National Cooperative Highway Research Program

NCHRP Synthesis 244

Guardrail and Median Barrier Crashworthiness

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Guardrail and Median Barrier Crashworthiness

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to state department of transportation (DOT) roadway design, traffic, structural, maintenance, and research engineers and others concerned with highway safety issues. This synthesis describes the current state of the practice for the use of guardrails and median barriers and their crashworthiness. It includes information about the crashworthiness and typical applications of the most common, permanently installed, nonproprietary guardrail and median barrier systems used in the United States today. A significant amount of detail is included in the text to aid the design, selection, and locating processes for safe and effective guardrails and median barriers.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board presents data obtained from a review of the literature and a survey of state DOTs. The synthesis presents a description of the typical longitudinal barriers in use today, including drawings, the extent of their use, and the most recent testing on each guardrail and barrier system, with particular emphasis on NCHRP Report 230 and 350 requirements. In addition, it discusses the maintenance issues, cost constraints, and common problems with each type of barrier. The synthesis only discusses the crashworthiness of guardrails and median barriers; their transitions and terminals are not discussed.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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This study was managed by Stephen F. Maher, P.E., Senior Program Officer, who worked with the consultant, the topic panel, and the Project 20-5 committee in the development and review of the report. Assistance in topic panel selection and project scope development was provided by Sally D. Liff, Senior Program Officer. Linda S. Mason was responsible for editing and production, with assistance from Susan Brown. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

GUARDRAIL AND MEDIAN BARRIER CRASHWORTHINESS

SUMMARY

Catastrophic accidents involving airliners, ships, and trains receive a great deal of media attention, but almost 95 percent of all transportation fatalities occur on roadways and highways. These traffic deaths, occurring one or two at a time all over the nation every day of the year, do not usually receive widespread attention, but the cumulative toll is more than 40,000 deaths, more than 3.5 million disabling injuries, and a societal cost of more than $100 billion a year.

Thirty years ago more than 50,000 Americans died in traffic accidents each year. This unacceptable level of death and suffering resulted in many government and private initiatives focused on improving highway safety. As a result, the total number of fatalities dropped annually; in 1994, just over 40,000 people were fatally injured in traffic accidents. Although this reduction is laudable on its own, the fact that it was made with a concurrent doubling in vehicle miles traveled (VMT) is remarkable. In 1966, 5.5 people were fatally injured for every 100 million VMT. In 1992 this rate was 1.8 fatalities per 100 million VMT, less than one-third the rate of 30 years ago. If the fatality rate had remained unchanged since 1966, 123,000 people would have died on U.S. roadways in 1992 alone. These statistics demonstrate that the many efforts at improving highway safety have indeed been effective.

This improvement in safety over the past several decades can be attributed to many different programs and initiatives. One part of the overall strategy for improving safety has been the use of roadside safety appurtenances such as guardrails and median barriers. Guardrails and median barriers, devices that are used to redirect vehicles away from more hazardous objects, are among the most basic roadside safety features used today. They are designed to prevent vehicles from leaving the roadside and becoming involved in more hazardous collisions. Many different types of guardrails and median barriers have been designed, tested, installed, and evaluated over the past three decades. For many years there were numerous types of guardrail and median barrier systems, each tailored to a particular site, specific operating condition, or perceived performance objective. Many of these systems have become obsolete and fallen by the wayside during the past decade. Other newer systems have been developed to take their place in response to the ever-changing roadway and traffic environment. Today, the majority of guardrail and median barrier installations consist of just a few versatile barrier systems. Most states have found that having a few versatile systems to install and maintain is more economical than having numerous systems each tuned to a different performance objective.

Guardrails and median barriers are the foundation of the roadside safety hardware inventory. The choice and characteristics of guardrail terminals and transitions largely depends on the types of guardrails and median barriers to which they are connected. Choosing the best guardrail or median barrier for a particular application involves understanding the behavior of a barrier in a collision, the limitations of the barrier, and the cost of installing and maintaining the barrier. Unfortunately, this type of information is not currently available in any one document. Assembling, reading, and understanding the full range of crash test reports, technical papers, policy memoranda, and other documents related to the crashworthiness of guardrails and median barriers is an impossibly large task for any

engineer in a typical transportation agency. The purpose of this synthesis is to assemble much of this information in one document that practicing engineers can use to make decisions about selecting, designing, and locating guardrail and median barrier improvements. This synthesis presents information about the crashworthiness and typical applications of the most common, permanently installed nonproprietary guardrails and median barriers used in the United States.

Essentially all guardrails and median barriers used in the United States are nonproprietary designs, although there are several proprietary systems that are used in Europe and other parts of the world. Other parts of the roadside safety inventory such as terminals and crash cushions are dominated by proprietary designs, but because guardrail and median barrier designs date back many decades, they have tended to remain in the public domain.

Deciding which guardrail or median barrier system to use in a particular situation can be a difficult task. The engineer must balance the expected performance of the barrier in a collision with the cost of installing and maintaining the barrier and the cost of repairing the barrier after a collision. Crash testing specifications, system selection criteria, and location guidelines have evolved steadily over the past several decades, sometimes leaving a practitioner confused about which systems are appropriate for particular applications. Specifying the "best" guardrail or median barrier requires that an engineer successfully balance all these competing factors when selecting a particular system.

Typical post-and-beam guardrails and median barriers are composed of a rail that is used to redirect a vehicle parallel to the road and posts that hold up the rail and dissipate energy when they are displaced, deformed, or fractured. Post-and-beam guardrails and median barriers fall into two broad categories: weak-post and strong-post systems.

The post in a weak-post guardrail or median barrier is intended primarily to hold the rail at the correct height, ensuring that the rail contacts a vehicle in the most appropriate location. The posts contribute relatively little to dissipating the impact energy of a vehicle; the rail contribution is more significant. The most common weak-post guardrails and median barriers use cables, W-beams, or box beams as rail elements. These systems can be very cost-effective and safe if there is enough area behind the barrier for the vehicle to recover or stop.

In contrast, the post in a strong-post guardrail or median barrier is responsible for a significant amount of energy dissipation. Common strong-post guardrails and median barriers use relatively large steel or wood posts with guardrail blockouts to inhibit wheel snagging. Common strong-post systems use W-beam or thrie-beam rails and sometimes include rubrails. These systems do not deflect laterally as much as weak-post barriers, so they can be used when there is less area for an errant vehicle to recover.

Continuous reinforced concrete barriers are often used as median barriers because they can minimize the chance of a vehicle crossing a median even when there is relatively little space in the median for an errant vehicle to recover. Concrete barriers also rarely need repairs even after a collision, which is an important advantage in reducing freeway congestion and possible injury to maintenance workers. Concrete median barriers have been widely used for more than three decades; the variety of designs includes the popular New Jersey barrier, the F-shape barrier, and, most recently, the constant-slope barrier.

During the past decade aesthetic barriers have become important in scenic areas and historic communities. Although such barriers will never constitute a large proportion of the mileage on roadways in the United States, they are an important facet of the roadside hardware inventory for agencies that maintain roadways in historic communities or aesthetically sensitive areas. Fortunately, recent research has provided a number of new guardrails and median barriers that are both effective and visually attractive.

Much has been learned about guardrail and median barrier crashworthiness during the past 30 years. Researchers once believed that simply keeping a vehicle from penetrating the guardrail or rolling over was sufficient to ensure that vehicle occupants were not seriously injured. Each new crash testing specification has attempted to make the link between performance in crash tests and performance in the field more firm, resulting in increasingly detailed procedures and criteria. Several decades ago, many different types of barriers were used on the nation's roadways. Although many of these barriers still are shown in state standards and specifications, most roadway miles of guardrail and median barrier are represented by a handful of versatile systems. While the barrier population has iterated toward a few robust solutions, the vehicle fleet has changed from a relatively homogeneous fleet dominated by large passenger cars to a diverse population of pickup trucks, minivans, sport-utility vehicles, and compact passenger cars. Despite these changes, guardrails and median barriers are still expected to shield and protect errant motorists from potentially hazardous collisions. The next decade may see the emergence of a new generation of highway barriers that is better suited to the fast-changing vehicle fleet. Designing, selecting, and locating safe and effective guardrails and median barriers is as challenging and important a task as it has ever been. Each chapter in this synthesis brings together detailed information to aid these processes.

CHAPTER ONE

INTRODUCTION

Guardrails are one of the most basic roadside safety features in use today. Guardrails are designed to prevent vehicles from leaving the roadside and becoming involved in more hazardous collisions. Typical post-and-beam guardrails and median barriers are composed of a rail that is used to redirect a vehicle parallel to the road and posts that hold up the rail and dissipate energy when they are displaced, deformed, or fractured. The other major type of guardrails and median barriers are continuous concrete walls. This synthesis includes information about the crashworthiness and applications of the most common nonproprietary guardrails and median barriers used in the United States today.

In 1967, the American Association of State Highway and Transportation Officials (AASHTO) published the report *Highway Design and Operational Practices Related to Highway Safety* (the Yellow Book). The Yellow Book popularized the "forgiving roadside" concept (*1*). A forgiving roadside was one where hazards were (a) eliminated, (b) relocated, (c) made into breakaway devices, or (d) shielded (*1*). The fourth option, shielding a hazard, is often accomplished using longitudinal barriers. Many hazards, such as steep side slopes, are difficult to treat any other way. A variety of devices have been developed over the past 30 years to treat specific hazards along the roadway. This report discusses the use and crashworthiness of these types of barrier systems.

PURPOSE OF GUARDRAILS AND MEDIAN BARRIERS

Figure 1 shows the three parts of a typical guardrail installation: the "standard section" of guardrail, the terminal or end treatment, and the transition. All three parts of a typical installation work together to shield vehicles from roadside hazards. Guardrails, median barriers, and bridge railings are longitudinal barriers that are placed parallel to the roadway "to prevent penetration and to safely redirect an errant vehicle away from a roadside or median hazard" (*2*). When two longitudinal barriers with different deflection characteristics must be connected, a transition should be used to ensure that the change between the more flexible system and the stiffer system is smooth and will minimize the chance of the vehicle snagging on the end of the stiffer system. The guardrail terminal or end treatment is a device that is used to shield the end of the guardrail, which would itself be a serious hazard if it were simply terminated where the guardrail is no longer needed. Transitions and terminals are very important components of a complete guardrail or median barrier system. Designers should use great care to match guardrails, transitions, and terminals correctly and to provide the necessary grading required for proper performance. Only the crashworthiness of guardrails and median barriers is discussed in this document.

A median barrier is another type of longitudinal barrier whose sole function is to prevent vehicles from crossing a median and becoming involved in a potentially serious collision in the opposing lane of traffic. Roadside guardrails are often used in wide medians exactly like they would be used on the roadside. These barriers, though in the median, are not median barriers. In this report a median barrier will always refer to a symmetric traffic barrier (a barrier face on both sides) that is used to prevent median crossover accidents. Guardrails can be used either on the roadside or in the median.

Guardrails and median barriers are used extensively on the highway and roadway network. Two small segments of the

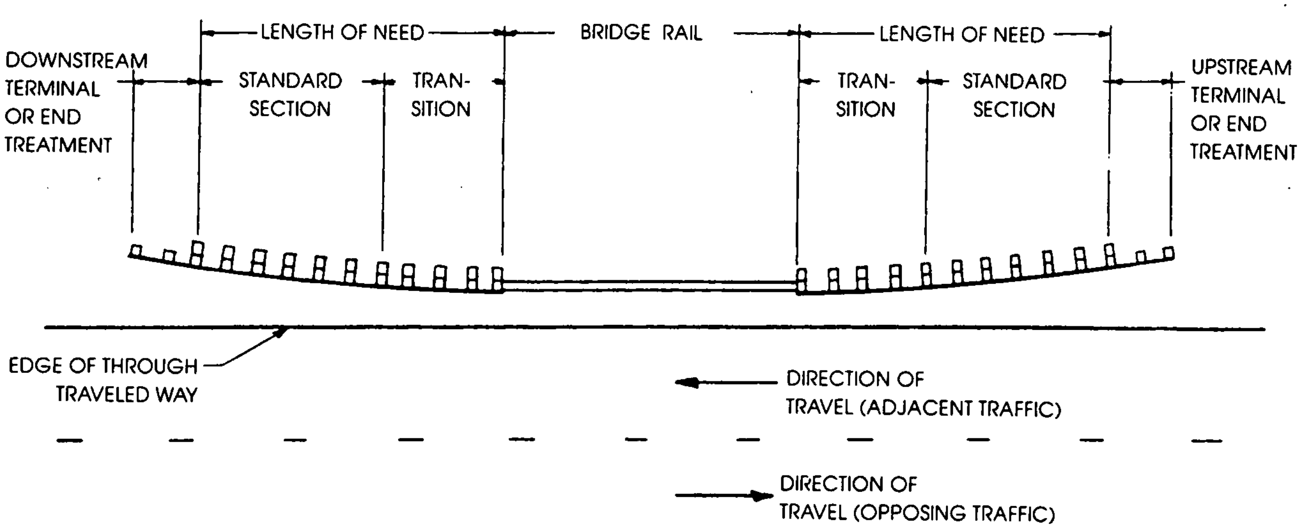


FIGURE 1 Typical components of a guardrail installation (*2*).

Interstate highway system were examined in 1995 to see what percentage of the roadside was shielded by guardrails and median barriers and to find out the typical length of guardrail installations. A 10.6-km section of I-70 in western Maryland had 46 roadside guardrail installations of the G4(1S) (SGR04a) system with an average length (including terminals) of 230 m, and 27 median installations of the G4(1S) (SGR04a) guardrail with an average length (including terminals) of 275 m. Roadside guardrails shielded 28 percent of the roadside and 20 percent of the median. The installation lengths were less than 640 m for 85 percent of the roadside installations and 88 percent of the median installations (Figure 2), suggesting that on this roadway, guardrail lengths were relatively short.

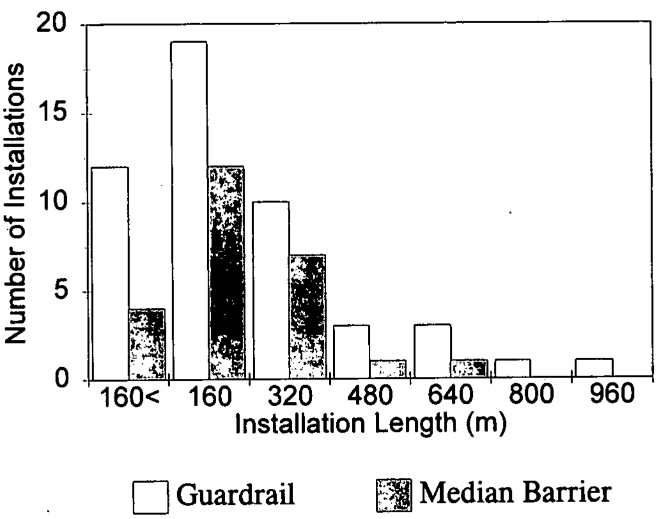


FIGURE 2 Guardrail installation lengths on a 10.6-km segment of I-70 in western Maryland.

A 24.1-km section of the Pennsylvania Turnpike displayed a much greater diversity of barrier types and much longer guardrail and median barrier lengths. The following installations were observed:

- Nine roadside installations of the G4(1S) (SGR04a) guardrail with an average installation length of 230 m (a total of 8.7 percent of the roadside),
- Three installations of roadside New Jersey barriers with an average length of 800 m (a total of 3 percent of the roadside),
- One 9800-m-long section of New Jersey median barrier (a total of 40 percent of the median), and
- Two installations of a strong-post W-beam median barrier with no blockout with an average installation length of 6.4 km (a total of 52 percent of the median length).

These two highways are very different in terms of age, design standards in use during construction, and median width. The percentage of roadside and median length protected by barriers varies widely from highway to highway, state to state, and region to region, but these example inventories demonstrate the large amount of time, effort, and money invested in roadside safety hardware in the United States. There are approximately 6.4 million km of roadways and highways in the United States (*3*). Even if only 10 percent use guardrails or median barriers, this would suggest that there are about 1.25 million km of guardrails and median barriers on U.S. roadways. If this inventory costs on average $50/m, a conservative estimate of the value of the guardrail and median barrier inventory in the United States is approximately $64 billion. Such a large investment in roadside safety infrastructure certainly warrants careful attention from highway engineers.

Developing better guardrails and median barriers as well as guidelines for using them has been an active area of research and policy making for nearly 40 years. Three primary areas have emerged in the past several decades, each with its own lineage of documents and guidelines: first, procedures for performing full-scale crash tests; second, guidelines for locating and selecting guardrails and median barriers; and third, guidelines for assessing the effectiveness of guardrails and median barriers through in-service evaluation. Figure 3 illustrates the progression of important reports, documents, and guidelines in each of these three areas.

Two important points are evident from Figure 3: (a) procedures and evaluation criteria evolve over time and (b) the scope of activities expands. The first recommendations for full-scale crash testing were contained on a single page; 31 years later, the current recommendations require 132 pages. The first recommendations addressed only guardrails, whereas the current recommendations address guardrails, median barriers, guardrail terminals, transitions, crash cushions, truck-mounted attenuators, signs, luminaires, and work-zone barriers. Test and evaluation procedures have been continuously refined as the research community has gained experience in designing and testing guardrails and median barriers.

HISTORY OF CRASH TEST REQUIREMENTS FOR GUARDRAILS AND MEDIAN BARRIERS

The current recommended crash test procedures and evaluation criteria are only the most recent in a succession of documents published first by the Highway Research Board (HRB) and then the National Cooperative Highway Research Program (NCHRP). As summarized in Figure 3, this series of reports includes the following:

- 1960—*Proposed Full-Scale Testing Procedures for Guardrails* (HRB 482) (*4*)
- 1974—*Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances* (Report 153) (*5*)
- 1978—*Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances* (Circular 191) (*6*)
- 1981—*Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances* (Report 230) (*7*)
- 1993—*Recommended Procedures for the Safety Performance Evaluation of Highway Features* (Report 350) (*8*).

Full-scale crash testing as a research methodology was developed by the automobile companies in the 1930s as the

Decade	Test and Evaluation	Selecting and Locating: Warranting	Selecting and Locating: Cost-Effectiveness	In-Service Evaluation
1960	HRB 482 *(2)*	HRB SR 81 *(23)* Report 36 *(24)* Report 54 *(25)*		
1970	Report 153 *(3)* TRC 191 *(4)*	Report 118 *(26)* Barrier Guide *(20)*	Report 148 *(27)* Barrier Guide (Chapter VII) *(20)* Report 197 *(28)*	
1980	Report 230 *(7)*	Roadside Design Guide (2)	Roadside Design Guide *(2)* (Appendix B)	Report 230 *(7)* (Chapter 4, last section)
1990	Report 350 *(6)*			Report 350 *(8)* (Chapter 7)

FIGURE 3 Milestones in testing, evaluating, selecting, locating, and assessing guardrails and median barriers.

automobile first began to be widely accessible to the public (*9*). Crash testing of guardrails began sporadically after the Second World War, when several states performed or sponsored rudimentary crash tests to explore the dynamic performance of guardrails. By the late 1950s, states such as California and New York and automobile manufacturers such as General Motors were performing numerous crash tests and developing new barrier systems. Serious research into the design and testing of guardrails and median barriers began around 1958 when California and General Motors independently performed large crash test evaluation programs aimed at assessing the performance of existing guardrails (*10–12*). These early programs were soon followed by a large evaluation and test project in New York that began in the early 1960s (*13*). These early research projects produced a large number of basic guardrail and median barrier designs, many of which are still in use today.

The 2040-kg large-car test (Test 10) recommended in Report 230 is essentially the same test that was recommended in HRB 482. The emergence of smaller vehicles and the increasing volume of trucks and buses on the roadways prompted the roadside safety research community to begin extending the range of vehicles used in testing. The 1020-kg compact-car test was added to the test matrix in Report 153, and the 820-kg subcompact-car test was added in Report 230. Report 230 specifies an impact angle of 15 degrees for both the "required" 1020-kg compact-car test (Test 11) and the 820-kg subcompact-car test (Test 12). Between 1981, when Report 230 was first published, and 1985 (the midpoint of NCHRP Project 22-4, when many longitudinal barriers were retested in accordance with Report 230), the consensus of researchers began to favor eliminating the 1020-kg car test (Test 11) and changing the 15-degree impact angle in the 820-kg car test (Test 12) to 20 degrees (Test S13). Report 230 also added nine supplemental tests for guardrails and median barriers. These supplemental tests included the 20-degree 820-kg car test (Test S13), which has since become the standard small-car crash test for longitudinal barriers.

Report 230 began to recognize that roadside safety hardware must function for a broader class of vehicles than just passenger sedans. Other supplemental tests were added in Report 230 for impact tests with school buses (Tests S16, S17, and S18), intercity buses (Tests S15 and S19), tractor-trailer trucks (Test S20), and tanker trucks (Test S21). The test vehicles recommended for crash test evaluations of guardrails and median barriers in Report 230 are given in Table 1, and the complete Report 230 crash test matrix is included in Appendix A.

TABLE 1

VEHICLES RECOMMENDED FOR CRASH TESTING IN REPORT 230 AND REPORT 350

Type	Mass (kg)	Wheelbase (mm)	Report 230 Designation	Report 350 Designation
Mini passenger car	700	2300	-	700C
Small passenger car	820	2300	1800S	820C
Compact passenger car	1020	2465	2250S	-
Large passenger car	2040	3075	4500S	-
Large pickup truck	2000	3350	-	2000P
Single-unit truck	8000	5350	-	8000S
School bus	6260	6450	20000P	-
Small intercity bus	9070	-	32000P	-
Large intercity bus	13 335	6,600	40000P	
Tractor van-trailer truck	36 000	4800[a]	80000A	36000V
Tractor tanker-trailer truck	36 000	4800[a]	80000F	36000T

[a]This value is the wheelbase of the tractor unit only.

Report 350, the current recommendations for performing crash tests, was published in 1993. One of the most important changes in Report 350 was the recognition that the large passenger sedan (e.g., the 2040-kg passenger car used in Report 230) had virtually disappeared from the vehicle population. New vehicle types such as minivans, full-size vans, sport-utility vehicles, and pickup trucks emerged in place of the large passenger car. By the mid 1990s, these types of vehicles accounted for about 40 percent of new vehicle sales (*14*).

To account for this shift in the vehicle population, a 2000-kg pickup truck was used to replace the Report 230 2040-kg large car (Test 11) (*15*). The 820-kg car test (Test S13) was retained, and the 1020-kg passenger car was eliminated from further consideration. Report 350 added a supplemental test that uses a 700-kg minicar in recognition of the increasing numbers of very small cars on the nation's roadways. Report 350 also introduced the concept of test levels for guardrails and median barriers. Each test level subjects the barrier to increasingly demanding tests. Larger vehicles such as the 8000-kg single-unit truck (Test 4-12), the 36 000-kg tractor-trailer truck (Test 5-12), and the 36 000-kg tanker truck were incorporated into the test level matrix.

The test vehicles recommended for crash test evaluations of guardrails and median barriers in Report 350 are given in Table 1, and the complete Report 350 crash test matrix for guardrails and median barriers is included in Appendix A. Just as changes were made to Report 230 in the years after its publication, similar changes in applying Report 350 to research and policy issues will surely take place within the next several years. As shown in Figure 3, full-scale crash testing procedures are always evolving in response to changes in the vehicle fleet and operating conditions on the nation's highways.

Before 1993, the Federal Highway Administration (FHWA) informally used recommended crash test and evaluation procedures such as Report 230 and its antecedents as criteria for determining the acceptability of roadside hardware, including guardrails and median barriers, for use on Federal-aid projects. When Report 350 was published, FHWA decided to formally adopt Report 350 as one of its "guides and references" when judging the acceptability of roadside hardware (*16,17*). These recommendations were adopted into the *U.S. Code of Federal Regulations* (23 CFR Part 625). In addition to reviewing the recommendations of Report 350, the regulation explains the detailed procedure for submitting crash test results and supporting research to FHWA for review in making a decision on the acceptability of any particular roadside safety feature.

The crash test information was derived from an extensive literature review of FHWA reports, NCHRP reports, and papers that appeared in the annual Transportation Research Records and earlier Highway Research Records as well as a variety of reports and papers, both published and unpublished, from state departments of transportation (DOTs), testing organizations, and individual researchers. This report is not an exhaustive compilation of all the tests that have ever been performed on guardrails and median barriers, but rather a summary of the most recent and relevant tests available on common guardrails and median barriers. Guardrails were the first roadside safety devices subjected to full-scale crash testing, and as such the history of guardrail testing goes back 40 years. The most recent testing on each guardrail and median barrier system, with particular emphasis on Report 230 and Report 350 requirements, is summarized.

Although much of the crash testing information is distributed in a host of reports, several reports deserve special mention because of the large quantity of testing that is documented in them. When Report 230 was published in 1981, there was a need to retest a large number of common guardrails and median barriers to determine if they met the then-new guidelines. These tests are documented in the report *Performance of Longitudinal Traffic Barriers* (Report 289) (*18*). Many of these tests are still the most definitive small-car tests available. An extensive number of tests were performed in the 1960s and 1970s. There are several good compilations of this early testing, most notably, the following:

- *Guardrail Performance and Design* (Report 115) (*19*), and
- *Guide for Selecting, Locating, and Designing Traffic Barriers* (1977 Barrier Guide) (*20*).

Recently, FHWA sponsored numerous tests using the 2000-kg pickup truck recommended in Report 350. Most of these tests were performed at the Texas Transportation Institute between 1994 and 1996, and at this time only the preliminary reports are available (*21*).

Each section in this synthesis includes the following basic information about each guardrail and median barrier system:

- A description of the longitudinal barrier, including drawings from *A Guide to Standardized Highway Barrier Hardware* (the Hardware Guide) (*22*);
- A description of the states that use each system, including a map with an estimate of the amount of usage of each barrier;
- A discussion of the crashworthiness of each barrier in terms of the Report 230 and Report 350 crash tests and tables summarizing the results; and
- A discussion of the typical applications, maintenance issues, cost constraints, and common problems with each type of barrier.

The drawings included in this report from the Hardware Guide represent the most common versions of each guardrail and median barrier, but they are not the only versions (*22*). Many states use slightly different details; however, the details shown in this report and in the Hardware Guide are believed to be the best versions because they generally conform to the way the guardrail or median barrier was crash tested.

Information on the geographical distribution of barrier designs was obtained in a survey. The survey asked respondents what barriers were currently being installed; therefore, in some cases a particular barrier is not shown on the distribution maps although there are such barriers in the state.

The purpose of the crash test data tables in this report are to identify the best available baseline tests rather than to catalog all the tests ever performed on a particular device. For example, there are many 4500-lb car tests on strong-post W-beam barriers (G4 systems). Many of them, however, were performed before not only Report 350 and Report 230 but also Report 153. Therefore, the types of vehicles, variability of test conditions, evaluation criteria, and knowledge about exactly what was tested is often not well documented. The 4500-lb car test was rerun on the G4(1S) guardrail in 1987 and is documented in an FHWA research report (*15*). The test in the FHWA project was used because it was performed under Report 230 conditions and is more recent. More recent tests are better baseline tests because (a) they correspond more closely to the current criteria, (b) experimental procedures have improved greatly over the past 30 years, and (c) the newer test vehicles correspond more closely to the current vehicle population. These newer tests better illustrate the performance of these systems than tests performed 20 or 30 years ago, because test and evaluation criteria are more uniformly applied and newer vehicles are used. Tests are considered "passing" in this report on the basis of evaluations of the original researchers. There was no attempt to reexamine each test and determine anew if the hardware did or did not pass. The researchers who actually performed the original tests were in the best position to evaluate each test; therefore, their conclusions are retained. In some cases neither Report 350 nor Report 230 tests were available in the literature. Consequently, the most recent test that could be found was used. In such cases, of course, all the Report 230 evaluation criteria were not available because the test reports would have been published prior to the publication of Report 230.

Although all of these systems were originally developed, tested, and documented in the literature in the U.S. customary system of units, all the information in this report is given in SI units. All the drawings, crash test results, and system descriptions use SI units so that engineers, policy makers, and designers will have the information in a form that will be more useful in the future as the highway industry adopts the SI system.

SELECTING AND LOCATING GUARDRAILS AND MEDIAN BARRIERS

Soon after the first crash test guidelines were published in 1962, the first guidelines for using and installing guardrails were published by HRB in 1964 in *Special Report 81: Highway Guardrails: Determination of Need and Geometric Requirements with Particular Reference to Beam-Type Guardrail* (HRB SR 81), as shown in Figure 3 (*23*). This report provided guidance on where guardrails should be used and summarized an investigation into the policies being used by the states during the late 1950s and early 1960s.

Two principal approaches to deciding where to place guardrails and median barriers and how to select the particular devices have evolved. The first approach from a historical perspective is the "warranting" approach. Certain geometric and operational characteristics of a site are examined to determine if it is appropriate to place a guardrail in a particular location. For example, the 1977 AASHTO Barrier Guide contains a chart the engineer can use to determine if a guardrail is appropriate for shielding roadside slopes. If the roadside slope in a fill section is more than one vertical to three horizontal and the roadway embankment is greater than 4.5 m high, a guardrail is generally warranted.

The guidelines in HRB SR 81 were updated and extended in a series of NCHRP projects that resulted in several subsequent reports:

- 1967—*Highway Guardrails—A Review of Current Practice* (Report 36) (*24*)
- 1968—*Location, Selection, and Maintenance of Highway Guardrails and Median Barriers* (Report 54) (*25*)
- 1971—*Location, Selection, and Maintenance of Highway Traffic Barriers* (Report 118) (*26*).

FHWA asked each of its division offices to examine the policies and standards in each state to determine if they at least met these standards. Report 118 was greatly revised and expanded later in the decade and published as the 1977 AASHTO Barrier Guide, a document that was superseded by the 1989 and the 1996 AASHTO *Roadside Design Guide* (*2*).

The other major approach to designing the roadside is the cost-effectiveness, or benefit-cost, method. This method was first applied to roadside safety hardware problems in response to a need for prioritizing highway improvement projects described in the report *Roadside Safety Improvement Programs on Freeways: A Cost-Effectiveness Priority Approach* (Report 148) (*7*). Because there is never enough funding to address all the roadside safety needs of a particular highway agency, a method for allocating funding on the basis of the benefit and effectiveness of the project was required. The first widely disseminated version of cost-effectiveness procedures is Chapter 7 of the 1977 Barrier Guide (*10*).

One advantage of a cost-effectiveness method is that it is based on probabilistic techniques that provide a uniform, consistent, and quantifiable method for making decisions. Unfortunately, this strength also is a weakness of sorts because the method requires a great deal of data and computation. The first problem, the lack of data, is being addressed in several NCHRP projects (*28*). Development of better mathematical models of encroachment, collision, and severity probabilities is continuing in an attempt to improve the cost-effectiveness method (*29*).

The second problem was addressed by placing the procedures in a computer program. The 1977 Barrier Guide method was available as a computer program as early as 1975 (*30*). The basic method used in the 1977 Barrier Guide was updated in the next decade and can be found in Appendix A of the *Roadside Design Guide* (*2*). This method also was implemented as a computer program called Roadside, the first widely used cost-effectiveness program for making roadside safety hardware decisions. Unfortunately, the cost-effectiveness method has not fully reached its potential, and there has been continuing research on refining the method as well as developing better computer software tools (*31,32*).

Despite the lack of adequate tools, cost-effectiveness is already playing an important role in managing the roadside and developing policies on selecting, locating, and maintaining guardrails and median barriers. For example, the Pennsylvania DOT examined accident data, roadside hardware inventories, and contract costs to assess the overall cost-effectiveness of its roadside safety barrier location and selection policies (*33*). This examination allowed the agency to justify, for example, *not* placing guardrails to protect some side slopes when the traffic volume and speed are low, because the probability of an accident occurring at a low-volume, low-speed site is low. Such policies allow the agency to focus scarce resources on the locations with the highest probability of an accident occurring. Although cost-effectiveness procedures are still not mature, these techniques may become increasingly important to practitioners as more emphasis is placed on value engineering highway projects and managing roadside safety resources.

IN-SERVICE EVALUATION OF GUARDRAILS AND MEDIAN BARRIERS

While guardrails and median barriers have been a common feature of the roadside for nearly five decades, information about how they actually perform under field conditions is very difficult to obtain. The importance of in-service evaluations has been widely recognized by the roadside safety community for more than a decade, although in-service evaluations are still uncommon. Report 230 was the first evaluation procedure to recommend that formal in-service evaluations be performed routinely (*7*). More than a decade later, Report 350 reemphasized the importance of in-service evaluation (*7,8*). Report 230 and Report 350 recognized that without effective in-service evaluations, it is impossible to determine if barriers developed and tested under laboratory conditions perform as expected in the field. Performing research, developing more effective roadside hardware, and devising public policy without in-service evaluations has been very difficult.

Through most of the 1980s, FHWA tried to encourage states to perform in-service evaluations by using the "experimental" and "operational" classifications of roadside hardware. When a device passed all the recommended full-scale crash tests, FHWA typically was asked to approve the device for use on Federal-aid projects. Normally, FHWA granted experimental status to a device with the recommendation that an in-service evaluation be performed and submitted to FHWA to document the user's experience with the system. In principle, FHWA could then examine the in-service performance of the device to determine if it was performing as intended and to ensure that no unexpected problems were occurring in the field. If the hardware was performing satisfactorily, FHWA would upgrade the hardware to operational status. For a variety of reasons, few states responded to this request for in-service evaluations, and by November 12, 1993, FHWA dropped the experimental status altogether (*17*). Today, hundreds of thousands of miles of roadside hardware are installed on the nation's highways and there is only a very limited appreciation for the performance of these devices under real-world conditions. The need to better manage roadside safety hardware inventories and the recommendation of FHWA that states implement highway safety management systems may make in-service evaluation a more important part of the roadside safety effort (*34*).

CHAPTER TWO

COMPARISON OF GUARDRAIL AND MEDIAN BARRIER SYSTEMS

This chapter compares guardrail and median barrier systems based on their cost, performance, and usage. The data for these comparisons came from a survey that was sent to all 50 states and a review of the roadside safety literature. The 39 survey respondents provided information about installation costs, repair costs, designs, and applications for most common guardrails and median barriers. The survey respondents included roadway design engineers (67 percent), traffic engineers (10 percent), standards engineers (10 percent), and a variety of other types of engineers with, on average, 20 years of experience working on roadway design problems (see Appendix C, Question 36). In addition to information about barrier usage and costs, the recipients were asked 36 questions about barrier design details, applications, and maintenance concerns. The survey form is reproduced in Appendix B, and a summary of the responses is provided in Appendix C.

DESIGNS

A wide variety of guardrail and median barrier designs are in use throughout the United States. Some of the most common guardrail designs are shown in Figure 4 *(35)*. Guardrails and median barriers can be categorized into three basic groups: weak-post-and-beam systems, strong-post-and-beam systems, and continuous concrete barriers. In general, weak-post systems result in the largest lateral barrier deflections and the smallest vehicle deceleration rates, whereas continuous concrete barriers result in essentially no barrier deflection and larger vehicle deceleration rates. Guardrails and median barriers must balance the need to prevent penetration of the barrier with the need to minimize the forces experienced by vehicle occupants. Where there is adequate room for deflection to be accomplished by allowing the vehicle to intrude onto the roadside, weak-post guardrails are often used. When there is some limited room for lateral deflections, strong-post guardrails are used. Where there is very little room for barrier deflection or where the penalty for penetrating the barrier is very high, concrete barriers have generally been used. The guardrails and median barriers described in this chapter are generalizations of widely used systems, the actual details used in a particular state may be somewhat different.

Post-and-beam barriers have long been categorized by their design lateral deflection.Weak-post guardrails and median barriers generally have larger dynamic lateral deflections and the posts absorb relatively little energy. In contrast, strong-post guardrails and median barriers feature larger posts that absorb more energy resulting in smaller lateral dynamic deflections. The area immediately behind a barrier should be free of hazardous objects since an impacting vehicle may deform the barrier enough to allow contact with the object behind the barrier. A tree located 500 mm behind a three-cable guardrail, for example, might be struck since the guardrail may deflect as much as 3350 mm in an impact with a large passenger sedan. Table 2 shows the design deflections used by states responding to the survey. Report 118 and the 1977 Barrier Guide both provided charts arranging the common guardrails and median barriers by their maximum dynamic deflection in the Report 230 large-car crash test (Test 10) *(20,26)*. As shown in Table 2, most states use design deflections that are similar to the maximum dynamic deflection reported in the 1977 Barrier Guide (the column under "Barrier Guide" in Table 2) or the more recent *Roadside Design Guide*. In Tables 2 through 4, the minimum and maximum values reported by the survey respondents are given along with the mode (i.e., the most frequently observed value). When three or fewer states responded, no mode value is given unless two states reported the same value. Thus, of the 29 states that provided design deflections for the strong wood-post W-beam guardrail (SGR04b), the smallest design deflection was 610 mm, the largest was 1675 mm, and the most common was 915 mm.

Establishing and maintaining the optimal guardrail and median barrier height has also been a recurring research issue for many systems. In the late 1970s the state of New York found that weak-post guardrails with top-of-rail heights of 760 mm were not performing as well as rails with a top height of 685 mm *(36)*. The importance of establishing correct guardrail and median barrier heights was also demonstrated in a crash test program performed at Southwest Research Institute in the mid 1980s (37). This study found that barrier heights, the bumper heights of impacting vehicles, and the terrain geometry in front of the barrier all affected the barrier performance. Perhaps because of this research, no respondent to the state survey indicated that guardrail and median barrier heights were adjusted downward if the barrier contributed to a sight distance problem (Appendix C Question 11). Reducing the rail height may improve a sight distance problem while creating a guardrail performance problem. Table 5 shows middle-rail heights used in the states responding to the survey. As shown in Table 5, weak-post barrier heights still vary between 609 and 684 mm, although most research and the *Roadside Design Guide* clearly favor a value of 610 mm. Strong-post W-beam guardrails are most commonly built with a barrier middle-rail height of 529 mm; strong-post thrie-beam barriers generally have rail heights of 562 mm, except for the modified thrie-beam guardrail, which generally uses a height of 610 mm.

Post embedment is closely related to barrier height since guardrail posts generally are manufactured in lengths of 1600 mm for weak-post barriers and 1830, 1980, and 2060 mm for strong-post barriers. Greater embedment depth usually results in a stronger but more costly post. Table 6 shows the embedment depths used for a variety of post-and-beam guardrails in

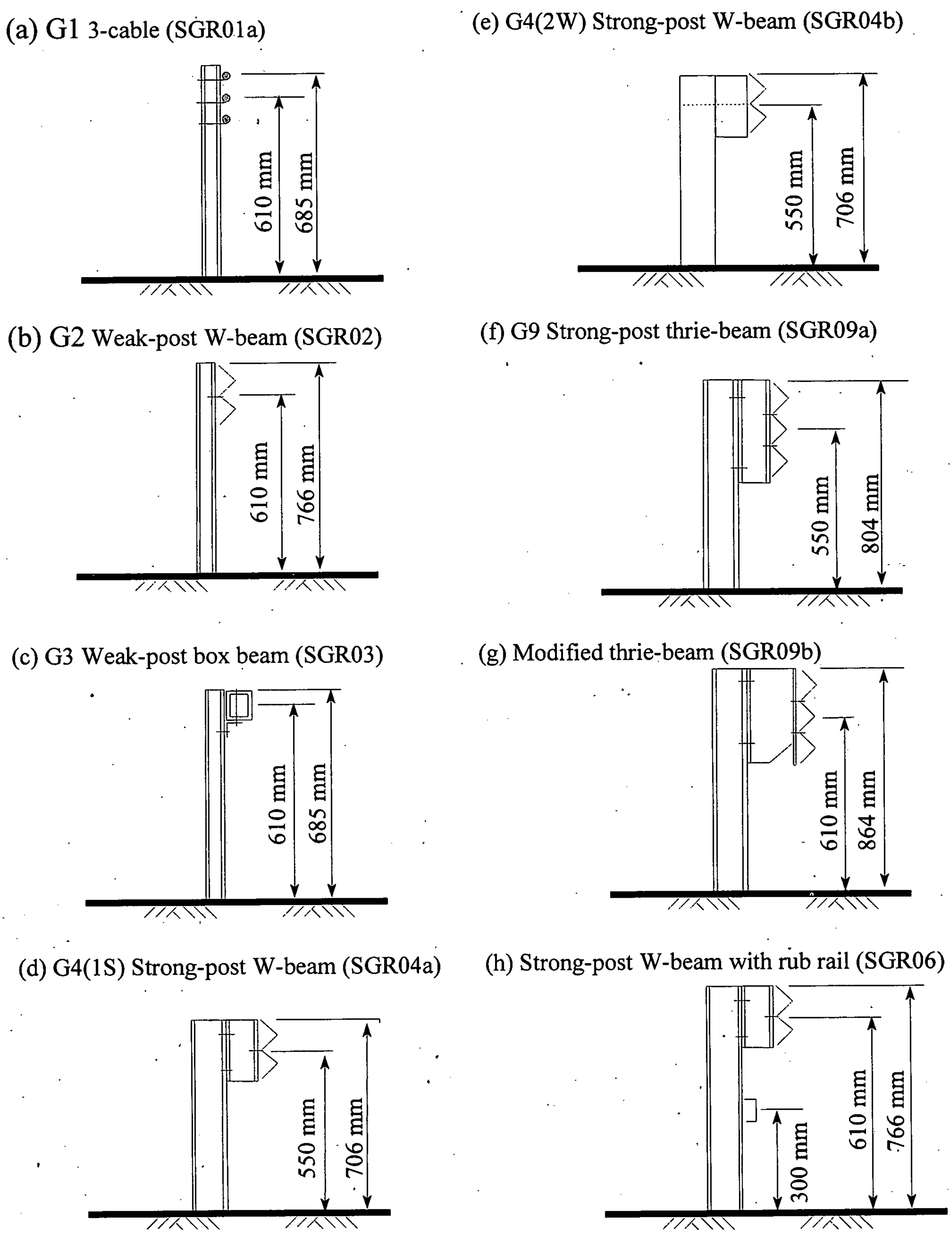


FIGURE 4 Common guardrail designs (after *(35)*).

TABLE 2

DESIGN DEFLECTIONS OF POST-AND-BEAM GUARDRAILS

Barrier Type	Hardware Guide Designator	Barrier Guide Designator	Barrier Guide	Design Deflection (mm)			Number of States
				Min.	Mode	Max.	
Weak-post guardrail							
Steel-post cable	SGR01a	G1	3350	3350	3350	3660	8
Wood-post cable	SGR01b	GR1	1830	3350	3350	3350	3
Steel-post W-beam	SGR02	G2	2225	2440	2440	2440	3
Steel-post box beam	SGR03	G3	1460	1525	1525	1525	3
Strong-post guardrail							
Steel-post W-beam	SGR04a	G4(1S)	800	610	915	1675	27
Wood-post W-beam	SGR04b	G4(2W)	700	610	915	1675	29
Steel-post W-beam w/rubrail	SGR06a	–	–	–	–	–	0
Wood-post W-beam w/rubrail	SGR06b	–	–	–	–	–	0
Steel-post thrie beam	SGR09a	G9	460	610	610	1675	12
Wood-post thrie beam	SGR09c	G9	–	460	460	1675	17
Modified thrie beam	SGR09b	–	–	915	915	915	5

TABLE 3

POST SPACING FOR POST-AND-BEAM GUARDRAILS AND MEDIAN BARRIERS

Barrier Type	Hardware Guide Designator	Barrier Guide Designator	Barrier Guide	Post Spacing (mm)			Number of States
				Min.	Mode	Max.	
Weak-post guardrail							
Steel-post cable	SGR01a	G1	5000	4880	4880	4880	8
Wood-post cable	SGR01b	G1	3800	3810	3810	3810	3
Steel-post W-beam	SGR02	G2	3810	3810	3810	3810	3
Steel-post box beam	SGR03	G3	1830	1830	1830	1830	3
Strong-post guardrail							
Steel-post W-beam	SGR04a	G4(1S)	1905	1905	1905	2030	27
Wood-post W-beam	SGR04b	G4(2W)	1905	1905	1905	2030	29
Steel-post W-beam w/rubrail	SGR06a	–	1905	1905	1905	1905	6
Wood-post W-beam w/rubrail	SGR06b	–					
Steel-post thrie beam	SGR09a	G9	1905	930	1905	2030	12
Wood-post thrie beam	SGR09c	G9	1905	930	1905	2030	17
Modified thrie beam	SGR09b	–	1905	1905	1905	1905	5

the states that responded to the survey. It is important to note that other factors such as the soil characteristics (soil type, compaction, moisture content, etc.), whether the soil is frozen, and the geometry of the slope can also have a major effect on the strength of a post and hence the guardrail system. In northern states where soil is frozen during the winter, frost action can heave posts upward. Longer posts can help to alleviate some of these serviceability problems.

Post lengths were increased when the guardrail was close to a slope breakpoint according to 65 percent of the survey respondents (Appendix C Question 2). Nine of the 30 responses to Appendix C Question 2 indicated that posts could be located as close as 305 mm from the slope breakpoint, and only five states indicated distances greater than 610 mm. When soil conditions were poor, 15 percent of the survey respondents indicated that either longer posts or posts with soil plates were used (Appendix C Question 14). Sometimes bedrock or very stiff soils can make embedding the posts difficult. Most of the respondents (68 percent) did not have alternatives to treat this situation (Appendix C Question 15). Of the states that did address the problem of too little soil cover, most indicated that the holes were drilled to the standard embedment and the hole was back-filled with either grout or concrete. Crossing a box culvert can also cause post depth restrictions. Half the states responding to the survey allow at least one post to be omitted in order to span a drainage feature such as a culvert (Appendix B Question 21). Many states also mount the shortened post to the top of the culvert structure (73 percent), although care must be taken to ensure that the connection is crashworthy (Appendix C Question 22).

Post spacing is another fundamental design variable for post-and-beam guardrail and median barrier systems. In general, most states use the post spacings recommended in the research (Table 3), although most of the components are manufactured such that there are only limited choices that can be implemented for post spacings. Most states decrease post spacing locally if an isolated object such as a tree, boulder, or utility pole is located too close behind the barrier. The majority

TABLE 4

MINIMUM MEDIAN WIDTHS BY MEDIAN BARRIER TYPE

Barrier Type	Hardware Guide Designator	Barrier Guide Designator	Reported Minimum Median Widths (mm) Min.	Mode	Max.	Number of States
Weak-post guardrail						
Steel-post cable	SGM01a	MB1	7500	7500	7500	1
Wood-post cable	SGM01b	–	–	–	–	0
Steel-post W-beam	SGM02	MB2	3000	3000	6000	3
Steel-post box beam	SGM03	MB3	3750	–	9000	2
Strong-post guardrail						
Steel-post W-beam	SGM04a	MB4S	1250	3000	12250	11
Wood-post W-beam	SGM04b	–	1250	1750	8000	7
Steel-post W-beam with rubrail	SGM06a	–	2500	–	8000	2
Wood-post W-beam with rubrail	SGM06b	MB4W	6000	–	8000	2
Steel-post thrie beam	SGM09a	MB9	1750	–	6000	3
Wood-post thrie beam	SGM09c	–	1750	–	7250	3
Modified thrie beam	SGM09b	–	8000	8000	8000	1
Concrete median barrier						
New Jersey	SGM11	MB5	600	1750	8000	3
F shape	SGM10	–	1750	1750	8000	4
Constant slope	SGM14	–	1250	2500	4250	8

TABLE 5

BARRIER MIDDLE-RAIL HEIGHTS OF GUARDRAILS AND MEDIAN BARRIERS

Barrier Type	Hardware Guide Designator	Barrier Guide Designator	Barrier Guide	Barrier Middle-Rail Height (mm) Min.	Mode	Max.	Number of States
Weak-post guardrail							
Steel-post cable	SGR01a	G1	610	610	–	685	8
Wood-post cable	SGR01b	G1	610	635	635	635	3
Steel-post W-beam	SGR02	G2	610	604	–	684	3
Steel-post box beam	SGR03	G3	610	609	–	684	3
Strong-post guardrail							
Steel-post W-beam	SGR04a	G4(1S)	550	529	529	554	27
Wood-post W-beam	SGR04b	G4(2W)	550	529	529	554	29
Steel-post W-beam w/ rubrail	SGR06a	–	610	404	529	634	6
Wood-post W-beam w/ rubrail	SGR06b	–	610	529	529	529	4
Steel-post thrie beam	SGR09a	G9	550	457	562	612	12
Wood-post thrie beam	SGR09c	G9	550	507	562	562	17
Modified thrie beam	SGR09b	–	610	562	612	612	5

of survey respondents (83 percent) indicated that post spacing is not decreased when breakaway objects such as small signs and breakaway luminaire supports are located behind guardrails (Appendix C Question 4). With the exception of three-cable guardrails, post spacings were not usually decreased for horizontal curves or steep side slopes (Appendix C Question 3). There are limits to how much reduction in dynamic deflection can be achieved by reducing post spacing, so if a hazardous object is too close to the back of a guardrail it may be necessary to either remove the hazard or switch to another type of guardrail with less dynamic deflection.

Rigid concrete barriers are the third basic type of guardrail and median barrier system. These barriers are generally used either when there is no room to allow lateral deflection or where the consequences of penetrating the barrier would be very severe. Every respondent to the survey indicated that some type of rigid concrete guardrail or median barrier is used in his or her state (Appendix C Question 24). Perhaps the most typical application of concrete barriers is to prevent cross-over accidents on narrow medians. Without a reliable barrier in the median, vehicles could cross over the median and become involved in potentially severe or fatal head-on collisions. Rigid concrete barriers are highly effective in minimizing this type of accident since they are very strong and have essentially no lateral deflection. The trade-off for this reduced risk of penetration is a higher risk of being redirected at

TABLE 6

POST EMBEDMENT DEPTH FOR POST-AND-BEAM GUARDRAILS AND MEDIAN BARRIERS

Barrier Type	Hardware Guide Designator	Barrier Guide Designator	Barrier Guide	Post Embedment Depth (mm) Min.	Mode	Max.	Number of States
Weak-post guardrail							
Steel-post cable	SGR01a	G1	825	760	840	840	8
Wood-post cable	SGR01b	G1	980	760	915	915	3
Steel-post W-beam	SGR02	G2	825	760	–	1070	3
Steel-post box beam	SGR03	G3	914	760	915	915	3
Strong-post guardrail							
Steel-post W-beam	SGR04a	G4(1S)	1100	810	1120	1320	27
Wood-post W-beam	SGR04b	G4(2W)	1100	760	1120	1320	29
Steel-post W-beam w/ rubrail	SGR06a	–	1100	1090	1270	1525	6
Wood-post W-beam w/ rubrail	SGR06b	–	1100	1220	–	1270	4
Steel-post thrie beam	SGR09a	G9	1153	940	940/1220	1220	12
Wood-post thrie beam	SGR09c	G9	1153	915	1140	1295	17
Modified thrie beam	SGR09b	–	1173	1170	–	1220	5

high speed into the traveled way. The challenge for the roadside designer is to balance these risks and obtain the solution that causes the least overall harm to the driving public.

Concrete barriers with a three-surface profile have long been popular both as concrete median barriers, roadside barriers, and bridge rails. In the early 1970s, 19 state departments of transportation (DOTs) used the New Jersey median barrier (Figure 5, left) 8 used a shape developed at the General Motors (GM) Proving Grounds and typically known as the GM barrier, and the remaining states used some variation of one or the other *(38)*. In the mid 1970s the Federal Highway Administration (FHWA) sponsored a project to, among other things, identify the "best" profile for such three-faced barriers. The result was the F-shape barrier (Figure 5, middle). More recently, the constant-slope barrier (Figure 5, right) has become a popular experimental median barrier. Generally, concrete barriers with a higher "breakpoint" (the intersection of the two nonvertical planes) have resulted in less vehicle damage and lower occupant risk values. Unfortunately, higher susceptibility to rollover is the price associated with lower vehicle damage and occupant risk. Barriers with a more vertical face generally cause fewer stability and rollover problems but are associated with higher occupant risk values and vehicle damage. As is often the case, roadside designers must balance competing design objectives: reducing occupant risk while stopping a vehicle safely. The increase in the proportion of smaller, less stable cars may make higher breakpoint barriers a little less attractive than they were in years past.

In recent years the maintenance aspects of barrier deflection have become more important to highway agencies, especially those that maintain congested urban roadways. Barriers that allow larger deflections generally result in more damage that must be repaired after an accident. This damage is a hazard to traffic until it is repaired, and adjacent lanes may have to be closed. Maintenance workers are also exposed to hazardous working conditions when they must make extensive

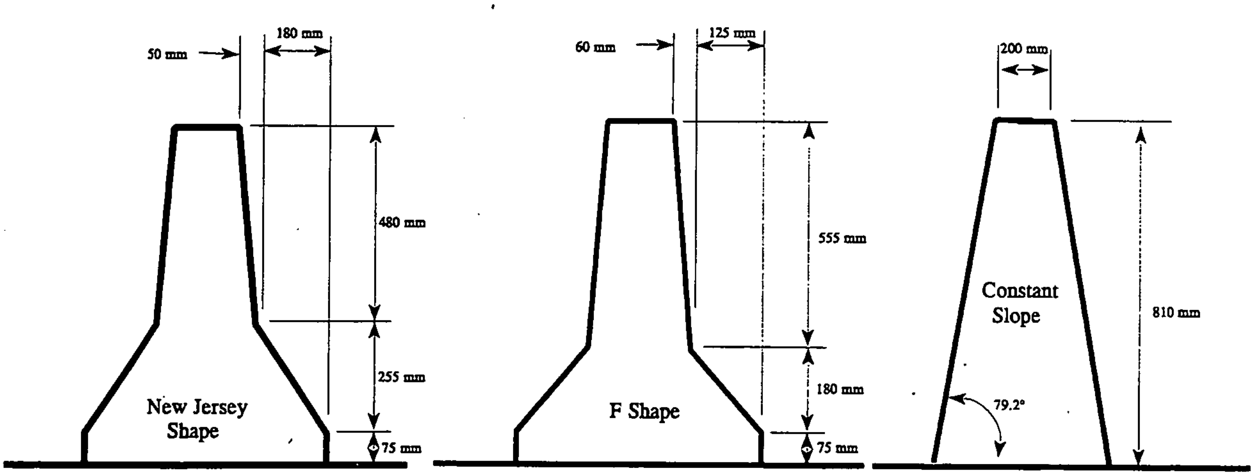


FIGURE 5 Concrete median barriers (after *(35)*).

repairs to barriers on high-volume, high-speed roadways. Such considerations have caused some agencies to place a high priority on more rigid barriers that require less maintenance after a collision.

APPLICATIONS

Guardrails and median barriers should always be selected and located so that the entire site works together to provide a safe driving environment. Guardrails and median barriers must always be matched with appropriate terminals to reduce the severity of end-on impacts, and smooth crashworthy transitions should always be provided between longitudinal barriers of differing stiffness. Sometimes balancing all the safety considerations can be a challenge. Providing access to driveways, fields, and businesses, for example, necessitates leaving openings in the guardrails that are then a potential hazard for end-on impacts. Crashworthy guardrail terminals were used at driveways and other similar openings in 73 percent of the states that responded to the survey (Appendix C Question 1). Usually, the same types of terminals were used in these restricted situations as were used in unrestricted applications. Since most W-beam guardrail terminals are about 11m long and involve a flare, this limits the spacing of openings that can safely be added on a guardrail-lined roadway. Intersecting streets also can impose restrictions on the use of guardrails. Ninety percent of the survey respondents indicated that curved guardrails were used at intersecting streets, but in such cases the radius was most often limited to no less than 2.5 m (Appendix C Question 17). Some guardrail designs for these situations have been developed and will be discussed in Chapter 4. Providing emergency access in narrow medians also requires the engineer to ensure that police and medical service personnel can cross quickly to the opposing lane of traffic and that a crashworthy continuous median barrier is provided. There are a few design alternatives for providing median gaps, but 83 percent of the respondents indicated that removable sections were not used (Appendix C Question 19). Roadway designers must carefully balance all aspects of the roadway to provide the greatest overall level of safety.

Figures 6 through 16 show the number of states that commonly, rarely, or never use specific barriers for specific applications. Guardrails are intended primarily to prevent an errant vehicle from striking a hazardous object by redirecting the vehicle away from the hazard. This redirecting action is used to shield the vehicle and its occupants from numerous hazards including untraversable embankments and steep side slopes (Figure 6), signs and luminaire supports (Figure 7), utility poles and trees (Figure 8), rocks and boulders (Figure 9), culvert headwalls (Figure 10), bridge piers (Figure 11), bridge ends and approaches (Figure 12), and bodies of water (Figure 13). In addition to these shielding functions, guardrails are also sometimes used to separate pedestrian and bike traffic from vehicle traffic (Figure 14) and to contain heavy vehicles (Figure 15). Some guardrails provide shielding functions for particular classes of roads such as low-speed low-volume roadways (Figure 16).

Figures 6 through 16 show which barriers are typically used in these applications as reported by the survey respondents. For example, the wood and steel strong-post W-beam guardrails are

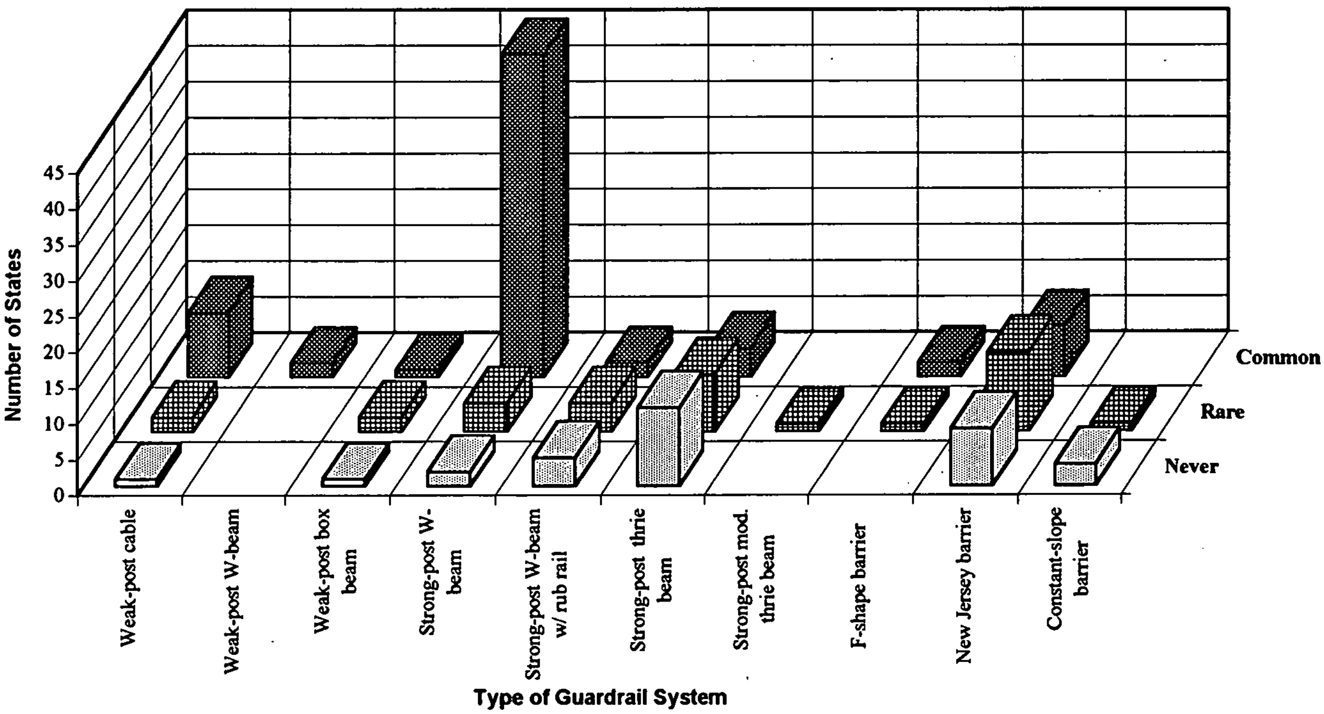


FIGURE 6 Typical guardrail usage—embankments.

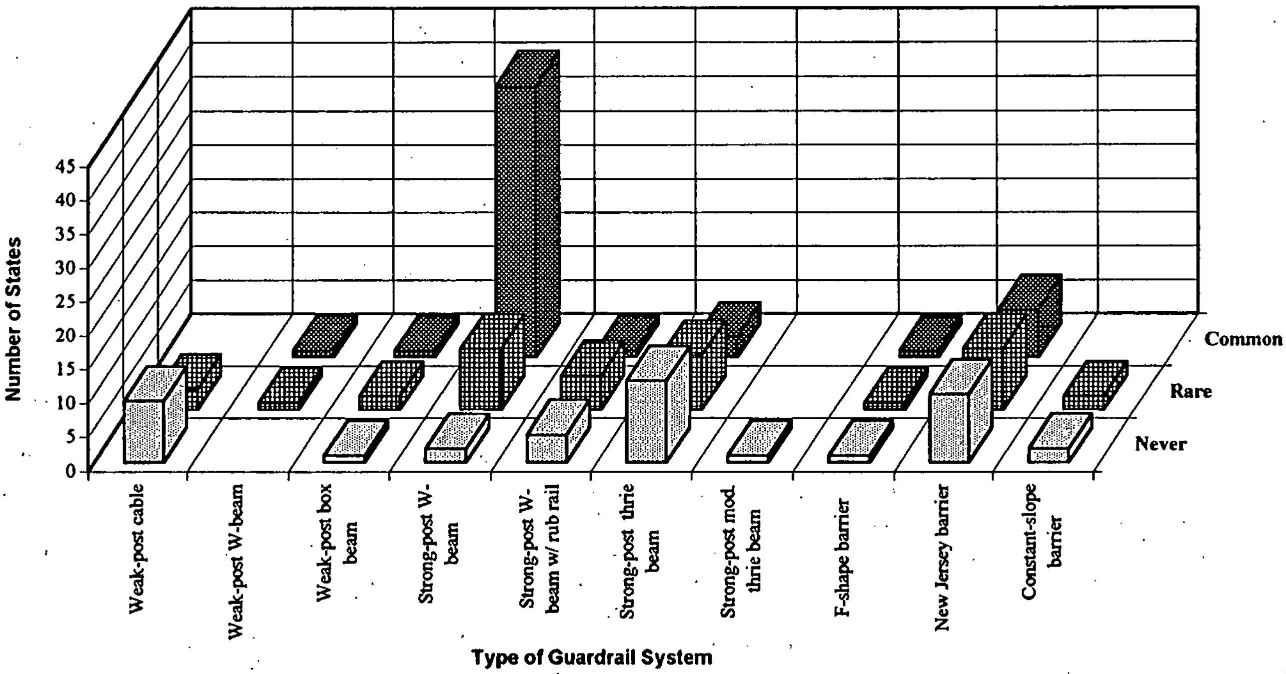


FIGURE 7 Typical guardrail usage—signs and luminaries.

