)

Figure 22. Barrier and Vehicle Damage in 1980 Ford Fairmont – Guide Rail Collision

Conclusions

The preceding analysis has examined the NASS/CDS in-depth investigation reports of 13 guide rail collisions which occurred in Ocean County, New Jersey between 2000 and 2005. We conclude the following:

- <u>Successful Performance.</u> The guide rail performed well in all but two of the 13 cases. In 10 cases, the guide rail either redirected the vehicle back onto the highway or prevented the vehicle from a much more dangerous collision, such as traversing a steep side slope or entering a body of water.

- <u>Guide Rail Vaulting.</u> In one collision, a mid-size pickup truck vaulted a guide rail after impact, rolled over and ended up in a marsh. The driver suffered a serious injury. This case is an unfortunate example that illustrates previous research which has shown that guide rail can act as a rollover trip hazard for light trucks.

- <u>Fatalities.</u> The data set contained two fatal crashes resulting in three fatalities. In the first of the fatal crashes, the fatal injuries were the result of impact to another car followed by a very minor impact to a guide rail. The driver was 79 years old. In the second of the fatal crashes, an elderly couple (80 and 83) vaulted a non-standard guide rail on a county road and died on impact with a culvert. The advanced age of all three occupants was likely a contributing factor in the fatal outcome of these crashes.

Field Investigations of NJ Guide Rail Crash Sites

Introduction

One objective of this research program was to determine how guide rail are performing in New Jersey through field investigations of these crash types. To achieve this objective, a crash investigation team was formed to conduct investigations of damaged guide rail on state and interstate roadways in New Jersey. In conjunction with New Jersey State Police, a crash notification structure was developed to inform the investigation team of impacts to guide rail. For each impact, the investigation was performed according to the developed data collection plan. The findings of each investigation were summarized in a crash investigation report and the associated data stored in a database developed specifically for guide rail crashes. A special focus was on police reported collisions since these are more likely to test the upper performance limits of the guide rail and reveal potential problems.

This section describes the development of the accident notification plan, the data collection plan, the Guide Rail Crash Performance Database, and the results of the investigated crashes.

Guide Rail Crash Notification Plan

The purpose of this section is to present the notification scheme for impacts to guide rail in New Jersey.

Development of Notification Process

Before a guide rail crash can be investigated, the research team must be notified that a crash has taken place. Establishing a reliable system of accident notification has proven to be one of the more challenging aspects of this project. The research team has explored several notification schemes, listed below, as potential candidates for a reliable notification scheme.

- NJDOT Traffic Operations Email Notification
- Crash Investigation Team Scouting
- NJDOT Maintenance/Maintenance Contractors
- Tow Truck Operators/Towing Companies
- New Jersey State Police

NJDOT Traffic Operations Email Notification. The first scheme involved crash notification through electronic mail from NJDOT traffic operations. This division of NJDOT monitors traffic conditions throughout the state and maintains an email listserv to notify interested parties (including other DOT members and media) of locations where traffic incidents have caused a traffic backup or at least one lane closure. Although a majority of the causes are crash related, other conditions such as construction, ice and flooding are reported by this mechanism. Typically, two messages are sent for each incident: an initial notification indicating the event has occurred and a second notification indicating that it has been cleared. Each email notification includes the time, location (roadway, direction, milepost, and county), brief description of the incident, traffic delay description, and estimated duration to clear the incident.

The research team monitored these electronic mail notifications daily for crashes with guide rail involvement noted in the description. Although there were a large number of email notifications, there were only an extremely limited number of guide rail crashes discerned from the incident descriptions (less than 0.2 percent). In approximately one month, there were a total of 793 crash notifications with only one indicating a guide rail impact noted in the incidence description. There were two hypothesized explanations for the low prevalence of guide rail collisions: (1) guide rail collisions typically occur in the shoulder or median and thus may not cause a traffic delay and may not be reported via this mechanism, or (2) guide rail impacts that caused a delay were simply described as a “motor vehicle accident” in the description making this crash mode indistinguishable from any other crash mode.

Crash Investigation Team Scouting. To test the second hypothesis, the research team selected a three-county area and performed drive-by investigations of the NJDOT traffic operations collision notifications. The three county areas consisted of Gloucester, Camden and Burlington and the investigations were performed over approximately a one month period. There were 72 sites “scouted” by the investigation teams, none of which indicated a guide rail impact in the notification. Only 2 sites were found to have guide rail damage, both of which were deemed infeasible to investigate due to location with respect to traffic. Because of the expense of traveling to each site and the limited return in terms of guide rail impacts, this avenue was not pursued any further.

NJDOT Maintenance/Maintenance Contractors. Concurrently with the NJDOT traffic operations notification and investigation team scouting efforts, the research team developed contacts with NJDOT maintenance personnel and guide rail repair contractors. The research team again concentrated on the smaller three-county area. Based on our conversations with maintenance personnel, maintenance crews in many districts in New Jersey routinely patrol the roadways for damaged infrastructure. These routine inspections coupled with notification from state and local police departments appear to be the primary mechanisms that NJDOT personnel are alerted of damaged guide rail sections. Unfortunately, this notification avenue was not as fruitful as originally hoped.

Tow Truck Operators/Towing Companies. Another potential notification avenue explored by the research team involved local towing companies and tow truck drivers. The scheme consisted of tow truck drivers or their respective companies being remunerated for phoning in a notification of a guide rail collision on a state or interstate roadway in New Jersey. Ideally, the tow truck drivers would be at the scene of a guide rail crash that had required a vehicle be towed due to damage. A total of 26 local towing companies were visited to advertise this initiative through both word of mouth and informative flyers. Over the course of two months there were only 2 crash notifications via this avenue, one of which did not have noticeable barrier damage. As such, this avenue was also no longer pursued.

