SPECIAL REPORT 323:
IN-SERVICE PERFORMANCE EVALUATION OF GUARDRAIL END TREATMENTS

TRB-SASP-14-05
In-Service Performance of Energy-Absorbing W-Beam Guardrail End Treatments: Phase 1

Examples of State Highway Agency Practices Regarding Design, Installation, Maintenance, and Evaluation of Guardrail End Treatments

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Paper prepared for the
Committee for the Study of In-Service Performance
of W-Beam Guardrail End Treatments, Phase 1
Transportation Research Board

2017

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ACKNOWLEDGMENTS

The authors wish to thanks all the state DOT representatives who agreed to be interviewed for this important topic. We also wish to thank the committee, topic panel, and Mr. Joseph Morris of TRB for their suggestions and support throughout the project.

INTRODUCTION

For the purposes of this paper, guardrail end treatments (GETs) are crash-worthy mechanical devices installed at the leading end of W-beam guardrail, which is a widely used type of longitudinal barriers installed on roadsides throughout the United States. There are two (2) primary categories of GET systems in current use, energy-absorbing and non-energy-absorbing. This project focuses on energy-absorbing W-beam GETs, however much of the information presented applies to both categories. Nearly all GET systems that meet current crash testing standards are proprietary devices manufactured and supplied nationwide by private companies. There are a relatively small number of different systems (brands and models) in widespread use. These systems are installed on nearly all types of roads and highways throughout all fifty (50) states, and are exposed to a relatively high rate of vehicle impacts due their sheer numbers and typical close proximity to travel lanes.

In order to be deemed crashworthy, new GET designs are subjected to full-scale crash tests conducted in accordance with standardized national procedures. During and after the controlled tests, GET systems are evaluated for structural adequacy, occupant risk, and vehicle trajectory. Once a GETs performance is judged to have met the specified crash-test performance criteria, it is typically eligible for installation on public roadways. The Federal Highway Administration (FHWA) has traditionally accepted a role in evaluating laboratory crashworthiness of devices, and issues "eligibility letters", indicating that a particular GET system has been judged to have met the specified performance criteria and is eligible for federal-aid reimbursement of costs incurred by state departments of transportation (DOTs) for installation on their highway network.

The vast majority of GETs in the United States are purchased, installed, and owned by state DOTs, and to a lesser extent other highway agencies. Policies, procedures and practices for managing the full life-cycle of roadside safety systems, including GETs, vary among the fifty-

plus (50+) state DOTs. Methods of administering a complete program related to these systems include the following primary categories:

1. Device Selection Criteria and Application Design.
2. Construction and Installation Process.
3. Inventory and Management.
4. Maintenance.
5. In-Service Performance Evaluation.

While most practices within these categories are similar, others were developed or evolved independently making them unique to individual agencies. Practices related to these areas of operations have an effect on performance, longevity, and overall cost of GET installations on a statewide level.

This paper topic is intended to identify a sampling of these practices, and highlight details of comprehensive and innovative programs currently in place for management of GETs. It is part of a larger project to develop methods that DOTs can use to improve their techniques for evaluating field performance of the various GET systems. A majority of the information needed for this paper topic was gathered by conducting interviews with key personnel at ten (10) state DOTs. The following agencies were selected based on size of their highway network, past involvement with roadside safety research, and willingness to participate:

1. California Department of Transportation (Caltrans)
2. Florida Department of Transportation (FDOT)
3. Kansas Department of Transportation (KDOT)
4. Missouri Department of Transportation (MoDOT)
5. New York State Department of Transportation (NYSDOT)
6. North Carolina Department of Transportation (NCDOT)
7. Ohio Department of Transportation (ODOT)
8. Pennsylvania Department of Transportation (PennDOT)
9. Texas Department of Transportation (TxDOT)
10. Washington State Department of Transportation (WSDOT)

In most cases, the authors interviewed one (1) individual from each agency, and asked a series of questions related to each of the five (5) categories. In some cases, multiple personnel within an agency were interviewed based on their specific expertise and position with the organization. Interview questions were developed by the authors, and reviewed by the topic subcommittee before the interviewing began. Responses to the questions were documented, and supplemental information provided by the interviewees was collected.

The paper is organized into five (5) sections, one (1) for each of the functional categories listed above. Within each category, there is a narrative description of each DOTs response to questions related to that function. In addition, there are several charts and tables that provide quick reference to practices that are common to multiple agencies. A Conclusions sections provides opinions drawn from assessing typical and routine practices, as well as unique and innovative techniques that promote sound and consistent evaluation of GETs and their applications. This information may be used to further develop exceptional practices, and promote their implementation by a greater number of highway agencies. In addition, there is an

Appendix to the paper that includes links to agency resources, such as Manuals, Standard Drawings & Specifications, Approved Products Lists, and other pertinent information.

GUARDRAIL END TREATMENT DESIGN AND SELECTION PRACTICES

This section focuses on methods and procedures used by state DOTs to specify details and application of new GET units to be installed as part of highway construction projects. Below are descriptions of GET design practices identified during interviews with personnel from each state agency surveyed.

California DOT

Caltrans publishes their own Highway Design Manual, which references the AASHTO Roadside Design Guide (RDG) in some areas related to GET design. Design guidance is also provided in Chapter 7 of their Traffic Safety Manual. These documents describe preferred lengths and layouts of guardrail locations. Occasionally, designers prepare special provisions for unique situations. Standard plans do not call out proprietary devices. They callout Type 11A "INLINE", Type 11B "FLARED", or Type 11C "BURIED END ANCHOR". Their design guidance recommends FLARED GETs as the preferred type, if space exists, due to reduced nuisance impacts & maintenance.

Site conditions are reviewed with a ground-up approach, which starts with identifying an adequate GET pad area. Then, slopes are considered in order to select the terminal type that fits the site. Headquarters provides a list of devices that fit each configuration. Occasionally, non-standard special provisions may specify a device by brand name for unique situations.

Since 2015, Caltrans designers have started considering crash history in their roadside design practices. Design proposals are reviewed by the Maintenance Division and Traffic Safety Specialist in each district to provide input on current conditions at each site. Caltrans also publishes memos that provide guidance on whether to replace in-kind or upgrade roadside systems based on statewide experiences.

In addition, Caltrans is very committed to employee training, and conducts training programs for design, construction, and maintenance. Training is provided in each of twelve (12) districts. Attendees are primarily Caltrans employees, but occasionally consultant designers attend for long-term projects. Currently, designer training certification is not required, but employee record of attendance is recorded.

Caltrans maintains a Qualified Products List (QPL) for GETs. There is a product review committee made up of personnel from the Crash Testing Unit, Maintenance Division, Traffic Safety Division, and others. Product evaluation submissions must contain crash test reports and videos. All GET types are included in the same category, and each manufacturer/model is identified as flared or tangent. Only the ET series has been removed from the QPL, due to perceived poor performance. Others, such as BCT and NCHRP 230 devices have been taken off when moving to new crash-test evaluation criteria.

Florida DOT

FDOT uses their own design guidelines, named the Plans & Preparation Manual, which references the AASHTO RDG. In 2018, it will be renamed to the Florida Design Manual. Approach GETs are classified by Test Level (TL). TL-2 is used at locations where the design speed is less than or equal to 45 mph, and TL-3 is acceptable for all other design speeds. GETs are further classified as follows:

- Flared. This type is preferred for locations where sufficient space is available to offset the barrier end from approaching traffic.
- Parallel. Used only when sufficient space is not available for a flared terminal.
- Double Faced. Used for double-faced/median guardrail installations.

GETs are specified in FDOT Standard Specifications Section 536, and shown on Standard Plans Sec. 400. The latest edition is dated February 2016.

Their project design plans call out the required Test Level, and whether each location is Flared or Parallel. After the project is awarded, contractors are free to choose particular make and model from the agency's Approved Products List (APL). Highway geometry, roadside characteristics, crash history, and traffic volume/mix are considered when designing Length-of-Need (LON) guardrail runs and in selecting the type of barrier, but not specifically for GETs. FDOT maintains a unique bidding system where the guardrail panel and connection hardware within the length of the GET is included in the linear foot of the guardrail run, and an additional pay item for the anchor (terminal) is added for any proprietary components. The reasoning behind this methodology relates to ensuring consistency in the installed guardrail length. By specifying the total linear feet from "end of rail" to "end of rail", they can reliably guarantee that the system is installed with the exactly LON desired, regardless of the cataloged length of the various GET systems, which may vary among approved models.

FDOT does not require that designers receive training specific to GETs, but they encourage, and have facilitated participation in roadside safety design courses offered by the Federal Highway Administration/National Highway Institute (FHWA/NHI).
The requirements for GET systems to be placed on the APL include:

- FHWA Eligibility Letter.
- System must pass the full MASH testing matrix, and submit test reports for all tests.

Once a system is on the APL, the manufacturer must provide website links to their product drawings, details of parts, installation manuals, and proper installation checklists. All these materials must be signed and sealed by a Professional Engineer (PE) registered in Florida. To date, no known systems have been denied APL approval or had their approval status revoked.

Kansas DOT

KDOT designers use the AASHTO RDG and their State Design Manual as guidelines for selecting and specifying new GET installations. The state manual provides only general information for roadside safety issues, and does not provide guidance specifically for GETs.

They consider roadside geometry, hazard location, crash history, and traffic volume when selecting a type of GET for a particular location.

KDOT hosts FHWA/NHI courses regularly, but there is no written policy or mandate that designers receive training. They also promote the informal practice of experienced engineers training younger ones.

Standard specifications and drawings show generic GET details for parallel and flared applications. Project plans include a Guardrail Layout Sheet for each run of guardrail that shows specifics on location and configuration (tangent or flared) of GETs. Rarely, they callout a specific product or tradename to be installed at a particular location.
Design consultants access all manuals and standards from their KDOT Authentication & Resource Tracking (KART) online system.

KDOT maintains a QPL for GETs. General requirements that must be met in order for a particular GET system to be placed on the QPL are available on their website under Prequalified Materials, Terminal Systems. Systems are listed by supplier and brand, and must have an FHWA letter. In-house roadside safety experts review applications, including crash test reports and videos. They reserve the right to not approve any systems based on their review, or based on reported experience from other agencies on issues. KDOT belongs to the Midwest Roadside Safety Pooled-fund group of DOTs. Member agencies discuss issues and experiences with GET systems. They do not have written policy for the above process, but that is how they complete the QPL review process. They try to keep the number of different systems to a minimum for maintenance purposes. The QPL does not provide links to manufacturers' manuals or checklists, but they expect the most current manufacturer details and checklists to be provided to jobsite with delivery of the system. GETs are specified, accepted and paid per unit installed (EACH). The ET-PLUS is the only system that was removed from their QPL.

Missouri DOT

MoDOT designers use the AASHTO RDG and the State Engineering Policy Guide (EPG) as their design guidelines for selecting and specifying new GET installations. The following factors are taken into account when selecting a GET: Geometry and other roadside characteristics; traffic volume and mix; and, crash history when available to the designer. GET training and certification for designers is encouraged, but not required. Their designers attend FHWA/NHI training courses and receive course updates from the instructors when available.

They use state standard specifications and drawings to specify new GET installations. Project specifications call for a specific "Type & Class" of GET. All systems are considered 50-ft. long regardless of their actual length.

MoDOT uses a QPL for GETs. Requirements that must be met in order for a particular GET system to be placed on the QPL include an FHWA Eligibility Letter and no known reports of poor field performance from other state DOTs. They are working on revisions to their requirements to improve the QPL approval process. There are three (3) categories of GETs in the QPL, as follows:

- Non-Flared Type A Crashworthy End Terminal.
- Flared Type A Crashworthy End Terminal.
- Flared Non-Energy-Absorbing Type A Crashworthy End Terminal.

The current list of approved GETs is available on their website. One (1) system had its approval revoked due to reported poor field performance.
Beginning on July 1, 2016, they require that all approved systems meet the AASHTO Manual for Assessing Safety Hardware (MASH). All "NCHRP 350" devices will be removed from the QPL on that date, leaving two (2) systems on the list: Soft-Stop and MSKT. Their basis of payment for GETs is "EACH" for a 50-ft length End Terminal.

New York State DOT

NYSDOT designers use their own Highway Design Manual, which references the AASHTO RDG. Roadway geometry (curvature, grade, lane width) are not taken into account when selecting GETs. They only use tangent GETs (flared are not approved for use), due to many locations with insufficient lateral distances for flared GETs. At locations with gentle slopes beyond the shoulder break, they frequently use generic turned-down ends (for both W-beam and box beam guardrail), which are set well back from traffic, near the limit of the clear zone. Traffic volume/mix and crash history are not taken into account when selecting GETs, and GET training and certification of designers is not required.

NYSDOT State Standard Drawings and Specifications show generic terminals, and reference the state APL. FHWA Eligibility Letter is the primary requirement for a particular GET system to be placed on the APL. However, they reserve the right to judge the performance for themselves before putting a system on the APL. They typically request crash videos, description of repairs needed as a result of those tests, and detailed drawings. In addition, they look at the videos and crash reports to see if any tests are marginal pass, and may not approve the system based on that. Also, they look at potential problems with repair and maintenance, and may not approve based on those observations.

There is only one category in the APL. All approved W-beam GETs must be energy-absorbing and able to be used in a tangent configuration. A link to the current APL is provided in the Appendix. The FLEAT and the SRT were not approved because they are flared systems. The ET-PLUS had installations suspended due to publicity issues, but they observed no performance problems on the NYSDOT system. NYSDOT placed the ET-Plus back on their APL on June 14, 2016. The basis of payment for GETs is EACH unit installed.

North Carolina DOT

NCDOT publishes their own State Design Manual, which references the AASHTO RDG for most roadside design issues. Their designers do not typically consider roadway geometry, crash history, or traffic volume/mix when selecting the type of GET for a particular location. It is noted that they do consider crash history when selecting a type of impact attenuator for a location.

Standard Drawing 862.01 (12 sheets) shows guardrail and GET placement details. Approved devices are shown on their QPL, and the contractor may select from the list. Occasionally, special provisions are used to specify a particular device. Product status categories in the QPL are Approved, Approved for Provisional Use, Accepted for Field Trial Use, Under Evaluation, and Requested Additional Information. QPL submittals require an FHWA Letter, drawings, and crash test videos (if available), and are reviewed by a committee.

NCDOT designer training is not required, but they have hosted the FHWA/NHI courses, and 95% of attendees were DOT employees.

Ohio DOT

ODOT publishes their own highway design manual, but it refers to the AASHTO RDG for roadside design issues. For energy-absorbing terminals, they specify either Type B (Flared) or Type E (Tangent) depending on roadside slope. There is no preferred type, but Type B (Flared) is less common due to the grading requirements. They allow Type A (turn-down end), if it is placed outside the clear zone. Also, a buried-in-backslope terminal is used where applicable. ODOT Standard 606 shows generic guardrail layout.

Training for designers is not required, and the FHWA/NHI course is optional. Design engineering consultants must be agency-approved, but approval requirements are not specific to guardrail.

Contractors select devices from the APL for each type. Approved proprietary devises are listed with access to manufacturers' drawings and installation manuals. Non-proprietary designs are shown in the standard plans. New GET product evaluations require an FHWA letter. Crash test reports and videos are not required. Once initially approved, new devices are installed at three (3) test locations, and their performance is reviewed for one (1) year. The evaluation primarily looks at extent of damage and repair costs. Maintenance personnel request that they limit the number of approved devices in order to reduce the variety that they must repair. The contract basis of payment is for EACH Type (B or E) installed.

Pennsylvania DOT

The PennDOT State Design Manual (Publication 13M) is used for selecting and specifying new GET installations. It references the AASHTO RDG in some places as a supplement. GETs are covered in Chapter 12, and the most recent edition is 2015.

Flared terminals are preferred if geometry & roadside characteristics allow. Snowplow damage, which is more likely to occur with tangent GETs is a big concern. Crash history and traffic volume/mix are not specifically considered when specifying the type of system.

Training for designers is encouraged, but not required. The FHWA/NHI Roadside Design Guide course is offered on a regular basis, and 60-70 designers typically attend. PA was one of the pilot states for the course. In addition, PA is now a group partner with the American Traffic Safety Services Association (ATSSA), and may utilize their courses in the future.

GETs are specified in the state standard specifications and plans, which reference the agency QPL (Publication 35). The standards do not show details of proprietary products, but refer to manufacturers' drawings and installation manuals. Designers specify the type of GET for a particular location from the following categories in the QPL: Tangent, Fared, Energy-Absorbing, and Non-Energy-Absorbing. Once a project is awarded, the contractor picks the specific devices to be installed on a project from those listed on the QPL. The basis of payment for GETs is EACH unit installed.

PennDOT does not have detailed written requirements that must be met in order for a particular GET system to be placed on the QPL. Typically, only an FHWA Eligibility Letter is required. The QPL review process begins with the Materials Division, and they forward applications to other affected divisions for comment prior to approvals. There is no product

approval committee. The current QPL of all approved GETs is shown in Publication 35, Bulletin 15. There a link to this publication in the Appendix. They are in the process of adding more manufacturers' details to the QPL for reference.
Use of the ET-PLUS was suspended, but the system was not revoked from the QPL. No systems have ever been revoked.

Texas DOT

TxDOT publishes a state Roadway Design Manual, however, there are few details related to GETs. Otherwise, they use the AASHTO RDG as guidelines for applications of GETs. They currently have three (3) standard details for GETs, which show proprietary systems, as follows: SKT with wood posts; SKT with steel posts; and, the X-LITE system. They are in the process of adding the SOFT-STOP system. Standard details are generated for each GET approved, and show general information with regard to layout and slope requirements. Specific installation procedures refer to manufacturer instructions, which are provided to jobsite with the systems. In some cases, they consider specifying only non-extruding GETs for areas that may have pedestrians or other objects in close proximity. Designers occasionally choose one specific manufacturer model over another. However, this is rare and requires a letter from the Design Division approving justification for sole-source installations. The basis of payment for GETs is EACH unit installed.