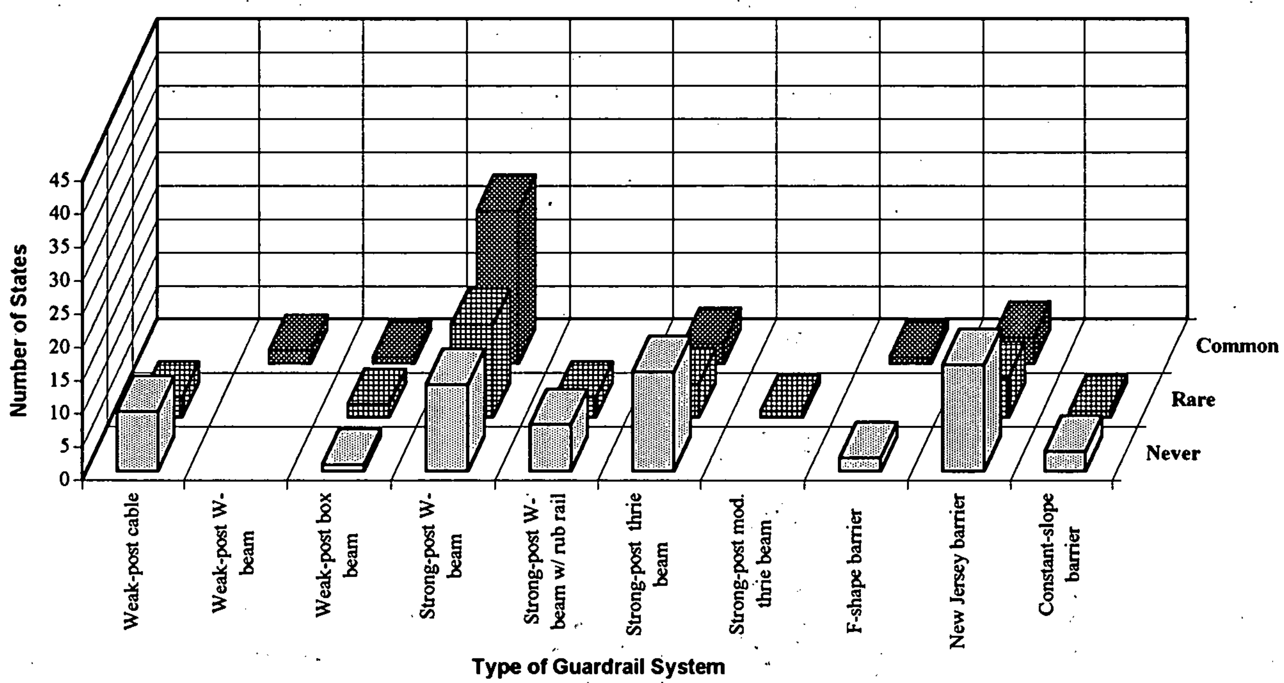


FIGURE 8 Typical guardrail usage—utility poles and trees.

the most commonly used barrier systems used to shield embankments as shown in (Figure 6). In fact, in almost every application depicted in Figures 6 through 16, the strong-post W-beam guardrail is the most commonly used barrier. Although there are no data to demonstrate it, the usage of different barrier systems was probably much more diverse 20 and 30 years ago. As states have gained experience in building and maintaining guardrails, they have steadily reduced the number of different barrier systems so that, by now, a few barrier systems are used in the majority of states for the majority of applications. There are two primary reasons for this: the small incremental cost difference between different types of post-and-beam guardrails and the difficulty of maintaining inventories for a wide variety of systems. Specifying one or two versatile guardrails in a state's standard reduces the amount of material that must be stockpiled and the training required for construction, maintenance, and repair personnel. While the strong-post W-beam guardrail is the most common type of guardrail and

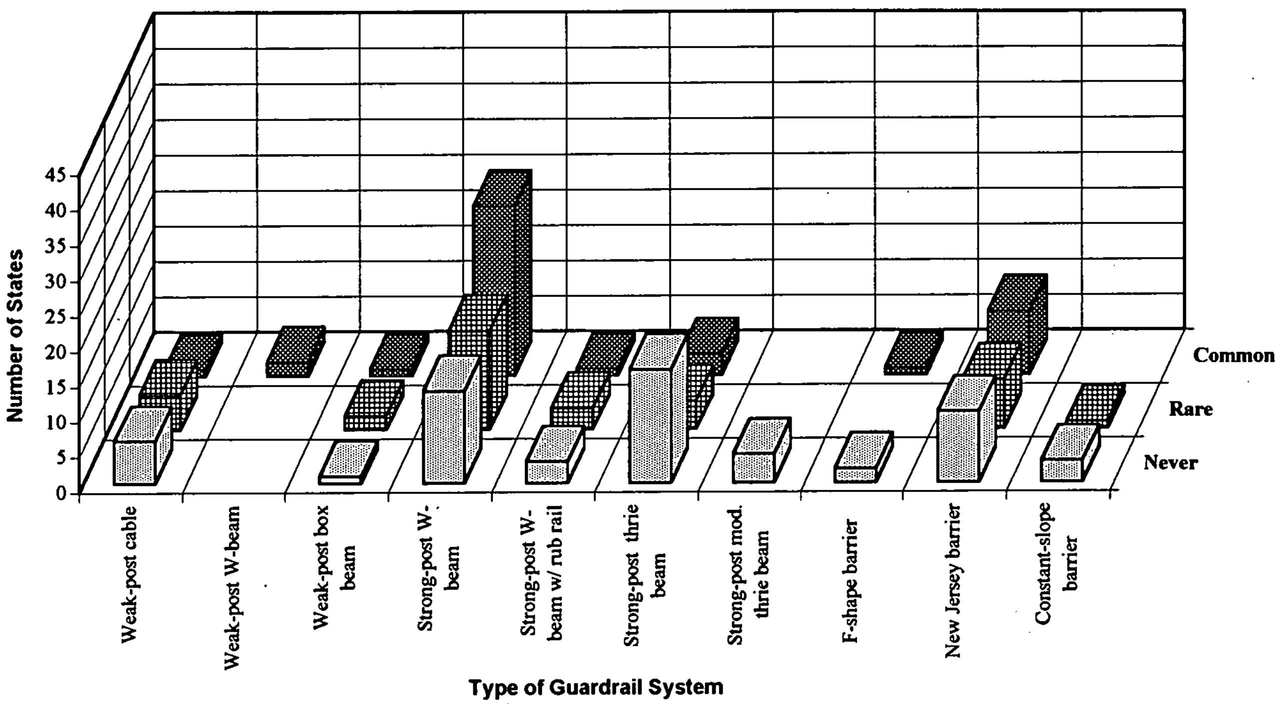


FIGURE 9 Typical guardrail usage—rocks and boulders.

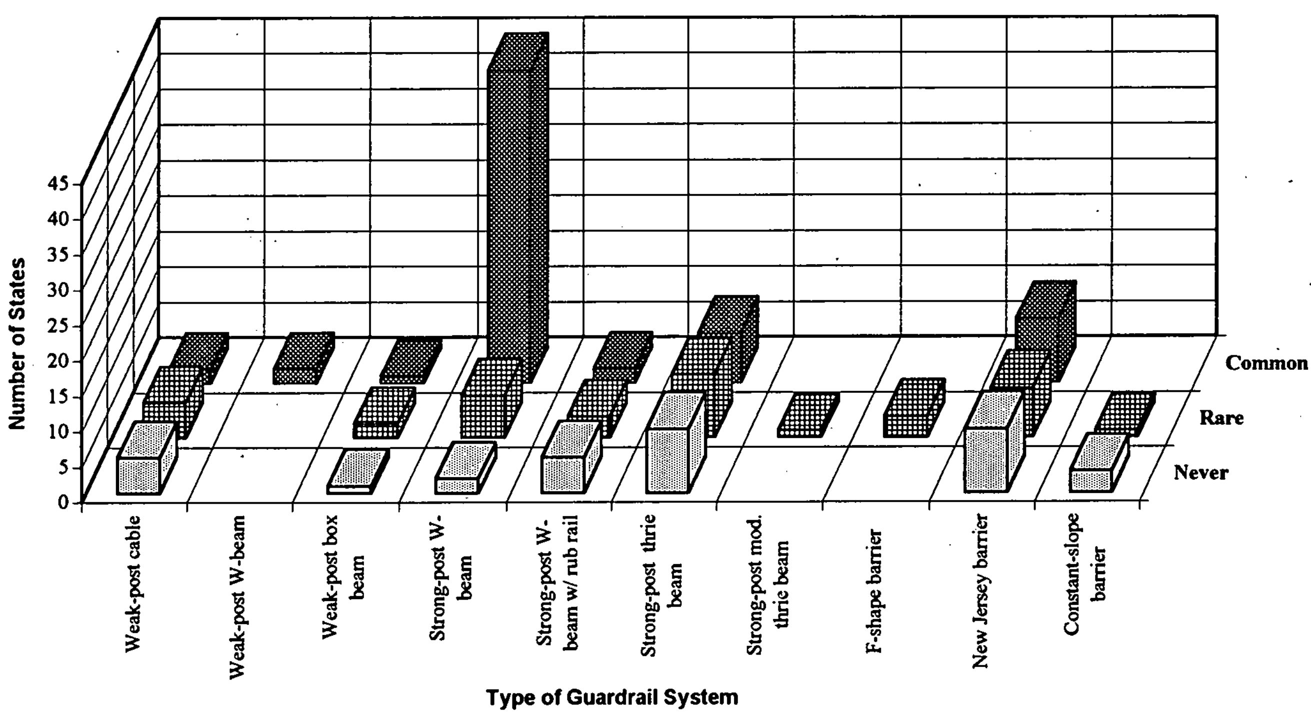


FIGURE 10 Typical guardrail usage—culvert headwalls.

median barrier in place today, increasing demands for higher-performance barriers and barriers that perform well for a broad range of vehicle types may shift the guardrail and median barrier population toward more thrie-beam and concrete barriers.

Median barriers (e.g., symmetric two-face barriers) have one primary purpose: to prevent a vehicle from crossing the median and becoming engaged in a potentially serious head-on collision in the opposing lanes of traffic. When medians are very wide, median barriers are usually not used since the chance of completely crossing a wide median is relatively low. The *Roadside Design Guide* recommends that median barriers are optional when medians are wider than 10 m and are not required at all if the median is wider than 15 m (2). Median barriers become increasingly important as median width decreases. Table

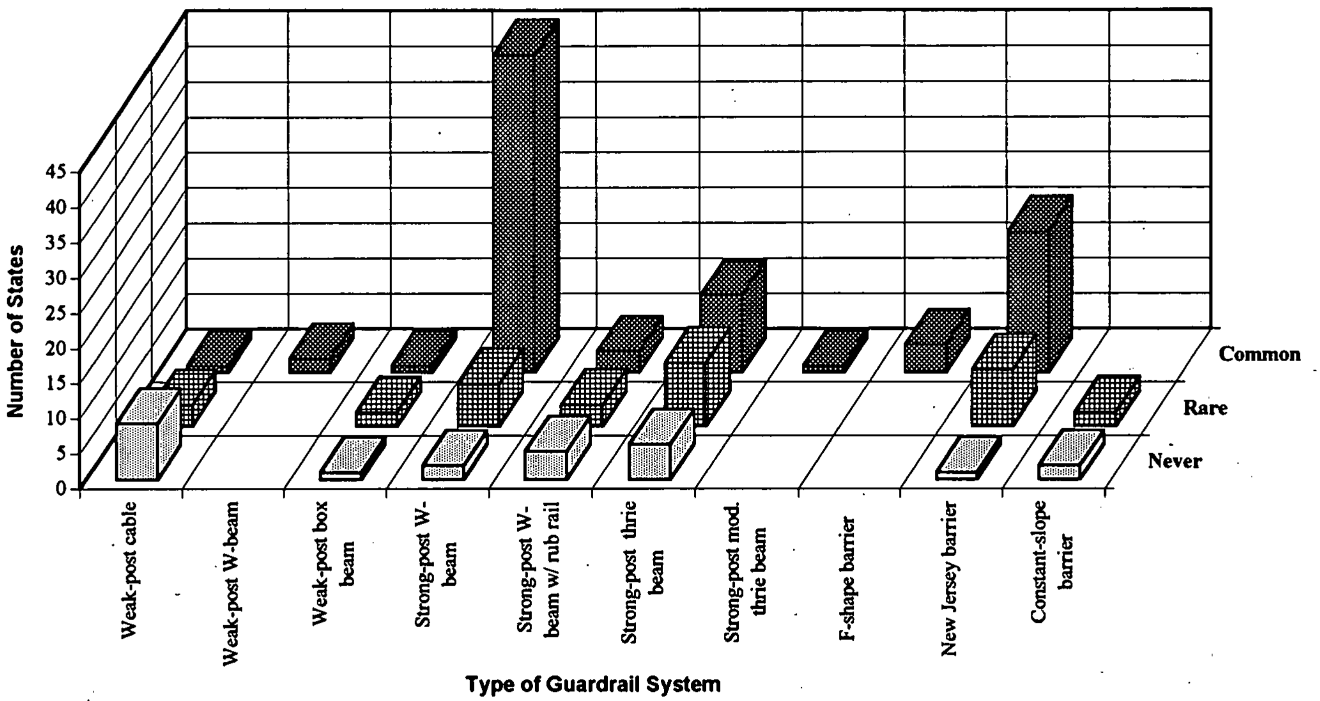


FIGURE 11 Typical guardrail usage—bridge piers.

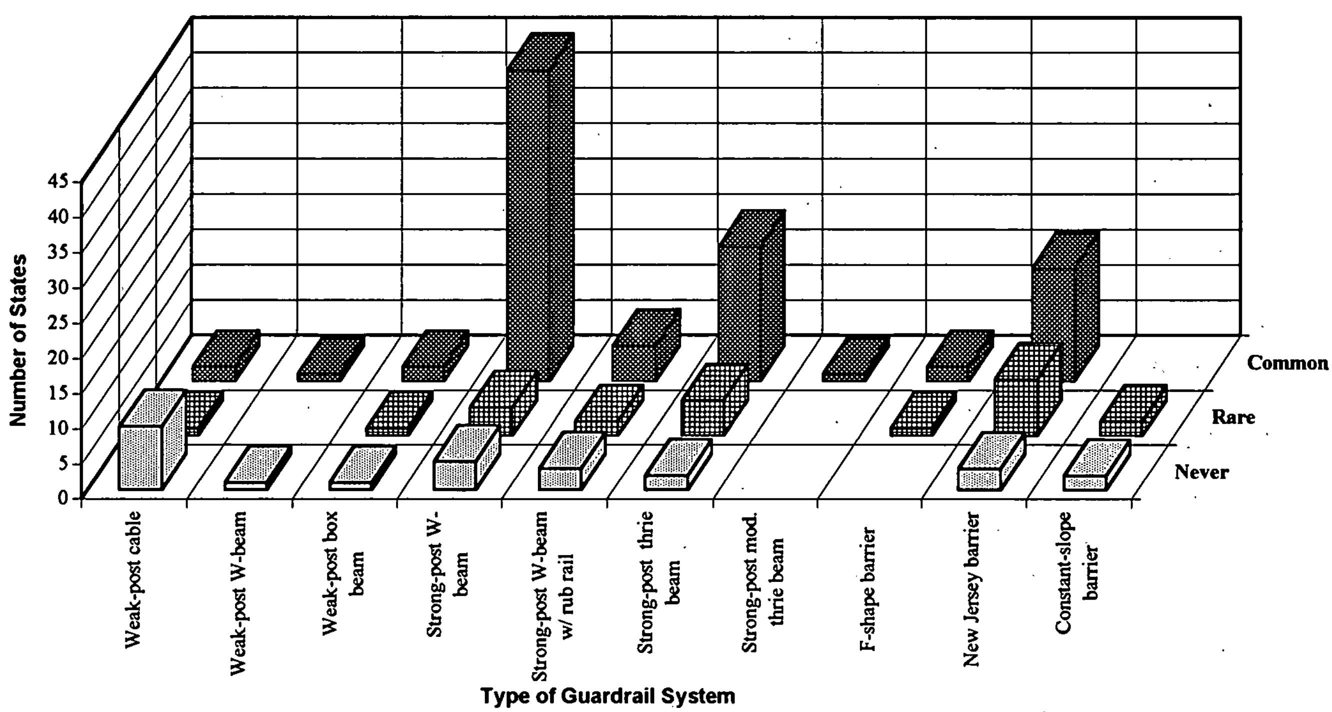


FIGURE 12 Typical guardrail usage—bridge approaches.

4 shows the typical median widths associated with different types of median barriers. As would be expected, Table 4 shows that very flexible weak-post guardrails like the three-cable guardrail (SGR01) are generally used in medians no less than 8 m wide, whereas rigid concrete barriers such as the New Jersey and F-shape barriers can be used in medians as narrow as 2 m, just large enough to accommodate the barrier and the roadway shoulders.

Most respondents (58 percent) indicated that there were minimum shoulder width requirements when guardrails are specified (Appendix C Question 5). Generally, shoulders needed to be at least 1250 mm wide and the guardrail was most often

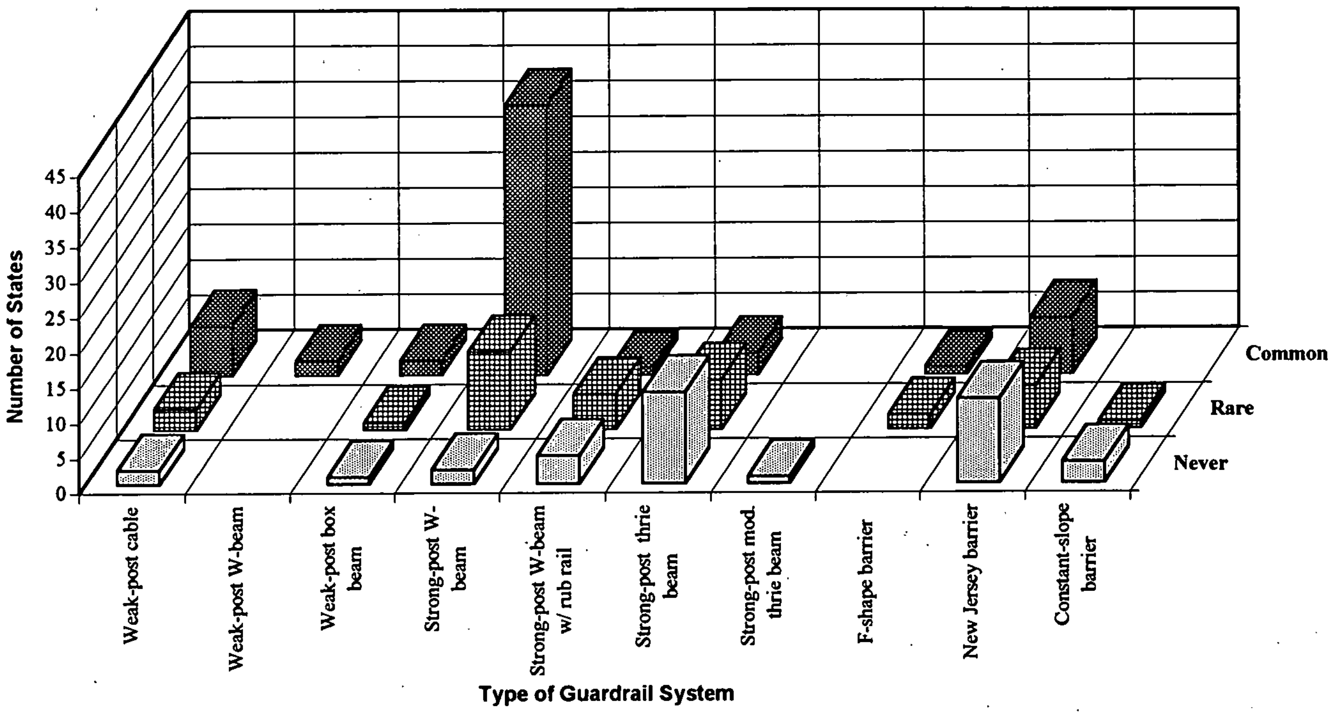


FIGURE 13 Typical guardrail usage—bodies of water.

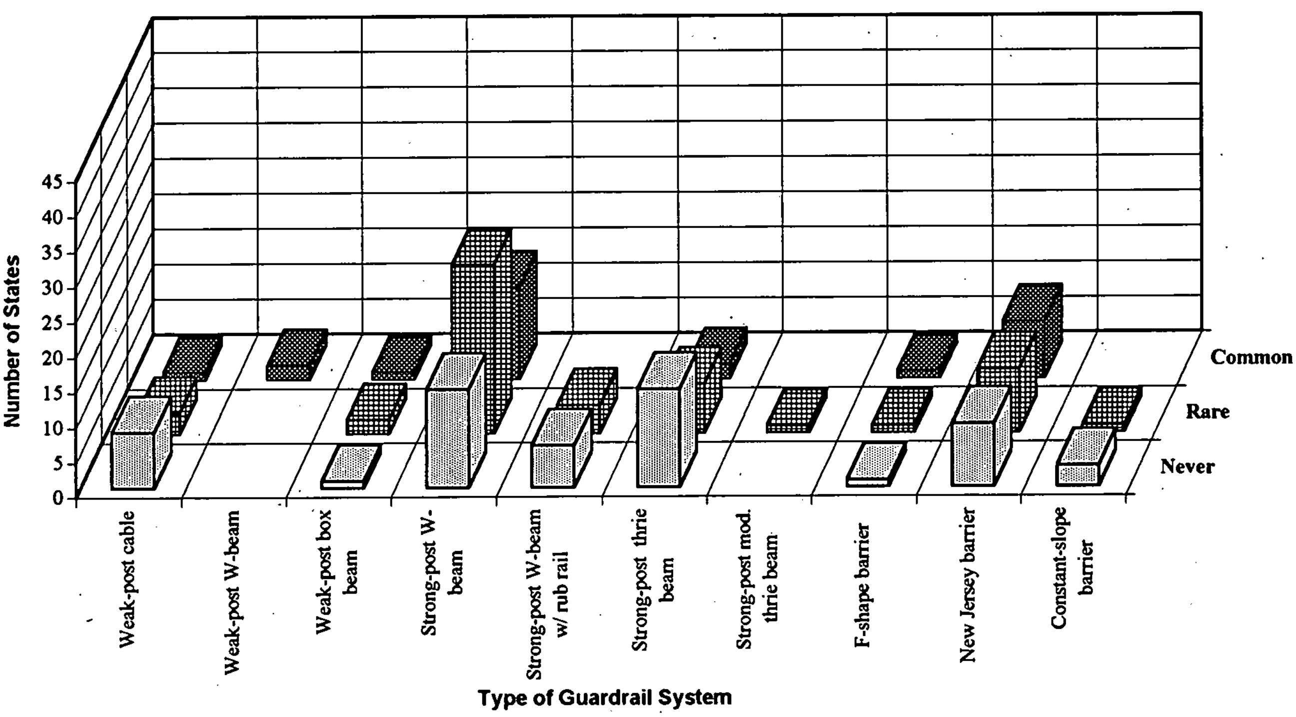


FIGURE 14 Typical guardrail usage—bicycles and pedestrians.

located 610 mm from the edge of the shoulder. Essentially the same shoulder requirements appear to apply to median barriers, according to the survey respondents, a 1250 mm-wide shoulder with the median barrier offset an additional 610 mm from the shoulder (Appendix C Question 6). Some states allow considerably less shoulder width and barrier offset for the important case of concrete median barriers (Appendix C Question 7). Shoulder widths of less than 610 mm appear to be permitted in a few states when concrete median barriers are used, although the standard 1250 mm-wide shoulder appears to be the most common. When guardrails or median barriers are "close" to the roadway, 45 percent of the respondents indicated that special delineation is added to the barrier (Appendix C Question 8). Five of the respondents indicated that some

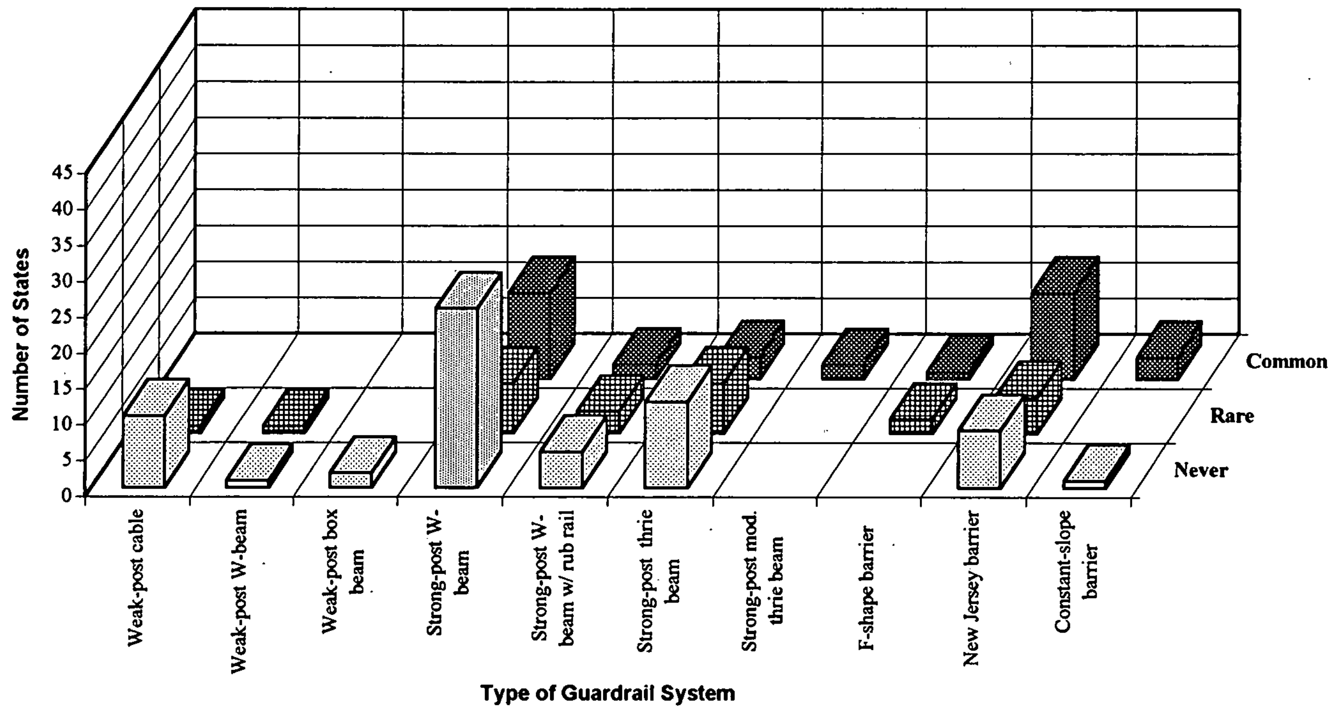


FIGURE 15 Typical guardrail usage—heavy vehicle containment.

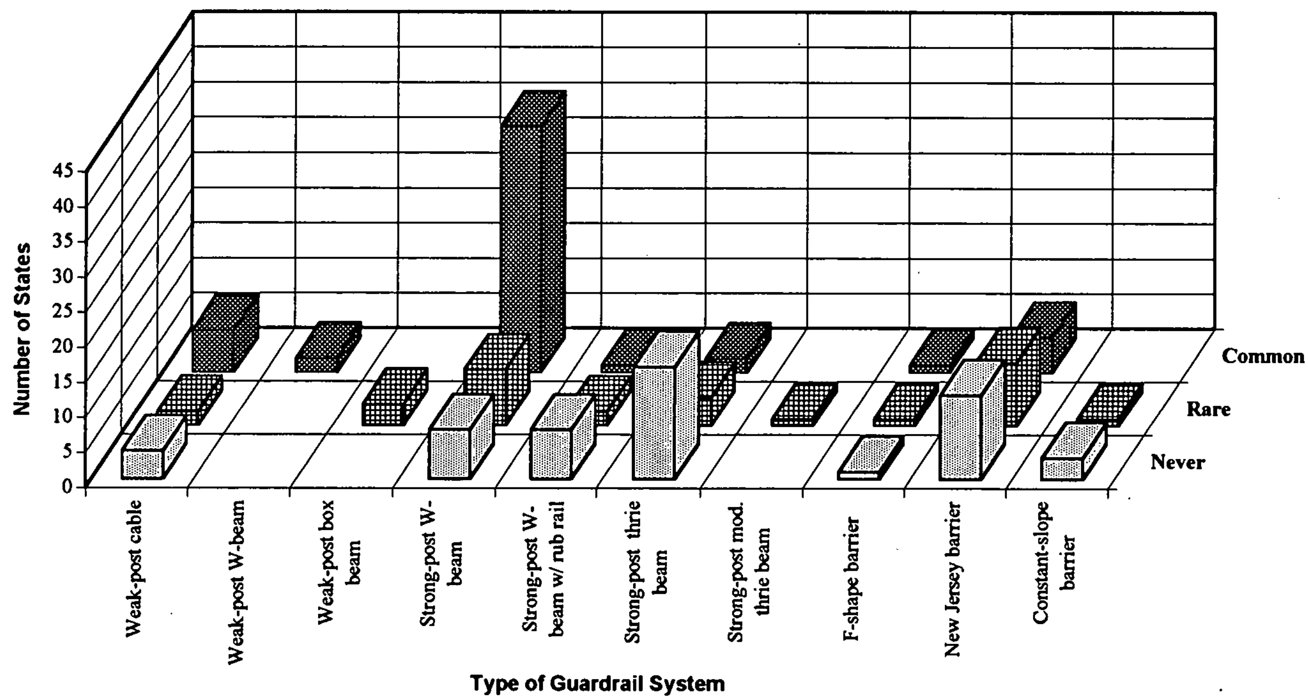


FIGURE 16 Typical guardrail usage—lower service level roadways.

type of delineators are always used on guardrail and median barrier installations regardless of the distance from the edge of the roadway.

The aesthetics of roadways have become increasingly important to many local communities, and this has created a demand for more visually appealing guardrails and median barriers. The majority of survey respondents did not have an aesthetic barrier alternative in their state standards for either guardrails (68 percent) or median barriers (83 percent) (Appendix C Questions 9 and 10). The alternatives used in the states that did have an aesthetic barrier in their standards varied from typical guardrails and median barriers with some type of treatment to color the normally galvanized rail (e.g., colored epoxy paint and weathering steel) to the special-purpose guardrails and guardwalls described in Chapter 6.

INSTALLATION AND REPAIR COSTS

As with any constructed facility, the costs associated with each type of guardrail or median barrier are important factors to consider when making decisions about installing, maintaining, and repairing guardrails and median barriers. In recent years a variety of economic decision-making techniques such as benefit-cost, cost-effectiveness, and value engineering have made the installation, maintenance, and repair costs for guardrails and median barriers an explicit part of the maintenance and design process. Although 85 percent of the states responding to the survey allow guardrail and median barrier installation decisions to use life-cycle cost comparisons, only 38 percent of the respondents indicated that life-cycle costs are used (Appendix C Questions 32 and 33). Installation costs, as used in this report, refer to the cost of materials and labor to construct a guardrail or median barrier system but exclude other construction costs such as grading and site work. The installation costs are summarized in Table 7. Survey respondents were asked to provide a low, typical, and high installation for each type of barrier used in that state. The cost values reported do not include any adjustments for geographical differences in labor and materials costs except that installation costs from Hawaii were excluded because they were consistently much higher than installation costs in the continental United States. In general, barrier installation cost is inversely proportional to the dynamic deflection, weak-post barriers generally having the lowest installed cost, rigid concrete barriers generally having the highest, and strong-post barriers falling in the middle range.

Some barriers require periodic maintenance, which should be included in the overall life-cycle cost of the barrier.

TABLE 7
INSTALLATION COST OF COMMON GUARDRAILS AND MEDIAN BARRIERS

Barrier Type	Hardware Guide Designator	Barrier Guide Designator	Installation Cost ($/m) Low	Typical	High	Number of States
Weak-post guardrail						
Steel-post cable	SGR01a	G1	15	35	66	7
Wood-post cable	SGR01b	G1	13	19	49	3
Steel-post W-beam	SGR02	G2	23	31	92	3
Steel-post box beam	SGR03	G3	62	70	79	3
Strong-post guardrail						
Steel-post W-beam	SGR04a	G4(1S)	28	42	121	25
Wood-post W-beam	SGR04b	G4(2W)	26	39	127	26
Steel-post W-beam w/rubrail	SGR06a	–	46	151	174	3
Wood-post W-beam w/rubrail	SGR06b	–	49	79	98	2
Steel-post thrie beam	SGR09a	G9	39	94	115	11
Wood-post thrie beam	SGR09c	G9	30	82	184	14
Modified thrie beam	SGR09b	–	39	82	328	4
Concrete roadside barrier						
F-shape	–	–	62	115	118	5
New Jersey	–	–	30	102	492	27
Constant slope	–	–	53	84	131	4
Weak-post median barrier						
Steel-post cable	SGM01a	MB1	15	16	17	1
Wood-post cable	SGM01b	—				0
Steel-post W-beam	SGM02	MB2	33	43	82	3
Steel-post box beam	SGM03	MB3	66	79	85	2
Strong-post median barrier						
Steel-post W-beam	SGM04a	MB41S	39	53	92	12
Wood-post W-beam	SGM04b	–	33	48	76	7
Steel-post W-beam w/rubrail	SGM06a	–	39	148	164	2
Wood-post W-beam w/rubrail	SGM06b	MB4W	39	41	43	1
Steel-post thrie beam	SGM09a	MB9	75	107	131	2
Wood-post thrie beam	SGM09c	—	47	76	99	2
Modified thrie beam	SGM09b	—	–	–	–	0
Concrete median barrier						
F-shape	SGM10	—	43	171	361	4
New Jersey	SGM11	MB5	43	98	345	32
Constant slope	SGM14	—	76	131	361	7

TABLE 8

GUARDRAIL AND MEDIAN BARRIER MAINTENANCE COSTS FROM STATES THAT SEPARATELY BUDGET MAINTENANCE AS FUNCTION OF AMOUNT OF STATE-CONTROLLED ROADWAYS

State	State-Controlled Roadways (km)	Guardrail and Median Barrier Maintenance Spending ($)	($/km)
Alabama	14 705	1,100,000	75
California	23 691	1,777,000	75
Delaware	5527	180,000	33
Idaho	7812	60,000	8
Iowa	14 685	700,000	48
Kansas	16 105	450,000	28
Maine	12 516	630,000	50
Nevada	7718	350,000	45
New Hampshire	6010	650,000,000	108
New Jersey	2562	1,700,000	663
North Carolina	110 470	2,000,000	18
Oregon	16 882	615,000	36
Utah	8116	187,000	23
Vermont	4287	50,000	12
Virginia	80 602	3,644,000	45
Washington	28 593	1,310,000	46
Wisconsin	17 743	2,100,000	118
Average			84
Average with maximum and minimum excluded			51

Maintenance costs are any costs that are not related to the initial construction or repair to the system after a collision. The cable tension in three-cable guardrails, for example, should be periodically checked and adjusted. This type of inspection and adjustment activity should be classified as a maintenance cost. Survey respondents were also asked to provide maintenance costs for the barriers used in each state, but the quantity and quality of the data received were poor. There are several reasons for this including (a) the maintenance-free nature of some barriers like concrete barriers, and (b) the fact that many states do not explicitly account for maintenance costs. Only 25 percent of the survey respondents indicated that maintenance costs were budgeted separately (Appendix C Question 27). Table 8 shows the budgeted maintenance funds for the 17 states that did indicate that maintenance costs were budgeted separately. The total amount is indicated as well as the dollar amount budgeted per kilometer of state-maintained roadway. The values vary widely between a low of $8/kilometer and a high of $663/kilometer. The differences could probably be accounted for considering the amount of guardrail and barrier usage in a state, the exact definition in each of "maintenance," and the volume of traffic on the roadway. Perhaps it is significant that the lowest value in Table 8 comes from a sparsely populated western state with low roadway volumes (Idaho) and the highest comes from a densely populated eastern state with very high traffic volumes (New Jersey). The conventional wisdom has been that the installed cost advantage for weak-post barriers is offset by higher maintenance and accident repair costs. Unfortunately, the data from the state survey did not provide much information on this argument—not a single state was able to provide data on the maintenance costs for weak-post guardrails.

Table 9 shows the repair costs experienced by the 39 states that responded to the survey. Each survey respondent provided an estimate of a low, typical, and high value for the repair cost per accident and incident. Although weak-post barriers have a lower cost, it should be remembered that many collisions with rigid concrete barriers result in no damage and therefore no repair cost. Unfortunately, it is not possible to collect data on the cost per incident (reported as well as unreported accidents) on various barriers so a true measure of their safety effectiveness is not easy to obtain.

MAINTENANCE CONSIDERATIONS

Correctly selecting, locating, and installing a guardrail or median barrier is only the first step in providing a safer roadway environment. If guardrails and median barriers are to remain crashworthy and functional, they must be properly maintained. Maintenance and repair activities are performed solely by state crews in 45 percent of the states that responded to the survey (Appendix C Question 26). Only three percent of the states exclusively use private contractors for maintenance and repair activities. Most states appear to use a mixture of state crews and private crews

Police routinely notify highway maintenance personnel in 78 percent of the states that responded to the survey (Appendix C Question 28). Only 38 percent of the survey respondents indicated that their states have a policy on the timeliness of guardrail and median barrier repair, and even these policies do not appear to be very specific (Appendix C Question 29). An attempt is made to recover the costs of repairing damaged guardrails and median barriers in 90 percent of the states that responded to the survey (Appendix C Question 30).

TABLE 9
REPAIR COST OF COMMON GUARDRAILS AND MEDIAN BARRIERS

Barrier Type	Hardware Guide Designator	Barrier Guide Designator	Repair Cost ($/accident)			Number of States
			Low	Typical	High	
Weak-post guardrail						
Steel-post cable	SGR01a	G1	200	250	1,200	3
Wood-post cable	SGR01b	G1	–	–	–	–
Steel-post W-beam	SGR02	G2	–	250	–	1
Steel-post box beam	SGR03	G3	–	–	–	–
Strong-post guardrail						
Steel-post W-beam	SGR04a	G4(1S)	300	750	1,200	4
Wood-post W-beam	SGR04b	G4(2W)	22	600	1,500	7
Steel-post W-beam w/rubrail	SGR06a	–	600	1,000	1,500	1
Wood-post W-beam w/rubrail	SGR06b	–	600	1,000	1,500	1
Steel-post thrie beam	SGR09a	G9	800	1,500	2,000	2
Wood-post thrie beam	SGR09c	G9	700	1,500	2,000	3
Modified thrie beam	SGR09b	–	800	1,500	2,000	1
Concrete roadside barrier						
F-shape	–	–	–	–	–	–
New Jersey	–	–	250	400	1,000	2
Constant slope	–	–				
Weak-post median barrier						
Steel-post cable	SGM01a	G1	–	–	–	–
Wood-post cable	SGM01b	G1	–	–	–	–
Steel-post W-beam	SGM02	G2	–	–	–	–
Steel-post box beam	SGM03	G3	–	–	–	–
Strong-post median barrier						
Steel-post W-beam	SGM04a	G4(1S)	–	–	–	–
Wood-post W-beam	SGM04b	G4(2W)	600	1,200	3,000	2
Steel-post W-beam w/rubrail	SGM06a	–	–	–	–	–
Wood-post W-beam w/rubrail	SGM06b	–	–	–	–	–
Steel-post thrie beam	SGM09a	G9	1,200	1,600	3,000	1
Wood-post thrie beam	SGM09c	G9	800	1,200	2,400	1
Modified thrie beam	SGM09b	–	–	–	–	–
Concrete median barrier						
F-shape	SGM10	–	–	–	–	–
New Jersey	SGM11	–	100	800	1,000	3
Constant slope	SGM14	–	120	800	1,200	1

CRASHWORTHINESS

In 1962, Highway Research Board Circular 482 recommended the use of only one test vehicle, a large 2040-kg passenger sedan. At the time this single vehicle represented the majority of the passenger vehicle population *(4)*. As the vehicle population has grown and changed, new vehicles have been added to the recommended matrix of crash tests (see Appendix A). Report 350, the most recent test and evaluation procedures, includes six vehicles ranging from a 700-kg mini passenger car to a 36 000-kg tanker truck *(8)*. As recently as 1980 light trucks (pickup trucks, vans, minivans, and sport-utility vehicles) accounted for about 20 percent of the passenger vehicles sold *(14)*. By 1994, 40 percent of the passenger vehicles sold were light trucks. Some of these vehicles, like minivans, did not even exist a little more than a decade ago. Not only has the passenger vehicle fleet diversified in terms of the types of vehicles, but the size of vehicles has also become smaller. Report 230 added an optional small 820-kg vehicle, which quickly became a standard part of most crash test programs. Vehicles as light as 700 kg can be purchased, although such vehicles appear to be the lower limit of passenger vehicle mass *(39)*. The vehicles recommended for crash testing in Report 230 and Report 350 were presented in Table 1. Designing guardrails and median barriers for such a diverse group of vehicle types has become very challenging.

When asked to name the three most critical research topics dealing with longitudinal highway barriers, 22 of the 39 state DOT respondents (56 percent) said that establishing the Report 350 test levels of existing barriers or developing Report 350 certifiable barriers was the most important research need (see Appendix C Question 34). This opinion was echoed recently at the 1995 summer meeting of the Roadside Safety Features Committee (A2A04) of the Transportation Research

Board at which "vehicle and roadside safety hardware compatibility and reconciliation of motor vehicle safety standards and roadside hardware evaluation standards" was the highest-priority research problem statement (*40*). There is a great deal of concern about how the current inventory of guardrail and median barrier hardware will perform under the new Report 350 guidelines and, more important, how that will affect the installation, maintenance, and repair of devices already installed on the roadway network.

FHWA has adopted the testing procedures and evaluation criteria described in Report 350 as a part of the "guide and references" section of 23 CFR, Part 625 *(17)*. The *Federal Register* notice announcing the adoption of Report 350 stated:

> Also, contingent upon the results of ongoing research and service performance information available at the time, the FHWA anticipates that approximately 5 years after the adoption of this rule that all new installations of traffic barriers and other roadside safety features on [National Highway System] projects will be only those that have been judged to meet the testing and evaluation criteria in *Report 350*. At the same time, the FHWA anticipates that the suitability of all traffic barriers and other roadside safety features will be determined through an evaluation and selection procedure that considers the needs of all classes of vehicles and is acceptable to FHWA*(16)*.

This paragraph suggests that by August 16, 1998, FHWA will require all roadside hardware used on the National Highway System (NHS) to satisfy the Report 350 guidelines. Although there are no warrants for selecting and locating roadside appurtenances according to the six test levels, identifying the apparent test level of currently acceptable hardware is a first step in addressing the *Federal Register* announcement.

Table 10 shows the apparent Report 350 test levels of common guardrails and median barriers based on crash tests already performed and in the roadside safety literature. All the tests referred to in Table 10 are more explicitly described and explained in later chapters, which describe each type of guardrail and median barrier in detail. The purpose of Table 10 is to summarize the overall status of the guardrail and median barrier inventory with respect to Report 350. Report 350 Test 3-10 is essentially identical to Report 230 Test S13, the small-car longitudinal barrier test. Testing of the small car documented in Report 289 should be considered to satisfy the requirements of Report 350 Test 3-10. Report 350 Test 3-11, the test involving a 2000-kg pickup truck, has turned out to be a difficult test for many common guardrail and median barrier systems and has been the focus of much of the full-scale testing in the past several years. The higher-level Report 350 tests involve several types of heavier vehicles that were sometimes used in Report 230 supplemental tests and in bridge railing tests of the American Association of State Highway and Transportation Officials (AASHTO). Test 3-11, the 2000-kg Test Level 3 pickup truck test, has been the most demanding test and often the critical test in determining whether a guardrail or median barrier is a Test Level 2 or 3 barrier.

TABLE 10

SUMMARY OF REPORT 350 TESTS OF COMMON GUARDRAILS AND MEDIAN BARRIERS ACCEPTABLE UNDER REPORT 230

System Test Level	Hardware Guide Designator	Barrier Guide Designator	Report 350 Test 10	Report 350 Test 11	Report 350 Test 12
Roadside guardrail					
Test Level 2					
Weak steel-post W-beam	SGR02a	G2	Pass	Pass	NR
Test Level 3					
Weak steel-post cable	SGR01a	G1	Pass	Pass	NR
Steel-post W-beam	SGR02a	G2	Pass	Fail	NR
Steel-post box beam	SGR03	G3	Pass	Pass	NR
Steel-post W-beam	SGR04a	G4(1S)	Pass	Fail	NR
Wood-post W-beam	SGR04b	G4(2W)	Pass	Pass	NR
Steel-post thrie beam	SGR09a	G9	Pass	Fail	NR
Steel-post thrie beam	SGR09a	–	Pass	Pass	NR
Modified thrie beam	SGR09b	–	Pass	Pass	NR
Merritt Parkway	–	–	Pass	Pass	NR
Median barrier					
Test Level 3					
Steel-post cable	–	MB1	Pass	Pass	NR
Steel-post box beam	SGM03	MB3	Pass	Pass	NR
Test Level 4					
Constant-slope barrier	SGM14	–	Pass	Pass	Pass
Test Level 5					
New Jersey barrier	SGM11b	–	Pass	Pass	Pass
Ontario tall wall	SGM12	–			Pass

NR = Not required for this test level

All the guardrails and median barriers shown in Figure 4 and listed in Table 10 were considered to be acceptable systems under the Report 230 guidelines. The Report 350 tests appropriate for the hardware are listed across the top of the page and the barriers are divided into test level groupings. Each barrier system is identified by the designator used in the 1995 Hardware Guide as well as the designators used in the 1977 AASHTO Barrier Guide *(20,22)*. The table indicates whether the test at that level passed or failed, or has never been performed. Specific information about the test numbers, evaluation parameters, and causes of failures are discussed in later sections about each specific device. It has been presumed that if a system passes the tests required at a particular test level, it would also pass the tests at a lower test level.

An examination of Table 10 reveals some important issues and identifies possible areas for future research. Although there are as yet no guidelines to assist engineers in deciding when a particular test level is warranted, Test Level 3 would presumably be appropriate for Interstate and U.S. highways since it corresponds closely to the recommendations in Report 230. This correspondence suggests that the current generation of roadside hardware that was developed and tested according to Report 230 should correspond to Test Level 3.

The strong-post W-beam guardrail (SGR04) is the most common guardrail system used in the United States today. The strong steel-post W-beam guardrail (SGR04a), the G4(1S), failed the Test Level 3 2000-kg pickup truck test. The strong wood-post W-beam guardrail (SGR04b), the G4(2W), passed all the Test Level 3 tests although the impact-side wheel was torn from the vehicle in the pickup truck test. These two tests have raised serious questions about the crashworthiness of strong-post W-beam guardrails in general and about the presumed equivalence of wood and steel post systems in particular. Both small-car tests (Test 3-10 conditions) found in the literature exhibited snagging problems as well, although the researchers at the time classified them as marginally passing. These tests may indicate a genuine performance problem that is occurring in the field, or they may reflect the severe test conditions used in evaluating guardrails. Determining if the test performance is indicative of what is actually occurring in the field is of extreme importance since strong-post W-beam guardrails are by far the most common longitudinal barrier on the NHS.

With the notable and important exception of the weak-post W-beam guardrail (SGR02), the weak-post guardrails can be categorized as Test Level 3 systems. The basic design philosophy of the weak-post guardrails is, perhaps, more forgiving of the stability peculiarities of the pickup truck. Weak-post systems are usually designed to "grab" the vehicle and allow large deflections: these relatively elastic deflections then return the vehicle to the shoulder. The weak-post W-beam guardrail did not pass the Test Level 3 pickup truck since the vehicle rode over the barrier.

As shown in Table 10, the standard steel-post thrie-beam guardrail (SGR09a) failed the Test Level 3 2000-kg pickup truck test (Test 3-11). The modified thrie-beam guardrail was originally developed to satisfy a need for a higher-performance guardrail that would be effective with a wide range of vehicle types. The modified thrie-beam guardrail passed the critical Test Level 3 pickup truck test (Test 3-11), although even with a 355-mm-deep blockout, the impacting front wheel was torn away from the vehicle.

The Test Level 3 2,000-kg pickup truck test (Test 3–11) has proven to be very demanding for post and beam guardrails and median barriers especially those with steel posts. It is not clear if these test results reflect test conditions that are too demanding of the current generation of roadside hardware or if there is a wide-spread potential problem with the performance of common guardrails when struck by multi-purpose vehicles like pickup trucks and vans. Interestingly, several exploratory tests were performed on common guardrails using full-size vans and are documented in Report 289 *(18)*. The full-size van rolled over when striking the weak-post W-beam guardrail (SGR02) at 100 km/hr and 25 degrees. Several tests using both large and small pickup trucks were performed as part of a study of the performance limits of longitudinal barriers *(41)*. Again, snagging problems were observed in these tests; when the snagging was particularly severe rollover occurred.

Whenever the basic guidelines used.to evaluate hardware are changed, the roadside safety community reexamines the current generation of hardware with respect to the new guidelines. When Report 230 was published, NCHRP sponsored a study to explore the performance of guardrails in small-car impacts since the addition of an 820-kg vehicle was one of the important new features of Report 230. Much the same process will be required to fill in all the blanks in Tables 1 and 5 and resolve the issues discussed here. Clearly, several major issues must be addressed before all roadside features on the NHS are considered to satisfy Report 350.

IN-SERVICE PERFORMANCE

Most existing in-service evaluations have focused on the installation, maintenance, and accident experience with one type of roadside hardware. Several examples of these types of in-service evaluations are described in later sections dealing with specific guardrails and median barriers. As rare as in-service evaluations have been, there have been even fewer comparative evaluations in which the in-service performance of one type of guardrail is compared directly with another.

The state of New York examined the performance of its barrier inventory between 1967 and 1969 and VanZweden and Bryden reported the results in 1977 *(37,42,43)*. Although weak-post guardrails and median barriers tended to be installed on newer, higher-speed roadways in which the impact conditions might be expected to be more severe, the combined injury and fatality rate for weak-post barriers was 10 percent, half the 20 percent rate for strong-post barriers. Researchers found the difference between these injury rates to be significant, although it is very important to remember that weak-post guardrails and median barriers must be installed with appropriate deflection space. Although this study is based on data that are now nearly 30 years old, the data seem to suggest that the

TABLE 11

GUARDRAIL AND MEDIAN BARRIER PERFORMANCE FROM POLICE ACCIDENT REPORTS IN NEW YORK, 1967–1969 *(36)*

	Penetrated[a]						Contained					
	Injury		Noninjury		Total		Injury		Noninjury		Total	
Barrier Type	No.	%[b]	No.	%	No.	%	No.	%	No.	%	No.	%
Weak-post guardrail and median barrier												
3-cable (SGR01a)	11	13.7	69	86.2	80		8	2.7	287	97.3	295	
W-beam (SGR02)	10	15.4	55	84.6	65		17	11.6	130	88.4	147	
Box beam (SGR03)	4	28.6	10	71.4	14		7	9.6	66	90.4	73	
Box beam (SGM03)	0	0.0	2	100.0	2		9	22.0	32	78.0	41	
Total	25	15.4	136	84.5	161	22.5	41	7.4	515	92.6	556	77.5
Strong-post guardrail and median barrier												
W-beam (SGR04a)	96	32.7	197	67.2	293		103	13.7	649	86.3	752	
W-beam (SGM04a)	12	34.3	23	65.7	35		20	18.2	90	81.8	110	
Total	108	32.9	220	67.1	328	27.6	123	14.3	739	85.7	862	72.4

[a]Penetration in this study was any event (underride, override, or rail penetration) that resulted in the vehicle coming to rest behind the barrier. Containment was any event in which the vehicle remained on the traffic side of the barrier.
[b]Percentages are row percentages.

combination of barriers and warrants for their use were well matched in New York at the time.

Table 11 indicates that 25 percent of the weak-post barrier collisions and 27.6 percentage of the strong-post barrier collisions in New York during the study period resulted in the vehicle coming to rest behind rather than in front of the barrier. The injury rates (the percentage of fatal plus injury accidents) for weak- and strong-post barriers were 15.5 and 19.0 percent of the accidents where the vehicle came to rest behind the barrier, twice the rate of cases in which the vehicle was contained (7.4 and 8.9 percent for weak- and strong-post guardrails, respectively). Table 11 illustrates the importance of making sure that barriers perform their primary function: containing vehicles and preventing them from penetrating the barrier.

> The design of longitudinal traffic barriers has been influenced greatly by two basic assumptions: (a) occupants are subjected to the highest risk of injury during the vehicle's initial collision with a barrier, and (b) the probability of severe occupant injury is directly related to the intensity of vehicle collision accelerations *(44)*.

Ray and others examined these assumptions and found that what happened to the vehicle after leaving the guardrail was a better predictor of the severity of occupant injury than the severity of the initial guardrail collision. An examination of the 1982–1983 Longitudinal Barrier Special Studies (LBSS) cases of the National Accident Sampling System (NASS) indicated that if a vehicle struck a guardrail and did not override, underride or penetrate the barrier, the chance of serious occupant injury was very small *(45)*. Of the 55 accident cases in the LBSS data involving guardrails and median barriers, there was only one severe injury or fatal injury accident (0.2 percent). The injury in the one fatal accident was caused not by high occupant forces in the initial barrier collision but by the redirection of the vehicle into a tree at the end of the guardrail. The vehicle was redirected into another roadside object in 80 percent of the cases after losing contact with the guardrail or median barrier. Figures 17 and 18 summarize a further investigation of accident data from North Carolina and New York that confirmed the importance of redirection in guardrail and median barrier collisions *(46)*. When vehicles were smoothly redircted from the guardrail and did not become involved in any subsequent events after separating from the guardrail, the injury rate in both states was 5.6 percent (Figures 17 and 18). In contrast, when the vehicle penetrated the barrier, the injury was between 17 and 24 percent. Vehicles that were redirected and then experienced a subsequent collision had between three and five times the percentage of injury accidents as vehicles that did not experience a subsequent event (Figures 17 and 18). These studies show the importance of site considerations to the performance of barriers in the field. An otherwise satisfactory barrier can be seriously compromised by incorrect location or length of need.

Hunter and others used the LBSS data to compare the performance of different types of guardrails (48). They were not able to discriminate between specific barrier types because of the small number of cases, but they were able to group the cases into weak-post, strong-post, concrete, and other guardrails and median barriers. The results of the analysis relating to non-end accidents are summarized in Table 12. The data of guardrail and median barrier collisions conform to the conventional wisdom that barriers that allow more lateral deflection result in, on average, less severe collisions. This finding is reflected by the lower percentage of serious injury accidents (e.g., A+K) for weak-post barriers than for strong-post and concrete barriers. The percentage of serious and fatal injuries for the weak-post barriers is at least half that of strong-post barriers for both guardrails and median barriers. Likewise, the percentage of vehicles being redirected increases from high-deflection weak-post systems where some

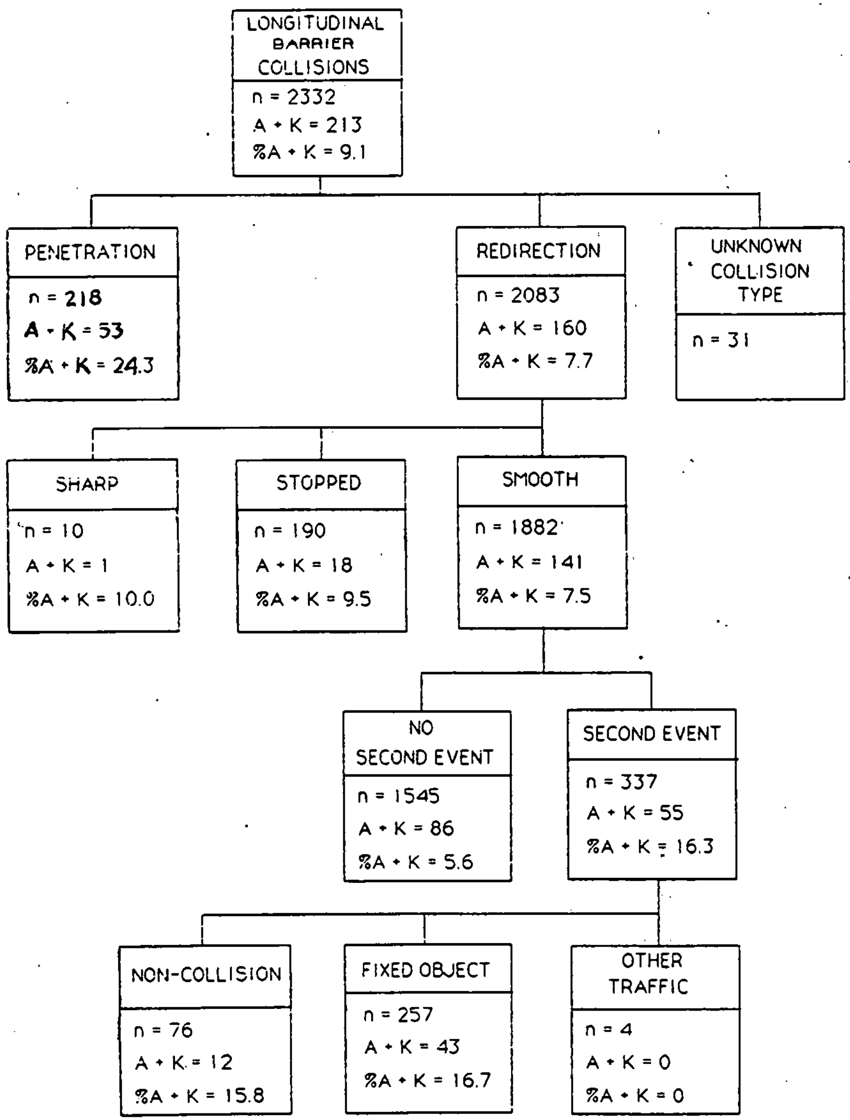


FIGURE 17 Fault-tree for New York guardrail and median barrier accident cases. 1982–1983 *(46)*.

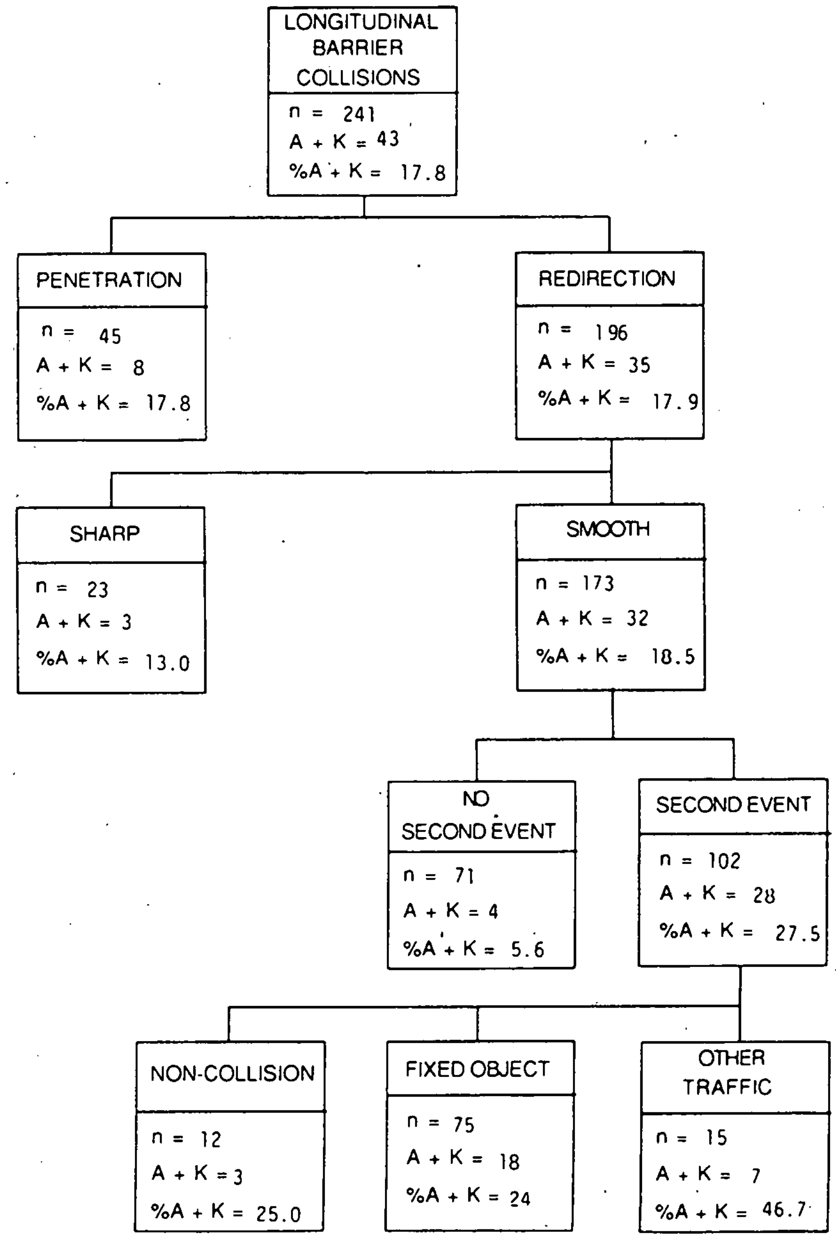


FIGURE 18 Fault-tree for North Carolina guardrail and median barrier accident cases, 1980–1981 *(46)*.

TABLE 12

COMPARISON OF GUARDRAIL AND MEDIAN BARRIER PERFORMANCE FROM LBSS DATA *(47)*

	A + K (%)	Redirect (%)	Snag (%)	Penetrate[a] (%)	Other (%)
Guardrail					
Weak-post	0.0	61	23	11	5
Strong-post	16.0	76	7	16	1
Concrete	7.1	87	0	13	0
Other (obsolete)	10.2	53	15	28	4
Median barriers					
Weak-post	8.8	82	12	3	3
Strong-post	17.5	88	5	5	2
Concrete	16.2	91	0	5	4
Other (obsolete)	11.5	78	7	15	0

[a] Penetration is defined as any case where the vehicle goes over, under, or through the barrier. The original report uses a different category for each.

snagging and penetration is more common, to rigid concrete barriers, where it is more unusual.

Unreported accidents are a major barrier to interpreting police-reported accident data and are a fundamentally important issue that must be addressed in performing in-service evaluations. Counting the number of failures (i.e., police-reported accidents) is relatively easy but correctly assessing the effectiveness of a device requires that the number of successes (i.e., collisions in which the driver and vehicle were able to leave the scene) must also be known. Breakaway sign supports are a good example of this phenomenon. Accident data from some states have indicated a relatively high percentage of A+K injuries in breakaway sign collisions. This finding is probably not an indication that these systems do not function as intended but rather an indication that in all but the most extreme situations, the driver and vehicle leave the scene. If 1,000 such collisions occurred and only 100 were reported, the fact that perhaps 20 of the reported accidents involved A+K injuries (e.g., a reported A+K rate of 20 percent) does not tell the whole story. The device, in fact, would be 98 percent effective in reducing A+K accidents.

SUMMARY

Making decisions about what barrier is most appropriate for a given set of circumstances involves a careful examination of the design details, cost considerations, crashworthiness characteristics of the barrier, and prior experience. The previous sections have presented general information about broad classes of guardrails and median barriers such as weak-post barriers, strong-post barriers, and concrete barriers. The following chapters and sections provide more detailed information that will allow for a more specific comparison between alternative barrier systems. The previous sections have demonstrated that weak-post guardrail and median barriers usually result in a lower proportion of injury accidents (Tables 11 and 12). This reduced severity, however, is counteracted by a higher proportion of potentially serious barrier penetrations. Strong-post and concrete barriers will reduce the proportion of vehicles going over, under, or through the barrier but will result in a somewhat higher percentage of injury accidents. When guardrails are installed and located correctly, they are a very effective roadside safety device as illustrated by the "smooth redirection" cells in Figures 17 and 18.

CHAPTER THREE

WEAK-POST BARRIER SYSTEMS

Weak-post guardrails and median barriers are intended for use in locations where there is enough room for lateral deflection of the system. Some weak-post systems can be expected to deflect as much as 4000 mm, so these systems should be used only when the site conditions can accommodate such deflections. This section includes the most commonly used weak-post barrier system designs.

Perhaps the single most important document on the development of weak-post guardrail and median barrier systems is the paper "New Highway Barriers: The Practical Application of Theoretical Design" published in 1967 *(13)*. This paper describes the theoretical development and crash testing of the standard three-cable guardrail (SGR01a), the weak-post W-beam guardrail (SGR02), the box-beam guardrail (SGR03), and the box-beam median barrier (SGM03).

WEAK-POST THREE-CABLE GUARDRAILS AND MEDIAN BARRIERS

System Description

The primary objective of weak-post guardrails is to gradually redirect an impacting vehicle by elastically stretching the cables, thus minimizing the forces on the vehicle and its occupants. During an impact the cables wrap around the bumper and front fender of a vehicle. The kinetic energy of the vehicle is dissipated by breaking and bending the posts and stretching the cables. Adequate clear space free of fixed objects and other hazards must be available behind the barrier to accommodate the anticipated deflection. Using adequate end anchors is also important for providing controlled stretching of the cable. There are several varieties of this barrier, the principal difference being the type of weak post used. The most common and the oldest type of weak-post cable guardrail system uses a S75×8.5 steel section. This guardrail (SGR01a), shown in Figure 19, was developed by the state of New York in the 1960s and has been widely used in the Northeast and Upper Midwest ever since. Figure 20 and the other drawings in this document were taken from the 1996 *Guide to Standardized Highway Barrier Hardware (22)*. The drawings from the Hardware Guide represent the most widely used crash-tested versions of the barriers in use throughout the United States, although a particular state's design may be slightly different. The component numbers refer to other drawings in the Hardware Guide that should be examined for detailed information about the size, fabrication, and use of the components.