New Jersey State Police. The most effective notification avenue has been the New Jersey State Police (NJSP). A majority of the guide rail impacts investigated in this project have been a result of notification by the NJSP. On a weekly basis, the NJSP would notify the research team of the location of recent police-reported collisions involving guide rail. The effort was concentrated on three separate state police stations, Woodstown, Bellmawr, and Bordentown, located in southern and central New Jersey. In terms of roadway coverage, the area included roughly 40 miles of the Interstate 295 corridor, a portion of State Route 42, and a small portion of Interstate 76 and 676. Information sent weekly is summarized in Table 3.

Table 3. NJSP Notification Data Summary

Category	Data Element
General	Police case number
	Crash date
	Road condition/weather
Location	Route number/name
	Direction of travel
	Mile post
Occupant	Age
	Gender
	Restraint Use

Response Logistics

After a crash notification has been made, a team of a least two investigators would visit the site and determine if an investigation was feasible. To be feasible for investigation, a site must have a guide rail still in a damaged state and be safe enough for the investigators to access. Many of the potential crash sites were in narrow medians or near the travel ways. We emphasized repeatedly that they should not attempt an investigation that would in anyway put them in peril. If a full investigation was not feasible, the investigators would document the site only with one or more photographs, if possible. If a full investigation was feasible, the investigators would begin the data collection process. Each investigation team was equipped with the proper onsite inspection tools including safety gear, various measuring instruments, and a digital camera.

Data Collection and Forms

In the event that a full site investigation was feasible, the research team would perform a detailed site investigation. This section presents the data collection protocol to be utilized during each site investigation. Data collected from onsite inspections were analyzed to evaluate the effectiveness of guide rail systems in New Jersey. Onsite data collection can be broken out into three main categories: general site information, site photography, and barrier performance measures. A description of the data elements collected is provided below. A copy of the data collection forms can be found in the appendices.

General Site Information

This information is intended to provide details about the guide rail, the crash and the roadway where the crash occurred. Table 4 is a list and brief description of each of these data elements. Note that these elements span three of the data collection forms in the appendices: General Site Inspection Form, Crash Details Form, and Barrier Data Form.

Table 4. General Site Information

Data Element	Description
Route Number	Route number where crash occurred.
Mile Post	Mile post nearest the crash location.
Date	Date of crash site inspection.
Date of Impact	Date of collision (if known).
Name of Investigator	Name of persons performing the inspection.
Number of Lanes	Total number of lanes in each direction.
Direction of Travel	Direction of travel where crash occurred.
Roadway Type	Roadway type/classification (e.g. state highway)
Speed Limit	Roadway authorized speed limit (mph)
Number of Posts in Damaged Section	The total number of posts encompassing the crash site including the first and last reference posts.
Location of Reference Post	Distance and direction that the first and last reference posts are located from a known mile post. The first reference post should be the closest undamaged post before the impacted section. The last reference post should be the closest undamaged post after the impacted section.
Rail Type	Type of barrier rail (W-beam, thrie beam, etc).
Rail Height	Total distance (inches) from the ground to rail top.
Post Type	Type of barrier post (i.e. S3x6 weak post). Include type of footing (i.e. soil, concrete) if different from shoulder type.
Post Spacing	Fill in the distance (inches) between barrier posts.
Blockout Type	Fill in blockout type (if applicable).

Table 4. General Site Information (Continued)

Data Element	Description
End Terminal Type	Fill in end terminal type (if applicable).
Shoulder Type	Shoulder material (asphalt, soil, or other).
Post Rail Connection	Connection type joining rail and post (bolt type).
Standard Installation	(Yes/No) Barrier to current NJDOT standards?
Police Report	(Yes/No) If yes, include report number.
Guide Rail Location	Barrier location with respect to roadway (e.g. right shoulder)
Guide Rail Purpose	Apparent warrant for the barrier (e.g. steep slope)
Upstream End	Description of upstream barrier termination (e.g. type of end terminal, transition to other barrier, or other)
Downstream End	Description of downstream barrier termination (e.g. type of end terminal, transition to other barrier, or other)
Shoulder Width	Width of shoulder (feet)
Roadside Slope	Characterize slope of shoulder and roadside behind barrier. Figure and slope measurements as necessary.

If a police report was available for a particular guide rail crash, additional information was collected. These supplementary data elements are summarized in Table 5. All of these data elements were entered on the Crash Details form, if the police report was available and the information was coded by the officer.

Table 5. Supplementary General Site Information

Data Element	Description
Weather Condition	Weather at the time of the crash.
Vehicle Type	Vehicle make and model.
Vehicle Year	Vehicle model year.
Total Occupants	Total number of occupants present in vehicle.
Seat Belt Use	(Yes/No) Note for driver and most severely injured occupant
Airbag Present	(Yes/No) Note for driver and most severely injured occupant
Airbag Deployed	(Yes/No) Note for driver and most severely injured occupant
Driver Injury Severity	Police-reported injury severity of driver (KABCO scale).
Highest Injury Severity	Police-reported injury severity of most severely injured occupant (KABCO scale).

Photography

Although they are not directly used in statistical analyses, photographic images are crucial to the accident reconstruction process. Investigators should document the following with photographs:

1. *General Scene and Impact Site*: Photograph the impact site and general scene, including roadway images up and downstream of the collision site. This will provide information about the general roadway environment and the relative location of the traffic barrier. Include an approach shot on the General Site Inspection Form and additional photos (with descriptions) on the Supplemental Photo Data Form.

2. *Guide Rail Post and Component Damage*: Photograph the crash site including pictures of individual damaged posts. Each post should be identified with a number. Include these in the Component Details Forms with the damage information collected for each post.

3. Photograph any tire marks or unusual terrain conditions that would indicate a crash. Due to the unique nature of each crash, it is important to photograph any other distinctive characteristics that may be present at the crash site. Include any of these photos on the Supplemental Photo Data Form.

