IN-SERVICE PERFORMANCE OF GUARDRAIL TERMINALS IN WASHINGTON STATE

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16. ABSTRACT

This research study was conducted to evaluate the in-service performance of existing guardrail end treatments and unrestrained pre-cast concrete barrier in Washington State. For a selected area of the state highway system over a one-year period, local area maintenance personnel were tasked to document incidents, including extent of damage and repair costs, into a database using NCHRP Project 22-13 methodology. Additional information (accident severity, e.g.) from police reports was gathered from the incidents and added to the database. The installation characteristics measured for Breakaway Cable Terminals (BCT) and Slotted Rail Terminals (SRT), along with the related crash data for these devices, showed overall acceptable performance when struck. Review of the incident severities, together with the displacement and damage data on struck barriers in the study area, revealed no significant difference in BCT and SRT performance. The installation, damage, and displacement characteristics examined on struck concrete barrier showed that the pin and loop connections were holding well in incidents and the barrier displacements during incidents were within the WSDOT design specification for such systems.

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In-Service Performance of Guardrail Terminals In Washington State

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INTRODUCTION

Guardrail terminals or end treatments are installed to provide safe termination to the ends of longitudinal roadside barriers [1], placed to shield motorists from the potentially more severe impact with other roadside fixed objects or adverse terrain. Before end treatments were introduced, experience with the impalement of crash vehicles on the exposed ends of guardrails had amply demonstrated the grave consequences for errant vehicles striking the untreated ends of roadside barriers [15]. Since then, the roadside safety community has been engaged in a sustained effort aimed at developing guardrail end-treatments to mitigate this hazard [34].

The breakaway cable terminal (BCT) was hailed as a promising solution to the problem at the time of its development in the early 1970's. The device quickly gained ground as the guardrail end treatment of choice and evolved into one of the most widely used guardrail end treatments. By 1992, it was estimated that there were hundreds of thousands of the device on highways nationwide [22].

Over time however, reports of difficulties and poor performance by the BCT began to mount, attributed mainly to departures from its designed configuration and unsatisfactory performance when struck head-on by small cars [45]. As a result, the FHWA in a memorandum dated Sept 29th, 1994, declared the BCT obsolete and gave a one-year deadline for cessation of its use in new projects on the National Highway System (NHS) [10].

That action, however, did not call for wholesale replacement of existing BCT units. Instead it suggested that damaged BCT units be replaced with crashworthy terminals and that existing units with incorrect flares be replaced in conjunction with regularly scheduled roadway work in the same area [10].

In the meantime, pursuant to the provisions of the ISTEA Act of 1991, the FHWA had in 1993 adopted the NCHRP Report 350-Recommended Procedures for the Safety

Performance Evaluation of Highway Features. In a memo titled "NCHRP Report 350 Hardware Compliance Dates" dated August 28th, 1998, the FHWA revised its earlier guidance on the discontinuance of the BCT. This time it added a new requirement that existing BCT installations now be replaced in conjunction with 3R work [11]. The new FHWA guidance raised considerable concern in many states, given the large numbers of existing BCT installations and the potential impact on the limited resources available to highway agencies.

Prior to 1995, the BCT was the most prominent guardrail end treatment used on highways in Washington State. New installations ceased in mid 1995 following the 1994 FHWA direction. A number of MELT end treatments were installed in 1995 & 1996. Subsequently, WSDOT began installing Report 350 compliant terminals, most prominently the SRT, but also some ET-2000, SKT, and FLEAT. Washington State undertook this in-service study of its BCT and other terminals to help determine its policy for replacement.

Unrestrained pre-cast concrete barriers use in WA State has grown since its first installations in the 1970s. Interest in its in-service evaluation was prompted by the fact that, although it is of the standard safety shape, the pin and wire loop jointing system used to hold the segments together had yet to be crash tested to Report 350 guidelines. Because the data collection areas for the guardrail end treatments also included locations with this type of system, it was cost-effective to evaluate this device at the same time.

LITERATURE REVIEW

Introduction

The purpose of this review is to obtain information on the procedures and processes for in-service evaluation of roadside safety devices, including factors considered and types of data collected. Of immediate interest are the seven devices targeted in this study:

- Six types of guardrail terminals – BCT, MELT, SRT, ET-2000, SKT and FLEAT, and
- Unrestrained pre-cast concrete barrier (outside work zones)

Evolution of In-service Performance Evaluation Procedures

Roadside safety features are complex engineered devices and the roadside safety community has long been aware of the need for in-service performance evaluation as an integral part of the total design and development process for such devices [(37)]. An in-service evaluation of a roadside safety feature seeks to monitor and document the manner in which the device performs under real world conditions. The aims are:

- To determine if the device performs as anticipated in its design,
- To obtain data for assessing the collision and injury rates associated with use of the device, and
- To reveal unsuspected problems that may not have been evident during the preceding phases of the design process [(51)].

Efforts to improve roadside safety through the design of roadside safety features date back to the 1960s [(45)]. During the 1970s few states and highway agencies had conducted in-service evaluations of these devices [(37)]. At the time, however, formal guidelines for such evaluations did not exist and Powers [(36)] points out that, as a result, those early in-service evaluations lacked consistency and uniformity in the analysis approach used.

The first formal guidelines for in-service performance evaluation were issued in 1981[(30)] as part of NCHRP Report 230. The guidelines stipulated six objectives and seven characteristics deemed desirable in an in-service evaluation. Because the guidelines were general in nature it was recognized that more detailed instructions would be needed by agencies seeking to apply them. Solomon and Boyd developed these a few years later in a report titled, "Model Procedure for In-service Evaluation of Roadside Safety Hardware

Devices" [51]. The work was sponsored by the FHWA and intended as a manual on in-service evaluations of roadside safety features.

In 1993 NCHRP Report 350 [31] reiterated the 1981 guidelines for in-service evaluation and called attention to the more detailed instructions available in Solomon and Boyd's report. Despite these guidelines, few in-service evaluations were performed by highway agencies before putting new devices into widespread use. Surveys of highway agencies found that there was the perception that the required procedures were cumbersome, required too much time and effort to implement [53], and did not provide any beneficiary results.

Triggered by the FHWA directives mandating the replacement of existing BCT installations on highways, there has been a significant shift in perception on the value of conducting in-service evaluation on safety devices. The BCT, which failed the crash test to Report 350 criteria, has been in widespread use in most states for well over 20 years. The installations are widely perceived to be meeting the safety requirements needed as guardrail terminals. Replacing the large numbers of the device in use could result in a significant drain on the limited resources of State highway agencies. To help the states with the process to analyze the BCT and other devices, NCHRP Project 22-13 was initiated in 1996 to establish a practical and viable procedure for gathering, compiling, and maintaining in-service performance data perform data to improve roadside safety [38].

Under Project 22-13, the in-service performance evaluation of a variety of traffic barriers and end treatments were carried out at selected sites in Connecticut, Iowa and North Carolina. The detailed procedures that were developed contained many innovative features. Under a second phase of the project, these procedures were carefully reviewed and documented in a procedures manual [42]. Key features include:

- Establishment of clear and measurable objectives for the proposed in-service evaluation,

- Identification of the key sources of the data to be collected and establishment of continuing links with such sources throughout the study period,
- Inventory of existing installations of the target features in the designated study area,
- Adherence to a standardized method for measurement and collection of data elements to assure consistency and comparability in the data collected from the different studies,
- Prompt visits to collision sites to gather data for assessing the damage to the struck device and its pre-impact installation condition where possible,
- Use of carefully designed data collection forms to ensure that sufficient data relating to the selected study variables are consistently collected, and
- Adherence to the sampling profile during data collection as stipulated at the outset of the project.

In-Service Study Variables

Guardrail Terminals

An important aspect of planning for the in-service evaluation project is the selection of variables and factors to include in the study. These should be variables and factors that might be expected to influence the outcome of a collision with the target safety features or which could be of use in evaluating the observed performance of the devices [(51)]. Past studies focusing on collision performance of roadside features, traffic barriers in general or specific types of traffic barriers including specific end treatments, can offer useful insights into these variables. Some of these studies are briefly reviewed below.

Bryden and Fortuniewicz [(5)] reported on an in-service evaluation of traffic barriers in New York State. The main objective of the study was to find out how barrier type and barrier mounting height, vehicle type and size, roadway features, and various impact conditions influence the resulting accident severity. Data for the study was gathered from 3302 roadside crash sites across New York State over a twelve-month period, from July 1, 1982 to June 30, 1983. Three variables – vehicle damage, barrier impact response and secondary collision - were investigated as measures of barrier performance. Results showed all three variables to be closely associated with injury severity. The study also found that barrier type and mounting height, vehicle type and passenger car weight all significantly influenced resulting accident severity.

Pigman and Agent [35] reported on in-service evaluation of breakaway cable terminal and median breakaway terminal installations in Kentucky. Primary data for the study was gathered from 1980 to 1987 and consisted of 110 crash incidents involving the BCT and 36 involving MBCT installations. The BCT evaluation focused on the influence of the installed configuration on performance. Three types of flare configuration were found among BCT installations in the State. These were:

- A 4.5 degree simple curve with a six foot offset at the first post,
- A 37.5 foot parabolic curve with a four foot first post offset, or
- A straight layout of the 37.5 foot terminal with no offset at the first post.

They found that correctness of configuration (i.e. parabolic flare with four foot first post offset) showed strong relationship to good barrier performance and low injury severity. Impact angle was also shown in the study to be strongly related to barrier function and injury severity.

In a 1992 paper titled "Guardrail End Treatments in the 1990s", Ivey, Bronstad and Griffin III [22] provided an overview of widely used end treatments, in which they highlighted a number of promising improvements and new developments. A good portion of the review was devoted to factors that influence BCT performance based on lessons learned from over twenty years of real world experience with the device. Among factors found to consistently result in poor performance of the device were:

- Not adhering to the 37.5 foot parabolic flare with a four foot first post offset in the installation,

- Installation of the terminal on a steep slope or near a slope break,
- Installing the rail height too high or too low,
- Inadequate foundation for the end posts.

The authors also indicated in the paper that the BCT failed the full-scale crash test using the small (1,800-lb) car even when correctly installed. They also pointed out that the MELT, originally developed as replacement for the BCT, had exhibited the same limitations of the BCT.