The state of South Dakota has experimented with using a 6-kg/m flanged-channel post with either a rectangular or trapezoidal soil plate (SGR01b) *(48)*. Minnesota and the province of Ontario have used 125-mm-diameter circular wood posts in their cable guardrails, and successful crash tests have been performed on 125-mm-diameter wood posts with a weakening hole (SGR01c) *(49)*. Cold-formed channel sections, so-called Charley posts, are also sometimes used when limited availability of hot-rolled sections makes the cold-formed sections more economical.

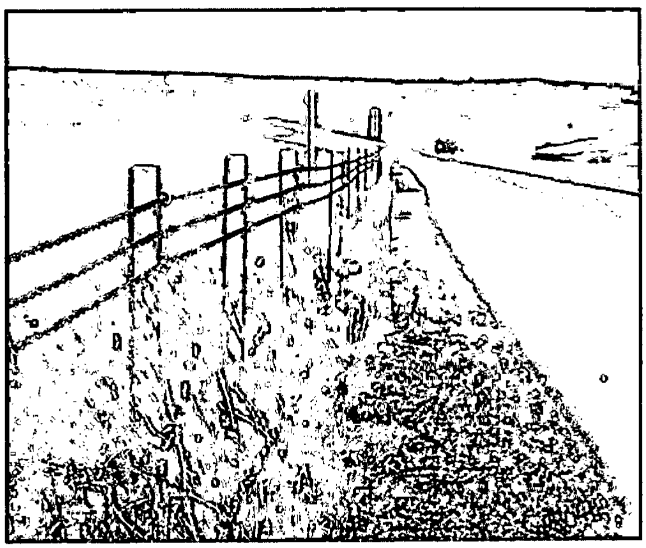


FIGURE 19 Typical weak steel-post three-cable guardrail (SGR01a).

Distribution

Weak-post cable guardrails have been used widely in many northern states for more than 40 years. New York in particular has played a key role in developing and improving cable guardrail systems. As shown in Figures 21 and 22, cable guardrails are particularly popular in northern states, especially in the Upper Midwest and New England. In Figures 21 and 22, as well as all the subsequent distribution maps in this document, the percentage of usage refers to the approximate amount of new installations of the barrier. For example, in Figure 21, 30 to 59 percent of guardrails installed in New York in 1995 are three-cable guardrails. The wood-post version of this barrier is also very popular in Ontario and other Canadian provinces. Figure 21 shows a map with states that installed three-cable guardrails in 1995, and Figure 22 shows the states that installed three-cable median barriers in 1995. Figures 21 and 22 represent the percentage of new installations of three-cable guardrail. Pennsylvania, for example, has

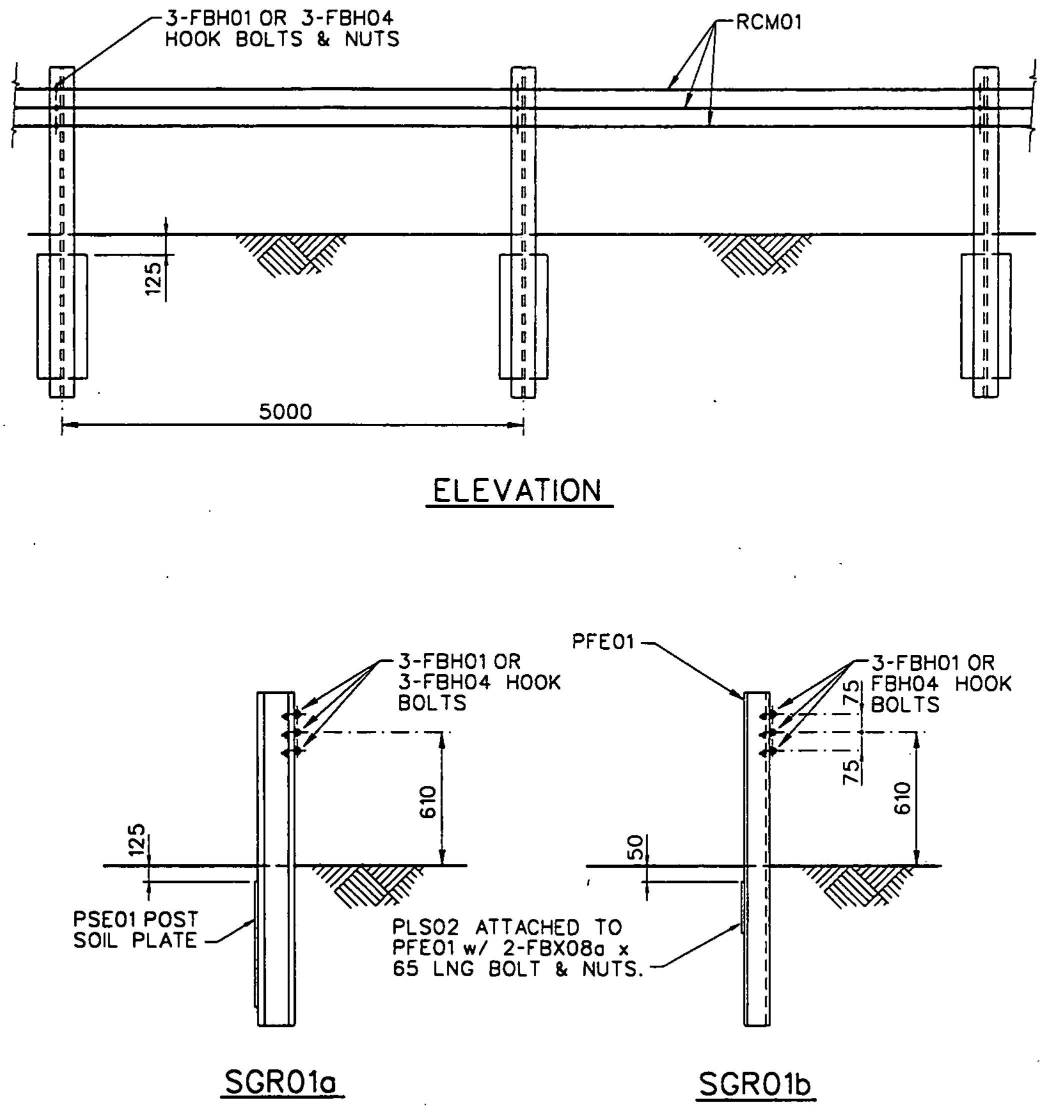


FIGURE 20 Weak-post three-cable guardrail and median barrier (SGR01a-b).

many miles of three-cable guardrail that were installed in the past and are still being maintained, but it no longer uses three-cable guardrails in new installations.

Crashworthiness

The standard G1 cable guardrail has been tested many times, although most of the large-car testing is now very old *(13,18,19)*. Successful small-car tests of this system, summarized in Table 13, were performed in the mid-1980s and are documented in Report 289 *(18)*. The Test Level 3, 2000-kg pickup truck test recently was performed on the steel-post three-cable guardrail with successful results, as shown in Table 14 *(50)*. (Table 14, and similar tables that follow, shows the evaluation criteria for Report 350 Test Level 3. The letter headings correspond to the headings used in Report 350 and reproduced here in Appendix A.)

New York examined the performance of guardrails and median barriers in use in the state and published the results in a 1977 report *(37)*. Police-reported accidents on New York State—maintained roadways were examined for the years 1967 through 1969. Of the 3,496 guardrail and median barrier accidents, 375 involved light-post three-cable guardrails (SGR01a). The cable guardrail was penetrated in 27 percent of the collisions, a surprisingly high proportion. This finding prompted New York to reexamine its barrier height standards, and eventually the state reduced the height of the top cable from 760 to 685 mm, as shown in Figure 22. Four fatalities were recorded that involved weak-post three-cable guardrails, two involving penetrated barriers. The injury rate (fatalities and hospitalizations) for weak-post cable guardrails was 5 percent). When there was no barrier penetration, the chance of injury was under 0.03. The weak-post cable guardrail was found to have an average repair cost in 1967 through 1969 of \$90/accident, which was less than half of the \$201/accident average cost of strong-post W-beam guardrails. Besides noting the necessity of reexamining barrier height standards for all barriers, the New York study concluded that weak-post

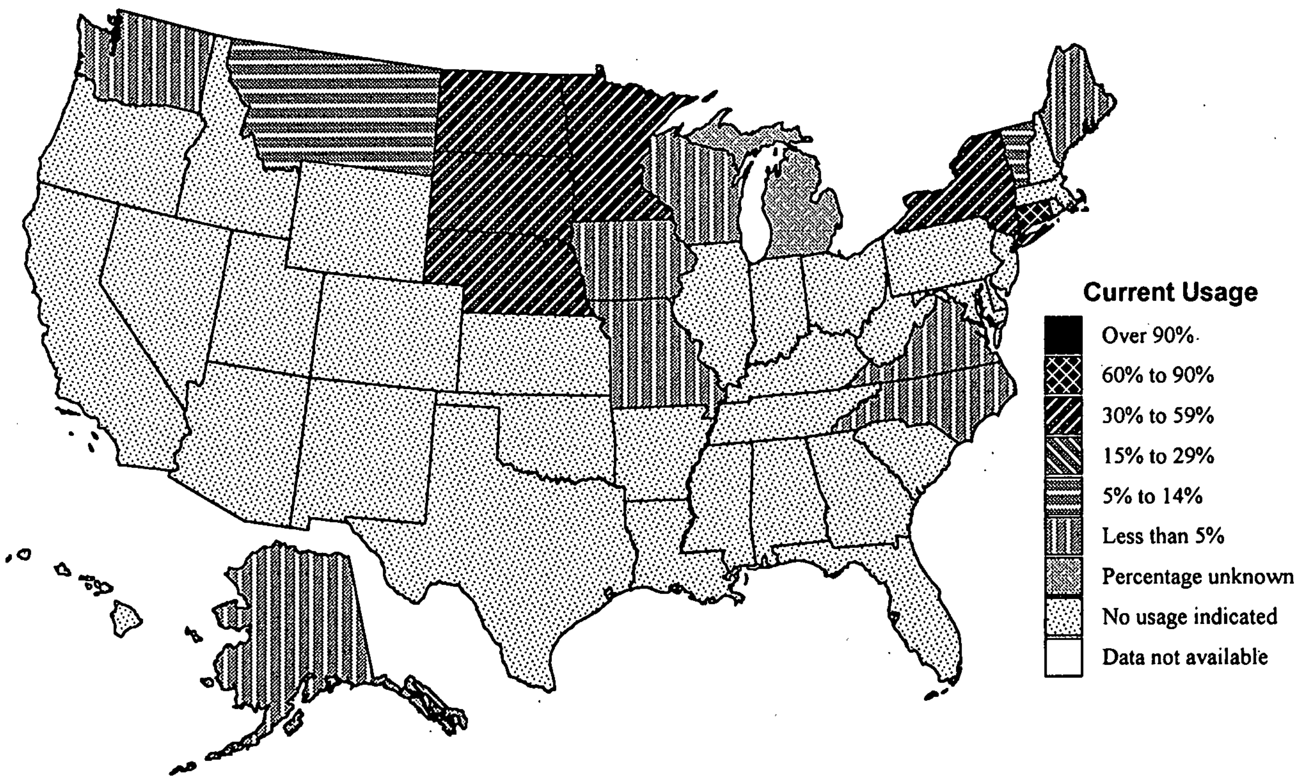


FIGURE 21 States currently installing three-cable guardrails.

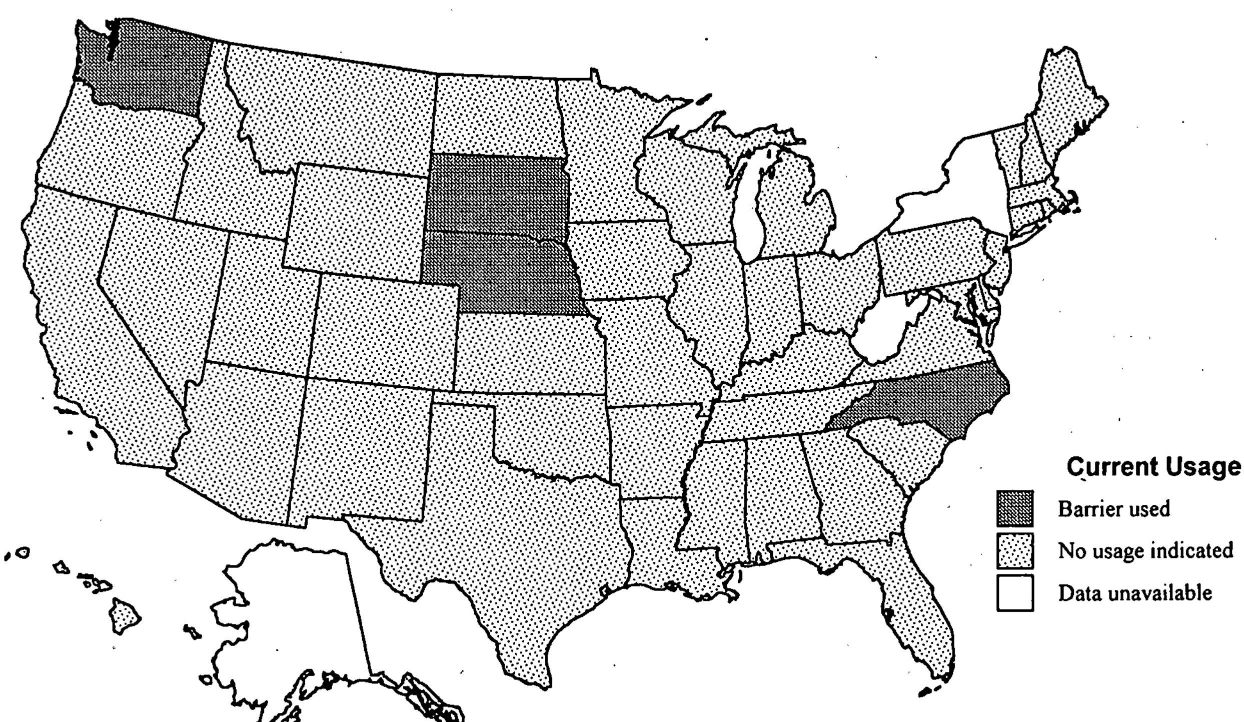


FIGURE 22 States currently installing three-cable median barriers.

TABLE 13

NCHRP REPORT 230 CRASH TESTS OF WEAK STEEL-POST THREE-CABLE GUARDRAIL (SGR01a)

	Test Number		
	10	12	S13
Impact condition			
System	SGR01a	SGR01a	SGR01a
Test number	100	GR-5	GR-16
Test contractor	NY-DOT	SwRI	SwRI
Impact velocity (km/hr)	92.9	97.4	95.3
Impact angle (degrees)	23.0	15.8	19.5
Vehicle type	4500S	1800S	1800S
Vehicle mass (kg)	2168	NR	NR
Structural adequacy			
A. Smooth redirection	Smooth	Smooth	Smooth
Dynamic deflection (mm)	2400	1100	1770
D. Detached elements	NR	None	None
Evaluation	Pass	Pass	Pass
Occupant risk			
E. Vehicle remains upright	Yes	Yes	Yes
F. Occupant risk			
Lateral impact velocity (m/sec)	NA	3.2	3.4
Longitudinal impact velocity (m/sec)	NA	3.0	2.7
Lateral ridedown acceleration (g's)	NA	8.7	5.6
Longitudinal ridedown acceleration (g's)	NA	1.7	4.5
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
H. Intrusion into traveled way	NR	NR	None
I. Exit conditions			
Exit velocity (km/hr)	65.2	NR	No exit
Exit angle (degrees)	15.0	1.7	No exit
Evaluation	Pass	Pass	Pass
Reference	*13*	*18*	*18*

NR = not reported; NA = not applicable to this test condition; SwRI = Southwest Research Institute

guardrails, particularly the weak-post three-cable guardrail, tended to result in less severe accidents since the injury rate was half that of strong steel-post W-beam guardrails as shown in Table 11.

The performance of the standard G1 cable guardrail system (SGR01a) was also examined in Iowa in the late 1970s *(51)*. The Iowa accident and maintenance records were examined for 1977 and 1978. A total of 31 cable guardrail collisions were found in the accident data, 1 fatal accident with 1 fatally injured vehicle occupant and 4 injury accidents with a total of 10 injured vehicle occupants. The average property damage in terms of dollars per collision was calculated for the cable guardrail and all guardrails. The average property damage loss in cable guardrail accidents from 1977 through 1978 was $1,874, $760 less than the average property damage loss for guardrails in general. Of the 31 police-reported accidents, the vehicle penetrated the barrier in 7 cases (23 percent), a surprisingly high proportion of barrier penetration although consistent with the New York study (Table 11). Another interesting aspect of this study was that the maintenance records indicated that 58 cable guardrails had been repaired in the same period. This fact suggests that 27 accidents caused damage to guardrails but were not reported to the police. The average repair cost after a cable guardrail impact was $114 for materials and $98 for labor resulting in a total repair cost of $212 per cable guardrail accident from 1977 through 1978. An average of six posts were replaced after an accident, indicating an average length of contact with the barrier of about 30 m. The study concluded that cable guardrails were performing adequately and seem to result in accidents that are less severe and less costly.

The modified South Dakota (SGR01b) cable guardrail is similar to the G1 cable guardrail system except that it uses lighter, somewhat more economical posts. The South Dakota cable guardrail system is closely modeled after the typical weak steel-post three-cable guardrail (SGR01a) described in the *Roadside Design Guide*, the only difference being the type of post used *(2)*. A series of full-scale crash tests performed in late 1986 and early 1987 confirmed that barrier performance was acceptable when a 6-kg/m flanged-channel post (hat shape) made of rail steel was substituted for the standard S75×8.5 steel post *(49,52)*. Tests were conducted with both small and large cars to demonstrate conformance with the guidelines in Report 230, and the results are summarized in Table 15 *(7)*. A 200- by 600-mm soil plate was bolted to the post, and a top rail height of 760 mm was used in this original series of tests. In 1989, two additional tests were

TABLE 14

NCHRP REPORT 350 TEST LEVEL 3 CRASH TESTS OF WEAK STEEL-POST-THREE-CABLE GUARDRAIL (SGR01a)

	Test Number	
	3-10	3-11
Impact condition		
System	SGR01a	SGR01a
Test number	GR-16	471470-28
Test contractor	SwRI	TTI
Impact velocity (km/hr)	95.3	95.1
Impact angle (degrees)	19.5	26.7
Vehicle type	820C	2000P
Vehicle inertial mass (kg)	NR	2000
Vehicle gross mass (kg)	905	2075
Structural adequacy		
A. Containment	Yes	Yes
Vehicle response	Smooth	Smooth
Dynamic deflection (mm)	1770	2400
Evaluation	Pass	Pass
Occupant risk		
D. Compartment penetration	None	None
F. Vehicle remains upright	Yes	Yes
H. Occupant impact velocity		
Lateral impact velocity (m/sec)	3.4	NA
Longitudinal impact velocity (m/sec)	2.7	NA
I. Occupant ridedown acceleration		
Lateral ridedown acceleration (g's)	5.6	NA
Longitudinal ridedown acceleration (g's)	4.5	NA
Evaluation	Pass	Pass
Vehicle trajectory		
K. Intrusion into traveled way	None	Minimal
L. Longitudinal occupant risk		
Impact velocity (m/sec)	NA	4.3
Ridedown acceleration (g's)	NA	4.0
M. Exit angle (degrees)	No exit	2.0
Evaluation	Pass	Pass
Reference	*18*	*13*

TTI = Texas Transportation Institute

TABLE 15

NCHRP REPORT 230 CRASH TESTS OF FLANGED-CHANNEL POST THREE-CABLE GUARDRAIL (SGR01b)

	Test Number	
	10	S13
Impact condition		
System	SGR01b	SGR01b
Test number	SD-2	SD-3
Test contractor	SwRI	SwRI
Impact velocity (km/hr)	96.0	98.0
Impact angle (degrees)	25	21
Vehicle type	4500S	1800S
Vehicle mass (kg)	2900	860
Structural adequacy		
A. Smooth redirection	Yes	Yes
Dynamic deflection (mm)	3000	1900
D. Detached elements	None	None
Evaluation	Pass	Pass
Occupant risk		
E. Vehicle remains upright	Yes	Yes
F. Occupant risk		
Lateral impact velocity (m/sec)	NA	4.0
Longitudinal impact velocity (m/sec)	NA	2.0
Lateral ridedown acceleration (g's)	NA	5.0
Longitudinal ridedown acceleration (g's)	NA	2.0
Evaluation	Pass	Pass
Vehicle trajectory		
H. Intrusion into traveled way	No	No
I. Exit conditions		
Exit velocity (km/hr)	0.0	0.0
Exit angle (degrees)	0.0	0.0
Evaluation	Pass	Pass
Reference	*48*	*48*

TABLE 16

NCHRP REPORT 230 CRASH TESTS OF WEAK WOOD-POST THREE-CABLE GUARDRAIL (SGR01c)

	Test Number		
	10	12	S13
Impact condition			
System	SGR01c	SGR01c[a]	SGR01c
Test number	1769-C-4-87	4798-2	1769-C-3-87
Test contractor	ENSCO	TTI	ENSCO
Impact velocity (km/hr)	101	95.4	99
Impact angle (degrees)	26	14.5	20
Vehicle type	4500S	1800S	1800S
Vehicle mass (kg)	2041	857	814
Structural adequacy			
A. Smooth redirection	Yes	Rolled	Yes
Dynamic deflection (mm)	2440	920	1370
D. Detached elements	NR	NR	NR
Evaluation	Pass	Fail	Pass
Occupant risk			
E. Vehicle remains upright	Yes	No	Yes
F. Occupant risk			
Lateral impact velocity (m/sec)	NA	4.7	4
Longitudinal impact velocity (m/sec)	NA	7.4	4
Lateral ridedown acceleration (g's)	NA	7.2	10
Longitudinal ridedown acceleration (g's)	NA	12.8	6
Evaluation	Pass	Fail	Pass
Vehicle trajectory			
H. Intrusion into traveled way	NR	None	NR
I. Exit conditions			
Exit velocity (km/hr)	NR	Rolled	77
Exit angle (degrees)	NR	90	10
Evaluation	Pass	Fail	Pass
Reference	*55*	*41*	*55*

[a]The post in this test did *not* have weakening hole.

conducted on this system with a smaller trapezoidal soil plate and no performance problems were observed *(49)*. The flanged-channel post cable guardrail system (SGR01b) has not been tested according to Report 350, although it is expected that the performance would be similar to the S75×8.5-post system. FHWA developed a pocket maintenance guide for this system *(53)*.

The 130-mm-diameter wood-post cable guardrail with no weakening hole was developed in the late 1960s and is still used in several midwestern states and in Canada, most notably Minnesota and Ontario. It was given in Report 118 as a "Research and Development" system, based on the results of a single full-scale test *(26)*. While not listed in Report 118, the system had also been tested in Ontario with essentially similar results although the Canadian system was tested with several side slope and slope rounding geometries *(54)*. That report lists a design deflection of 2130 mm for the wood-post system, somewhat stiffer than the steel-post G1 (SGR01a) guardrail. This same barrier was still classified as a Research and Development barrier in the 1977 AASHTO Barrier Guide, based on the lack of additional full-scale crash tests *(20)*. Characteristics of this barrier are also discussed in the AASHTO *Roadside Design Guide (2)*. Full-scale tests performed in 1985 confirmed that the performance of this wood-post system was acceptable in the standard strength test with a large sedan, but a small-car resulted in a rollover for Test 12, as shown in Table 16 *(41)*. This behavior was attributed to excessive strength of the posts in the longitudinal direction. A subsequent study determined that modifying the wood posts by boring a 40-mm-diameter hole parallel to the cables and located 125 mm below grade resulted in satisfactory performance for both the small- and large-car tests, as shown in Table 16 *(55)*. The weak wood-post system, shown in Figure 23, has not been tested using Report 350 guidelines.

In an attempt to complete the design, a series of terminals were developed and tested, all without success. None of the alternate wood-post terminal designs was able to provide adequate anchorage for the system without resulting in rollovers for small cars that struck near the departure end of the barrier. The mid-section of this barrier is capable of providing acceptable impact performance, but a terminal capable of acceptable performance for high-speed impacts has not yet been developed. The modified New York cable terminal could be used with the Minnesota wood-post system to provide a crashworthy system on high-speed facilities *(56)*.

The increasing popularity of passenger vehicles with aerodynamic styling featuring a sloping front has caused concern

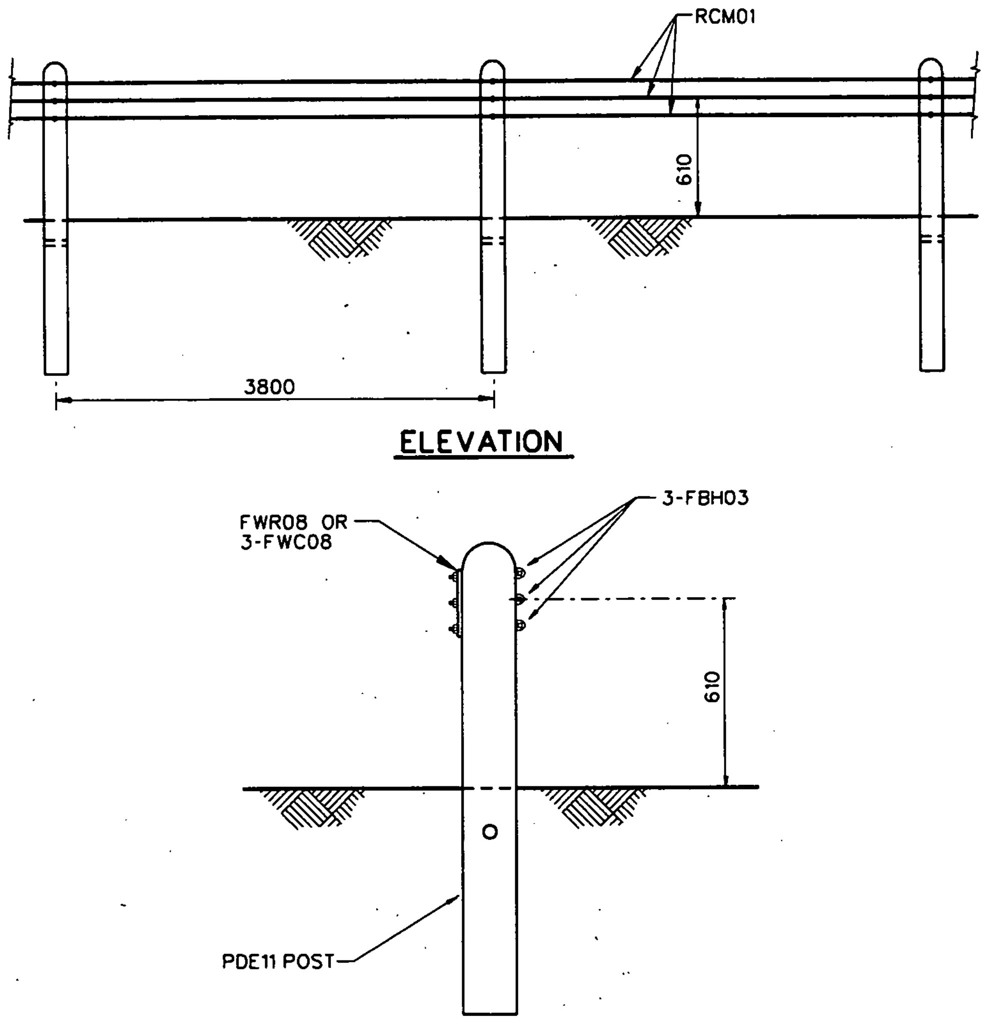


FIGURE 23 Weakened wood-post three-cable guardrail barrier (SGR01c) *(22)*.

among some researchers. There has been anecdotal evidence that such vehicles sometimes strike cable guardrails, resulting in the cable sliding up the side of the vehicle and cutting through the A-pillar and penetrating the passenger compartment *(57)*. While the potential for severe collisions seems apparent, this behavior has not been observed in full-scale crash tests of sloped-front vehicles and cable guardrails *(58)*.

Although three-cable guardrails have been the most common type of cable guardrail and median barrier system, some recent research has suggested that two-cable guardrails may be effective on low-volume rural roads *(58)*. Full-scale tests were performed on two-cable guardrails using S75×8.5 steel posts, 6-kg/m flanged-channel posts, and 130-mm-diameter wood posts. All the tests corresponded to neither Report 230 or Report 350. The two-cable systems with all three types of posts were considered to have good impact performance.

Applications

One of the key advantages of cable guardrails is their low installation cost. The average installation cost for steel-post cable guardrail (SGR01a) is $35/meter and can be as low as $15 per meter when flanged-channel posts are used (SGR01b). Wood-post cable guardrails have an average cost of $19/meter. Cable systems have the lowest installation cost of guardrails and median barriers as shown in Table 7.

Although their low installation cost makes cable guardrails attractive, their presumed higher maintenance costs are a disadvantage. Ensuring that the cables remain at an acceptable tension is important for the proper functioning of the barrier system. According to a study by the New York Department of Transportation (NYDOT), cables continuously lose tension and therefore must be retensioned periodically to maintain a system's integrity *(59)*. This tensioning must be monitored and performed by trained maintenance crews, which can entail significant annual expense. Unfortunately, no states provided maintenance cost information for cable guardrails. The state of New York examined several alternatives to reduce problems with slack guardrail cables *(60)*. The systems generally experienced the most tension loss in the first winter after installation. If the barrier cables are retensioned after the first year, the rate of tension loss will be much less in subsequent years. Substituting prestretched cable for normal cable did not greatly reduce the tension loss problem, the prestretched and normal cable experiencing very similar rates of tension loss. Periodic retensioning, perhaps every 2 years, is the only known method for maintaining proper tension in the cables.

Most accident repairs do not require heavy equipment, and replacement posts can be installed using manual equipment without the need to auger or otherwise excavate post holes. The average cost of repairing a cable guardrail after an accident is only $250, the lowest repair cost of all guardrail types included in the state survey (Table 9). Though no data are available to demonstrate it, many state departments of transportation (DOTs) consider the total life-cycle cost of cable guardrails less even when higher maintenance costs are included. Other state DOTs, however, believe that the life-cycle cost is higher since it is presumed that, given the same severity of collision, cable guardrail is damaged more heavily than some other types of barriers would be. The increased amount of barrier damage, coupled with the extra cost of maintaining good cable tension, may make the life-cycle cost higher.

Cable guardrails are ideal for applications where there is adequate room for the barrier to deflect in an impact. It is especially well-suited for low-volume roadways on which a lower probability of roadside encroachments makes it difficult to justify higher cost traffic barriers. In addition, the three-cable guardrail and median barrier is considered a Report 350 Test Level 3 barrier, whereas some other weak- and strong-post guardrails have passed the Test Level 2 tests. As long as adequate deflection space is available behind the barrier, this low-cost barrier provides protection fully equivalent to higher-cost light-post guardrails. Damage to the barrier from even moderately severe impacts requires that repairs be completed before the barrier is again effective. For higher volume roadways on which collisions are more frequent, this need for prompt repair may cause difficulties for maintenance workers. If good response time cannot be ensured, however, this barrier may be at a disadvantage compared with barriers that remain functional even after an impact.

Cable guardrails have other advantages besides low installation cost and good crash test performance. A major advantage in states that experience heavy snowfall is its very slender cross section. Since it presents almost no wind resistance, it does not cause snow drifts to accumulate on the roadway as do some strong-post guardrail systems (Appendix C, Question 18). In addition, snow can be pushed through the guardrail during plowing operations so the barrier is not damaged. Even more important, a snow berm is not built up in front of the guardrail, which could result in a vehicle being launched over the guardrail. This particular feature is one of the primary reasons that this system is so popular in upper midwestern states. These advantages, however, are accompanied by some disadvantages. Snowplows sometimes unintentionally strike and bend or break off cable guardrail posts. When the snow and ice are particularly wet and heavy, the spray from plows may also damage the cable guardrails.

Cable guardrails are an attractive alternative for scenic areas since they present almost no impediment to the view from the roadway. Sight distance is also improved with cable guardrails since the rail does not obstruct a driver's vision. Weathering steel or painted posts may be used with this system to enhance its suitability for aesthetically sensitive locations. Most states that use weathering steel posts require that the part of the post embedded in the soil be galvanized since direct contact with the soil will quickly deteriorate uncoated steel.

Weak-post cable guardrails are often used as median barriers on wide medians to prevent deliberate U-turns as well as median cross-over accidents. When used in a wide median, the middle cable should be placed on the opposite side of the post to ensure that at least one cable maintains good contact with the striking vehicle. Another application well-suited to this barrier is installation on gentle side slopes such as occur on roadways built with a "barnroof" cross section. It is generally accepted, however, that barrier installation on steep slopes should be avoided, because the effect on vehicle-barrier height interaction may result in override or underride. However, full-scale tests have indicated that the cable systems may be less prone to override than W-beam barriers, and thus may offer some advantage for installation on gentle side slopes.

When cable median barriers are used in narrower medians on high-volume, high-speed facilities, maintenance and repair can expose workers to risk of injury and can slow traffic. Since the cable barrier is more flexible, it may sustain a relatively large amount of damage that requires workers to remain on the median for a long time.

Developing effective and safe terminals has proven to be a difficult design problem for all types of longitudinal barriers including cable guardrails. Cable guardrail terminals usually slope down and are attached to a concrete anchor that is buried in the ground. Although typical cable guardrail terminals provide adequate anchorage in collisions with the mid-length of the barrier, they sometimes cause the vehicle to roll over if the impact is very near the end of the guardrail. The state of New York developed a cable terminal to improve the performance in "reverse direction" impacts near the end of the guardrail *(56)*. Although the performance of this terminal still leaves room for improvement in terms of making end-on collisions less severe, it is the best available terminal design for cable guardrails.

Summary

Weak-post cable guardrails have been very popular in northern states that must deal with snowy conditions. Cable guardrails and median barriers do not act like snow fences; they allow plowed snow to pass between the cables without building up in front of the guardrail. Cable guardrails and median barriers are inexpensive to install, have good crash test performance when given adequate room to deflect in an impact, and have other less tangible benefits such as improved sight distance, better aesthetics, and lower probability of causing berms to accumulate. Because of the their low installation cost, cable guardrails can often be installed on lower volume roadways where a more expensive barrier might not be cost-effective. These benefits, however, are accompanied by some disadvantages, including more damaged rail after a typical impact, the need to retension cables periodically, and the need to repair or replace damaged installations quickly since a damaged cable guardrail is ineffective until completely repaired. The maintenance and repair difficulties may make cable guardrails less attractive on urban roadways, where frequent collisions could become a nuisance.

The weak wood-post three-cable guardrail (SGR01c) is used only in Minnesota and a few Canadian provinces. Whereas the wood-post three-cable guardrail has acceptable Report 230 crash test performance, it is not clear if it would satisfy the Report 350 Test Level 3 conditions. There are also no successfully crash-tested terminals for the weak wood-post three-cable guardrail, so ending the guardrail can be problematic. The weak wood-post three-cable guardrail has not been tested according to the Report 350 recommendations, and it is expected that this system will decline in use in the coming decades.

Both the S-section and flanged-channel steel-post three-cable systems demonstrated acceptable Report 230 performance in crash tests. The S-section steel-post three-cable guardrail (SGR01a) has passed the Report 350 Test Level 3 crash tests and should continue to be a popular weak-post guardrail system in the coming decades. A crashworthy terminal is available for the steel-post design, but further work on better performing cable guardrails is still needed.

WEAK-POST W-BEAM GUARDRAILS AND MEDIAN BARRIERS

System Description

The weak-post W-beam guardrail and median barrier—called the G2 guardrail and the MB2 median barrier in the

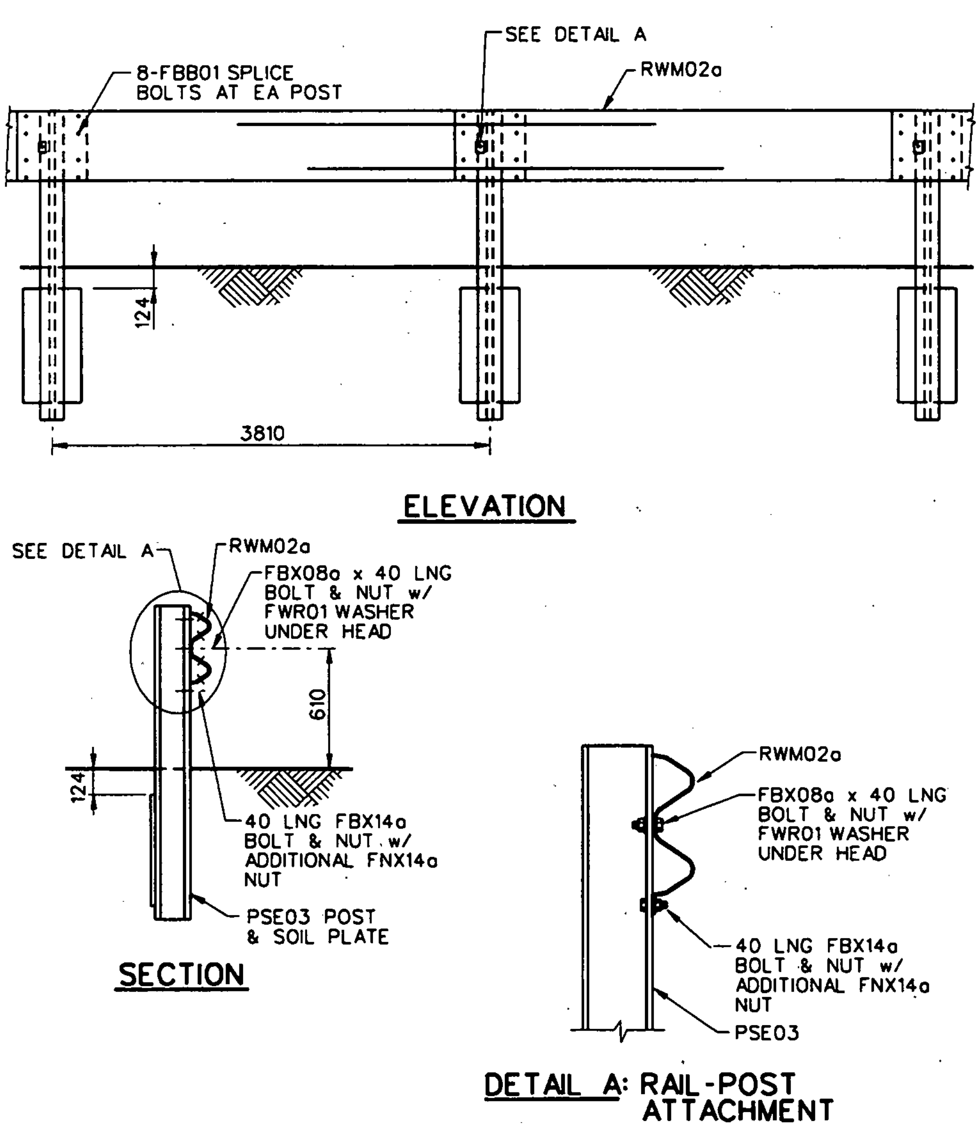


FIGURE 24 Weak-post W-beam guardrail (SGR02) *(22)*.

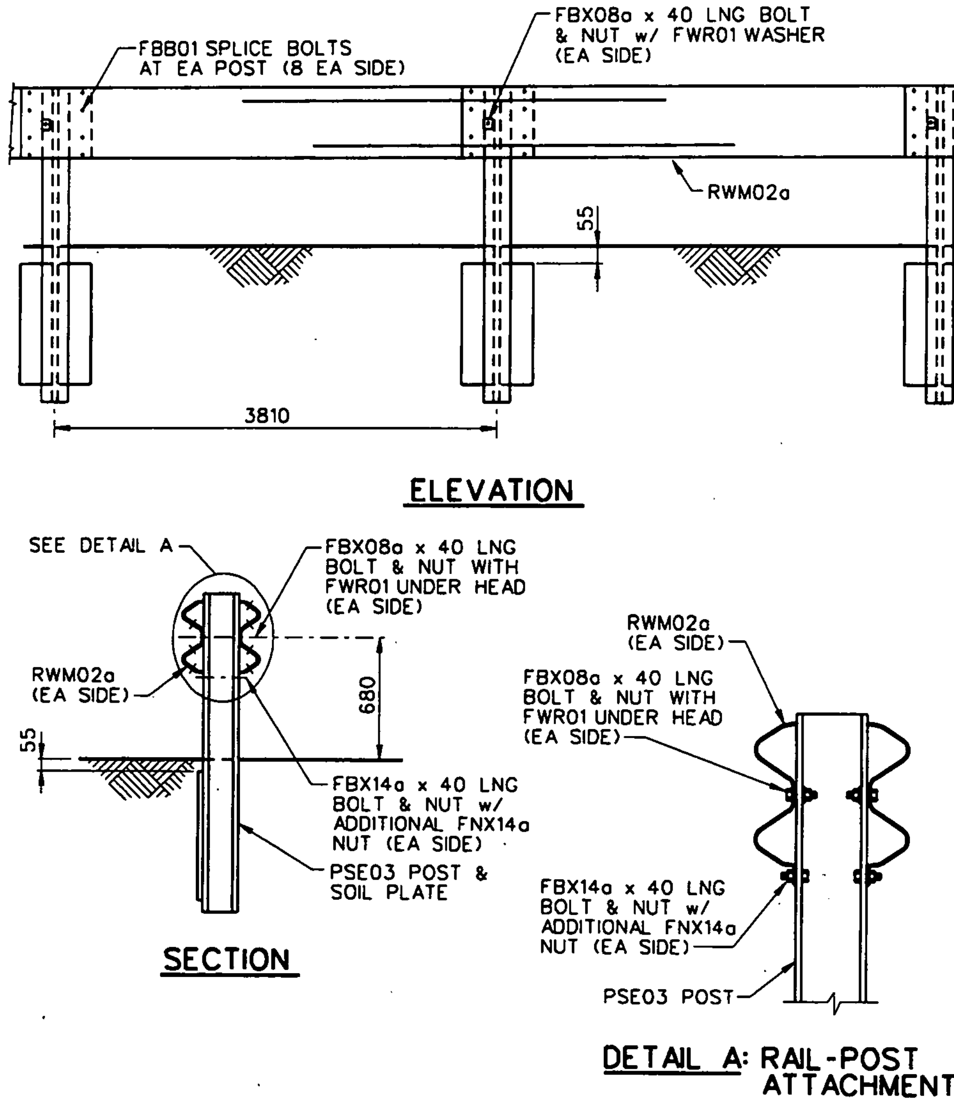


FIGURE 25 Weak-post W-beam median barrier (SGM02) *(22)*.

1997 AASHTO Barrier Guide—were pioneered by the state of New York in the early 1960s *(13,20)*. The weak-post W-beam guardrail and median barrier are composed of weak-post W-beam guardrails supported on weak S75×8.5 steel posts with rectangular soil plates. Figures 24 and 25 show design details for the weak-post W-beam guardrail and median barrier.

The weak-post W-beam guardrail performs much like the cable guardrail: the posts hold up the rail at the proper height, and on impact the weak posts break or bend away from the rail. The posts are spaced at 3810 mm, and the rail is connected to the post using 8-mm bolts with 44-mm^2 washers under the head. The bolts are designed to fail in an impact, allowing the rail to separate from the post. The rail separating from the post is an important feature of the design since this action allows the vehicle bumper to remain in contact with the rail. Once the rail is separated from the post, the W-beam section redirects the vehicle, acting like a cable that is anchored at the ends.

Since the rail-to-post attachment bolts are designed to fail and separate from the post, the load experienced by the rail when snow and ice are plowed against it can sometimes cause the bolt to fail and the rail to fall to the ground. The 14-mm-diameter bolt located just below the W-beam in Figure 24 is intended to help support the rail under snow loadings.

The 1997 Barrier Guide also showed a 150-mm-diameter circular wood-post version of the weak-post W-beam guardrail, but a study performed in the 1960s and 1970s demonstrated that the performance of this barrier type was unsatisfactory *(54,61)*. When a circular wood post is used, the post-to-rail connection bolt must be relatively long. During an impact, the connection bolt tended to bend and deform inside the hole in the wood post but without failing. Since the bolt did not fail, the rail was pulled down to the ground as the post rotated in the soil, allowing the vehicle to override the barrier. The weak wood-post W-beam guardrail has largely disappeared from the national barrier inventory over the past 20 years because of this substandard performance.

A full-scale test was performed on a weak-post W-beam guardrail using a 6-kg/m flanged-channel post rather than the

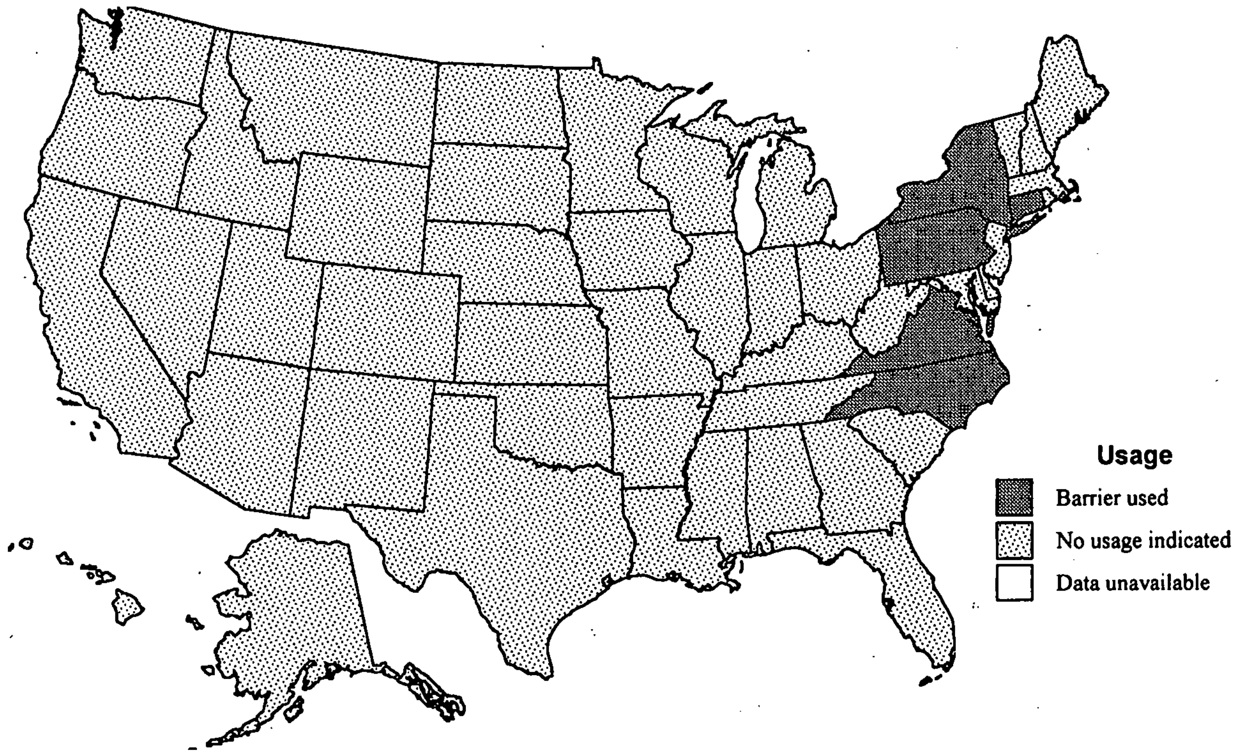


FIGURE 26 States currently installing the weak-post W-beam guardrail (SGR02) and the weak-post W-beam median barrier (SGM02).

S75×8.5 steel post normally used in an attempt to develop less expensive guardrails for low-volume rural roads *(58)*. Although the crash test performance was satisfactory, the test was performed at 80 km/hr and used a 1500-kg midsize passenger car, so the test corresponded to neither Report 230 or Report 350.

Distribution

Figure 26 shows the states that use the weak-post W-beam guardrail and the weak-post W-beam median barrier. Both systems are used in the east: New York, Pennsylvania, and Connecticut in particular. Every state that uses the weak-post W-beam guardrail also uses the weak-post W-beam median barrier.

Crashworthiness

The weak-post W-beam guardrail has been successfully crash tested using a variety of procedures over the past 30 years *(19,26)*. The crash test performance in Report 230 for the weak-post W-beam guardrail is summarized in Table 17. The system has satisfied the Report 230 crash tests, resulting in dynamic lateral deflections of about 2200 mm in the large-car Report 230 test (Test 10).

More recent crash tests have shown that newer vehicle types such as pickup trucks and vans pose performance problems for this barrier. A test of a large van documented in Report 289 first suggested that there might be problems with non-standard test vehicles when the van rolled over in a 100-km/hr collision *(18)*. A Test Level 3 crash test with the 2000-kg pickup truck recommended in Report 350 also resulted in the pickup truck riding over the barrier in a 100-km/hr crash test, as shown in Table 18 *(62)*. The Report 350 Test Level 2 test using the 2000-kg pickup truck was successful (Table 19). The performance in Report 350 crash tests for the weak-post W-beam guardrail are summarized in Table 18 for Test Level 3 and Table 19 for Test Level 2. It appears, therefore, that the weak-post W-beam guardrail only satisfies Report 350 Test Level 2 *(63)*.

The poor performance of this system in the Report 350 Test Level 3 pickup truck tests presents a serious problem for the future use of this barrier on higher speed, higher volume roadways. To date, no guidelines have been developed for using barriers based on their test levels, but it is expected that, on the basis of crash tests described in Tables 18 and 19, the use of the weak-post W-beam guardrail may not be acceptable on some higher volume, higher speed roadways.

Applications

The weak-post W-beam guardrail (SGR02) and median barrier (SGM02) usually should be used in applications where there is 2500 mm of clear area behind the barrier. Like cable guardrails, the weak-post W-beam guardrail is often used to shield steep side slopes or prevent median crossings. Some

TABLE 17

NCHRP REPORT 230 CRASH TESTS OF WEAK-POST W-BEAM GUARDRAIL (SGR02)

	Test Number		
	10	12	S13
Impact condition			
System	SGR02	SGR02	SGR02
Test number	105[a]	GR-3	GR-8
Test contractor	SwRI	SwRI	SwRI
Impact velocity (km/hr)	95	96	94
Impact angle (degrees)	28	15	19
Vehicle type	4500S	1800S	1800S
Vehicle mass (kg)	1838	842	889
Structural adequacy			
A. Smooth redirection	Airborne	Smooth	Smooth
Dynamic deflection (mm)	2230	410	805
D. Detached elements	NR	None	None
Evaluation	Pass	Pass	Pass
Occupant risk			
E. Vehicle remains upright	Yes	Yes	Yes
F. Occupant risk			
Lateral impact velocity (m/sec)	NA	5.3	4.5
Longitudinal impact velocity (m/sec)	NA	None	1.6
Lateral ridedown acceleration (g's)	NA	14.7	9.4
Longitudinal ridedown acceleration (g's)	NA	None	None
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
H. Intrusion into traveled way	Yes	None	None
I. Exit conditions			
Exit velocity (km/hr)	NR	81	89
Exit angle (degrees)	-9	-2	1
Evaluation	Pass	Pass	Pass
Reference	*19*	*18*	*18*

[a]This test was conducted before publication of Report 230, so all Report 230 evaluation criteria are not reported.

reduction in dynamic deflection can be achieved by reducing the post spacing, although the rail can be attached to the posts only where there are holes punched, usually every 1905 mm.

Weak-post W-beam guardrails and median barriers are relatively inexpensive to install, with typical costs of \$31/meter for guardrails and \$43/meter for median barriers, as shown in Table 7. Only one state responded with a typical accident cost value for the weak-post W-beam guardrail (Table 9), but this was also at the low end of the range (\$250/accident) of repair costs for guardrails and median barriers. This type of barrier is therefore one of the least costly alternatives in terms of its installation and repair costs.

As with other weak-post W-beam guardrails and median barriers, a typical collision results in more barrier damage than would be the case for a stiffer barrier system. The lower installation and repair costs, therefore, may be counterbalanced by a need to repair more barrier damage after a collision.

Suitable terminals are another problem area for this type of guardrail and median barrier. Most states use turned-down ends or buried-in-backslope designs to terminate weak-post W-beam guardrails. A September 29, 1994, FHWA memorandum now prohibits the use of turned-down end terminals even with weak-post guardrails on high-speed Federal-aid projects *(64)*. This memo recommends using a modified eccentric loader terminal (MELT) with a transition between the strong-post terminal and the weak-post line guardrail. This alternative is not a particularly attractive one since it places a strong, stiff, relatively expensive terminal at the end of a flexible lower cost barrier. The only acceptable method of terminating the weak-post W-beam guardrail right now is to bury the end in a backslope or attach it to a rock cut. Weak-post W-beam guardrail terminals that satisfy the Report 350 recommendations for at least Test Level 2 will need to be developed if the weak-post W-beam guardrail is to remain a viable guardrail and median barrier system in the future.

Summary

The low installation cost of the weak-post W-beam guardrail and median barrier make it an attractive option especially on lower volume roadways where a higher cost system might not be cost-effective. Similar to other weak-post barrier systems, the large dynamic deflection results in relatively small occupant forces, although the area behind the rail must be kept clear of objects. The system has acceptable Report 230 performance. The weak-post W-beam passed the Report 350

TABLE 18

NCHRP REPORT 350 TEST LEVEL 3 CRASH TESTS OF WEAK-POST W-BEAM GUARDRAIL (SGR02)

	Test Number	
	3-10	3-11
Impact condition		
System	SGR02	SGR02
Test number	GR-8	7147-21
Test contractor	SwRI	TTI
Impact velocity (km/hr)	94.0	99.8
Impact angle (degrees)	19	24.4
Vehicle type	820C	2000P
Vehicle inertial mass (kg)	NR	2000
Vehicle gross mass (kg)	889	2076
Structural adequacy		
A. Containment	Yes	No
Vehicle response	Smooth	Override
Dynamic deflection (mm)	805	2400
Evaluation	Pass	Failed
Occupant risk		
D. Compartment penetration	None	None
F. Vehicle remains upright	Yes	Yes
H. Occupant impact velocity		
Lateral impact velocity (m/sec)	4.5	NA
Longitudinal impact velocity (m/sec)	1.6	NA
I. Occupant ridedown acceleration		
Lateral ridedown acceleration (g's)	9.4	NA
Longitudinal ridedown acceleration (g's)	–	NA
Evaluation	Pass	Pass
Vehicle trajectory		
K. Intrusion into traveled way	None	None
L. Longitudinal occupant risk		
Impact velocity (m/sec)	NA	4.1
Ridedown acceleration (g's)	NA	4.2
M. Exit angle (degrees)	1.0	0.0
Evaluation	Pass	Pass
Reference	*18*	*62*

TABLE 19

NCHRP REPORT 350 TEST LEVEL 2 CRASH TESTS OF WEAK-POST W-BEAM GUARDRAIL (SGR02)

	Test Number	
	2-10	2-11
Impact condition		
System	SGR02	SGR02
Test number	GR-8	7147-22
Test contractor	SwRI	TTI
Impact velocity (km/hr)	94	71.0
Impact angle (degrees)	19	26.1
Vehicle type	820C	2000P
Vehicle inertial mass (kg)	NR	2000
Vehicle gross mass (kg)	889	2076
Structural adequacy		
A. Containment	Yes	Yes
Vehicle response	Smooth	Smooth
Dynamic deflection (mm)	805	1400
Evaluation	Pass	Pass
Occupant risk		
D. Compartment penetration	None	None
F. Vehicle remains upright	Yes	Yes
H. Occupant impact velocity		
Lateral impact velocity (m/sec)	4.5	NA
Longitudinal impact velocity (m/sec)	1.6	NA
I. Occupant ridedown acceleration		
Lateral ridedown acceleration (g's)	9.4	NA
Longitudinal ridedown acceleration (g's)	–	NA
Evaluation	Pass	Pass
Vehicle trajectory		
K. Intrusion into traveled way	None	None
L. Longitudinal occupant risk		
Impact velocity (m/sec)	NA	4.1
Ridedown acceleration (g's)	NA	4.8
M. Exit angle (degrees)	1	9.5
Evaluation	Pass	Pass
Reference	*18*	*63*

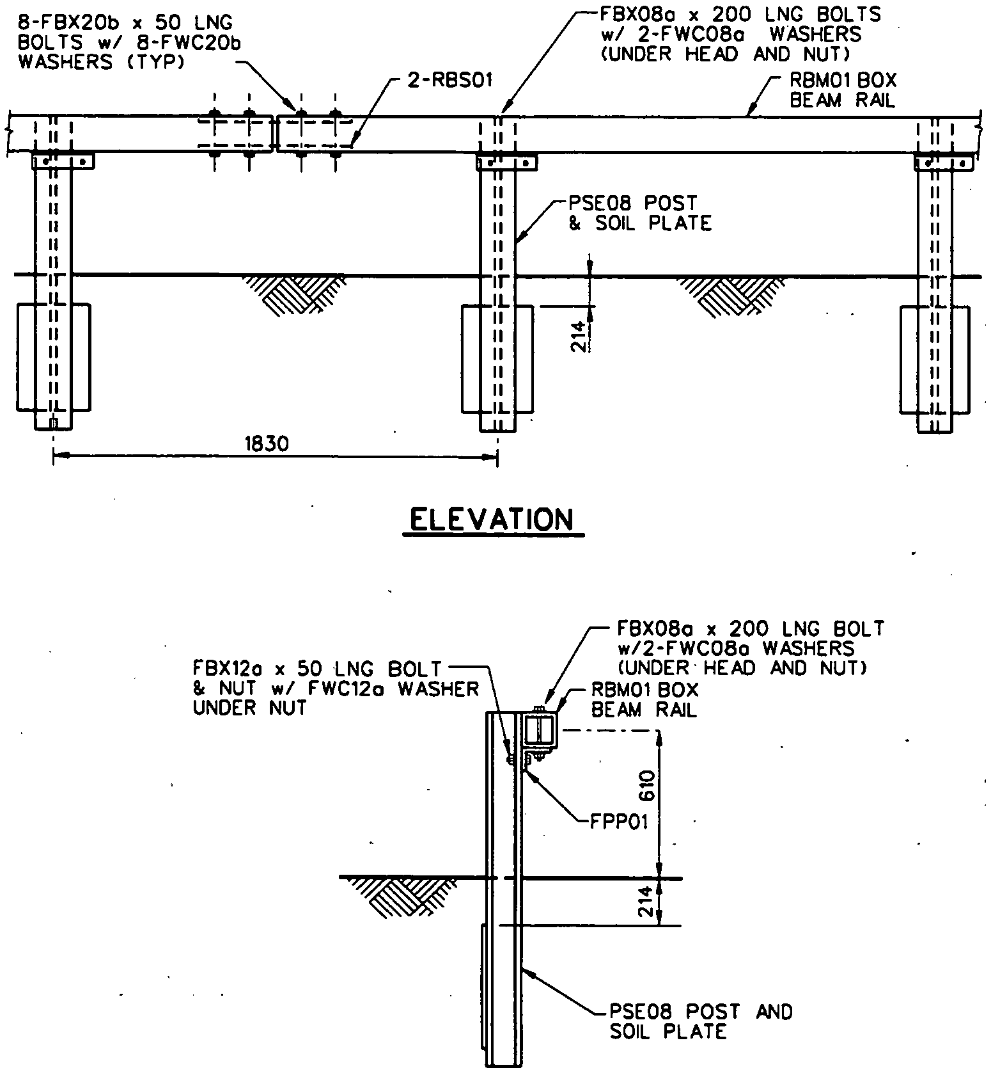


FIGURE 27 Weak-post box-beam guardrail (SGR03) *(22)*.

Test Level 2 crash tests but failed the more demanding Test Level 3 pickup truck test. In addition to these test failures, FHWA's recent policy on turned-down end treatments leaves this system without a crash-tested terminal. The future of the weak-post W-beam guardrail and median barrier is not particularly promising given the poor crash-test results with vans and pickup trucks and the lack of any acceptable terminals. Unless some improvements are made to the weak-post W-beam guardrail, it will no longer be acceptable when FHWA requires that all barrier systems satisfy Report 350, currently scheduled for late 1998. Since the systems are used in only a few states, there probably will not be any nationwide pressure for developing new terminals or improved weak-post W-beam guardrails.

WEAK-POST BOX-BEAM GUARDRAIL AND MEDIAN BARRIERS

System Descriptions

The weak-post box-beam guardrail (SGR03) consists of a TS152×152×4.78 rectangular steel tube mounted on the face of S75×8.5 steel posts spaced at 1830 mm. The rail is connected to the post using an angle bracket that is bolted to both the rail and the post. The box-beam rail height, measured to the middle of the rail, is usually set at 610 mm (Figure 27). This design was developed in the state of New York during the early 1960s *(13)*.

Usually median barrier designs are just the mirror reflection of the roadside guardrail. In the case of the box-beam median barrier, however, the median barrier version is much different from the roadside version of the barrier. In the median barrier design (SGM03), a TS203×152×6.4 rail element is mounted on the top of the S75×8.5 weak posts. The rail is not physically bolted to the post; instead, a steel plate or paddle protrudes up from the post into a slot in the rail. This arrangement allows the rail to pull free from the post in an impact and maintain its proper height during the collision. The box-beam median barrier design is shown in Figure 28. Like the box-beam guardrail, the median barrier was extensively redesigned and tested by the state of New York during the early 1960s *(13)*.

As are all weak-post guardrail and median barrier systems the box-beam guardrail and median barrier are designed such

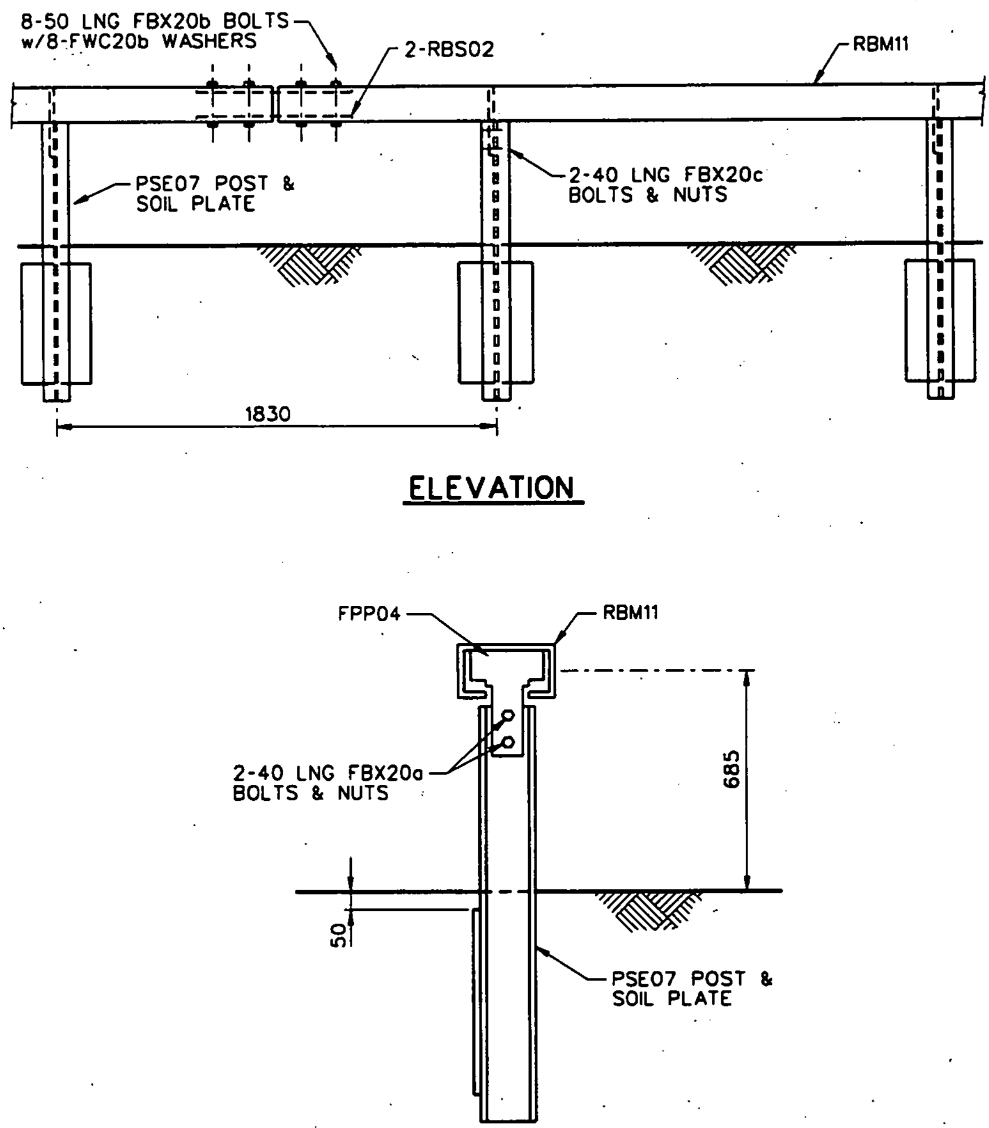


FIGURE 28 Weak-post box-beam median barrier (SGM03) *(22)*.

that the post and rail separate in an impact. The rail wraps around the vehicle's bumper and fender and redirects the vehicle as the posts dissipate energy by fracturing or bending over during the collision.