Barrier Performance Measures

These measurements/descriptions are intended to provide detail regarding the performance of the guide rail during the impact. Table 6 is a list and brief description of each of these data elements. Note that these elements span three of the data collection forms in the appendices: General Site Inspection Form, Crash Details Form, and Component Details Form.

Table 6. Barrier Performance Data Elements

Data Element	Description
Description of Damaged Area	Fill in the number of damaged posts encompassing the crash, direction the vehicle was traveling, and whether the barrier redirected the vehicle. Note any unusual circumstances or observations.
Location of Impact	Distance and direction of first damaged component from reference post #1.
Angle of Impact	The approximate angle that the vehicle was traveling just before impact (with respect to the barrier). Note what evidence was used to calculate the impact angle (skid marks, tire ruts, or other).
Barrier Penetration	(Yes/No) Did the vehicle penetrate the barrier?
Max Deflection at Rail Height	Maximum rail and/or post deflection at rail top (inches)

Table 6. Barrier Performance Data Elements (Continued)

Data Element	Description
Max Deflection at Ground Line	Maximum post deflection at ground line (inches)
Number of Posts Snagged	Number of posts where vehicle snagging is apparent (if applicable)
Number of Failed Splices	Number of failed splice connections (if applicable)
Total Damaged Length	Damaged barrier length (feet)

Guide rail performance data was also collected for each damaged post. Table 7 is a list and brief description of each of these data elements.

Table 7. Component Details Form

Data Element	Description
Post Number	Assign post number based on reference post.
Deflection at Rail Height	Deflection of post top (inches) parallel and perpendicular to barrier orientation.
Deflection at Ground Line	Deflection of post at ground line (inches) parallel and perpendicular to barrier orientation.
Backup Plate/Splice	Presence of backup plate or splice location indication.
Angle Between Post and Ground	Use digital level to measure the angle between the post and the ground. (vertical post = 90˚)
Post-Blockout Connection	Document connection (bolt type and number)
Rail-Blockout Connection	Document connection (bolt type and number, washer presence)
Description of Damage to Post	Qualitative description of the damage to the post (including bending, shear, and torsion).
Connection Failure	Any connection failures?

Results of Field Investigation

<u>Guide Rail Crash Investigation Summary</u>

The research team has performed 26 full site investigations of guide rail crashes in New Jersey between March 2004 and December 2006. There were a total of 19 impacts involving guide rail length of need and 7 involving guide rail end terminals. For eight of the guide rail impacts, the research team was able to obtain the Police Accident Report (PAR). A majority of the investigations were performed on steel strong post w-beam barriers (19 of 26). The blockout types were primarily steel and wood (11 steel, 11 wood) with the remainder being recycled plastic (3 sites) or none present. Location of the barriers with respect to the roadway was typically the right shoulder (16 sites) with the remainder located in the median (8 sites) and on exit ramps (2 sites). The average barrier offset from the edge of the closest travel lane was 14.5 feet. Post anchorage was predominately in soil (19 sites) with the remainder in asphalt (6 sites) or isolated concrete buckets (1 site).

Table 8 summarizes the average vehicle impact angle and resulting barrier damage parameters. The average vehicle impact angle was 19 degrees but note that the investigation teams were only able to discern this quantity in 11 of the investigated collisions. The average number of damaged posts was 7 with an average damaged barrier length of 60 feet. Maximum barrier deflection was 18 inches on average. Note that the maximum deflection was considered meaningless in cases where the rail was penetrated (no longer continuous) or the end terminal gated properly.

Table 8. Vehicle Impact Angle and Barrier Damage Summary

Quantity	Average	Range	Number of Cases
Vehicle Impact Angle	19°	7° to 30°	11
Number of Damaged Posts	7	1 to 27	26
Maximum Deflection	18 inches	2 to 48 inches	21
Damaged Length	60 feet	3 to 400 feet	26

For the 19 length of need impacts investigated, barrier penetration was observed in a single case involving a tractor trailer impact. In two other instances, a strong post w-beam guide rail was able to contain and redirect a tractor trailer. Roughly 40 percent (7 cases) of the length of need crashes resulted in a secondary collision. In 5 cases, the vehicle struck the same guide rail at another point downstream while in 2 cases the vehicle was redirected across the roadway. Injury data was available for 5 of the collisions, with no injury reported in 2 cases. The other 3 crashes involved two instances of occupant complaining of pain and a single case with moderate injury (head laceration).

Of the 7 end terminal crashes investigated, 5 involved Slotted Rail Terminals (SRT 350, Trinity), one involved a Connecticut Attenuating Terminal (CAT 350), and one Modified Eccentric Loader Terminal (MELT). No vehicle spearing was noted in any of the cases. Injury data was available for 3 of the collisions with no injury reported in two cases. The third involved vehicle overturn and subsequent driver fatality.

During the field data collection time period, the research team has also collected photographic images of damaged barrier at 25 locations during cursory investigations. A cursory investigation refers to one where the investigation team only captured photographic information of the damaged guide rail site (i.e. the team was not able to perform a full investigation due to damaged barrier location). This information can be found in the NJ Guide Rail Crash Performance Database and has not been included herein. A copy of the NJ Guide Rail Crash Performance Database is available separately, on a DVD.

Individual Case Synopsis

A brief synopsis of selected crash site investigations are provided below.

I-295 NB MP 28.3: A tractor trailer traveling on I-295 southbound (SB) crossed the unprotected median and impacted the strong steel post w-beam barrier (steel blockouts) shown in Figure 23. The unidentifiable end terminal (most likely a breakaway cable terminal) and roughly 400 feet of guide rail was damaged; the impacting heavy vehicle penetrated the guide rail and impacted the sound-wall that the guide rail was shielding. As the strong post w-beam barrier is tested to NCHRP test level 3, it is not designed to redirect heavy vehicles such as tractor trailers.