Mak, Bligh, Ross and Sicking [(28)] described development and crash testing of the Slotted Rail Terminal (SRT), stressing that despite its similarity to the BCT, the new SRT did not exhibit the BCT's sensitivity to installation details and performed well even when struck by the small car. While noting that the SRT had already successfully passed the crash test to Report 230 criteria, the authors went on to describe its successful performance in the crash test to Report 350 guidelines.

Given its history, the obvious variables for an in-service evaluation study of the SRT must include same ones found to be significant in the performance of both the BCT and the MELT.

Ivey et al [(22)], cited earlier, highlighted the ET-2000 as one of the promising new devices, which was rapidly gaining the necessary operational experience. Ohio State was among the first to adopt the ET-2000 for large-scale use and the Ohio DOT embarked on a three-year in-service evaluation of the device in October 1992 [(32)]. During the study, data was gathered from a total of 306 crash sites around the state. Variables considered in the study included injury severity, impact location on the device, angle of impact, speed and length of rail extruded. Over the study period, crashes involving the device recorded a low injury rate with no fatalities. The assessment by the Department, based on the results of the in-service evaluation, was that device was performing well.

Ray, Clark, and Hopp [41] evaluated the in-service performance of BCT and MELT installations in Iowa. During the study they gathered a total of thirty-seven BCT and fourteen MELT hits that occurred over a two-year period from 1997 to 1999. The authors noted that, with correctly installed BCT and MELT terminals, the observed in-service rates for disabling or fatal injuries were considerably lower than those noted in previous in-service evaluations. They further demonstrated that these rates were not significantly different from those observed for the ET-2000 in the Ohio in-service evaluation study. The installation variables used for analysis were: rail height, distance from the ground surface of the center of the breakaway hole in post #1, correctness of the foundations on post #1 and #2, first post offset, correctness of the parabolic flare measured by the third post offset, as well as the tautness of the anchor cable between posts #1 and #2. The study applied the in-service evaluation Procedures methodology documented in a subsequent publication titled "In-service Performance Evaluation Procedures Manual" [42].

Unrestrained pre-cast Concrete Barriers

In a 1980 paper, Lisle and Hargroves [23] reported their findings of an in-service evaluation for the safety shaped unrestrained pre-cast concrete barrier system. Variables found to significantly influence barrier performance were the offset distance of the barrier curb face from the edge line and the impact angle. Though conducted in a work zone environment, there is no reason to believe that these variables would be less relevant outside the work zone. Reporting on the results of the crash test to Report 230 criteria for another system of pre-cast concrete barrier, Glauz in 1989 [16] showed that lateral placement from the edge line for the system was significantly associated with severity of the impact. The report also showed a significant relationship between impact severity and maximum joint displacement resulting from the impact.

STUDY APPROACH

Introduction

The most prominent roadside safety features in use during the data collection phase of the in-service evaluation included six guardrail terminals (BCT, MELT, SRT, ET-2000, SKT, FLEAT) and unrestrained pre-cast concrete barriers (UPCCB) used outside work zones.

Study Objectives

- Develop a database to store in-service performance data for the listed devices,
- Develop an inventory of the study area,
- Utilize local expertise (maintenance personnel) to gather incident and performance characteristic data,
- Examine police reports to gather severity and incident data,
- Evaluate the in-service performance of the devices,
- Report on the results of the in-service evaluation, and
- Develop parameters from the data analysis that can be used in future evaluations of the listed devices.

Study Variables

The following variables will be examined in this study: roadway curvature, traffic volume, shoulder type, device type, correctness of the installed configuration, angle and point of impact, lateral offset distance, vehicle type and weight, and collision scenario.

In-service evaluation database

A relational database was developed with on-line capabilities for data entry. To ensure that the right data elements were acquired during data gathering, data collection forms were developed using suggestions in NCHRP Project 22-13 [42] and revised in discussions with the maintenance personnel who would be the data collectors for the project. The forms also aided the data gatherers with their database entry tasks. Copies of the forms used in the study are included in Appendix A.

The following categories of information were needed from the data collection effort:

- Inventory Data - The safety feature's installation characteristics, roadway descriptions, and traffic data.
- Incident Data- Hardware damage and repair costs in crash incidents involving the selected safety features.
- Accident Data – The number and severity of occupant injuries, number and type of vehicles, and collision scenario for each crash incident.

Study Area Characteristics

A selection of highways defined by maintenance area boundaries was chosen for the study. The study area consisted of three contiguous maintenance areas in western Washington, the Southwest Region-Area 2, the Olympic Region-Area 1 and the Northwest Region-Area 4. Total mileage along the designated routes in the study area was approximately 752 miles. These routes fall into three classes: Interstate, National Highway System (NHS-Non-Interstate) and non-National Highway System (non-NHS). A listing of the routes and their classifications is contained in Appendix B.

Figure 1-Map of Study Area

A significant feature of the study area is that it straddles the busy I-5 corridor from Lewis County in the south to King County in the north. Based on 2001 AADT values, the data collection area accounted for some 6 billion vehicle-miles of travel during that year. A breakdown of the total vehicle-miles of travel by route type in the study area is given in Table 1 below. The interstate routes, which make up less than 15% of the total highway mileage in the study area, accounted for approximately 64% of the vehicle-miles of travel in the area during the year. In contrast, the non-National Highway System routes account for nearly 60% of the highways but carried only 3% of the vehicle-miles of travel in the area during the year.

Route Type	Miles	% Miles	Veh-Miles Traveled (in millions)	% Veh-Miles
Interstate Highways	110.61	14.7%	3,860	63.9%
NHS (Non-Interstate)	191.04	25.4%	2,000	33.1%
Non-NHS	450.36	59.9%	181	3.0%
Total	752.01	100.0%	6,040	100.0%

Table 1-Study Area Mileage and Traffic Volume by Route Type

DATA COLLECTION

Inventory Data Collection

Roadside Safety Feature Inventory

Without a system-wide inventory of the end treatment locations, the gathering of this data became the first phase of data collection for the project. A hardware survey of the study area was conducted between May 2000 and October 2000 by a team of Saint Martin's College students. They were first given a short training on the procedures for visually identifying roadside safety features, adapted from the sequential scheme suggested by Calspan in their 1999 report to the FHWA [52] on expert systems for crash data collection. Then the teams, comprising of a driver and an observer/recorder, drove the study area and visually identified and documented the targeted safety features. Besides the identification of device type, other pertinent data recorded for each installation included the route, direction, mile post, cross-sectional placement, and orientation (i.e. trailing end or leading end) where applicable.

The inventory survey documented over 2300 installations of the targeted guardrail terminal systems in the study area. A summary of the guardrail end treatment installation counts, broken down by type and area, is shown in Table 2. The data shows that the BCT is still the predominant system in use in the area, with some 2004 installations. The SRT, with 235 installations, was a distant second. Only limited quantities of the other four end treatments (MELT, ET-2000, SKT, and the FLEAT) were encountered.

Region	BCT	ET-2000	FLEAT	MELT	SKT	SRT	Total
NW-Area 4	448	27	0	40	1	55	571
OLY-Area 1	917	5	2	4	0	58	986
SW-Area 2	639	0	0	0	0	122	761
Total	2004	32	2	44	1	235	2318
% of Treatments	86.5%	1.4%	0.1%	1.9%	0.0%	10.1%	100.0%

Table 2-Guardrail End Treatments In Study Area

A breakdown of the total guardrail terminal installations by the route type and cross-sectional placement is shown in Table 3. The largest numbers of installations were located on the mainline shoulders (89.86%).

	Route Type			
Placement	Interstate	NHS (Non-Interstate)	Non-NHS	All
Intersection	0	21	45	66
	0.00%	2.32%	4.50%	2.85%
Main line Median	42	55	2	99
	10.19%	6.07%	0.20%	4.27%
Main line Shoulder	336	800	947	2083
	81.55%	88.30%	94.70%	89.86%
Ramp	34	30	6	70
	8.25%	3.31%	0.60%	3.02%
All	412	906	1000	2318
	100.00%	100.00%	100.00%	100.00%

Table 3-Guardrail End Treatments by Location and Route Class

For the unrestrained pre-cast concrete barrier installations, the total length in the study area was about 132 miles.

Region	Miles	%
NW-Area 4	58.21	44.0%
OLY-Area 1	42.73	32.3%
SW-Area 2	31.45	23.8%
Total	132.39	100.0%

Table 4-Length of UPCCB in Study Area

Geometric and Traffic Data

The second phase of the inventory data needs consisted of the main line geometric data (e.g. roadway curvature, shoulder width) and traffic volumes (measured as Annual Average Daily Traffic or AADT) for each route in the study area. The data was available from the WSDOT Traffic Data Office and was entered into the database. Later in the project, it became necessary to spend additional resources to develop corresponding data for ramps, an area of data that was incomplete in existing WSDOT data systems. The traffic data inventory table supplemented the roadside safety hardware inventory table to create a comprehensive inventory database for the project.

Incident Data Collection

Maintenance Reports

DOT maintenance personnel were tasked to investigate collision incidents involving the installations in their area over a one-year study period, 1st January to 31st December 2001.

The data collection plan required that the maintenance staff would visit each crash site to inspect the struck device as soon as possible, preferably within a few days of the report of the crash incident. During such a visit, the inspector would document:

- The installation characteristics of the struck device (to the extent possible), and
- The collision scenario and extent of the damage on the struck device.

The installation characteristics were gathered to determine the extent to which the configuration of the device prior to the collision conformed to its design parameters. This is important in the case of the BCT as it is particularly sensitive to deviations from its crash-tested configuration, as stated earlier. The damage information was to be used to assess the structural performance of the device when struck. Finally, data was entered for the cost of repairs and the down time until the device was restored to a serviceable condition.

At the end of the study period, a total of seventy-five crash incidents had been documented. This included thirty guardrail terminals hits and forty-five unrestrained pre-cast concrete barrier hits. Sixty of the seventy-five collisions (80%) occurred on the Interstate system. This was somewhat to be expected given the much higher traffic volumes on the Interstate system, as noted in the introduction.