Distribution

The weak-post box-beam guardrail and median barrier systems have long histories in such northeastern states as New York and Connecticut. The box-beam systems are also used on occasion in several other states, including Tennessee, Wyoming, and Montana (Figures 29 and 30).

Crashworthiness

Box-beam median barriers and guardrails have been tested according to Report 230, as shown in Tables 20 and 21. The small-car tests (Report 230 Tests 12 and 12M) are documented in Report 289 *(18)*, and large-car tests are documented in Report 115 *(19)*. The state of California also performed crash tests of both the box-beam guardrail and the box-beam median barrier in 1967 *(65)*.

The box-beam guardrail was recently tested successfully according to Report 350 Test 3-11, the 2000-kg pickup truck striking the barrier at 100 km/hr, as shown in Table 22 *(66)*. The earlier small-car tests for Report 230 are identical to the small-car tests required for Report 350, so both the box-beam guardrail and median barrier are considered to have passed the Test Level 3 small-car tests. The Test Level 3 test for the 2000-kg pickup truck (Test 3-11) has not been performed for the median barrier.

Applications

The weak-post box-beam median barrier has been particularly popular as a median barrier on moderately narrow (e.g.,

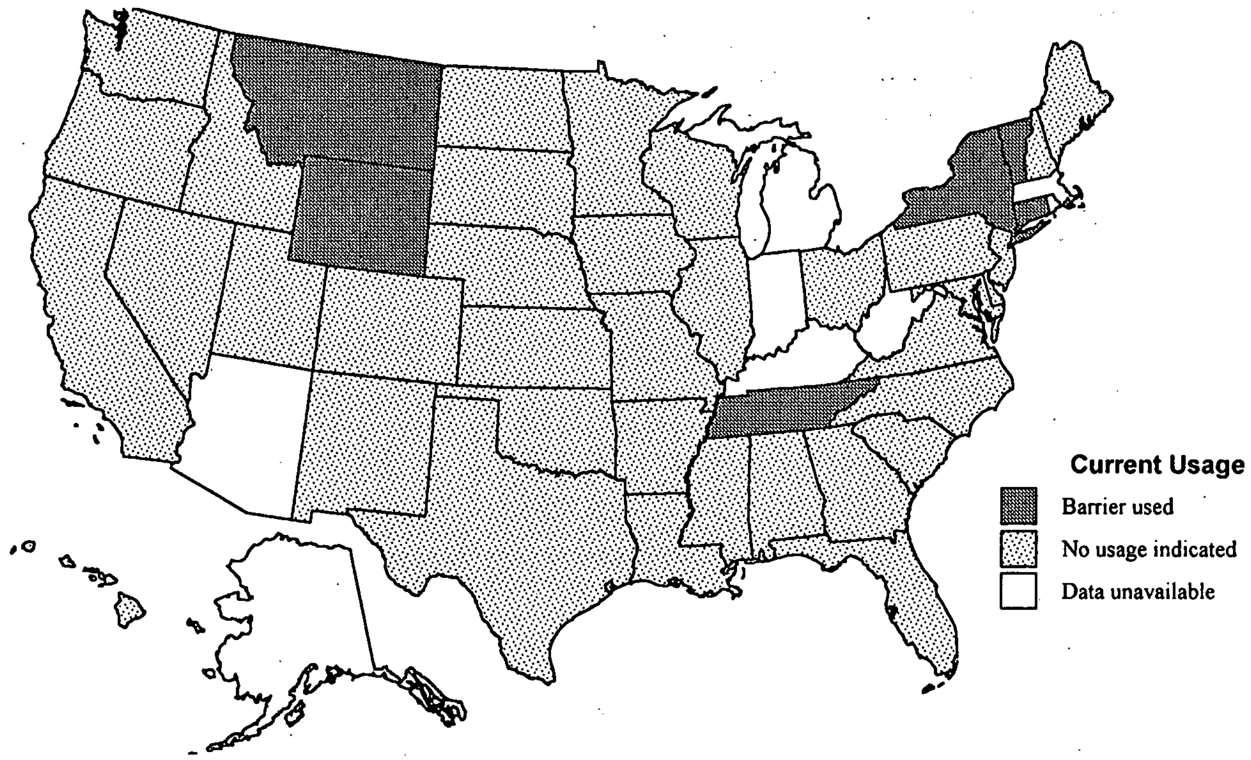


FIGURE 29 States currently installing the weak-post box-beam guardrail (SGR03).

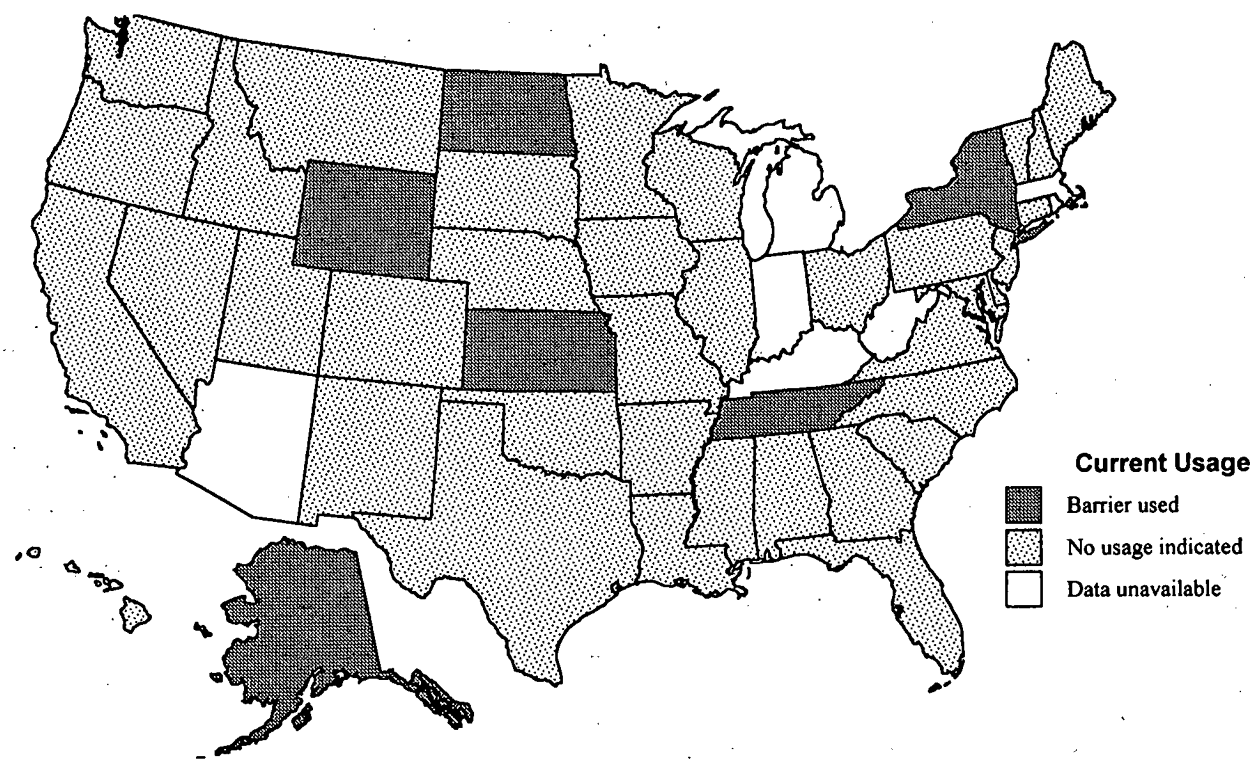


FIGURE 30 States currently installing the weak-post box-beam median barrier (SGM03).

TABLE 20

NCHRP REPORT 230 CRASH TESTS OF WEAK-POST BOX-BEAM GUARDRAIL (SGR03)

	Test Number		
	10	12	S13
Impact condition			
System	SGR03	SGR03	SGR03
Test number	114	GR-4	GR-10
Test contractor	SwRI	SwRI	SwRI
Impact velocity (km/hr)	92.9	97.2	95.4
Impact angle (degrees)	26.0	15.3	18.4
Vehicle type	4500S	1800S	1800S
Vehicle mass (kg)	1828	869	889
Structural adequacy			
A. Smooth redirection	Yes	Yes	Yes
Dynamic deflection (mm)	1460	160	400
D. Detached elements	NR	None	None
Evaluation	Pass	Pass	Pass
Occupant risk			
E. Vehicle remains upright	Yes	Yes	Yes
F. Occupant risk			
Lateral impact velocity (m/sec)	NA	5.4	5.9
Longitudinal impact velocity (m/sec)	NA	5.6	4.2
Lateral ridedown acceleration (g's)	NA	10	8.7
Longitudinal ridedown acceleration (g's)	NA	6.2	1.3
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
H. Intrusion into traveled way	No	NR	NR
I. Exit conditions			
Exit velocity (km/hr)	NR	75.3	79.7
Exit angle (degrees)	0.0	2.4	1.9
Evaluation	Pass	Pass	Pass
Reference	*19*	*18*	*18*

TABLE 21

NCHRP REPORT 230 CRASH TESTS OF WEAK-POST BOX-BEAM MEDIAN BARRIER (SGM03)

	Test Number		
	10	12	S13
Impact condition			
System	SGM03	SGM03	SGM03
Test number	112	MB-2	GR-12
Test contractor	SwRI	SwRI	SwRI
Impact velocity (km/hr)	82.1	99.1	94.1
Impact angle (degrees)	26.9	14.4	19.4
Vehicle type	4500S	1800S	1800S
Vehicle mass (kg)	1706	898	905
Structural adequacy			
A. Smooth redirection	Smooth	Smooth	Smooth
Dynamic deflection (mm)	1400	180	310
D. Detached elements	NR	NR	NR
Evaluation	Pass	Pass	Pass
Occupant risk			
E. Vehicle remains upright	Yes	Yes	Yes
F. Occupant risk			
Lateral impact velocity (m/sec)	NA	5.2	5.2
Longitudinal impact velocity (m/sec)	NA	4.2	5.4
Lateral ridedown acceleration (g's)	NA	5.9	8.5
Longitudinal ridedown acceleration (g's)	NA	3.6	9.0
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
H. Intrusion into traveled way	No	NR	NR
I. Exit conditions			
Exit velocity (km/hr)			
Exit angle (degrees)	0.0	2.6	6.2
Evaluation	Pass	Pass	Pass
Reference	*19*	*18*	*18*

TABLE 22

NCHRP REPORT 350 TEST LEVEL 3 CRASH TESTS OF WEAK-POST BOX-BEAM GUARDRAIL AND MEDIAN BARRIER (SGR03 AND SGM03)

	Test Number		
	3-10	3-11	3-10
Impact condition			
System	SGR03	SGR03	SGM03
Test number	GR-10	471470-33	GR-12
Test contractor	SwRI	TTI	SwRI
Impact velocity (km/hr)	95.4	95.2	94.1
Impact angle (degrees)	18.4	25.5	19.4
Vehicle type	1800S	2000P	820C
Vehicle gross mass (kg)	889	2076	905
Structural adequacy			
A. Containment	Yes	Yes	Yes
Vehicle response	Smooth	Smooth	Smooth
Dynamic deflection (mm)	400	1150	310
Evaluation	Pass	Pass	Pass
Occupant risk			
D. Compartment penetration	None	None	None
F. Vehicle remains upright	Yes	Yes	Yes
H. Occupant impact velocity			
Lateral impact velocity (m/sec)	5.9	NA	5.2
Longitudinal impact velocity (m/sec)	4.2	NA	5.4
J. Occupant ridedown acceleration			
Lateral ridedown acceleration (g's)	8.7	NA	8.5
Longitudinal ridedown acceleration (g's)	1.3	NA	9.0
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
K. Intrusion into traveled way	NR	Minimal	NR
L. Longitudinal occupant risk			
Impact velocity (m/sec)	NA	6.3	NA
Ridedown acceleration (g's)	NA	5.8	NA
M. Exit angle (degrees)	1.9	0.7	6.2
Evaluation	Pass	Pass	Pass
Reference	*18*	*66*	*18*

3750 mm in Table 4) medians. This type of barrier prevents median cross-over accidents, and if the median is at least 3 m wide, there is adequate room for the barrier to deflect, even in large car and pickup truck accidents. The box-beams median barrier typically costs about $80/meter (Table 7). The typical cost of a box-beam guardrail or median barrier is more than a strong post W-beam guardrail or median barrier. One reason for the modest usage of box-beam barriers may be that states choose the less costly strong-post barriers because they also get the benefit of smaller dynamic deflections. The box-beam guardrail costs 75 percent more and has a dynamic deflection 80 percent higher than the strong-post W-beam guardrail, making the box-beam guardrail appear less attractive. The relatively higher cost of box-beam barriers is due to the extra cost of fabricating rails, splices, posts, and brackets and the fact that the system is more complicated than some other barrier systems.

Like the G2 weak-post W-beam guardrail (SGR02), the most typical method for terminating a box-beam guardrail or median barrier is to use a turned-down end terminal. A September 29, 1994, FHWA memorandum now prohibits the use of turned-down end terminals even with weak-post guardrails on high-speed Federal-aid projects *(64)*. The state of Wyoming sponsored the development of a new energy-absorbing terminal to replace the turned-down end *(67)*. This device, the WY-BET terminal, has been crash tested and can be used to anchor and safely terminate box-beam systems.

Summary

Box-beam guardrails and median barriers can be used where barrier deflections of 1500 mm are acceptable. The box-beam guardrail has passed the Report 350 Test Level 3 tests, suggesting that the use of box-beam guardrails and median barriers will remain standard into the next century. The 2000-kg pickup truck test still needs to be performed on the box-beam median barrier system, although it seems reasonable to expect, on the basis of performance of the box-beam guardrail and the cable systems, that the box-beam median barrier will satisfy the Test Level 3 requirements as well. Box-beam guardrails and median barriers can cost as much or more than typical strong-post W-beam guardrails, so even though the barrier provides good impact performance, selecting a less expensive strong-post barrier with less dynamic deflection is often more cost-effective. As with other weak-post guardrails and median barriers, the move away from turned-down end terminals has greatly reduced the options for ending these systems, although there is at least one proprietary terminal for the box-beam guardrail and median barrier.

CHAPTER FOUR

STRONG-POST BARRIER SYSTEMS

Strong-post guardrails and median barriers are intended for use in locations where there is only limited room for lateral deflection of the system. Most of these systems have characteristic dynamic deflections of less than 1 m in impacts with typical large passenger cars. Strong-post guardrails prevent vehicles from leaving the roadway and becoming involved in a more hazardous collision. The beam of a guardrail provides a flexible barrier that deforms with the vehicle, dissipating energy in the process. Strong-post guardrails have evolved into one of the most important groups of roadside safety hardware since they are the most commonly used guardrail and median barrier systems.

STRONG-POST W-BEAM GUARDRAIL AND MEDIAN BARRIERS

System Description

The strong-post W-beam guardrail, shown in Figure 31, usually consists of a 12-gauge W-beam steel rail mounted on a blockout, which is in turn mounted on strong guardrail posts spaced at 1905 mm along the roadway. The posts are usually augured or driven into the soil, and typical mounting height to the middle of the guardrail is 530 mm (686 mm to the top of the rail). The distinctive feature of this system are the W-beam rail, strong posts mounted in soil to dissipate the energy, and post blockouts to minimize tire snagging.

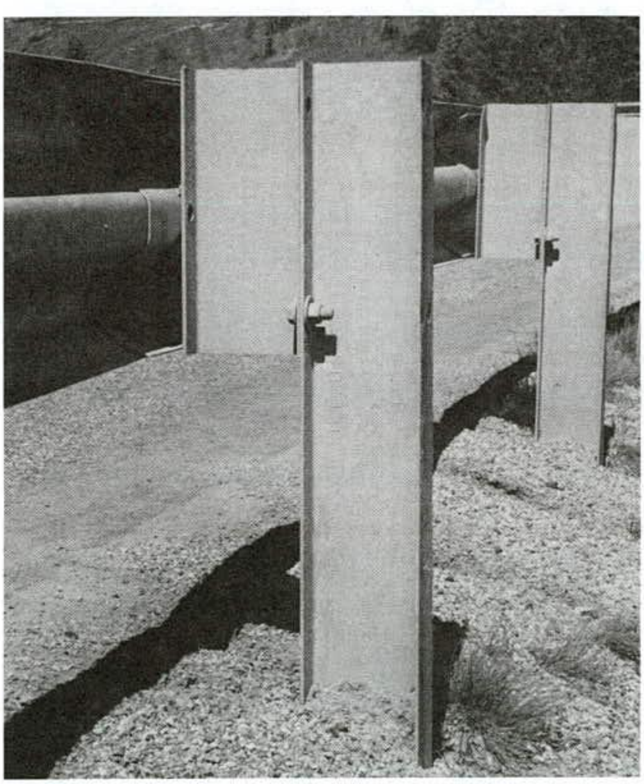


FIGURE 31 Typical installation of a strong steel-post W-beam guardrail (SGR04a).

A variety of posts and blockouts for the strong-post W-beam guardrail and median barrier are being used in different states or have been evaluated in the full-scale crash tests:

- Steel W150×16.6 (or W150×13.5) posts and blockouts,
- 140- × 190-mm wood posts and blockouts,
- 190- × 190-mm wood posts and blockouts,
- 140-mm-diameter circular wood post with a 190- × 140-mm rectangular wood blockout,
- Steel W150×12.6 (or W150×13.5) with a 140- × 190-mm wood blockout,
- Steel W150×12.6 (or W150×13.5) with a 140- × 190-mm recycled plastic blockout, and
- Steel 110- × 150-mm cold-formed channel-section (Charley) posts and blockouts.

The steel W150×12.6 and wood 140- × 190-mm post and blockout are the most common types used. Eight of the 39 survey responses indicated that blockouts made using a mixture of recycled plastic and wood are allowed although the practice is not yet widespread (Appendix C Question 25). In all of the cases listed here, the longer dimension of both the post and the blockout should be perpendicular to the traveled way to maximize the offset of the rail from the post as well as maximize the section modulus for bending. The performance of these systems, regardless of the post and blockout combination used, have usually been considered to be equivalent *(68,69)*. For example, Nordlin et al. tested strong-post guardrails with a 150- × 200-mm wood post and a 200- × 200-mm wood post and found that the permanent deflection of the rail was within 30-mm in each test *(70)*. As will be discussed later, more recent tests with the 2000-kg pickup truck have indicated that the different combinations, particularly the wood and steel posts, may not be as similar as was once thought.

The W-beam backup plate is an important feature of the steel strong-post W-beam system with steel blockouts. The W-beam was sheared off on the sharp edge of the blockout in some tests when there was no backup plate *(70)*. The 300-mm-long W-beam backup plates should be used on all steel, strong-post systems at nonsplice post locations *(68)*. At posts where there is a splice, the double-thickness of W-beam rail has the same effect as the backup plate. Backup plates are not necessary on wood-post systems (or on steel-post systems with wood blockout) since wood is not as hard and does not promote tearing when the rail wraps around the blockout.

W-beam rails should be overlapped in the direction of traffic to prevent the edge of the guardrail from becoming a snag point in an impact. If the guardrails are overlapped such that the top rail is on the outside (e.g., facing traffic), the exposed edge can catch on vehicle parts during an impact.

In the past, some states used strong-post W-beam guardrails without guardrail blockouts. This practice is discouraged because the absence of a blockout makes snagging of the vehicle wheels much more likely. Crash tests of strong-post W-beam guardrails without blockouts have resulted in very sharp redirection, serious wheel snagging, extensive intrusion into the traveled way, and sometimes rollover *(10)*.

Some states have used a rectangular washer under the head of the bolt that connects the rail to the post. This was originally done to improve the transfer of rail tension loads to the posts. The rectangular washers also prevent the rail from separating from the post in an impact and may result in the rail being pulled down allowing the vehicle to override the barrier. Allowing the rail to separate from the post in an impact results in a more consistent design that improves the performance of the guardrail. The use of the rectangular washers is therefore no longer recommended *(68)*.

Distribution

Strong-post W-beam guardrail and median barriers are by far the most common guardrails used in the United States; nearly every state uses some variation of the designs shown in Figures 32 and 33. As shown in Figures 34 and 35, this one barrier type accounts for more than 90 percent of all new barrier construction in many states. Figures 36 and 37 show the distribution of states that currently install strong-post W-beam median barriers.

Crashworthiness

Since the strong steel-post W-beam guardrail is one of the most widespread and basic barrier systems in use today, it is not surprising that there is a relatively large amount of testing experience with this system. The system, as shown in Table 23, has long been considered to satisfy the recommended criteria of Report 230, although some amount of snagging in the small car tests has been observed *(41)*. Recent tests with the full-size 2000-kg pickup truck, however, resulted in the pickup truck wheel snagging the post and the vehicle rolled over *(71)*. Rollover has been observed before using some non-standard test vehicles such as a small 1400-kg pick- up truck, a standard-size van, and a full-size 1800-kg pickup truck *(18,41)*. In a 1983 crash test of a Ford F150 pickup truck into a GR(1S) guardrail, the vehicle snagged and rolled just as it did in the more recent 1994 test *(41)*. Several other tests were run in the same test series to explore the performance limits of longitudinal barriers. A small Chevrolet S-10 pickup truck did

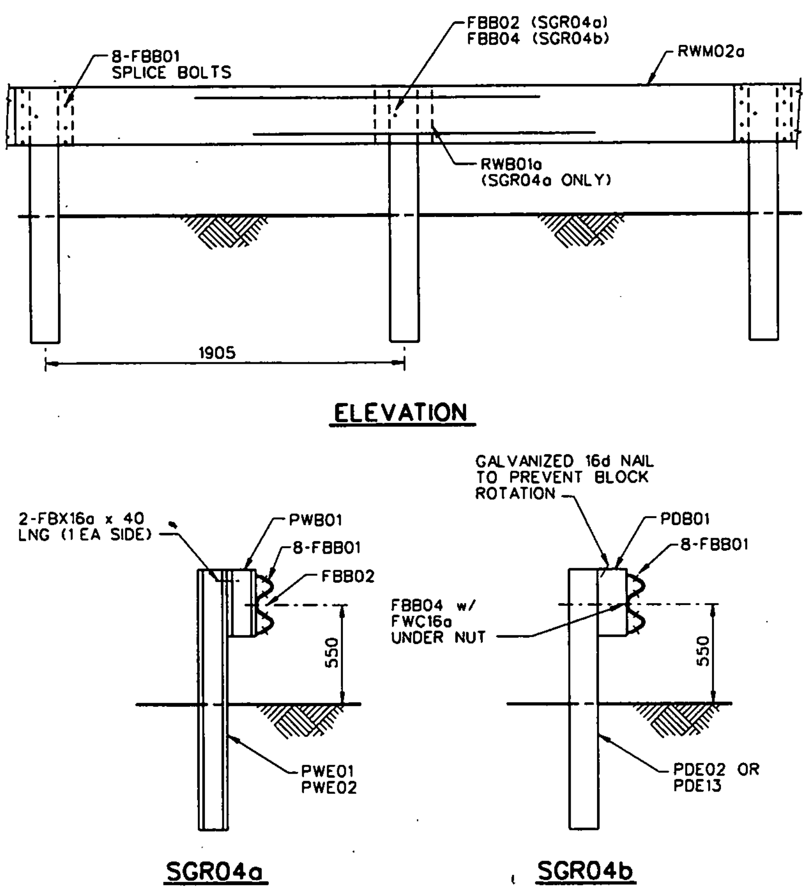


FIGURE 32 Strong-post W-beam guardrail (SGR04a-b).

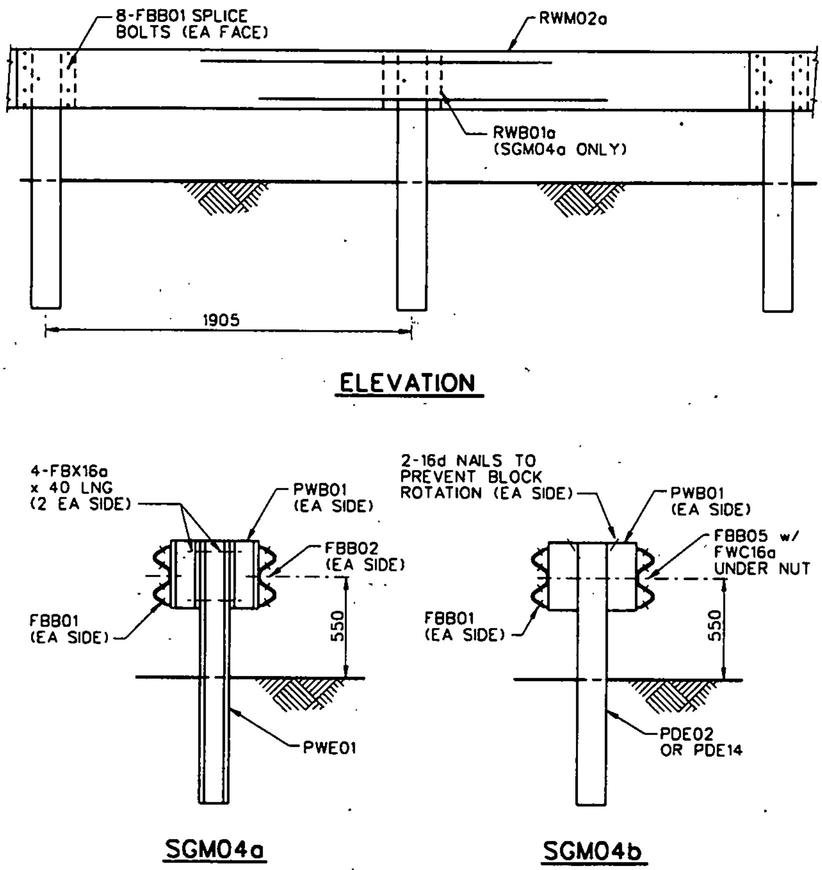


FIGURE 33 Strong-post W-beam median barrier (SGM04a-b).

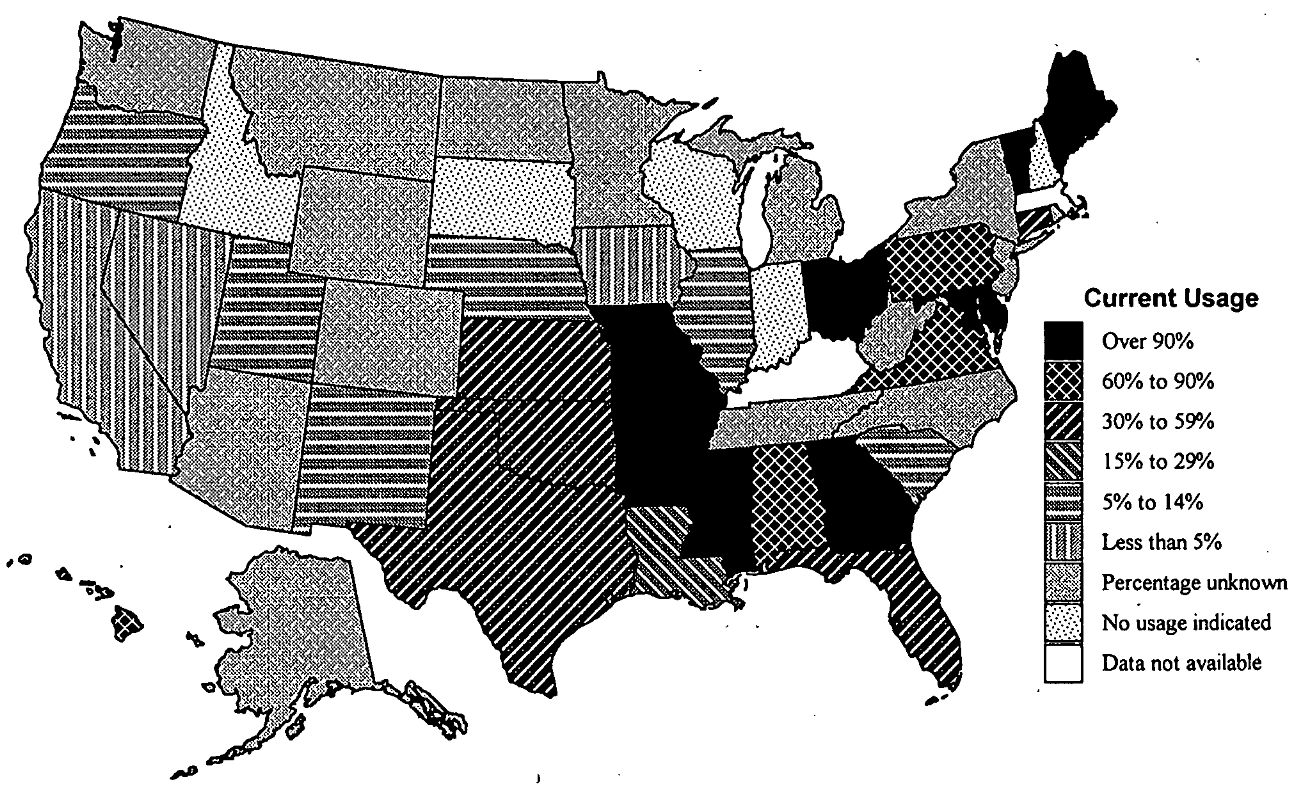


FIGURE 34 States currently installing the strong steel-post W-beam guardrail (SGR04a).

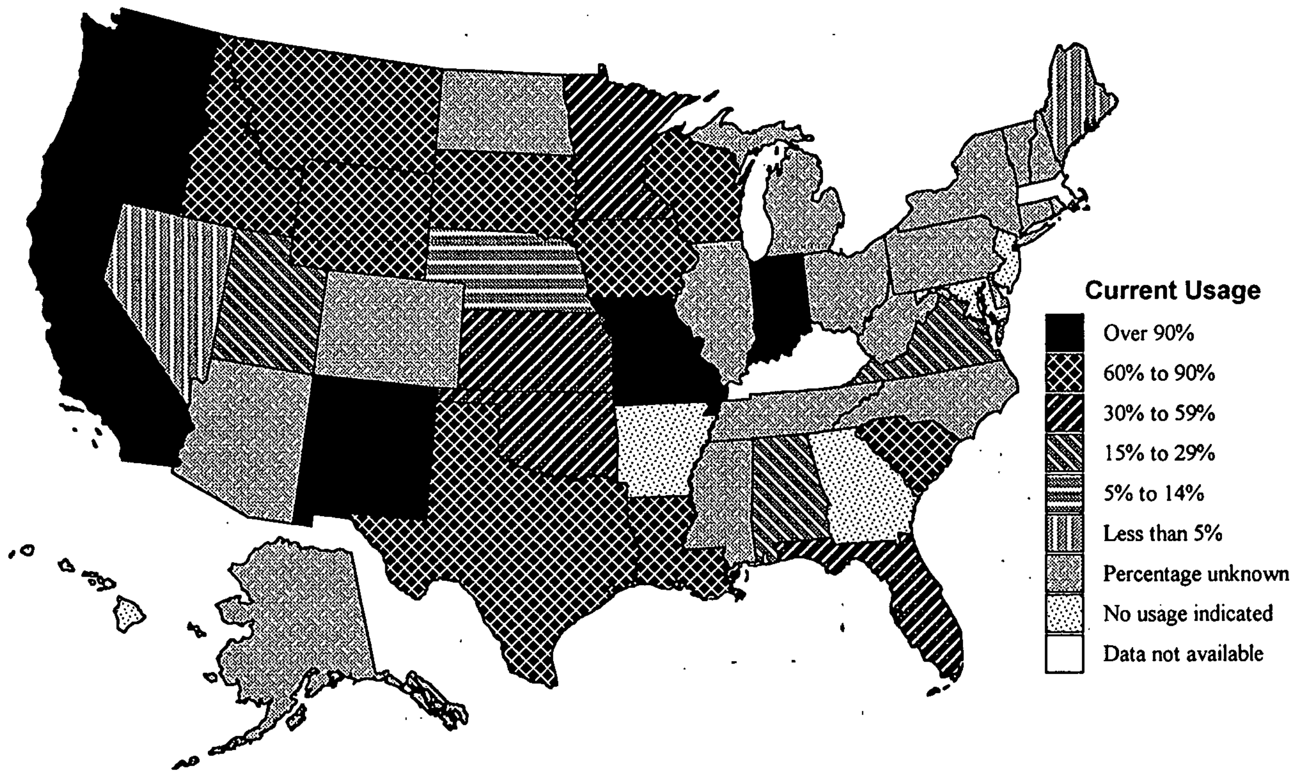


FIGURE 35 States currently installing the strong wood-post W-beam guardrail (SGR04b).

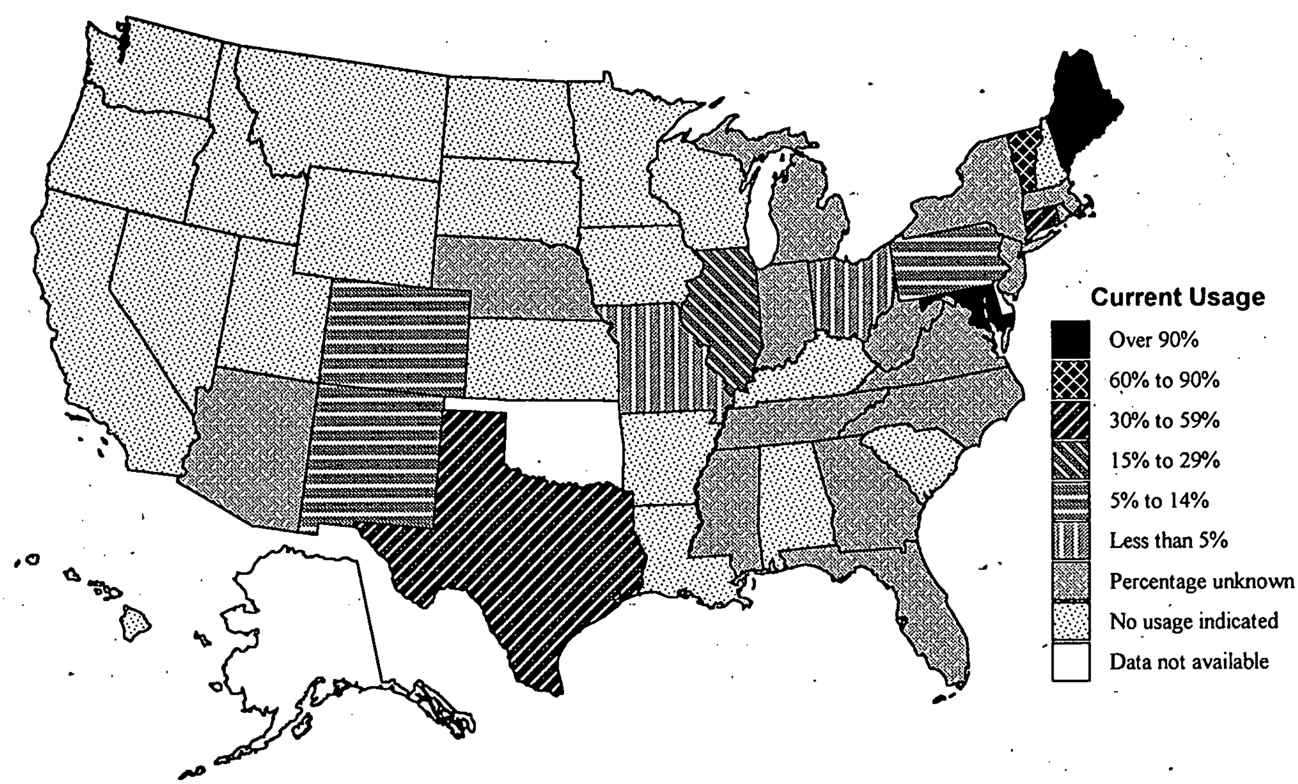


FIGURE 36 States currently installing the strong steel-post W-beam median barrier (SGM04a).

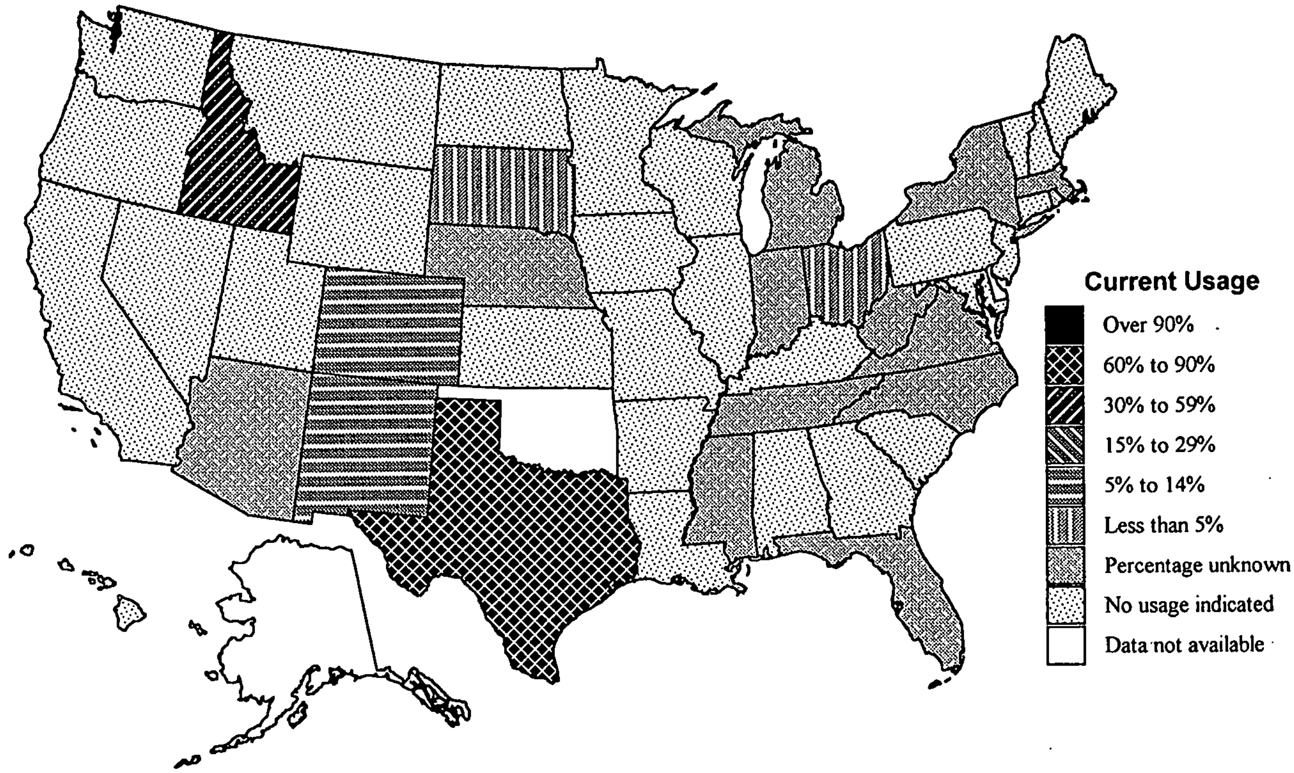


FIGURE 37 States currently installing the strong wood-post W-beam median barrier (SGM04b).

not roll over, but it did experience serious wheel snagging. Another test was run in this same test series with a large Dodge B200 van in which the van also rolled over. Even the small-car 20-degree tests shown in Tables 23 and 24 exhibited snagging and, in the case of Test GR-6, failed the occupant risk criteria. Snagging problems were also observed with the G4(1S) in impacts with midsize passenger vehicles *(15,72)*. These tests have raised important questions about the crashworthiness of the standard strong steel-post W-beam system (SGR04a) that are critical to assessing the impact on the existing inventory of roadside safety hardware.

The wood-post version of the strong-post W-beam guardrail has long been considered to be equivalent to the steel-post version because of the similarity of the dynamic deflections of both systems (Tables 23 and 24). Recent tests with the 2000-kg pickup truck in Report 350 Test 3-11 have indicated that wood-post systems may enjoy an advantage over steel-post systems. Although there was snagging in the test of the wood-post system (SGR04b) and the 2000-kg pickup truck, it was considered an acceptable risk (Table 25). In contrast, a crash test of the steel-post system (SGR04a) with the 2000-kg pickup truck resulted in the vehicle rolling over. The results of the recent Report 350 crash tests shown in Tables 25 and 26 indicate that the strong wood-post system (SGR04b) marginally satisfies Test Level 3, while the strong steel-post system satisfies only Test Level 2. This is a significant departure from the conventional assumption that the performance of the steel- and wood-post systems is essentially equivalent.

The basic failure mechanisms of wood and steel posts are quite different. Steel wide-flange sections, like the W150×13 or W150×12.6 commonly used as guardrail posts, generally fail in torsion by twisting around the long axis of the post and bending to the ground. If the soil is a well-graded, well-compacted base material, the steel post may twist and bend to the ground with very little deformation of the soil. Typical wood posts, like the nominal 140- × 190-mm wood post, rotate in the soil and either fail in bending or cause a failure in the soil. Wood posts often push through the soil, moving the post face back away from the vehicle at the groundline. If the soil is very stiff or if the soil and post are frozen, the post may fracture below the groundline at the location of maximum bending moment. The small amount of extra clear space provided by the post rotating through the soil may be just enough to make the difference between moderate wheel snagging and wheel snagging that is severe enough to remove the wheel from the vehicle. In both situations the overall dynamic deflection of the rail may be similar, as shown in Tables 23 and 24, though the failure of the posts is different.

All post-and-beam guardrail and median barrier designs depend on the soil for providing foundation support. Despite the importance of soil in guardrail and median barrier performance it is still not well understood. Many states require that the slope breakpoint be at least 610 mm behind the guardrail posts. Full-scale and pendulum tests showed that when the slope is flatter than 3:1, a standard 1830-mm-long guardrail post located at the slope breakpoint will develop its

TABLE 23
NCHRP REPORT 230 CRASH TESTS OF STRONG STEEL-POST W-BEAM GUARDRAIL (SGR04a)

	Test Number			
	10	12	S13	S18
Impact condition				
System	SGR04a	SGR04a	SGR04a	SGR04a
Test number	SPI-1	4798-05	4798-04	4098-2
Test contractor	SwRI	TTI	TTI	TTI
Impact velocity (km/hr)	95.9	95.7	96.4	96.0
Impact angle (degrees)	25.3	15.0	21.5	15.0
Vehicle type	4500S	1800S	1800S	20000P
Vehicle mass (kg)	2037	953	995	9095
Structural adequacy				
A. Smooth redirection	Smooth	Smooth	Moderate snagging	Rolled
Dynamic deflection (mm)	905	256	410	Penetrated
D. Detached elements	None	None	None	Yes
Evaluation	Pass	Pass	Pass	Fail
Occupant risk				
E. Vehicle remains upright	Yes	Yes	Yes	No
F. Occupant risk				
Lateral impact velocity (m/sec)	NA	5.8	5.6	NA
Longitudinal impact velocity (m/sec)	NA	4.1	5.6	NA
Lateral ridedown acceleration (g's)	NA	7.0	13.0	NA
Longitudinal ridedown acceleration (g's)	NA	1.3	3.6	NA
Evaluation	Pass	Pass	Pass	Fail
Vehicle trajectory				
H. Intrusion into traveled way	NR	None	None	None
I. Exit conditions				
Exit velocity (km/hr)	67.1	73.5	68.2	Rolled
Exit angle (degrees)	18.2	2.3	1.0	Rolled
Evaluation	Pass	Pass	Pass	Fail
Reference	*15*	*41*	*41*	*93*

NR = not reported; NA = not applicable to these test conditions; SwRI = Southwest Research Institute; TTI = Texas Transportation Institute

full strength in an impact *(73)*. If the slope is steeper than 3:1 and the posts are located at the breakpoint, however, longer posts (e.g., 2130 mm) should be used to ensure that the post has sufficient embedment to develop its full strength. The test results indicated that posts can be installed at the breakpoint of slopes when 2130-mm-long posts are used and soil conditions permit.

Questions about the strength of wood posts have surfaced repeatedly over the past three decades, in terms of both the strength of the soil and the posts *(69, 73–75)*. Since wood is a natural material, it has much more variable material properties than steel. Better characterizing the properties of wood in impacts and better methods for specifying wood materials will doubtless continue to be areas of research in the future.

The soil conditions are also important for providing adequate support to the guardrail posts during a collision. Crash tests are performed with a standardized soil that does not necessarily represent the type and range of soils that can be observed in the field. Since all the load being managed by a guardrail is ultimately transferred to the soil, soil conditions are an important though understudied aspect of the impact performance of guardrails. Rohde et al. recently examined the changes in behavior of guardrail posts in different soil conditions *(76)*. The properties of the soil (e.g., cohesion, water content and compaction) were found to have an effect on the pressure distribution acting on the post. In a related study, the density of clay soil was found to have a dramatic effect on the lateral guardrail deflection based both on full-scale crash tests and computer simulations *(77)*.

It is often desirable to strengthen a guardrail locally to reduce the dynamic deflection near an isolated hazard. For example, a guardrail protecting a steep side slope may pass in front of an isolated utility pole. If the pole is too close to the guardrail a vehicle may strike the pole while interacting with the guardrail. A variety of guardrail strengthening techniques have been used to reduce the dynamic deflection, including using

- 3.43-mm-thick (10-gauge) rather than 2.67-mm-thick (12-gauge) guardrail,
- Nested (e.g., overlapped) guardrails, and
- Reduced post spacing.

Recently, these different techniques for controlling lateral guardrail deflection were examined using bogie crash tests and computer simulations *(77,78)*. Nesting W-beam using the

TABLE 24

NCHRP REPORT 230 CRASH TESTS OF STRONG WOOD-POST W-BEAM GUARDRAIL AND MEDIAN BARRIER (SGR04b and SGM04b)

	Test Number			
	10	12	S13	12
Impact conditions				
System	SGR04b	SGR04b	SGR04b	SGM04b
Test number	273	GR-1	GR-6	MB-1
Test contractor	Caltrans	SwRI	SwRI	SwRI
Impact velocity (km/hr)	109.0	96.7	99.6	94.1
Impact angle (degrees)	24.0	15.5	21.7	17.2
Vehicle type	4500S	1800S	1800S	1800S
Vehicle mass (kg)	2250	902	875	883
Structural adequacy				
A. Smooth redirection	Smooth	Smooth	Smooth	Smooth
Dynamic deflection (mm)	710	195	265	65
D. Detached elements	NR	None	None	None
Evaluation	Pass	Pass	Pass	Pass
Occupant risk				
E. Vehicle remains upright	Yes	Yes	Yes	Yes
F. Occupant risk				
Lateral impact velocity (m/sec)	NA	5.7	7.0	NR
Longitudinal impact velocity (m/sec)	NA	NR	NR	6.5
Lateral ridedown acceleration (g's)	NA	13.8	12.9	NR
Longitudinal ridedown acceleration (g's)	NA	NR	NR	NR
Evaluation	Pass	Pass	Fail	Marginal
Vehicle trajectory				
H. Intrusion into traveled way	NR	NR	NR	NR
I. Exit conditions				
Exit velocity (km/hr)	NR	90.0	84.7	88.0
Exit angle (degrees)	14	1.6	5.2	5.3
Evaluation	Pass	Pass	Pass	Pass
Reference	*74*	*18*	*18*	*18*

Caltrans = California Department of Transportation

standard 1905-mm post spacing results in no more than a 10 percent decrease in dynamic deflection depending on whether steel or wood posts are used and the soil conditions. Reducing the post spacing to 952.5 mm, half the normal spacing, resulted in a decrease in dynamic deflection of 20 to 29 percent. When guardrails were both nested and the post spacing was reduced, dynamic deflection reductions of about one-third could be achieved. Interestingly, the density of the clay soil could have more effect on the dynamic deflection of a guardrail than nesting the W-beam, illustrating the importance of soil properties on the performance of guardrails.

Several states have had problems when using guardrails to cross box culverts that have relatively shallow soil cover. Spanning the box culvert with several short posts was one approach that was crash tested. Shorter posts resulted in the vehicle overriding and penetrating the barrier, so another design alternative was required. One alternative that has been crash tested is to attach the guardrail post to the top of the reinforced concrete box culvert *(79)*. This design (SGR05) is shown in Figure 38, and the crash test results are summarized in Table 27. Only a large-vehicle Report 230 test was performed since the barrier strength was of primary concern. Presumably, the small-car performance would be similar to that of the standard strong-post W-beam guardrail crash tests like those shown in Table 23. No Report 350 tests have been performed on this system to date. A structure-mounted post design like the one just described was available in the state standards of 9 of the 39 survey respondents (Appendix C Question 22).

Another common method for crossing shallow culverts mentioned by survey respondents and recommended in a 1991 FHWA memorandum is to omit one post and nest two W-beams over the gap (Appendix C Question 21) *(80)*. This design was recently tested for 3810- and 5715-mm spans *(81)*. In both cases, a strong wood-post W-beam guardrail with standard post spacings (SGR04b) was used on both sides of the culvert span. Two 7620-mm-long W-beams were nested and placed over the span with no guardrail posts located within the culvert span, as shown in the two right columns of Table 27; even when there are no posts in a 5715-mm long span over the culvert, this design performed acceptably.

Applications

One reason that the strong-post W-beam guardrail has become such a popular guardrail and median barrier alternative

TABLE 25

NCHRP REPORT 350 TEST LEVEL 3 CRASH TESTS OF STRONG WOOD-POST W-BEAM GUARDRAIL (SGR04b)

	Test Number	
	3-10	3-11
Impact condition		
System	SGR04b	SGR04b
Test number	GR-6	471470-26
Test contractor	SwRI	TTI
Impact velocity (km/hr)	99.6	100.8
Impact angle (degrees)	21.7	24.3
Vehicle type	1800S	2000P
Vehicle inertial mass (kg)	NR	2000
Vehicle gross mass (kg)	875	2074
Structural adequacy		
A. Containment	Yes	Yes
Vehicle response	Smooth	Snagged
Dynamic deflection (mm)	265	820
Evaluation	Pass	Pass
Occupant risk		
D. Compartment penetration	None	Minor
F. Vehicle remains upright	Yes	Yes
H. Occupant impact velocity		
Lateral impact velocity (m/sec)	7.0	NA
Longitudinal impact velocity (m/sec)	NR	NA
I. Occupant ridedown acceleration		
Lateral ridedown acceleration (g's)	12.9	NA
Longitudinal ridedown acceleration (g's)	NR	NA
Evaluation	Pass	Pass
Vehicle trajectory		
K. Intrusion into traveled way	NR	Yes
L. Longitudinal occupant risk		
Impact velocity (m/sec)	NA	7.5
Ridedown acceleration (g's)	NA	11.6
M. Exit angle (degrees)	5.2	8.1
Evaluation	Pass	Pass
Reference	*18*	*71*

TABLE 26

NCHRP REPORT 350 TEST LEVEL 3 CRASH TESTS OF STRONG STEEL-POST W-BEAM GUARDRAIL (SGR04a)

	Test Number	
	3-10	3-11
Impact condition		
System	SGR04a	SGR04a
Test number	4798-04	474170-27
Test contractor	TTI	TTI
Impact velocity (km/hr)	96.4	101.4
Impact angle (degrees)	21.5	26.1
Vehicle type	1800S	2000P
Vehicle inertial mass (kg)	843	2000
Vehicle gross mass (kg)	995	2075
Structural adequacy		
A. Containment		
Vehicle response	Smooth	Snag/roll
Dynamic deflection (mm)	410	910
Evaluation	Pass	Pass
Occupant risk		
D. Compartment penetration	None	Minor
E. Vehicle remains upright	Yes	No
H. Occupant impact velocity		
Lateral impact velocity (m/sec)	5.6	NA
Longitudinal impact velocity (m/sec)	5.6	NA
I. Occupant ridedown acceleration		
Lateral ridedown acceleration (g's)	13.0	NA
Longitudinal ridedown acceleration (g's)	3.6	NA
Evaluation	Pass	Fail
Vehicle trajectory		
K. Intrusion into traveled way	NR	Minor
L. Longitudinal occupant risk		
Impact velocity (m/sec)	NA	7.5
Ridedown acceleration (g's)	NA	7.8
Exit angle (degrees)	1.0	26.1
Evaluation	Pass	Fail
Reference	*41*	*71*

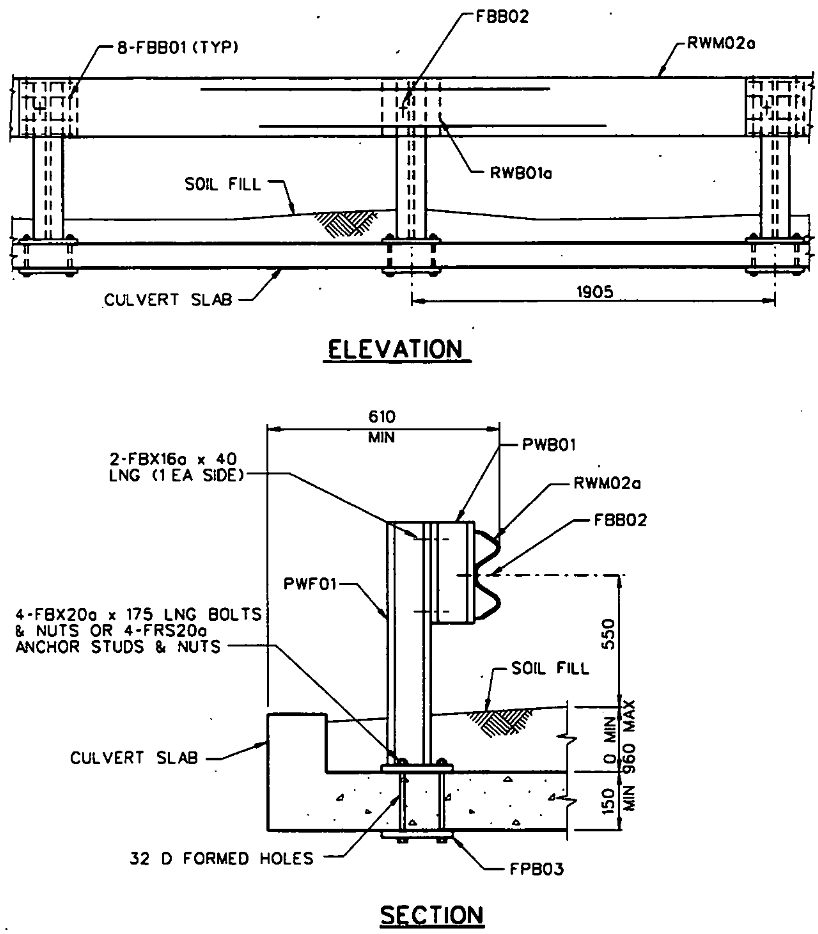


FIGURE 38 Culvert-mounted strong-post W-beam guardrail (SGR05) *(22)*.

is that it is a very versatile system. As shown in Figures 6 through 16, the W-beam guardrail is the most frequently used system for nearly every type of roadside hardware application. Many, perhaps even most, states depend heavily on these strong-post barriers as their primary guardrail and median barrier systems.

One common situation is the use of strong-post W-beam guardrails at intersecting roadways. Guardrails, even strong-post ones, depend on developing significant longitudinal tension in the rail element. When the rail is curved away from the roadway, the guardrail loses much of the anchorage that is responsible for developing the rail tension that redirects an errant vehicle. A design from the state of Washington was tested in which a 2400-mm-radius curved guardrail connected two roadways intersecting at 90 degrees *(82)*. Anchor terminals were located 3810-mm from the point of tangency on both sides, and breakaway CRT posts were used in the curved section. Tests with both large and small cars demonstrated satisfactory performance. The guardrail wrapped around the front of the vehicle and slowed the vehicle as it went down the steep slope behind the barrier. The large car penetrated the 2400-mm-radius barrier system in a 100-km/hr impact when the guardrail bolt initiated a tear on the rail when the first post was broken. When the system was retested without a guardrail bolt at the impact post (the "point" of the nose), good performance was achieved, prompting FHWA to recommend not placing a bolt at the center post location. A larger 10.7-m-radius system did not demonstrate good performance in a 100-km/hr 2000-kg passenger car test, although the system did perform adequately at a lower speed (80 km/hr).

Another 2400-mm curved design was tested; it was based on an Arizona design *(83)*. This design is stiffer than the Washington design and was tested at only 80 km/hr. FHWA distributed a memorandum with two curved guardrail designs for use at intersecting streets *(84)*. In the survey of the states conducted in this project, 35 of the 39 respondents said that curved guardrails were used at intersecting roadways. Of the 12 states that provided values for the minimum radius permitted, the two most common minimum radii reported were 2440 and 2600 mm.

In the past, many roadway designers assumed that curbs did not affect the performance of a W-beam guardrail as long as the curb was no closer to the traveled way than the front face of the barrier (e.g., in front of the post but behind the rail). Curbs were allowed to be used in conjunction with guardrails in 78 percent of the states responding to the survey (Appendix C Question 12). A full-scale crash testing program was performed using curbs ranging from a 100-mm-high AASHTO Type H curb to a 200-mm-high AASHTO Type A curb *(85)*. When struck by larger passenger vehicles such as a 2000-kg

TABLE 27

NCHRP REPORT 230 CRASH TESTS OF STRONG STEEL-POST W-BEAM GUARDRAIL ALTERNATIVES CROSSING SHALLOW CULVERTS

	Test Number		
	10	10	10
Impact condition			
System	SGR05	3810-mm nested W-beam span	5715-mm nested W-beam span
Test number	2405-3*	7147-2	7147-5
Test contractor	TTI	TTI	TTI
Impact velocity (km/hr)	99.4	100.9	98.0
Impact angle (degrees)	25.3	24.5	25.1
Vehicle type	4500S	4500S	4500S
Vehicle mass (kg)	2019	2043	2043
Structural adequacy			
A. Smooth redirection	Yes	Yes	Yes
Dynamic deflection (mm)	820	900	1000
D. Detached elements	NR	None	None
Evaluation	Pass	Pass	Pass
Occupant risk			
E. Vehicle remains upright	Yes	Yes	Yes
F. Occupant risk			
Lateral impact velocity (m/sec)	NA	4.8	4.3
Longitudinal impact velocity (m/sec)	NA	5.4	4.5
Lateral ridedown acceleration (g's)	NA	12.9	9.7
Longitudinal ridedown acceleration (g's)	NA	6.5	3.5
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
H. Intrusion into traveled way	No	No	No
I. Exit conditions			
Exit velocity (km/hr)	59.9	67.9	78.2
Exit angle (degrees)	15.6	11.0	10.4
Evaluation	Pass	Pass	Pass
Reference	*79*	*81*	*81*

*This test was performed prior to Report 230, so all the evaluation parameters were not available.

pickup truck and a 2000-kg passenger car, the barrier deflected enough to allow the impact-side wheels to contact the curb, resulting in the vehicle vaulting up over the guardrail. The test series demonstrated that the impacting wheel of the vehicle cannot be allowed to contact the curb. These crash tests prompted FHWA to issue a memorandum recommending that curbs not be used in conjunction with W-beam guardrails unless the acceptable impact performance of the design has been demonstrated in a full-scale crash test *(86)*.

In years past highway agencies often installed short (less than 30 m) unanchored sections of guardrail to protect such isolated hazards as cross-road culverts and trees. Care must always be taken to ensure that a guardrail does not become an even more significant hazard than the object it is supposed to be shielding. While these types of short unanchored sections have disappeared from most state-maintained roadways, they can be found on many local agency roads. The state of California performed a series of crash tests to determine the effectiveness of short sections of unanchored guardrails *(87)*. Any guardrail, regardless of its length, that is not adequately anchored will not be effective within 10 m of its end. Unanchored guardrails less than 19 m long were ineffective in terms of redirecting a typical 2000-kg large passenger vehicle at 100 km/hr and 25 degrees. On impact of an 11-m-long unanchored guardrail the 200-kg vehicle quickly pocketed into the guardrail and pulled free of all the guardrail posts except one. The guardrail had almost no effect on the redirection of the vehicle. Even when the guardrail length was nearly doubled, the vehicle still penetrated the rail. These tests demonstrate the importance of anchorage and more particularly of developing tensile forces in the guardrail.

Strong-post W-beam guardrails typically cost $40/meter (Table 7), regardless of whether steel or wood posts are used. Strong-post W-beam median barriers cost about $10/meter more than the guardrail version, or $50/meter.

The popularity of these systems results in lower materials costs since they are available in large quantities from many suppliers. A repair and maintenance manual for strong-post W-beam guardrails and median barriers is available from FHWA *(88)*. This manual has detailed procedures for estimating quantities and costs as well as construction repair procedures that should be useful to maintenance personnel.

Summary

Crashworthiness concerns about the performance of the SGR04 family of guardrails in the 2000-kg pickup truck test need to be addressed to establish the long-term place of this important part in the barrier hardware inventory. The strong-post W-beam guardrail and median barrier is the most popular guardrail system in use in the United States: every state uses one of its variations. All states have a large investment in this barrier system due to the large inventory of strong-post W-beam guardrails and median barriers. Gaining a better understanding of how design variables affect the performance of this system is well justified on the basis of its importance to the overall roadside safety effort.

There have been very few crash tests of the strong-post W-beam median barrier. The most recent test of the steel-post version (SGM04a) that could be found in the literature was 30 years old, and the test conditions were so far from current recommendations there was no point in including the values in a table *(13)*. The wood-post version was tested as a part of Report 289, and the results are shown at the right in Table 24 *(18)*. It would seem that demonstrating the performance of this widely used median barrier system would be an important priority in view of the problems being experienced with the strong-post W-beam guardrail.

The strong-post W-beam guardrails have become the most popular guardrails because they are relatively inexpensive and very versatile. There are numerous W-beam designs for special situations such as crossing box culverts and installing guardrails at intersecting streets. There are also many choices for guardrail terminals and transitions that can be used with W-beam guardrails. The effect of a variety of specific conditions such as soil properties, guardrails on slopes, guardrail and curb combinations, and local strengthening techniques have all been studied with respect to strong-post W-beam guardrails. The popularity and importance of this guardrail and median barrier system make understanding its behavior very important.