Formal training for designers is not required. The have hosted the FHWA/NHI courses in the past. TxDOT has a website specifically for training purposes. The roadside safety content is more related to crash cushions, rather than GETs. During the Summer/Fall of 2015, they conducted an in-house training program with maintenance personnel in 15 of their 25 districts. These sessions included details of guardrail installation, including terminals.
TxDOT standard drawings show the systems which are approved on the QPL. In order to be included in the standards, systems must have an FHWA eligibility letter, and crash test reports must be submitted. Crash test videos are not required, but are usually received. Once these are reviewed and approved, the system is installed on a trial basis. These installations are monitored for one (1) year. If there are no performance or maintenance issues that arise during that period, the system is included in the standards/QPL. There are no sub-categories of GETs on the QPL. They are lumped together as equals. The only system removed from the standards is the ET-PLUS, which was suspended in October 2014, and not reinstated. The basis of payment is for EACH GET unit installed.

Washington State DOT

WSDOT publishes their own design manual, which references the AASHTO RDG. Chapter 1610 of the manual addresses GETs, and there is link to this chapter in the Appendix. They ensure that geometry and roadside characteristics meet minimum requirements for GETs, but these factors are not considered in selection of specific GET systems. Training for designers is available, but not required.

New GET installations are "Type 31" for 31-inch guardrail, and all are energy-absorbing systems. The old "Type 1" GETs for 27" guardrail are still included in the manual for reference. There is no specific guidance on which system to use at a particular location. Approved systems are shown on their Standard Plans, Section C, Traffic Barriers. Standard Specifications, Division

9 refer to the drawings. There is a link to these documents in the Appendix. Systems proposed for approval must submit a) an FHWA letter, b) crash test reports and videos, and 3) in-service records from other states. The basis of payment is for EACH unit installed.

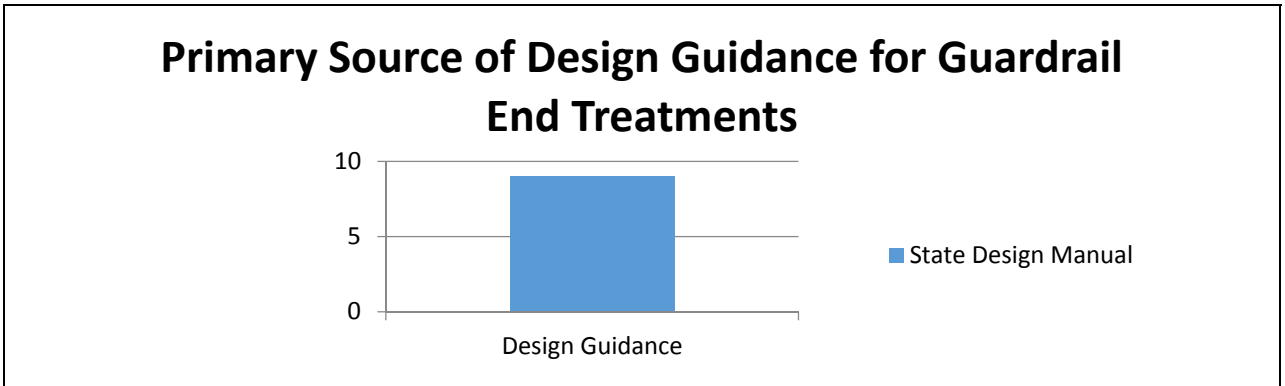
SUMMARY OF GUARDRAIL END TREATMENT DESIGN AND SELECTION PRACTICES

In all states interviewed, project design engineers prepare technical aspects of construction contract documents in the form of drawing plans and written specifications. They typically use resources such as design manuals and guidelines to assist in detailing the proper use of construction materials.

As shown in Figure 1 nearly all agencies interviewed maintain their own roadway design manual developed internally for their own purposes. However, few of these documents contain detailed information on the selection of GETs for particular locations. The state manuals often repeat or reference guidelines in the AASHTO RDG.

All of the DOTs interviewed use standard plans and specifications in their construction contract documents to identify and show details of the types of GET systems used in their state. A majority show generic layout of the GET systems, and reference an APL or QPL containing specific approved brands within one or more categories. The primary categories of W-beam GETs listed in state APL/QPLs are:

- Tangent or Parallel
- Flared
- Energy-Absorbing
- Non-Energy-Absorbing
- Median



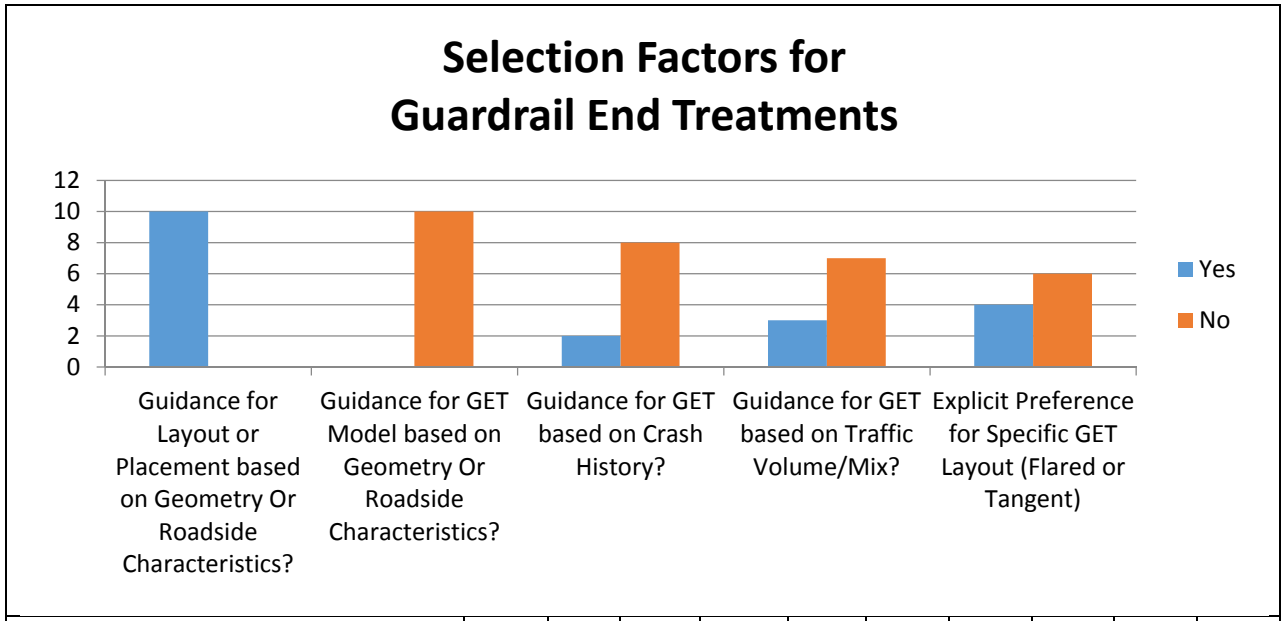
	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
State Design Manual*	Y	Y		Y	Y	Y	Y	Y	Y	Y

*All agencies utilize the AASHTO Roadside Design Guide.

FIGURE 1 Primary source of design guidance for guardrail end treatments.

Project designers typically prepare supplemental documents that specify the category of GET to be installed at each location within the project. Once the project is awarded, the construction contractor may choose which brand of system listed in the corresponding APL/QPL category is purchased and installed. Some states prefer only one (1) category of GETs, and only models in that category are listed in the APL/QPL. For example, NYSDOT uses only tangent w-beam GETs, due to concerns over lack of lateral distance required for flared GETs. Conversely, PennDOT allows both tangent and flared GETs, but prefers flared due to less frequent nuisance hits and concerns with snowplow damage occurring with tangent GETs. Other agencies reported the desire to limit the variety of devices installed the devices for uniformity in components needed for repairs. Most of the DOTs prefer energy-absorbing GETs, and are phasing-out non-energy-absorbing models. However, a few agencies realize value in buried-in-backslope terminals when possible, or flared systems to reduced impact frequency.

Factors used by designers to select the type or category of GET used at a particular location varies. Location of Areas of Concern (AOCs) was the primary consideration for placement of GETs, based on achieving the minimum LON of a guardrail run. Figure 2 shows factors used in specifying a type of GET for specific locations.

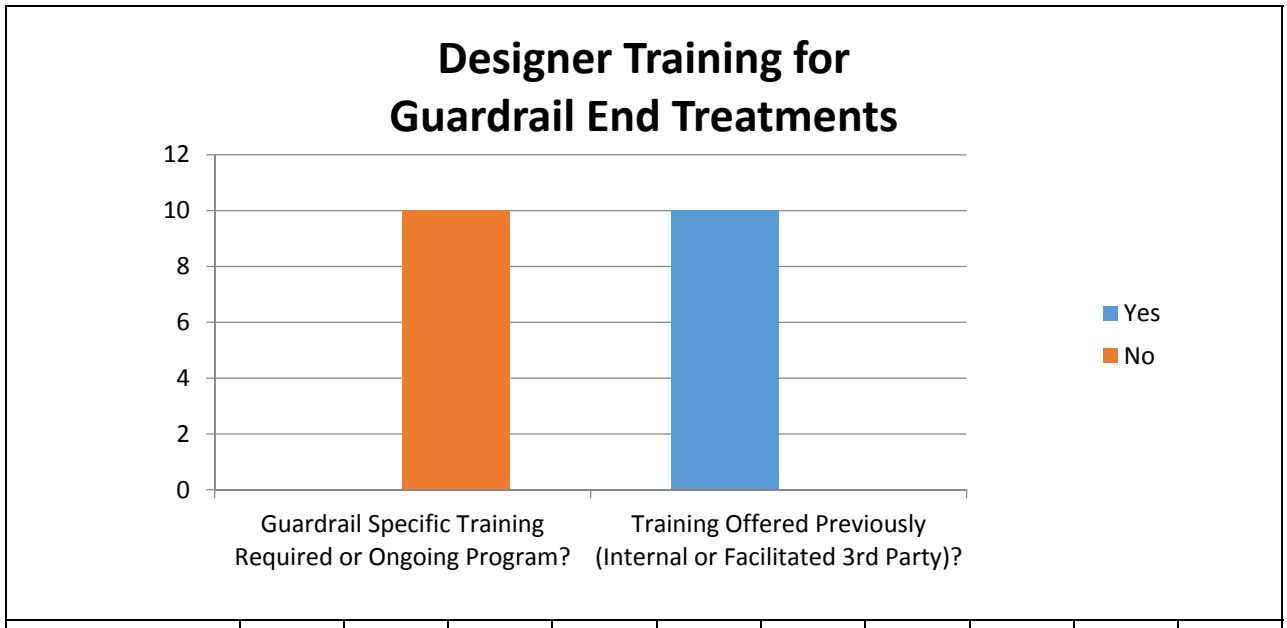


	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Guidance for Layout or Placement based on Geometry Or Roadside Characteristics?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Guidance for GET Model based on Geometry Or Roadside Characteristics?										
Guidance for GET based on Crash History?	Y		Y							
Guidance for GET based on Traffic Volume/Mix?	Y		Y	Y						
Explicit Preference for Specific GET Layout (Flared or Tangent)	Y		Y			Y		Y		

FIGURE 2 Selection factors for type of guardrail end treatments.

In all states interviewed, roadside geometry, such as slopes behind the system played a role in deciding what Type or Category of GET to use. In many cases, roadside slopes are too steep to accommodate flared GETs. None of the states interviewed consider roadside geometry when selecting the brand or model to be installed at a particular location. Two (2) agencies (Caltrans and KDOT) reported that crash history is considered in selecting type of GET. Three (3) agencies (Caltrans, KDOT, and MoDOT) reported that they look at traffic volume when selecting the type of GET for a particular location.

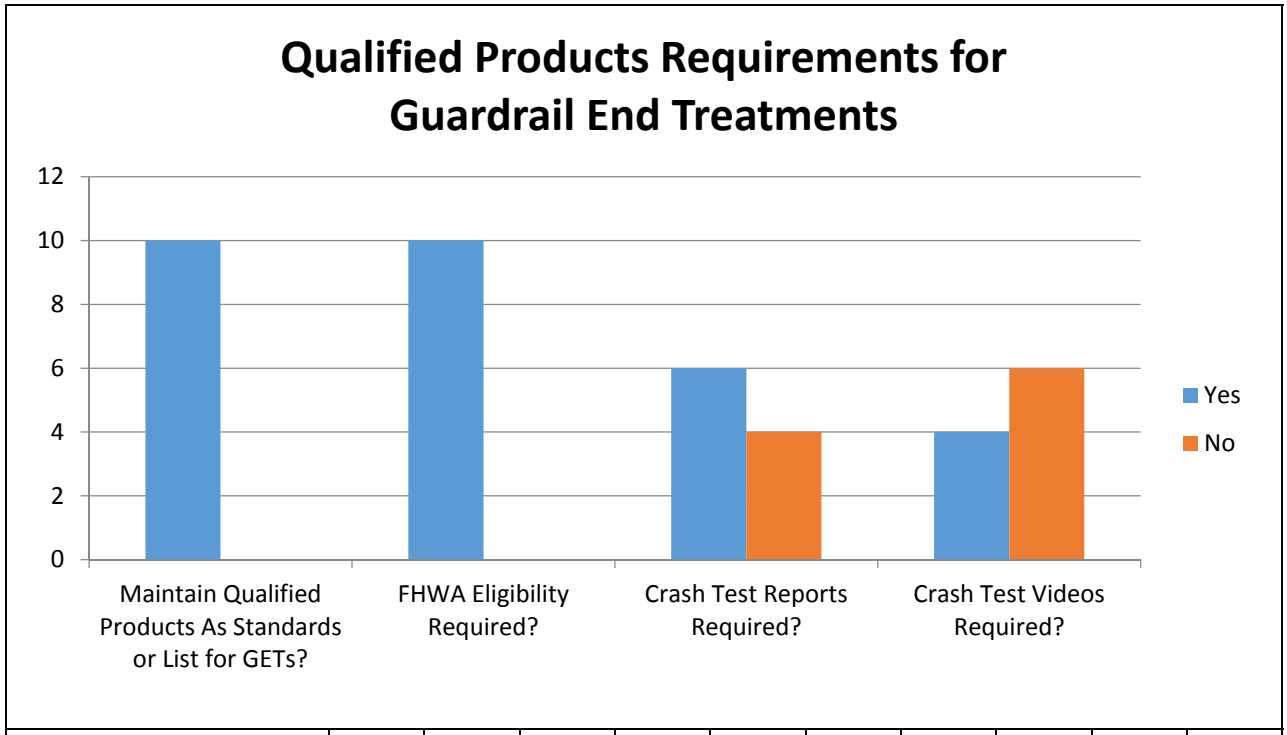
As shown in Figure 3, guardrail-specific designer training and certification was not mandated in any state that was interviewed. However, nearly all of them have conducted or hosted a training course in recent years. These courses were typically the FHWA/NHI/ATSSA courses listed in the Appendix. A few states have internally-developed designer training programs. Nearly all have plans to increase training opportunities for their designers, either by continuing to host FHWA/NHI courses or by developing in-house training. However, there was very limited intent to formally require specific guardrail design and selection training as a pre-requisite for design engineers.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Guardrail Specific Training Required or Ongoing Program?										
Training Offered Previously (Internally or Facilitated 3rd Party)?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

FIGURE 3 Designer training for guardrail end treatments.

Figure 4 shows that every state interviewed maintains some form of APL or QPL that lists specific brand and models of GETs that are allowed for use by the agency. Additionally, every state relies on the FHWA Eligibility Letter as the primary requirement for consideration to be included on their list. In most cases, this was the only required document, emphasizing the importance of the FHWA eligibility review process, and the dependence they have on the FHWA Office of Safety to review crash test performance. Six (6) states interviewed require that crash test reports be submitted for evaluation in addition to the FHWA letter. A few stated that they look at the reports to assess the level of damage to the GET units in order to assess anticipated repair costs. Four (4) agencies interviewed also require that crash test videos be provided as well.