Figure 23. Strong Steel Post Barrier Damage at I-295 NB MP 28.3

I-295 NB MP 46.1: A vehicle traveling northbound (NB) on I-295 left the roadway and impacted a modified eccentric loader terminal (MELT) at approximately 15 degrees (tire tracks evident in soil). The terminal appeared to break away as intended, damaging only three posts. The breakaway wooden posts of the terminal were anchored in concrete buckets, presumably due to the high moisture condition of the soil in the area.

I-295 NB MP 32.2: A single breakaway post of a flared SRT 350 end terminal was sheared at the ground line with less than an inch of rail deflection. The end terminal provided safe termination of a strong steel post w-beam barrier (recycled plastic blockouts) in place to shield a densely wooded area. Despite the small amount of rail deflection, markings on the w-beam face suggest a vehicular impact.

I-95 SB MP 6.3: A tractor trailer heading southbound on I-95 departed the roadway on the left and impacted a strong steel post w-beam barrier (steel blockouts) protecting an overhead sign support in the median. Based on tire ruts left at the scene, the impact angle was determined to be approximately 15 degrees. Although the barrier has not been designed to redirect heavy vehicles, it appears that the tractor trailer was brought to a controlled stop. A total of 150 feet of barrier was damaged.

Figure 24. Barrier Damage at I-95 SB MP 6.3

I-95 NB MP 8.1: The driver of a four door passenger sedan traveling northbound on I-95 lost control, departed the roadway on the left, and impacted a CAT 350 end terminal (shown in Figure 25) causing damage to the front of the vehicle. Approximately 32 feet of guide rail was damaged due to the impact. Based on the field investigation, the end terminal appeared to break away as intended with no evidence of vehicle spearing. According to the PAR, both occupants of the vehicle reported no injuries.

Figure 25. CAT 350 End Terminal Damage at I-95 NB MP 8.1

I-295 SB MP 14.3: A steel strong post w-beam roadside barrier (steel block-outs) located in the median (see Figure 26) was struck in two locations by a small passenger vehicle. The median width varies but is approximately 10 feet at the impact location and there is roughly a four foot differential in vertical alignment of the north and southbound lanes resulting in a 3:1 (H:V) slope of the median toward the southbound lanes. Note that the posts of the barrier were anchored in bituminous material. Based on tire marks on the pavement, the vehicle struck the barrier first at a 25 degree angle and then a 40 degree angle. There was no penetration in either case. Maximum barrier deflection was 20 inches for the 32 feet (7 post section) of total barrier damaged.

Figure 26. Barrier Damage at I-295 SB MP 14.3

I-295 NB MP 64.5: A passenger vehicle traveling on I-295 NB departed the roadway to the right and impacted a strong steel post w-beam guide rail (steel blockouts) in two locations, first with the front of the vehicle followed by the rear of the vehicle. Barrier damage resulting from the second impact is shown in Figure 27. A total of 27 feet of barrier was damaged with a maximum deflection of 6 inches. Based on the PAR, there were no injuries sustained by the driver of the vehicle.

Figure 27. Secondary Impact Damage at I-295 NB MP 64.5

I-295 SB MP 8.2: An SRT 350 terminal, located on the right shoulder, was struck by a non-tracking small passenger vehicle at an angle of approximately 17° (determined from tire skid marks). The guide rail is anchored in bituminous material and offset approximately 3 feet from the end of the 12 foot shoulder (15 feet from the edge of the southbound right lane). The pavement slope to the barrier follows the crown in the road and is approximately 13:1 (H:V). The grass area behind the barrier has a steeper slope, approximately 3.5:1 (H:V), followed by a reverse in slope of the same magnitude.

As designed, the posts of the terminal failed allowing penetration of the vehicle without the rail penetrating the occupant compartment. After the barrier impact, however, the vehicle rolled. The location of the tire marks suggest that the strut located between post 1 and 2 of the end terminal may have aided in tripping the vehicle as it was sliding sideways. Approximately 35 feet (9 post section) of barrier was damaged, which comprises essentially the entire end terminal. Note that based on the inspection of the damaged section the end terminal appeared to be installed to standard with the exception of the rail height (25 inches as opposed to 27.5 inches).

Figure 28. SRT 350 Damage Resulting in Vehicle Rollover and Driver Fatality on I-295 SB

CR 551 EB MP 9.9: A vehicle impacted a non-standard strong post w-beam guide rail (see Figure 29) installed along the south roadside of County Route 551 (undivided, rural, 2-lane roadway). The purpose of the barrier was to shield vehicles from a concrete box culvert and associated stream. Boxing glove-type end terminals (without cable anchorage) provide a terminus for each end of the 60-foot barrier. The barrier is installed a slope of approximately 3:1 (H:V) with total length 8.5 ft; this slope abuts a near flat slope.

Figure 29. View of Damaged End Terminal (Left) and Failed Splice Location (Right)

Although the exact impact location could not be determined, the impact location appeared to be in close proximity to the eastbound end terminal location. The total length of the guide rail damaged was 47.2 feet and the maximum deflection was approximately 3 feet (at rail height). Based on site evidence, there was no penetration of the barrier despite the soft soil conditions evident at the site and the non-standard barrier installation. Also, there was no evidence that any portion of the vehicle contacted the top of the concrete culvert.

<u>I-295 NB MP 41.6</u>: A vehicle traveling northbound on I-295 departed the roadway to the right and impacted a length of need section of steel strong post (wood blockouts) barrier installed on the right shoulder. The guide rail is anchored in soil and offset approximately 2 feet from the end of the 12 foot shoulder (14 feet from the edge of the northbound right lane). The intent of the barrier is to shield a steep side slope (approximately 2.5:1) and, based on the inspection, appeared to be installed to NJDOT standards.