STRONG-POST W-BEAM GUARDRAIL AND MEDIAN BARRIER WITH RUBRAIL

System Description

The strong-post W-beam median barrier with rubrails (SGM06), shown in Figure 39, is similar to the strong-post W-beam median barrier (SGM04b) except that a rubrail is added 300 mm from the ground and the W-beam height is 60 mm higher. Like most other strong-post barriers, the strong-

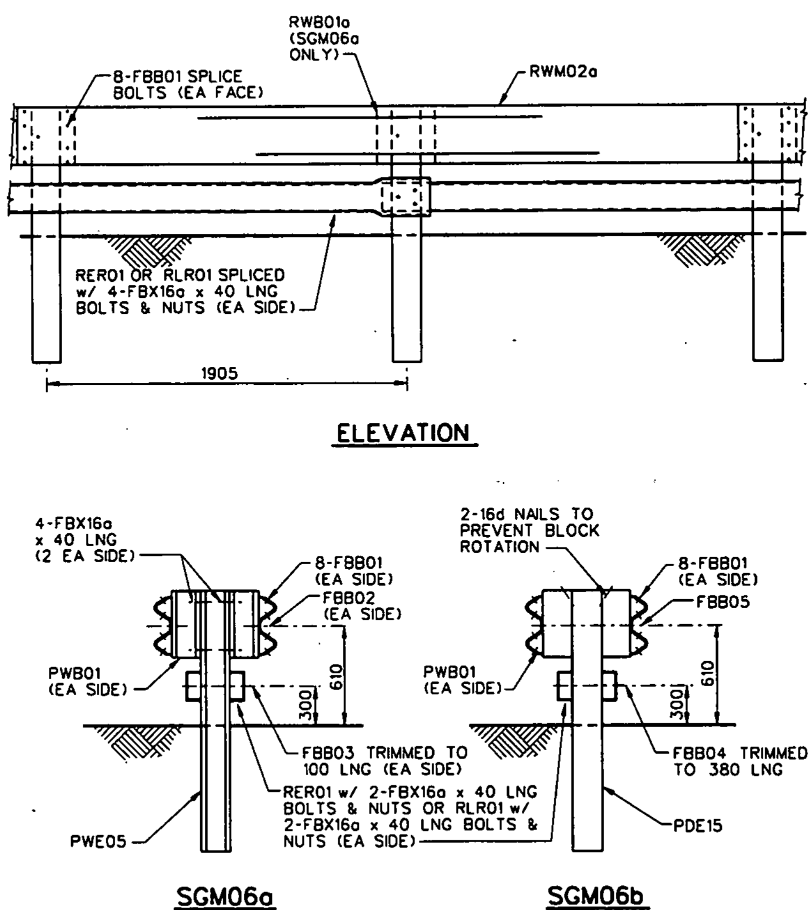


FIGURE 39 Strong-post W-beam median barrier with rubrail (SGM06a) *(22)*.

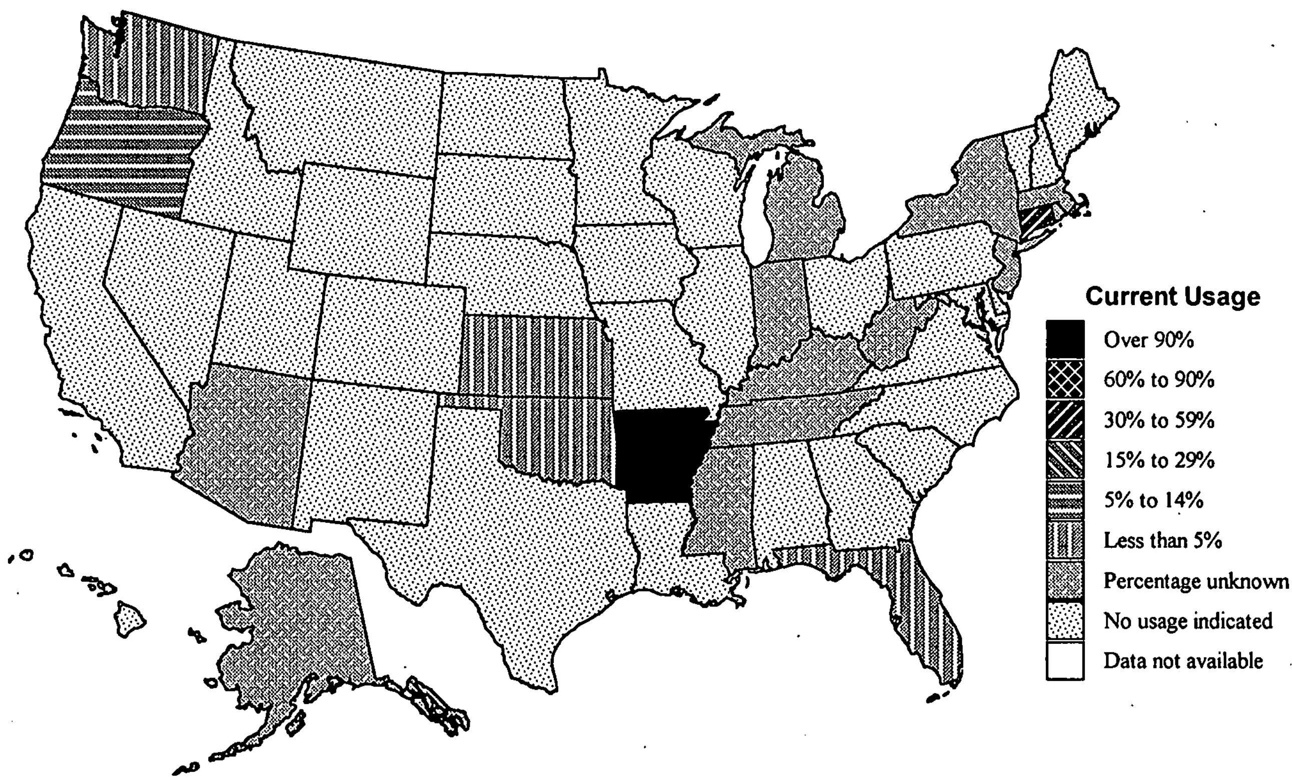


FIGURE 40 States currently installing the strong-post W-beam guardrail with rubrail.

post W-beam median barrier with rubrail consists of a steel 12-gauge guardrail mounted on a blockout, which is in turn mounted on a post driven into the soil. A hot-rolled channel-section or cold-formed channel rubrail is mounted on the post 300 mm above the ground to inhibit wheel snagging.

Distribution

Thirty years ago this system was fairly popular. As shown in Figures 40 and 41, these guardrail and median barrier systems are no longer widely used. The system costs more than a strong-post W-beam median barrier, and many states did not observe a corresponding improvement in barrier performance. This barrier is still found in a few states, although it is believed that the remaining installations are holdovers from earlier decades, and there are few if any new installations. As shown in Figure 40, a number of states have a few installations of a roadside strong-post W-beam with a channel-section rubrail, although tests for a roadside version have never been performed—or at least have never been reported in the roadside safety literature except for a test with a curb section.

Crashworthiness

Since this system has decreased in popularity, it is not surprising that there have been very few crash tests performed on it in the past several decades. The most recent test, summarized in Table 28, was performed in 1987 and is documented in Report 289 *(18)*. The only large-car tests (Report 230 Test 10) were performed about 30 years ago, long before Report 230 was published *(26,89)*. The G9 thrie-beam median barrier (SGM09a-b) was developed in part to eliminate the need for the more expensive W-beam guardrail with rubrail *(90)*.

Applications

This system was intended for use in relatively narrow medians on high-volume, high-speed roadways. Prior to the development and widespread use of concrete median barriers, this barrier was the only alternative for narrow medians. This system can often create maintenance problems since the guardrail and rubrail can accumulate road debris as well as snow and ice. The cost of the strong-post W-beam median barrier with rubrail, as shown in Table 7, is almost $150/meter, much higher than a typical strong-post thrie-beam median barrier and even higher than a New Jersey barrier. The modified thrie beam costs approximately the same but has less dynamic deflection; it is effective for impact with larger vehicles. The extra expense is probably due to the use of a relatively heavy hot-rolled channel section as a rubrail. When thrie-beam guardrails were developed in the 1970s, the strong-post W-beam guardrail with a rubrail became even less attractive since the thrie-beam guardrail provided a similar type of barrier system at less cost and with reduced complexity.

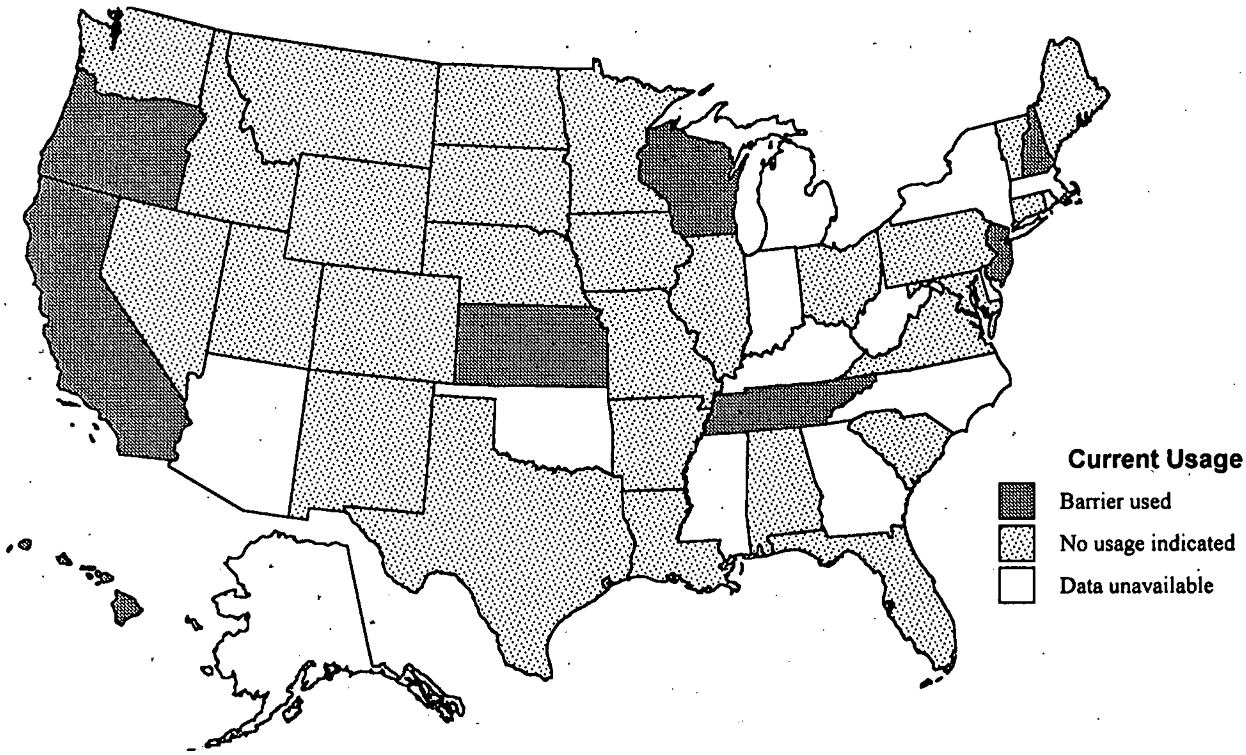


FIGURE 41 States currently installing the strong-post W-beam median barrier with rubrail (SGM06a).

TABLE 28

NCHRP REPORT 230 CRASH TESTS OF STRONG-POST W-BEAM MEDIAN BARRIER WITH RUBRAIL (SGM06b)

	Test Number	
	10	12
Impact condition		
System	SGM06b	SGM06b
Test number		MB-2
Test contractor	Caltrans	SwRI
Impact velocity (km/hr)	97.0	99.1
Impact angle (degrees)	32.0	14.5
Vehicle type	4500S	1800S
Vehicle gross mass (kg)	1814	898
Structural adequacy		
A. Smooth redirection	Yes	Smooth
Dynamic deflection (mm)	945	175
D. Detached elements	NR	None
Evaluation	Pass	Pass
Occupant risk		
E. Vehicle remains upright	Yes	Yes
F. Occupant risk		
Lateral impact velocity (m/sec)	NA	5.2
Longitudinal impact velocity (m/sec)	NA	4.2
Lateral ridedown acceleration (g's)	NA	3.9
Longitudinal ridedown acceleration (g's)	NA	3.6
Evaluation	Pass	Pass
Vehicle trajectory		
H. Intrusion into traveled way	NR	NR
I. Exit conditions		
Exit velocity (km/hr)	NR	79.2
Exit angle (degrees)	High	2.6
Evaluation	NR	Pass
Reference	*97*	*18*

There are many problems with using this barrier. The higher guardrail mounting height and the rubrail restrict the sight distance. The low rubrail can collect a considerable amount of trash and other debris, creating an unsightly maintenance and drainage problem. The system cannot be used on curved alignments without costly shop-bending of the rubrail.

Summary

Whereas the strong-post W-beam guardrail with rubrail has demonstrated acceptable Report 230 performance for the median barrier, the roadside barrier has never been tested. It is also unlikely that the strong-post W-beam guardrail with rubrail will be assessed according to Report 350 since it is not widely used. This barrier system obstructs sight distance, accumulates road debris, and is not particularly aesthetically pleasing. The cost of the barrier is very high when compared with higher-performance, lower-cost systems such as the modified thrie-beam. The strong-post W-beam guardrail with rubrail served an important role in the development of roadside safety hardware, but it has become largely obsolete. This barrier will probably disappear completely from the roadside hardware inventory within the next several decades.

STRONG-POST THRIE-BEAM GUARDRAIL AND MEDIAN BARRIERS

System Descriptions

Thrie-beam barriers were originally developed to extend the performance capabilities of strong-post guardrails to the more diverse population of vehicles that was emerging in the late 1970s. Passenger cars were becoming smaller, a fact recognized in Report 230 by including the 1800S test vehicle in addition to the 2250S test vehicle, and special-purpose vehicles such as pickup trucks, vans and sport-utility vehicles were becoming increasingly common. There are two basic types of strong-post thrie-beam barriers: the standard G9 system with either steel or wood posts (SGR09a and SGR09c) and the modified thrie-beam guardrail (SGR09b).

Olson et al., at the Texas Transportation Institute, performed several tests using two W-beams where the top corrugation of one was nested into the bottom corrugation of the other, resulting in a 506-mm-deep section *(91)*. Walker and Warner used a similar offset lapped W-beam to develop an energy-absorbing bridge rail-to-guardrail transition design *(92)*. Bronstad and Michie performed the first crash tests using 2.67-mm (12-gauge) thrie-beam sections instead of the offset lapped W-beam sections *(90)*. The performance achieved in

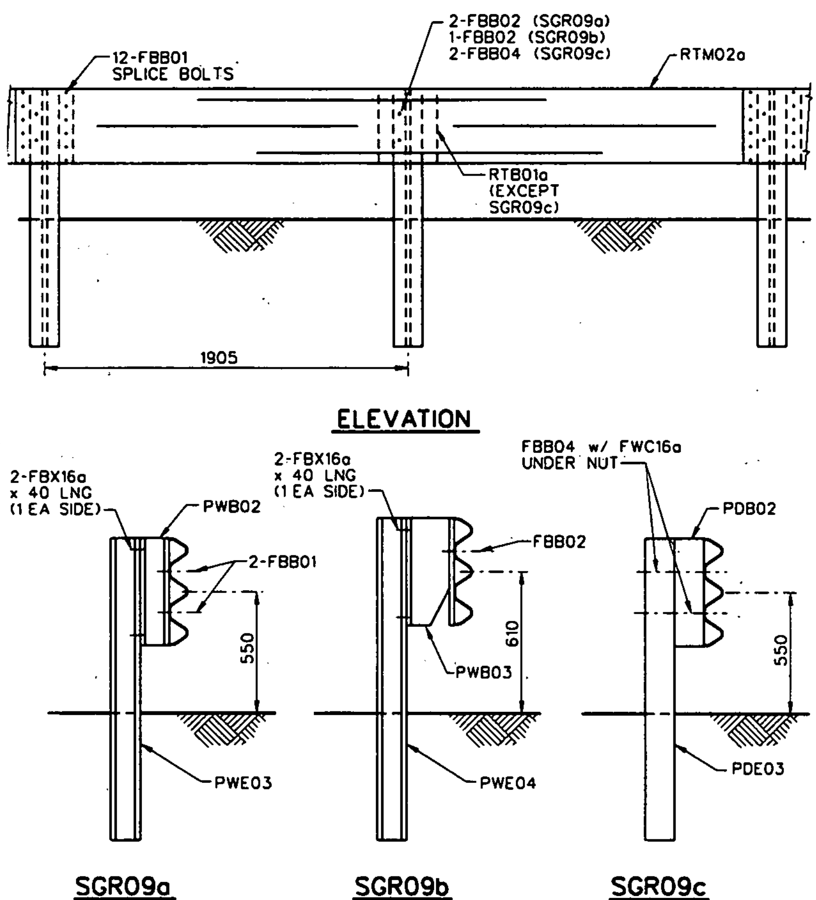


FIGURE 42 Strong-post thrie-beam guardrail (SGR09a) *(22)*.

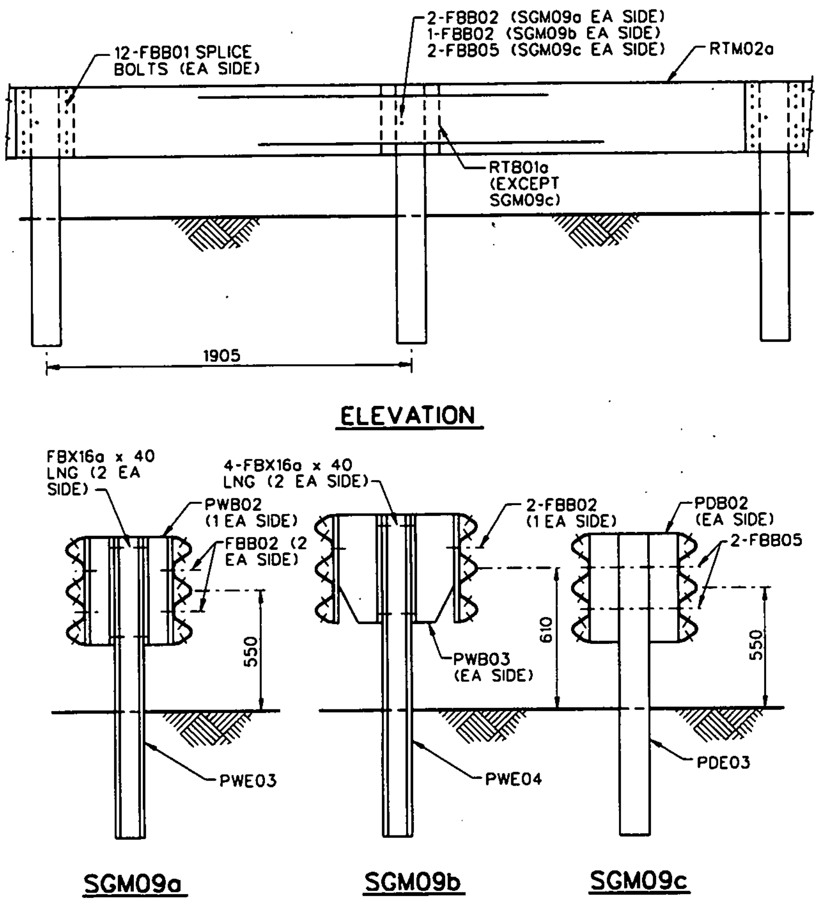


FIGURE 43 Strong-post thrie-beam median barrier (SGM09a-c) *(22)*.

these tests was quite good, and the thrie-beam barrier began to take its place in the roadside safety arsenal as a higher-performance guardrail and median barrier system.

The first strong-post thrie-beam guardrails, Options "a" and "c" in Figures 42 and 43, were simple extensions of the then-existing W-beam guardrail designs. Like strong-post W-beam guardrails, steel and wood posts generally have been considered equivalent from the perspective of impact performance. A strong steel or wood guardrail post with a blockout supported the thrie beam with the top of the barrier located at 813 mm above the grade. The center of the thrie beam was located 560 mm above the ground, about 30 mm higher than the standard strong-post W-beam guardrails. The 508-mm-deep-thrie beam allowed the mounting height of the rail to be increased from 813 mm while still extending almost 70 mm lower than the standard W-beam guardrail. The potential for rollover is reduced since the top of the rail is closer to the center of gravity on heavy vehicles and the protection for smaller vehicles is also increased because the rail extends lower.

The thrie-beam backup plate, like the W-beam backup plate, is an important feature of the steel strong-post thrie-beam systems with steel blackouts. Tests in the early 1970s showed that W-beam guardrails can be sheared off on the sharp edge of the steel blockout when there was no backup plate *(70)*. The 300-mm-long thrie-beam backup plates should be used on all steel strong-post thrie-beam systems with steel blockouts at nonsplice post locations. At posts where there is a splice, the double-thickness of thrie-beam rail has the same effect as the backup plate. Backup plates are not necessary on wood-post systems since wood is not as hard and does not promote tearing when the rail wraps around the blockout. The thrie-beam guardrails take advantage of other lessons learned on W-beam guardrails, such as the importance of lapping the rail splices in the direction of travel and advantages of letting the rail-to-post bolt pull through the slot uninhibited by a rectangular washer.

The modified thrie-beam guardrail, Option "b" in Figures 42 and 43, was developed in a project aimed at exploring the upper performance limits of the standard G4(1S) and G9 guardrails *(93,94)*. The modified thrie-beam guardrail was the result of improvements to the basic G9 thrie-beam guardrail. The performance of these barriers in collisions with larger vehicles such as school buses was disappointing.

The modified thrie-beam guardrail was designed specifically to reduce the incidence of rollover in larger vehicle collisions. This was accomplished in two ways: increasing the beam mounting height to 864 mm and using a specifically designed blockout. Blockouts are most often used to reduce the likelihood of a vehicle wheel snagging on the post. The modified thrie-beam blockout is 356 mm deep, much deeper than a typical blockout. The blockout has a unique notch at the

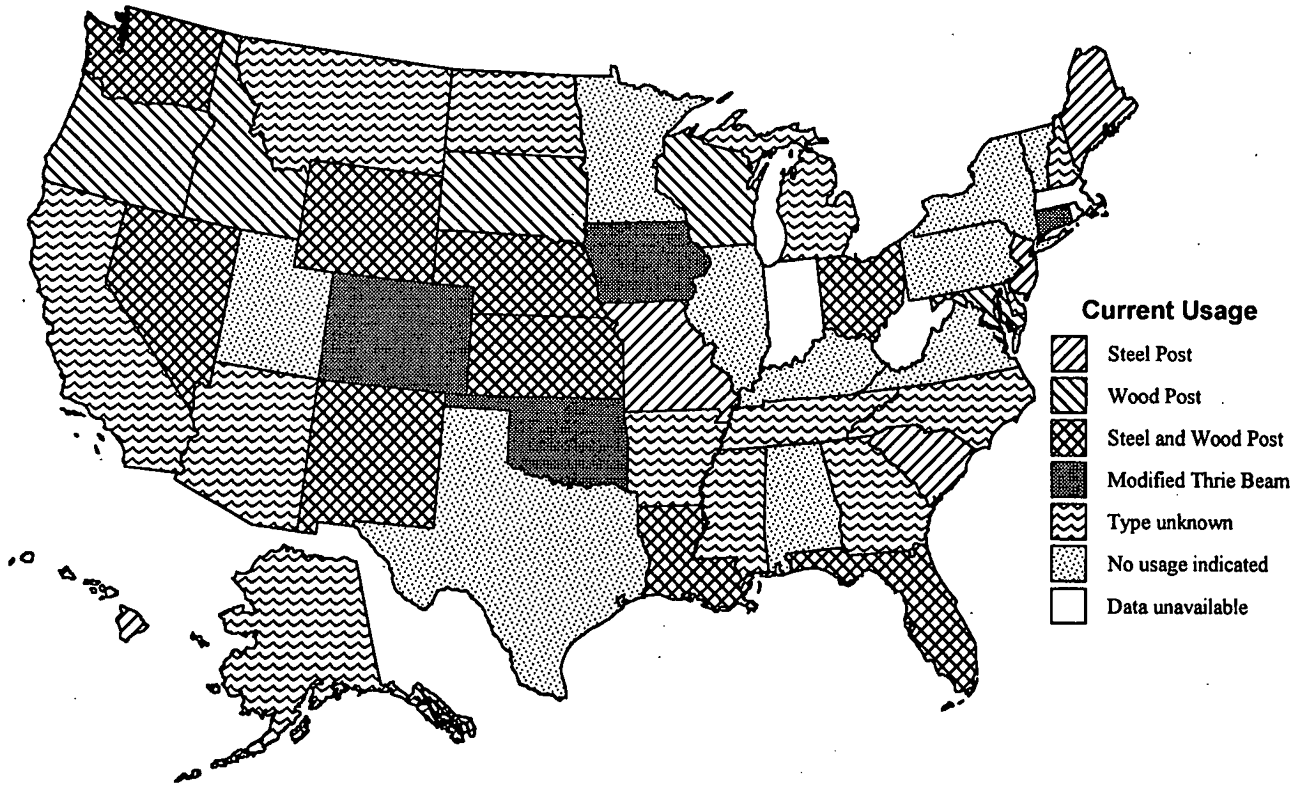


FIGURE 44 States currently installing the strong-post thrie-beam guardrail (SGR09a-c).

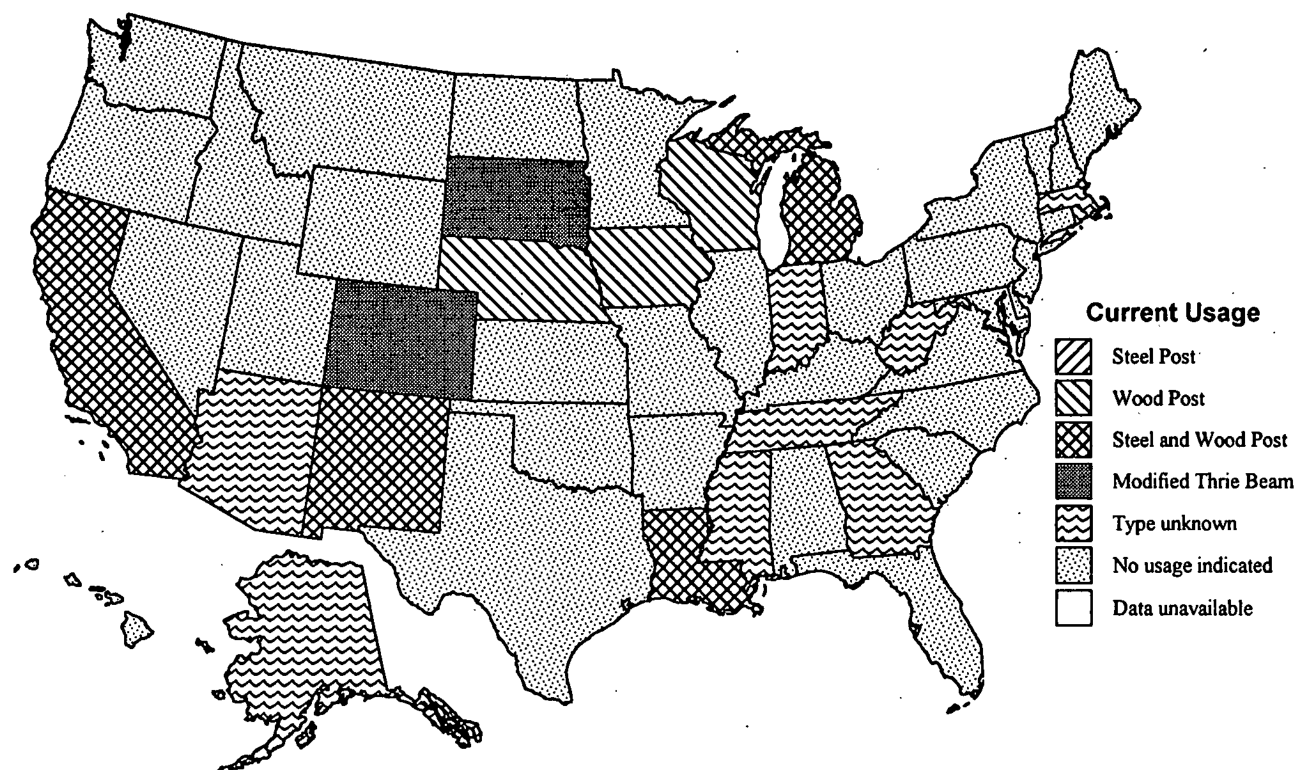


FIGURE 45 States currently installing the strong-post thrie-beam median barrier (SGM09a-c).

TABLE 29
NCHRP REPORT 230 CRASH TESTS OF STRONG STEEL-POST THRIE-BEAM GUARDRAIL (SGR09a)

	Test Number			
	10	12	S13	S18
Impact condition				
System	SGR09a	SGR09a	SGR09a	SGR09a
Test number	AS-45*	GR-2	GR13	4098-1
Test contractor	SwRI	SwRI	SwRI	TTI
Impact velocity (km/hr)	90.8	95.4	95.8	89.5
Impact angle (degrees)	25.2	15.4	22.6	13.5
Vehicle type	4500S	1800S	1800S	20000P
Vehicle mass (kg)	1814	884	907	9081
Structural adequacy				
A. Smooth redirection	Yes	Smooth	Smooth	Rolled
Dynamic deflection (mm)	460	150	385	Penetrated
D. Detached elements	NR	None	None	Yes
Evaluation	Pass	Pass	Pass	Fail
Occupant risk				
E. Vehicle remains upright	Yes	Yes	Yes	No
F. Occupant risk				
Lateral impact velocity (m/sec)	NA	6.2	5.7	NA
Longitudinal impact velocity (m/sec)	NA	NR	4.3	NA
Lateral ridedown acceleration (g's)	NA	10.6	11.4	NA
Longitudinal ridedown acceleration (g's)	NA	NR	1.0	NA
Evaluation	Pass	Marginal	Pass	Fail
Vehicle trajectory				
H. Intrusion into traveled way	NR	NR	NR	None
I. Exit conditions				
Exit velocity (km/hr)	NR	83.9	74.8	NR
Exit angle (degrees)	NR	4.0	2.2	NR
Evaluation	NR	Pass	Pass	NR
Reference		*18*	*18*	*93*

*Test was performed prior to publication of Report 230, so not all Report 230 evaluation parameters were collected or reported.

bottom. During an impact, the thrie beam pushes against the blockout, closing the notch and allowing the thrie-beam rail to remain nearly vertical throughout the collision. Usually when a guardrail is struck, the effective rail height is reduced as the post rotates in the soil. With the deeper, notched blockout, the thrie beam remains essentially vertical, preventing a reduction in effective rail height.

Distribution

Thrie-beam barriers evolved in the 1970s as state transportation personnel and researchers began to observe some performance problems with W-beam guardrails, particularly the weak-post W-beam guardrail. In some cases vehicles were overriding the barrier, and it seemed clear that obtaining the correct barrier height was essential for proper performance but difficult to achieve in the field. Thrie-beam guardrails and median barriers are almost always included in state standards as shown in Figures 44 and 45. Some states only use them in specific situations in which a higher performance barrier is needed, while other states make more general use of them. Colorado, for example, uses the modified thrie-beam guardrail at several locations on steep downgrades on curves with significant truck traffic. Thrie-beam median barriers are the only nonconcrete median barriers approved for use in California.

The modified thrie-beam guardrail (SGR09b) has been used on an experimental basis in three states: Colorado (four sites), Rhode Island (two sites), and Michigan (three sites) *(95)*. The sites chosen for modified thrie-beam guardrails have tended to be problem sites where frequent accidents had caused continual maintenance and repair activities. The modified thrie-beam guardrail has proven to be a good choice for difficult sites in which the presence of heavy vehicles and occurrence of frequent accidents indicate a need for a higher performance barrier system. The field performance of these systems has been quite good.

Crashworthiness

The crash test experience with the strong steel-post G9 thrie-beam guardrail (SGR09a) is summarized in Table 29 and with the strong wood-post M9 thrie-beam median barrier (SGM09a), Table 30. The performance of the G9 thrie-beam barrier (SGR09a) in the required Report 230 tests (Tests 10,

TABLE 30

NCHRP REPORT 230 CRASH TESTS OF STRONG STEEL-POST THRIE-BEAM MEDIAN BARRIERS (SGM09a)

	Test Number	
	10	11
Impact condition		
System	SGM09a	SGM09a
Test number	AS-1[a]	AS-3[a]
Test contractor	SwRI	SwRI
Impact velocity (km/hr)	106.0	87.0
Impact angle (degrees)	26.8	16.8
Vehicle type	4500S	2250S
Vehicle mass (kg)	2041	998
Structural adequacy		
A. Smooth redirection	Yes	Yes
Dynamic deflection (mm)	970	100
D. Detached elements	NR	NR
Evaluation	Pass	Pass
Occupant risk		
E. Vehicle remains upright	Yes	Yes
F. Occupant risk		
Lateral impact velocity (m/sec)	NA	NR
Longitudinal impact velocity (m/sec)	NA	NR
Lateral ridedown acceleration (g's)	NA	NR
Longitudinal ridedown acceleration (g's)	NA	NR
Evaluation	Pass	Pass
Vehicle trajectory		
H. Intrusion into traveled way	NR	NR
I. Exit conditions		
Exit velocity (km/hr)	NR	NR
Exit angle (degrees)	NR	NR
Evaluation	Pass	Pass
Reference	*90*	*90*

[a] Test was conducted prior to publication of Report 230, so all Report 230 evaluation parameters were not collected or reported.

12, and S13) was very good, but when Supplemental Test S18 was performed using a 9081-kg school bus, the bus was contained, but rolled onto its side. This unsatisfactory performance in the large-vehicle test was the motivation for developing the modified thrie-beam guardrail (SGR09b).

The performance of the modified thrie-beam barrier (SGR09b) was substantially better for the heavy-vehicle tests (Table 31) *(93)*. The barrier was able not only to redirect safely the 9100-kg school bus, but also to redirect a 14 500-kg intercity bus, two very demanding crash tests. A median barrier version of the modified thrie-beam was also tested under Report 230 Supplemental Test S15 conditions (18 000-kg intercity bus). The thrie-beam rail splice on the impact side of the median barrier pulled apart and the bus rolled over after being redirected. A modified thrie-beam median barrier successfully redirected a single-unit truck in a subsequent test under essentially Report 350 Test Level 4 conditions (Table 32) *(55)*.

The modified thrie-beam guardrail was approved for use as an operational barrier by FHWA in two memos, one dated May 20, 1985, and other dated May 31, 1985. The three states where experimental installations of the modified thrie-beam guardrail were installed all performed in-service evaluations of the barrier. All of these studies are anecdotal since there were only a handful of installations and the evaluation time was limited to just several years. The Colorado installation on I-70 (Floyd's Hill) experienced seven accidents between 1983 and 1989, five of these involving typical passenger cars and two involving heavy vehicles *(96,97)*. None of the occupants was injured in four of the five passenger-car accidents; the occupant of the other passenger car sustained nonincapacitating injuries. The two heavy-vehicle accidents were extremely severe. The first involved two army convoy single-unit trucks striking the barrier at large angles. The barrier was penetrated, allowing the trucks to go over a very steep, very high embankment: two fatalities resulted. The second accident happened only 8 days later and involved a tractor-trailer truck that had rolled over and slid sideways into the barrier. Both of these heavy vehicle accidents subjected the barrier to conditions well beyond its performance capabilities. After this last collision the modified thrie-beam system was replaced by a roadside New Jersey barrier. All of the Colorado installations have shown evidence of many nuisance hits. These relatively

TABLE 31

NCHRP REPORT 230 CRASH TESTS OF MODIFIED STRONG STEEL-POST THRIE-BEAM GUARDRAIL (SGR09b)

	Test Number			
	12	S13	S15	S18
Impact conditions				
System	SGR09b	SGR09b	SGR09b	SGR09b
Test number	4098-4	4098-5	4098-6	4098-3
Test contractor	TTI	TTI	TTI	TTI
Impact velocity (km/hr)	101	99.1	95.9	89.8
Impact angle (degrees)	15.0	18.0	14.0	15.0
Vehicle type	1800S	1800S	40000P	20000P
Vehicle mass (kg)	2276	2108	14,515	9090
Structural adequacy				
A. Smooth redirection	Yes	Yes	Yes	Yes
Dynamic deflection (mm)	240	310	900	870
D. Detached elements	None	None	None	None
Evaluation	Pass	Pass	Pass	Pass
Occupant risk				
E. Vehicle remains upright	Yes	Pass	Yes	Yes
F. Occupant risk				
Lateral impact velocity (m/sec)	6.0	NR	NA	NA
Longitudinal impact velocity (m/sec)	3.2	NR	NA	NA
Lateral ridedown acceleration (g's)	NR	NR	NA	NA
Longitudinal ridedown acceleration (g's)	NR	NR	NA	NA
Evaluation	Pass	Pass	Pass	Pass
Vehicle trajectory				
H. Intrusion into traveled way	NR	NR	None	None
I. Exit conditions				
Exit velocity (km/hr)	89.0	79.8	NR	NR
Exit angle (degrees)	2.7	1.0	NR	NR
Evaluation	Pass	Pass	NR	NR
Reference	*93*	*93*	*93*	*93*

minor collisions required almost no maintenance, whereas had the system been a typical W-beam system, more costly maintenance would probably have been required.

Both the standard G9 thrie-beam guardrail (SGR09a) and the modified thrie-beam guardrail (SGR09b) have recently been tested according to Report 350 *(98,99)*. As shown in Table 33, the 2000-kg pickup truck rolled over the standard G9 thrie-beam barrier in an impact under Test Level 3 conditions, while the 2000-kg car was redirected successfully in the modified thrie-beam test (Table 34) although there was significant wheel-post contact that resulted in the impact-side front wheel being torn from the vehicle. That the modified thrie-beam guardrail with its 360-mm-deep blockout still experienced wheel snagging problems in the pickup truck collision is very interesting. Some researchers are beginning to conclude that the torsional weakness of rolled W-shapes as posts and blockouts may play an important role in the occurrence of wheel snagging.

Applications

Thrie-beam guardrails can be used in any situation in which strong-post guardrails are used. In general, the modified thrie-beam guardrail (SGR09b) is a superior choice and is not significantly more expensive to install than the standard thrie-beam guardrail (SGR09a).

Average installation costs for thrie-beam guardrails vary about $80/meter for the wood-post thrie-beam guardrail to about $93/meter for the steel-post and modified thrie-beam guardrails (Table 7). The cost data for thrie-beam median barriers are similar though very erratic because of the smaller number of states reporting costs for median barriers. These data indicate that wood-post thrie-beam systems are about $10/meter less expensive than either steel-post option. Interestingly, the mean cost for the standard G9 system was identical to that for the modified thrie-beam guardrail, although the number of states reporting costs for the modified thrie-beam guardrail was small.

Repair costs for all three types of thrie-beam barrier were about 50 percent higher than for typical strong-post W-beam guardrails, as reported in Table 9. The typical reported repair cost for all thrie-beam guardrails and median barriers was about $1,500/accident, about twice the typical repair cost of strong-post W-beam guardrails.

The modified thrie-beam guardrail is a particularly good choice in locations that are struck frequently or where heavy-vehicle accidents are a problem. All four of the modified thrie-

TABLE 32

NCHRP REPORT 230 AND 350 CRASH TESTS OF MODIFIED STRONG STEEL-POST THRIE-BEAM MEDIAN BARRIER (SGM09b)

	Test Number	
	S15	4-12
Impact condition		
System	SGM09b	SGM09b
Test number	4798-12	1769-D-2-88
Test contractor	TTI	ENSCO
Impact velocity (km/hr)	95.9	82.1
Impact angle (degrees)	14.5	15.0
Vehicle type	40000P	Single-unit truck
Vehicle mass (kg)	18,146	8,170
Structural adequacy		
A. Smooth redirection	Splice-failed	Yes
Dynamic deflection (mm)	1400	700
D. Detached elements	None	None
Evaluation	Fail	Pass
Occupant risk		
E. Vehicle remains upright	No	Yes
F. Occupant risk		
Lateral impact velocity (m/sec)	NA	NA
Longitudinal impact velocity (m/sec)	NA	NA
Lateral ridedown acceleration (g's)	NA	NA
Longitudinal ridedown acceleration (g's)	NA	NA
Evaluation	Fail	Pass
Vehicle trajectory		
H. Intrusion into traveled way	None	None
I. Exit conditions		
Exit velocity (km/hr)	NR	33.6
Exit angle (degrees)	NR	1.0
Evaluation	NR	Pass
Reference	*41*	*55*

TABLE 33

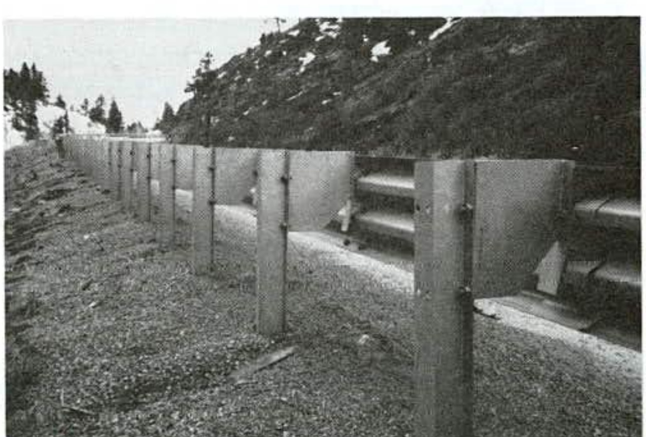
NCHRP REPORT 350 TEST LEVEL 3 CRASH TESTS OF STRONG STEEL-POST THRIE-BEAM GUARDRAIL (SGR09a)

	Test Number	
	3-10	3-11
Impact condition		
System	SGR09a	SGR09a
Test number	GR-13	471470-31
Test contractor	SwRI	TTI
Impact velocity (km/hr)	95.8	102.2
Impact angle (degrees)	22.6	26.1
Vehicle type	1800S	2000P
Vehicle mass (kg)	907	2076
Structural adequacy		
A. Containment	Yes	Yes
Vehicle response	Smooth	Rolled
Dynamic deflection (mm)	385	1070
Evaluation	Pass	Pass
Occupant risk		
D. Compartment penetration	None	114
F. Vehicle remains upright	Yes	No
H. Occupant impact velocity		
Lateral impact velocity (m/sec)	5.7	NA
Longitudinal impact velocity (m/sec)	4.3	NA
I. Occupant ridedown acceleration		
Lateral ridedown acceleration (g's)	11.4	NA
Longitudinal ridedown acceleration (g's)	1.0	NA
Evaluation	Pass	Fail
Vehicle trajectory		
K. Intrusion into traveled way	NR	Yes
L. Longitudinal occupant risk		
Impact velocity (m/sec)	NA	8.0
Ridedown acceleration (g's)	NA	7.0
Exit angle (degrees)	2.2	35
Evaluation	Pass	Fail
Reference	*18*	*99*

TABLE 34

NCHRP REPORT 350 TEST LEVEL 3 CRASH TESTS OF MODIFIED STRONG STEEL-POST THRIE-BEAM GUARDRAIL (SGR09b)

	Test Number	
	3-10	3-11
Impact condition		
System	SGR09b	SGR09b
Test number	4098-5	471470-30
Test contractor	TTI	TTI
Impact velocity (km/hr)	99.1	100.2
Impact angle (degrees)	18.0	25.1
Vehicle type	1800S	2000P
Vehicle gross mass (kg)	2108	2076
Structural adequacy		
A. Containment	Yes	Yes
Vehicle response	Smooth	Snag
Dynamic deflection (mm)	310	1020
Evaluation	Pass	Pass
Occupant risk		
D. Compartment penetration	None	None
F. Vehicle remains upright	Yes	Yes
H. Occupant impact velocity		
Lateral impact velocity (m/sec)	NR	NA
Longitudinal impact velocity (m/sec)	NR	NA
I. Occupant ridedown acceleration		
Lateral ridedown acceleration (g's)	NR	NA
Longitudinal ridedown acceleration (g's)	NR	NA
Evaluation	Pass	Pass
Vehicle trajectory		
K. Intrusion into traveled way	NR	Minor
L. Longitudinal occupant risk		
Impact velocity (m/sec)	NA	7.8
Ridedown acceleration (g's)	NA	9.7
M. Exit angle (degrees)	1.0	11.1
Evaluation	Pass	Pass
Reference	*93*	*98*



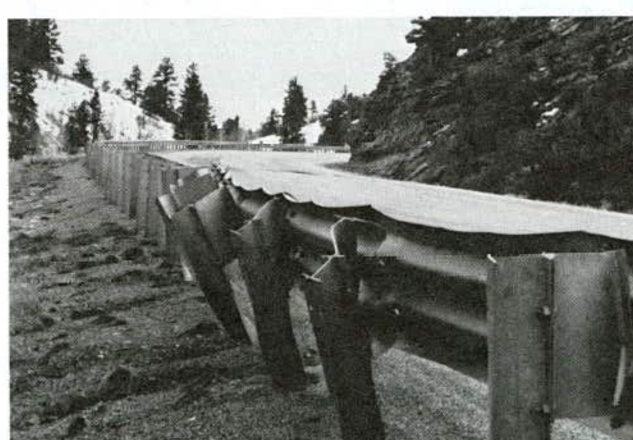


FIGURE 46 Undamaged *(left)* and damaged *(right)* thrie-beam guardrail.

beam guardrail installations in Colorado, like the site shown in Figure 46, were built at locations that had experienced occasional heavy-vehicle accidents and numerous passenger car collisions. The four Colorado sites are all on steep down-grades on the outside of curves with steep, high side slopes *(49,95)*.

The modified thrie-beam guardrail is also a good alternative for sites that experience frequent, relatively minor passenger car collisions. This system will usually sustain much less damage than a typical W-beam guardrail. Many nuisance hits that would require extensive repairs on more common guardrail systems essentially do not damage the modified thrie-beam guardrail. The additional expense of installing a modified thrie-beam guardrail often may be offset by reduced maintenance and repair costs. An installation, maintenance, and repair pocket guide has been developed by FHWA for the modified thrie-beam guardrail *(100)*.

Florida used the modified thrie-beam median barrier (SGM09b) to satisfy the 2.5 percent requirement for innovative median barriers given in Section 1058 of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) *(101)*. According to the 1992 and 1993 FHWA annual reports on compliance with ISTEA, Florida installed more than 22 km of modified thrie-beam median barrier in 1992 *(102)*.

Summary

As with most other strong-post guardrail and median barriers, addressing the crash test performance problems with the 2000-kg pickup truck is very important. Also like most other strong-post guardrails, there has been very little testing to establish the performance characteristics of the median barrier versions of the thrie-beam designs. As shown by the one test of the modified thrie-beam median barrier, good performance in guardrail tests is not a guarantee of good performance in median barrier tests.

CHAPTER FIVE

CONCRETE MEDIAN BARRIERS

Concrete median barriers are used to prevent median crossover accidents. Concrete median barriers are very popular highway safety appurtenances that can be installed on narrow medians and are effective in keeping vehicles from crossing into opposing lanes of traffic. Many states, like California, use a concrete median barrier when the average daily traffic is more than 20,000 vehicles and the median width is less than 9750 mm. For wider medians, more flexible post-and-beam median barriers are used *(2)*. Every state that responded to the state survey (Appendix C Question 24) said that some type of concrete median barrier was used. This report is limited to permanently installed nonproprietary guardrails and median barriers, so even though they are widely used, temporary concrete median barriers are not discussed.

The New Jersey barrier is the most common concrete barrier, but it is not the only one. In the early 1970s, 36 states used some type of concrete median barrier: 19 of them used the New Jersey barrier, 8 used the General Motors (GM) barrier, and the rest used variations of one or the other *(38)*. A study was performed to determine which of the options resulted in the best crash test performance. In addition to the New Jersey and GM barriers, six other shapes, one of which was the F-shape barrier, were identified and tested. More recently, several states have begun to use the constant-slope barrier as an alternative to the New Jersey median barrier.

There are three primary construction techniques used for building concrete median barriers: cast-in-place, slipform, and precast. Hawaii primarily uses cast-in-place barriers; Minnesota primarily uses slipforming; and some states—such as Maine, New Hampshire, and Montana—use only precast barriers. Most states, however, use a combination of all three, although slipforming appears to be the most widely used method (see Appendix C Question 24). Figure 47 shows a photograph of a typical slipforming operation. As shown in Table 35, 9 of the 24 states responding to the survey use the slipforming technique in more than 70 percent of their concrete median barrier construction.

Section 1058 in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) requires the states to install "innovative" median barriers on 2.5 percent of new or replacement median barrier installations. The act states:

> Not less than 2.5 percent of the mileage of new or replacement permanent median barriers included in awarded contracts along Federal-aid highways. . . . shall be innovative safety barriers . . . . For purposes of this section, the term "innovative safety barrier" means a median barrier other than a guardrail, classified by the Federal Highway Administration as "experimental" or that was classified as "operational" after January 1, 1985 *(101)*.

The Federal Highway Administration (FHWA) no longer classifies barriers as "experimental" and "operational" as listed in the ISTEA legislation, but it has taken the position that a tall (e.g., greater than 1070 mm) New Jersey barrier, tall F-shape barrier, the Ontario tall wall, and the constant-slope median barrier satisfy the requirements of the act *(102,103)*. Many states have been installing these newer types of concrete median barriers in order to comply with the requirements of the legislation (Table 36).

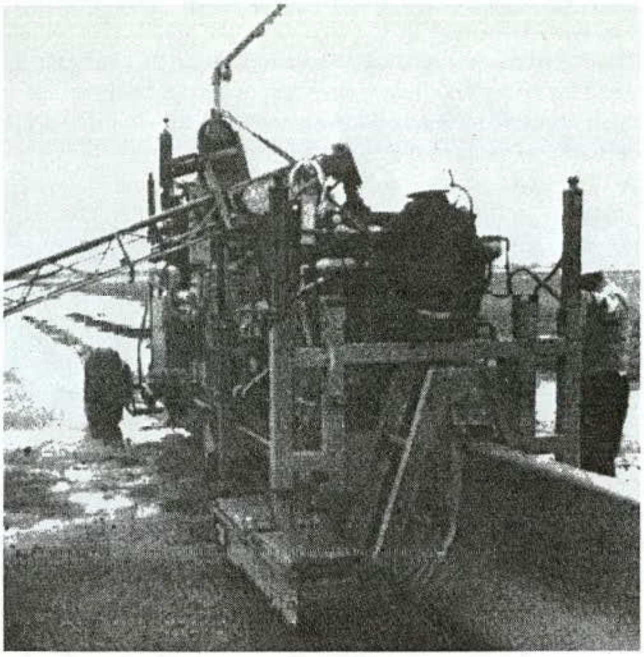


FIGURE 47 Slip-forming a concrete median barrier.

TABLE 35

CONCRETE BARRIER CONSTRUCTION METHOD USED IN 24 STATES

Amount of Usage	Precast	Slipformed	Cast-in-Place
None	9	5	5
Less than 30 percent	7	4	13
Between 30 and 70 percent	1	6	4
More than 70 percent	5	9	2

See Appendix C Question 24 for data on particular states and a list of states included.

NEW JERSEY MEDIAN BARRIER

System Description

Although it is not clear exactly when or where the first concrete median barriers were used, concrete median barriers

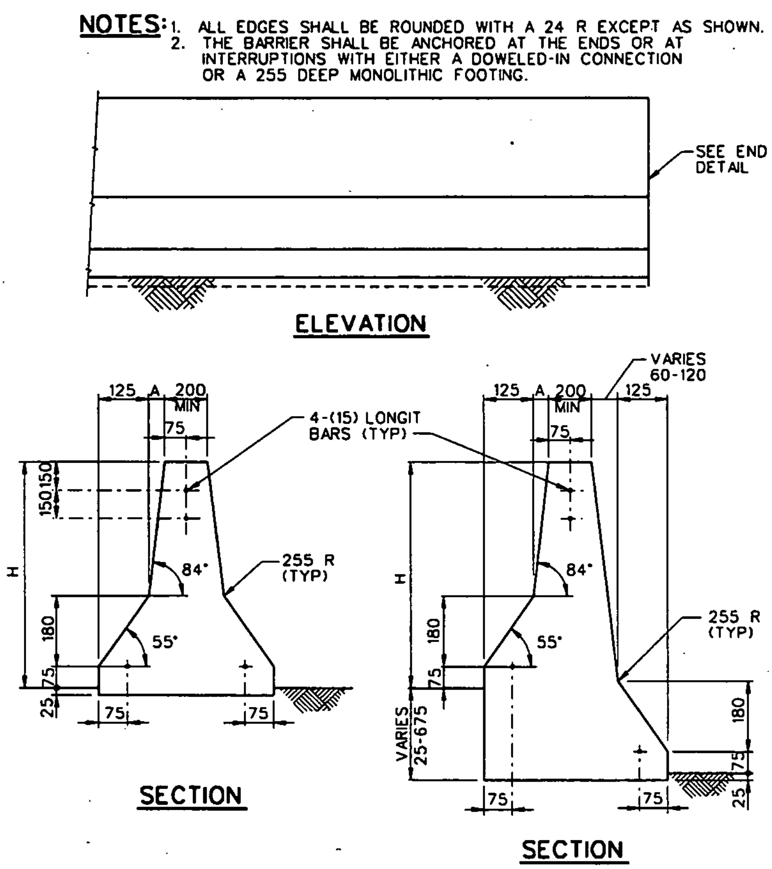
TABLE 36

INSTALLATION OF INNOVATIVE MEDIAN BARRIERS IN 1993 AND 1994 *(102,103)*

Barrier	1992		1993	
	No. of States	km	No. of States	km
Tall New Jersey shape	8	66.9	4	46.1
Tall F-shape	2	1.7	3	4.9
Constant slope	10	41.6	15	100.0
Ontario tall wall	1	2.1	1	65.8
Modified thrie beam	1	22.4	1	0.1
Steel-back timber	0	0.0	1	3.2

were used in the mid-1940s on US-99 on the descent from the Tehachapi Mountains to the central valley south of Bakersfield, California (*104*). This first generation of concrete barriers was developed to (a) minimize the number of out-of-control trucks penetrating the barrier, and (b) eliminate the need for costly and dangerous median barrier maintenance in high-accident locations with narrow medians—concerns that are as valid today as they were 50 years ago.

The first concrete median barrier used in New Jersey was installed in 1955 and was originally only 460 mm tall. After operational problems were observed, the height was increased to 610 mm and then in 1959 to 810 mm. The barrier was developed without crash tests; the state highway department simply observed the accident experience at the site and continued to make changes until the accident experience dropped off (*65,105*). By the early 1960s, both California and New Jersey were experimenting with developing barriers that could be used in narrow medians on high-volume, high-speed highways (*106*). The rapid adoption of the New Jersey concrete median barrier was illustrated by California, where 42 km of



SYSTEM	A	H
SGM10a	60	810
SGM10b	85	1070

FIGURE 48 New Jersey median barrier (SGM11a-b) *(22)*.

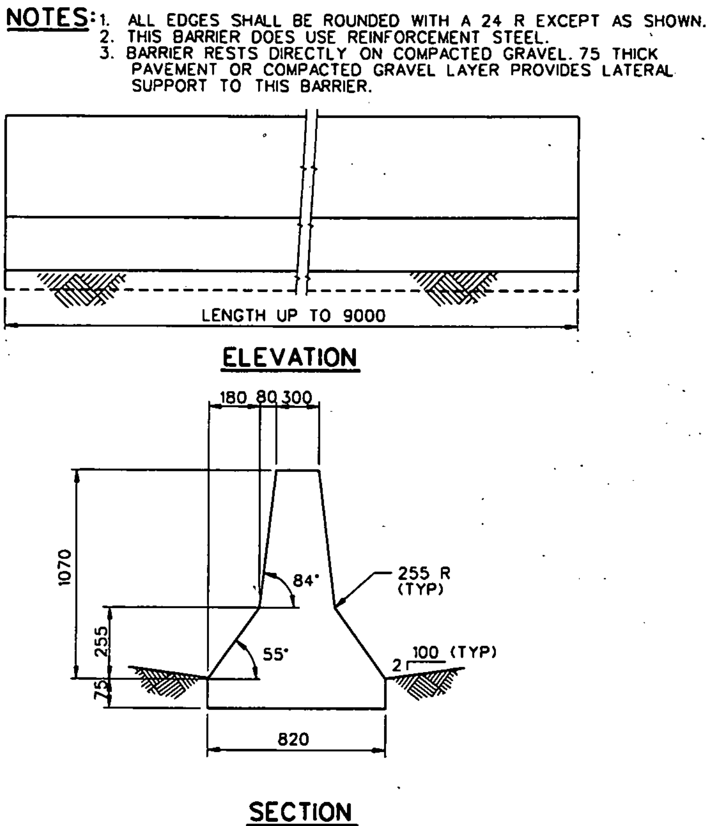


FIGURE 49 Ontario tall-wall median barrier (SGM12) *(22)*.

this barrier was installed in 1971, 170 km in 1972, and by 1988 more than 1100 km of concrete median barrier had been installed (*107,108*). The use of the New Jersey barrier, shown in Figure 48, has expanded to nearly all the states. Most of these barriers have been installed in medians less than 10 m wide *(108)*.

The Ontario tall wall, shown in Figure 49, is a variation of the New Jersey median barrier (109). The tall wall is a 1070-mm-high unreinforced concrete section that rests directly on compacted base material. The tall wall uses the same profile as the New Jersey barrier, but the lower 75 mm is below the paved surface, resulting in a slope breakpoint at the same elevation above the pavement as the F-shape barrier (see next section).

Distribution

The New Jersey barrier is the most widely used concrete median barrier, as shown in Figure 50. A study in the 1970s found that, at the time, 19 states used the New Jersey barrier (38). In 1995, as shown in Figures 50 and 51, nearly every state had at least a few installations of the New Jersey barrier. It is still, despite recent inroads by the F-shape and constant-slope barriers, the most-used concrete median barrier in the United States. The New Jersey barrier is also used widely in roadside applications (Figure 51).

Crashworthiness

The state of California performed a series of three full-scale crash tests in 1967 with an 810-mm-high cast-in-place unreinforced New Jersey median barrier that consisted of 6100-mm-long sections embedded 250 mm into the soil *(65)*. The performance of the system was quite good, especially when compared with the only other alternative at the time for narrow medians, a W-beam median barrier. Similar tests a year later in Ontario confirmed the California results, and the New Jersey barrier quickly became the standard for narrow medians *(54)*.

The design objective of the New Jersey barrier is to prevent penetration of the barrier and redirect a vehicle with as little vehicle damage as possible. Crash tests have even been performed with test drivers at low angles (10 degrees) and low speeds (up to 65 km/hr) in which the driver stated that he experienced "little discomfort" and had "good control of the vehicle both when in contact with the barrier and on exit"*(54)*. Returning the vehicle to the roadway with little damage is an advantage from the point of view of minimizing the risk to vehicle occupants during the collision, but it can also cause problems when an out-of-control vehicle reenters a fast-moving traffic stream. There is a trade-off between minimizing the severity of the initial barrier collision and returning the vehicle to the traffic stream, where it may become involved in another possibly more serious collision.

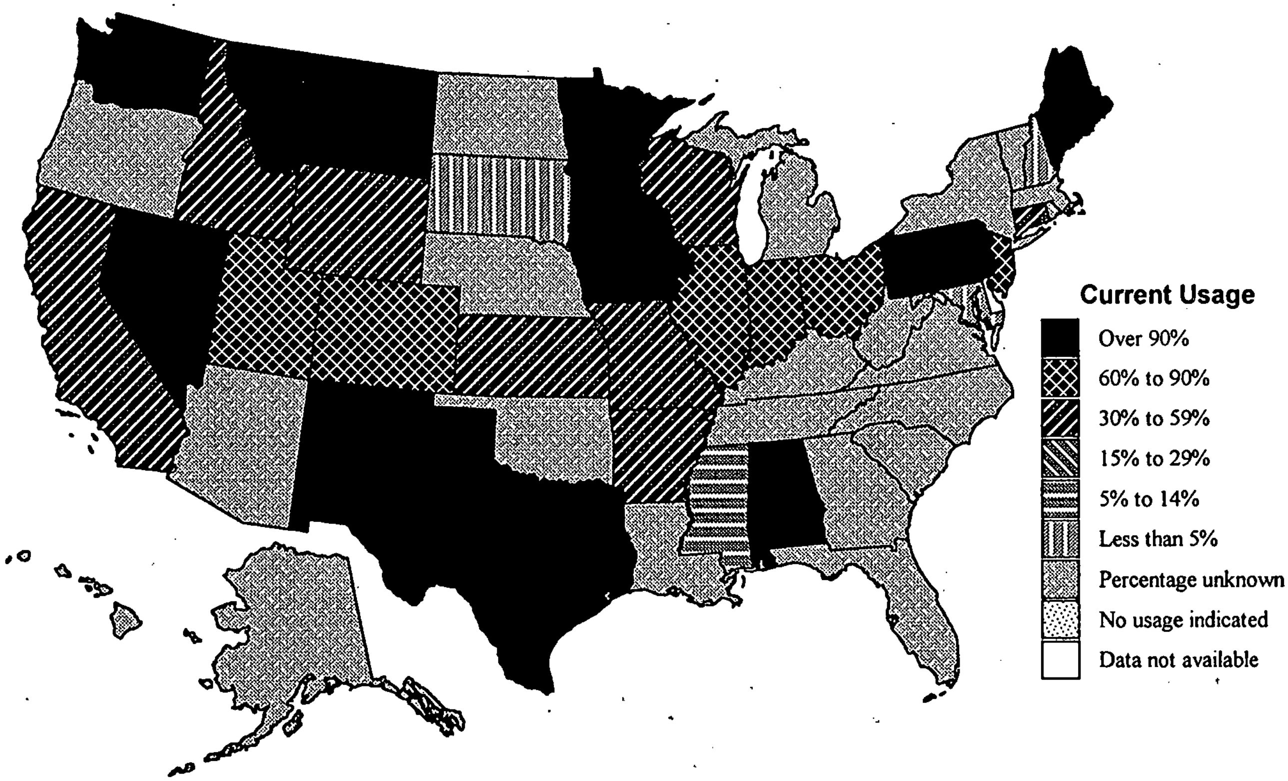


FIGURE 50 States currently installing or maintaining the New Jersey shape concrete median barrier (SGM11a-b).

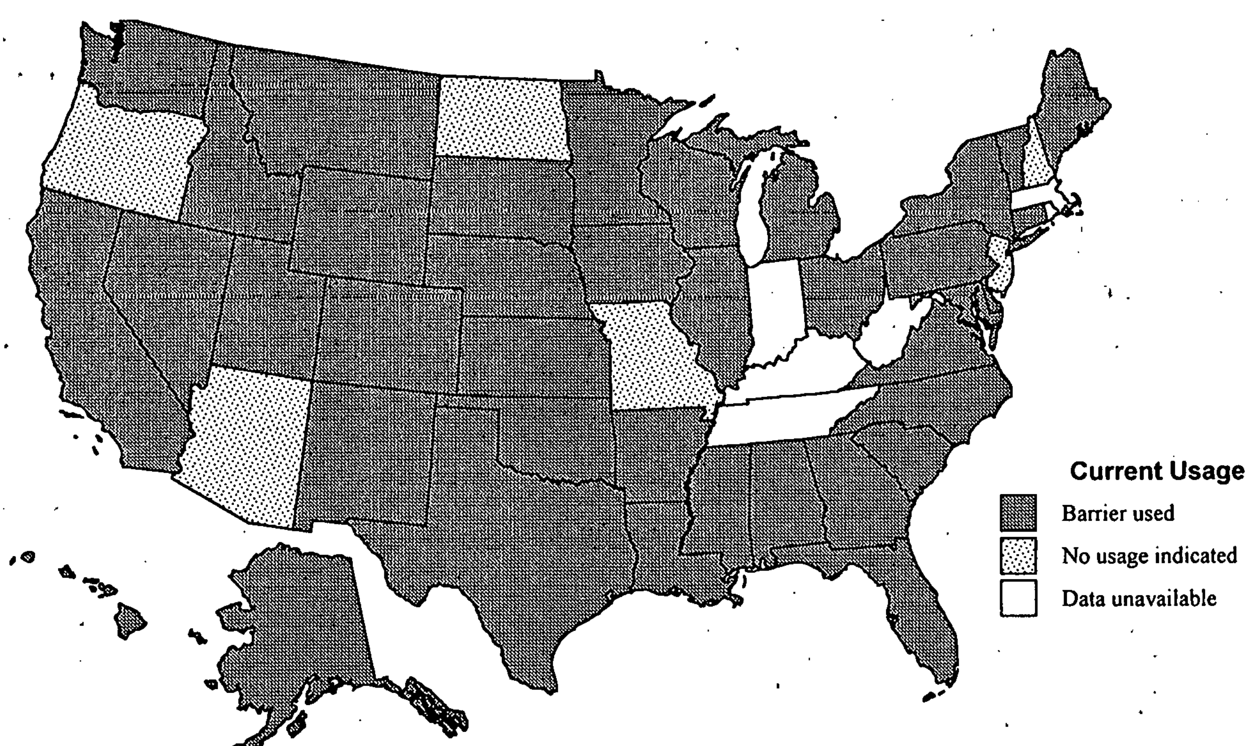


FIGURE 51 States currently installing the New Jersey roadside barrier.