Police Reports

The final component of the in-service performance data gathered for the project was incident data from police and driver accident report forms. The reports were extracted from the Washington State highway accident records database.

Among the thirty incidents involving guardrail terminals documented by maintenance supervisors, twenty were successfully matched with their corresponding police accident reports. Only four of the six guardrail terminal types were represented in accident data; the BCT, SRT, ET-2000, and MELT. For the forty-five incidents involving unrestrained pre-cast concrete barriers, eighteen were successfully matched with their corresponding accident reports.

GUARDRAIL TERMINALS - DATA ANALYSIS

Introduction

The thirty incidents involving guardrail terminals were examined for quality of installation, their structural responses when struck, their repair costs, and safety performance.

Locations of Struck Devices

The tabulation shows that all but one of the struck guardrail terminals were located on the main line right shoulder and on the ramps, which together accounted for 96.7% of all struck terminals. Only one struck terminal was located in the main line median.

Table 5 also shows that more than twice as many of the struck guardrail terminals were located on the Interstate highways relative to the incidents on NHS (Non-Interstate) and non-NHS routes. This trend is consistent with expectations, because of the higher exposure the features experience on the Interstate locations.

Placement		Route Type			Total
		Interstate	NHS (Non-Interstate)	Non-NHS	
Main line Median	Count	1			1
	% of Total	3.3%			3.3%
Main line Shoulder	Count	7	5	1	13
	% of Total	23.33%	16.7%	3.3%	43.33%
Ramp	Count	9	3	4	16
	% of Total	30.0%	10.0%	13.3%	53.3%
Total	Count	17	8	5	30
	% of Total	56.7%	26.7%	16.7%	100.0%

Table 5-Struck Guardrail Terminals by Route Type and Location

The breakdown of struck guardrail terminals by device type and location, in Table 6, shows that BCT installations had the most incidents, with a total of eighteen hits, followed by SRT installations with nine hits. By contrast, the MELT installations had two reported hits and the ET-2000 installations experienced only one reported collision. While the general trend appears to reflect the overwhelming proportion of BCT installations among guardrail terminals, the proportion of SRT collisions appeared to be higher than might be expected. The authors believe this may suggest that some of the SRT installations are in locations with a higher susceptibility for collisions, as the SRT now replaces many of the struck BCT installations on the highway system.

Placement		Device Type				Total
		BCT	ET-2000	Melt	SRT	
Mainline Median	Count				1	1
	% within Type				11.1%	3.3%
Mainline Shoulder	Count	8	1		4	13
	% within Type	44.4%	100.0%		44.4%	43.3%
Ramp	Count	10		2	4	16
	% within Type	55.6%		100.0%	44.4%	53.3%
Total	Count	18	1	2	9	30
	% within Type	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6-Struck Terminals by Device Type and Location

Terminal Type and Extent of Terminal Damage

The length of rail damaged and the number of posts broken both provide an indication of the damage to the feature suffered in the collision. These measures are summarized by device type measured in the Washington study and are shown in Tables 7 and 8. Only twenty-five of the thirty incidents could be measured. The mean length of BCT rail damaged (18 feet) was slightly less than the figure reported by M. H. Ray et al [41] for their Iowa study (6.2 meters, or 20.34 feet). The mean number of BCT posts damaged or broken in the Washington study (3.1 posts) was about twice the mean number of posts (1.6 posts) reported broken in the Iowa study. By contrast, the mean distance that the nose of the struck BCT moved downstream in Iowa was more than twice the distance recorded in the Washington study.

Device Type	Measured Cases	Mean (ft)	Minimum (ft)	Maximum (ft)	No Data	Total
BCT	16	18.0	0.0	45.0	2	18
SRT	7	19.5	12.0	29.0	2	9
ET-2000	1	12.0	12.0	12.0	0	1
Melt	1	12.0	12.0	12.0	1	2
All	25	18.1	0.0	45.0	5	30

Table 7-Length of Rail Damaged

Device Type	Measured Cases	Mean	Minimum	Maximum	No Data	Total
BCT	16	3.1	1.0	7.0	2	18
SRT	7	3.3	2.0	6.0	2	9
ET-2000	1	2.0	2.0	2.0	0	1
Melt	1	1.0	0.0	2.0	1	2
All	25	3.1	0.0	7.0	5	30

Table 8-Number of Posts Damaged

Device Type	Measured Cases	Mean (ft)	Minimum (ft)	Maximum (ft)	No Data	Total
BCT	16	4.1	0.0	20.0	2	18
SRT	7	10.6	0.0	30.0	2	9
ET-2000	1	10.0	10.0	10.0	0	1
Melt	1	0.0	0.0	0.0	1	2
All	25	6.3	0.0	20.0	5	30

Table 9-Distance Nose Moved Downstream

Collision Type and Vehicle Type

The collision scenario data, measured by the maintenance team for twenty incidents and extracted from police reports on an additional eight incidents, provided more complete information on the collision characteristics of the struck device and type of vehicle involved in each collision. The data for these twenty-eight incidents summarized in Table 10 show that end-on hits on the terminal ranked highest at 71% (20 out of 28), with the remaining eight collisions involving mid-terminal hits. This supports the view reported earlier by Ray et al [41] based on their Iowa study that end-on collisions are the dominant incident type in real world collisions involving guardrail terminals.

Collision Scenario	End Treatment Type BCT	ET2000	MELT	SRT	TOTAL	% OF TOTAL
End-On Terminal Hits						
1. Redirected Behind	9	0	0	3	12	42.9%
2. Redirected in Front	1	1	1	1	4	14.3%
3. Broadside	0	0	0	2	2	7.1%
4. Stopped in Contact	1	0	0	0	1	3.6%
5. Overrode	1	0	0	0	1	3.6%
All End-On Hits	12	1	1	6	20	71.4%
Mid-Terminal Hits						
1. Redirected	2	0	0	0	2	7.1%
2. Penetrated	0	0	0	2	2	7.1%
3. Reverse Direction	1	0	0	0	1	3.6%
4. From Behind	0	0	1	0	1	3.6%
5. Overturned/Vaulted	2	0	0	0	2	7.1%
All Mid-Terminal Hits	5	0	1	2	8	28.6%
Total All Hits	17	1	2	8	28	100.0%

Table 10-Collision Type and Device Type

Data on the vehicle types involved in the reported hits was available for twenty-one of the thirty incidents and is summarized in Table 11. Of the twenty-one cases, twelve involved passenger cars and four involved pickup trucks. The distribution reflects the Report 350 criteria for crash testing of the most prominent vehicles, the passenger car (small car) and the pickup truck.

Type of Vehicle	End Treatment Type BCT	ET2000	MELT	SRT	TOTAL	% OF TOTAL
Passenger Car	6	1	1	4	12	57.1%
Pick Up Truck	3	0	0	1	4	19.0%
Sports Utility	2	0	0	1	3	14.3%
Van	0	0	0	0	0	0.0%
Bus	0	0	0	0	0	0.0%
Tractor Trailer	1	0	0	1	2	9.5%
Total	12	1	1	7	21	100.0%

Table 11-Vehicle Type and Device Struck

Installation Characteristics of Struck Devices

Guardrail terminals perform best when installed in conformity with their crash-tested configurations. The BCT is especially sensitive to this phenomenon [22]. To characterize the BCT installation quality, as many as eight determinants were considered by Ray et al [41] in the in-service performance evaluation of the BCT and the MELT in Iowa. These variables are measured to determine if the devices responded correctly when struck.

For the Washington State study, the maintenance personnel examined four conditions.

A. The use of breakaway wood posts in posts #1 and post #2 positions.

Examination of the struck installations at the crash sites in this project showed that the correct type of wood posts were used in the first two positions on all the BCT, MELT, SRT and ET-2000 installations.

B. The correctness of distance from the center of the breakaway hole to the ground line in post #1.

While the distance of center of the breakaway hole from the ground line varied somewhat from installation to installation, the mean values for the different systems all fell between the allowable range of 1.0 inch (minimum) and 4.5 inches (maximum) for this variable [41], as can be seen in Table 12.

	Distance Center Breakaway Hole to Ground line		
Device Type	Mean (in)	Minimum (in)	Maximum (in)
BCT	2.25	2.00	6.00
ET-2000	2.00	2.00	2.00
MELT	2.00	2.00	2.00
SRT	3.29	2.00	8.00
All Terminals	2.52	2.00	8.00

Table 12-Guardrail Terminal Installation Quality

C. The offset at post #1.

The offsets at post #1 for the different systems are shown in Table 13. The mean values for the BCT at 3.8 feet and the SRT at 3.2 feet lie well above the allowable lower limit of 3.0 feet for this variable [41]. For a number of these locations in which the post #1 offsets fell below the lower limit, it appeared that the topography had made it impossible to achieve the required offset.

There was only one measurement recorded for the MELT and this value fell a bit short of the allowable lower limit for this variable, which has the same value as for the BCT and SRT. For the ET-2000, it is designed to be installed in a straight alignment with a fifty to one taper to keep the wide extruder head away from the shoulder edge. Typically this results in an offset of one to two feet at post #1. The measurement for the one ET-2000 that was struck exceeded the upper limit of this value. However, with only one case each, no significance is made for either of these two types.

Device Type	# Measured	Mean (ft)	Minimum (ft)	Maximum (ft)	No Data	Total
BCT	17	3.8	1.5	7	1	18
SRT	8	3.21	2	4.24	1	9
MELT	1	2.58	2.58	2.58	1	2
ET-2000	1	2.91	2.91	2.91	0	1
All	27	3.54	1.5	4.24	3	30

Table 13-Guardrail Terminals Post #1 Offset

D. The correctness of the parabolic flare.

The correctness of the flare for the terminals is considered an important design element and is evaluated by measurement of the offset to the third post [41]. The nominal design value is 1.8 feet for BCT and SRT installations, with the acceptance range of 1.3 feet to 2.3 feet, and about half of the measurements fell within the range. The BCT and SRT installations outside of the range varied equally from shy to wide, but mostly within a foot of the range. The nominal design value is 1.16 feet for the MELT installation, with the acceptance range of 0.66 feet to 1.66 feet, and for the one measured case, it was documented that the flare was limited due to roadway geometry. Also, the ET-2000 is a non-flared terminal and is not included for this determinant.