Figure 30. Barrier Damage at I-295 NB MP 41.6: View from South

Based on the inspection, the barrier appeared to perform correctly; there was no indication of penetration by the vehicle and two of the posts broke away from the rail to allow for rail to remain engaged with the vehicle. The vehicle type is unknown; however, based on the damage was most likely a passenger vehicle. No tire marks were present at the scene to determine the impact angle. Approximately 36 feet (7 post section) of barrier was damaged with a permanent deflection of approximately 2 feet.

I-295 NB MP 25.1: A vehicle traveling on northbound I-295 departed the roadway to the left and impacted a length of need section of steel strong post (steel blockouts) barrier installed in the median (see Figure 31). The intent of the barrier is to shield the concrete columns supporting a roadway overpass (CR 47). The guide rail is anchored in bituminous material and offset approximately 17 feet from the edge of pavement of the northbound lanes. The depressed grassed median area has a slope of approximately 13:1 (H:V). Based on the inspection, the barrier appeared to be installed to NJDOT standard specifications.

Based on the inspection of the damaged section, the barrier appeared to perform correctly; there was no indication of penetration by the vehicle and four of the posts broke away from the rail to allow for rail to remain engaged with the vehicle. Severe damage to the posts was observed due to the relatively stiff bituminous anchor material. Based on the tire marks at the scene, the vehicle impacted the barrier roughly at an angle of 24 degrees. Approximately 30 feet (6 post section) of barrier was damaged with a permanent deflection of approximately 1.5 feet.

Figure 31. Barrier Damage at I-295 NB MP 25.1

I-195 WB MP 0.14: Damage to an SRT 350 installed along the left shoulder of the exit ramp from I-195 West (MP 0.14) to I-295 North was investigated. The impacted end terminal is attached to the upstream end of a strong steel post (steel blockout) w-beam barrier intended to shield vehicles from a steep slope. The barrier is anchored in a soil and gravel combination. Note that based on the inspection of the damaged section the barrier appeared to be installed to standard specifications.

Figure 32. SRT 350 Damage at I-195 WB MP 0.14

The end terminal appeared to contain the encroaching vehicle. Based on the evidence at the scene, the barrier appeared to be hit from the reverse side (although no tire marks were present to confirm this hypothesis). Approximately 30 feet (9 post section) of barrier was damaged with a permanent deflection of approximately 1 foot towards the edge of pavement. A total of 3 posts were sheared completely at or below the ground line, 1 was fractured at the ground line, and the remaining posts sustained only blockout or rail movement.

SH-42 SB MP 12.2: A passenger vehicle traveling southbound on State Highway 42 departed the roadway to the right and impacted a length of need section of steel strong post w-beam roadside barrier (steel block-outs) in two locations. The barrier face is offset 12 feet from the edge of the rightmost travel lane and the slope of pavement leading is sloped approximately 2% towards the barrier. The barrier was anchored in bituminous material and appeared to be installed to NJDOT standard specifications.

Based on inspection, the barrier appeared to perform correctly; there was no indication of penetration by the vehicle. The barrier was struck in two locations (roughly 15 feet apart) by the same vehicle. The impact angle could not be determined by the evidence at the scene but it appears that the vehicle struck the barrier first with the front and then spun and contacted again with the rear of the vehicle. Both impacts had little evidence of post damage with most of damage primarily limited to the rail element. Approximately 12 feet (two 2 post sections) of barrier were damaged with a permanent deflection of 10 inches and 4 inches, respectively.

Figure 33. Initial Impact (Foreground) and Second Impact (Background) at State Highway 42 SB MP 12.2

<u>I-295 SB MP 43.9</u>: A tractor trailer traveling southbound on I-295 departed the roadway to the right and impacted a length of need section of steel strong post w-beam roadside barrier (steel block-outs). The guide rail is anchored in soil and the rail is offset approximately 5 feet from the edge of the pavement for the entire damaged length. Note that based on the inspection of the damaged section the barrier appeared to be installed to standard specifications with the exception of 4 posts in which no evidence of bolts could be found.

Figure 34. Barrier Damage at I-295 SB MP 43.9

Based on inspection, the barrier appeared to perform correctly; there was no indication of penetration by the vehicle. The w-beam was struck in two locations along a 362.5 ft. (61 post section) length of barrier with a permanent deflection of 16 inches in the first location. There was additional damage farther down the rail; however at the time of inspection it could not be determined if this damage was from the same crash. A total of 19 posts were bent, at least 2 posts were snagged, and the rail was torn at 5 posts. The impact angle could not be determined from the evidence at the site.

I-295 NB MP 19.3: A damaged length of need section of steel strong post w-beam median guide rail (steel blockout) in the median (see Figure 35). The intent of the barrier is to prevent vehicles from crossing into the opposing lanes of traffic and/or impacting a nearby concrete overpass pier. Note that based on the inspection of the damaged section, the barrier appeared to be installed to standard specifications.

Figure 35. Barrier Damage at I-295 NB MP 19.3

Based on inspection, the barrier appeared to perform correctly; there was no indication of penetration by the vehicle. The w-beam was struck in one location and most of the damage was restricted to the rail element. Skid marks at the scene indicate an impact angle of approximately 17 degrees. No significant damage to any posts was observed. Approximately 12.5 feet (3 post section) of barrier was damaged with a permanent rail deflection of 6 inches.

I-295 NB MP 41.3: A small passenger vehicle was traveling northbound on I-295 in the center lane. Vehicle swerved to avoid hitting another vehicle and lost control striking the strong post steel w-beam guide rail with the front of the vehicle, damaging a total of 3 posts. The rail was not significantly deflected, and the maximum post deflection was 24 inches. Vehicle did not penetrate the barrier and there was no secondary collision. The PAR indicated the driver sustained an injury based on a complaint of pain.