Computer simulations as well as crash test experience have indicated that vehicles, particularly smaller vehicles, are more prone to roll over in shallow-angle impacts with the New Jersey barrier. For this reason many of the tests shown in Tables 37 and 38 were performed with angles smaller than those generally recommended by either Report 230 or Report 350. Mak and Sicking performed computer simulations and analyses that demonstrated the risk of vehicle rollover for passenger cars increases as weight decreases (*110*). Weight, in this context, was a measure of not only the mass of the vehicle but also its inertial stability (e.g., smaller vehicles tend to have relatively higher centers of gravity that are located closer to the front) and the tendency for front-wheel-drive vehicles to "climb" up the barrier face in an impact. It is the combination of these characteristics that can cause stability problems in impacts with concrete barriers such as the New Jersey barrier. There has been concern that new types of test vehicles like the 2000-kg pickup truck might not perform well in impacts with the New Jersey barrier since pickup trucks, though heavier, also have high, far-forward centers of gravity. As shown in Table 38, however, the Report 350 crash tests did not indicate a performance problem, since although the 2000-kg pickup climbed up the barrier, it did not overturn (*111*). The results summarized in Table 38 indicate that the 1070-mm-high New Jersey median barrier satisfies Report 350 Test Level 5 conditions.

Several full-scale crash tests have been performed by the California Department of Transportation to explore the performance of precast and cast-in-place New Jersey barriers in high-angle, low-speed collisions. A 1620-kg midsize passenger car struck a cast-in-place New Jersey barrier at 70 km/hr and 45 degrees, resulting in very sharp vehicle redirection and high anthropometric dummy responses that indicate an unrestrained human occupant would have sustained life-threatening injuries (*112*). Serious collisions are also possible at low speeds when the impact angle is high, as demonstrated in a crash test in which a small 820-kg passenger car struck a concrete median barrier at 45 km/hr and 52 degrees, resulting in the vehicle rolling over (*113*). Despite the severity of these collisions with respect to the occupant, the barrier experienced no serious distress even when struck by a 1330-kg passenger car at 81 km/hr and 74 degrees (*114*). Such collisions are very severe,

TABLE 37

NCHRP REPORT 230 CRASH TESTS OF NEW JERSEY CONCRETE MEDIAN BARRIER (SGM11)

	Test Number			
	10	11	12	S20
Impact condition				
System	SGM11a	SGM11a	SGM11b	SGM11b
Test number	4798-3	CMB-9[a]	4798-01	4798-13
Test contractor	TTI	SwRI	TTI	TTI
Impact velocity (km/hr)	94.3	94.8	96.4	83.8
Impact angle (degrees)	16.2[b]	15.5	14.0	16.5
Vehicle type	4500S	2250S	1800S	80000A
Vehicle mass (kg)	2052	1021	809	36,402
Structural adequacy				
A. Smooth redirection	Smooth	Smooth	Smooth	Smooth
Dynamic deflection (mm)	0.0	0.0	0.0	0.0
D. Detached elements	NR	None	None	None
Evaluation	Pass	Pass	Pass	Pass
Occupant risk				
E. Vehicle remains upright	Yes	Yes	Yes	NA
F. Occupant risk				
Lateral impact velocity (m/sec)	NA	NR	6.0	NA
Longitudinal impact velocity (m/sec)	NA	NR	3.8	NA
Lateral ridedown acceleration (g's)	NA	NR	13.9	NA
Longitudinal ridedown acceleration (g's)	NA	NR	1.0	NA
Evaluation	Pass	NR	Pass	NA
Vehicle trajectory				
H. Intrusion into traveled way	NR	NR	NR	NA
I. Exit conditions				
Exit velocity (km/hr)	79.0	NR	89.0	NA
Exit angle (degrees)	5.0	NR	2.5	NA
Evaluation	Pass	Pass	Pass	Pass
Reference	*41*	*38*	*41*	*41*

NR = not reported; NA = not applicable to these test conditions

[a] Impact angle was much less than the 25-degree angle required.

[b] Test was performed prior to publication of Report 230, so all the evaluation parameters were not collected.

TABLE 38

NCHRP REPORT350 TEST LEVEL 5 CRASH TESTS OF 1070-mm-TALL NEW JERSEY CONCRETE MEDIAN BARRIER (SGM11b) AND ONTARIO TALL WALL MEDIAN BARRIER (SGM12)

	Test Number			
	5-10	5-11	5-12	5-12
Impact condition				
System	SGM11b	SGM11b	SGM11b	SGM12b
Test number	4798-01	405491-1	4798-13	7162-1
Test contractor	TTI	TTI	TTI	TTI
Impact velocity (km/hr)	96.4	101.2	83.8	79.8
Impact angle (degrees)	14.0	25.6	16.5	15.1
Vehicle type	820C	2000P	36,000V	36,000V
Vehicle mass (kg)	809	2000	36 402	36 287
Structural adequacy				
A. Smooth redirection				
Vehicle response	Smooth	Smooth	Smooth	Smooth
Dynamic deflection (mm)	0.0	0.0	0.0	0.0
Evaluation	Pass	Pass	Pass	Pass
Occupant risk				
D. Compartment penetration	None	Minor	NA	
E. Vehicle remains upright	Yes	Yes	NA	NA
H. Occupant impact velocity				
Lateral impact velocity (m/sec)	6.0	NA	NA	NA
Longitudinal impact velocity (m/sec)	3.8	NA	NA	NA
I. Occupant ridedown acceleration				
Lateral ridedown acceleration (g's)	13.9	NA	NA	NA
Longitudinal ridedown acceleration (g's)	1.0	NA	NA	NA
Evaluation	Pass	Pass	Pass	Pass
Vehicle trajectory				
K. Intrusion into traveled way	NR	None	NA	NA
L. Longitudinal occupant risk				
Impact velocity (m/sec)	NA	5.9	NA	NA
Ridedown acceleration (g's)	NA	4.5	NA	NA
I. Exit angle (degrees)	2.5	1.3	NA	NA
Evaluation	Pass	Pass	NA	NA
Reference	*41*	*111*	*41*	*109*

and it is doubtful that any type of traffic barrier would perform well in such a circumstance.

Choosing the New Jersey barrier, like choosing any roadside barrier, involves assessing the trade-offs associated with the barrier characteristics. Rigid concrete barriers like the New Jersey barrier can virtually eliminate cross-median penetrations by even large trucks, redirect smaller vehicles with little risk of injuring the occupant in the barrier collision, and require almost no maintenance even after serious collisions. These positive aspects are gained at the expense of a higher chance of rolling small vehicles over and returning out-of-control vehicles into the traffic stream. As shown in Table 37, the New Jersey barrier has been crash tested successfully according to the recommendations of Report 230 for the standard tests as well as with heavier vehicles.

The Ontario tall wall has also been tested under Report 350 Test Level 5 conditions, as shown in Table 38 *(109)*. Tests 3-10 and 3-11 have not been run, but good performance is presumed based on the successful results of the New Jersey barrier tests shown in Table 38. This unreinforced "tall wall" concrete median barrier was cast in place directly on a compacted fill, and lateral support was provided by a 75-mm-thick asphaltic concrete pavement on both sides of the barrier.

Applications

The original purpose of the New Jersey barrier was to provide a barrier for narrow medians that would minimize the chance of vehicles penetrating the barrier and reduce the amount of maintenance required. The New Jersey barrier is a relatively expensive guardrail or median barrier to construct, costing about $100/meter (Table 7). These costs vary widely between states depending on the type of construction method used (e.g., cast-in-place, slipformed, or precast) as well as the type of foundation and drainage details used for the design. According to the data in Table 7, the New Jersey median barrier is between $30 and $70/meter less expensive than the F-shape and constant-slope barriers, although the cost difference is probably due to the more widespread availability of slipforms and precast sections that use the New Jersey shape.

New Jersey median barriers are typically used in medians as narrow as 1750 mm. The typical median barrier itself is 610 mm wide, and some amount of shoulder is required on both sides of the barrier. Room is needed for providing on-roadway drainage and, in some parts of the country, for plowed snow to accumulate. In addition, drivers tend to "shy away" from large objects near the traveled way. If the barrier is too close to the edge of the traveled way, drivers may crowd toward other adjacent lanes. As shown in Table 4, the typical minimum median width is 1750 mm.

New Jersey barriers have been constructed by casting the barrier in-place in forms, slipforming, and using precast barrier segments. The first New Jersey barriers were cast-in-place and unreinforced and had relatively deep monolithic foundations *(65)*. These barriers involved time-consuming and costly excavation and forming, and often traffic lanes had to be closed while barriers were installed on existing roadways. Contractors developed slipforming techniques that allowed them to install a barrier quickly on top of a foundation that had been previously poured. California researchers began to consider eliminating the foundation altogether. One of the first alternatives that was tested was embedding four tensioning strands in the concrete as it was slipformed. After the concrete cured, the cables were tensioned to provide extra strength *(107)*. Although some states still occasionally use this technique, post-tensioning has been largely replaced by the use of standard reinforcing steel as the concrete construction equipment industry was able to develop slipforming techniques that would work with preassembled reinforcement cages.

A variety of foundation details are in use for supporting concrete median barriers, including

- Using dowels to connect a cast-in-place, precast, or slipformed barrier to a reinforced concrete foundation, rigid concrete pavement, or buried drainage structure. The dowels should be embedded at least 100 mm into both the foundation and the bottom of the barrier. Foundations with a below-grade depth of 200 mm are common. The advantage of this method is that the barrier can be slipformed or cast in place on top of a pre-installed foundation.
- Embedding the barrier below the pavement surface to provide an integral foundation. California at one time used a monolithic barrier that included a 250-mm-deep foundation.
- Slipforming the barrier directly on a flexible pavement or compacted base material with little or no embedment of the barrier below the grade.

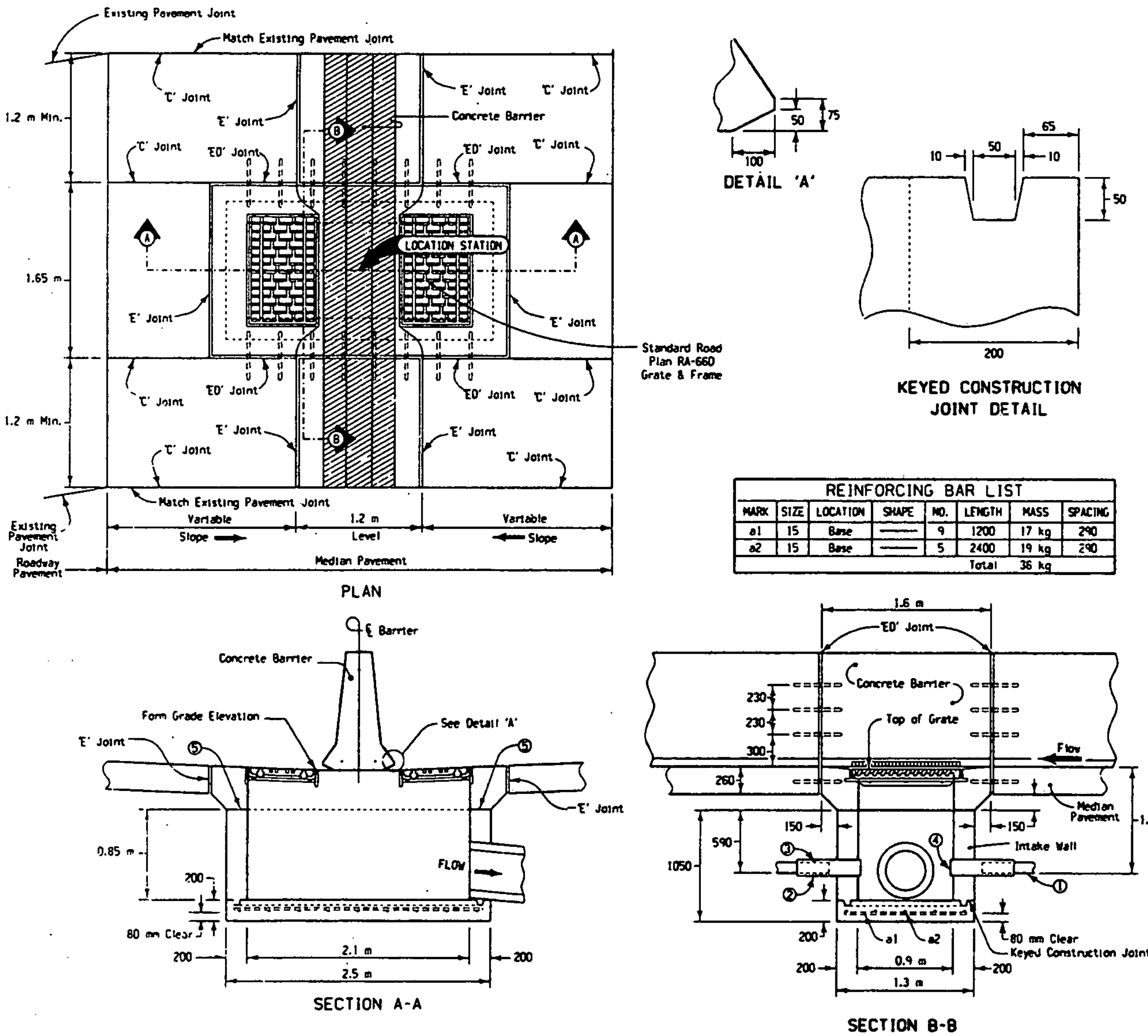
The tests summarized in Tables 37 and 38 that were performed at TTI used sections that were cast in place directly on top of a compacted fill with a 75-mm-thick layer of asphaltic concrete placed on both sides of the barrier to provide lateral support *(41)*. The paved surface in these 1983 tests went up to the first slope breakpoint, which is different from the drawings shown in Figure 48. A somewhat earlier test from California showed that a 36.6-m-long continuous barrier slipformed directly onto an asphalt pavement with no foundation had enough strength to redirect the large 2000-kg car with no lateral deflection *(115)*. The detail shown in Figure 48 is a compromise between these two options using a 25-mm embedment. When shallow embedment or no embedment is used, it is critical that either the barrier be very long (e.g., 36.6 m in the California test) or there be a strong moment-resisting connection between barrier segments.

Maintaining the proper barrier height and crosssection is also affected significantly by the choice of a foundation. When roadways are resurfaced, the addition of pavement overlays can effectively reduce the height of the barrier and lower the critical-slope breakpoint (320 mm above grade for the New Jersey barrier). Adding overlays is generally considered acceptable as long as the breakpoint is at least 255 mm above the grade. This allows the pavement to go to the top of the 75-mm tall vertical edge of the New Jersey barrier. The barrier height, however, is also being reduced so if the addition of overlays is expected, adding a little extra height to the barrier may extend its useful life. In many states it is unlikely that more than two 40-mm-thick overlays would be applied to a roadway before the pavement surface is ground down and removed or recycled, so overlay concerns may not be as difficult in practice as they are in principle.

When resurfacing does compromise the barrier cross section and height, the choice of foundation type will affect the options available for resurfacing and maintaining the integrity of the barrier. Precast sections that are dowelled onto a foundation or a drainage structure can, in principle, be reset. Barriers that are cast or slipformed directly onto a compacted base are typically very long, and resetting such a barrier would be impractical. It is probably more cost-effective to grind down and remove or recycle the pavement than it is to reconstruct or reset the concrete barriers.

Drainage features are also often installed in the center of a relatively narrow median, leading to potential conflicts between the installation of the barrier and the proper drainage of the roadway. When retrofitting medians with New Jersey median barriers when the median already contained catch basins, California used steel channel sections to bridge the gap. The crash test performance of this system was judged to be adequate (*116*). California has also used precast concrete median barriers that contain a drainage conduit inside a foundation. The precast segments are fitted with a watertight gasket between the sections to seal the joints. Although this design is relatively common in more urban areas, it has never been crash tested. Another more common solution used during the past several decades has been to combine the catchment basin with the concrete median barrier (Figure 52) (*117*). This is probably the best solution since it does not disrupt the continuity of the median barrier or obstruct the flow of runoff into the drainage system.

The New Jersey barrier was originally developed as a concrete median barrier, but it has also been widely used as a bridge railing and as a roadside barrier. The roadside barrier version is often incorporated into retaining walls, rock cuts, noise walls, and other structures along the roadway. Support details are critical when designing a roadside installation. The median barrier version is inherently more stable since it must be at least 610 mm wide to accommodate the sloped surfaces on both sides. A roadside version might be half this width and



REINFORCING BAR LIST

MARK	SIZE	LOCATION	SHAPE	NO.	LENGTH	MASS	SPACING
a1	15	Base	——	9	1200	17 kg	290
a2	15	Base	——	5	2400	19 kg	290
					Total	36 kg	

FIGURE 52 Integral concrete median barrier and drainage catch basin *(117)*.

therefore much less stable, so a reinforced concrete foundation is usually required for a roadside New Jersey barrier.

Concrete barriers of all types, including the New Jersey barrier, require virtually no maintenance even after relatively serious collisions. This feature is a distinct advantage to roadway agencies from the points of view of both economics and operations. Concrete barriers are generally used in higher-speed, higher-volume locations, so performing maintenance on such a barrier would be hazardous to workers and could also obstruct traffic.

New Jersey median barriers are often installed in narrow medians where headlight glare from opposing traffic can create a significant safety hazard. In recent years many states have retrofitted existing 810-mm-high concrete median barriers with slipformed concrete glare screens. This type of glare screen requires less maintenance than metal glare screens, and they also are more effective since they block completely the view of the on-coming headlights. California has recently crash tested a slipformed, 510-mm-tall reinforced concrete glare screen installed on top of an 810-mm-tall concrete median barrier. The glare screen did not harm the impact performance of the barrier. One particular concern was that the impact forces would break parts of the glare screen, causing debris to fall into the road, but this did not happen in these tests (*118*).

"Tall" (e.g., 1070 to 1420 mm) New Jersey median barriers can be used to satisfy the 2.5 percent requirement for innovative median barriers given in Section 1058 of ISTEA *(101)*. According to the 1992 and 1993 FHWA annual reports on compliance with Section 1058 of ISTEA, more than 65 km of tall New Jersey median barrier was installed in 1992 in eight states and an additional 46 km of barrier was installed in four states in 1993*(102,103)*. The purpose of the taller wall is to improve the performance of the barrier in truck and bus collisions, although the taller barrier is also an effective low-maintenance glare screen. The Ontario tall wall is also an acceptable "innovative" median barrier, and one state, Indiana, installed more than 65 km of this barrier in 1993 *(103)*.

Summary

The New Jersey concrete median barrier has become one of the most basic types of roadside safety appurtenances in use today. Its widespread use ensures that it is well worth the effort to develop a better understanding of how this type of barrier performs and how it can best be constructed and maintained.

Concrete median barriers are sometimes used to separate lanes of traffic that follow different vertical grades (Figure 48, right). Many states use 675 mm as the maximum amount of grade separation allowed, but this value is based solely on simple statics and field experience. The possibility of tipping a grade-separated concrete barrier increases if segmented concrete barriers are used since the connections between the precast barriers are much more flexible. The stability of grade separated precast concrete barriers should be examined so that better design guidelines can be formulated for this common situation.

The foundation of the median barrier has been steadily refined and reduced because installing footings in medians is expensive and disrupts traffic. Full-scale crash testing has demonstrated that much less foundation support is required than originally thought, although many still used much more substantial footings. Continuous slipformed concrete median barriers without footings have been the standard in states such as California for nearly 20 years without any apparent stability or strength problems.

It is also interesting that the early concrete median barriers were unreinforced or only lightly reinforced with one or two longitudinal bars in the top of the stem to prevent concrete fragments from being propelled into the opposing lanes in a severe impact. Reinforcement has been used for several decades, but the success of systems like the Ontario tall wall suggest that lightly reinforced or even unreinforced sections may be adequate in many situations if the top of the barrier is thick enough. The Ontario tall wall, which is 300 mm wide at the top, redirected a 36 000-kg tractor-trailer at 80 km/hr and 15 degrees without significant barrier damage even though shrinkage cracks that extended completely through the cross section had formed at approximately 10-m intervals. Serviceability requirements to prevent cracking in the concrete may determine design criteria for lightly reinforced concrete barriers rather than strength requirements. Some states, such as California, do not use contraction joints in concrete median barriers and have experienced no serious cracking problems. This issue should also be examined.

The New Jersey barrier has been evolving since it was first installed more than 50 years ago. Experimentation with the shape of the barrier has led in recent years to other types of barriers (F-shape and constant-slope) that will be discussed in the next sections. Despite these new variations, the New Jersey barrier will continue to be one of the most widely used barrier systems on roadways in the United States.

F-SHAPE MEDIAN BARRIER

System Description

The F-shape concrete median barrier, shown in Figure 53, was developed in a research project at Southwest Research Institute in the late 1970s *(38)*. Its somewhat cryptic name, F-shape barrier, comes from the fact that this geometry was the sixth alternative identified and so it was designated with the sixth letter of the alphabet: F.

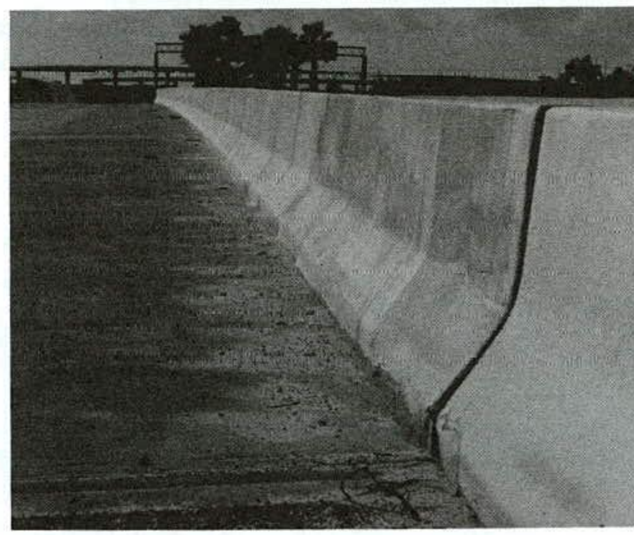
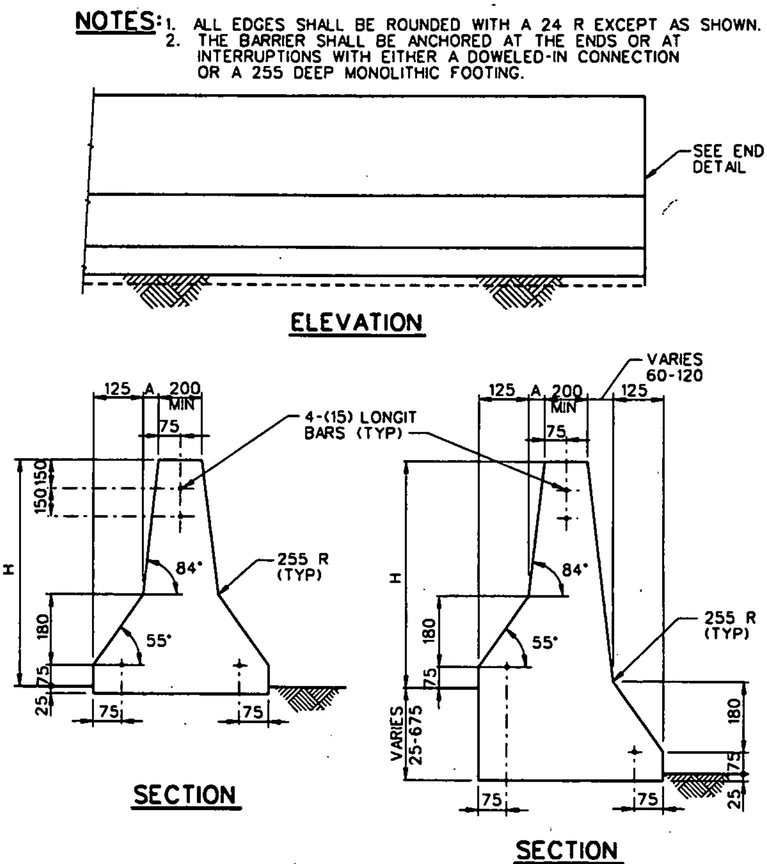


FIGURE 53 F-shape median barrier installation.

The F-shape was the next evolutionary step in the development of concrete median barriers, whereas the New Jersey barrier was one of the first. The key difference between the F and New Jersey barriers is that the upper-slope breakpoint is 75 mm lower on the F-shape barrier than it is on the New Jersey barrier. Research studies have shown that the vehicle stability and trajectory are sensitive to the location of the slope breakpoint *(38,110)*. The now-obsolete GM barrier had the highest slope breakpoint (380 mm), the New Jersey barrier has a slope breakpoint elevation of 330 mm, and the F-shape barrier has the lowest breakpoint elevation, at 255 mm (Figure 54).

Distribution

The F-shape barrier, though it was developed in the late 1970s, has attracted only moderate use. The states that use the F-shape concrete barrier as a roadside or median barrier are shown in Figures 55 and 56. Many of these states—for example, Florida—also use the F-shape barrier as their primary bridge railing system.



SYSTEM	A	H
SGM10a	60	810
SGM10b	85	1070

1994

FIGURE 54 F-shape concrete median barrier (SGM10a-b) *(22)*.

Crashworthiness

The F-shape is generally considered to yield better performance than the New Jersey barrier since it results in better vehicle stability. Unfortunately, the original crash tests performed on this barrier and summarized in Table 39 were performed before the publication of Report 230, so the occupant risk and vehicle trajectory parameters were not collected. No Report 350 tests have been performed on the F-shape median barrier, but extensive tests were performed using F-shape bridge railings *(119)*. These bridge railing tests, summarized in Table 40, were performed according to the AASHTO *Guide Specifications for Bridge Railings* for Performance Level 2 (PL-2) *(120)*. AASHTO PL-2 is considered roughly equivalent to Report 350 Test Level 4 although the 2000-kg pickup test (Test 4-11) uses a lighter truck (2000 versus 2450 kg) and a higher impact angle (25 versus 20 degrees) *(17)*. Since the similar New Jersey median barriers have exhibited structural adequacy for tests with heavy vehicles (Table 38), it is reasonable to assume that an F-shape barrier with the same height, width, and foundation details would also be structurally adequate. The tests performed by Buth et al. showed that the F-shape bridge railings resulted in better vehicle stability than the New Jersey barrier, and this conclusion should also hold for median barriers as well.

Applications

The F-shape barrier, like all other concrete barriers, was developed primarily for use on narrow medians of high-volume, high-speed highways. This barrier is also often used as a roadside barrier on high-volume, high-speed roads and is frequently incorporated into other structures such as retaining walls. The F-shape median barrier typically costs about $170/meter as shown in Table 7, about 70 percent higher than the New Jersey barrier. This higher cost is probably due to a lack of availability of forms and equipment for the F-shape: if it reaches the same widespread use as the New Jersey barrier, the costs should approach each other.

Like the New Jersey barrier, the F-shape may be cast-in-place, slipformed, or precast, and many different types of foundation details may be used to support the barrier. F-shape barriers may be doweled into a foundation, rigid pavement, or drainage structure; embedded into the subbase; or cast directly on a flexible pavement or compacted base. The same types of

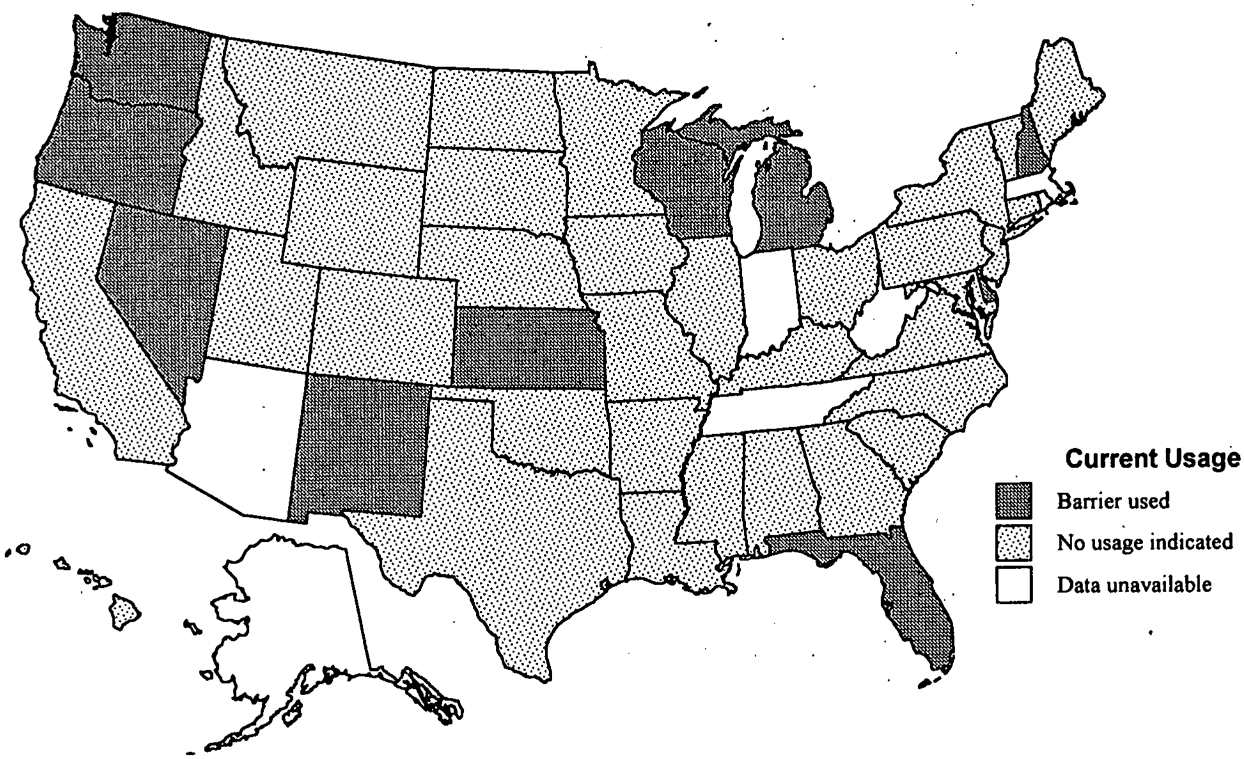


FIGURE 55 States currently installing the F-shape concrete median barrier (SGM10).

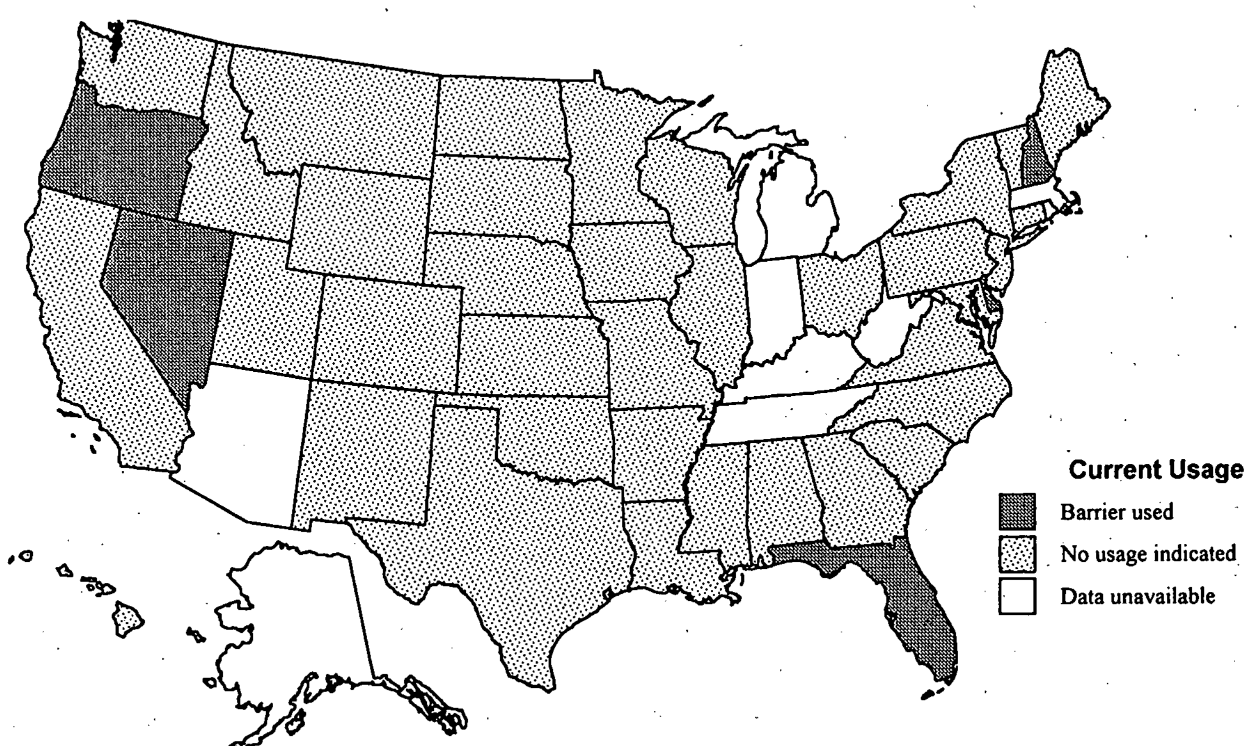


FIGURE 56 States currently installing the F-shape concrete roadside barrier.

TABLE 39

NCHRP REPORT 230 CRASH TESTS OF F-SHAPE CONCRETE MEDIAN BARRIER (SGM10a)

	Test Number	
	10	11
Impact condition		
System	SGM10a	SGM10a
Test number	CMB-12	CMB-13
Test contractor	SwRI	SwRI
Impact velocity (km/hr)	98.8	90.8
Impact angle (degrees)	15.2[a,b]	14.3[b]
Vehicle type	4500S	2250S
Vehicle mass (kg)	1982	1021
Structural adequacy		
A. Smooth redirection	Smooth	Smooth
Dynamic deflection (mm)	0.0	0.0
D. Detached elements	None	None
Evaluation	Pass	Pass
Occupant risk		
E. Vehicle remains upright	Yes	Yes
F. Occupant risk		
Lateral impact velocity (m/sec)	NA	NR
Longitudinal impact velocity (m/sec)	NA	NR
Lateral ridedown acceleration (g's)	NA	NR
Longitudinal ridedown acceleration (g's)	NA	NR
Evaluation	Pass	
Vehicle trajectory		
H. Intrusion into traveled way	NR	NR
I. Exit conditions		
Exit velocity (km/hr)	NR	NR
Exit angle (degrees)	NR	NR
Evaluation	NR	NR
Reference	*38*	*38*

[a] Impact much less than the required 25 degrees.
[b] Tests were performed prior to publication of Report 230, so all the evaluation parameters were not reported.

pavement overlay considerations discussed with respect to the New Jersey barrier also apply to the F-shape barrier. Pavement overlays can compromise the crashworthiness of the barrier by changing the effective height of the barrier and the location of the slope breakpoint. On the basis of the successful California crash tests of glare screens slipformed on top of New Jersey barriers, glare screens slipformed on F-shapes should not affect their crashworthiness *(118)*. In short, the same considerations that apply to the New Jersey barrier apply to the F-shape as well. The only real difference between the two barriers is the location of the slope breakpoint and the resulting improved vehicle stability in a collision.

"Tall" and variable-height F-shape median barriers can be used to satisfy the 2.5 percent requirement for innovative median barriers given in Section 1058 of ISTEA *(101)*. According to the 1993 and 1994 FHWA annual reports on compliance with Section 1058 of ISTEA, only 1.7 km of tall F-shape was installed in 1992 in two states and about 4 km of tall F-shape median barrier had been installed in three states in 1993 (Table 36) *(102,103)*. The purpose of the taller wall is to improve the performance of the barrier in truck and bus collisions, although the taller barrier is also an effective low-maintenance glare screen.

Summary

The future of the F-shape barrier is uncertain. Though it has been available for almost two decades, it has failed to replace the New Jersey barrier—perhaps because roadway designers were not convinced that the improvement in performance was worth the cost and trouble of switching to a new standard. In more recent years the constant-slope barrier has provided a more dramatically different solution. Since both barriers share many characteristics, the list of research needs for the F-shape is nearly identical to that for the New Jersey barrier: developing asymmetric barrier standards, the optimal amount of reinforcement, and ideal foundation details need to be determined. In addition to these generic research needs, full-scale Report 350 crash tests for higher test levels like Test Level 5 should be performed to determine the upper level of performance of the F-shape barrier. An 810-mm-tall F-shape would appear to be adequate as a Test Level 4 system, as shown by the tests summarized in Table 38. The results of the tests for the New Jersey barrier and Ontario tall wall indicate that a 1070-mm-tall F-shape might be acceptable at Test Level 5. Further testing would be needed to determine if the F-shape barrier satisfies Test Level 6, the highest Report 350 test level.

TABLE 40

AASHTO PL-2 CRASH TESTS OF 810-mm-TALL F-SHAPE CONCRETE BRIDGE RAILING

	Test Number		
	PL-2(1)	PL-2(2)	PL-2(3)
Impact condition			
System	F bridge rail	F bridge rail	F bridge rail
Test number	7069-3	7069-4	7069-11
Test contractor	TTI	TTI	TTI
Impact velocity (km/hr)	96.7	105.2	83.8
Impact angle (degrees)	21.4	20.4	14.8
Vehicle type	820C	2000P[a]	8000S
Vehicle inertial mass (kg)	817	2470	8172
Structural adequacy			
A. Containment			
Vehicle response	Smooth	Smooth	Smooth
Dynamic deflection (mm)	0.0	0.0	0.0
Evaluation	Pass	Pass	Pass
Occupant risk			
D. Compartment penetration	None	None	NA
F. Vehicle remains upright	Yes	Yes	NA
H. Occupant impact velocity			
Lateral impact velocity (m/sec)	7.2	NA	NA
Longitudinal impact velocity (m/sec)	5.8	NA	NA
I. Occupant ridedown acceleration			
Lateral ridedown acceleration (g's)	4.9	NA	NA
Longitudinal ridedown acceleration (g's)	2.1	NA	NA
Evaluation	Pass	Pass	NA
Vehicle trajectory			
K. Intrusion into traveled way	Minimal	Minimal	NA
L. Longitudinal occupant risk			
Impact velocity (m/sec)	NA	3.8	NA
Ridedown acceleration (g's)	NA	1.2	NA
M. Exit angle (degrees)	6.2	7.4	NA
Evaluation	Pass	Pass	NA
Reference	*119*	*119*	*119*

[a]Pickup truck was ballasted to meet AASHTO requirements rather than Report 350 recommendations, so it was heavier than the standard 2000P vehicle.

CONSTANT-SLOPE MEDIAN BARRIER

System Description

The constant-slope concrete median barrier uses a single sloping face of approximately 80 degrees rather than the three-slope face used in the New Jersey and F-shape barriers. The angle that provided the best impact performance was examined by performing computer simulations with the HVOSM RD-2 computer program *(110)*. The objective of this study was to reduce the risk of rollover while minimizing the forces experienced by the occupant as measured by the occupant risk criteria. The geometry shown in Figure 57 represents the barrier system tested by the Texas Transportation Institute, but states are continuing to make slight modifications to the shape of the barrier. California, for example, uses somewhat taller sections (915 rather than 810 mm and 1420 rather than 1070 mm) to allow for future pavement overlays. The angle of the single slope, although still about 80 degrees, has been modified slightly in the California design to promote even dimensions and to accommodate a thicker section at the top (320 rather than 200 mm). The next several years should see a standardization in the geometry of the constant slope barrier.

The constant-slope median barrier is the most recent step in the evolution of concrete median barrier systems (*121*). Several states have adopted it in recent years as a means of satisfying ISTEA's mandate for using innovative median barriers. The constant-slope median barrier is designed for permanent installations where a New Jersey or F-shape median barrier might otherwise be used.

Distribution

Although the constant-slope median barrier was tested only in the late 1980s, it is being used in a number of states as an innovative median barrier (Figure 58). Other states are just beginning to install constant-slope barriers to gain experience in constructing and maintaining this type of barrier. California, for example, approved the use of a constant-slope median barrier for experimental use late in 1993 (*122*). Most of the states that are experimenting with the constant-slope barrier are using it

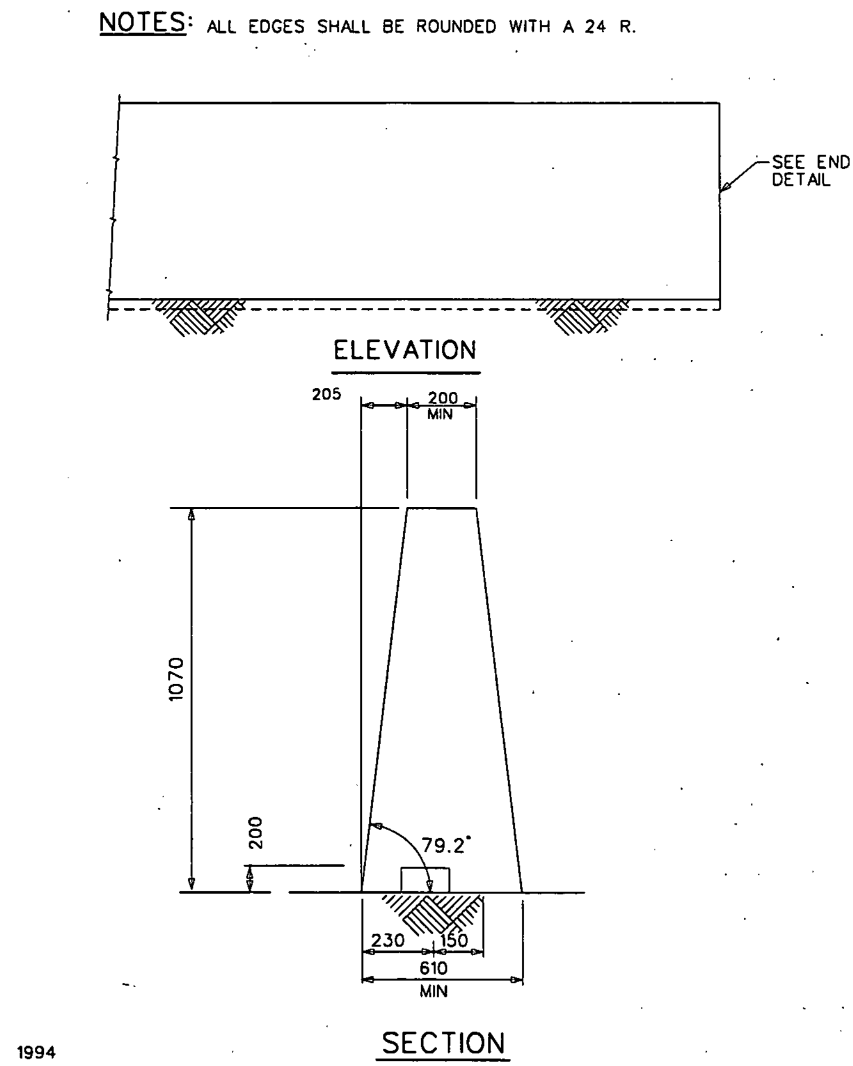


FIGURE 57 Constant slope concrete median barrier (SGM14a-b).

in median applications rather than as a roadside barrier, as is apparent by comparing Figures 58 and 59. If the in-service experience with this barrier is good, it should become a very popular system.

Crashworthiness

Vehicles are generally more stable in collisions with vertical-faced barriers. Sloped barrier faces result in less stable collisions but lower occupant impact accelerations and velocities. Bridge rail testing has demonstrated that the best stability characteristics were achieved with a simple vertical wall, although the occupant risk parameters were only marginal *(119)*. The constant-slope concrete median barrier is an attempt to balance the design between improved stability and reduced occupant responses. Unfortunately, the promise of better stability was not fully realized when the system was tested *(121)*. The maximum roll angle in a typical large passenger car collision with a New Jersey barrier is about 20 degrees, whereas for the constant-slope barrier it is a considerably higher, 32 degrees. This result seems to indicate that the fore-slope angle of a concrete barrier is an important feature in terms of the roll angle and overall stability of a vehicle in a collision.

The constant-slope concrete median barrier has been tested according to the recommended guidelines in Report 230, (Tables 40 and 41), and there are plans to test the barrier according to Report 350 in the fall of 1996. The constant-slope system has, however, been tested as a bridge rail for Report 350 Test Level 4 (including the 2000-kg pickup truck and the 8000-kg single-unit truck tests) *(123)*. These tests, summarized in Table 42, suggest that as far as the shape of the barrier is concerned, a constant-slope median barrier should satisfy Test Level 4, although both the New Jersey and F-shape barriers appear to have better vehicle stability characteristics.

Applications

The constant-slope barrier is used in the same types of applications as the New Jersey and F-shape median barriers,

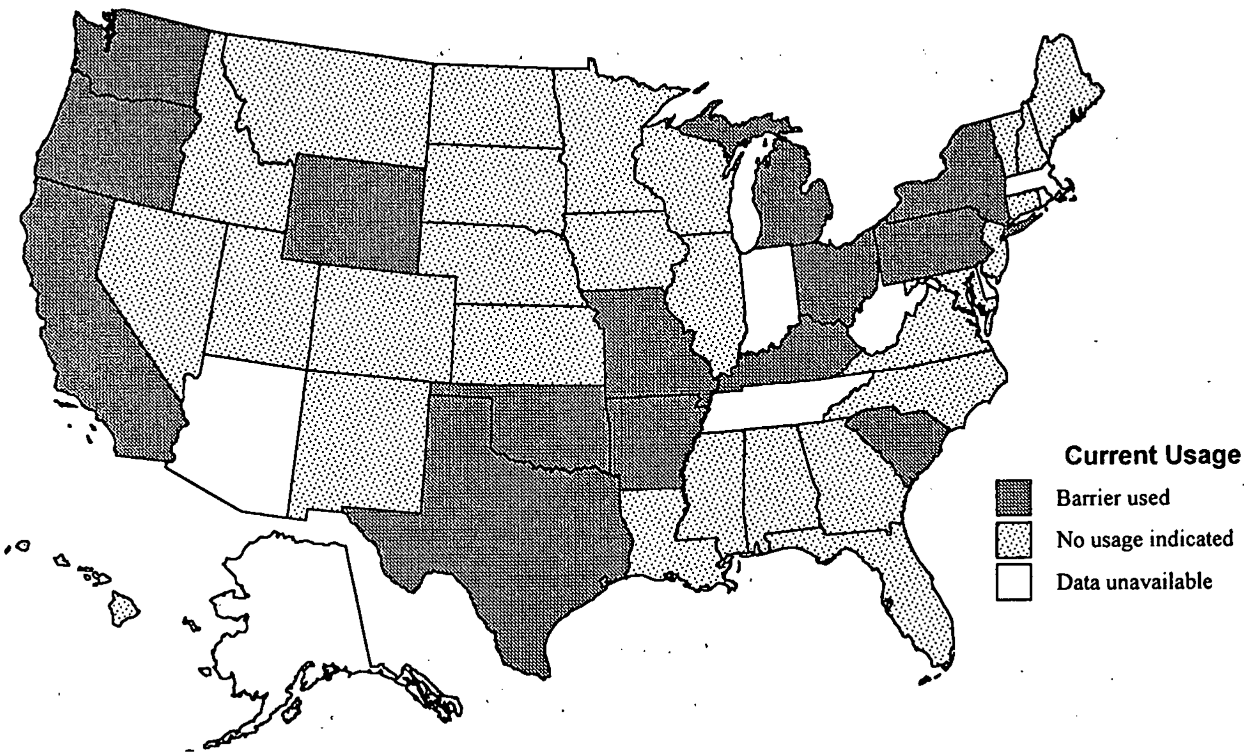


FIGURE 58 States currently installing the constant slope concrete median barrier (SGM14a-b).

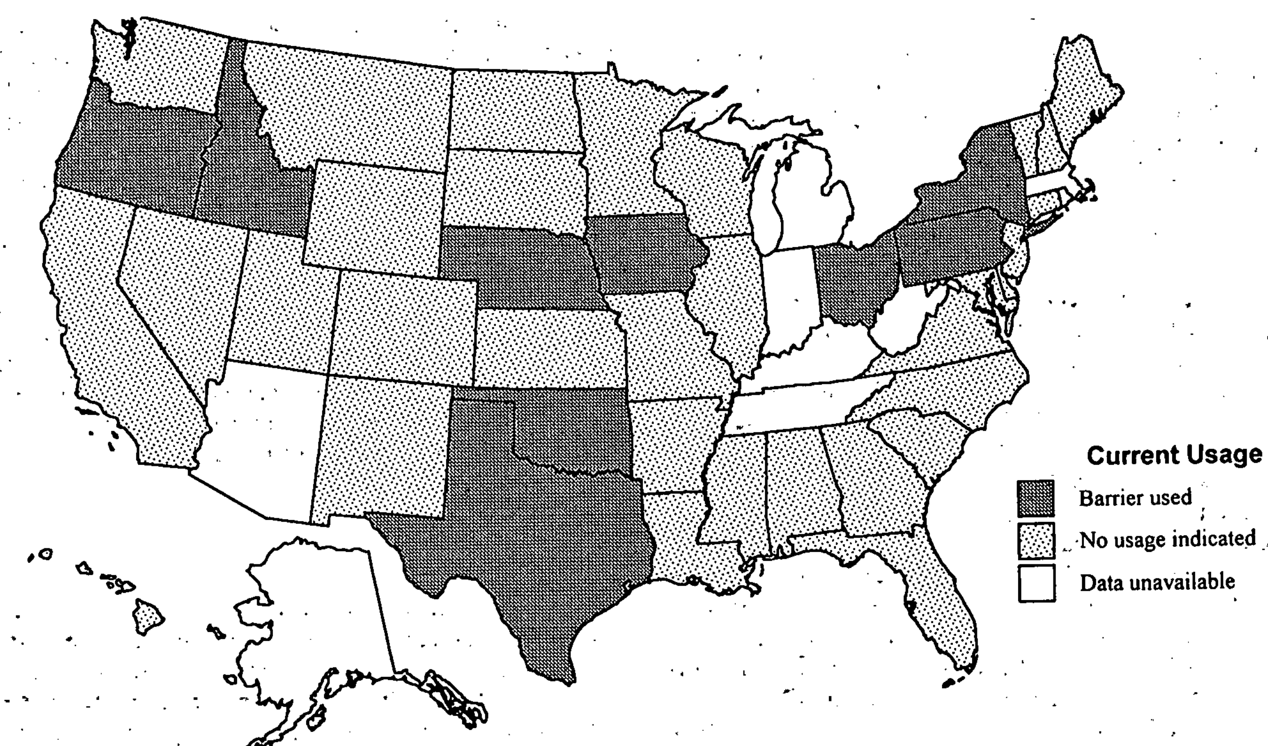


FIGURE 59 States currently installing the constant slope concrete roadside barrier.

TABLE 41

NCHRP REPORT 230 CRASH TESTS OF CONSTANT-SLOPE CONCRETE MEDIAN BARRIER

	Test Number	
	10	S13
Impact condition		
System	SGM14	SGM14
Test number	9429C-3	9429C-2
Test contractor	TTI	TTI
Impact velocity (km/hr)	101.5	97.7
Impact angle (degrees)	26.5	19.9
Vehicle type	4500S	820C
Vehicle mass (kg)	2043	817
Structural adequacy		
A. Smooth redirection	Airborne	Airborne
Dynamic deflection (mm)	0.0	0.0
D. Detached elements	NR	NR
Evaluation	Pass	Pass
Occupant risk		
E. Vehicle remains upright	Yes	Yes
F. Occupant risk		
Lateral impact velocity (m/sec)	NA	8.4
Longitudinal impact velocity (m/sec)	NA	4.8
Lateral ridedown acceleration (g's)	NA	15.3
Longitudinal ridedown acceleration (g's)	NA	6.3
Evaluation	Pass	Pass
Vehicle trajectory		
H. Intrusion into traveled way	No	No
I. Exit conditions		
Exit velocity (km/hr)	83.3	83.8
Exit angle (degrees)	8.5	4.3
Evaluation	Pass	Pass
Reference	*121*	*121*

namely, on high-volume, high-speed highways. The constant-slope median barrier has a typical cost of about $130/meter (Table 7). This cost should probably continue to fall and approach the $100/meter cost of a New Jersey median barrier if the constant-slope barrier becomes more widely used. The California Department of Transportation estimates that the cost of a 915-mm-tall constant-slope barrier will be $80/meter for slipformed barriers and $115/meter for precast barriers *(122)*.

Concrete median barriers such as the New Jersey and F-shape barriers have a cross-sectional profile that varies with the height above the ground. As pavement overlays are added to the roadway during the life of the barrier, the effective height of the F-shape and New Jersey barriers is reduced. If the asphalt surface is not milled or the barrier reset, then the slope breakpoint of the New Jersey and F-shape barriers will not be at the correct height and the crashworthiness performance may be compromised. The constant-slope barrier avoids this problem since the slope is not a function of the height above the ground. As long as the total height to the top of the barrier is acceptable, pavement overlays do not change the shape of the barrier at all. The California versions of this barrier are 915 mm high rather than 810 mm and 1422 mm high rather than 1070 mm. Both heights are more than 100 mm taller than the usual barrier height dimensions to allow room for future pavement overlays while also providing a glare screen. Some research has recently been completed on constant-slope barriers with slipformed glare screens *(124)*. The barrier performed acceptably with no serious distress to the glare screen, and no large pieces of concrete became dislodged from the barrier.

According to the 1993 and 1994 FHWA annual reports on compliance with Section 1058 of ISTEA, nearly 42 km of constant-slope barrier was installed in 10 states in 1992, and 100 km in 15 states in 1993 (Table 36) *(101-103)*. The constant-slope median barrier was approved by FHWA as an operational device in a February 11, 1992, memorandum, so it satisfies the requirements of the legislation. Since there are relatively few median barriers that satisfy the definition of "innovative," the constant-slope barrier has been one of the more popular choices for meeting the mandate (Table 36).

Summary

Some of the same research concerns given for the New Jersey and F-shape barriers apply to the constant-slope barrier: adequate foundation designs, the amount of reinforcement required, and the stability of asymmetric barriers. The test results for the constant-slope barrier also suggest that the search for a concrete barrier profile that balances the forces experienced by the occupant with the post-impact stability of the vehicle is not yet over. Though the constant-slope barrier is a relatively new system, it provides another solution aimed at balancing the needs of safely redirecting and stopping errant vehicles while preventing cross-median accidents. The roadside safety community should examine carefully the in-service performance of this barrier to see if it performs as expected in the field.

TABLE 42

NCHRP REPORT 350 TEST LEVEL 4 CRASH TESTS OF CONSTANT-SLOPE CONCRETE MEDIAN BARRIER (SGM14) AND CONSTANT-SLOPE BRIDGE RAILING

	Test Number		
	4-10	4-11	4-12
Impact condition			
System	SGM14	CS Bridge rail	CS Bridge rail
Test number	9429C-2	7147-15	7147-16
Test contractor	TTI	TTI	TTI
Impact velocity (km/hr)	97.7	97.2	82.1
Impact angle (degrees)	19.9	25.5	10.0
Vehicle type	820C	2000P	8000S
Vehicle mass (kg)	817	2000	8172
Structural adequacy			
A. Containment			
Vehicle response	Airborne	Airborne	Airborne
Dynamic deflection (mm)	0.0	0.0	0.0
Evaluation	Pass	Pass	Pass
Occupant risk			
D. Compartment penetration	NR	Minor	NA
E. Vehicle remains upright	Yes	Yes	No
F. Occupant impact velocity			
Lateral impact velocity (m/sec)	8.4	NA	NA
Longitudinal impact velocity (m/sec)	4.8	NA	NA
I. Occupant ridedown acceleration			
Lateral ridedown acceleration (g's)	15.3	NA	NA
Longitudinal ridedown acceleration (g's)	6.3	NA	NA
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
K. Intrusion into traveled way	None	None	NA
L. Longitudinal occupant risk			
Impact velocity (m/sec)	NA	5.4	NA
Ridedown acceleration (g's)	NA	7.8	NA
M. Exit angle (degrees)	8.5	3.3	NA
Evaluation	Pass	Pass	Pass
Reference	*121*	*123*	*123*

CHAPTER SIX

AESTHETIC GUARDRAILS AND MEDIAN BARRIERS

Over the past decade, there has been interest in using guardrails and median barriers that are more aesthetically pleasing alternatives to the guardrails and median barriers discussed earlier in this report. The primary goal of barrier hardware designers has been to develop effective hardware at the minimum cost: aesthetics have not typically been a high priority. Only in recent years has the importance of more intangible qualities such as aesthetics become a concern in developing roadside hardware.

The primary function of roads in parks, historic communities, or scenic areas is to provide access to aesthetically sensitive areas. Many typical guardrails compromise this basic function of scenic roadways. The need to provide safe roadways does not, however, stop at the boundaries of a scenic or historic area. The 620-km-long Natchez Trace Parkway, to cite a particular example, experienced 200 accidents in 1986, 5 of which involved fatalities. In 1990 there were 7,831 traffic accidents in National Parks, 40 of which were fatal. There are almost 13 000 km of roadways in National Parks alone, and more than half of this mileage (7818 km) is paved. There are 3.8 million vehicle-km traveled (VKT) on National Park roadways so the accident rate is 2.1 accidents per 100 million VKT and the fatality rate is 0.11 per 100 million VKT. The fatality rate on all roadways in the United States was 1.51 deaths per 100 million VKT in 1990 (*125*).

Although the fatality rate is an order of magnitude less than the national average rate, it is still not negligible. There has been a need to develop barrier systems that fit in with a variety of aesthetically sensitive surroundings so that the twin goals of protecting scenic beauty and providing safe roads do not conflict. Aesthetic barrier designs are of interest not only in parks and recreational areas. Many local communities have expressed interest in using special barriers where protecting the scenic beauty or historical appearance is important. Of the states responding to the survey, 68 percent did not have an aesthetic guardrail barrier option and 83 percent did not have an aesthetic median barrier option (Appendix C Questions 9 and 10). In the 30 percent of states that do have an aesthetic barrier in their standard, the barrier that is identified most often is a standard strong wood-post W-beam guardrail (SGR04b) with weathering steel (ASTM A606).

None of the systems discussed in this chapter has experienced extensive use and, in fact, it is unlikely that they will ever be used other than as special-purpose barriers because of their higher expense. These systems are not in *A Guide to Standardized Highway Barrier Hardware*, so there are no standardized drawings of these systems in this document although drawings are available in a Federal Highway Administration (FHWA) summary report (*126*). All these systems are generally intended for lower-volume, lower-speed roadways rather than high-volume, high-speed highways.

STEEL-BACKED TIMBER GUARDRAIL

System Description

Timber guardrails have been used for decades in National Parks and National Forests as traffic barriers and traffic control devices. Timber is an attractive material in situations where blending in with the natural surroundings is important. Unfortunately, barriers made of unreinforced timber are not effective in many types of collisions. Typical timber guardrails have a mounting height that is too low, and there is no continuity between rail segments. The steel-backed timber guardrail, shown in Figure 60, was developed to overcome these deficiencies while still taking advantage of the aesthetic qualities of wood.

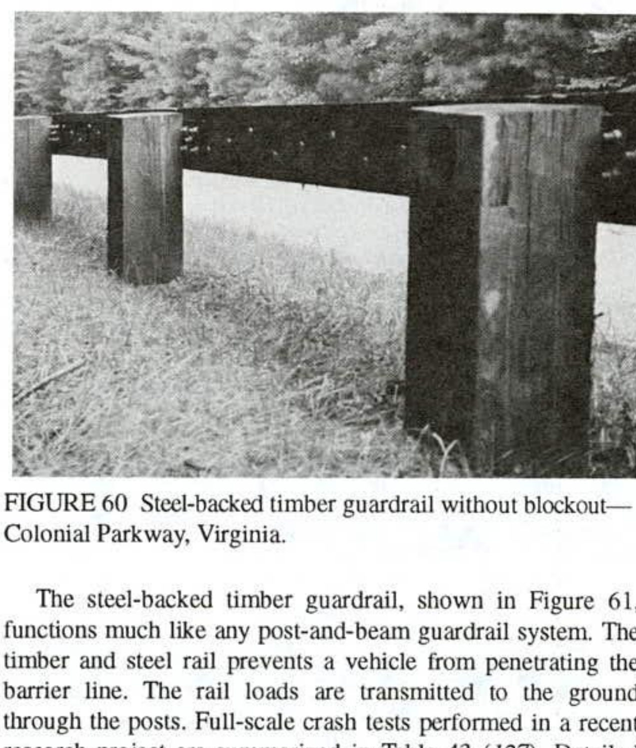


FIGURE 60 Steel-backed timber guardrail without blockout—Colonial Parkway, Virginia.

The steel-backed timber guardrail, shown in Figure 61, functions much like any post-and-beam guardrail system. The timber and steel rail prevents a vehicle from penetrating the barrier line. The rail loads are transmitted to the ground through the posts. Full-scale crash tests performed in a recent research project are summarized in Table 43 (*127*). Detailed specifications for constructing this barrier can be found in the *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects* (*128*). The steel-backed timber guardrail was approved for use on Federal-aid projects in 1990 (*129*).

There have been several versions of this guardrail system installed in several National Parks. FHWA's Federal Lands Highways Division (FLHD) has two versions of this system in its current standards: a blocked-out version and an unblocked-out version. The unblocked-out version has been crash tested

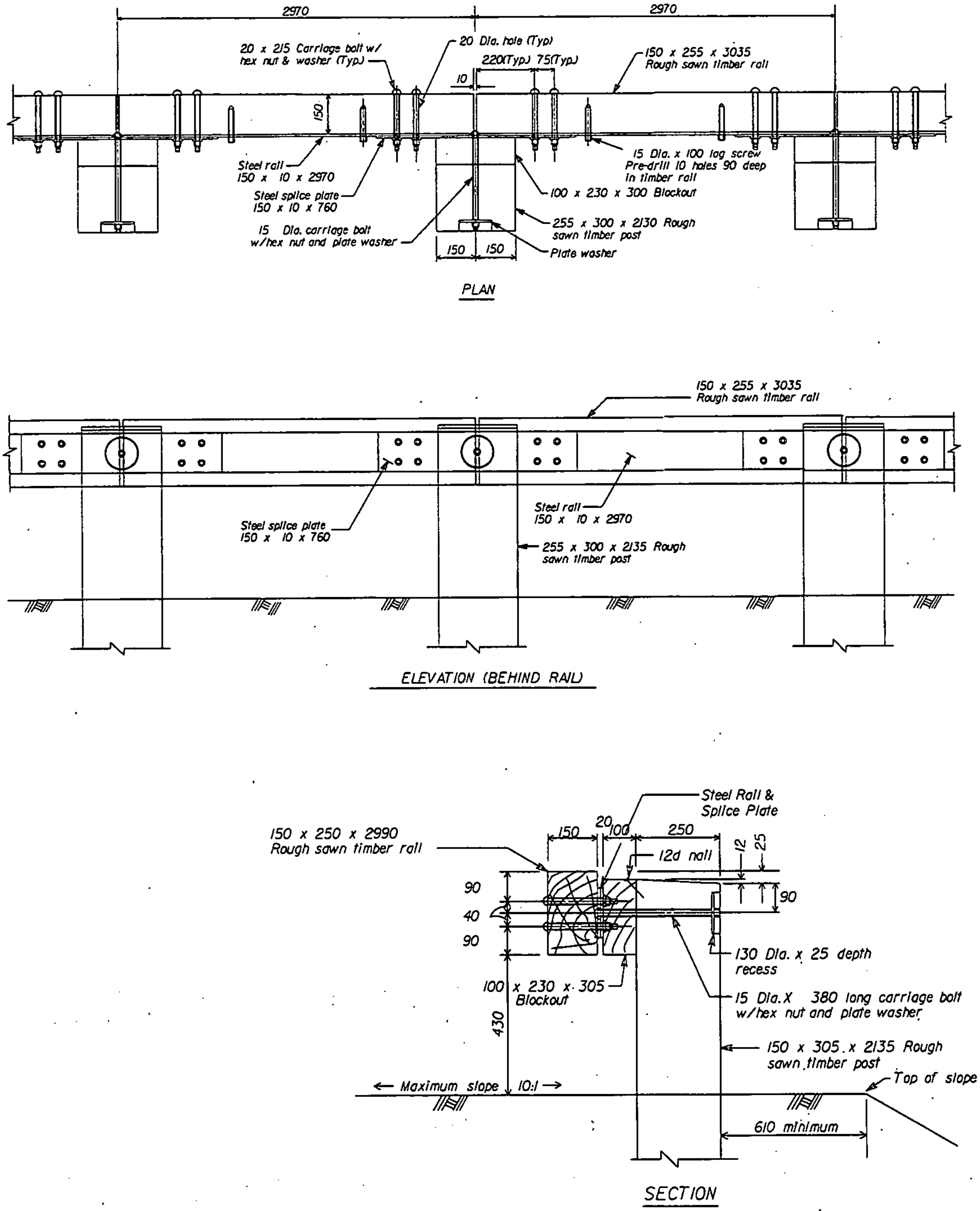


FIGURE 61 Steel-backed timber guardrail (after *(126)*).

successfully for lower speeds (i.e., 80 km/hr). The blocked-out version, which was tested at 100 km/hr, is thought to be a more crashworthy system because the blockout minimizes the chance of vehicle wheels snagging on the posts. The addition of the blockout does not significantly affect the cost of the system. The FLHD recommends using the steel-backed timber guardrail with a blockout for all installations unless there is an objection for aesthetic reasons.