Device Type	# Measured	Mean (ft)	Minimum (ft)	Maximum (ft)	No Data	Total
BCT	16	2.05	1.00	3.42	2	18
SRT	8	1.65	0.83	2.83	1	9
MELT	1	0.41	0.41	0.41	1	2
ET-2000	N/A	N/A	N/A	N/A	1	1
All	25				5	30

Table 14-Guardrail Terminals Post #3 Offset

Although no attempt was made at assigning individual installation scores to devices as was done by Ray in the Iowa study, the findings for the struck installations show that for the most part their installation characteristics were within acceptable limits.

Repair Costs

Repair cost data gathered during this study are summarized by device type and shown in Table 15. The average cost of repairs for struck BCT installations of $926 as compared to the average cost of $2186 for struck SRT installations. The mean value for the BCT is in the same range as that reported by Ray et al from their Iowa study [(44)]. WSDOT maintenance will replace a BCT with an appropriate replacement terminal when the damage to the BCT extends to the anchor, which adds additional expense to the repair cost. There were two incidents where the BCT was replaced with a SRT, at an average cost of $2571. The average repair costs on the ET-2000 and the MELT were similar to the BCT, but the small number of cases limits the confidence in any conclusion.

Device Type	# Measured	Mean	Minimum	Maximum	No Data	Total
BCT	15	$926	$601	$1,906	1	16
ET-2000	1	$926	$926	$926	0	1
MELT	2	$1,060	$508	$1,612	0	2
SRT	6	$2,186	$616	$3,800	3	9
BCT to SRT	2	$2,571	$2,555	$2,586	0	2
All	26	$1,394	$508	$2,817	4	30

Table 15-Repair Costs

Study Sample for Safety Analysis

During the study period from January 1, 2001 to December 31, 2001, maintenance personnel gathered and documented thirty single-vehicle guardrail terminal collisions. Matching police reports for twenty of these hits were found in the 2001 Washington State Highway Accident database (TRIPS) and were classified as police-and-maintenance reported collisions. Occupant injury data was available from the TRIPS database. For the ten maintenance-only-reported collisions, it was assumed that they had involved no occupant injuries and were classified for this phase of the project as property damage only collisions. Only four guardrail terminal systems were represented in the study sample, as previously shown in Table 6.

Distribution of Injury Severities

The distribution of injury severity by device type is shown in Table 16. Injury severity classification is based on the KABCO scale in which 'K' refers to an occupant injury resulting in death, 'A' refers to disabling occupant injury, 'B' refers to evident injury, 'C' refers to possible injury and 'O' refers to no injury or property damage only. There were no fatal injuries with a total of four disabling injuries in the sample of thirty collisions. There were no disabling or fatal injuries reported in the few collisions involving the ET-2000 or the MELT and no analysis will be made for these devices with the limited sample. The BCT and SRT are the only devices for which a meaningful comparison can be made.

Device Type		Severity Category			Total
		A+K	B+C	O	
BCT	Count	3	4	11	18
	% within Device Type	16.70%	22.20%	61.10%	
ET-2000	Count	0	1	0	1
	% within Device Type		100.00%		
MELT	Count	0	1	1	2
	% within Device Type		50.00%	50.00%	
SRT	Count	1	2	6	9
	% within Device Type	11.10%	22.20%	66.70%	
TOTAL	Count	4	8	18	30
	% of All Devices	13.30%	26.70%	60.00%	

Table 16-Severity Distribution for Study Sample by Device Type

Comparison of the BCT and SRT Terminals

To compare the two devices, the 90% confidence tolerance for the observed occupant injury severity was computed and the results are shown in Table 17.

Device Type		Severity Category			Total
		A+K	B+C	O	
BCT	Count	3	4	11	18
	%	16.7%	22.2%	61.1%	100.0%
	90 % Confidence	+/- 14.45	+/- 16.12	+/- 18.9	
SRT	Count	1	2	6	9
	%	11.1%	22.2%	66.7%	100.0%
	90 % Confidence	+/- 17.23	+/- 22.8	+/- 25.85	

Table 17-Severity Distribution for BCT and SRT Only

Plots of the disabling or fatal injury collision proportions (A+K), the possible and evident collision proportions (B+C) and the property damage only collision (O) proportions together with the corresponding 90% confidence intervals for both devices are shown in Figure 2. The chart reveals a substantial overlap of the confidence intervals for the two devices in all three categories. This implies there is no significant difference between the two devices in their injury-related performances.

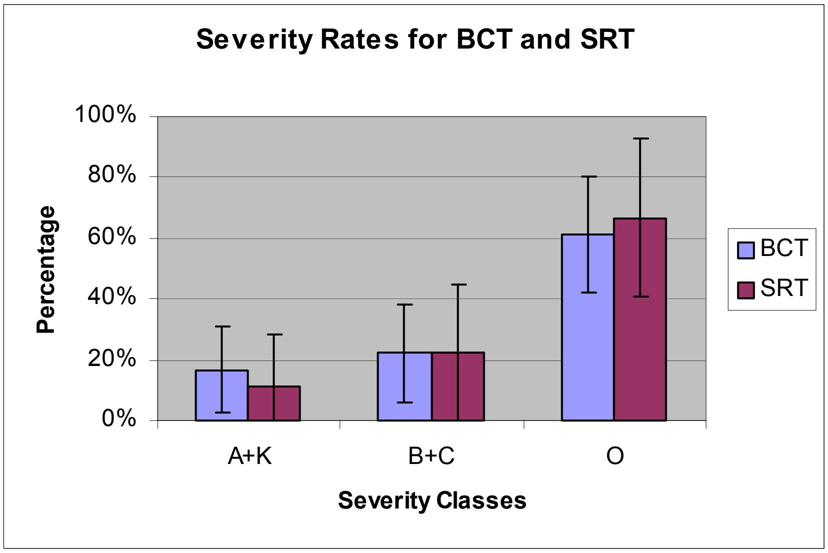

Figure 2-Severity Rates for BCT and SRT

As a further comparison, the Chi-Square test was used to investigate whether the observed difference between the two devices in their injury severity proportions was statistically significant. The observed and expected frequencies are shown in Table 18 and the Chi-Square test results are summarized in Table 19 below. The computed Chi-Square statistic is 0.154. However, to be significant at the 0.10 level (90% Confidence level) the computed Chi-Square has to be greater than 4.61 for two degrees of freedom. This means that the null hypothesis of no statistically significant difference in the injury severity proportions for these two devices cannot be rejected. This finding reinforces the conclusion that the safety performances of the BCT and SRT as observed in this study are in fact comparable.

Observed and Expected Frequencies for BCT and SRT						
			Severity Cat			Total
			A+K	B+C	O	
DeviceType	BCT	Count	3	4	11	18
		Expected Count	2.7	4.0	11.3	18.0
	SRT	Count	1	2	6	9
		Expected Count	1.3	2.0	5.7	9.0
Total		Count	4	6	17	27
		Expected Count	4.0	6.0	17.0	27.0

Table 18-Observed and Expected Severity Distribution for BCT and SRT

Chi-Square Tests			
	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	.154(a)	2	.926
Likelihood Ratio	.160	2	.923
N of Valid Cases	27		
(a) 4 cells (66.7%) have expected count less than 5. The minimum expected count is 1.33.			

Table 19-Chi-square Test Results

Comparison to Statewide Terminal End Incidents

The statewide injury severity proportions for guardrail leading end accidents from the Washington State accident database for the four-year period of 1999-2002 were compared to the corresponding proportions documented for guardrail terminals in the in-service project.

Device Type		Severity Category			Total
		A+K	B+C	O	
Study Area Terminals	Count	4	8	18	30
	% within Device Type	13.3%	26.7%	60.0%	
	90 % Confidence	+/- 10.2%	+/- 13.4%	+/- 14.7%	
Statewide Leading End	Count	35	187	245	467
	% within Device Type	7.5%	40.0%	52.5%	
	90 % Confidence	+/- 2.0%	+/- 3.7%	+/- 3.8%	

Table 20-In-Service Project vs. Statewide Leading End

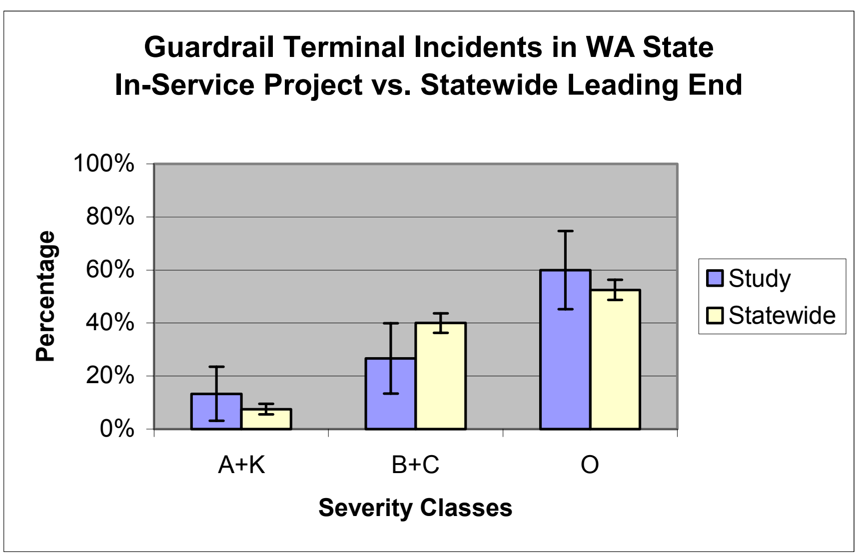

Figure 3-In-Service Project vs. Statewide Leading End

The confidence intervals for the severity proportions overlap between the study area and the statewide leading end average, which implies there is no significant difference between the two groups for all three injury severity classes.