Figure 36. Barrier Damage at I-295 NB MP 41.3

<u>SH-42 SB MP 13.0</u>: A damaged length of need section of steel strong post (steel blockouts) barrier installed on the right shoulder of the southbound lanes of SH 42 (MP 13.0). The guide rail is anchored in soil and offset approximately 1 foot from the edge of the 15 foot paved shoulder (16 feet from the edge of the southbound right lane). The intent of the barrier is to shield a steep side slope and body of water. Note that the slope is mild (13:1 – equivalent to the shoulder slope) until approximately 5 feet behind the barrier. Also, the barrier appeared to be installed to standard specifications (although the rail height was on the lower end of the acceptable range).

Figure 37. Damage from First Impact at State Highway-42 SB MP 13.0

Based on the inspection, the barrier appeared to perform correctly; there was no indication of penetration. The PAR indicated that the 2005 Chevrolet Equinox impacted the barrier on the right shoulder and then was redirected across all 4 lanes and impacted the w-beam barrier in the median (Damage to the median barrier was observed but not inspected due to site inaccessibility). The tire marks evident on the shoulder indicated an impact angle of 18º. Approximately

14 feet (4 post section) of barrier was damaged with a mild permanent deflection of 6 inches. The lone driver was reported to be restrained by manual belts and a deployed airbag. Based on the relatively minor damage to the site investigated, the research team speculates that the secondary event prompted the deployment. Note that the driver sustained a moderate injury (laceration) to the head.

Conclusions

The following conclusions are evident based on the field investigation of 26 guide rail crashes in New Jersey:

1. In general, guide rail appears to be performing adequately.
2. Occupant injury is typically minor, if any, unless the vehicle subsequently rolls over.
3. Secondary collisions still appear to be a problem.
4. Although not designed for heavy vehicles, guide rail can provide some redirection capabilities for this class of vehicle

Conclusions

The goal of this study was to evaluate fatal and injury-causing guide rail accidents in New Jersey. The project has investigated this issue through the combination of a comprehensive literature survey, examination of U.S. and state accident databases, and site investigation of guide rail crash sites. Following are the research program conclusions

Survey of Literature and Ongoing Research

The reasons why guide rail impacts sometimes lead to fatality or injury are complex and not completely understood. Guide rail crash performance is the subject of active research both nationally and at the state level. Guide rail problems include, but are not limited to, many of the following issues (1) improper installation, (2) impacts with end treatments, (3) unfavorable roadside conditions, e.g. soft soil or excessive side slope (4) side impact, (5) improper redirection after a crash, (6) wheel snagging, and (7) secondary impacts with fixed objects. Guide rail performance can be affected not only by barrier design, but also by vehicle design. Poor guide rail performance may result from (1) light trucks overturning on impact with guide rail, (2) cars “submarining” under the rail, (3) airbag-induced injuries, and (4) incompatibility with heavy trucks.

Analysis of NJ Crash Records

This analysis has investigated the crash performance of guide rail in New Jersey. The analysis was based on New Jersey Crash Records from 2003-2005 and FARS 2000-2005.

1. Each year in New Jersey, approximately 10,000 vehicle occupants are exposed to crashes involving a guide rail impact. In crashes in which the guide rail was the most harmful object struck approximately 10-12 persons were fatally injured and 100 persons received incapacitating injuries. Approximately 40 fatal crashes involved a guide rail impact of some nature.

2. In general, guide rail in New Jersey perform well in crashes. Guide rail crashes fortunately result in only a small fraction (1.5%) of New Jersey highway deaths. Three-fourths of all occupants exposed to guide rail crashes suffer no injuries.

3. State highways are overrepresented in serious guide rail collisions. State highways account for 23% of all guide rail crashes, but 30% of all fatal and incapacitating guide rail crashes.

4. The State of New Jersey does not have an unusually high percentage of guide rail fatalities. New Jersey ranks only 20th among the states in terms of guide rail fatalities as a percentage of all traffic fatalities

In-depth Crash Investigations

The study has examined the NASS/CDS in-depth investigation reports of 12 guide rail collisions which occurred in Ocean County, New Jersey between 2000 and 2005. We conclude the following:

- Successful Performance of Guide rail. The guide rail performed well in all but two of the 13 cases. In 10 cases, the guide rail either redirected the vehicle back onto the highway or prevented the vehicle from a much more dangerous collision, such as traversing a steep side slope or entering a body of water.

- Guide rail vaulting is a problem. In one collision, a mid-size pickup truck vaulted a guide rail after impact, rolled over and ended up in a marsh. The driver suffered a serious injury. This case is an unfortunate example that illustrates previous research which has shown that guide rail can act as a rollover trip hazard for light trucks.

- Fatalities have several contributing factors. The data set contained two fatal crashes resulting in three fatalities. In the first of the fatal crashes, the fatal injuries were the result of impact to another car followed by a very minor impact to a guide rail. The driver was 79 years old. In the second of the fatal crashes, an elderly couple (80 and 83) vaulted a non-standard guide rail on a county road and died on impact with a culvert. The advanced age of all three occupants was likely a contributing factor in the fatal outcome of these crashes.

Identified Problems with Guide Rail Crash Performance

1. Secondary Impacts. Over half of all fatal guide rail collisions involved a secondary event – either a second impact or a rollover. Many of these secondary events, e.g. trees, poles, and rollovers, typically carry a much higher fatality risk than a guide rail impact.

2. Guide Rail as a Potential Rollover Hazard. In New Jersey, 14% of all fatal guide rail collisions result in a rollover. Although all vehicles can overturn, light trucks having a high center of gravity may be especially at risk. When light trucks collide with guide rail there is a significantly greater chance of guide rail “vaulting” and roll-over.

3. Motorcycles. Motorcycle riders account for over one-fourth of all New Jersey guide rail crash fatalities – a surprisingly high fraction. Nationally, motorcycle riders now account for more fatalities than the passengers of any other vehicle type involved in a guide rail collision.

4. Side Impacts. Frontal impacts are the most common type of guide rail impact, but side impacts are the most lethal crash mode. Side impacts are

only 16% of all crashes, but result in 27% of all fatal guide rail crashes. Particularly dangerous are side impacts into guide rail end treatments.