The 250- × 300-mm wood posts, with the wider dimension of the post installed parallel to the traveled way, and a small 100- × 230-mm blockout are used to support the 150- × 250-mm wood rail with a steel reinforcing strap. Earlier versions of this system had a counter-sunk hole in the back of the guardrail post to accommodate the head of the post-rail attachment bolt. Problems with wood splitting between the top of the post and the hole resulted in the elimination of this detail in the most recent FLHD specifications. The wooden rail faces the traffic side of the barrier and a steel reinforcing plate is lag-bolted to the back of the wood rail for the entire length of the rail. A steel splice plate is used to attach the steel reinforcing

TABLE 43

NCHRP REPORT 230 CRASH TESTS OF STEEL-BACKED TIMBER GUARDRAIL WITH AND WITHOUT BLOCKOUTS

	Test Number		
	10	12M	10
Impact condition			
System	Blocked out	Blocked out	Unblocked out
Test number	1818-5-6-87	1818-8-88	1818-14-87
Test contractor	ENSCO	ENSCO	ENSCO
Impact velocity (km/hr)	100.0	102.2	81.8
Impact angle (degrees)	24.4	20.0	25.0
Vehicle type	4500S	1800S	4500S
Vehicle mass (kg)	1955	822	1951
Structural adequacy			
A. Smooth redirection	Smooth	Smooth	Snag
Dynamic deflection (mm)	NR	200	130
D. Detached elements	None	None	None
Evaluation	Pass	Pass	Pass
Occupant risk			
E. Vehicle remains upright	Yes	Yes	Yes
F. Occupant risk			
Lateral impact velocity (m/sec)	NA	5.6	NA
Longitudinal impact velocity (m/sec)	NA	8.1	NA
Lateral ridedown acceleration (g's)	NA	11.6	NA
Longitudinal ridedown acceleration (g's)	NA	12.8	NA
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
H. Intrusion into traveled way	None	None	Minor
I. Exit conditions			
Exit velocity (km/hr)	42.0	60.8	58.6
Exit angle (degrees)	10.0	5.5	8.0
Evaluation	Pass	Pass	Pass
Reference	*126*	*126*	*126*

NR = not reported; NA = not applicable to this test condition

rails from adjacent rails, the blockout, and the timber post. Continuity between the timber rails is provided by the steel reinforcing plates and splice plates. The wood rail is 3040 mm long and the top of the rail is mounted 686 mm above the ground at the traffic face.

Typical unreinforced timber rails were attached to the posts but not to each other. In an impact the entire tensile and bending load in the rail had to be resisted by the two posts supporting the rail. Since the load could not be distributed to other posts and rails in the system, the impacted components would fracture, allowing the vehicle to penetrate the system. The steel backup rail provides continuity between rail elements. Impact loads can be distributed to other posts in the system as well as the anchor, since the wooden rails and the steel backup rails are all spliced together. The steel backup rails are 2970-m-long plates made of weathering steel that are joined together with a steel splice plate at each post. Lag screws spaced 255 mm apart attach the steel and wooden rail elements together ensuring that they behave as a single composite beam. The steel is placed on the face of the rail opposite traffic primarily for aesthetic reasons, but tensile bending stresses are also greatest on the nontraffic face of the rail. Steel is a more effective material in tension than wood, so the backup plate is placed at the location where it is most effective.

Distribution

A number of steel-backed timber guardrails have been installed, primarily in National Parks on the East Coast. There are earlier versions of the steel-backed timber guardrail on the southern part of the George Washington Parkway and the Colonial Parkway, both in Virginia. An installation conforming to the drawings shown in this report is being built along the northern part of the Natchez Trace National Parkway in Williamson County, Tennessee.

Crashworthiness

The steel-backed timber guardrail was designed to be a very stiff guardrail system, behaving more like a bridge rail or a concrete barrier than a typical post-and-beam guardrail. The

Report 230 tests for both the blocked-out and unblocked-out versions of this system are summarized in Table 43. Both types of barriers cause a significant amount of vehicle damage, although the tests were judged to be passing. The large passenger car snagged the impact-side wheel on a post in the test of the system that did not use blockouts during a relatively low-speed (80-km/hr) impact. For this reason, the FLHD recommends the unblocked-out version for only lower-speed roadways. If blockouts are used, the steel-backed timber guardrail may be used on a high-speed facility (e.g., 100 km/hr).

Applications

The steel-backed timber guardrail is ideal for sites at which a strong-post W-beam guardrail would normally be used if aesthetics were not a factor. Only the wooden elements of the system can be seen from the road, so it is more aesthetically pleasing than a typical W-beam or thrie-beam barrier. The steel elements of the barrier are manufactured from weathering steel, which blends in with surrounding natural colors.

There have been a number of installations of this barrier system, but the system has only recently been standardized so there are several design variations. The design of the barrier has evolved over the past several years, each installation incorporating improved features. All the installations to date have used the guardrail with rather than without the blockout. The FLHD encourages the use of the guardrail with blockouts in all situations but allows the guardrails without blockouts on roads where the speed is less than 80 km/hr.

The steel-backed timber guardrail is very stiff, so it should sustain little damage in all but the most severe collisions. After a serious collision, several posts or rail elements might be damaged. Damaged elements should be replaced using essentially the same procedures used in constructing the device. If posts are displaced in the soil but otherwise undamaged, the post should be realigned using a chain and truck. The soil behind the realigned post should be retamped with a compactor if possible. Aside from having damage from collisions repaired, this system should require no routine maintenance.

Rhode Island used a median version of the steel-backed timber guardrail to satisfy the 2.5 percent requirement for innovative median barriers given in Section 1058 of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) *(101)*. According to the 1993 FHWA annual reports on compliance with Section 1058 of ISTEA, Rhode Island installed about 3 km of steel-backed timber median barrier in 1993 *(103)*.

The FLHD reports a range of construction costs from \$85 to \$165/meter. Construction costs for the steel-backed timber guardrail averaged \$130/meter of barrier on the Colonial Parkway installations in Virginia in 1988, which is probably a good median cost for planning purposes. Typical strong-post guardrails like the G4(1S) generally cost about \$60/meter—a little less than half the cost of the steel-backed timber system. Although it is more expensive than a more typical barrier, the steel-backed timber guardrail is the least expensive of all the aesthetic guardrails developed so far.

Providing an adequate terminal is an important though difficult design task for all types of guardrails and median barriers, and the steel-backed timber guardrail rail is no exception. The FLHD recommends the use of a terminal that is tapered back from the road and sloped into the ground or an earth berm. If the site includes a backslope, the end of the barrier can be tapered back and buried in the slope, producing a safer alternative than the simple turned-down and tapered-back terminal. A concrete block is buried in the ground to provide anchorage for the guardrail system. The taper used is the same as is suggested in the AASHTO 1989 *Roadside Design Guide* for other types of guardrails *(2)*.

This terminal design is probably adequate for installations for which traffic volumes are low and speeds are moderate, as is typical in most parks and aesthetically sensitive areas. The tapered-back and turned-down terminal should not be used on high-speed, high-volume roadways because there is a chance that the terminal would launch vehicles striking it head-on at high speeds. Standard guardrail terminals could also be used on this barrier, but aesthetic considerations usually preclude this option.

MERRITT PARKWAY GUIDERAIL

System Description

The Merritt Parkway guiderail, shown in Figure 62, was developed by the Connecticut Department of Transportation to

FIGURE 62 Merritt Parkway Guiderail.

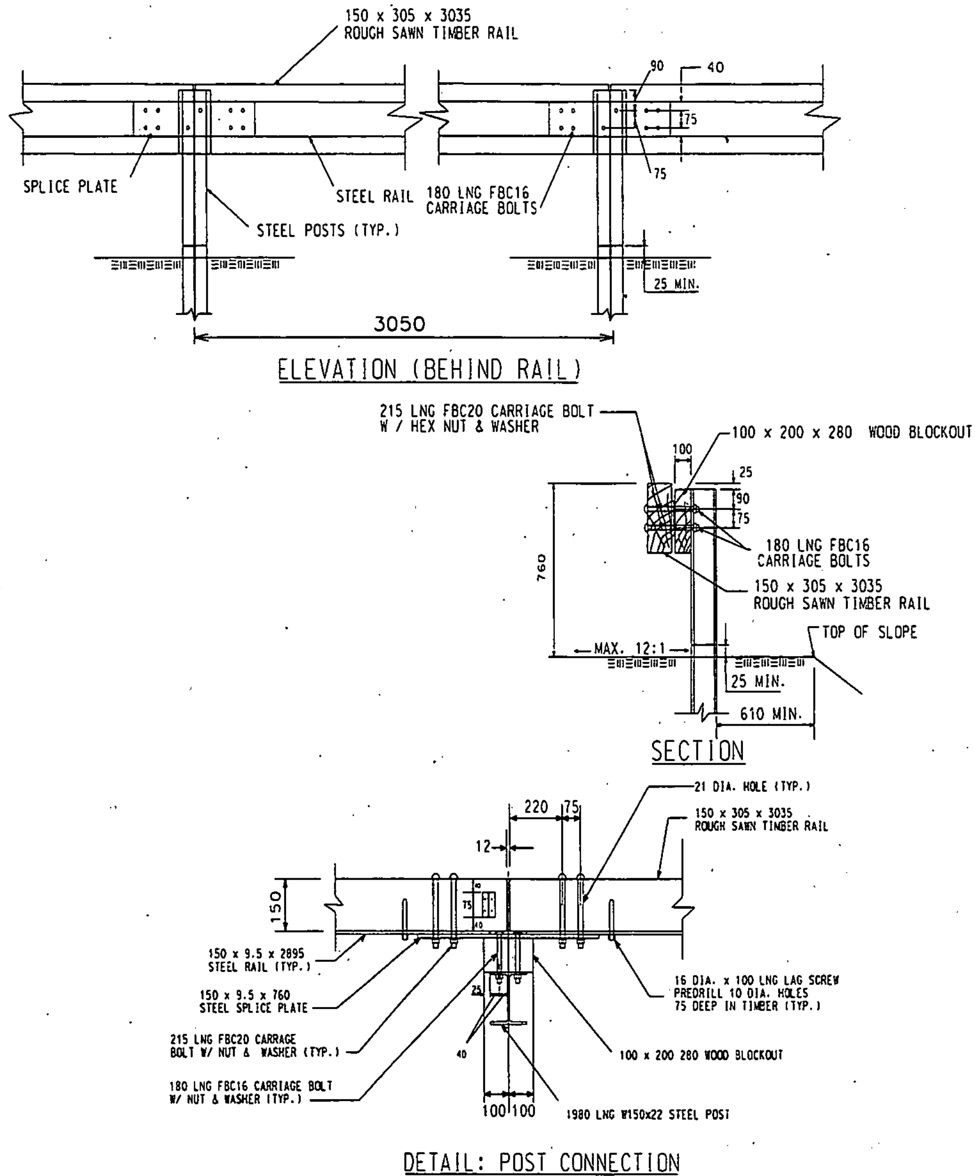


FIGURE 63 Schematic of Merrit Parkway guardrail.

use on restoration projects on the 60-km-long scenic Merritt Parkway in southern Connecticut. Conceptually, the Merritt Parkway guiderail is similar to the steel-backed timber guardrail discussed in the last section (Figure 63) (*130*). Unlike the steel-backed timber guardrail, the Merritt Parkway guiderail uses weathering steel wide-flanged posts rather than timber posts and a deeper timber rail that is mounted somewhat higher than the steel-backed timber guardrail.

The Merritt Parkway guiderail consists of a 150- × 300-mm timber rail with a 9.5-mm-thick, 152-mm-wide steel plate lag-bolted to the nontraffic face of the barrier. The timber rail is 50 mm deeper than the steel-backed timber guardrail. The rail height for the Merritt Parkway guiderail is 760 mm, which is 75 mm higher than the steel-backed timber guardrail. The steel-reinforced timber rails are mounted on 100- × 200- × 280-mm timber blockouts, which in turn are mounted on W150 × 22.5 weathering steel posts spaced at 2896 mm on center.

Crashworthiness

The Merritt Parkway guiderail was approved for use on Federal-aid projects in a 1996 FHWA letter based on the crash tests summarized in Table 44 (*131*). The full-scale crash tests shown in Table 44 conformed to Report 350 Test Level 3 requirements. The differences (deeper timber rail and higher mounting height) between the steel-backed timber guardrail and the Merritt Parkway guiderail were made primarily to improve the impact performance with the 2000-kg pickup truck required by Report 350. In addition to the full-scale crash testing of the basic guardrail system, a successful test was also

TABLE 44
NCHRP REPORT 350 TEST LEVEL 3 CRASH TESTS OF MERRIT PARKWAY GUIDERAIL

	Test Number		
	3-10	3-11	3-11
Impact condition			
System	MPG w/out curb	MPG w/out curb	MPG w/curb
Test number	405501-2	405501-1	405501-3
Test contractor	TTI	TTI	TTI
Impact velocity (km/hr)	99.3	100.0	99.3
Impact angle (degrees)	20.3	25.2	25.2
Vehicle type	820C	2000P	2000P
Vehicle inertial mass (kg)	820	2000	2000
Vehicle gross mass (kg)	896	2000	2000
Structural adequacy			
A. Containment			
Vehicle response	Smooth	Smooth	Smooth
Dynamic deflection (mm)	750	1150	1020
Evaluation	Pass	Pass	Pass
Occupant risk			
D. Compartment penetration	Minimal	Minimal	None
F. Vehicle remains upright	Yes	Yes	Yes
H. Occupant impact velocity			
Lateral impact velocity (m/sec)	5.3	NA	NA
Longitudinal impact velocity (m/sec)	6.0	NA	NA
I. Occupant ridedown acceleration			
Lateral ridedown acceleration (g's)	8.2	NA	NA
Longitudinal ridedown acceleration (g's)	4.3	NA	NA
Evaluation	Pass	Pass	Pass
Vehicle trajectory			
K. Intrusion into traveled way	Minimal	None	Minimal
L. Longitudinal occupant risk			
Impact velocity (m/sec)	NA	8.1	7.0
Ridedown acceleration (g's)	NA	9.6	10.1
M. Exit angle (degrees)	8.8	14.6	12.5
Evaluation	Pass	Pass	Pass
Reference	*129*	*129*	*129*

MPG = Merritt Parkway guiderail; TTI = Texas Transporation Institute

performed on the system with a 100-mm-high curb in front of the installation (Table 44). As are most other aesthetic guardrails, the Merritt Parkway guiderail is a relatively stiff system that allows relatively little dynamic deflection and often results in minor wheel snagging in high-speed impacts with larger passenger vehicles. Limited snagging is not necessarily a performance problem as long as the vehicle is not suddenly stopped or spun back into the roadway.

Applications

When viewed from the roadway, the Merritt Parkway guiderail looks like a timber railing since the traffic face of the rail is wood and the posts are made using weathering steel. This system was designed specifically for use on high-speed roadways where aesthetic considerations cannot be ignored—like the historic Merritt Parkway. Many other aesthetic guardrails have been tested only for lower test level conditions indicative of lower speed park or residential roadways. The first installations of this system are scheduled to be constructed in 1997, so there are no detailed cost, maintenance, or field performance data as yet. The Connecticut Department of Transportation is planning to monitor the performance of this barrier system in an in-service evaluation project that should provide useful information *(131)*.

Like other aesthetic guardrails, there are relatively few options for terminating the Merritt Parkway guiderail. The preferred methods at this time are to

- Flare the installation away from traffic and terminate the rail by sloping it down into the ground at a point outside the clear zone,
- Anchor the end of the rail to a rock face or bury it in a steep cut section, or
- Place a crash cushion in front of the end of the guardrail.

More terminal options would, however, make the system more versatile. The Connecticut DOT did test a transition design that can be used to attach the rail to a concrete wall *(129)*.

STEEL-BACKED LOG GUARDRAIL

System Description

The steel-backed log guardrail was designed to look like log barriers and fences often seen in national and state parks. Unlike the typical traditional log guardrails, however, the steel-backed log guardrail was designed to be an effective traffic barrier at least in lower-speed applications. The steel-backed log guardrail is similar in concept to the steel-backed timber guardrail, where a steel plate is lag-bolted to the side of a timber log opposite traffic to achieve a composite action (*132*).

The steel-backed log guardrail is shown schematically in Figure 64. The rail is a 250-mm nominal diameter timber log that is flattened on the nontraffic face. A 150-mm-wide, 10-mm-thick weathering steel plate is lag-bolted to the nontraffic face of the rail to provide additional flexural capacity as well as rail continuity. The railing, with the reinforcing steel plate, is mounted on a specially shaped cast iron blockout, which is in turn mounted on a 300-mm-diameter circular timber post. The posts are spaced 1676 mm apart, and the center of the log guardrail is positioned 530 mm from the ground surface. A steel splice plate provides continuity between rail elements as well as the blockout and post. The blockout provides for 100 mm of clearance between the back of the log rail and the front face of the post.

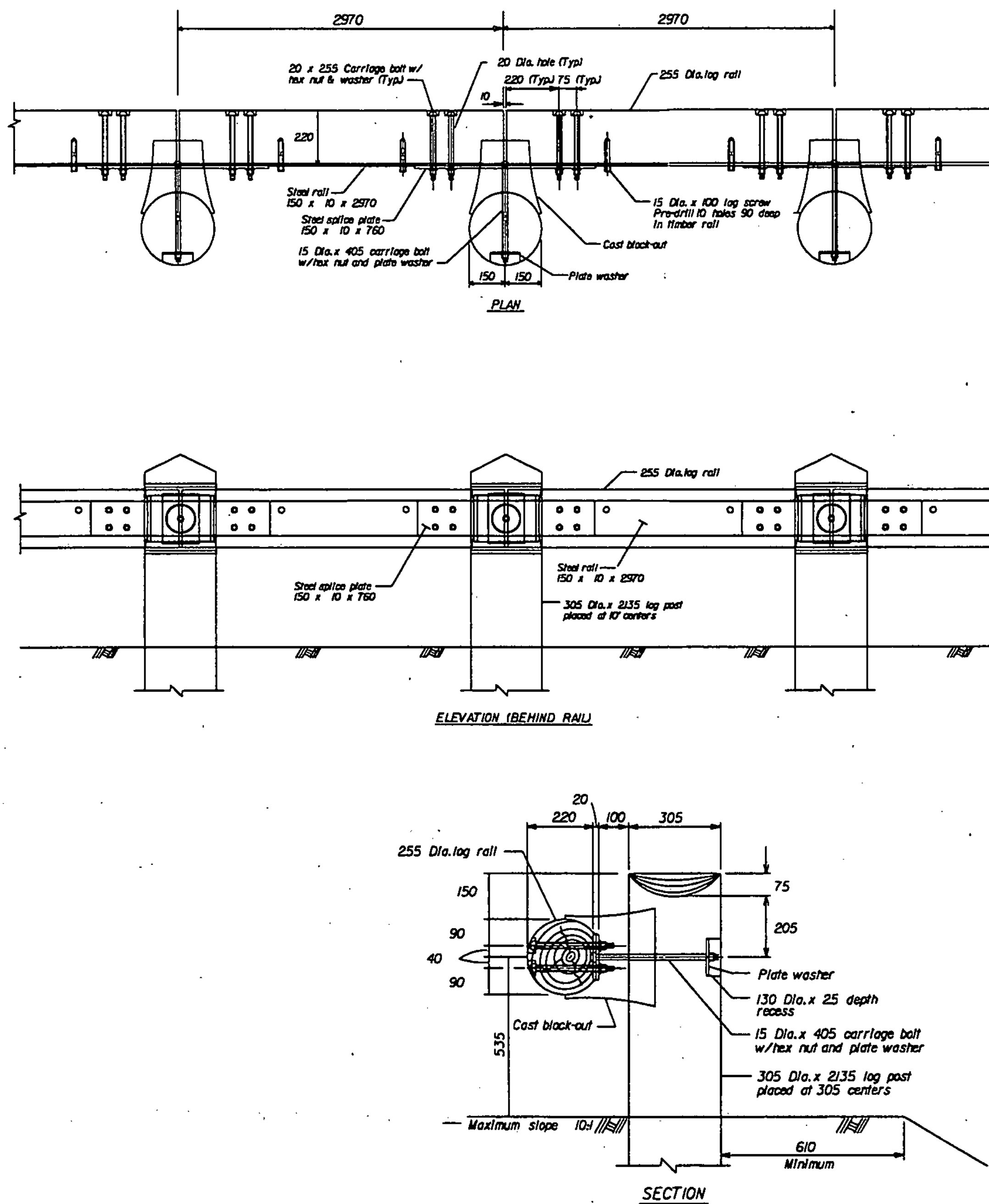


FIGURE 64 Steel-backed log guardrail (after (*132*)).

TABLE 45

NCHRP REPORT 350 TEST LEVEL 2 CRASH TESTS OF STEEL-BACKED LOG RAIL

	Test Number	
	2-10	2-11
Impact condition		
System	Log rail	Log rail
Test number	SBLR-1	SBLR-2
Test contractor	UNL	UNL
Impact velocity (km/hr)	81.4	74.2
Impact angle (degrees)	19.2	20.9
Vehicle type	820C	2000P
Vehicle inertial mass (kg)	839	2450
Vehicle gross mass (kg)	914	2524
Structural adequacy		
A. Containment		
Vehicle response	Smooth	Smooth
Static deflection (mm)	75	232
Evaluation	Pass	Pass
Occupant risk		
D. Compartment penetration	None	None
F. Vehicle remains upright	Yes	Yes
H. Occupant impact velocity		
Lateral impact velocity (m/sec)	6.4	NA
Longitudinal impact velocity (m/sec)	7.4	NA
I. Occupant ridedown acceleration		
Lateral ridedown acceleration (g's)	4.8	NA
Longitudinal ridedown acceleration (g's)	3.9	NA
Evaluation	Pass	Pass
Vehicle trajectory		
K. Intrusion into traveled way	NR	Minor
L. Longitudinal occupant risk		
Impact velocity (m/sec)	NA	4.5
Ridedown acceleration (g's)	NA	13.1
M. Exit angle (degrees)	2.0	No exit
Evaluation	Pass	Pass
Reference	*132*	*132*

UNL = University of Nebraska–Lincoln

Crashworthiness

Like most other aesthetic guardrails, the steel-backed log guardrail is very stiff and behaves more like a bridge rail than a typical strong-post guardrail. The crash tests of this system, summarized in Table 46, were performed according to the AASHTO Bridge Railing Specifications for Performance Level 1 rather than according to Report 350 (*120*). The AASHTO small-car test is a slightly higher speed test than Report 350 Test 3-10, and the AASHTO pickup truck test uses a somewhat higher speed and a 20- rather than 25-degree impact angle. The evaluation and test criteria are the only available indications of the Report 350 performance, so the values in Table 45 are presented in terms of the Report 350 evaluation criteria.

Applications

Only timber components can be seen from the traffic side of the railing, so this system would be more acceptable in aesthetically sensitive areas. It is not known if this system has been installed in the field, so there is no information available about the installation, maintenance, or repair costs or the observed in-service performance.

There are no crash-tested terminals or transitions for this system. Presumably, the system is ended by flaring the rail away from the traveled way and terminating it outside the clear zone.

STONE-MASONRY GUARDWALL

System Description

Native stone walls have been used along roadways in scenic areas for many decades. Dry-stone walls in some parks originally were built in the 1930s as part of the Works Progress Administration (WPA) and therefore have become historically significant in themselves. Most of these walls were built primarily to keep pedestrians and motorists from intentionally leaving the road or falling over a steep precipice. They were not designed to redirect errant motor vehicles.

In a collision, dry- and mortared-stone walls usually do not perform well. Such walls are often not high enough to prevent the striking vehicle from vaulting over the wall. Unreinforced stone walls are also not structurally adequate to withstand the impact loading of a typical passenger vehicle. The rough stone

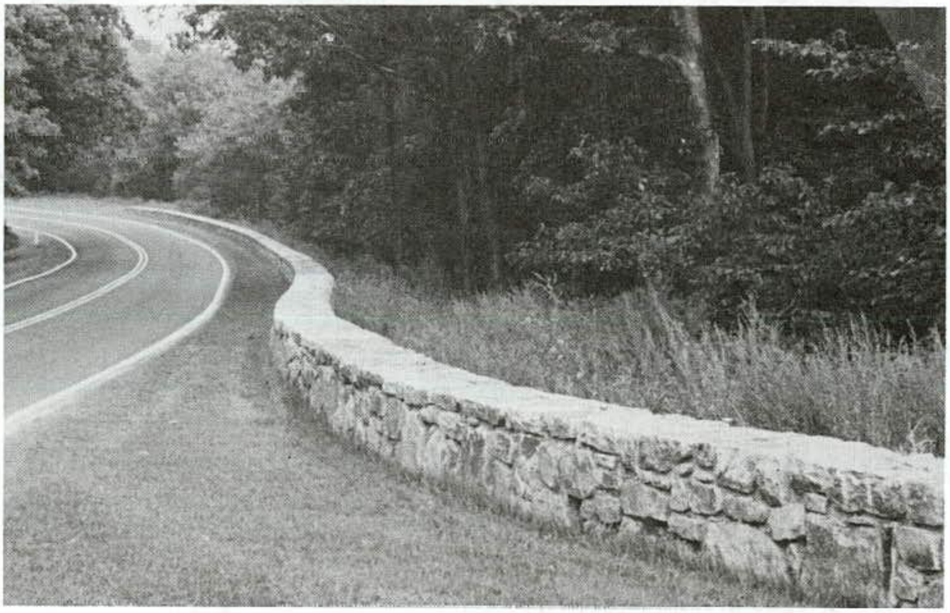


FIGURE 65 Stone masonry guardwall—Skyline Drive, Virginia.

can cause extensive vehicle damage even though a lot of energy might have been dissipated, often the vehicle would still penetrate the wall. The stone-masonry guardwall (Figures 65 and 66) is actually a mortared-stone wall built over a reinforced concrete core wall. The core wall provides the required strength, while the stone provides a visually appealing surface.

As shown in Figure 67, the stone facia and core wall are supported by a continuous reinforced concrete mat foundation.

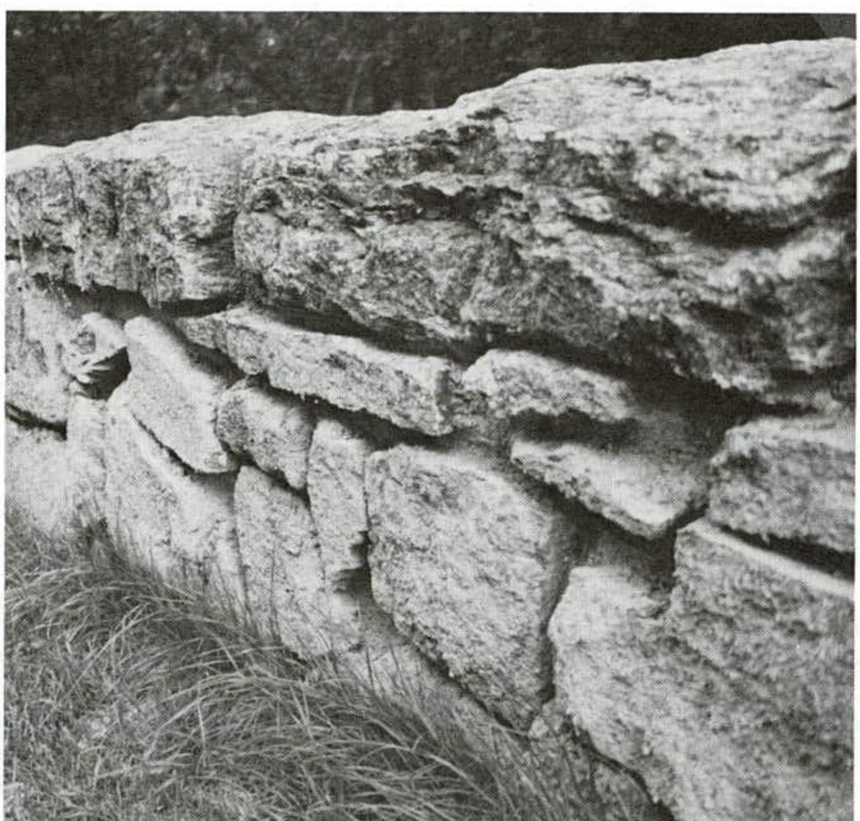


FIGURE 66 Closeup of a stone masonry guardrail.

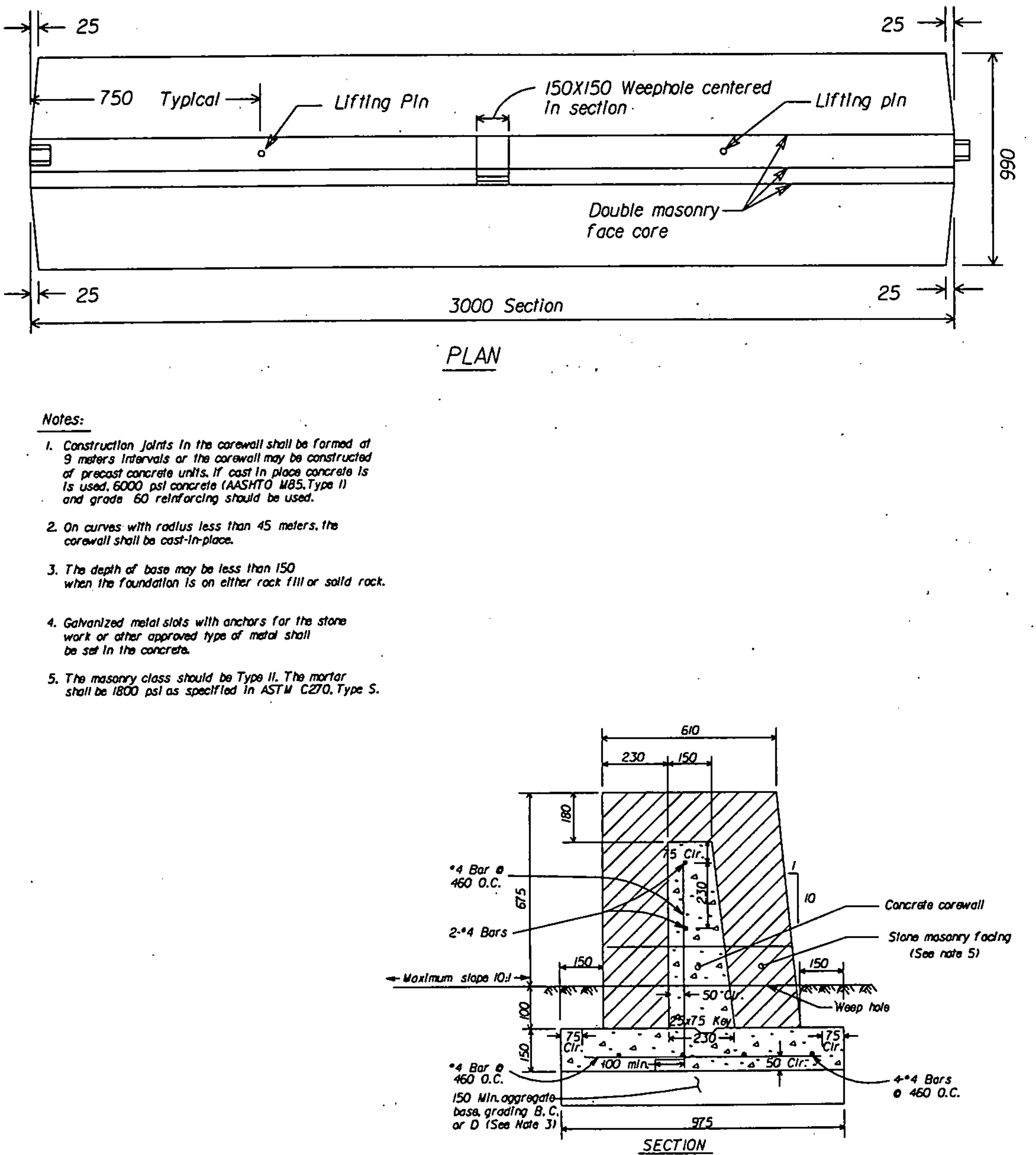


FIGURE 67 Schematic of stone masonry guardwall (after *(126)*).

The foundation is 150 mm thick and is poured on a bed of compacted gravel. The top of the foundation is placed 100 mm below the expected final grade. The reinforced core wall provides most of the shear and bending strength required in an impact. The wall is 150 mm thick at the top and 230 mm thick at the bottom. The reinforcement is relatively light since the wall is very thick and the core wall is near the neutral axis of the wall, where reinforcement would not be particularly effective. Longitudinal bars provide flexural strength and vertical bars that are hooked into the foundation provide flexural strength about the longitudinal axis. The core wall can be cast-in-place or precast. A key is formed in both the foundation and the core wall to provide a positive mechanical interlock that is effective in resisting the lateral shear load of an impacting vehicle. The stone facing is built using natural stone and masonry on top of and behind the core wall. The installations on the Skyline Drive in Northern Virginia used native mica schist stone in the facing wall. The impact performance will be affected by the smoothness of the stonework on the traffic face. Detailed specifications for the barrier system can be found in *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (128)*. FP-85 requires that none of the stonework projects more than 40 mm beyond the mean face of the wall. The smoother the stone face, the better the impact performance will be. If the mortar beds are thicker, the mortar may break apart during a collision. This system was approved for use on Federal-aid projects in a 1990 FHWA memorandum *(129)*.

Distribution

Stone-masonry guardwalls like those described in this section have been built along the Skyline Drive through the Shenandoah National Park in Northern Virginia, as well as on the Foothills Parkway near the Great Smoky Mountains National Park in eastern Tennessee.

Crashworthiness

The stone-masonry guardwall functions like a typical rigid concrete barrier, but because the surface is rough rather than smooth, the barrier causes more vehicle damage than is typical in rigid barrier impacts. The impact forces are distributed to the foundation and ground through a reinforced concrete core wall.

Crash tests of this system are summarized in Table 46. The occupant risk values in these tests were higher than those generally observed in longitudinal barrier tests. Usually, the lateral occupant impact velocity is the critical value in a longitudinal barrier test, but in these tests the occupant impact velocity was high in both the lateral and longitudinal directions. One possible reason may be the roughness of the stone. The rough stone digs into the sheet metal of the vehicle, causing it to slow down rapidly. This quicker deceleration results in higher occupant responses. Crash test experience has shown that the top of the core wall must be at least 510 mm above the finished ground line. If the core wall is lower than 510 mm, an impact may cause the stonework on the top of the core wall to break off. This was the reason that Report 230 Test 10 Criterion D in Table 46 was judged as failing.

Applications

Since the stone guardwall requires a foundation, it is more expensive than typical guardrail systems. To date, this system has been used primarily in road segments cut into steep slopes. There is little or no room for barrier deflections, so the use of a rigid barrier system like the stone guardwall is justified.

The stone-masonry guardwall is a good choice for aesthetically sensitive areas, or for historic communities where more typical barriers might be too austere. Locations that would normally warrant a rigid concrete barrier if aesthetics were not considered would be well-suited to the stone-masonry guardwall.

The FLHD recommends this barrier for roadways where the design speed is 97 km/hr or less. This system should not be used in combination with a curb since no crash tests have been performed for this situation. The present version of the stone-masonry guardwall cannot be used as a median barrier

TABLE 46

NCHRP REPORT 230 CRASH TESTS OF STONE GUARDWALL

	Test Number	
	10	12M
Impact condition		
System	–	–
Test number	1818-5-4-87	1818-5-3-87
Test contractor	ENSCO	ENSCO
Impact velocity (km/hr)	97.0	99.0
Impact angle (degrees)	25.0	20.2
Vehicle type	4500S	1800S
Vehicle mass (kg)	1955	821
Structural adequacy		
A. Smooth redirection	Minor rolling	Smooth
Dynamic deflection (mm)	0.0	0.0
D. Detached elements	Yes	None
Evaluation	Fail	Pass
Occupant risk		
E. Vehicle remains upright	Yes	Yes
F. Occupant risk		
Lateral impact velocity (m/sec)	NA	5.8
Longitudinal impact velocity (m/sec)	NA	10.6
Lateral ridedown acceleration (g's)	NA	7.9
Longitudinal ridedown acceleration (g's)	NA	11.7
Evaluation	Pass	Pass
Vehicle trajectory		
H. Intrusion into traveled way	None	None
I. Exit conditions		
Exit velocity (km/hr)	NR	70.8
Exit angle (degrees)	NR	4.5
Evaluation	Pass	Marginal
Reference	*126*	*126*

because the nontraffic face is battered rather than vertical. In principle it should be possible to develop a median barrier version that uses a core wall with a stone face on both traffic faces, although such a system would have to be analyzed and tested before use.

This rigid system should require very little maintenance. Most collisions will not damage the barrier, and there are no routine maintenance needs. A more serious collision may damage the stone face or the core wall. If the core wall is undamaged, the broken or dislodged stones in the facia may be replaced. Damage to the core wall will probably require reconstruction of a segment of the wall.

Since this system requires a significant amount of manual labor by skilled tradesmen, it is the most expensive aesthetic barrier system covered in this report. The construction cost for this system, according to the FLHD, can be between \$870 and \$1640/meter. The 1988 price for the stone-masonry guardwall installations on the Foothills Parkway in east Tennessee was \$870/meter. Local availability of specific types of stone and skilled stone masons will have a dramatic effect on the cost of this barrier.

This system is terminated by sloping the barrier away from the roadway so that the offset from the edge of the pavement is at least 610 m. The wall is also sloped down vertically and buried. Sometimes the barrier can be buried in an earth berm. Like all the aesthetic barrier systems, there are very few alternatives for providing safe transitions and terminals. This lack of alternatives limits the use of these systems to lower-speed, lower-volume roadways.

PRECAST SIMULATED STONE GUARDWALL

System Description

Although the barrier in Figure 68 looks like natural stone, it is actually made of precast concrete panels textured and colored to simulate natural stone masonry. This guardwall has been installed on the Baltimore-Washington Parkway. The ability to design the color and pattern of the stonework is an architectural advantage to this system, which is useful when the barrier is to be installed near existing stone-masonry structures. The pigments used to color the simulated stone on the barriers shown in Figure 68 were selected specifically to match the stonework on existing bridges on the Baltimore-Washington Parkway. The precast simulated stone guardwall functions like other rigid concrete barriers. Table 47 summarizes the two crash tests performed on this system.

The design details are illustrated in Figure 69. The T-shaped, 3000-mm-long precast panels are ship-lapped at the ends. When assembled, the panel joints appear to be mortar beds in a stone-masonry wall. The panel is constructed such that both faces look like a wall of randomly laid quarried stone. A variety of stone coloring schemes can be used to give the appearance of a natural stone wall. The particular colors and textures can be designed to match existing stone structures on or near the roadway. The panels are connected with a tongue-and-groove connection. A silicone sealant is used at

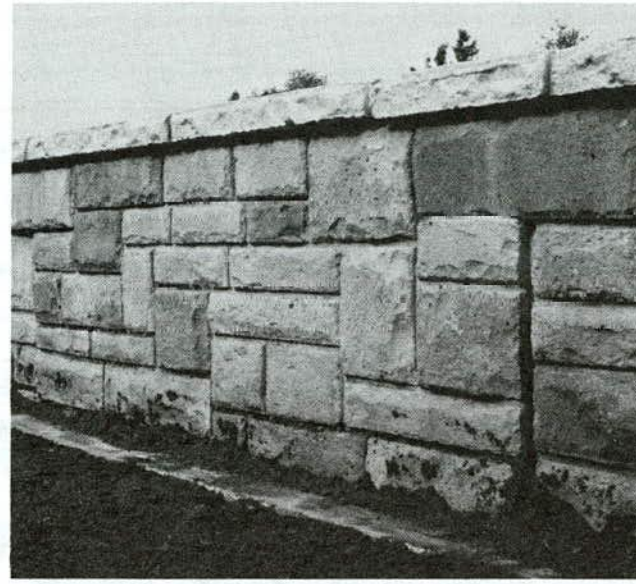


FIGURE 68 Precast simulated stone guardwall—Baltimore-Washington Parkway, Maryland.

the real joints. The silicone color should be matched to the color of the false joints to simulate the color of masonry. The panels have an inverted T-shaped cross section. The wide part of the section provides a 305-mm-deep foundation for the upper part of the panels. The top edge of the inverted T should be placed such that it is flush with the finished ground line. The precast panel rests on a 150-mm-thick bed of crushed and compacted aggregate. After the cap stone is installed, the top of the wall is 686 mm above the finished groundline.

A cap stone is set on the top of the precast panel. A tongue-and-groove connection is used to align the cap stone on the panel. The joint between the panel and the cap stone is sealed with the same silicone sealant used between panel joints. A proper foundation is necessary for transmitting collision forces to the ground as well as ensuring that the wall will not settle over time. The precast panels are set directly on a bed of compacted aggregate. The crash tests summarized in Table 47 were all performed with the barrier located 3700 m behind a 90-mm-high mountable curb. The slope of the approach terrain should be 10:1 or flatter. The 3700-mm offset was considered to be the critical lateral offset rather than the minimum offset, so the barrier can be used at any offset with a 90-mm-high mountable curb.

Crashworthiness

As shown in Table 47, this barrier has been tested successfully according to the recommendations of Report 230 for longitudinal barriers *(7)*. The FLHD has approved this barrier for roadways with design speeds of 97 km/hr or less. This system was also approved for use on Federal-aid projects in a 1990 FHWA memorandum *(129)*. Like other aesthetic barriers, the precast guardrail is a rigid barrier system and as such the exit velocity is relatively high and the vehicle damage is also more severe than would be the case in a typical rigid barrier.

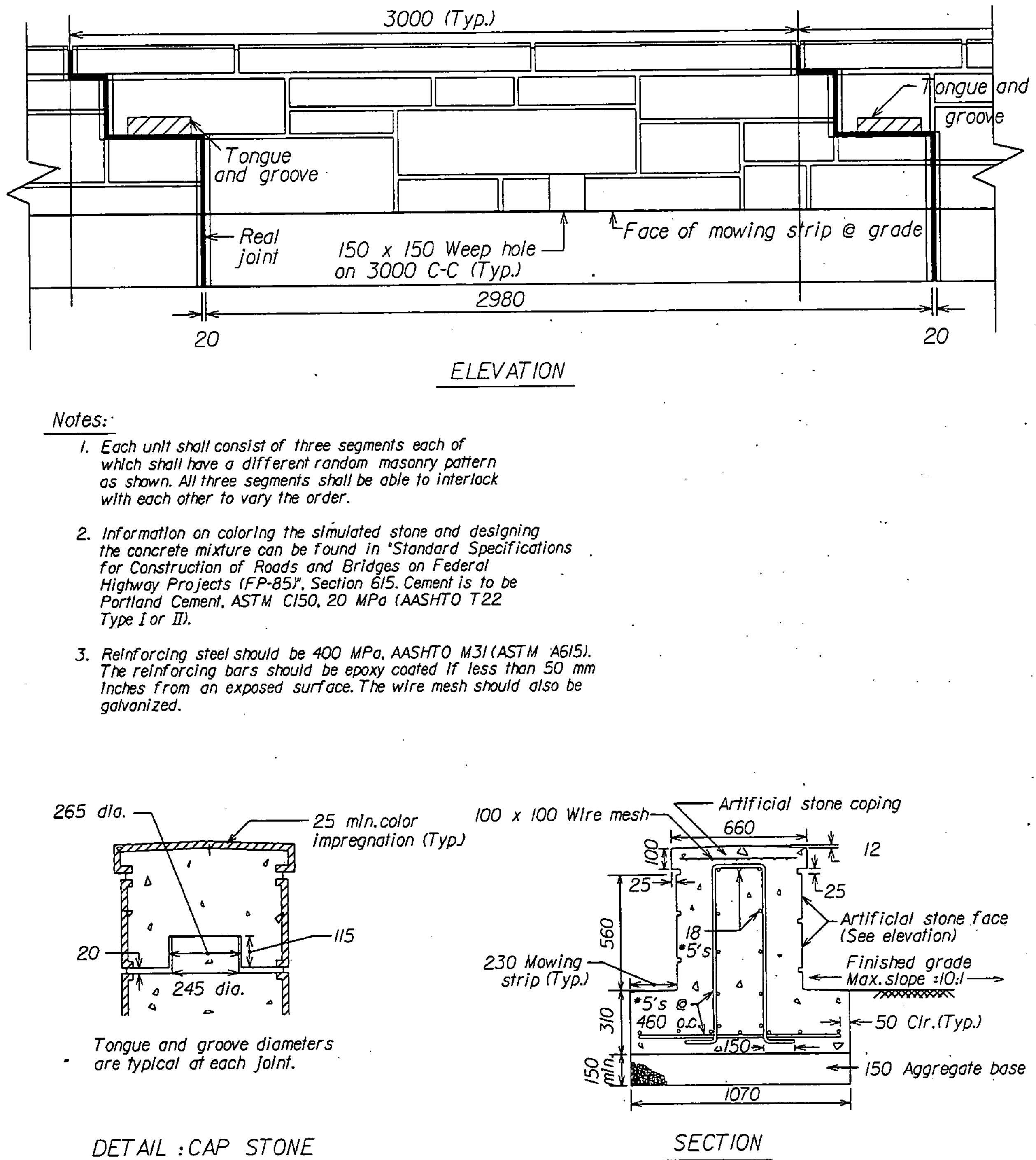


FIGURE 69 Schematic of precast simulated guardwall (after *(126)*).

Applications

This barrier is a good choice for sites that would normally require a concrete barrier at sites that are not aesthetically sensitive. The ability to tailor the pattern and coloring of the simulated stone is an advantage if the guardwall must blend in with other structures near the roadway. Since the barrier is made of precast units, the on-site phase of construction can probably be accomplished more quickly than if a cast-in-place system were used. If the intended site is busy or congested, this system might help minimize the disruption to the traveling public.

This barrier system can also be used as a median barrier since both faces of the barrier are simulated stone. The FLHD allows this barrier system to be used as a median barrier located at any offset behind a mountable 90-mm-high curb.

TABLE 47

NCHRP REPORT 230 CRASH TESTS OF PRECAST SIMULATED STONE GUARDWALL

	Test Number	
	10	12M
Impact condition		
System	-	-
Test number	1818-12-88	1818-7-88
Test contractor	ENSCO	ENSCO
Impact velocity (km/hr)	99.0	99.0
Impact angle (degrees)	25.0	21.0
Vehicle type	4500S	1800S
Vehicle mass (kg)	197655	815
Structural adequacy		
A. Smooth redirection	Yes	Yes
Dynamic deflection (mm)	0.0	0.0
D. Detached elements	None	None
Evaluation	Pass	Pass
Occupant risk		
E. Vehicle remains upright	Yes	Yes
F. Occupant risk		
Lateral impact velocity (m/sec)	NA	9.2
Longitudinal impact velocity (m/sec)	NA	7.6
Lateral ridedown acceleration (g's)	NA	16.3
Longitudinal ridedown acceleration (g's)	NA	12.3
Evaluation	Pass	Pass
Vehicle trajectory		
H. Intrusion into traveled way	None	None
I. Exit conditions		
Exit velocity (km/hr)	60.5	66.0
Exit angle (degrees)	1.0	5.0
Evaluation	Pass	Pass
Reference	*136*	*136*

The most difficult aspect of constructing this barrier system involves finding a precast contractor capable of manufacturing the panels. Site preparation involves excavating a foundation trench and back-filling it with aggregate. After the aggregate is compacted, the precast panels can be placed. The panels are attached by tongue-and-groove connections in the ship-lapped ends. For modest degrees of curvature the panels can be rotated to conform with the roadway alignment. After the panels are connected, the cap stone should be placed. The silicone sealant is then applied to the real joints and the cap stone joint. The terrain between the wall and the curb should then be graded to the final grade and seeded with grass if necessary.

The stone-masonry guardwall is an essentially maintenance-free system. The guardwall usually will not require repair after all but very severe collisisons. In such cases, a segment of the guardwall may need to be replaced.

The FLHD reports that the cost of this barrier varies between $340 and $690/meter. The availability of contractors capable of building the precast units could affect the cost of this system in certain locations. Currently, two contractors have been approved by the FLHD to produce these units.

The terminal section is sloped vertically to eliminate the otherwise blunt end. Although this detail is probably adequate for most low-speed roadways, it is not recommended on high-speed facilities since the sloped end can launch a vehicle in a head-on impact. Other, more conventional terminals could be used with this barrier, but aesthetic considerations will usually preclude this option.

CHAPTER SEVEN

CONCLUSIONS

The preceding chapters have summarized the crashworthiness characteristics of a number of common, permanently installed, nonproprietary guardrails and median barriers. Like all design activities, designing the roadside involves balancing many concerns to arrive at a solution that is effective from the perspectives of both cost and performance. When guardrails and median barriers are carefully selected, properly installed, and adequately maintained, they can be very effective tools for improving the safety of a roadway. The roadside designer must be careful to choose barriers appropriately and weigh the advantages and disadvantages of each. No guardrail or median barrier is a "perfect" solution: weak-post guardrails reduce the severity of the impact and cause less vehicle damage but may allow more vehicles to penetrate the guardrail; concrete barriers essentially eliminate the risk of penetration but increase the severity of the impact to the occupant and may redirect vehicles back into the roadway. The primary advantages and disadvantages of each of the barriers discussed in this report are given here.

WEAK-POST GUARDRAILS AND MEDIAN BARRIERS

Weak Steel-Post Three-Cable Guardrails and Median Barriers

Advantages

- Acceptable Report 230 performance,
- Acceptable Report 350 Test Level 3 performance,
- Flexible barrier with attendant low occupant forces,
- Reduced snow drifting and accumulation,
- Inexpensive installation,
- Aesthetically appealing, and
- Minimized sight-distance problems.

Disadvantages

- More barrier damage in a typical accident,
- Periodic monitoring of cable tension required, and
- At least 3350 mm of clear area required behind the rail.

Weak Wood-Post Three-Cable Guardrails and Median Barriers

Advantages

- Acceptable Report 230 performance,
- Flexible barrier with attendant low occupant forces,
- Reduced snow drifting and accumulation,
- Inexpensive installation,
- Aesthetically appealing, and
- Minimized sight-distance problems.

Disadvantages

- Not tested according to Report 350,
- No Report 230 or Report 350 tested terminals,
- More barrier damage after a typical accident,
- Periodic monitoring of cable tension required, and
- At least 3350 mm of clear area required behind the rail.

Weak-Post W-Beam Guardrails and Median Barriers

Advantages

- Acceptable Report 230 performance,
- Acceptable Report 350 Test Level 2 performance,
- Flexible barrier with attendant low occupant forces, and
- Inexpensive installation.

Disadvantages

- Failed Report 350 Test Level 3 criteria,
- No FHWA-accepted terminals,
- More barrier damage after a typical accident, and
- At least 2225 mm of clear area required behind the rail.

Weak-Post Box-Beam Guardrails and Median Barriers

Advantages

- Acceptable Report 230 performance,
- Acceptable Report 350 Test Level 3 performance for the guardrail,
- Acceptable Report 350 Test Level 3 performance for the median barrier likely,
- Flexible barrier with attendant low occupant forces, and
- Reduced snow drifting and accumulation.

Disadvantages

- More barrier damage after a typical accident,
- Relatively expensive weak-post barrier,
- No nonproprietary Report 350 tested terminals,

- Numerous parts and bolts that may become a maintenance problem, and
- At least 1460 mm of clear area required behind the rail.

STRONG-POST GUARDRAILS AND MEDIAN BARRIERS

Strong-Post W-Beam Guardrails and Median Barriers

Advantages

- Acceptable Report 230 performance,
- Acceptable performance for the wood-post version for Report 350 Test Level 3,
- Moderate installation cost,
- Semirigid system with moderate occupant forces,
- Numerous proprietary and nonproprietary terminal and transition alternatives,
- Design details for many special situations (e.g., low-fill culverts and intersecting streets),
- Still partially effective after an accident,
- Many options for local strengthening (e.g., nested rails and reduced post spacing), and
- Moderate dynamic deflection.

Disadvantages

- Steel-post version failed Report 350 Test Level 3 criteria,
- Undesirable wheel snagging in tests exhibited on both steel- and wood-post versions,
- Unclear equivalence of wood and steel post versions,
- No recent tests of the median barrier versions, and
- Variability of timber materials and soils possibly causing large variations in dynamic deflection.

Strong-Post W-Beam with Rubrail Guardrails and Median Barriers

Advantages

There are no strong advantages to using the strong-post W-beam with rubrail guardrails and median barriers aside from the fact that the median barrier is an acceptable Report 230 system. Other barriers provide better performance at less cost.

Disadvantages

- No recent crash tests of the median barrier version,
- No Report 230 crash tests of the guardrail,
- No Report 350 crash tests of either the guardrail or median barrier,
- Sight distance hampered,
- Not aesthetically attractive,
- Debris collected by rubrail, and
- Expensive relative to the amount of dynamic deflection.

Strong-Post Thrie-Beam Guardrails and Median Barriers

Advantages

- Acceptable Report 230 performance
- Acceptable Report 350 Test Level 3 performance for modified thrie-beam,
- Modified thrie-beam effective with trucks and buses,
- Numerous proprietary and nonproprietary terminal and transition alternatives,
- Moderate cost, given the low dynamic deflection,
- Still partially effective after an accident, and
- Moderate dynamic deflection.

Disadvantages

- Standard G9 thrie beam failed Report 350 Test Level 3 criteria,
- Standard G9 thrie beam not very effective with larger vehicles,
- Unclear equivalence of wood- and steel-post versions,
- Possible sight-distance problems, and
- Variability of timber materials and soils possibly causing variability in dynamic deflection.

CONCRETE MEDIAN BARRIERS

New Jersey Median Barrier

Advantages

- Acceptable Report 230 performance,
- Acceptable performance demonstrated through Report 350 Test Level 5,
- Minimized chance of cross-median collisions,
- Essentially maintenance-free even after relatively severe accidents,
- Variety of construction techniques available,
- Use on narrow medians possible,
- Possible inclusion of glare screen on top,
- Use as "innovative" barrier possible if at least 1070 mm tall,
- Effective in impacts with large trucks and buses, and
- Essentially no dynamic deflection.

Disadvantages

- Stability problems for some vehicles especially at extreme impact angles,
- Vehicle redirection back into the roadway with little loss of speed,

- Rigid barrier with attendant high occupant forces,
- Research needed on the connection and foundation details for precast grade-separated median barriers,
- Reduction of effective height and lowering of slope breakpoint possible on pavement overlays,
- Elaborate drainage structures possibly required,
- Possible sight-distance problems, and
- Expensive barrier that requires specialized construction equipment and personnel.

F-Shape Median Barriers

Advantages

- Acceptable Report 230 performance,
- Satisfaction of Report 350 Test Level 5 likely at appropriate height,
- Minimized chance of cross-median collisions,
- Essentially maintenance-free even after relatively severe accidents,
- Variety of construction techniques available,
- Used on narrow medians possible,
- Possible inclusion of glare screen on top,
- Use as "innovative" barrier possible if at least 1070 mm tall,
- Effective in impacts with large trucks and buses, and
- Essentially no dynamic deflection.

Disadvantages

- No Report 350 pickup truck tests,
- Vehicle redirection into the roadway with little loss of speed,
- Rigid barrier with attendant high occupant forces,
- Research needed on the connection and foundation details for precast grade-separated median barriers,
- Reduction of effective height and lowering of slope breakpoint possible on pavement overlays,
- Elaborate drainage structures possibly required,
- Possible sight-distance problems, and
- Expensive barrier that requires specialized construction equipment and personnel.

Constant-Slope Median Barriers

Advantages

- Acceptable Report 230 performance,
- Satisfaction of Report 350 Test Level 4 likely at appropriate height,
- Minimized chance of cross-median collisions,
- Essentially maintenance-free even after relatively severe accidents,
- Better vehicle stability in impacts than either the F-shape or New Jersey barriers,
- Barrier height and shape not compromised by pavement overlays,
- Variety of construction techniques available,
- Use on narrow medians possible,
- Possible inclusion of glare screen on top,
- Use as "innovative" barrier possible,
- Effective in impacts with large trucks and buses, and
- Essentially no dynamic deflection.

Disadvantages

- No Report 350 pickup test,
- Report 350 Test Level 4 performance based on bridge rail tests,
- Stability problems for some vehicles especially at extreme impact angles,
- Vehicle redirection back into the roadway with little loss of speed,
- Rigid barrier with attendant high occupant forces,
- Research needed on the connection and foundation details for precast grade-separated median barriers,
- Elaborate drainage structures possibly required,
- Possible sight-distance problems, and
- Expensive barrier that requires specialized construction equipment and personnel.

AESTHETIC GUARDRAILS AND MEDIAN BARRIERS

Steel-Backed Timber Guardrails

Advantages

- Acceptable Report 230 performance,
- Aesthetically attractive,
- One of the least costly aesthetic barrier alternatives,
- Median barrier version acceptable as an "innovative" barrier, and
- Very little dynamic deflection.

Disadvantages

- No Report 350 pickup test,
- Relatively stiff system with attendant high occupant forces
- No Report 230 or Report 350 tested terminals, and
- Expensive barrier compared with strong-post guardrail alternatives.

Merritt Parkway Guiderails

Advantages

- Acceptable Report 350 Test Level 3 performance,

- Aesthetically attractive,
- One of the least costly aesthetic barrier alternatives, and
- Very little dynamic deflection.

Disadvantages

- Relatively stiff system with attendant high occupant forces,
- No Report 230 or Report 350 tested terminals, and
- Expensive barrier compared with strong-post guardrail alternatives.

Steel-Backed Log Guardrail

Advantages

- Acceptable Report 350 Test Level 2 performance,
- Aesthetically attractive, and
- Very little dynamic deflection.

Disadvantages

- No Report 350 Test Level 3 tests,
- Relatively stiff system with attendant high occupant forces,
- No Report 230 or Report 350 tested terminals, and
- Expensive barrier compared with strong-post guardrail alternatives.

Stone Masonry Guardwall

Advantages

- Acceptable Report 230 performance,
- Aesthetically attractive, and
- Essentially no dynamic deflection.

Disadvantages

- No Report 350 Test Level 3 tests,
- Rigid system with attendant high occupant forces,
- No Report 230 or Report 350 tested terminals, and
- Expensive barrier compared with concrete barrier alternatives.

Pre-Cast Simulated Stone Guardwall

Advantages

- Acceptable Report 230 performance,
- Aesthetically attractive,
- Match of "stone" color and texture to existing stone structures possible,
- Use as guardrail or median barrier possible, and
- Essentially no dynamic deflection.

Disadvantages

- No Report 350 Test Level 3 pickup test,
- Rigid system with attendant high occupant forces,
- No Report 230 or Report 350 tested terminals,
- Specialized precasting experience required for proper coloring and texture, and
- Very expensive barrier compared with concrete barrier alternatives.

SUMMARY

Many of the guardrails and median barriers discussed here were developed decades ago using now-obsolete test and evaluation criteria. Some systems, such as the strong-post W-beam guardrail and the New Jersey concrete median barrier, have emerged as primary barrier systems that are used nationwide in a wide variety of applications. Once-common systems, including the weak wood-post W-beam guardrail and the strong-post W-beam guardrail with a channel-section rubrail, have nearly disappeared because of the better crashworthiness performance, lower initial cost, and greater versatility of other systems. This decades-long process of optimizing guardrail and median barrier systems has resulted in several guardrails and median barriers that are very effective when struck by passenger sedans.

The era of the large passenger sedan, however, has ended with the emergence in the past decade of a diverse vehicle fleet that includes 700-kg minicars; 90 000-kg, triple tractor-trailer trucks; rear-wheel-drive full-size sedans; front-wheel-drive compact cars; minivans; sport-utility vehicles; aerodynamically styled sports cars; and full-size vans. Today, guardrails and median barriers are expected to perform satisfactorily for a wider range of vehicles under a wider range of impact conditions than ever before. Recent research has resulted in a number of surprising crash test failures and has forced the research community to address basic questions about which vehicles should be used in crash tests and which impact conditions are most relevant to real-world accidents.

Developing and installing roadside hardware that satisfies the recommendations of Report 350 are important not only because of the report's status as the latest test and evaluation criteria, but because the changes in Report 350 were made to better reflect current conditions on the nation's highways. The most problematic change in Report 350 has been the replacement of the 4,500-lb large passenger sedan with the 2000-kg pickup truck. Full-scale tests with the 2000-kg pickup truck have resulted in crash test failures in tests with several important and widely used guardrails and median barriers, including the weak-post W-beam guardrail (SGR02), the strong steel-post W-beam guardrail (SGR04a), and the strong steel-post thrie-beam guardrail (SGR09a). The 2000-kg pickup truck represents a large and growing segment of the vehicle population that cannot be overlooked when designing the roadside of the next century. Developing hardware to meet the challenges posed by the 2000-kg pickup truck test vehicle should improve the collision performance of guardrails and median barriers for a broader class of vehicles. The result of applying the recommendations of Report 350 may well be a new generation of guardrails and median barriers that perform for an even more diverse population of vehicles and impact conditions.

Guardrails and median barriers are the oldest type of roadside safety hardware in use on the roadway network and have played an important role in improving the safety of the nation's highway system. These systems have evolved for nearly 40 years as roadside safety practitioners sought the most effective methods for protecting motorists, in the face of a vehicle fleet and operating conditions that are changing constantly. The design of guardrails and median barriers will, no doubt, continue to evolve. Roadside designers and researchers will continue to anticipate and respond to the ever-changing highway environment with the constrained resources at their disposal. This report has summarized the crashworthiness characteristics of common, permanently installed, non-proprietary guardrail and median barrier systems so that engineers have the information they need to assess the cost, effectiveness, and safety performance of these systems and make wise decisions about their use.

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GLOSSARY OF GUARDRAIL AND MEDIAN BARRIER TERMS

The following glossary was compiled on the basis of several earlier glossaries of roadside safety terms included in the 1977 Barrier Guide (*20*), the *Roadside Design Guide* (*2*), and Report 350 (*8*).

AASHTO—American Association of State Highway and Transportation Officials

ACI—American Concrete Institute

AISC—American Institute of Steel Construction

AISI—American Iron and Steel Institute

ASTM—American Society for Testing and Materials

Blockout—A component of a guardrail or median barrier that separates the guardrail from the guardrail post. The purpose of the blockout is to keep the impacting wheels from contacting the guardrail post.

Cast in place—A technique for constructing concrete structures in which forms are built on the construction site and the concrete is placed in the final desired location of the barrier.

Clear zone—The area along the roadside starting at the edge of the traveled way that can be used by a vehicle that has left the roadway to come to a safe stop.

Concrete median barrier—A concrete barrier located in a median. There are several types of concrete median barrier, including the New Jersey and the F-shape barriers. The specific dimensions differentiate one from the other. Some concrete median barriers are sometimes referred to as concrete safety shapes.

Construction barrier—A barrier that is placed at a location for a limited period of time such as a barrier erected to protect workers during roadway construction.

Cost effective—A decision-making analysis method for choosing between alternatives that assesses the likely reduction in accident costs that would result from a roadside improvement with respect to the cost of the improvement.