Computation of Collision Rates Normalized for Traffic Volumes

One of the dilemmas in collecting collision data on roadside safety features is the fact that reported collisions often constitute only a portion of the total number of collisions, as Ray et al [40] and Council and Stewart [8] have pointed out. Minor collisions where the vehicle was able to drive away and are not reported will be missed, and as a result, injury severity rates are often higher than the actual rates. One widely used strategy for addressing the problem is to compute injury collision rates based on frequencies normalized by traffic exposure [39]. In this study, developing the hardware inventory data allowed the injury severity rates to be calculated. The results, shown below in Tables 21 and 22, are plotted with their corresponding 90% confidence level intervals in Figure 4. Because the 90% confidence intervals for rates in the three severity categories overlap for both the BCT and the SRT, it is concluded that there is no significant difference between the injury-related performances of the BCT and the SRT in this study area.

The Collision Rate for BCT is:				
Collisions/Year =	18			
Injury Collisions per Year =	7			
Sum of ADT per Million Vehicle Passings (MVP)	24,996	90% Confidence Limits		
		Precision	Lower Limit	Upper Limit
Collisions Per MVP =	0.0007	0.0003	0.0004	0.0010
All Injury Collision Per MVP =	0.00028	0.0002	0.0001	0.0005
A + K Injury Collision Per MVP =	0.00012	0.0001	0.0000	0.0002
B + C Injury Collision Per MVP =	0.0002	0.0001	0.0000	0.0003
O Collision Per MVP =	0.0004	0.0002	0.0002	0.0007

Table 21-Collision Rates for BCT

The Collision Rate for SRT is:				
Collisions/Year =	9			
Injury Collisions per Year =	3			
Sum of ADT per Million Vehicle Passings (MVP)	3,047	90% Confidence Limits		
		Precision	Lower Limit	Upper Limit
Collisions Per MVP =	0.0030	0.0016	0.0013	0.0046
All Injury Collision Per MVP =	0.0010	0.0009	0.0000	0.0019
A + K Injury Collision Per MVP =	0.0003	0.0005	0.0000	0.0009
B + C Injury Collision Per MVP =	0.0007	0.0008	0.0000	0.0014
O Collision Per MVP =	0.0020	0.0013	0.0006	0.0033

Table 22-Collision Rates for SRT

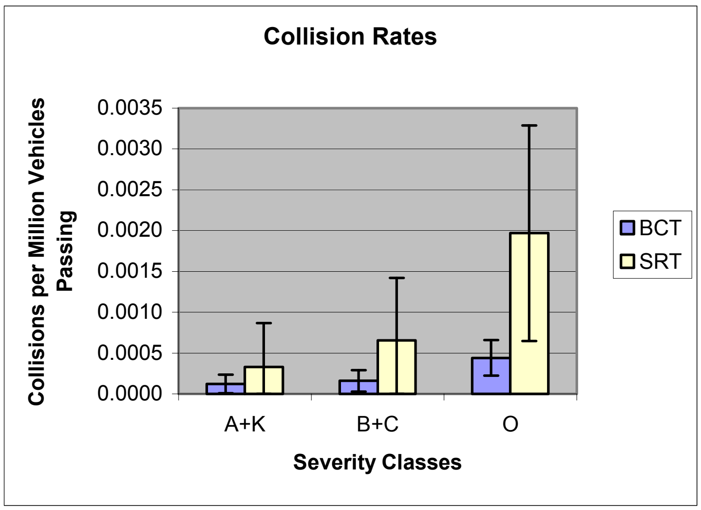

Figure 4-Normalized Collision Rates for BCT and SRT

Comparison of Washington State and Iowa In-Service Evaluations

The rates above were compared to the rates normalized in the similar study of the BCT in Iowa [41]. The WA State study area expanded the study size by covering almost twenty times more mileage and total exposure for vehicles passing the BCT installations than in Iowa. From Table 23, the rate per hundred million vehicles passing for all injury collisions is 0.028 and the disabling or fatal (A+K) rate is 0.012. These injury collision rates were substantially lower (by a factor of 10) than in the Iowa study.

BCT Collision Rates per 100 Million Vehicles Passing		
	IOWA	WA
All Injury Collisions	0.3	0.028
Disabling or Fatal (A+K) Injury Collisions	0.1	0.012

Table 23-Comparison of Collision Rates from IOWA and WA BCT Studies

Accounting for the Effects of Roadway Geometrics on Collision Rates

In a recent work, Weir, Noga and Ray [54] adapted the work by Harwood and others [18] on accounting for the effect of roadway geometry on highway accident rates. The method, in addition to accounting for traffic exposure levels, adjusts for the effect of roadway geometric features, like shoulder widths, lane widths, alignment, and grade, through the use of appropriate Accident Modification Factors (AMF). The results are base injury collision rates that are independent of the influence of highway geometric features at the collision sites. Such geometry neutral collision rates facilitate more meaningful comparison between the performances of two or more devices.

Shoulder width and curve length were the factors used in the calculations in the study. Base collision rates for BCT and SRT installations were calculated for the study area and the results are shown in Table 24 and 25. In Figure 5, the plots show that the confidence intervals for the two devices overlap in all the injury categories, implying that there is no statistical difference between the safety performances of the two devices.

Base Collision Rates for BCT:				
Collisions/Year =	18			
Injury Collisions per Year =	7			
Sum of ADT X Accident Modification Factors per Million Vehicle Passings (MVP) =	25,300			
		90% Confidence Limits		
		Precision	Lower Limit	Upper Limit
Collisions Per MVP =	0.0007	0.0003	0.0004	0.0010
All Injury Collision Per MVP =	0.0003	0.0002	0.0001	0.0004
A + K Injury Collision Per MVP =	0.0001	0.0001	0.0000	0.0002
B + C Injury Collision Per MVP =	0.0002	0.0001	0.0000	0.0003
O Collision Per MVP =	0.0004	0.0002	0.0002	0.0007

Table 24-Base Collision Rates for BCT

Base Collision Rates for SRT:				
Collisions/Year =	9			
Injury Collisions per Year =	3			
Sum of ADT X Accident Modification Factors per Million Vehicle Passings (MVP) =	3,070			
		90% Confidence Limits		
		Precision	Lower Limit	Upper Limit
Collisions Per MVP =	0.0029	0.0016	0.0013	0.0045
All Injury Collision Per MVP =	0.0010	0.0009	0.0000	0.0019
A + K Injury Collision Per MVP =	0.0003	0.0005	0.0000	0.0009
B + C Injury Collision Per MVP =	0.0007	0.0008	0.0000	0.0014
O Collision Per MVP =	0.0020	0.0013	0.0006	0.0033

Table 25-Base Collision Rates for SRT

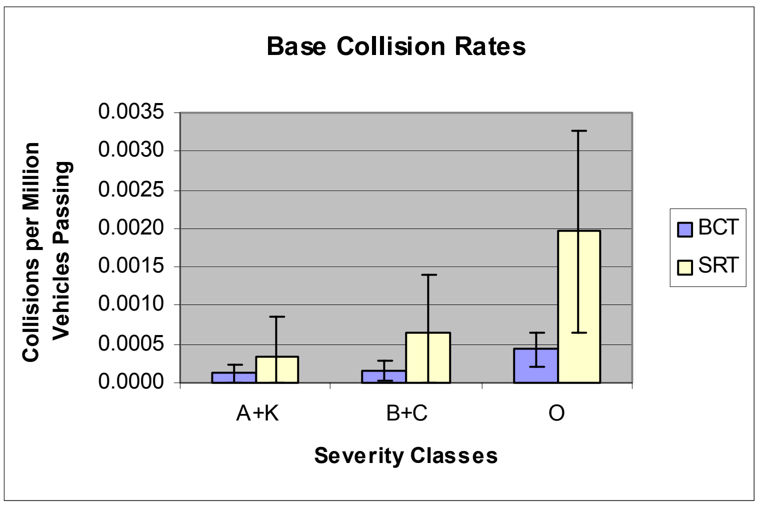

Figure 5-Base Collision Rates for BCT and SRT

CONCRETE BARRIER - DATA ANALYSIS

Introduction

The unrestrained pre-cast concrete barrier (UPCCB) has a typical New Jersey face and a height of thirty-two inches. It has a width of six inches at the top and twenty-four inches at the base and has a curb face of three inches high. The pre-cast segments come in lengths of 10 feet or 12.5 feet and are held together by pin and wire loop connections. These connections permit displacement and rotation at joints when segments are struck with sufficient force.

The UPCCB had not been crash tested when this project began. However in March 2001, two crash tests, conducted with the pickup truck [57], revealed that the barrier met Report 350 criteria.

Locations of Struck Barriers

During the data collection phase the data collectors reported a total of forty-five collisions involving the unrestrained pre-cast concrete barriers.

Placement		Route Type: Interstate	NHS (Non-Interstate)	Non-NHS	Total
Main line Median	Count	27		1	28
	% of Total	60.0%		2.2%	62.2%
Main line Shoulder	Count	11			11
	% of Total	24.4%			24.4%
Ramp	Count	5	1		6
	% of Total	11.1%	2.2%		13.3%
Total	Count	43	1	1	45
	% of Total	95.6%	2.2%	2.2%	100.0%

Table 26-UPCCB Incidents by Route Type and Location

Barrier Offset From Edge-line

Among variables that have been associated with performance of the UPCCB barrier system when struck are the lateral offset of the barrier curb-face from the edge-line and the angle at which the device is struck [23]. During the data collection phase, it was often not feasible for the data collectors to reliably measure the angle at which the device is struck, but data on lateral offsets was collected.

Thirty-five locations were able to be measured and the result showed that barrier offsets from edge-line were on the average 3.21 feet for installations in the main line median areas, about 9 feet for installations on main line shoulders, and about 4.5 feet for installations on the ramps.

Type	# Measured	Min (ft)	Max (ft)	Mean (ft)	No Data	Total
Main line Median	21	0	13	3.21	7	28
Main line Shoulder	10	0	10	9.2	1	11
Ramp	4	0	8	4.5	2	6
Total	35	0	13	5.07	10	45

Table 27-UPCCB Measured Lateral Offset Distances

Maximum joint displacement of a Struck Barrier

When struck by an errant vehicle, depending upon the force of the impact, one or more barriers may be displaced. The number of joints displaced provides indication of the number of segments and total length of barrier run displaced. The WSDOT design standard for maximum joint displacement for unrestrained barrier is set at three feet, or two feet when there is a drop-off or steep fill slope behind. An analysis of the data gathered showed that, in nearly 74% of the incidents, the recorded maximum joint displacement for this barrier was less than or equal to two feet.