Actions to Remedy Identified Problems

The following solutions have been proposed and implemented to address the identified problems with guide rail crash performance. The success of these solutions should be evaluated in a future guide rail crash performance project.

Secondary Impacts: In order to reduce the fatal guide rail collisions involving a secondary event, NJDOT is revising their Standard Construction Detail CD-609-9.1 entitled: Recovery Area at Flared and Tangent Terminals. This detail requires design specific information to be added and included in the contract plans regarding the size of the recovery area at each guide rail terminal. This will enable the designer to make sure that the recovery area is free of fixed objects and place the proper notes on the construction plans. Design guidance on how to fill out the detail is to be included in the NJDOT Roadway Design Manual.

Guide rail as a Potential Rollover Hazard: In order to reduce the fatal guide rail collisions involving a rollover, NJDOT is revising a Standard Construction Detail CD-609-9.2 entitled: Grading Treatment at Flared and Tangent Terminals. This detail requires design specific information to be added and included in the contract plans regarding the type of grading treatment (standard or alternate) at each guide rail terminal. This will enable the designer to make sure that the proper grading treatment at every terminal and place the proper notes on the construction plans. Design guidance on how to fill out the detail is to be included in the NJDOT Roadway Design Manual.

Both noted revised details can be found in Appendix B.

References

AASHTO, Roadside Design Guide, 3rd Edition. American Association of State Highway and Transportation Officials (2002)

Bligh, Roger P. *Performance of Current Safety Hardware for NCHRP 350 Vehicles*. Transportation Research Circular #440, TRB, National Research Council, , pp. 29-34. (April 1995)

Bligh, Roger P. et al, "*NCHRP Project 22-14 (01), Improvement of the Procedures for the Safety-Performance Evaluation of Roadside Features: Final Report (draft)"* National Academies of Science, Transportation Board (2002)

Eskandarian, Azim et al, "NCHRP 22-15, Improving the Compatibility of Vehicles and Roadside Safety Hardware: Final Report (draft)", National Academies of Science, Transportation Board (2003)

Gabler, H.C. and Hollowell, W.T , "The Crash Compatibility of Cars and Light Trucks*", Journal of Crash Prevention and Injury Control*, Vol. II, No. 1 (January 2000)

Hunter et al., "Comparative Performance of Barrier and End Treatment Types Using the Longitudinal Barrier Special Study File," Transportation Research Record #1419, Transportation Research Board, National Research Council, Washington, D.C. (1993)

Mak, K.K. and Sicking, D.L. "Development of Roadside Safety Data Collection Plan," Report #FHWA-RD-92-113, Texas Transportation Institute, Texas A&M University System, College Station, Texas (February 1994)

Michie, J.D., "Roadside Safety: Areas of Future Focus", *Roadside Safety Issues Revisited*, Transportation Research Circular 453, Transportation Research Board, National Academy of Sciences, Washington, DC (1996)

NHTSA, *Traffic Safety Facts 2005, Early Edition*, pp. 54, National Traffic Safety Administration, U.S. Department of Transportation, Washington, DC, Report No. DOT HS 810 631 (November 2006)

Ray, M.H. and McGinnis, R.G. *Guardrail and Median Barrier Crashworthiness*, Synthesis No. 244, Transportation Research Board, National Academy of Sciences, Washington, DC (1997).

Ray, M.H., M. E. Bronstad, and J.G. Viner "Importance of Vehicle Structure and Geometry on the Performance of Roadside Safety Features", SAE Paper 870076 (February 1987)

Ray, M. H., J. D. Michie, and M. Hargrave. *Events That Produce Occupant Injury in Longitudinal Barrier Accidents*. Transportation Research Record 1065, TRB, National Research Council, Washington, D.C., pp. 70-75 (1986)

Ray, Malcolm H.; Michie, Jarvis D.; Hunter, William; and Stutts, Jane. *Analysis of the Risk of Occupant Injury in Second Collisions*. Transportation Research Record 1133, Transportation Research Board, p 17-22 (1987)

Ray, Malcolm H., Project 22-13(2), "*Expansion and Analysis of In-Service Barrier Performance Data and Planning for Establishment of a Database: Final Report*" (draft) National Academies of Science, Transportation Board.

Sicking, Dean, "*Project 17-22, Identification of Vehicular Impact Conditions Associated with Serious Ran-Off-Road Crashes: Interim Report (draft)*", National Academies of Science, Transportation Board (expected 2003)

Stephens, Barry, "Safety Appurtenance Design and Vehicle Characteristics" Transportation Research Circular 453, Transportation Research Board, National Academy of Sciences, Washington, DC (1996)

Stout, D., "Traffic Barriers on Curves, Curbs and Slopes," Final Report, Contract No. DTFH61-87-C-00126, Federal Highway Administration, Washington, D.C. (March 1993)

Appendix A – Guide Rail Site Investigation Data Collection Forms

General Site Inspection Form

Location:	**Date:**
Date of Impact:	**Investigators:**

Route Number:	**Milepost:**
Number of Lanes:	**Direction of Travel:**
Roadway Type:	**# of Posts in Damaged Section:**
Description of damaged area:	
Location of Reference Post (w/ respect to nearest milepost):	**Location of Impact:**
	Angle of Impact:
Post Spacing (in):	**Police Report:**
Rail Height (in):	**Barrier Penetration:**
Rail Type:	**Post Type:**
Post Rail Connection:	**Block Out Type:**
Type of Terminal:	**Shoulder Type:**
Standard Installation	
Approach View of Impact:	

Supplemental Photo Data Form

Location:	Date:
Date of Impact:	Investigators:

Auxiliary Photographic Information
Description:

Crash Details Data Form

Location:	**Date:**
Date of Impact:	**Investigators:**

Vehicle Authorized Speed Limit:	**Mph**	**Weather Condition:**
Vehicle Type:		
Vehicle Year:		**Total Occupants:**

Safety Devices:	**Driver:**	**Most Severely Injured Occupant:**
Seatbelt Used (Y or N)?		
Airbag Present (Y or N)?		
Airbag Deployed (Y or N)?		