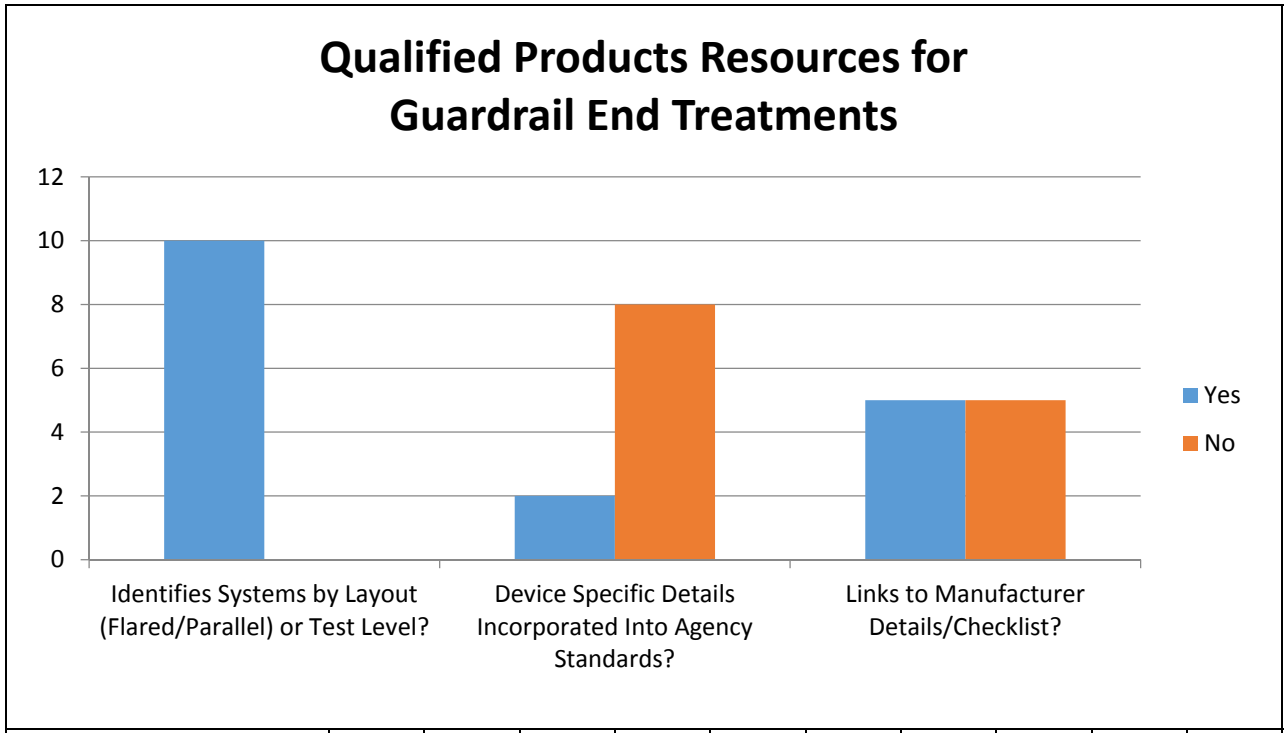
	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Maintain Qualified Products As Standards or List for GETs?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
FHWA Eligibility Required?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Crash Test Reports Required?	Y	Y	Y			Y			Y	Y
Crash Test Videos Required?	Y		Y			Y				Y

FIGURE 4 Qualified products requirements for guardrail end treatments.

Figure 5 shows characteristics of the APL/QPLs maintained by the agencies interviewed. Agencies typically assign a "Type" or "Class" to the different categories of GETs. In most cases, state standards specify and show generic systems for each category, and refer to the APL/QPL for specific bands and models. Two (2) agencies (KDOT and TxDOT) show the approved proprietary devices directly on their standard plans.

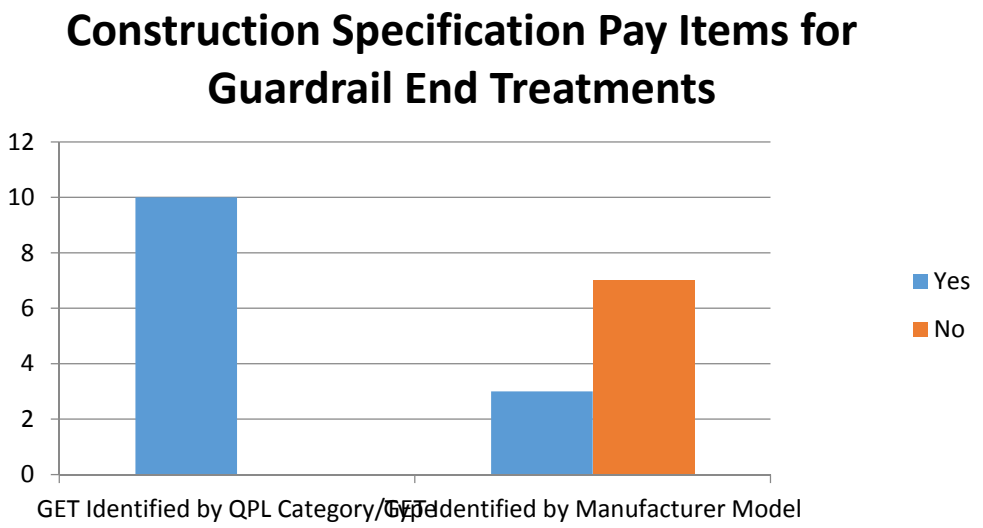
Five (5) agencies provide manufacturers' details, manuals, checklists, and links to their websites directly in their APL/QPL. Most often those materials are also expected to be supplied by the manufacturer with the actual GET units at time of delivery to the jobsite.

As shown in Figure 6, all agencies interviewed itemize and pay a lump sum for "EACH" GET installed on their construction projects. In addition, all agencies interviewed have GET pay items that match the categories in the APL/QPL, and only three (3) (Caltrans, KDOT, and TxDOT) identify the pay items by specific manufacturer model.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Identifies Systems by Layout (Flared/Parallel) or Test Level?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Device Specific Details Incorporated Into Agency Standards?			Y						Y	
Links to Manufacturer Details/Checklist?	Y	Y				Y	Y	Y		

FIGURE 5 Qualified products resources for guardrail end treatments.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Basis of Payment LF		Y								
Basis of Payment Per Each	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
GET Components Identified										
GET Identified by QPL Category/Type	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
GET Identified by Manufacturer Model	Y		Y						Y	

FIGURE 6 Construction specification pay items for guardrail end treatments.

GUARDRAIL END TREATMENT CONSTRUCTION AND INSTALLATION PRACTICES

This section focuses on agency policies and procedures used during field installation of new GETs as part of highway construction projects. Below are descriptions of these practices identified during interviews with personnel from each state agency surveyed.

California DOT

A majority of Caltrans GETs are installed by contractors. Proper installation is guided by manufacturers' written instructions and checklists, which are provided to jobsite with delivery of the system. Installer training is not required, however installers typically obtain manufacturer training. Manufacturers are invited to participate in the statewide training programs.

Starting in 2016, construction contracts require two (2) signatures on the installation checklist for each GET location to certify that they were installed correctly. The required

signatures are from the contractor and the Caltrans resident construction engineer. The checklist is then reviewed by the District Traffic Safety Coordinator, and placed in the project files.

Nearly 100% of construction inspectors are state Caltrans employees. Inspector training includes a 4- to 5-hour course, which is mandatory for state inspectors & resident engineers. Contractors get training from the manufacturers, but it is not required. A certificate of compliance from the manufacturer and the signed checklist are required for release of payment for new GET installations. In addition, an independent Safety Review Committee conducts a general safety review of all projects before final closing.

Florida DOT

In Florida, nearly 100% of GETs are installed by contractors through their Design & Construction Lettings. Very rarely, the Maintenance Division will upgrade devices via their own contract letting, but they would rather have work associated with roadside safety systems go through the Design Office.

Installer training is not currently required, but FDOT is evaluating the issue, and may begin requiring installers be certified by device manufacturers. FHWA/NHI training was conducted using Florida as a test state, but they felt that the course did not provide enough device-specific information.

Installation instructions and drawings are provided by the manufacturers, and are referenced in the APL. Construction inspectors are a mix of state workforce and consultants. When GET installations are completed, contractors submit a Certification of Completion statement and mill certifications for approval and release of payment.

Kansas DOT

For KDOT projects, nearly 100% of new GETs are installed by contractors, and a majority are completed by a single contractor that works throughout the state. Installer training certification is not required, however, they will use training when it is offered by national organizations or manufacturers. They have requested to get training from FHWA.

KDOT requires that GETs be installed in accordance with manufacturers' drawings and instructions, which are supplied with the units onsite. They do not have their own installation checklist. The project plans are used for measurement purposes and placement requirements.

Construction inspectors are primarily state employees. Consultant inspectors are used for larger projects, typically in urban areas. Inspector training certification is not required specifically for GETs. They do get general training via a state program. The general course is offered 1 or 2 times per year, but does not provide any detail related to guardrail installations.

Materials Certificate is required in order to accept and release payment for GET installations. Inspector may take photos of completed installations, but it is not required.

Missouri DOT

Essentially 100% new GET installations are completed by contractors as part of MoDOT construction projects. They currently do not require formal training for GET installers. The prime contractor must sign off on all installations certifying that they are installed correctly in

accordance with manufacturers' instructions. MoDOT is considering requiring GET installers to be certified by the manufacturer, but this is not in-place at this time.

Material certifications must be submitted to certify that each device installed is the same as the one that was crash tested and approved on the QPL. Manufacturers' Written Instructions are used to assist field personnel with completing GET installation properly to the satisfaction of project construction inspectors. They have developed a field guide for GET installers and inspectors. It is modeled after one used by the Ohio DOT, which was written by a consultant.

Approximately 90% construction inspectors are state work force employees. Some projects are Design/Build or Quality Management projects in which the state acts only as an auditor to the contractor. They do not require formal training for GET installation inspectors. Certifications from GET manufacturer and prime contractor are the primary documents required to release payment for GET installations.

New York State DOT

On NYSDOT projects, essentially all new GET installations are completed by contractors. State forces sometimes install new GETs when an existing system is too severely damaged or deteriorated to repair. When that is done as maintenance work, it may be done either by state crews or by a contractor working under a "where-and-when" contract, which are contracts to do undefined work, such as repair of system where the extent of damage is unknown.

Installer training certification is not currently required. They would like to get there, but there are many other issues being given higher priority. They have not seen problems with installations, as most of the barrier work is done by specialty subcontractors who are very well versed in what to do. Manufacturers' written instructions are used to assist field personnel with completing GET installation properly. Typically, the installers know what they are doing and inspectors, whether state or consultant staff, will inspect based on the manuals posted on their website and linked via the APL.

No specific documents are required to release payment for completed GET installations. They use a normal "sign-off" procedure, which is done by construction inspectors.

North Carolina DOT

Essentially 100% of new GET installations are completed by contractors on NCDOT projects. Training for individual installers is not required, but contractors must be pre-qualified by demonstrating their ability to perform duties required for installation.

They administer an in-state training program, named the NCDOT Installation & Maintenance Course for operations personnel and maintenance staff. A majority of construction inspectors are consultants, and they are not required to attend GET training. Some use a guardrail installation pocket guide from 1996, which is in the process of being updated. Project specifications state that manufacturers' written instructions are to be used for verification of proper installation. There are no extra requirements for release of payment, but they do conduct final inspections specifically for guardrail installations.

Ohio DOT

On the ODOT highway network, nearly 100% of new GET installations are completed by contractors. Installer training is not required. They hosted the FHWA/NHI course in 2013. There are only two (2) or three (3) guardrail contractors in the state, so they have a lot of experience with installing GETs. Manufacturers' instructions are used as a guide for proper installation. Standard Specifications are used for non-proprietary systems.

ODOT uses a mix of state employee and consultant inspectors, and all are general construction inspectors. None are specifically guardrail inspectors. Inspector training certification is required. They have an in-state training program called the Highway Technician Roadside Program. It is offered annually, and is attended by inspectors, as well as maintenance personnel, who often work as inspectors during the construction season. Inspectors sign-off on completed GET installations. Acceptance is recorded in their daily report, and it states that manufacturer instructions were followed.

Pennsylvania DOT

Contractors install nearly 100% of GETs on the PennDOT highway network. Installer training certification is not required at this time. However, national training programs are conducted in the state on a regular basis. The FHWA/NHI installer course is presented in the state every other year. Manufacturers' training programs are encouraged when available.

Manufacturers' written instructions and drawings are used by field personnel to ensure proper installation. PennDOT uses both state forces and consultants for inspection, but mostly contract inspection. Inspector training is encouraged, but not required. Inspectors are encouraged to attend manufacturers training when available.

Texas DOT

In Texas, approximately 90% of GETs are installed by contractors, and the remainder is completed by state maintenance forces. Formal training for installers is not currently required, but they are in the process of developing training criteria for GET installers. The training will likely be presented by video, and some type of certification or proof of attendance will be required.

Manufacturers’ drawings and instructions are used on the jobsite as the primary reference for proper installation of GETs. There is no TxDOT-developed checklist for approval of installations. A majority of their construction inspection is done by state workforce, and there is currently no GET-specific training required for inspectors.

Washington State DOT

Nearly 100% of new GETs are installed by contractors on the WSDOT highway network. Occasionally, maintenance forces complete “Low-Cost Enhancement” projects, which are small projects done in conjunction with other maintenance work being done in the area. Washington is the only agency interviewed where GET installer certification is explicitly required. Below is an excerpt outlining installer training requirements from the WSDOT Construction Manual, Section SS8-11.3 (1)c:

> "Installation of guardrail terminals listed in the Qualified Products List shall be by an installer that has been trained and certified by the manufacturer or is supervised by a representative of the manufacturer. The inspector should request to see the certification. The date on the certification must not be prior to the latest accepted effective date for the device. A listing of the latest accepted effective dates will be sent to each Project Engineers Office when changes are made or can be requested from the Design Office."

Nearly all construction inspectors are WSDOT employees. There is a state inspector training program, however, it is not offered during times of limited funding. Larger districts offer training more often than smaller ones.

SUMMARY OF GUARDRAIL END TREATMENT CONSTRUCTION AND INSTALLATION PRACTICES

A majority of the agencies interviewed reported that nearly 100% of new GETs are installed by sub-contractors working as part of larger highway construction projects. Some reported that occasionally their maintenance crews install complete GET units in order to upgrade an old or deteriorated system.

As shown in Figure 7, all but one (1) of the agencies reported that they do not require training or certification of GET installers, but encourage training by providing their own in-house training or hosting courses offered by manufacturers or nation organizations (FHWA/NHI or ATSSA). WSDOT is the only agency interviewed that requires GET installer training and certification issued by the device manufacturer.

Figure 8 shows that all of the DOTs interviewed use manufacturers' written instructions, drawings, and checklists as the primary source of guidance for proper installation of GETs. MoDOT and ODOT have issued their own detailed field guide directed at proper installation of GETs. A few other agencies use generic field guides, which may only superficially address guardrail barriers in general, or only apply to older, non-proprietary GETs.

Figure 9 shows that a majority of agencies do not require GET-specific training for their construction inspectors. Most of these agencies offer and/or require general training for inspectors, but the courses do not specifically cover inspection requirements for installation of GETs.

Caltrans has an internally-developed inspector training program that covers guardrail and GET installation. The four (4) to five (5) hour course is mandatory for state inspectors and resident construction engineers. They are in the process of developing an online refresher course for the inspector training program.

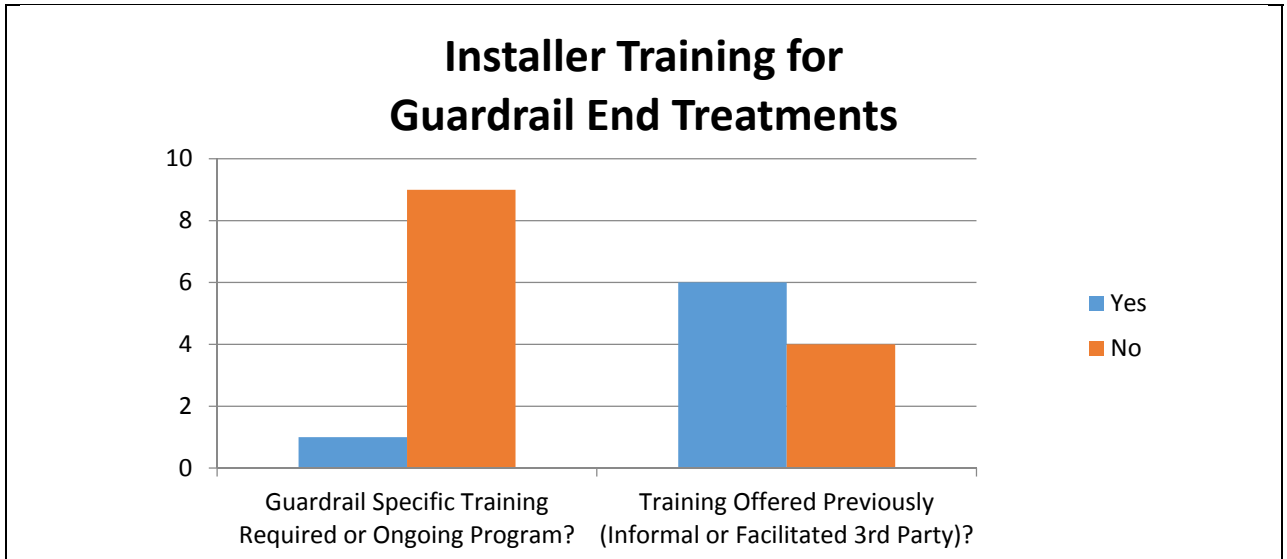
ODOT requires their state inspectors and maintenance personnel to attend a Highway Technician Roadside Program, which is offered annually. A unique circumstance that they noted is that their state maintenance forces often serve as inspectors during seasonal construction cycles.

GUARDRAIL END TREATMENT INVENTORY AND MANAGEMENT PRACTICES

All state DOTs own and maintain a large number of GET units installed throughout their highway network. This section focuses on types of asset inventory and management systems that may be in place to identify devices and track activity at the many GET installation sites. Below are descriptions of GET inventory and management practices identified during interviews with personnel from each state agency surveyed.