Type	# Measured	Min (ft)	Max (ft)	Mean (ft)	No Data	Total
Main line Median	21	0	4	1.92	7	28
Main line Shoulder	10	0	2	1.29	1	11
Ramp	4	0.2	2	1.34	2	6
Total	35	0	4	1.81	10	45

Table 28-UPCCB Incident Joint Displacements

Number of Joints Moved during Collision

Examining the number of barriers that have moved in an incident provides an indication of resistance provided by the system. The number of joints displaced can be used as a surrogate for the number of barriers displaced since the number of segments displaced is equal to the number of joints displaced plus one. In a displaced barrier run, the length is measured between the first and last joints that had not moved from their original positions. A tabulation of the number of joints moved against the lateral offset of barrier from edge-line shows that three joints or less were displaced in 62.9% of the cases and less than 14% had five or more joints displaced.

Lateral Offset Range		Number of Joints Displaced						
		1	2	3	4	5	6	Total
0 - <2	Count	0	2	5	1	1	0	9
	% of Total		5.7%	14.3%	2.9%	2.9%		25.7%
2 - <4	Count	0	2	1	2	0	0	5
	% of Total		5.7%	2.9%	5.7%			14.3%
4 - <6	Count	0	2	0	0	1	1	4
	% of Total		5.7%			2.9%	2.9%	11.4%
6 - <8	Count	1	1	0	2	0	0	4
	% of Total	2.9%	2.9%		5.7%			11.4%
>=8	Count	0	5	3	3	1	1	13
	% of Total		14.3%	8.6%	8.6%	2.9%	2.9%	37.1%
Total	Count	1	12	9	8	3	2	35
	% of Total	2.9%	34.3%	25.7%	22.9%	8.6%	5.7%	100.0%

Table 29-UPCCB Lateral Offset and Joints Displaced

Damage to Joint Connections

The types of damage to joint connections in struck barriers observed in this study are tabulated in Table 30. For the forty that could be measured, the joint connections remained intact for 75% of the struck barriers and showed no visible evidence of damage. In 20% of the cases only the pin was damaged (bent or broken). The remaining 5% were cases in which the displaced barrier had joints with separate pin or loop damage, although in no case simultaneously.

Type of Damage	# Measured	Percent
Damage to Loop or Pin	2	5%
Damage to Pin	8	20%
No Damage	30	75%
Total	40	100%

Table 30-UPCCB Frequencies of Damage to Joint

Study Sample for Safety Analysis

During the data collection period, forty-five collisions involving UPCCB were documented. Three of the incidents were found to be multiple-vehicle collisions and were excluded from the primary study sample.

Data collectors were able to obtain police reports for four of these hits directly from the investigating police officers. The search through the 2001 Accident database located the police reports for fifteen of the forty-two hits, which included the four police reports mentioned earlier. These fifteen collisions were classified as police-and-maintenance reported collisions. The remaining twenty-seven hits documented by maintenance for which no corresponding police reports were found were classified as maintenance-only reported collisions. They were assumed to be property damage only.

Distribution of Injury Severities

The breakdown by injury severity for the study sample and its comparison to the statewide injury severities for all concrete barrier collisions for the four-year period of 1999-2002 is shown in Table 31.

Device Type		Severity Category			Total
		A+K	B+C	O	
Study Area UPCCB	Count	1	7	34	42
	% within Device Type	2.38%	16.67%	80.95%	
	90 % Confidence	+/- 3.86%	+/- 9.46%	+/- 9.7%	
Statewide Concrete Barrier	Count	126	2134	3354	5614
	% within Device Type	2.24%	38.01%	59.70%	
	90 % Confidence	+/- 0.33%	+/- 1.07%	+/- 1.08%	

Table 31-In-Service Project vs. Concrete Barrier Statewide

Comparison to the Statewide Concrete Barrier Incidents

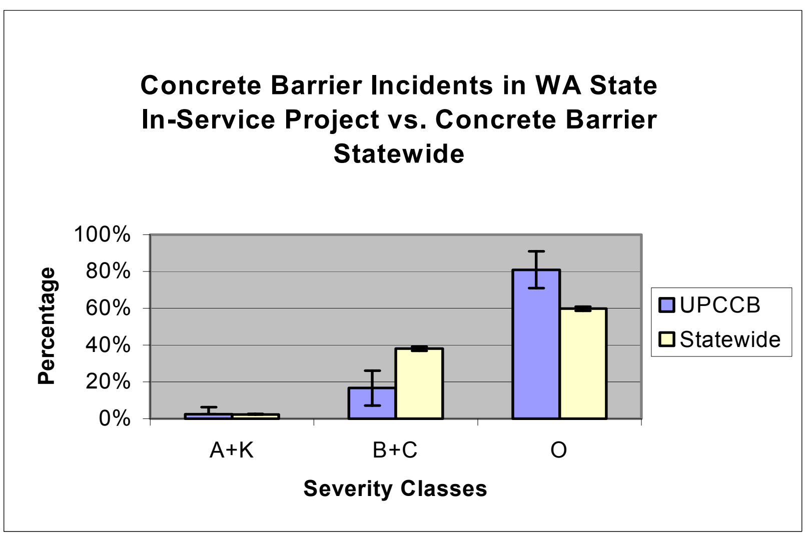

Figure 6-In-Service Project vs. Concrete Barrier Statewide

Examining the confidence intervals in Figure 6 for the UPCCB study sample and the statewide concrete barrier collisions shows that they overlap in the (A+K) injury category, which implies similar performance for the two groups. However, the confidence intervals do not overlap in either the (B+C) injury category or the property damage only (O) category, which would imply that the performances may significantly differ in these two categories. Thus, single vehicle collisions with the UPCCB would be expected to result in a lower proportion of (B+C) injuries and a higher proportion of property damage only collisions than the performance shown for statewide concrete barriers collisions.

Computation of Collision Rates Normalized for Traffic Volumes

Computations of the collision and injury rates normalized by traffic volume for the UPCCB systems are shown in Table 32 and plotted in Figure 7.

The Collision Rate for UPCCB is:				
Collisions/Year =	42			
Injury Collisions per Year =	8			
Sum of ADT x Million Vehicle Miles =	10,429			
		90% Confidence Limits		
		Precision	Lower Limit	Upper Limit
Collisions Per Million Vehicle Miles =	0.0040	0.0010	0.0030	0.0051
All Injury Collision Per Million Vehicle Miles =	0.0008	0.0004	0.0003	0.0012
A + K Injury Collision Million Vehicle Miles =	0.0001	0.0002	0.0000	0.0003
B + C Injury Collision Million Vehicle Miles =	0.0007	0.0004	0.0003	0.0011
O Collision Million Vehicle Miles =	0.0033	0.0009	0.0023	0.0042

Table 32-Collision Rate for UPCCB

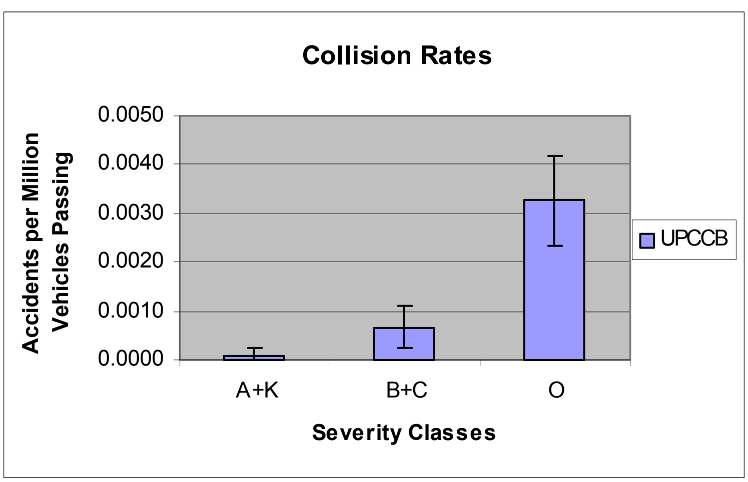

Figure 7-Normalized Collision Rates for UPCCB

Accounting for the Effects of Roadway Geometrics on Collision Rates

As was done earlier for guardrail terminals, base collision rates were calculated for the UPCCB in the study area. This was done by adjusting the observed collision and injury rates using Accident Modification Factors. The geometric features employed were shoulder width and curve length. The resulting base collision rates for the UPCCB are tabulated in Table 33 and plotted in Table 8.

Base Collision Rates for UPCCB:				
Collisions/Year =	42			
Injury Collisions per Year =	8			
Sum of ADT x Accident Modification Factors per Million Vehicle Miles =	6,870			
		90% Confidence Limits		
		Precision	Lower Limit	Upper Limit
Collisions Per Million Vehicle Miles =	0.0061	0.0016	0.0046	0.0077
All Injury Collision Per Million Vehicle Miles =	0.0012	0.0007	0.0005	0.0018
A + K Injury Collision Million Vehicle Miles =	0.0001	0.0002	0.0000	0.0004
B + C Injury Collision Million Vehicle Miles =	0.0010	0.0006	0.0004	0.0017
O Collision Million Vehicle Miles =	0.0050	0.0014	0.0036	0.0063

Table 33-Base Collision Rates for UPCCB

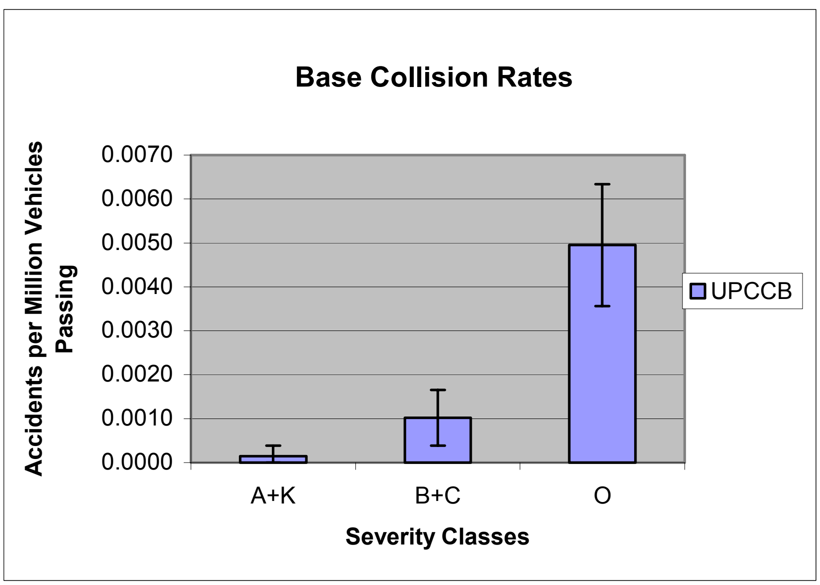

Figure 8-Base Collision Rates for UPCCB

SUMMARY & CONCLUSIONS

The research study evaluated the in-service performance of existing guardrail end-treatments and unrestrained pre-cast concrete barrier in Washington State. WSDOT now installs crash tested devices to Report 350 criteria for new guardrail terminal installations, but conducted the research study to evaluate the BCT terminal on its safety record and to consider its replacement plans. The unrestrained pre-cast median barrier was evaluated for its in-service performance while plans to crash test the feature proceeded.