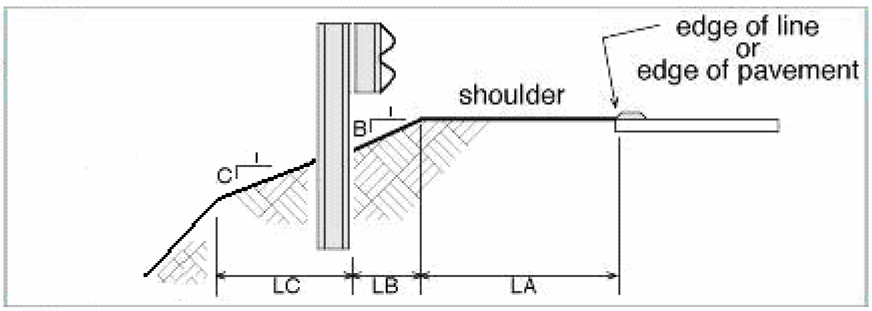
Driver Injury Severity:
Highest Occupant Injury Severity:

Impact Point: **post**	**Max deflection at ground line:** **in**
Max deflection at rail height: **in**	**# of post broken or bent:**
# of post snagged:	**# of splices that failed**
# of bolts that failed:	**Rail was torn or broken at:** **posts**
Total damaged length of guide rail: **feet**	

Barrier Data Form

Location:	Date:
Date of Impact:	Investigators:

Guide rail location:	Lane Width:
Guide rail Purpose:	
Type of Installation:	
Upstream End:	
Downstream End:	



H (Rail Height):		
A (Shoulder Slope):	LA (Shoulder Width):	ft
B (Grass Slope 1):	LB:	ft
C (Grass Slope 2):	LC:	ft
Notes:		

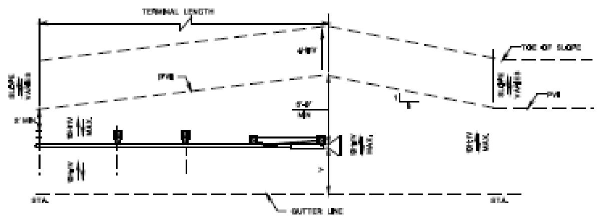
Component Details Form

Location:	**Date:**
Date of Impact:	**Investigators:**

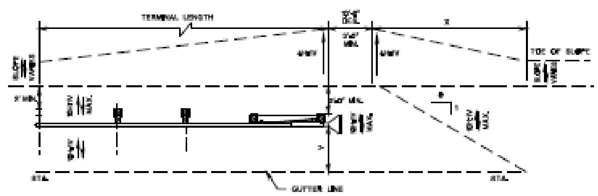
Post Number:			
Deflection at Rail Height (in)		**Deflection at Ground Line (in)**	
Parallel:	**Perpendicular:**	**Parallel:**	**Perpendicular:**
Backup Plate / Splice		**Angle Between Post and Ground:**	
Post – Blockout Connection		**Rail - Blockout Connection**	
Description of Damage to Post (Bending, Torsion, Shear:		Insert Photo of Post Here	
Description of Connection Failure (If Any):			

Post Number:			
Deflection at Rail Height (in)		**Deflection at Ground Line (in)**	
Parallel:	**Perpendicular:**	**Parallel:**	**Perpendicular:**
Backup Plate / Splice		**Angle Between Post and Ground:**	
Post – Blockout Connection		**Rail - Blockout Connection**	
Description of Damage to Post (Bending, Torsion, Shear:		Insert Photo of Post Here	
Description of Connection Failure (If Any):			

Appendix B – Revised Guide Rail Construction Details



STANDARD GRADING



ALTERNATE GRADING

GRADING	STANDARD/ALTERNATE
STATION TO STATION	

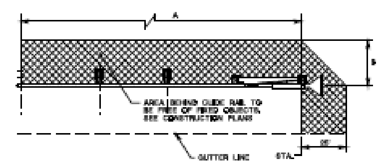
Y = OFFSET FROM GUTTER LINE	X	X + 10' (DES.)
* 1'-6"	34'-6"	34'-6"
4'-6"	47'-6"	52'-6"
7'-6"	60'-6"	[illegible]
10'-6"	73'-6"	[illegible]

GRADING TREATMENT AT FLARED AND TANGENT TERMINALS

* **NOTE:**

WHERE GUIDE RAIL IS INSTALLED FLUSH WITH THE GUTTER LINE, THE TANGENT TERMINAL SHALL BE CONSTRUCTED WITH A [illegible] STRAIGHT FLARE FOR ITS ENTIRE LENGTH SO THAT THE EXTRUDER HEAD DOES NOT PROTRUDE INTO THE ROADWAY.

ROADSIDE RECOVERY AREA		
STATION	A	B



NOTE:
THERE SHALL BE NO FIXED OBJECTS IN FRONT OF THE GUIDE RAIL FOR ITS ENTIRE LENGTH.

RECOVERY AREA AT FLARED AND TANGENT TERMINALS

NOTE TO DESIGNER:
THIS SHEET REQUIRES DESIGN SPECIFIC INFORMATION TO BE ADDED AND INCLUDED IN THE CONTRACT PLANS.

REMOVE THIS NOTE AFTER DESIGN SPECIFIC INFORMATION IS ADDED.

GRADING AND ROADSIDE RECOVERY AREA AT FLARED AND TANGENT TERMINALS

CD-609-9

NEW JERSEY DEPARTMENT OF TRANSPORTATION

CONSTRUCTION DETAILS

47/129