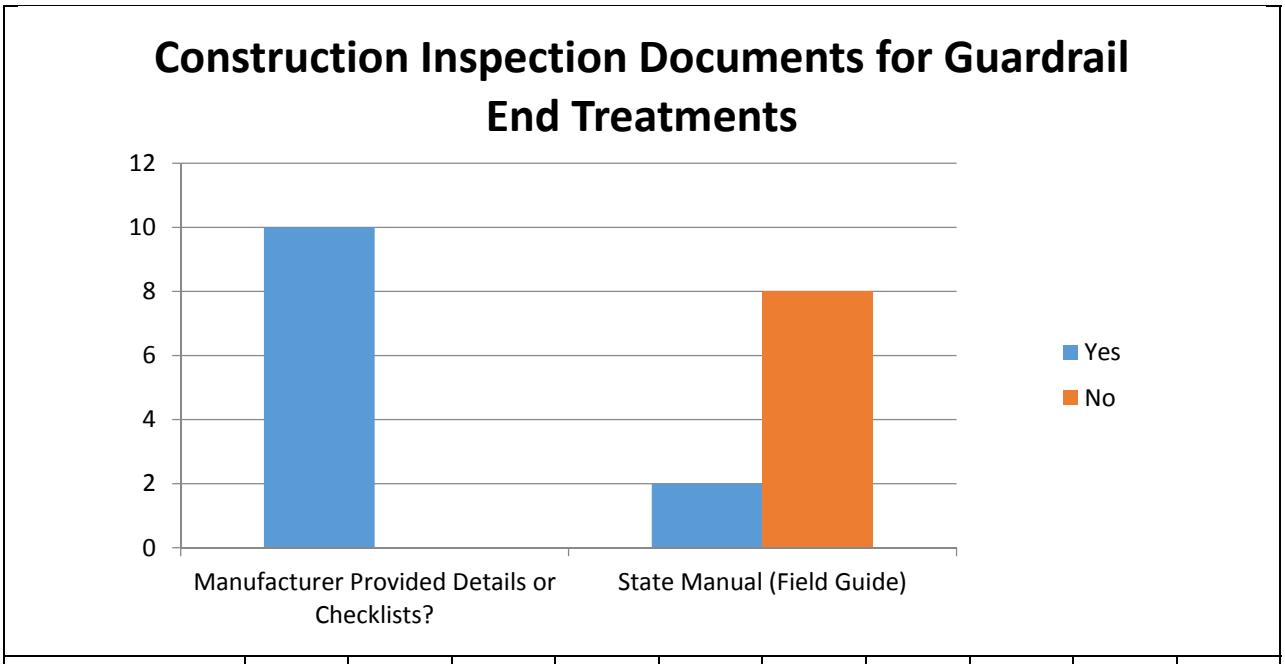
California DOT

Caltrans does not maintain a state-wide inventory of GETs. However, in 2014 they collected an initial inventory of GETs. The data was collected by district maintenance personnel during drive-by inspections. They identified the following characteristics of each location: brand/type (ET-2000, ET-PLUS, SKT, FLEAT, etc.); height (27” or 31”); location (Milepost); and, condition (undamaged or damaged). The statewide total count was approximately 38,545 units, and the data is stored in a spreadsheet. They plan to expand the information into an on-going GET inventory database. There are Caltrans inventory systems for other roadway features, including bridges, culvert, signs, and a general road network database.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Guardrail Specific Training Required or Ongoing Program?										Y
Training Offered Previously (Informal or Facilitated 3rd Party)?	Y	Y			Y		Y	Y	Y	

FIGURE 7 Installer training for guardrail end treatments.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Manufacturer Provided Details or Checklists?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
State Manual (Field Guide)				Y			Y			

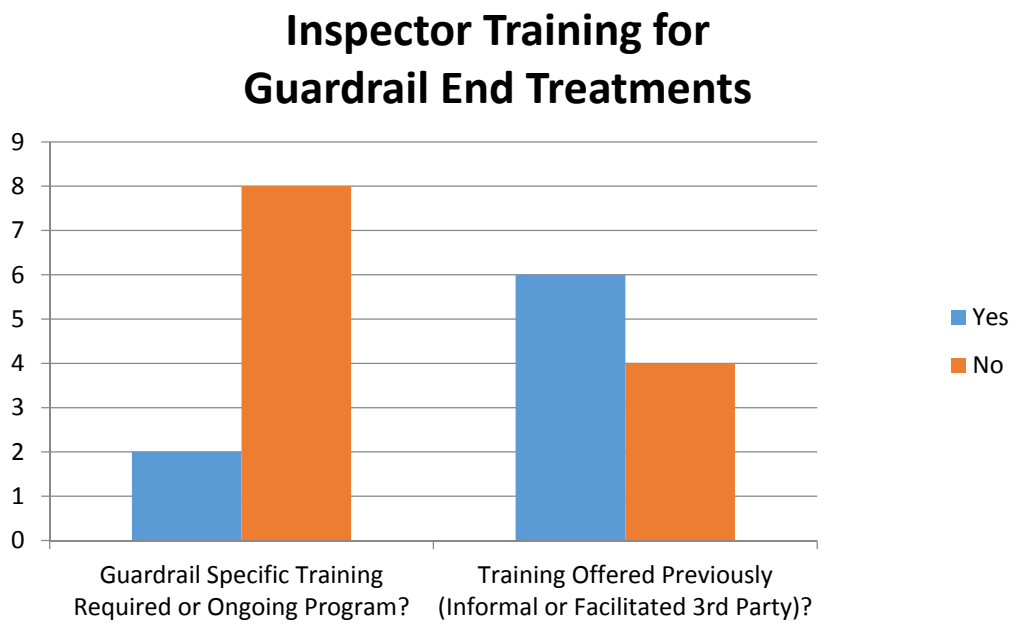
FIGURE 8 Construction inspection documents for guardrail end treatments.

Florida DOT

FDOT does not currently have an inventory system which includes GET installations. However, they are in the process of developing one as part of their Policy Management Procedures for Guardrail Inspection & Maintenance, Topic No 850-050-003-f. Data to populate the system will be collected by in-house and/or contract maintenance forces as part of guardrail inspections, which are done every 2 years. Inventory data will include: manufacturer, make, model, GPS location, and photos.

In conjunction with the inventory system, FDOT maintenance forces will begin collecting traffic incident data. Incidents involving damage to GETs and other roadside hardware will be identified by the Traffic Monitoring Centers or law enforcement who will contact the local DOT maintenance office. Maintenance forces will attempt to collect data before vehicles are removed from the site. In cases where that is not is not possible, the data will be collected before repair or replacement of the GET. The incident data will include everything from the police crash report, in addition to the following:

- Observations, such as whether the vehicle went under, over, or through the barrier.
- Photos.
- Installation project information.
- Location by route/direction/milepost.
- Inspection dates.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Guardrail Specific Training Required or Ongoing Program?	Y						Y			
Training Offered Previously (Informal or Facilitated 3rd Party)?	Y		Y				Y	Y	Y	Y

FIGURE 9 Inspector training for guardrail end treatments.

Training of data collectors for both the inventory and incident databases will begin in October 2016. They plan to place these systems into service in January 2017.
GETs are typically replaced in-kind by maintenance forces. However, they will contact the district design office to review the site and propose alternate designs if there are extenuating circumstances, such as inadequacies in the original installation, severe or unintended damage, repetitive incidents at the site, or inadequate runout distance.

Kansas DOT

KDOT does not have a statewide inventory of GETs. They have GET installation data stored in their Construction Management (CM) database, and it includes general location, device manufacturer/model, date of installation, and contractor, but it is not suited to be used as an active GET inventory system. The data is likely purged after 7 years. They do plan to implement an asset management system in the near future, and have a video-log of the state network. This could be used to begin an inventory of GETs, but there is currently a lack of resources and personnel necessary to track and enter the vast amount of data. KDOT has inventory systems in place for bridges and permanent signs.

Missouri DOT

MoDOT has a partial inventory of GETs installed on their highway network. A snapshot inventory was conducted in 2014. It includes only interstate and primary roadways in all seven (7) districts. These roadways compose approximately 20% of the mileage in their statewide network, and carry approximately 80% of the statewide traffic volume. The 2014 GET inventory includes the following data for each GET:

- GPS Lat./Long. location and route/direction/milepost location.
- Manufacturer and Model.
- Rail Height.
- Upstream and downstream end location for each run of guardrail.

They have not yet determined how often this system will be updated or whether it will be expanded to the remainder of the highway network. MoDOT maintains other inventory systems for signs and culverts.

They have recently obtained funding to completely upgrade roadway safety devices to MASH criteria on the interstate and primary roadways (20% of network). The cost for this program is estimated to be $180M. Other roads will go to MASH upgrade when installations are damaged. Undamaged units will remain in-place. They do not have a system in place for determining end-of-service-life for GETs, other than those replaced as part of other systematic upgrade programs. If an installation is damaged in service, then they replace the unit in-kind. They would like to develop and/or implement a mobile phone based application to scan and record impact/maintenance activity on a specific device at a location.

New York State DOT

NYSDOT does not have a formal inventory of GET installations. They have attempted to develop an asset management system for guide rail, but have not had the resources to implement it. They did a one-time survey of rustic weathering steel guide rail, which included location and condition assessment. This was done to begin a replacement program for that type of guide rail due to corrosion issues.

They do not have a specific method for determining end-of-service-life for GETs. Typically, GETs are replaced due to unrepairable crash damage, or replacement is done as part

of a capital project. Occasionally, they do a "Guide Rail Only" contract that is specifically aimed at replacing outmoded guide rail and terminals in one or several areas.

North Carolina DOT

NCDOT currently does not have an inventory of GETs installed on their highway network. They have inventory systems in place for pavements, culverts, bridges, and overhead sign supports. They feel that their highway network is too large to properly catalog all roadside features because they maintain a large portion of local roads in addition to their state highways. NCDOT has a video log system, which could be used for GET inventory. However, it only includes the primary and interstate system, so approximately 60,000 miles of secondary roadways would require further field review.

GETs are typically replaced in-kind, until a project calls for upgrades. There is no consistent approach to upgrading across the fourteen (14) regional districts, which are assuming an increasing amount of design responsibilities. It was noted that they just received new funding for safety initiatives on NHS routes. This will include upgrading of "pre-NCHRP 350" GETs.

Ohio DOT

A GET inventory was conducted in 2013. Data collectors were interns who used video logs. The database includes location (route/direction/milepost & GPS) and GET type (tangent or flared) for each installation. Device brand and condition information was not collected. Plans for maintaining the GET inventory are unknown.

Inventories of other features include bridges & railings, culverts, signs/signals, and rail crossings. They also use a system called the Transportation Inventory Mapping System (TIMS).

Pennsylvania DOT

PennDOT maintains a statewide inventory of GET installations. The database is part of their Road Management System (RMS). The data collection process is detailed in PennDOT Publication 33, Shoulder and Guide Rail Condition Survey Field Manual, and is named the STAMPP Program. They employ college summer interns to collect guide rail condition and inventory data including GETs. Every year, collectors cover one quarter (1/4) of the state network, providing a 4-year cycle to cover all PennDOT-maintained roadways. District 6 in Philadelphia uses some contractors for data collection. The database includes brand name, installation date if available, and "damaged" or "undamaged" condition assessment of each GET location. The system uses linear reference for reporting the location of each beginning and ending GET by: Roadway Side and County; Route; Segment ID; and Distance (offset) from beginning of segment. It does not include lateral offset from roadway.

New this year (2016), they added more description options for condition assessment of ET-PLUS installations only. Expanded checklist is shown in the last page of Publication 33, and it was brought into place because of concerns with the ET-PLUS specifically.

Counties use the database to plan their annual maintenance programs, and GETs are typically upgraded thru attrition when other roadway improvements are required in the area.

Texas DOT

In 2015, TxDOT developed an in-house mobile phone app to be used specifically for creating an inventory of GETs. Teams of personnel drove the entire state highway network and logged essentially all GETs in the state. Figure 10 is an image of the app interface.

Data collection was conducted in all twenty-five (25) of their districts, and took about one and a half (1-1/2) months to complete. Based on this 2015 survey, there are 133,992 GETs installed within the TxDOT highway network. Each location contains the Lat/Long location (of the survey vehicle), and the type/brand of system. There was not any GET condition information collected, but they plan to continually update the database as repairs and replacements occur at particular sites.

TxDOT does not have a specific method for determining end-of-service-life for GETs. Current systems are replaced in-kind after impact damage. When older (pre-NCHRP 350) systems are damaged, Maintenance forces will replace them with current devices listed on the QPL.

Washington State DOT

WSDOT recently conducted a statewide inventory of GETs, and has developed their own Highway Asset Tracking System (HATS) maintenance management system that is staff managed. Initial roadside inventory information was entered into the system in the early 2000's and ended in 2010. It has been updated by maintenance staff with damage and repair information for DOT-maintained property, including GETs, although new installation have not been tracked. More recently, they have provided over nine hundred (900) iPads to personnel to be used to update the HATS system. The system provides a notice to maintainers that GET

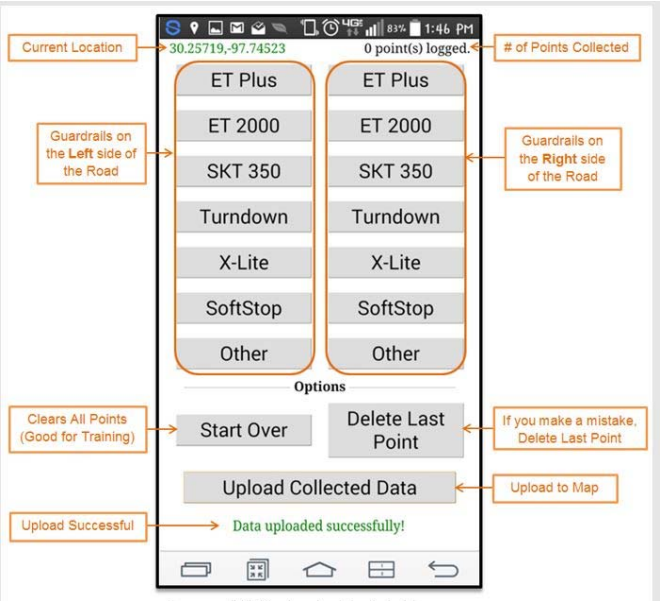


FIGURE 10 Screen capture of TXDOT end treatment inventory application.

repairs need to be done in accordance with manufacturers' instructions. For each GET location, the system includes location (Lat./Long. and Milepost), make/model of the device, and repair date. They can enter pictures or other documents into the system, but it is not required at this time. Most damaged GETs are replaced in-kind, unless it is an outdated system, or there is a directive from the design section to upgrade the guardrail to 31" height.

WSDOT also has other established databases for inventory of pavements and bridges.

SUMMARY OF GUARDRAIL END TREATMENT INVENTORY AND MANAGEMENT PRACTICES

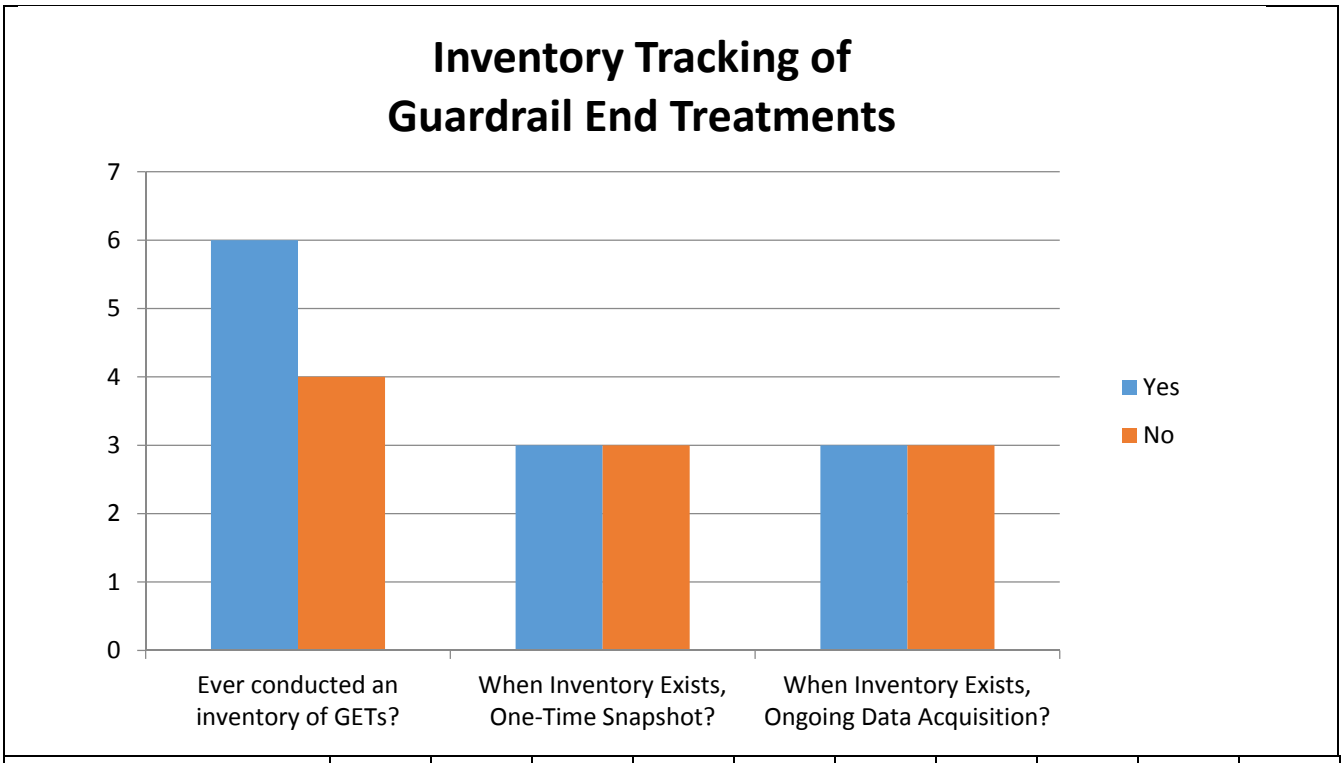
As shown in Figure 11, six (6) agencies interviewed have some type of inventory of their GET installations. All inventory systems are unique with a wide variety of detail, consistency, and frequency of updating. At Caltrans, MoDOT, and ODOT, the inventory data was collected very recently as a one-time snapshot, and plans for future updating are unknown. TxDOT and WSDOT have recently completed an initial inventory, and plan to keep it updated. PennDOT is the only agency interviewed that has an established inventory system that has been continually updated on a consistent periodic basis.

The process by which the inventory is collected varies greatly. Most agencies rely on drive-by inspections and GET unit counts with varying degrees of detail. ODOT and PennDOT employ summer student interns to populate and update their inventory system. TxDOT recently developed their own mobile telephone app in order to quickly identify system brands and GPS location coordinates for all GETs within their entire highway network. In addition, they are actively updating the inventory with new installations and repairs. It is noted that nearly all agencies that have no inventory of GET installations reported that they intend to conduct inventories in the near future, and are in process of developing a format and approach.