A web-based database system was developed for the collection and maintenance of performance data on roadside safety devices needed by the study. Forms were developed for consistency in the data gathering, in line with NCHRP Project 22-13. Local area maintenance personnel were recruited to gather the specific information that would be required in the analysis phase. Training was provided for the inspectors on the data requirements and they provided feedback at that time that led to revisions to the forms and database.

The maintenance personnel documented incidents, including extent of damage and repair costs, either directly into the database or by utilizing electronic forms to email the information to the research team. Pertinent information from police reports was also added to the system by the research team.

Finally, the data analysis phase of the project evaluated performance characteristics and severity rates for the targeted devices. To evaluate performance, measurements made by the maintenance personnel were used to examine the "quality" of the installations, which is a critical element in the performance of the BCT. The measurements that were chosen for guardrail terminals as well as for the UPCCB analysis were consistent with recommendations from NCHRP Project 22-13.

The study shows that the properly installed BCT feature is still a valid end treatment. The BCT and the SRT features were comparable in their severity responses and both are responding within acceptable expectations. Most of the BCT features that were struck and then evaluated had an acceptable level of correctness in their installations, which is critical to their performance.

Not enough data was gathered on the MELT, ET-2000, FLEAT, or SKT terminals to make conclusions in the report.

WSDOT has revised its policy as it relates to the BCT feature, in consideration of this study and other research. As the roadway is addressed systematically through the paving cycle, the BCT will be replaced on the Interstate system; for other routes, the BCT may remain as long as it meets the minimum offset of three feet and the guardrail run or anchor is not being reconstructed or reset.

The Unrestrained Pre-cast Concrete Barrier examined in the study demonstrated that the pin and loop jointing system holds up well in collisions and that barrier displacements were within the design specification for such a system. Also, the UPCCB demonstrated reduced severity rates in the evident and possible injury class in a comparison of the collisions gathered in the study to all concrete barrier leading end collisions in Washington State from the 1999-2002 timeframe. As the feature was successfully crash-tested to Report 350 criteria during the study period, the feature becomes an approved barrier to be used in appropriate applications.

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APPENDICES

Appendix A: In-Service Project Database Forms

FORM 1: GUARDRAIL TERMINAL PRE-COLLISION DATA

FORM 2: GUARDRAIL TERMINAL DAMAGE REPORT

FORM 3: PRECAST CONCRETE BARRIER PRE-COLLISION DATA

FORM 4: PRECAST CONCRETE BARRIER DAMAGE REPORT

FORM 5: PRECAST CONCRETE BARRIER DAMAGE-SHORT FORM

Appendix B: In-Service Project Roadway Inventory

STATE ROUTE INVENTORY

APPENDIX A-FORMS

IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY HARDWARE
STRUCK GUARDRAIL TERMINAL
FORM 1: PRE-COLLISION DATA COLLECTION

Device Type:

Date of Data Collection:

Location (route #, direction, milepost, placement):

<u>Terminal: Structure Details</u>

1. Vertical Distance: Center Breakaway Hole to Ground Line (in.):

2. Is Anchor Cable Loose? (Y/N):

3. Is there a Cable-Release Mechanism Attachment to Rail? (Y/N)

4. Is there a Ground-Strut between Posts 1 and 2? (Y/N)

5. This installation is protecting a Slope or Fixed Object?

6. Is tangent section of Guardrail Terminal located at Shoulder Edge? (Y/N)

7. Terminal is attached downstream to: (**see column (a) at bottom of page**):

8. Shoulder Type? (**See column (b) at bottom of page**):

9. Lateral offset at post # 1 (ft) ; post # 3 (ft) ; and post # 7 (ft)

APPENDIX A-FORMS

IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY HARDWARE
STRUCK GUARDRAIL TERMINAL
FORM 1: PRE-COLLISION DATA COLLECTION

Details along terminal profile								
Post No.	Rail Height From ground line: (top of rail) **(inch)**	Post Type **(c)**	Spacing to next post downstream **(d)**	Block out Used? **(Y/N)**	Rail to Post Connection Type **(e)**	Backup Plate Used? **(Y/N)**	Shelf Angle Used? **(Y/N)**	Foundation Type **(f)**
1								
2								
3								
4								
5								
6								

Comments:

(* This table denotes the option available and corresponds to the letters in the table above.

Term. Attached Downstream (a)	*Shoulder Type* **(b)**	**Post Type (c)**	**Post Spacing (d)**	Rail to Post Connection Type **(e)**	Foundation type **(f)**
Bridge Rail	Paved	6”x 8” Wood post	6’ – 3”	Bolt	Steel tube
Bridge Pier	Partially Paved	6” x 8” Wood Breakaway post	4’ – 2”	Bolt and Washer	Concrete Foundation
Cable Guardrail	Gravel	6” x 8” Wood CRT post	3’ – 1 ½”	None	None
W-Beam Guardrail	None	8” x 8” Wood post		Other	Other
	Other	W 6 x 9 Steel post			

APPENDIX A-FORMS

IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY HARDWARE
STRUCK GUARDRAIL TERMINAL
FORM 2: DAMAGE REPORT DATA COLLECTION

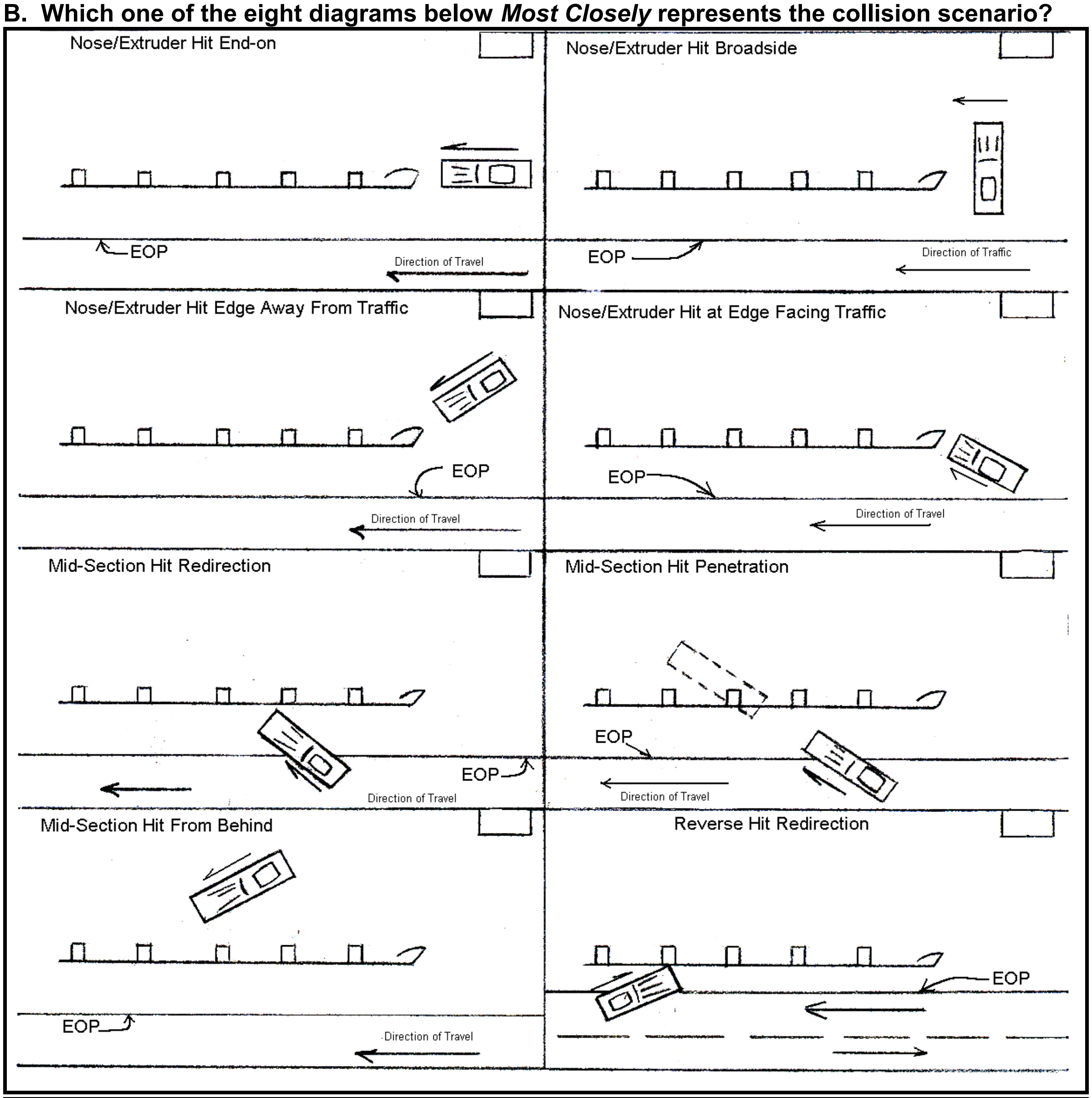
Device Type:

Date of Data Collection:

Location (route #, direction, milepost, placement):

A. **<u>Collision Scenario:</u>** Are you able to determine collision scenario? **<u>Y/N:</u>** If no, please explain in comment box.