Figure 12provides a breakdown of the types of information collected and included in GET inventory systems. In most cases, only a minimum number of data fields are included. The most common are location information and GET Type, Class, or Model. A majority indicated that installation project information, such as installation date an installer are available from other data systems, but it is not easily accessible and not intended to be used as an active inventory. Additionally, photographs are rarely included, as most of the inventory data is held in a spreadsheet or online database with no easy means of adding images.

WSDOT highlighted a well-developed internal inventory tracking system (HATS), which holds both GET location and type information, as well as repair history and the ability to attach other media files such as images or video. Their maintenence personnel update the system each time that any work is done at GET locations.

However, it is noted that when a GET Type or Model was captured in even the most advanced systems, they did not always represent the specific model but rather a generic tradename. As an example, there may be a data record for an "SRT" at a specific location, but it is not identified as to which design variation of that system, such as whether it is wood-post or steel-post, or which offset configuration. Knowing the specific GET model at a particular location is critically important to the in-service evaluation process. Fortunately, a majority of the agencies interviewed recognize the value of inventory systems, and are planning to continue improving the quantiy and quality of their data. These evolving inventory systems have a potential for providing some of the data required for evaluation of GET field performance.

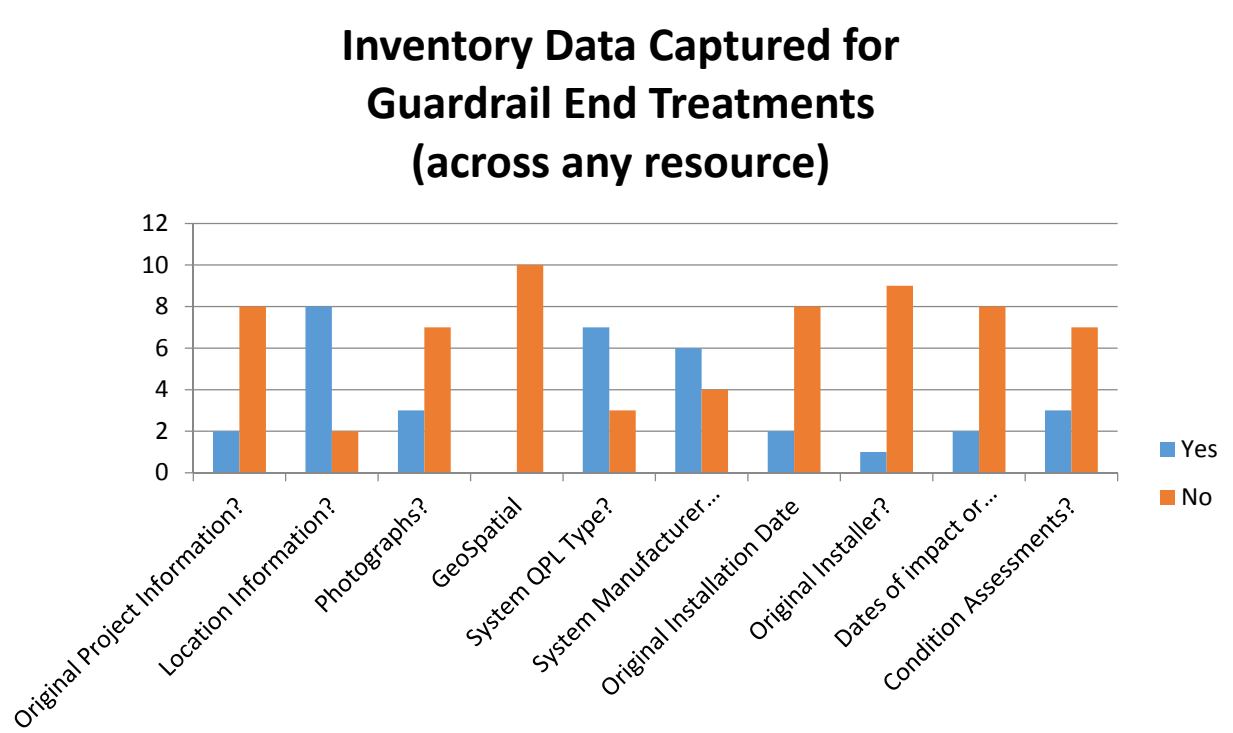


	CA	FL*	KS	MO	NC	NY	OH	PA	TX	WA
Ever conducted an inventory of GETs?	Y			Y**			Y	Y	Y	Y
When Inventory Exists, One-Time Snapshot?	Y			Y			Y			
When Inventory Exists, Ongoing Data Acquisition?								Y	Y	Y

* Scheduled to start a new inventory system in 2017.
** Includes interstate & primary highway network only.

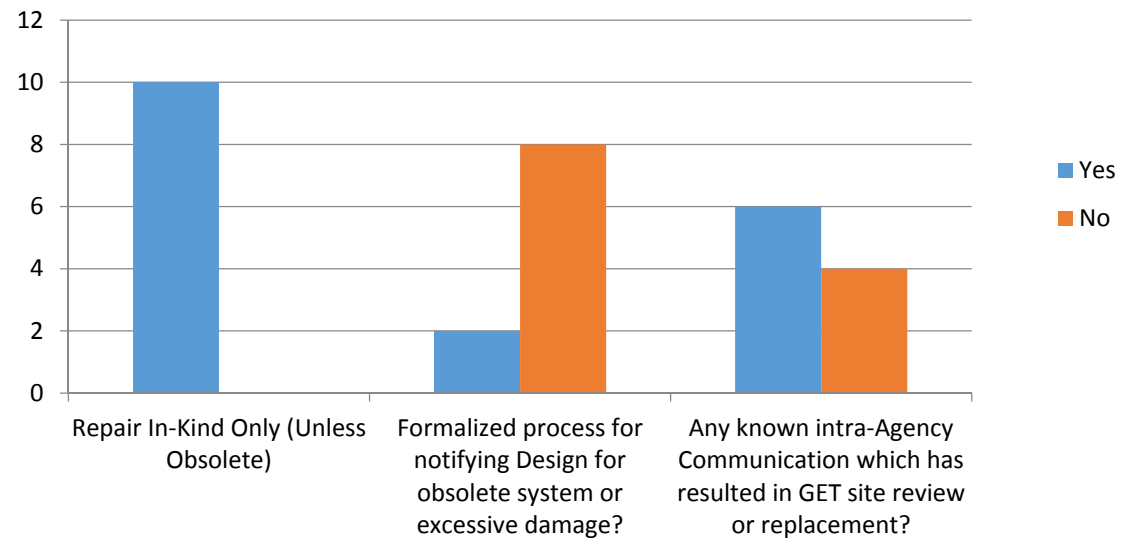
FIGURE 11 Inventory tracking of guardrail end treatments.

The final interview question in this sections asked if their agency has a method for determining the end-of-service-life for GET installations. Figure 13 shows that every agency typically repairs or replaces GETs in-kind with the same device model. Methods used to identify specific models are not well defined, and often the expertise of maintenance personnel is relied on to ensure that correct components are being used for the repair. In some cases, maintenance personnel request assistance from their Design office to review locations for possible upgrading to a newer system on the QPL, rather than repairing the unit in-kind. In other cases, excessive damage or repetitive impacts would prompt a design review of the installation. While most agencies confirmed a positive line of communication between their Design, Construction and Maintenance offices, rarely were these points of contact and process of notification codified into formal procedures.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Original Project Information?		Y	Y							
Location Information?	Y	Y	Y	Y			Y	Y	Y	Y
Photographs?							Y	Y		Y
GeoSpatial										
System QPL Type?	Y		Y	Y			Y	Y	Y	Y
System Manufacturer Model?	Y		Y	Y				Y	Y	Y
Original Installation Date		Y	Y							
Original Installer?			Y							
Dates of impact or maintenance?									Y	Y
Condition Assessments?	Y			Y				Y		

FIGURE 12 Inventory data captured for guardrail end treatments (across any resource).



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Repair In-Kind Only (Unless Obsolete)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Formalized process for notifying Design for obsolete system or excessive damage?	Y	Y								
Any known intra-Agency Communication which has resulted in GET site review or replacement?	Y	Y			Y	Y	Y			Y

FIGURE 13 End-of-service-life of guardrail end treatments.

GUARDRAIL END TREATMENT MAINTENANCE PRACTICES

This section focuses on agency policies and procedures used during field repair and maintenance GETs installed throughout their highway network. Below are descriptions of these practices identified during interviews with personnel from each state agency surveyed.

California DOT

Caltrans started periodic inspection of GETs in 2015, and plan on completing approximately 10% of the state network per year. These inspections use manufacturer installation manuals and checklists as the basis for rating each installation. The Maintenance Division does not determine end of service life or install upgraded systems, and makes in-kind repairs only. Traffic Safety Division determines when GETs are obsolete and specifies the new replacement system. Traffic Safety Coordinators in each district evaluate sites if there are repetitive impacts or hazardous conditions.

There is a mix of both contractors and state workforce that repair and maintain GETs. Six (6) of twelve (12) districts have guardrail maintenance contracts in place. They are experimenting more with contract maintenance to evaluate the cost-effectiveness vs. state workforce. Districts with employee maintenance stock their own parts, whereas maintenance contractors procure parts as needed for their repair work.

Caltrans actively trains their maintenance staff in-house. The courses cover documentation protocols, common installation issues that should be identified in the field, and methods to identify device type and condition of elements. At this time, the course is provided only to state workforce. 2015 was the first full year of participation, and approximately 675 maintainers attended. By coordinating training with supervisors, they relay the course materials to local crew personnel, which brings the total trained to approximately 800 Caltrans employees.

Impact-damaged GETs are required to be repaired within one (1) week of notification, while one (1) month is allowed for length-of-need guardrail. Caltrans would like to be notified of damage from law enforcement personnel, but there is no policy in place and it rarely occurs. The policy states that their District Dispatch Center notifies maintenance personnel that damage has occurred and orders an inspection of site. This process does not always work as planned, leaving the Maintenance Division to identify damage during routine patrols. Each crew does their own review of quality for GET repairs. The crew supervisor, and then district superintendent sign off on the manufacturers checklist, which then goes to the District Safety Coordinator. There are no special inspectors or separate audit for GET repairs.

Florida DOT

Formal on-site field inspections of GET installations are performed every two (2) years via asset management contracts. Crash cushions are inspected more frequently. Inspectors use FDOT Form 850-050-03f, “Guardrail Inspection Report”. Approximately 90% of GET repair and maintenance work is done by contracts, and it is moving towards 100%. “Asset Maintenance” contractors do repair for a base price over a section of roadway. These contractors stockpile an inventory of replacement parts for GETs. In addition, the contractors are entitled to seek damages from insurance claims where the driver of the vehicle is known. There are no specific

time-to-repair requirements, other than "as soon as possible". They do have time-to-repair requirements for other roadside hardware, such as cable barrier.

In areas with ITS camera coverage, the system notifies the maintenance contractor when there is an accident involving state property damage. In other areas, law enforcement/first responders usually contact district maintenance personnel directly. There is no formal requirement for this communication, but all parties have a positive working relationship. Independent reviews or certifications of maintenance repairs are not required. However, contract documents require that the contractor is responsible for quality, and completed repairs must meet the original APL details and completion checklist.

Kansas DOT

KDOT does not conduct systematic inspections of GETs. They identify damage and other problems during routine patrols or during other maintenance in the area. They have a written Maintenance Repair Guide, which provides some basic guidance on when to repair vs. replace damaged GETs. For example, if a w-beam run is more than 50% damaged, they replace the whole run. For quality of repairs, they rely on observations and experience of maintenance supervisors, and communication with the engineering division when needed. KDOT uses some maintenance contracts, but 90-95% of GET repairs are done by state maintenance forces. Exceptions are contracts issued for emergency repairs in critical locations.

Each of their six (6) districts maintains spare parts in inventory. There is a master parts list for each system. Occasionally, temporary guardrail components are put back into maintenance inventory after temporary use. KDOT does not have a policy setting a time limit for GET repairs, due to liability concerns. Their policy is to repair them within a reasonable timeframe. State and local police are good at notifying the DOT of any state property damage resulting from police-investigated incidents.

Repaired GETs are not routinely inspected prior to being placed back into service. However, severely damaged units may be "kicked-up" to the engineering division for their review and recommendations for repair, replacement, or upgrading at the site.

Missouri DOT

MoDOT does not have a formal cycle for periodic inspection of GET installations. They are conducted during routine drive-by patrols. If a unit is damaged, more thorough inspections are done to assess the level of repair effort that is required. They use the FHWA Guardrail Maintenance Guide and a state MoDOT Field Guide as a reference to assist in assessing the physical condition of in-service GETs and extent of repairs needed for damaged units.

No formal training of maintenance personnel is required. They use maintenance contracts for essentially 100% of GET repairs. There are four or five (4-5) guardrail specialty contractors in the state, who install nearly all the GETs as subcontractors, and are prime contractors for repair and maintenance contracts. There is a DOT contract administrator assigned to administer each maintenance contract.

MoDOT is currently conducting a demonstration project in the Kansas City area to test a new all-inclusive type of maintenance contract that specifies the following damage identification and repair process:

1. Maintenance contractors perform routine reconnaissance and report damage that they have identified.
2. Contractor prepares a job work order, which includes a list of repair parts.
3. DOT issues a notice to proceed.
4. Contractor completes the repairs and provides as-built documentation.
5. In at least one District, the maintenance contractor includes photos of the devices before and after repairs are completed.

The DOT does not maintain an inventory of repair parts for GETs. The maintenance contractors maintain inventory of all guardrail systems and GETs. For interstate and primary highways, damaged GETs must be repaired within three (3) days after notification of damage is received. This is considered an emergency response, used for high-volume roads. For other roads, the requirement is seven (7) days. The contractor incurs liquidated damages if the repairs are not completed within the specified time period.

The communication process for notification of GET impact damage begins with the DOT receiving notification from the state highway patrol or city police. The notification is forwarded to the maintenance contract administrator who determines whether the damage requires emergency response". Then, he or she ensures that the repairs are done on time. The maintenance contractor must certify that repairs were completed to the satisfaction of the contract administrator.

New York State DOT

NYSDOT conducts periodic inspections of GET installations via drive-by assessments during routine highway network patrols. In addition, there is typically at least one nominal complete inspection conducted annually. They do not have any formal reference materials for condition assessment of GET installations at this time. They have developed several resource documents, but have not adopted any as official guides. NYSDOT is currently in the process of updating their Highway Maintenance Guidelines, and plan to include information on how to identify a wide variety of acceptable and unacceptable conditions. These guidelines will be more flexible than federal/national guidelines to allow judgment and consideration of relative risks and of geographic location and the effects of travel on efficient use of maintenance resources.

NYSDOT does use maintenance contracts, as well as state forces to complete repairs of GETs. There are eleven (11) regions, and "residence" facilities within the regions. These residences maintain parts inventories for their needs. Records of parts inventories are not reported to the regional or statewide levels. The NYS Office of General Services (OGS) issues RFPs every two years for a host of replacement parts and kits. Any supplier may bid on any item that they may legally supply. The low bidder for each item must supply that item at that price to any NY state agency. Most of the GET repair parts used by the DOT are purchased off of the OGS contract.

They have guidelines but no specific policy requirements for the timeframe in which GET are repaired after impact damage, and there is no set process for receiving notification of impact damage. Several mechanisms may be involved. For severe accidents, they may be notified by first responders to assist with "heavy lifting" or traffic control issues. If the rail/terminal is clearly left in a seriously non-functional condition, they are likely to be notified by the police agency. For less severe crashes, they may not be notified and may not know of the

damage until it is spotted by DOT personnel. For nuisance hits where the vehicle drove away and the damage is not glaring, it may go unnoticed and considered part of the general condition of the system. However, since GETs may be compromised by hits that would not be a concern for guide rails, their drive-by inspectors pay closer attention to the condition of GETs. Forepersons of guide rail crews are generally experienced with maintenance of terminals, and inspect the repair work as it is being done. No independent inspections are performed. The experience of the crew chiefs/forepersons varies, as does that of the installers and inspectors for new installations. There have been essentially no issues with improper installations. One isolated issue occurred when they had to temporarily install an impact head that was improperly fabricated by the manufacturer.

North Carolina DOT

In North Carolina, nearly 100% of GET repair and maintenance work is completed by contractors. There is typically no formal requirement for periodic inspections in maintenance contracts, but they are informally inspected during routine patrols. It was noted that high-tension cable barriers are inspected weekly. At crash scenes, state police place a sticker “tag” on impact-damaged state property. This tag shows the incident number, which is used to identify the responsible party, so damage costs can be reimbursed. The old tag form was Form SAP-320, Notification of Damage. Now, they use a new “CARS” system, which is an online form that highway patrol uses to notify DOT of impact damage.

Maintenance crews use manufacturers' instructions and checklists to assess damaged units and complete repairs. Stocking of parts is the responsibility of maintenance contractors, and they are also required to be on-call for emergency repairs. Time-to-repair varies among the districts. Some are within weeks, and some take longer for non-emergency repairs. It was noted that cable median barriers are repaired more quickly. There is no independent review of GET repairs. State personnel review sites to ensure that repairs were completed, but the level of inspection detail is unknown.

Ohio DOT

GETs are inspected via drive-by inspections during routine patrols twice per month. In addition, GETs are visually reviewed once per year using annually updated video log images. Each of ODOTs twelve (12) districts has a guardrail (including GETs) repair contract in place. However, there is a mix of how those contracts are used. Some districts defer all GET repairs to the contractor, while others use them for only special repair and do a majority of GET maintenance in-house.

ODOT has published a “Roadside Safety Field Guide: Guidelines for the Installation and Maintenance of Roadside Safety Hardware, 2013”. They use it to assess GET condition and damage, and to implement proper repairs. Once repairs are completed, there is a formal on-site field inspection. ODOT maintains an inventory of repair parts for GETs. They use their Equipment and Inventory Management System (EIMS) to manage their parts inventory, and have separate part numbers for each component of proprietary systems.

Their timeframe for repairing damaged GETs varies by severity. Emergency repairs are completed within seventy-two (72) hours. Less urgent repairs are usually done within three (3) weeks. Approximately 40% of GET damage costs are reimbursed, indicating that the DOT

obtained the identity of the responsible party via an incident report. These reports are actively obtained for this purpose. The remainder are unreported incidents, and the damage is identified during routine drive-by inspections. When GETs are repaired under a maintenance contract, the work is verified in order to release payment. If repairs are completed by state workforce, then the maintenance supervisor reviews the quality of repairs and signs off on it.

Pennsylvania DOT

On the PennDOT highway network, drive-by inspections are done during routine patrols twice per year. Assistant managers and maintenance foremen conduct the inspections. More detailed visual inspection at the site is done if impact damage is noticed during the drive-by review. There are typically two-to-four (2-4) assistant managers per district, and two (2) foremen per assistant manager. No specific reference materials are used to assist in assessing damage to GETs. Approximately 75% of maintenance is done by contractors who follow the state standard road construction specifications. Contracts contain a pay item for "Replace In-Kind" with a line item for each specific device.

State maintenance forces maintain a limited inventory of GET replacement parts at the district level. They have parts for each manufacturer device that is installed in their district. These parts are purchased directly by PennDOT, and are only used if a contractor is unable to complete repairs within the required timeframe. GETs must be repaired within twenty-four (24) hours in urban, high-speed/high risk areas. Otherwise, repairs must be completed within thirty (30) days.

For severe crashes (fatality/serious injury), notification of GET damage comes from state police or local police forces. PennDOT has a good relationship with the enforcement agencies that cover their network. If a crash is property-damage-only (PDO) or not reported, the damage is typically found during routine patrols. The damaged unit is then reviewed by an assistant manager or foreman, and a work order of repairs is sent to the maintenance contractor who is responsible for the location. Repairs are visually inspected and signed-off when completed. Typically, photos of damage prior to repair are taken only for reportable crashes in order to aid in pursuing financial compensation from those responsible.

Texas DOT

Currently, TxDOT inspects GET installations only during routine drive-by patrols or when they are doing other work in the area. Starting in 2016, they have included guardrail assessment as part of their bridge inspection and management program. These inspections are conducted every two (2) years, and include specific inspection elements for GETs and the associated guardrail, including system height and condition assessment. It will, however, only include guardrail/GET installations that are attached to a bridge. The inspectors' reference materials will include photos to demonstrate guardrail-specific types of damage and deterioration, and a rating system.
A majority of GET repairs are done by maintenance contractors, who are responsible for maintaining an appropriate parts inventory. There is no specific timeframe for GET repairs after notification of damage, but it is done as soon as practical. Contractors are responsible for completing repairs in accordance with the manufacturers' drawings and instructions.

Washington State DOT

GET locations are inspected only during routine patrols. WSDOT publishes a maintenance manual, but references to GETs are not detailed. Some of the urban areas have specialized crews who have a greater level of knowledge of GET installations from experience. There is no formal GET training required for maintainers, and they are primarily state workforce employees. There is very little contract maintenance, except for emergency situations.

GET repair parts are stocked, but quantities vary among the twenty-four (24) maintenance areas. Repairs are made as soon as possible after damage is identified. Time-to-repair is typically within a few days, but there is no official policy. Damage is identified during routine patrols. Police typically do not notify the DOT of property damage, but do call them out for traffic control during major incidents. State police maintain a crash database that is accessible by the DOT so they can identify the party responsible for damaging state property. Police "tag" damaged state property by adhering a sticker directly on the damaged unit. The tag has a bar code and incident number that allows the DOT to obtain access to the accident report in order to recover repair costs from the responsible party, as well as obtain other details of the crash event.

SUMMARY OF GUARDRAIL END TREATMENT MAINTENANCE PRACTICES

A majority of agencies interviewed conduct periodic inspections of their guardrail systems as a whole, while fewer explicitly inspected GETs on a routine basis. As shown in Figure 14, half of the agencies conduct inspections only during routine drive-by patrols by maintenance forces. If they notice damage or deterioration, they initiate remedial action. Four (4) agencies (Caltrans, FDOT, ODOT, and PennDOT) conduct detailed on-site inspections of GET installations. Caltrans and ODOT conduct these inspections annually, while FDOT completes them every two (2) years.

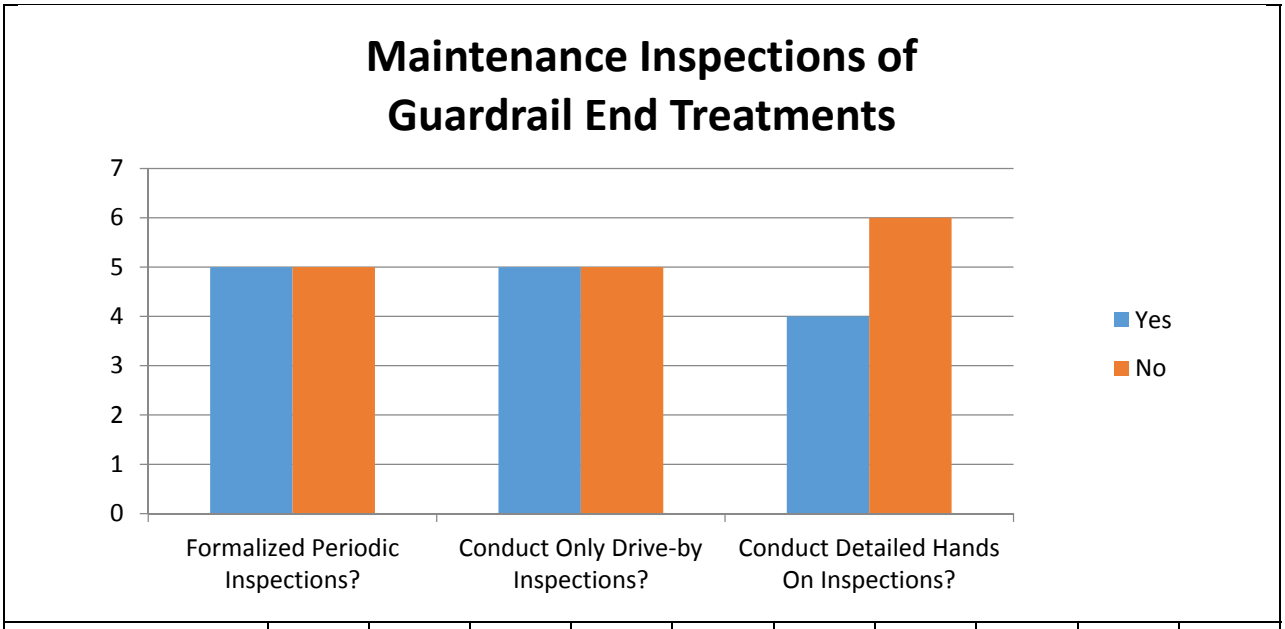
Reference materials used to assess physical condition of in-service GETs varies among the agencies. Figure 15 provides a breakdown of the number of agencies that use common reference materials. A majority of agencies publish their own highway maintenance manuals, but most of them do not provide guidance specifically for GETs. These agencies use manufacturers' manuals, drawings and checklists, or their own design standards for reference when evaluating the condition and repair requirements for GETs. MoDOT and ODOT have developed and use their own guardrail maintenance field guides. MoDOT uses the FHWA Guardrail Maintenance Guide as well.

Repair and maintenance of guardrail systems as a whole, including GETs is conducted by a mix of agency maintenance employees and highway maintenance contractors. Figure 16 shows percentages of the ten (10) agencies that use primarily state workforce versus those that administer maintenance contracts. Several mentioned that there is a trend towards using more contractors, however state workforce employees still maintain a large portion of GETs. In nearly all agencies that use maintenance contracts, the contracted firms are usually the same firms that install GETs as sub-contractors for construction projects.

When maintenance contracts are used, there is typically a state contract administrator who monitors GET repairs and signs-off when they are complete. In states where GET repairs are done by agency personnel, the foreman or supervisor of the crew is typically the individual

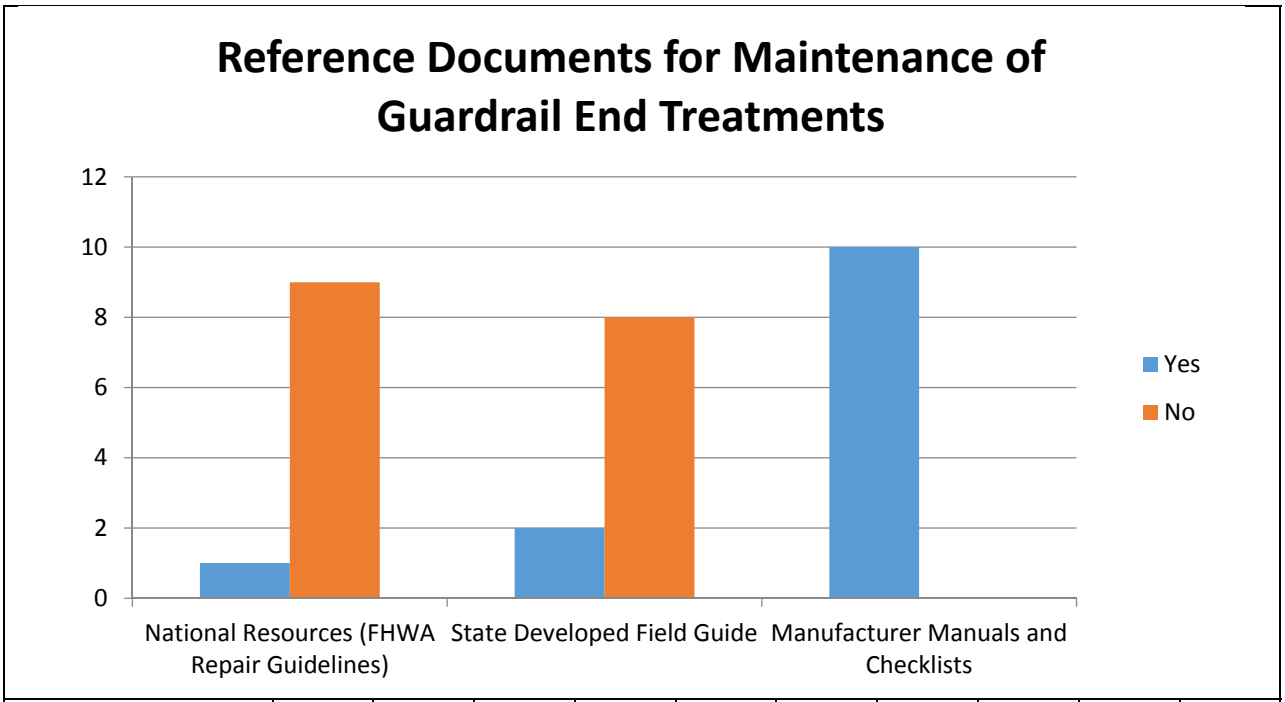
who signs-off on completed repairs. Figure 17 shows that a majority of agencies do not require independent audits or reviews of repaired GETs. Typically, the state contract administrator or crew foreman uses manufacturers' repair manuals and checklists to verify that systems have been repaired properly.

In California, the maintenance supervisor and the district Traffic Safety Coordinator must sign-off on the manufacturers checklist. For most of the other agencies, the repair crew needs only to attest that the device was repaired/installed in accordance with manufacturer instructions without obtaining any outside verification. It is noted that there appears to be a gap in the consistency of inspection requirements between maintenance repairs and initial construction. When systems are partially repaired or wholly replaced with a new unit, an independent validation of the installation should occur as if that assembly was under new construction with the associated inspection requirements, which are typically more stringent.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Formalized Periodic Inspections?	Y	Y				Y	Y	Y		
Conduct Only Drive-by Inspections?			Y	Y	Y				Y	Y
Conduct Detailed Hands On Inspections?	Y	Y					Y	Y		

FIGURE 14 Maintenance inspections of guardrail end treatments.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
National Resources (ex. FHWA Repair Guidelines)				Y						
State Developed Field Guide				Y			Y			
Manufacturer Manuals and Checklists	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

FIGURE 15 Reference documents for maintenance of guardrail end treatments.

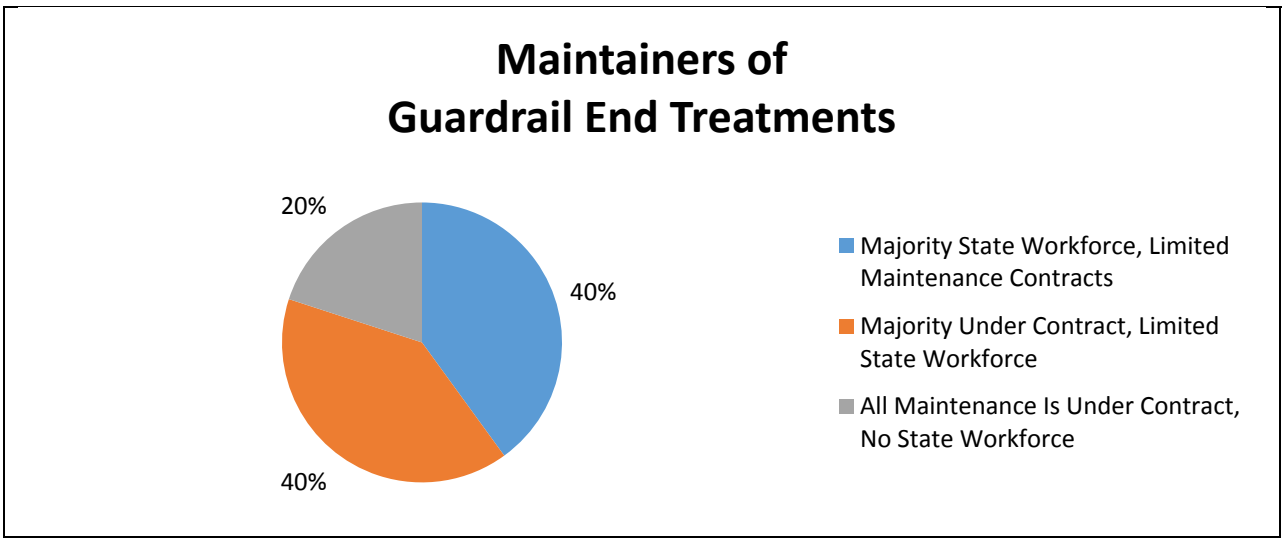
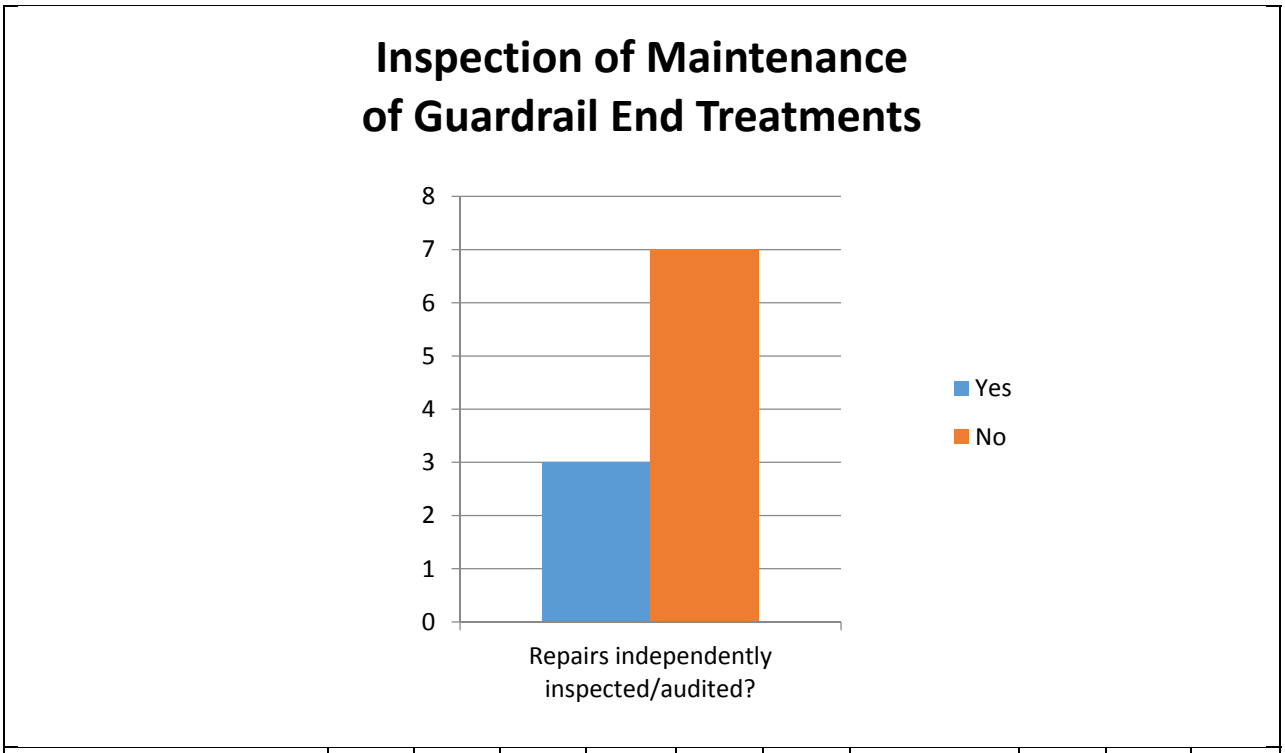


FIGURE 16 Maintainers of guardrail end treatments.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Repairs independently inspected/audited?	Y			Y			Y*			

* Only if contracted maintenance.