B. Which one of the eight diagrams below *Most Closely* represents the collision scenario?



IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY HARDWARE
STRUCK GUARDRAIL TERMINAL
FORM 2: DAMAGE REPORT DATA COLLECTION

C. Damage to End Treatment:

1. Max Rail Deflection at rail height (ft):
2. Total Rail Length Damaged (ft):
3. Total Rail Length Extruded (ft):
4. Total no. of secondary impacts:
5. Distance from post #1 to POI (ft):
6. How much did Post#1 foundation move at Ground Line?:
7. Was Soil tube at Post#1 pulled out?:
8. How much did Post#2 foundation move at Ground Line?:
9. Was Soil tube at Post#2 pulled out?:
10. Did cable release mechanism detach from Rail?:

D. Damage Details along Terminal Profile

Post No.	Ground Line Deflection (ft)	Deflection at top of Rail (ft)	Post Broken (y/n)	Post Bent (y/n)	Splice Failed (y/n)	Rail Torn or Broken (y/n)

E. Final Position of Nose/Extruder:

1. Nosed Moved (Y/N)
2. Distance moved from Post#1 (parallel to Edge Line) (ft)
3. Lateral distance from Edge Line (ft)

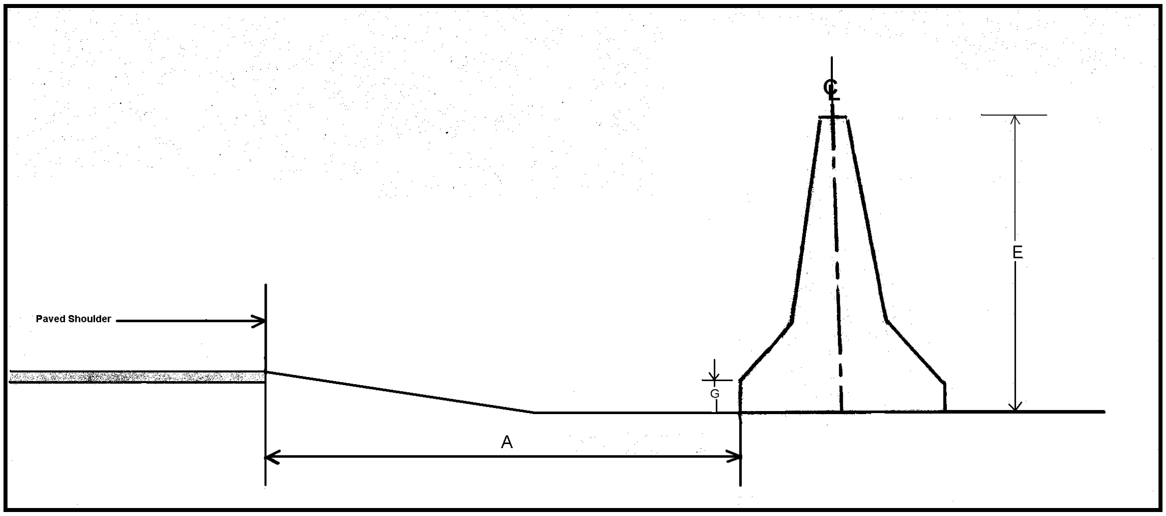
Comments:

APPENDIX A-FORMS

IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY HARDWARE
STRUCK UNRESTRAINED PRECAST CONCRETE BARRIER
FORM 3: PRE-COLLISION DATA COLLECTION

1. Device type: ______ Date of Data Collection: ______
2. Location (route #, direction, milepost, placement): ______

A. Roadside or Median Cross Section at struck segment:



1. Median cross section type (**see options below**): ______
2. Height to top of Barrier (**E**) (in.): ______
3. Vertical curb Height (**G**) (in.): ______
4. Distance: Shoulder Edge to barrier curb face (**A**) (ft): ______
5. Shoulder type (see below): ______

B. Comments: ______

***Answer Options:**

Median cross-section type	Depressed	Raised	Other		
Shoulder Type	Paved	Partially Paved	Gravel	None	Other

****(This table is read from left to right.)**

APPENDIX A-FORMS

IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY HARDWARE
STRUCK UNRESTRAINED PRECAST CONCRETE BARRIER
FORM 4: DAMAGE REPORT DATA COLLECTION

Device Type:

Date of Data Collection:

Location (route #, direction, milepost, placement):

A. **<u>Barrier Performance After Impact</u>: (Can you determine performance after impact scenario? If yes continue with question 1-6). If no, explain in line number 7.**

1) Vehicle redirected:

2) Vehicle rode up Barrier Face and rolled over:

3) Vehicle vaulted over barrier:

4) Vehicle penetrated barrier at separated joint:

5) Vehicle spun out and restruck barrier downstream:

6) Other (Describe):

7) If you cannot determine the performance after impact, please explain:

B. **<u>No. of Segments Displaced:</u>**

1) Total number of segments displaced :

C. **<u>Vehicle - Barrier Contact Distance</u>:**

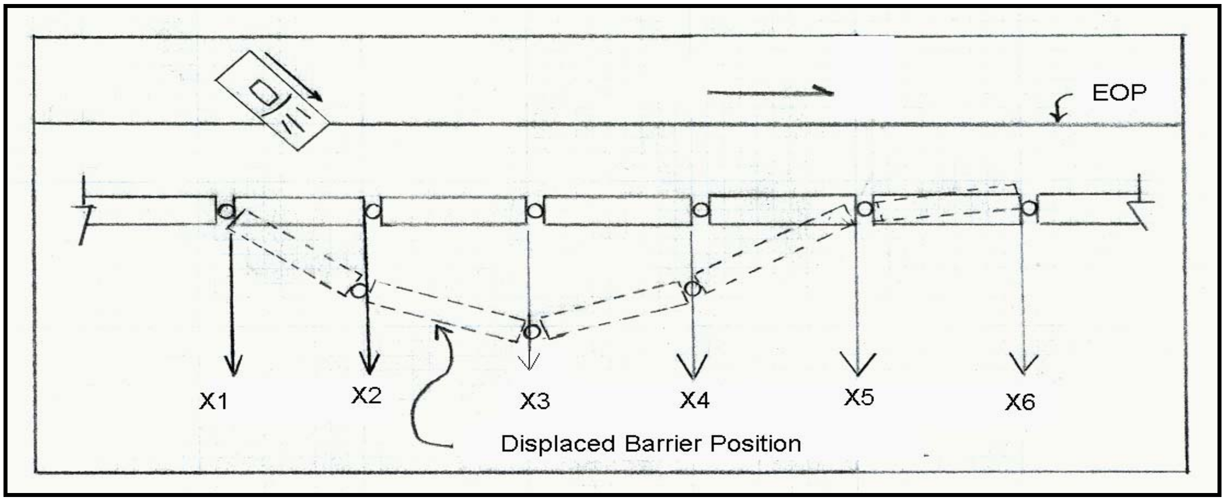
1) Total distance over which vehicle remained in contact with Barrier (ft):

2) Distance first POI to approach end of 1st displaced segment (ft):

3) Max height of tire marks on segments. (Inch)

APPENDIX A-FORMS

D. <u>Movement/Damage at each Joint</u>:



Joint Number	Lateral Displ. At Joint (ft)	Damage to pin and loop connection at joint. (b)	Damage to concrete at joint. (a)

<u>Comments:</u>

(Repeat for each displaced Barrier Segment starting from first displaced barrier upstream)

<u>(a) Damage to Concrete at joint</u>	Minor Spalling	Cracks	None	
<u>(b) Damage to pin and loop connection</u>	Pin Bent	Pin Broke	Loop Broke	Other

IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY HARDWARE
STRUCK UNRESTRAINED PRECAST CONCRETE BARRIER
FORM 5: SHORT FORM

1. **Date of site visit:** ☐
2. **Route#, Direction & Mile Post (Upstream end of Barrier Run):** ☐
3. **Number Of Segments Pushed Back into Alignment?** ☐
4. **Length of displaced barrier run: (ft)** ☐
5. **Dist. From Upstream to POI: (ft)** ☐
6. **Max Displ. from Alignment (ft)** ☐ **& Dist from Upstream. (ft)** ☐
7. **Dist from edge of shoulder to curb fare of undisturbed barrier (ft)** ☐
8. **Length of typical barrier segment:** ☐ **10 (ft)** ☐ **12 (ft)** ☐ **12.5** ☐ **Other** ☐
9. **Describe impact scenario and evidence of direction of travel of vehicle in comment box below, if known.**
10. **Comments:**
    a. **Indicate number of joint with damage to pin and loop connections, and describe damage.**
    b. **Indicate number of joint with damage to concrete, and describe damage.**
    c. **If no photos, indicate whether barrier placed on shoulder or median.**

APPENDIX B-STATE ROUTE INVENTORY

Type	SR	Beg MP	End MP	Total Miles
Interstate	5	55.10	155.60	100.50
	405	0	10.11	10.11
Total Interstate				110.61
NHS	12	2.90	99.61	96.71
	12	140.50	165.10	24.60
	16	0	4.90	4.90
	18	0	16.50	16.50
	101	362.50	367.91	5.41
	167	0	24.27	24.27
	509	0	3.20	3.20
	512	0	11.90	11.90
	518	0	3.55	3.55
Total NHS				191.04
Non-NHS	6	19	51.10	32.10
	7	0	50.40	50.40
	99	0	19.00	19.00
	123	0	9.80	9.80
	161	0	34.00	34.00
	162	0	19.78	19.78
	164	0	13.85	13.85
	165	0	19.84	19.84
	181	2.70	9.72	7.02
	410	3.21	65.51	62.30
	505	3.00	16.70	13.70
	506	0	11.51	11.51
	507	6.10	41.80	35.70
	508	0	32.20	32.20
	509	3.20	16.65	13.45
	510	0	10.70	10.70
	515	0	2.10	2.10
	516	0	30.22	30.22
	702	0	1.00	1.00
	706	0	12.31	12.31
	900	0	19.38	19.38
Total Non-NHS				450.36

Total Miles				752.01