FIGURE 17 Inspection of maintenance of guardrail end treatments.

GUARDRAIL END TREATMENT IN-SERVICE PERFORMANCE EVALUATION PRACTICES

This section focuses on agency experiences with formal and informal in-service performance evaluation (ISPE) of GETs. Below are descriptions of these experiences identified during interviews with personnel from each state agency surveyed.

California DOT

During the 1990s, Caltrans conducted ISPEs as part of their new products evaluation process, and followed FHWA guidelines. Since these ISPEs were discontinued around 2002, the original ET-2000 is likely the only GET that was subjected to one. For these ISPEs, “experimental” installations were monitored for crash history and damage assessment. The length of review was based on the number of impacts. If there were five (5) or more crashes in the first year, and performance was acceptable, then the device was approved for operational use. If there were fewer impacts, then duration of the study was extended. Now, systems are given full approval after extensive review by their Crash Test Evaluation & New Product Committee, which consists

of representatives from their Traffic Safety, Crash Testing, Construction, Structures, and Maintenance divisions.

Informal ISPEs are based on field personnel experience and are not typically documented. There is a perception that GETs are performing acceptably in the field, and there is not an ongoing need for ISPEs.

Caltrans participates in a program named MAIT (Multi-Disciplinary Accident Investigation Team). There are 6-8 teams throughout the state, and each is composed of Caltrans highway safety specialists from various disciplines, as well as law enforcement personnel. The MAIT teams are immediately called to the scene of "high profile" incidents, such as those involving buses, multiple fatalities, highway workers, or officers. They conduct detailed crash scene investigations with documentation and photos.

Additionally, Caltrans (Orange County) is participating in the current FHWA/NHTSA study on ISPE of GETs. Their participation has just started in July 2016, and the project is scheduled to be a three (3)-year pilot study.

Florida DOT

FDOT has not conducted any formal or informal ISPEs specifically for GETs. However, they have conducted ISPEs for other types of roadside safety hardware in the past. Starting in December 2012, they began a review of 27" w-beam guardrail, which guided their decision to move to 31" guardrail height for all new installations. This decision was based on the rate of capture vs. penetration of the barrier, and is published in report FDOT BDK 80-977-19. They have also has conducted ISPEs at trial installations of high-tension cable barrier.
FDOT does not typically conduct crash scene investigations, as it is a function of law enforcement. However, the new inventory and incident management program starting in 2017 will collect inventory and impact data. Data collection will begin for approach terminals and crash cushions, and will later include length-of-need impacts. These data-collection efforts are intended to provide much of the data necessary to conduct ISPEs.

Kansas DOT

KDOT has never conducted a formal ISPE of GETs. At one time, they tried to track crash cushion repair costs. However, it was a challenging effort due to lack of electronic data. Tracking man-hours and cost of parts using only paper data sources was complicated and time-consuming.

They feel that a very small percentage of fatalities involve GET impacts compared to poles and trees, and they are not seeing any issues with GET performance. Use of the ET-PLUS was discontinued based on other (Pooled-Fund) state evidence & anecdotal reports. Problems identified in those reports were not experienced in Kansas. Also, in moving to MASH and 31" guardrail height, they are not looking back to older systems, and are removing them.

All crash scene investigations are done by law enforcement personnel. A KDOT legal team may investigate very severe or high profile crashes, but not on the scene. They look at results of other states' ISPEs (formal or informal) to assist in their QPL evaluations. For one specific crash cushion device on their QPL, they independently reviewed the crash history in other DOTs, in order to quantify and define a claim that the system is intended for "severe duty".

Missouri DOT

The only MoDOT experience with formal in-service performance evaluation of GETs is their participation in the current FHWA study. They internally reviewed performance information related to the ET-PLUS issue, but it was not a formal ISPE. The ET-PLUS is the only system that they discontinued its use due to poor field performance. Prior to then, they have only evaluated performance of specific GET installations, if it was related to an incident for legal defense purposes. They have not conducted any ISPEs for other types of roadside safety devices.

MoDOT conducts crash scene investigations for incidents involving GETs. They used to be done only by consultants, but now there is a mix of state personnel. The DOT has two (2) certified accident reconstructionists. Previously, only fatal impacts were investigated. However, as part of the FHWA pilot project, they are now reviewing all PDO & A+K incidents as well as all single vehicle crashes. Additionally, state police conduct extensive investigations for incidents involving multiple fatalities or criminality. Site investigations are typically done within one-to-two (1-2) weeks of the incident, but may be years later due to legal proceedings. There is a 3-year statute of limitations, unless the victim is a minor, then the timeline is extended until they are eighteen (18) years old.

New York State DOT

Over the years, NYSDOT has conducted several investigations of the performance of various terminal systems. While the results have generally been informative, they may not be considered "formal" ISPEs as defined by NCHRP Report 490, which they consider to set the bar very high for formal evaluations.

They indicated that formal ISPEs are problematic because the power to conduct a proper ISPE is not all internal to the DOT. An essential requirement of an ISPE is that there is good, detailed crash outcomes information. One cannot evaluate performance if it is not known what happened to the occupants. There may be fatalities in cases where there is little damage to the rail, and conversely vehicle occupants may walk away unscathed from crashes in which the terminal was completely destroyed. The DOT does not have jurisdiction over any police agencies who are first responders. In many cases, they do not receive police accident reports, there are no police accident reports, or it will be a long time before they can get the reports. Right out of the starting gate, they are severely handicapped in getting the information needed to do an ISPE. If there was one change to come out of this study that would be beneficial to getting ISPEs done, it would be to have FHWA urge governors, not DOTs, to integrate the data movement from police agencies to DOTs for crash information. Additionally, the police agencies would need to expand their information gathering to better document detail of the vehicle-terminal interactions. Currently, much of the information gathering is focused on addressing prosecution and insurance issues.

Beyond the challenge of collecting pertinent information, there are resource limitations. The DOT lacks the funding, staff, and staff training to gather the information that would be needed from maintenance staff. Additionally, they would need processes to ensure the information flowed to appropriate repositories and that, once there, they need a process and trained staff to analyze the data and extract meaningful trends from it.

The most meaningful information for an ISPE would be the results of severe crashes and injuries. This is where performance limitations are best identified. For these severe crashes however, an accident reconstruction is typically needed to figure out exactly what happened and what limits were exceeded. They believe that most state DOTs do not have the services of an accident reconstructionist available in-house.

It is common practice for NYSDOT Maintenance forces to report to the Office of Design any instances where a crash outcome had a severe, or what is perceived to be an abnormal outcome. These reports are infrequent. There is essentially no effort to report, nor interest in, outcomes that appear normal or acceptable. NYSDOT does not conduct crash scene investigations, but they would like to see them done for all severe crashes or those with bad outcomes.

North Carolina DOT

NCDOT has not conducted a formal ISPE of GETs. However, in 2015, they reviewed data obtained from crash reports for incidents that occurred from 1990 to 2013. This effort looked at the sequence of events for impacts involving different categories of fixed objects. In 1990, there were 697 impacts with 18.9% in the K+A category. In 2013, there were 1268 impacts with only 2.8% resulting in K+A injuries. Partially based on this, they feel that roadside safety systems are performing adequately, and overall safety is improving. They indicated that only four (4) or five (5) impacts involved passenger compartment penetration over the course of their data review. The study did not consider the type of brand of device involved with each incident.

NCDOT monitors field performance of GETs internally, on an informal basis, but no specific action has taken place based on these efforts. They typically upgrade GETs only when new performance guidelines are published. They have field crash scene investigators on staff as part of their fatal investigation program. These DOT investigations are conducted weeks or months after the incident. In some cases, the device has already been repaired. Additionally, central office staff produce safety analyses reports for various highway sections. These reports are used by designers to assist them in evaluating roadway conditions that contribute to safety issues, in order to develop appropriate countermeasures.

Ohio DOT

ODOT conducted a formal ISPE of the original ET-2000 during the late 1990’s and early 2000’s. Availability of the report is unknown. They cited a lack of personnel as the primary reason that formal ISPEs are not conducted more often. Monitoring of field performance is done during the QPL review process, but it is geared more towards maintenance and repair issues and not safety performance. ODOT had suspended use of the ET-PLUS, but it has since been reinstated. They have also disallowed a cable barrier terminal due to problems with pullout strength in some soil conditions.

All crash investigations are done by law enforcement. The DOT is on-call for traffic control at accident scenes, but they do not do any on-scene investigations.

Pennsylvania DOT

PennDOT is very interested in ISPEs and this TRB project, but has never completed a formal ISPE. They need and desire more guidance on the processes and policies related to the results of ISPEs. The ET-PLUS was discontinued due to reported poor field performance. State Police do all crash scene investigations. Fatal accident investigations are done promptly at the scene.

Texas DOT

TxDOT has not conducted any formal ISPEs for GETs or any other roadside safety device. They do conduct informal in-service evaluations of trial installations of proprietary devices during the QPL process. These evaluations look at crash data, if available, but focus more on operational performance of the system (ease of repair, availability of parts, etc.). They do not conduct trial installations of their in-house developed devices, since they are very familiar with these systems by the time the development process is complete. The ET-PLUS is the only system that has been removed from the QPL due to reported poor field performance.

TxDOT relies on law enforcement to conduct crash-scene investigations, and does not routinely conduct them themselves. However, their maintenance forces are on-call at all times.

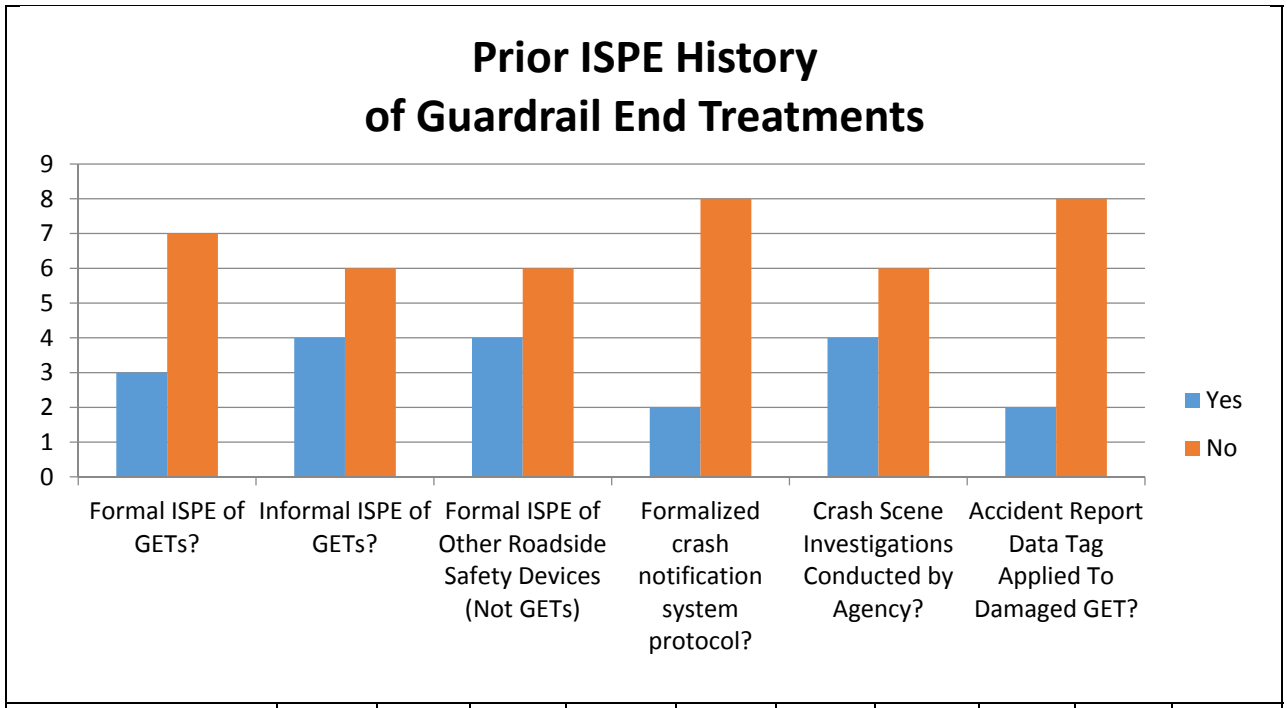
Washington State DOT

WSDOT conducted a formal ISPE of GETs, and report on the project was published in June 2004. During this study, the Breakaway Cable Terminal and Slotted Rail Terminal were evaluated using NCHRP Project 22-13 methodology. The results showed no significant difference between the systems' performance, and also that both systems demonstrated overall acceptable performance when impacted. WSDOT also conducted an ISPE of cable median barrier, and a report on the project was published in November 2003. No other known ISPEs have been done, primarily due to high costs involved with conducting them properly in accordance with NCHRP recommendations.

Use of the ET-PLUS was discontinued in 2014 based on national reports of poor field performance. Reintroduction of ET-Plus for repairs to existing installations is currently under consideration.

SUMMARY OF GET IN-SERVICE PERFORMANCE EVALUATION PRACTICES

As shown in Figure 18, three (3) agencies (Caltrans, ODOT, and WSDOT) reported having conducted a formal ISPE specifically for GETs. The WSDOT research project was completed in 2004, and the researchers attempted to follow the NCHRP ISPE guidelines. The Appendix contains a link to the report describing this ISPE project. Caltrans and ODOT each conducted an ISPE of the original ET-2000 during the late 1990's and early 2000's. Availability of reports describing these ISPE studies is unknown. Four (4) agencies (Caltrans, FDOT, NYSDOT, and WSDOT) reported that they have conducted ISPE for other type of roadside hardware, such as cable median barrier, concrete barrier, and LON guardrail.



	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
Formal ISPE of GETs?	Y						Y			Y
Informal ISPE of GETs?				Y	Y	Y			Y	
Formal ISPE of Other Roadside Safety Devices (Not GETs)	Y	Y				Y				Y
Formal crash notification system protocol?	Y*			Y						
Crash Scene Investigations Conducted by Agency?	Y*			Y	Y		Y			
Accident Report Data Tag/Sticker Applied to Damaged GETs?					Y					Y

*If incident involves Busses, Multiple Fatalities, Work Zone, or Highway Patrol Officers.

FIGURE 18 Prior ISPE history of guardrail end treatments.

MoDOT, NCDOT, NYSDOT, and TxDOT reported that they have conducted informal evaluations of GETs, but there are no written results available. It was noted that a majority of these informal evaluations were directed more towards maintenance and repair aspects of GETs, and not as much on crash performance.

Caltrans and MoDOT are the only agencies that receive notification of crash incidents directly from law enforcement personnel on a routine basis. Direct notification at Caltrans is limited to incidents involving buses, multiple fatalities, work zones, or highway patrol officers. These incidents trigger an immediate response from a MAIT (Multi-Disciplinary Accident Investigation Team).

Most agencies reported that they do not routinely conduct crash scene investigations, and consider that a function for law enforcement. Some said that occasionally DOT staff will investigate incidents in which significant state property damage occurred, or if there is pending litigation. Four (4) agencies (Caltrans, MoDOT, NCDOT, and ODOT) reported that they have crash investigators on staff or under contract to review incidents as needed. NCDOT and WSDOT have a property damage tagging/sticker system in place to facilitate timely access to incident reports that correspond to GET impact damage.

Many opinions were expressed as to why ISPEs are difficult to conduct. The primary factor is limited resources in both budget and manpower. Another factor reported is that there are few procedures in place for receiving timely notification of crashes, and access to incident investigation reports. In addition, agencies do not typically receive any information on vehicles or occupants involved in unreported GET impacts, which account for a majority of damage compared to reported incidents.

Availability of accurate and timely data is essential in order to conduct an effective ISPE. Table 1 shows an overall summary of agency practices which are considered useful for facilitating ISPEs.

An inventory system of existing GET installations is an important component of the data needs. Most of the agencies with inventory data have only recently started collecting it, and have so far only recorded basic attributes, such as GET type and location. In addition, each agency department has their own system to record values related specifically to construction, maintenance, asset management or accident data. Integration of these varied platforms could aid wider adoption of ISPE programs.

Within their inventory system, three (3) agencies (Caltrans, MoDOT, and PennDOT) record some type of periodic condition assessment, which may be useful in determining the condition of a GET before an impact. Original Installation Date is also a useful attribute in order to quickly and easily identify the age of GETs that may be included in an ISPE. Finally, few agencies take advantage of digital photographs as a means to record installation & site information.

Communication between field personnel, whether state maintenance workforce or contracted maintenance crews, and the agency personnel responsible for conducting design & safety reviews is a key component of a successful ISPE program. Few agencies have documented procedures to identify irregularities in the field, whether reporting excessive damage or through routine inspection. Further, a limited number of agencies independently audit maintenance efforts. However, the majority of those with a formalized inspection program do conduct detailed hands-on inspections.

Other communication protocols essential for effective ISPE is timely notification of crashes and access to incident reports. Only two (2) agencies interviewed (Caltrans and

MoDOT) consistently receive notification of GET impacts directly from first responders. Additionally, NCDOT and WSDOT are the only agencies that receive direct links between GET impact damage and the corresponding incident reports via their tagging/sticker policies.

TABLE 1 Summary of Available Inventory and Crash Data for In-Service Performance Evaluations

	CA	FL	KS	MO	NC	NY	OH	PA	TX	WA
GET Inventory										
Ever conducted an inventory of GETs?	Y			Y			Y	Y	Y	Y
One-Time Snapshot?	Y			Y			Y			
Ongoing Data Acquisition?								Y	Y	Y
Attributes Collected										
Original Project Information?		Y	Y							
Location Information?	Y	Y	Y	Y			Y	Y	Y	Y
Photographs?							Y	Y		Y
GeoSpatial										
System QPL Type?	Y		Y	Y			Y	Y	Y	Y
System Manufacturer Model?	Y		Y	Y				Y	Y	Y
Original Installation Date		Y	Y							
Original Installer?			Y							
Dates of impact or maintenance?									Y	Y
Condition Assessments?	Y			Y				Y		
End of Service Life										
Formalized process for notifying Design Division of obsolete system or excessive damage?	Y	Y								
Maintenance Inspections										
Formal Periodic Inspections?	Y	Y				Y	Y	Y		
Conduct Only Drive-by Inspections?			Y	Y	Y				Y	Y
Conduct Detailed Hands-on Inspections?	Y	Y					Y	Y		
Quality of Repairs										
Repairs independently inspected/audited?	Y			Y			Y			
Prior ISPE History										
Formal ISPE of GETs?	Y						Y			Y
Informal ISPE of GETs?				Y	Y	Y			Y	
Formal ISPE of Other Roadside Safety Devices (Not GETs)	Y	Y				Y				Y
Formal crash notification system protocol?	Y			Y						
Crash Scene Investigations Conducted by Agency?	Y			Y	Y		Y			
Accident Report Data Tag/Sticker Applied to Damaged GETs?					Y					Y

CONCLUSIONS

The paper contains details of interviews that were conducted with state DOTs, and a summary of responses for five (5) GET subject areas. This section highlights typical, unique, and exceptional practices identified during the interviews, and provides conclusions on how these practices may be applied to future in-service performance evaluation of GETs. Additionally, conclusions are provided for potential deficiencies in agency practices that may require modifications to accommodate ISPE techniques and data needs.

Design and Selection Practices

Although details vary, all DOTs have an established process in place for specifying GETs in their construction contract documents. Project design engineers prepare technical aspects of construction documents in the form of drawing plans and written specifications. They typically use resources such as design manuals and guidelines to assist in detailing the proper use of construction materials. For GET work items, a majority of DOTs use "standard" plans and specifications that are utilized for most projects within their jurisdiction. If necessary for unique situations, project designers may prepare supplemental documents to further detail usage and placement of GETs at particular locations.

All the agencies have a similar process in which standard plans and specifications reference an APL/QPL of systems allowed to be installed on their highway network. FDOT stands out as having very well organized standards and guidelines that are evaluated and updated regularly and frequently. They place high priority on roadside safety issues and assign in-house technical experts for different categories of safety devices. In addition, FDOT defines their guardrail and GET pay items to ensure full length-of-need protection is provided precisely where it is needed regardless of the cataloged lengths of different GET systems.

With regard to all agencies interviewed, there is some concern over the consistency related to devices approved on the APL/QPL versus those supplied to the jobsites. It is typically assumed that devices delivered to the jobsite are exactly the same as what is approved on the APL/QPL. In some cases, there may be variations of the device that are not reflected on the APL/QPL documants or standards. Changes to devices or their documentation may occur, whether through manufacturing tolerance changes or larger redesign of components. In these cases, standard plans need to be updated to match the most current model, which places a burden on agencies. Also, links to manufacturer installation details may be outdated, or be replaced with a different versions than those of the device that has been approved. Consistency with respect to the specific model, a matching detail, manual and checklist, are critical to ensuring the specified device is delivered and installed correctly. However, many agencies do not provide an up-to-date repository of device instructions, and rely on the manufacturer to supply the correct documentation at time of delivery.

Construction and Installation Practices

GET construction and installation procedures and practices are similar among the DOTs interviewed. Nearly all new GETs are installed by guardrail specialty contractors, and the work is monitored by state personnel or consultant inspectors. Exceptional practices in this area are related to training of GET installers and inspectors. Proper installation is often essential to the

proper function of GETs during vehicle impacts. While most of the agencies reported that they would like to, or are in the process of implementing training, Caltrans, ODOT and WSDOT are the only ones who already require GET training and certification for installers or inspectors. WSDOT requires that GET installers be trained and certified by the manufacturers. Caltrans and ODOT conduct their own mandatory inspector training programs that include sessions that specifically cover GET installation issues.

Construction procedures in general, and installation training in particular do not have direct impact on conducting ISPEs. However, proper installation is a key component of GET field performance. Any practice that encourages consistent and sound installations is beneficial for the overall ISPE process.

Inventory and Management Practices

Asset management is a timely and important topic for transportation agencies. In order to efficiently manage their vast infrastructure assets, DOTs need current and accurate inventory of their assets. Most agencies have developed and maintained some type of asset management system for their bridges and pavements, as these may be considered their most critical assets. Network-level inventories and management systems for other roadway assets, such as GETs are currently not as common or established with the DOTs interviewed for this study. A majority of agencies recognized the importance of having a statewide inventory of their GET installations, and most are beginning to plan for implementing some type of system. A few agencies have a GET inventory system in place, and some have recently completed their first data-collection sweep of their highway network.

As described above, three agencies (PennDOT, TxDOT and WSDOT) standout as having an extraordinary GET inventory practices. The current level of detail contained in their GET inventory databases varies, but there is room for improvement in each case. The data captured and available in all three (3) systems is essentially limited to location and type/brand of GET at each location. While having this data is a vast improvement over having no GET inventory, many other GET installation attributes are beneficial for network management and performance evaluation. Examples of data fields that could be included in a comprehensive GET inventory system include:

- Condition Assessment, including physical compliance with installation checklist.
- Dates and details of inspections, including photos.
- Dates and details of repairs, including before and after photos.
- Date and details of initial installation (Project Number, Contractor, Inspector).

Inventory databases that contain the above information need to be maintained and updated consistently. This process is only just beginning to occur within agencies that have collected an initial inventory of their GETs. PennDOT has maintained a GET inventory dating back many years, which is the oldest and most establish inventory of the DOTs interviewed. Until 2016, the condition assessment attribute for each GET installation was limited to “damaged” or “undamaged”. They have just begun including more description of damage, and measurements for compliance with proper installation details.

TxDOT recently completed initial data collection for a statewide inventory of GETs. The data they collected is limited to location and GET type/brand, and the extent of future updating is

unknown. However, the extraordinary aspect of their system is that they utilized a modern technology (smartphones) to collect the initial inventory in a very short period of time. They collected the two (2) basic data fields for nearly 134,000 GET installations in less than two (2) months. This is considered a great achievement, and can be used as model for other agencies that do not currently have any GET inventory. Once the basic initial data is collected on a statewide highway network, it provides a basis for expanding to a more comprehensive information system.

Of the agencies interviewed, WSDOT has developed the most robust information system for managing data on each GET installation in the state highway network. The system (TIMS) allows for collection, storage and access of detailed information associated with each GET site. Although they have only just begun to populate records in the database, WSDOT maintenance personnel plan to actively use and update the system, and have a vested interest in making it a successful resource for many divisions within their agency.

These inventory and management systems would likely be a valuable resource for conducting ISPEs. They have the potential to provide detailed information on GET site conditions that could be used to evaluate performance when investigating crash events. Physical measurements, photos, and other details of GET installations before a crash event occurs is crucial to determining causes of vehicle dynamics and resulting consequences. Although much of the network-level inventory data needed for ISPEs currently may be sparse, most the agencies interviewed recognize the importance of accurate data systems, and are either developing or planning to implement them.

Maintenance Practices

All the DOTs interviewed have a well-established highway maintenance division that is required to repair and maintain a wide variety of features within their highway infrastructure. Since all highway features can be considered vital to the efficiency and safety of the transportation system, issues related to GETs are a relatively small portion of their work activities. However, all of the agencies interviewed recognize the importance of proper GET maintenance and repair.

Most of the agencies interviewed inspect their GETs by drive-by observations during routine patrols. They identify the presence of damage or deterioration during this process, and then conduct a more extensive evaluation on-site. Five (5) of the agencies interviewed conduct more formal GET inspections on a scheduled basis. Of these, FDOT has the most comprehensive process. All their GETs are inspected every two (2) years by “asset management” contractors who complete an assessment form for each GET location.

Within the agencies interviewed, there is a fairly even split between those who use their own state workforce to complete GET repairs, and those who use maintenance contracts. There are advantages to each of these practices. Maintenance contractors typically have specialized crews that are very familiar with GET installation and repair requirements. In most cases with contract maintenance, the contractor firms are the same ones that complete new GET installations for construction projects. The benefit is that these contractors are essentially experts in the proper installation of GETs. The advantage of utilizing state workforce for repair of GETs is their close communication with other divisions within the agency. For example, repair crews have more opportunity to contact the DOT design division if they feel that a particular GET installation is not configured properly, or the correct application. In addition, they can more readily exchange ideas and observations related to continual improvement of the practices.

As related to ISPE, maintenance personnel from the agencies interviewed expressed a willingness to provide data and assistance related to assessment of GET damage and repair efforts required to bring systems back to their proper condition. If they receive adequate training and guidance, they are willing collect data related to GET hardware and enter it into any new or existing information system.

ISPE Practices

None of the agencies interviewed are currently conducting a formal ISPE of GETs, other than participation in the FHWA study. Nearly all expressed an interest in obtaining information on GET field performance, and in conducting ISPE themselves, if the processes were straightforward and not extraordinarily labor-intensive. Lack of available personnel was the primary reasons cited for why ISPEs have not been conducted in the past.

Although data collection has not yet commenced, FDOT is in the process of implementing information systems for GET inventory and incident management. They expressed that one of the primary motivations and uses of these systems are to provide resources for conducting ISPEs. FDOT plans to begin data collection for these systems on January 1, 2017, and their implementation process may provide guidance for other agencies.

Another beneficial practice was identified during interviews with NCDOT and WSDOT personnel. These agencies have a process in place in which law enforcement “tags” damaged GETs and other state property with an identification sticker as part of their on-site incident investigations. These tags identify the incident number, which allows for easy retrieval of the incident report. Incident reports are a primary source of information related to vehicles and occupants involved in the corresponding incident. This “tagging” process is driven by a desire to collect monetary compensation for state property damage. However, it can provide a direct link between information on damaged GETs and information on vehicles and occupants involved in the corresponding incident.

In addition to GET damage assessments and incident reports, detailed crash scene investigations are a source of information for ISPE. Most of the agencies interviewed do not employ their own crash scene investigators. The agencies typically rely on law enforcement personnel to perform that function. Four (4) agencies (Caltrans, MoDOT, NCDOT, and ODOT) conduct their own crash scene investigations, primarily for fatal or high-profile incidents. These practices were identified as those most likely to fulfill data requirements associated with conducting formal and relevant ISPEs on a more wide-scale basis. Methods of data collection are improving with advances in technology. A few agencies reported that using old paper data sources is a deterrent to conduction of ISPEs. Improvements to data collection methods, organization and retrieval are anticipated to help promote ISPEs in the future.

APPENDIX - REFERENCE MATERIALS

National Resources

American Association of State Highway and Transportation Officials (AASHTO)

Roadside Design Guide (RSDG).
Task Force 13 Guide to Standardized Barrier Hardware.

Federal Highway Administration, National Highway Institute (NHI)

Course No. 380085, Guardrail Installation Training.
Course No. 380032A, Roadside Safety Design.
Course No. 380034A&B, Design, Construction, and Maintenance of Highway Safety Appurtenances and Features.

American Traffic Safety Services Association (ATSSA)

Guardrail Installation Training (GIT).
Guardrail Inspection (GI).
Longitudinal Barrier Systems (LBS).

California DOT

Standard Plans
http://www.dot.ca.gov/hq/esc/oe/project_plans/HTM/stdplns-US-customary-units-new15.htm
Approved Products List for Highway Safety Features
http://www.dot.ca.gov/hq/esc/approved_products_list/pdf/highway_safety_features.pdf

Florida DOT

Plans & Preparation Manual
http://www.dot.state.fl.us/rddesign/PPMManual/PPM.shtm
Plans & Preparation Manual, Chapter 4, Roadside Safety
http://www.dot.state.fl.us/rddesign/PPMManual/2016/Volume1/Chap04.pdf
Standard Specifications:
http://www.dot.state.fl.us/programmanagement/Implemented/SpecBooks/default.shtm
Design Standard Drawings
http://www.dot.state.fl.us/rddesign/DS/16/STDs.shtm

Kansas DOT

Index of Prequalified Materials and Material Sources
http://ksdot.org/burmatrres/pql/default.asp
Standard Specifications for State Road & Bridge Construction
https://www.ksdot.org/bureaus/burConsMain/specprov/2015specprov.asp

KDOT Standard Drawings
https://kart.ksdot.org/StandardDrawings/Default.aspx

Missouri DOT

Engineering Policy Guide (EPG)
Standard Drawing 606.30G, Guardrail, Terminal Ends, Crashworthy (2012).
Standard Specifications, Sections 606.30 & 1040.4, Crashworthy Guardrail End Terminals.
Qualified Products Listing, End Terminals, Crash Cushions, and Barrier Systems (link).
http://www.modot.org/business/standards_and_specs/endterminals.htm

New York State DOT

Engineering Instruction 12-018, Design Guidance for Use of Energy-Absorbing End Terminals for Corrugated Beam Systems.
https://www.dot.ny.gov/portal/pls/portal/mexis_app.pa_ei_eb_admin_app.show_pdf?id=11041
NYSDOT Highway Design Manual, Chapter 10, Roadside Design, Guide Rail and Appurtenances.
https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm/chapter-10
List of Approved Corrugated Beam Guide Rail End Terminal (Energy-Absorbing).
https://www.dot.ny.gov/divisions/engineering/technical-services/technical-services-repository/alme/pages/12-1.html
List of Proprietary Attenuators and Guide Rail Terminals.
https://www.dot.ny.gov/main/business-center/engineering/specifications/details-of-proprietary-attenuators

North Carolina DOT

Standard Drawing 862.01, Guardrail Placement (scroll to page 162).
https://connect.ncdot.gov/resources/Specifications/2012%20Roadway%20Standard%20Drawings/Division%2008%20-%20Incidentals.pdf
Approved Products List, Product Group - Guardrail.
https://apps.ncdot.gov/vendor/ApprovedProducts/

Ohio DOT

Location & Design Manual, Volume I, Section 600, Roadside Design.
https://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/roadway/Pages/locationanddesignmanuals.aspx
Standard Construction Drawings.
http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/roadway/Pages/StandardConstructionDrawing.aspx
Approved Products List and new product process.
http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/roadway/Pages/Approved%20Products.aspx
Construction and Material Specifications

http://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/Pages/2010CMS.aspx
Transportation Inventory Management System (TIMS).
http://gis.dot.state.oh.us/tims/map
Roadside Safety Field Guide: Guidelines for the Installation and Maintenance of Roadside Safety Hardware, 2013".
https://www.dot.state.oh.us/Divisions/Planning/LocalPrograms/LTAP/Documents/Ohio_Guardrail_Installation_Pocket_Guide.pdf

Pennsylvania DOT

State Design Manual, Chapter 12 (Via Page 9 on Publication List page):
http://www.dot.state.pa.us/public/pubsforms/Publications/PUB%2013M.pdf)
Publication 33, Shoulder and Guide Rail Condition Survey Field Manual, April 2016.
Note: The last page (116 of 116) is the ET-Plus End Treatment Inspection Checklist, which was newly implemented for the 2016 survey.
http://www.dot.state.pa.us/public/PubsForms/Publications/PUB%2033.pdf
Construction Specifications:
http://www.penndot.gov/ProjectAndPrograms/Construction/Pages/ConstructionSpecifications.aspx
Standard Drawings:
http://www.dot.state.pa.us/public/Bureaus/design/pub72m/PUB72COV.pdf
New Product Evaluation and Research:
http://www.penndot.gov/ProjectAndPrograms/ResearchandTesting/Pages/New-Products-Evaluation-And-Research-Product-Evaluation.aspx
Qualified Products List:
http://www.dot.state.pa.us/public/pdf/BOCM_MTD_LAB/PUBLICATIONS/PUB_35/Current_Edition/Bulletin15.pdf
Roadway Management & Testing:
http://www.penndot.gov/ProjectAndPrograms/ResearchandTesting/RoadwayManagementandTesting/Pages/default.aspx

Texas DOT

Design Division Standard SGT(8)31-14, Single Guardrail Terminal (SKT-31) Wood Post.
Design Division Standard SGT(8S)31-14, Single Guardrail Terminal (SKT-31) Steel Post.
Design Division Standard SGT(9S)31-14, Single Guardrail Terminal (X-LITE) (Steel Post).
TxDOT Roadway Standards
http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/rdwylse.htm
TxDOT Roadway Design Manual (Chapter 7 & App. A covers end treatments)
http://onlinemanuals.txdot.gov/txdotmanuals/rdw/rdw.pdf
TxDOT Specification Book (Item 544 Guardrail End Treatments)
ftp://ftp.dot.state.tx.us/pub/txdot-info/des/spec-book-1114.pdf

Washington State DOT

Design Manual, Chapter 1610, Traffic Barriers
http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1610.pdf
Traffic Barriers – Design Page with Manufacturers' Drawings
http://www.wsdot.wa.gov/design/policy/trafficbarriers.htm
Design Standard Drawings, Section C, Traffic Barriers
http://www.wsdot.wa.gov/Design/Standards/#Section%20C
Standard Specifications, Division 9, Materials, 2016
http://www.wsdot.wa.gov/publications/manuals/fulltext/M41-10/Division9.pdf
Construction Manual, Chapter 8, Miscellaneous Construction
http://www.wsdot.wa.gov/publications/manuals/fulltext/M41-01/Chapter8.pdf
Qualified Products List
http://www.wsdot.wa.gov/biz/mats/QPL/QPL_Search.cfm
In-Service Performance of Guardrail Terminals In Washington State, June 2004.
http://www.wsdot.wa.gov/research/reports/fullreports/580.1.pdf