Crash test—Physical tests of a barrier system that use actual vehicles and actual roadside hardware to assess the likely performance of the hardware in an impact. Performance is usually measured in terms of the structural adequacy, impact severity, and vehicle trajectory.

Crashworthiness—The characteristic of a barrier system or vehicle that describes its performance in an impact. A crashworthy barrier is one that can be struck by an errant vehicle at or below the roadway operating speed with a low probability of causing severe or fatal injuries to the vehicle occupants.

End treatment—The end of a guardrail or median barrier. End treatments generally are intended to provide anchorage for the system. They are not necessarily crashworthy.

FHWA—Federal Highway Administration, U. S. Department of Transportation

Flail space—A hypothetical area around a vehicle occupant where the occupant can move without being injured. Injuries are assumed to occur when the occupant reaches the edges of the flail space.

Flexible barrier—Guardrails and median barriers that experience large lateral dynamic deflections in impacts with vehicles. Flexible barriers are also called weak-post guardrails and median barriers.

Full-scale crash test—A crash test that uses actual production vehicles and full-size barriers.

Glare screen—The extension of a barrier or a device on top of a barrier that is used to shield drivers from the headlight glare of on-coming traffic in the opposing lanes.

Guardrail—A longitudinal barrier that is used to shield vehicles from hazardous objects or untraversable slopes. Guardrail is also sometimes used to refer to the longitudinal rail component of a guardrail (e.g., the W-beam or thrie beam).

HRB—Highway Research Board of the National Academy of Sciences (renamed the Transportation Research Board in the 1970s).

Impact angle—For guardrails and median barriers the impact angle is the angle measure between the centerline of the vehicle and the tangent line of the barrier. An impact angle is recommended in the appropriate crash testing guidelines for full-scale crash tests.

Impact speed—The velocity at which a vehicle strikes a barrier. An impact speed is recommended in the appropriate crash testing guidelines for full-scale crash tests.

Length of need—The total length of a guardrail or median barrier that is required to adequately shield a hazard from errant vehicles. The length of need is measured parallel to the roadway.

Longitudinal barrier—Any barrier such as a guardrail or median barrier whose primary purpose is to prevent penetration of the barrier and safely redirect an errant vehicle away from a hazard.

Median—The portion of a divided highway that separates opposing lanes of traffic.

Median barrier—A longitudinal barrier that is used to prevent vehicles from going across a median and striking vehicles in the opposing lanes of traffic.

NCHRP—National Cooperative Highway Research Program of the National Academy of Sciences

NHTSA—National Highway Traffic and Safety Administration, U.S. Department of Transportation

Occupant impact velocity—The hypothetical velocity with respect to the vehicle at which an occupant modeled as a point mass would reach the edge of the flail space.

Passenger vehicle—A vehicle intended to transport primarily humans.

Permanent barrier—A barrier that is installed at a location such that it becomes a normal part of the roadside environment as opposed to temporary or construction barriers that remain on site for only limited amounts of time.

Pocketing—A term denoting a large lateral deflection of a longitudinal barrier that occurs within a relatively small longitudinal span. Pocketing can cause unacceptable barrier performance.

Post-and-beam guardrails and median barriers—A type of flexible guardrail or median barrier that is composed of a longitudinal rail element that is supported by posts embedded in the soil. Post-and-beam guardrails and median barriers may be further characterized as strong-post or weak-post guardrails and median barriers.

Post-tensioned—A construction technique in which cables or threaded rods are embedded in concrete when the concrete is placed. After the concrete has cured the cables or rods are tightened, causing tensile stresses in the cables or rods and compressive stresses in the concrete section.

Precast—A construction technique in which concrete is placed and cured in a manufacturing facility and then delivered to the job site as finished concrete segments.

Redirect—A guardrail or median barrier that changes the direction of an errant vehicle's path away from a hazard is said to have redirected the vehicle. Ideally, the vehicle path should be changed such that after the impact the vehicle is traveling approximately parallel to the barrier.

Rigid barrier—A guardrail or median barrier that experiences essentially no lateral dynamic deflection during an impact.

Roadside—In general, the area beyond the shoulder but within the right-of-way limits. Sometimes the area off the road and to the right of the direction of travel is refered to as the roadside to distinguish it from the median.

Roadside barrier—A longitudinal barrier used to shield vehicles from objects on the roadside or untraversable terrain. Also used to describe longitudinal barriers placed on the right side of the roadway as opposed to the median.

Roadside safety hardware—Any of a group of devices meant to either shield motorists from hazardous objects or break away when struck by an errant vehicle.

Roadway—The portion of a highway intended for vehicle travel.

Rubrail—A second longitudinal rail in some guardrail designs that is positioned below the primary guardrail components. The purpose of the rubrail is to minimize the chance of the vehicle wheels snagging on the guardrail posts.

SAE—Society of Automotive Engineers

Semirigid barrier—Guardrails or median barriers that experience modest lateral dynamic deflections in an impact. Semirigid barriers are also often called strong-post guardrails and median barriers.

Severity—The seriousness of a collision or accident usually measured in terms of the injury to the occupants of a vehicle.

Shielding—When a longitudinal barrier prevents an errant vehicle from striking an off-road object, traversing a hazardous slope, or entering a body of water by redirecting the vehicle away from the hazard.

Shy distance—The lateral distance where drivers react to the presence of an object near the road by crowding against the opposite lane edge.

SI—International System of Units; also commonly referred to as metric units.

Side slope—The vertical profile of the terrain perpendicular to the centerline of the roadway.

Slipform—A construction technique in which concrete is placed in forms that can be slowly slipped longitudinally along the roadway.

Snagging—When a part of an impacting vehicle such as a wheel abruptly engages a part of the barrier in such a way that the vehicle may spin out, snagging is said to have occurred.

Strong-post guardrail or median barrier—A longitudinal barrier that dissipates energy by breaking or bending guardrail posts as well as deforming and stretching the guardrail.

Temporary Barrier—A barrier that is placed at a location for a limited period of time. Barriers erected to protect workers during roadway construction are temporary barriers.

Terminal—A device designed to make the end of a guardrail or median barrier crashworthy. Terminals may absorb energy or direct the vehicle away from the end in an impact.

Test level—A set of test conditions defined in terms of vehicle mass, vehicle type, impact angle, impact speed, and impact location. NCHRP Report 350 defines six test levels for guardrails and median barriers.

Traffic barrier—Another name for longitudinal barriers, roadside barriers, median barriers, and guardrails. A traffic barrier prevents a vehicle from penetrating the barrier and shields errant vehicles from more serious hazards.

Transition—A longitudinal barrier that connects two other longitudinal barriers of different stiffness. The purpose of a transition is to smoothly increase the stiffness of the barrier from the flexible system to the more rigid system. Transitions are commonly used between guardrails and bridge railings.

Traveled way—The part of a highway intended for vehicle traffic excluding the shoulders.

TRB—Transportation Research Board of the National Academy of Sciences

USCU—U. S. Customary Units (sometimes called "English" units)

Vehicle—One of a variety of machines designed to transport humans or cargo including passenger cars, pickup trucks, vans, trucks, buses, tractor-trailer trucks, and tanker trucks.

Warrants—Criteria that identify a potential hazard along the roadside or in the median that may require the use of a guardrail or median barrier. The criteria may be functions of the site geometry, traffic conditions, economics, or crashworthiness or a combination of these factors.

Weak-post guardrail or median barrier—A longitudinal barrier that dissipates energy primarily by stretching the guardrail. The primary function of the posts in such a system is to hold the rail up until the impact occurs.

APPENDIX A

Crash Testing Specifications

The following section contains several sections from Report 230 and Report 350 that pertain specifically to test conditions or evaluation criteria for guardrails and median barriers. In particular, the tables and text describing the crash test matrices and the evaluation criteria are included so that readers can easily cross-reference discussion in the text and tables of this report with the recommendations of Report 230 and Report 350. For more detailed information about testing, instrumentation, data analysis, or other aspects of full-scale crash testing, the reader is referred to the full reports.

TEST ARTICLE

General

All key elements or materials in the test article or appurtenance that contribute to its structural integrity or impact behavior should be sampled and tested. To ensure that all critical elements are considered, a careful after-test examination of the tested appurtenance is essential. The material specifications, such as ASTM, AASHTO, etc., should be reported for all key elements. The results of random sample tests should confirm not only that the stated specifications have been met but also that the key elements in the test article were representative of normal production quality (not "Sunday" samples, etc.). The tester should offer a judgment on the effects marginal and over specification materials might have on appurtenance performance. In addition, the specified, but unverified, properties of all other materials used in the test article should be reported.

The test article should be constructed and erected in a manner representative of installations in actual service and should conform to the specifications and drawings of the manufacturer or designer. To assure uniformity and integrity of structural connections, current American Welding Society specifications for highway bridges, Aluminum Association Specifications for Aluminum Bridges and Other Highway Structures, and American Institute of Steel Construction bolting procedures should be used. A deviation from fabrication, specification, or erection details should be delineated in the test report.

Installation Details

For tests examining performance of the length-of-need section, the rails or barrier elements should be installed straight and level and anchored. Horizontally curved installations, sloped shoulders, embankments, dikes, and curbs should be avoided for general performance tests; when used, the nonstandard features should be reported. Length of the test section excluding terminals should be at least three times the length in which deformation is predicted, but not less than 75 ft (23 m) for bridge rails and 100 ft (30 m) for guardrails and median barriers. A freestanding barrier, such as a concrete median barrier, which depends on frictional resistance between it and the ground to resist movement should be tested on the same type of ground or pavement surface where it will be used or where it might have the least frictional resistance. For example, loose sand under the concrete barrier may create a ball bearing effect. The type of pavement surface as well as end anchorages or terminals used should be reported.

When testing terminals for longitudinal barriers, the test article should be erected on level grade. A 100-ft (30-m) length-of-need barrier section should be attached to the terminal and anchored at the downstream end.

For tests of a transition joining two barrier systems, the more flexible system (in lateral direction) should be installed in the upstream position. A minimum of 50 ft (15 m) of each of the two barrier systems in addition to the transition should be used; the two systems are to be anchored at their ends.

A rigid, nonyielding backup structure (such as a concrete pier) should be used to simulate a highway feature (such as a bridge pier, elevated gore, or bridge end) when appropriate. For crash cushions which have side hit redirection capability and may have application where they may be struck on one side by direct traffic and on the other side by opposing direction traffic, the test article should be installed with side hit deflector hardware oriented to accommodate both types of side hits. The crash cushion should be anchored as required by specifications or drawings.

The breakaway or yielding support should be oriented in the least preferred impact direction (i.e., the direction that theoretically produces the maximum resistance force or energy) consistent with reasonably expected traffic situations. For breakaway or yielding appurtenances designed to function identically when impacted from either direction, testing should verify this feature. The supports should be full-height structures, including sign, call box, or mast arm; an equivalent weight may be substituted for the luminaire.

TEST VEHICLE

Description

The standard vehicles, described in Table 2, are used to evaluate the principal performance factors of structural adequacy, occupant risk, and vehicle trajectory after collision.

The 1800S, 2250S, and 4500S vehicles should be in good condition and free of major body damage and missing structural parts (i.e., doors, windshield, hood, etc.). Special purpose vehicles such as used for highway patrol are not generally acceptable because they do not possess suspension and handling characteristics found in typical vehicles. Any manufacturer-installed equipment (power brakes and steering, air conditioning, etc.) is permitted so long as the equipment is contained within the body shell. The vehicle fuel tank should be purged and the battery removed from remotely powered test vehicles to reduce exposure to needless hazards. The 2250S and 4500S vehicles should have a front-mounted engine; the location and type of transmission is unspecified; the 1800S vehicle should have a front-mounted engine and front-wheel drive. The vehicle bumper should be standard equipment and unmodified for the test; its configuration and height above grade should be reported. The model year of the 1800S, 2250S, and 4500S test vehicles should be within 4 years of the year of test, with a maximum age of 6 years unless otherwise specified.

Five heavy test vehicles are included in Table 2 along with tentative static and dynamic properties. Although several agencies have begun using one or more of these vehicle types, experience accumulated to date is insufficient to clearly establish appropriateness of these vehicles for appurtenance testing or to establish experimentally verified static and dynamic properties for all five heavy vehicles. The heavy test vehicles are presented to encourage research sponsoring or testing agencies to select vehicle types within this group and to adjust their properties to the target values when appurtenance performance with other than, or in addition to, 1800S, 2250S, and 4500S vehicles is desired. It is noted that the number of heavy vehicles is increasing, and it appears that some of current appurtenances may need modification or redesign to handle them adequately.

TABLE 2. STATIC AND DYNAMIC PROPERTIES OF TEST VEHICLES[a]

Designation	1800S	2250S	4500S	20,000P	32,000P	40,000P	80,000A	80,000F
Type	Minicompact Sedan	Subcompact Sedan	Large Sedan	Utility Bus	Small Inter-city Bus	Large Inter-city Bus	Tractor/ Van Trailer	Tractor/ Fluid Tanker
Mass—lb								
Test Inertial[b]	1800 ±50	2250 ±100	4500 ±200	13,800 ±500	20,000 ±750	29,400 ±1000	—	—
Dummy[c]	165	165 ±165	165 ±165	6,200 ±500	6,000 ±1,000	6,000 ±1,000	—	—
Ballast (loose)[d]	0	0	0	0	6,000 ±1,000	4,000 ±1,000	—	—
Gross Static[e]	1950 ±50	2500 ±100	4500±300	20,000 ± 500	32,000 ± 750	40,000 ± 1000	80,000 ±2000	80,000 ±2000
Typical Mass Moments of Inertia[f] lb-ft-s²								
I_{zz}—Yaw	667[h]		4167	48,000		125,000		
I_{yy}—Pitch	496[g]		4625	51,600		156,500		
I_{xx}—Roll	150[g]		—	5,660		23,000		
Typical Center of Mass-in.								
g—Height from grade	19.5	21.8	27.0	41		55.8		
h—From front axle	32.1	40.5	49.8	159		216		
c—Wheel base	87.0	97	121	254		260		
Reference DOT-FH	11-9287 11-9486	11-9462	11-8130	11-9462		11-9462		

Notes:

(a) Many of the vehicles and vehicle property requirements are new with this document; hence, typical data have not been measured or reported. Test agencies should measure and report vehicle properties in a format shown in Figures 1 and 2 in Chapter Four. Vehicle masses (test inertial, dummy, ballast and gross static) and center-of-mass location should be physically measured for each test vehicle; mass moments-of-inertia may be acquired from appropriate references for identical vehicle type and loading arrangement.

(b) Includes basic vehicle structure and all components, test equipment and ballast that are rigidly secured to the vehicle structure. This mass *excludes* the mass of anthropomorphic and anthropometric dummies, irrespective of restraint conditions, and ballast and test equipment that are not rigidly secured to the vehicle structure.

(c) For 1800S vehicle, one 50th percentile anthropometric or anthropomorphic dummy is specified; for other vehicle types, occupant mass may be simulated by 50th percentile anthropomotric, anthropomorphic, bags of sand or a combination thereof. See text for position and restraint conditions.

(d) Ballast that simulates cargo and test equipment that is loose or will break loose from tie-down during early stages of appurtenance collision.

(e) Sum of test inertial, dummy, and loose ballast mass; all component masses should be within specified limits.

(f) For vehicle in test inertial condition.

(g) Value for unloaded 1976 Honda Civic (dry fuel tank and mass of 1509 lb); value for 1800S vehicle will be slightly higher.

(h) Value for 1976 Honda Civic (curb mass of 1758 lb) with test instruments but without dummies at 1834 lb.

Vehicle 20,000P is a utility bus with a nonintegral body box and truck chassis and a seating capacity of about 65. The vehicle body, suspension, suspension-to-frame connection, and front bumper should be inspected to verify adequate structural condition. The vehicle bumper should be standard equipment and unmodified for the test; its configuration and height above grade should be reported. The vehicles should have a complete complement of seats for positioning simulated occupants.

Vehicles 32,000P and 40,000P are small and large intercity buses, respectively. The vehicles should be structurally sound; latches for all window and cargo doors on the impact side of the vehicle should be in operable condition. As with the 20,000P utility bus, the intercity buses should have a complete complement of seats.

Vehicle 80,000A is a tractor-trailer, preferably with the trailer being a van. Critical components of the rig such as the tractor bumper and fifth wheel connection must be in good condition. (Non-standard items such as extra fuel tanks should be away from the impact zone if it appears they could affect the vehicle redirection.)

Vehicle 80,000F is a tractor-trailer, preferably with the trailer being a liquid container. Requirements pertaining to 80,000A also apply to 80,000F.

Mass Properties

Vehicle mass properties are important factors in the vehicle/appurtenance collisions. Properties of sprung and unsprung mass, curb mass, test inertial mass, dummy mass, and loose ballast and loose equipment mass are normally considered in some aspect of vehicle testing. For this document, the mass properties of most importance are:

1. *Curb mass*—the standard manufacturer condition in which all fluid reservoirs are filled and the vehicle contains no occupants and cargo. In general, the test inertial mass should not vary significantly from the curb mass.
2. *Test inertial mass*—the mass of the vehicle and all items and test equipment that are rigidly attached to the vehicle structure throughout the appurtenance collision. Mass of dummies, irrespective of the degree of restraint, is not included in the test inertial mass. Test inertial mass is a composite of both sprung and unsprung masses.
3. *Dummy mass*—mass of anthropometric, anthropomorphic, or other simulated occupant loading.
4. *Loose ballast mass*—the mass of simulated cargo and test equipment that is unrestrained or that is likely to break loose from the restraints during the appurtenance collision.
5. *Gross static mass*—the total of the test inertial, loose ballast, and dummy masses.

If needed to bring the test inertial mass within limits of Table 2, fixed ballast may be added in the following manner. Concrete or metal blocks may be positioned in the passenger compartment of passenger sedans and rigidly attached to the vehicle structure by metal straps capable of sustaining loads equivalent to 20 times the blocks' mass. For trucks, the test inertial mass may be adjusted by attaching concrete or steel beams to the truck bed with metal straps capable of sustaining loads equivalent to 10 times the beams' mass. With exception of seats, spare tires, battery, fluids and optional equipment, components should not be removed from the vehicle to meet mass requirements.

Anthropometric or anthropomorphic dummies or sand bags may be used to simulate occupant loading. Anthropometric dummies are 50th percentile male SAE 572 Part B test devices fully instrumented to comply with FMVSS 208. An anthropomorphic dummy may be any 50th percentile male dummy with mass distribution and flexibility similar to the SAE 572 Part B dummy, but it is not necessarily instrumented with accelerometers and femur load cells. Sand in 100 to 150-lb (45 to 78-kg) masses may be packaged in soft cloth, plastic, or paper bags.

With the exception of tests with the 1800S vehicle, use of anthropometric and anthropomorphic dummies is optional. Tests with the 1800S vehicle and preferably with the 2250S vehicle, one anthropometric or anthropomorphic dummy is specified primarily to evaluate typical unsymmetrical vehicle mass distribution and its effect on vehicle stability although the dummy may also, but necessarily, be used to acquire supplementary occupant dynamic and kinematic response data; use of other types of simulated occupant loading is not recommended. Placement of the single dummy is as follows: for redirectional collisions, the dummy should be in the front seat adjacent to the impact side; for off-center, head-on impacts into terminals, crash cushions, or breakaway/yielding supports, the dummy should be in the front seat on the opposite side of the vehicle longitudinal centerline from the impact point. If otherwise not specified, the dummy should be in the driver seat. The dummy is to be unrestrained.

For the 2250S and 4500S vehicles, when one optional dummy is used, the placement and restraint condition are similar to the 1800S vehicle. When two optional dummies are used, the dummy on the opposite side from the impact for redirectional or off-center type of tests should be restrained. For other type tests both dummies should be unrestrained.

For 20,000P, 32,000P, and 40,000P vehicles, passenger loading may be simulated by appropriately sized bags of sand that are positioned unrestrained in all seats. Distribution of passenger loading is to be reported.

Anthropometric or anthropomorphic dummy mass or other simulated occupant loading in any test vehicle, irrespective of restraint condition, is not included in the vehicle test inertial mass.

For cargo trucks, unrestrained bags of sand may be used as loose ballast; distribution of the loose ballast mass is to be reported.

The gross static mass, which is the sum of the test inertial mass, dummy mass, and loose ballast mass, is to be measured and reported.

Speed and Braking

The vehicle may be pushed, towed, or self-powered to the programmed test speed. If pushed or towed, the prime mover should be disengaged prior to impact, permitting the vehicle to be "free-wheeling" during and after the collision; for self-powered vehicles, the ignition should be turned off just prior to impact. Application of brakes should be delayed as long as safely feasible to establish the unbraked runout trajectory; as a minimum, brakes should not be applied until the vehicle has

TABLE 3. CRASH TEST CONDITIONS FOR MINIMUM MATRIX

Appurtenance	Test Designation	Vehicle Type[d]	Impact Speed (mph)	Impact Angle[e] (deg)	Target Impact Severity[f] (ft-kips)	Impact Point[g]	Evaluation Criteria[h]
Longitudinal Barrier[a] Length-of-Need	10	4500S	60	25[i]	$97^{-9,+17}$	For post and beam systems, midway between posts in span contianing railing splice	A,D,E,H,I
	11	2250S	60	15[i]	$18^{-2,+3}$	For post and beam systems, vehicle should contact railing splice	A,D,E,F,(G),H,I
	12	1800S	60	15[i]	$14^{-2,+2}$	For post and beam system, vehicle should contact railing splice	A,D,E,F,(G),H,I
Transition	30	4500S	60	25[i]	$97^{-9,+17}$	15 ft upstream from second system	A,D,E,H,I
Terminal	40	4500S	60	25[i]	$97^{-9,+17}$	At beginning of lenth-of-need	A,D,E,H,I
	41	4500S	60	0[i]	$541^{-53,+94}$	Center nose of device	C,D,E,F,(G),H,J
	42	2250S	60	15[i]	$18^{-2,+3}$	Midway between nose and lenth-of-need	C,D,E,F,(G),H,I,J
	43	2250S	60[o]	0[i]	$270^{-26,+47}$	Offset 1.25 ft from center nose of device	C,D,E,F,(G),H,J
	44	1800S	60	15[i]	$14^{-2,+2}$	Midway between nose and length-of-need	C,D,E,F,(G),H,I,J
	45	1800S	60[o]	0[i]	$216^{-21,+37}$	Offset 1.25 ft from center nose of device	C,D,E,F,(G),H,J
Crash Cushion[b]	50	4500S	60	0[j]	$541^{-53,+94}$	Center nose of device	C,D,E,F,(G),H,J
	51	2250S	60[o]	0[j]	$270^{-26,+47}$	Center nose of device	C,D,E,F,(G),H,J
	52	1800S	60[o]	0[j]	$216^{-21,+37}$	Center nose of device	C,D,E,F,(G),H,J
	53[l]	4500S	60	20[j]	$63^{-6,+11}$	Alongside, midlength	C,D,E,H,I,J
	54	4500S	60	10-15[j]	$541^{-53,+94}$	0-3 ft offset from center of nose of device	C,D,E,F,(G),H,J
Breakaway or Yielding Support[c]	60	2250S	20	[k]	$30^{-4,+4}$	Center of bumper[m,n]	B,D,E, F,(G),H,J
	61	2250S	60	[k]	$270^{-26,+47}$	At quarter point of bumper[n]	B,D,E,F,(G),H,J
	62	1800S	20	[k]	$24^{-3,+3}$	Center of bumper[m,n]	B,D,E,F,(G),H,J
	63	1800S	60	[k]	$216^{-21,+37}$	At quarter point of bumper[n]	B,D,E,F,(G),H,J

(a) Includes guardrail, bridgerail, median and construction barriers.
(b) Includes devices such as water cells, sand containers, steel drums, etc.
(c) Includes sign, luminaire, and signal box supports.
(d) See Table 2 for description.
(e) + 2 degrees
(f) IS = $1/2\ m\ (v \sin \theta)^2$ where m is vehicle test inertial mass, slugs; v is impact speed, fps; and θ is impact angle for redirectional impacts or 90 deg for frontal impacts, deg.
(g) Point on appurtenance where initial vehicle contact is made.
(h) See Table 6 for performance evaluation factors; ( ) denotes supplementary status.
(i) From centerline of highway.
(j) From line of symmetry of device.
(k) Test article shall be oriented with respect to the vehicle approach path to a position that will theoretically produce the maximum vehicle velocity change; the orientation shall be consistent with reasonably expected traffic situations.
(l) See Commentary, Chapter 4 Test Conditions for devices which are not intended to redirect vehicle when impacted on the side of the device.
(m) For base bending devices, the impact point should be at the quarter point of the bumper.
(n) For multiple supports, align vehicle so that the maximum number of supports are contacted assuming the vehicle departs from the highway with an angle from 0 to 30 deg.
(o) For devices that produce fairly constant or slowly varying vehicle accelerations; an additional test at 20 mph (32 kph) is recommended for staged devices, those devices that produce a sequence of individual vehicle deceleration pulses (i.e. "lumpy" device) and/or those devices comprised of massive components that are displaced during dynamic performance (see commentary).

TABLE 4. TYPICAL SUPPLEMENTARY CRASH TEST CONDITIONS

Appurtenance	Test Designation	Vehicle Type[d]	Impact Speed (mph)	Impact Angle[e] (deg)	Target Impact Severity[f] (ft-kips)	Impact Point[g]	Evaluation Criteria[h]
Longitudinal Barrier[a] Length-of-Need	S13	1800S	60	20[i]	$25^{-2,+4}$	For post and beam system, at mid span.	A,D,E,H,I
	S14[p]	4500S	60	15[i]	$36^{-4,+6}$	For post and beam system, vehicle should contact railing splice.	A,D,E,H,I
	S15[q]	40,000P	60	15[i]	$237^{-23,+41}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S16[r]	20,000P	45	7[i]	$14^{-2,+3}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S17[r]	20,000P	50	15[i]	$77^{-9,+16}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S18[r]	20,000P	60	15[i]	$111^{-11,+19}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S19	32,000P	60	15[i]	$97^{-9,+17}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S20[s]	80,000A	50	15[i]	[t]	For post and beam sytem, vehicle should contact railing splice.	A,D[s]
	S21[s]	80,000F	50	15[i]	[t]	For post and beam system, vehicle should contact railing splice.	A,D[s]
Transition	S31[p]	4500S	60	15[i]	$36^{-4,+6}$	15 ft upstream from second system	A,D,E,H
	S32[q]	40,000P	60	15[i]	$237^{-23,+41}$	15 ft upstream from second system	A,D,E
Terminals	S46[p]	4500S	60	15[i]	$36^{-4,+6}$	At beginning of length-of-need	A,D,E,H
	S47[q]	40,000P	60	15[i]	$237^{-27,+41}$	At beginning of length-of-need	A,D,E
Crash Cushion[b]	(NONE)						
Breakaway or Yielding Support[c]	S64	1800S	40	[k]	$96^{-14,+15}$	Center of bumper[m,n]	B,D,E,F,(G),H,J

For notes (a) through (o), see Table 3.

(p) Multiple Service Level 1 structural adequacy test; see Commentary, Chapter 4.

(q) Multiple Service Level 3 structural adequacy test; see Commentary, Chapter 4.

(r) Utility bus stability test; S16 for Multiple Service Level 1 appurtenance; S17 for Multiple Service Level 2 appurtenance; S18 specified for Multiple Service Level 3 appurtenance.

(s) Cargo/debris containment test; vehicle, cargo, and debris shall be contained on traffic side of barrier.

(t) Not appropriate for articulated vehicles.

TABLE 6. SAFETY EVALUATION GUIDELINES

Evaluation Factors		Evaluation Criteria	Applicable to Minimum Matrix Test Conditions (see Table 3)
Structural Adequacy	A.	Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	10, 11, 12, 30, 40
	B.	The test article shall readily activate in a predictable manner by breaking away or yielding.	60, 61, 62, 63
	C.	Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	41, 42, 43, 44, 45, 50, 51, 52, 53, 54
	D.	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	All
Occupant Risk	E.	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	All
	F.	Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. (0.61m) forward and 12 in. (0.30m) lateral displacements, shall be less than: Occupant Impact Velocity-fps Longitudinal: $40/F_1$; Lateral: $30/F_2$ and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations—g's Longitudinal: $20/F_3$; Lateral: $20/F_4$ where F_1, F_2, F_3, and F_4 are appropriate acceptance factors (see Table 8, Chapter 4 for suggested values).	11, 12, 41, 42, 43, 44, 45, 50, 51, 52, 54, 60, 61, 62, 63
	G.	(Supplementary) Anthropometric dummy responses should be less than those specified by FMVSS 208, i.e., resultant chest acceleration of 60g, Head Injury Criteria of 1000, and femur force of 2250 lb (10 kN) and by FMVSS 214, i.e., resultant chest acceleration of 60 g, Head Injury Criteria of 1000 and occupant lateral impact velocity of 30 fps (9.1 m/s).	11, 12, 41, 42, 43, 44, 45, 50, 51, 52, 54, 60, 61, 62, 63
Vehicle Trajectory	H.	After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	All
	I.	In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	10, 11, 12, 30, 40, 42, 44, 53
	J.	Vehicle trajectory behind the test article is acceptable.	41, 42, 43, 44, 45, 50, 51, 53, 54, 60, 61, 62, 63

~~ommended to examine the dynamic performance of a breakaway or yielding support for conditions intermediate to those denoted in the minimum matrix.~~

~~It is stressed that test conditions given in Tables 3 and 4 are not all-inclusive. There are other conditions that may need to be examined due to the peculiarity of the test article or unique feature of potential installation sites. The engineer is encouraged to carefully examine the test articles for vulnerable details and to devise additional test conditions to explore these.~~

Objectives of Test Conditions

Test conditions for each appurtenance have been established to evaluate one or more dynamic performance factors. The principal intent of tests given in Tables 3 and 4 is discussed in the following.

Longitudinal Barrier (Length-Of-Need)

Test 10 (4500S/60 mph/25 deg)

This test is considered primarily a strength test of the installation in preventing the vehicle from penetrating or vaulting over the system. The vehicle should be smoothly redirected without exhibiting any tendency to snag on posts or other elements or to pocket. Moreover, the vehicle should remain upright throughout the collision, and its after-collision trajectory should not present undue hazard to the vehicle occupants or to other traffic. Although occupant risk evaluation is a secondary factor for this test, vehicle dynamics and kinematics should be measured and reported.

Test S13 (1800S/60 mph/20 deg)

The objective of this test is to investigate the dynamic interactions of the small car with redirective barriers. Because the 1800S vehicle has small diameter wheels, generally with the forward wheels being driven, there is concern that a forward wheel will wedge under the lower beam of a beam and post system and snag on a post *(38)*. Further, there is concern for vehicle rollover during or after collisions with typical shaped barriers due to critical inertial properties of this vehicle *(39)*. Goals for this test are (1) that the vehicle should be smoothly redirected without exhibiting any tendency to snag on post or other elements or to pocket, (2) that the vehicle should remain upright throughout the collision, and (3) its after-collision trajectory should not present undue hazard to other traffic.

In the past, all longitudinal barriers were evaluated for the single set of strength conditions denoted by Test 10 irrespective of their ultimate application. Two other strength or multiple service level tests are given in Table 4 that may be used in lieu of, or in addition to, Test 10.

Test S14 (4500S/60 mph/15 deg)

This test evaluates a longitudinal length-of-need section for MSL 1 condition. In general, such barriers are intended for highways with low traffic volume. As with Test 10, this is primarily a strength test, and the test article should perform to the same criteria as Test 10.

Test S15 (40,000 P/60 mph/15 deg)

This test evaluates a longitudinal length-of-need section for MSL 3 condition. Barriers developed to this strength are intended for highways with high traffic volume and a high percentage of heavy vehicles. This is primarily a strength test, and the test article should perform to the same criteria as Test 10.

Selection of the appropriate multiple service level is beyond the scope of this report; however, in the absence of such selection, the testing agency should continue the use of Test 10. Also at this time, it is not clear as to whether MSL 3 barriers might be proposed at potential sites where large angle impacts with 4500S vehicles might occur. This problem may be addressed by inclusion of Tests 10, 30, and 40 in the test matrix for MSL 3 longitudinal barriers.

Two additional tests are presented in the minimum matrix for the length-of-need section for evaluating occupant risk: 2250S and 1800S vehicles at 60 mph (97 kph) and 15 deg. Establishment of these conditions was based on the following factors: (1) With other factors being equal, the redirection of small cars impacting a system where stiffness is dependent on deformed shape alone will be more severe than for a large car. Also, the small cars have a shorter wheel base and a narrower track, making them more vulnerable to rollover during redirection. (2) The 60-mph (97-kph) and 15-deg impact represent an appropriately severe test for measuring redirection performance of the test article in terms of vehicle accelerations and vehicle damage. Hopefully, the vehicle should be in a condition after the test that would enable it to be driven from the collision site to a safe area.

Test 11 (2250S/60 mph/15 deg)

The prime purpose of this test is to assess the potential risk or hazard to vehicle occupants during collision with the test article. However, the vehicle must remain upright and be smoothly redirected. For example, the 2250S vehicle has in some tests snagged or pocketed with abrupt accelerations or spinouts, or the vehicle has rolled over after colliding with certain concrete safety shapes. For vehicles remaining upright and smoothly redirected, occupant risks are projected based on vehicle accelerations and calculated kinematics of occupants within the compartment space.

Test 12 (1800S/60 mph/15 deg)

This is a new occupant risk test involving the 1800S vehicle. It is a goal for this test to eventually replace Test 11. However, at this time there is no assurance that existing appurtenance or new practical concepts will fully meet all performance requirements. In the interim until sufficient crash test experience is gained with the 1800S vehicle, test articles fully meeting performance requirements of Test 11 should be considered acceptable irrespective of Test 12 results. In the event that Test 12 is performed prior to Test 11 and the test article performance is judged to fully meet the performance requirements, then the testing agency may assume Test 11 conditions are met without performing the second occupant risk test.

Three supplementary tests (i.e., S16, S17, and S18) are given in Table 4 to evaluate the capability of the length-of-need section in keeping a heavy vehicle upright during redirection. Keeping all vehicles upright during all crash tests is a worthy goal as occupant risks are generally more severe and less predictable in a vehicle rollover. There are selected sites where the number of heavy vehicles, including utility buses such as those used to transport school children, farm workers, etc., is significant, and the possible added cost of a barrier to keep the redirected vehicle upright at these sites is considered acceptable. For the stability tests, the 20,000P utility bus is specified as (1) it represents an important percentage of heavy vehicles; (2) it has a relatively high center-of-mass, thereby making it susceptible for being upset during redirection; (3) the arrangement of passenger surrogates in a standard condition is readily achieved; and (4) the effects of shifting passenger mass during redirection is believed to increase the rollover potential and make the test more critical. It is noted that the utility bus structure has been found to exhibit failures during 60-mph (97-kph) and 15-deg impacts; these failures have obscured the barrier evaluation. In particular, the front suspension/vehicle frame connection has failed in at least two tests which permitted considerable unsymmetrical rearward displacement of the front wheel assembly. This failure in itself was judged sufficient to cause the vehicle to roll over. Thus, the tests were more an evaluation of the vehicle crashworthiness rather than a demonstration of the barrier capabilities.

Two evaluation factors are applied to the three stability tests: (1) vehicle containment and (2) whether the bus remains upright or rolls over during redirection.

Test S16 (20,000P/45 mph/7 deg)

The impact severity of this test is approximately one-half the MSL 1 strength test (Test S14); this test is considered appropriate for test articles developed to the MSL 1 requirements. One test at these conditions has been conducted to date on a MSL 1 bridge rail with acceptable results.

Test S17 (20,000P/50 mph/15 deg)

The impact severity of this test is about 50 percent greater than the MSL 1 strength test (Test S14); this test is considered appropriate for test articles developed to the MSL 2 requirements. No tests have been performed to date with these conditions; thus the relative ease or difficulty in meeting these conditions is unknown. It should be noted that the weight-horsepower ratio and slow acceleration of these vehicles make travel at 60 mph (97 kph) difficult, and for the most part, the routes utilized by this type of vehicle together with the stop-and-go nature of their mission precludes a significant amount of travel at speeds in excess of 50 mph (80 kph).

Test S18 (20,000P/60 mph/15 deg)

The impact severity of this test is slightly in excess of the MSL 2 strength test (Test S15); this test is considered appropriate for test articles developed to the MSL 3 requirements. As discussed earlier, a number of tests conducted with these conditions have resulted in vehicle failures that have obscured the test article performance.

Another special requirement for length-of-need sections of some longitudinal barriers is to contain all cargo and debris as well as the vehicle on the traffic side of the barrier. Such a barrier may be required at special sites where the trajectory of cargo and/or debris over the barrier could present undue hazard to nearby traffic, pedestrians, or facilities. For example, bridges that span busy parks, schools, industrial plants, or heavily traveled highways may require a high level of assurance that the cargo of heavy vehicles will be contained on the bridge along with the redirected vehicle. Thus, a heavily loaded tractor-trailer is selected as a critical vehicle to redirect along with its cargo. Evaluation criteria are whether or not the vehicle and cargo is contained on the traffic side of the longitudinal barrier.

Test S20 (80,000A/50 mph/15 deg)

This is a new test that has not been performed to date. The vehicle is a tractor-trailer with a mass of 80,000 lb (36,000 kg). The tractor is unspecified, although cab-over-engine design is preferred. The trailer is to be a van type, and the ballast is to be bagged sand uniformly stacked within the van without tie-downs. Although it is preferred that the tractor and trailer remain upright during redirection, the articulated vehicle is known to be unstable during and after such a collision. The testing agency should extensively measure pretest vehicle properties and report them in a format similar to that shown in Figure 2.

Test S21 (80,000F/50 mph/15 deg)

This is a new test that has not been performed to date. With exception of the fluid tanker trailer, discussion presented in Test S19 applies. The trailer should have a 8000-gal (30,000-liter) capacity filled with water.

Because of the articulated nature of the vehicle, it is believed that test conditions specified by S20 and S21 are less severe with regard to longitudinal barrier loading than the MSL 3 strength test. This is due in part to the staged redirection of the vehicle; the tractor is redirected and then the trailer is redirected. However, this will not be known until sufficient crash test experience is gained with S20 and S21.

Longitudinal Barriers (Transitions)

Transitions of concern generally occur between longitudinal barriers with different lateral flexibility. Transitions may occur between (1) two barrier systems with the same multiple service level, (2) two barrier systems of different multiple service level, or (3) two different types of longitudinal barriers such as guardrail to bridge rail. Because the transition normally will be situated in a length-of-need, it should be evaluated according to the length-of-need strength test according to the higher service level regardless of the service level order in the transition. The principal failure mode is for the vehicle to pocket or snag, with this generally occurring at transitions from flexible to rigid systems. Transitions from rigid to flexi-

TABLE 2.1. Recommended properties of 700C, 820C, and 2000P test vehicles

Property	700C (Small Car)	820C (Small Car)	2000P (Pickup Truck)
MASS (kg)			
Test Inertial	700 ± 25	820 ± 25	2000 ± 45
Dummy	75	75	---
Max. Ballast	70	80	200
Gross Static	775 ± 25	895 ± 25	2000 ± 45
DIMENSIONS (cm)			
Wheelbase	230 ± 10	230 ± 10	335 ± 25
Front Overhang	75 ± 10	75 ± 10	80 ± 10
Overall Length	370 ± 20	370 ± 20	535 ± 25
Track Width[b]	135 ± 10	135 ± 10	165 ± 15
CENTER OF MASS LOCATION[a] (cm)			
Aft of Front Axle	80 ± 15	80 ± 15	140 ± 15
Above Ground	55 ± 5	55 ± 5	70 ± 5
LOCATION OF ENGINE	Front	Front	Front
LOCATION OF DRIVE AXLE	Front	Front	Rear
TYPE OF TRANSMISSION	Manual or Automatic	Manual or Automatic	Manual or Automatic

[a] For "test inertial" mass
[b] Average of front and rear axles.

For tests with the 2000P vehicle, the supporting truck should be placed on a clean, dry, paved surface. Asphaltic or portland cement concrete surfaces are recommended. Conditions such as a polished surface or a bleeding asphaltic surface that could lower available tire-pavement friction should be avoided.

For tests with the 2000P vehicle, the supporting truck should be in second gear with park brakes on. Front tires should have no steering angle, that is, they should not be turned to the left or to the right.

2.4. TEST VEHICLES

2.4.1. Description of Test Vehicles

Impact performance of a highway safety feature may be evaluated by use of a commercially available, production model vehicle or by a validated surrogate vehicle. To date, with the exception of breakaway support structures, safety features have been evaluated by use of production model vehicles.

2.4.1.1 Production Model Test Vehicles

Recommended properties of production model test vehicles are given in Tables 2.1 and 2.2. Vehicles 700C and 820C are small cars, vehicle 2000P is a pickup truck, vehicle 8000S is a single-unit truck, vehicle 36000V is a tractor/van-type trailer unit, and 36000T is a tractor/tank trailer unit. Note that the numeric portion of the test vehicle designation is the vehicle's mass in kilograms.

In general, any test vehicle should be in good condition and free of major body damage and missing structural parts (i.e., doors, windshield, hood, etc.). Special purpose vehicles are not generally acceptable because they do not possess suspension and handling characteristics found in typical vehicles. Any manufacturer-installed equipment (power brakes and steering, air conditioning, etc.) is permitted so long as the equipment is contained within the body shell. The vehicle fuel tank should be purged and the battery removed from remotely powered test vehicles to reduce exposure to needless hazards. The bumpers on vehicles 700C, 820C, and 2000P should be standard equipment and unmodified for the test; configuration and height above grade should be reported. Tire size should be in accordance with the manufacturer's suggested size for each respective test vehicle. Highway, all season tires should be used on test vehicles 700C, 820C, and 2000P; mud or snow tires should not be used.

It is recommended the 700C vehicle be selected from one of the top two models, in terms of sales for the given model year, for cars with a curb mass of approximately 750 kg or less. It is recommended that the 820C vehicle be selected from one of the top two models, in terms of sales for the given model year, for cars with a curb mass in the 750 kg to 845 kg range. Car sales data may be obtained from the annual "Market Data Book," *Automotive News*, or "Automotive Year Book," *Wards Reports, Inc.* Reference should be made to the commentary for further discussions relative to the 820C vehicle.

TABLE 2.2 Recommended properties of 8000S, 36000V, and 36000T test vehicles

Property	8000S (Single-Unit Van Truck)	36000V (Tractor/Van Trailer)			36000T (Tractor/Tank Trailer)		
		Tractor[g]	Trailer[e]	Combination	Tractor[g]	Trailer[f]	Combination
Mass (kg)							
Curb	5,450 ± 450	N/S	N/S	13,200 ± 1,400	N/S	N/S	13,200 ± 1,400
Ballast[d]	As Needed	N/A	As Needed	N/A	N/A	As Needed	N/A
Test Inertial	8,000 ± 200	N/S	N/S	36,000 ± 500	N/S	N/S	36,000 ± 500
Dimensions (cm)							
Wheelbase	535 (max)	480 (max)	N/S	N/A	480 (max)	N/S	N/A
Overall Length	870 (max)	N/S	1,525 (max)	1,985 (max)	N/S	N/S	1,985 (max)
Trailer Overhang[a]	N/A	N/A	220 (max)[c]	N/A	N/A	185 (max)	N/A
Cargo Bed Height[b] (Above Ground)	130 ± 5	N/A	132 ± 5	N/A	N/A	N/A	N/A
Center of Mass Location (cm)							
Ballast[d] (Above Ground)	170 ± 5	N/A	185 ± 5	N/A	N/A	205 ± 10	N/S
Test Inertial (Above Ground)	125 ± 5	N/S	N/S	N/S	N/S	N/S	N/S

[a] Distance from rearmost part of trailer to center of trailer tandems.
[b] Without ballast.
[c] If trailer equipped with slide axles, they should be set at rearmost position.
[d] See Section 2.4.2.2 for recommended ballasting procedures.
[e] It is preferable that the trailer structure be of the "semi-monocoque" type construction. It is preferable that a sliding undercarriage (slide axles) be used to attach the trailer tandems to the trailer frame.
[f] It is preferable that a gasoline tank trailer with an elliptical cross section be used.
[g] Tractor should be a cab-behind-engine model, not a cab-over-engine model.
N/A - Not Applicable. N/S - Not Specified.

CHAPTER 3

TEST CONDITIONS

3.1 GENERAL

Guidelines are presented for the impact performance evaluation of various safety features. Individual tests are designed to evaluate one or more of the principal performance factors: structural adequacy, occupant risk, and post-impact behavior of vehicle. These evaluation criteria are presented in Chapter 5.

Depending on the feature being evaluated, there are up to six test levels that can be selected. In general, the lower test levels are applicable for evaluating features to be used on lower service level roadways and certain types of work zones while the higher test levels are applicable for evaluating features to be used on higher service level roadways or at locations that demand a special, high-performance safety feature. It will be noted that test levels 4 through 6 are applicable to longitudinal barriers only.

Note that the requirements of test level 3 are similar to those defined in the "Crash Test Conditions for Minimum Matrix" given in *NCHRP Report 230* (*1*). It is to this level that most crash-tested safety features in use on U.S. highways have been qualified. Since the issuance of *Report 230*, there has been a greater recognition of the merits of tailoring performance and cost of safety features to site requirements. This is the reason for the multiple test levels presented here. It is beyond the scope of this document to define warrants for the various test levels.

It is the responsibility of the user agency(s) to determine which of the test levels is most appropriate for a feature's intended application. Agencies should develop objective guidelines for use of roadway safety features, considering factors such as traffic conditions, site conditions, traffic volume and mix, and the cost effectiveness of candidate safety alternatives. However, it is anticipated that safety features qualified for test level 3 will remain acceptable for a wide range of high-speed arterial highways. Test level 2 qualified features are expected to be deemed acceptable for most local and collector roads and many work zones. Test level 1 qualified features are expected to be deemed acceptable for some work zones and very low-volume, low-speed local streets and highways. Applicability of test levels 4 through 6 will probably be determined by volume of truck and heavy vehicle traffic and/or the consequences of penetration beyond the longitudinal barrier.

Although tests with the 700C vehicle are desirable, they are optional because (1) this vehicular type represents only a very small portion of the vehicular mix and (2) there is no assurance that an existing feature will meet the recommended performance criteria or that new features can be found that will fully meet the recommended performance criteria for these tests. In the interim until sufficient testing experience is acquired with the 700C type vehicle, the test article should perform acceptably with all appropriate tests using the 820C and 2000P type vehicles and preferably should perform acceptably during tests with the 700C type vehicle. It may be assumed that test articles performing acceptably with 700C and 2000P type vehicles will also perform acceptably with the 820C vehicle; thus, the 820C vehicle tests need not be performed.

It is important to note that tests recommended herein are based in large part on past experience. It is not possible to anticipate the form that new designs will take nor the critical impact conditions of these new designs. As such, the test matrices presented in this section must not be viewed as all-inclusive. When appropriate, the responsible agency should devise other critical test conditions consistent with the range of expected impact conditions. Also, if warranted, additional tests can be conducted to evaluate a feature for nonidealized conditions, such as longitudinal barrier with curvilinear alignment, the placement of a feature on nonlevel terrain, or the placement of a feature behind a curb.

It is not uncommon for a designer/tester to make design changes to a feature during the course of conducting the recommended test series or after successful completion of the test series. Changes are often made to improve performance or to reduce cost of the design or both. Questions then invariably arise as to the need to repeat any or all of the recommended tests. Good engineering judgment must be used in such instances. As a general rule, a test should be repeated if there is a reasonable uncertainty regarding the effect the change will have on the test.

Note that each test in a given matrix has a specific "test designation" of the form "i-jk." The "i" refers to the test level and "jk" refers to the test number. Test designations preceded by an "S" refer to tests with the optional 700C vehicle.

3.2 TEST MATRICES

3.2.1 Longitudinal Barriers

3.2.1.1 General

Recommended tests to evaluate longitudinal barriers for six test levels are presented in Table 3.1. Reference should be made to the Glossary for definitions of length of need (LON) and transitions. These guidelines are applicable to both permanent barriers and temporary barriers used in work or construction zones. However, except under very unusual conditions, a temporary barrier would not normally be designed for impact conditions greater than test level 3.

TABLE 3.1. Test matrix for longitudinal barriers

Test Level	Barrier Section	Test Designation	Impact Conditions[c] Vehicle	Nominal Speed (km/h)	Nominal Angle, θ (deg)	Impact Point	Evaluation Criteria[e] (See Table 5.1)
1	Length of Need	1-10 S1-10[a] 1-11	820C 700C 2000P	50 50 50	20 20 25	(b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M
	Transition	1-20[d] S1-20[a] 1-21	820C 700C 2000P	50 50 50	20 20 25	(b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M
2	Length of Need	2-10 S2-10[a] 2-11	820C 700C 2000P	70 70 70	20 20 25	(b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M
	Transition	2-20[d] S2-20[a] 2-21	820C 700C 2000P	70 70 70	20 20 25	(b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M
3 Basic Level	Length of Need	3-10 S3-10[a] 3-11	820C 700C 2000P	100 100 100	20 20 25	(b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M
	Transition	3-20[d] S3-20[a] 3-21	820C 700C 2000P	100 100 100	20 20 25	(b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M
4	Length of Need	4-10 S4-10[a] 4-11[d] 4-12	820C 700C 2000P 8000S	100 100 100 80	20 20 25 15	(b) (b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M A,D,G,K,M
	Transition	4-20[d] S4-20[a] 4-21[d] 4-22	820C 700C 2000P 8000S	100 100 100 80	20 20 25 15	(b) (b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M A,D,G,K,M
5	Length of Need	5-10 S5-10[a] 5-11[d] 5-12	820C 700C 2000P 36000V	100 100 100 80	20 20 25 15	(b) (b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M A,D,G,K,M
	Transition	5-20[d] S5-20[a] 5-21[d] 5-22	820C 700C 2000P 36000V	100 100 100 80	20 20 25 15	(b) (b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M A,D,G,K,M
6	Length of Need	6-10 S6-10[a] 6-11[d] 6-12	820C 700C 2000P 36000T	100 100 100 80	20 20 25 15	(b) (b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M A,D,G,K,M
	Transition	6-20[d] S6-20[a] 6-21[d] 6-22	820C 700C 2000P 36000T	100 100 100 80	20 20 25 15	(b) (b) (b) (b)	A,D,F,H,I,(J),K,M A,D,F,H,I,(J),K,M A,D,F,K,L,M A,D,G,K,M

[a] Test is optional. See Section 3.1.
[b] See Figure 3.1 for impact point.
[c] See Section 3.3.2 for tolerances on impact conditions.
[d] Test may be optional. See Section 3.2.1.2.
[e] Criteria in parenthesis are optional.

3.2.1.2 Description of Tests

Test 10

Test 10 is conducted for the LON section for all test levels. The purpose of this small car test is to evaluate the overall performance of the LON section in general, and occupant risks in particular.

Tests 11 and 21

Test 11 for the LON section and Test 21 for the transition section are conducted for test levels 1 through 3. They are intended to evaluate strength of the section in containing and redirecting the 2000P test vehicle. Tests 11 and 21 are optional for test levels 4, 5, and 6. They should be conducted if a reasonable uncertainty exists regarding impact performance of the system for these tests. It is recommended that results of Tests 12 and 22 be carefully examined prior to conducting Tests 11 and 21. Tests 12 and 22 will establish basic structural adequacy of the barrier. However, satisfactory performance for Tests 12 and 22 does not assure satisfactory performance for Tests 11 and 21. For example, there may be geometric incompatibilities between the barrier and the 2000P vehicle that could result in excessive snagging or pocketing.

Test 20

Test 20 for a transition section is an optional test to evaluate occupant risk and post-impact trajectory criteria for all test levels. It should be conducted if there is a reasonable uncertainty regarding the impact performance of the system for this test. Results of Test 21 should be carefully examined prior to conducting Test 20. Test 21 will establish the structural adequacy of the transition. However, satisfactory performance for Test 21 does not assure satisfactory performance for Test 20. For example, there may be geometric incompatibilities between the transition and the 820C vehicle which could cause a failure from excessive snagging or pocketing.

Tests 12 and 22

Test 12 for the LON section and Test 22 for the transition section are conducted for test levels 4, 5, and 6. They are intended to evaluate strength of the section in containing and redirecting the heavy test vehicles.

As noted in Figure 3.1, Section 3.4.2 contains guidance on determination of the critical impact point (CIP). As discussed therein, depending on barrier design, there may be two CIPs. For example, a bridge rail with a splice located between support posts may have two CIPs: one that would produce maximum loading on the splice and another that would have the greatest potential for causing wheel snagging or vehicular pocketing. As another example, a transition may have a CIP in the vicinity of the upstream end and another in the vicinity of the downstream end. Therefore, if one test cannot evaluate both points of concern, it may be necessary to conduct the relevant test(s) at both points of concern. See further discussion on this matter in Section 3.4.2.

3.2.2 Terminals and Crash Cushions

3.2.2.1 General

Recommended tests to evaluate terminals and crash cushions are presented in Table 3.2. Reference should be made to the Glossary for definitions of these features. These guidelines are applicable to both permanent features and temporary features used in work or construction zones. Note that impact performance requirements of a terminal and a redirective crash cushion are the same.

Impact performance requirements, and hence capabilities, of a nonredirective crash cushion are considerably less than those for a redirective crash cushion. A redirective crash cushion is subjected to more tests, and the requirements of those tests are more rigorous. For example, it is recommended that Test 38 be conducted at the critical impact point of the redirective crash cushion. A similar test would be difficult to pass for a nonredirective crash cushion. As a consequence, conditions or sites at which a nonredirective crash cushion can be used may be limited. It is the responsibility of the user agency to determine where features addressed in this document have application, including redirective and nonredirective crash cushions.

Reference is made herein to "gating" and "nongating" features or devices. A gating device is one designed to allow controlled penetration of the vehicle when impacted between the end and the beginning of the length of need (LON) of the device. The widely used breakaway cable terminal (BCT) is a gating device. A nongating device is designed to contain and redirect a vehicle when impacted downstream from the end of the device. A terminal or crash cushion with redirection capabilities along its entire length is a nongating device.

3.2.2.2 Description of Tests

Following is a description of each test. Reference should be made to Figures 3.2 and 3.3 for vehicle/test article orientation at impact.

Tests 30 and 40

These tests are conducted with the vehicle approaching parallel to the roadway, with impact to the left or right of the vehicle's centerline. They are intended primarily to evaluate occupant risk and vehicle trajectory criteria. The vehicle should be offset to the most critical side, that is, the side which will result in the greatest occupant risk during and subsequent to impact, recognizing the direction the vehicle will tend to roll, pitch, and yaw subsequent to impact. If the impact is to the right of the vehicle's centerline, the vehicle will tend to rotate clockwise (as viewed from above) or counterclockwise if the impact is to the left. It may also roll and pitch depending on the geometry and impact behavior of the test article.

Tests 31 and 41

These tests are conducted with the vehicle approaching parallel to the roadway with impact at the vehicle's centerline. For a device designed to decelerate a vehicle to a stop, these tests are intended to evaluate the capacity of the device to

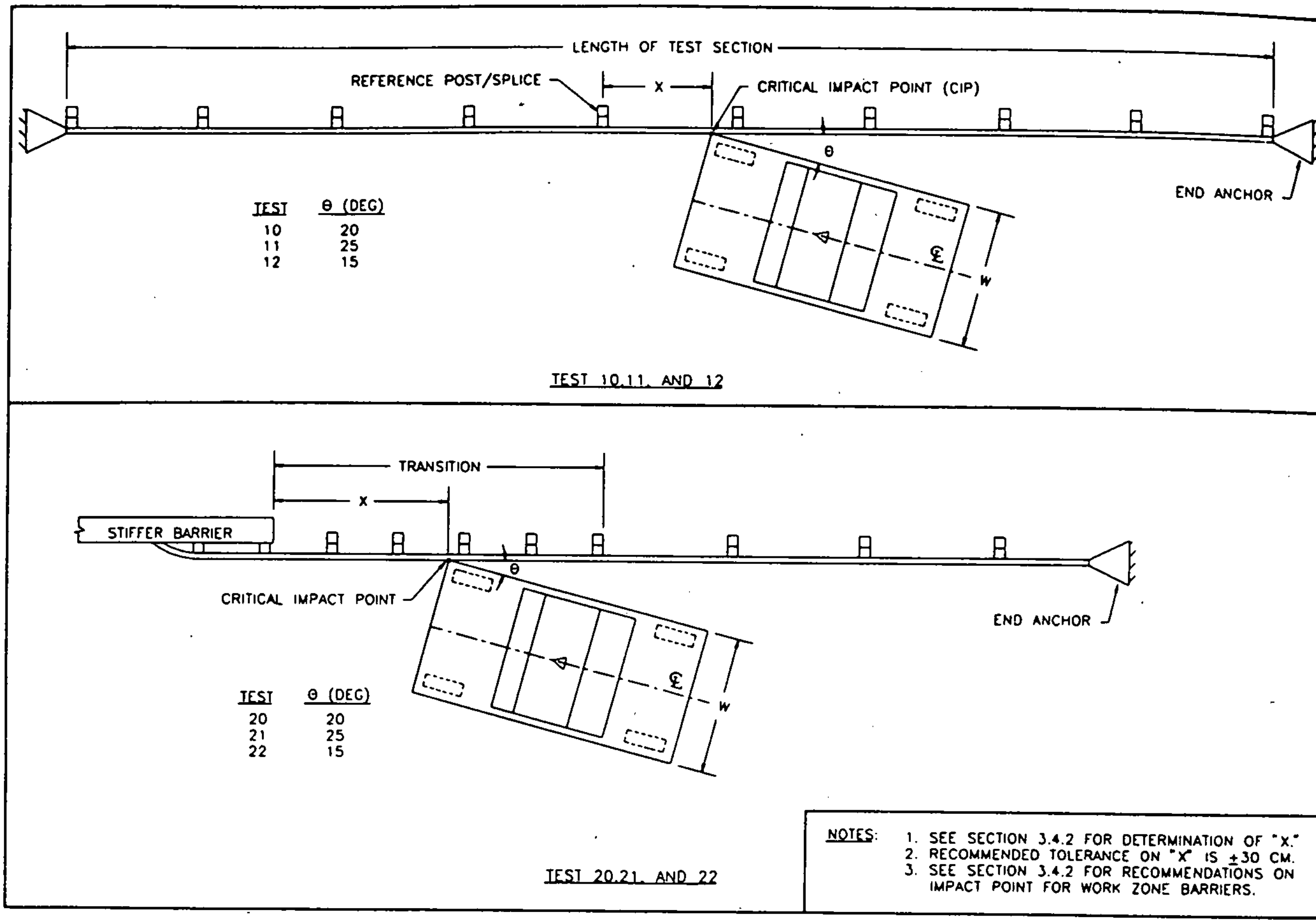


Figure 3.1. Impact conditions for longitudinal barrier tests.

absorb the kinetic energy of the 2000P vehicle (structural adequacy criteria) in a safe manner (occupant risk criteria). For other types of devices these tests are intended primarily to evaluate occupant risk and vehicle trajectory criteria.

Tests 32 and 33

Tests 32 and 33 are intended primarily to evaluate occupant risk and vehicle trajectory criteria. For some devices, it may be possible to demonstrate through engineering analysis, with a high degree of confidence, that Tests 32 and 33 are less severe than Tests 30 and 31. For example, in all probability Tests 32 and 33 would be less severe than Tests 30 and 31, respectively, for the breakaway cable terminal (BCT) for W-beam guardrail; the BCT is a gating device. In such cases, Tests 32 and 33 may be optional. However, Tests 32 and 33 should be conducted for a gating device if there is a reasonable uncertainty about the impact performance of the system for these tests.

Tests 34 and 35

These tests are applicable to gating devices only. In Test 34, impact should be at a CIP (see definition in Glossary) between the end of the device and the beginning of the LON. Whereas definitive criteria are presented in Section 3.4.3 for estimating the CIP for selected devices, no such criteria are available for this particular application. Therefore, selection of the CIP for Test 34 should be based on test experience with similar devices, computer simulation if possible, and judgment. In selecting the CIP, consideration should not only be given to the point with the greatest potential for causing snagging or pocketing but also the point with the greatest potential for producing vehicular overturn. For example, in testing a sloped-end terminal, vehicular stability is the primary concern, not snagging or pocketing, and the CIP may not be midway between the end of the terminal and the beginning of the LON. In the absence of a determinable CIP, Test 34 may be conducted with the initial impact point midway between the end of the device and the beginning of the LON. Test 34 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. Test 35 is intended primarily to evaluate the ability of the device to contain and redirect (structural adequacy criteria) the 2000P vehicle within vehicle trajectory criteria at the beginning of the LON.

Tests 36, 37, and 38

These tests are applicable to nongating devices only. In Tests 36 and 37, the impact point should be at the end of the practical to establish absolute limits on test article trajectory, debris scatter, or barrier displacement. Rather, it is important to accurately record and report test article trajectory and debris scatter so that a user agency can make an objective assessment of the appropriateness of the safety feature for the intended application.

A factor listed in item D concerns deformations and intrusions into the occupant compartment. Of necessity, this factor must be assessed in large part by the judgment of the test agency and the user agency, or both. Risk of injury from a deformation depends on location, extent, and rate of deformation. In the absence of a widely accepted measure of risks associated with deformations or intrusions, it is essential that adequate documentation in the form of photographs and measurements of occupant compartment damage be made and reported. Photographs of the interior prior to the test should also be made to permit direct comparisons of before and after conditions. Until an acceptable methodology is developed, the procedure given in Appendix E may be used to compute and document an Occupant Compartment Deformation Index (OCDI). Although the OCDI should be used for information purposes only and should not be used to determine acceptance of a test, its use will permit some degree of quantification of occupant compartment damage. As experience is gained with its use, definitive acceptance criteria may be established in the future.

Although not a specific factor in assessing test results, integrity of the test vehicle's fuel tank is of concern. It is preferable that the fuel tank remain intact and unpunctured. Damage to or rupture of the fuel tank, oil pan, floor pan, or other features that might serve as a surrogate of a fuel tank should be reported.

For the majority of tests, a key requirement for occupant risk evaluation is for the impacting vehicle to remain upright during and after the collision, although moderate rolling, pitching, and yawing are acceptable. This requirement has the effect of minimizing the vertical component of vehicular acceleration; thus, this component is not normally evaluated in a typical crash test. Although it is preferable that all vehicles remain upright, this requirement is not applicable to tests involving the 8000S, 36000V, and 36000T vehicles, and all tests within test level 1 for terminals and crash cushions. See Appendix A, Section A3.2.2, for a discussion of these exceptions.

Occupant risk is also assessed by the response of a hypothetical, unrestrained front seat occupant whose motion relative to the occupant compartment is dependent on vehicular accelerations. The "point mass" occupant is assumed to move through space until striking a hypothetical instrument panel, windshield, or side structure and subsequently is assumed to experience the remainder of the vehicular acceleration pulse by remaining in contact with the interior surface. The two performance factors are (1) the lateral and longitudinal component of occupant velocity at impact with the interior surface and (2) the highest lateral and longitudinal component of resultant vehicular acceleration averaged over any 10-ms interval for the collision pulse subsequent to occupant impact. Performance factor two is referred to as the ridedown acceleration. Methods for calculating the impact velocity and ridedown acceleration components are given in Appendix A, Section A5.3. Generally, low values for these factors indicate less hazardous safety features. While a surrogate occupant is required in tests with the 820C and 700C vehicles and is optional in other tests, its dynamic and kinematic responses are not required or used in occupant risk assessment; hypothetical occupant compartment impact velocity and ridedown accelerations are calculated from vehicular accelerations.

It is also necessary to assess risk of injury to the driver of a supporting truck in a TMA system. Because the types of impacts in this case are primarily unidirectional and the supporting truck is accelerated forward, the driver will not move forward, at least initially, and is restrained from flailing rearward by the seat and headrest, which should be standard on these vehicles. As such, the primary risk of injury would stem from ridedown accelerations as the vehicle is accelerated forward. It is therefore recommended that ridedown acceleration criteria be used as the primary assessment of the risk of injury to the driver of a supporting truck in a TMA system.

TABLE 5.1. Safety evaluation guidelines

Evaluation Factors	Evaluation Criteria	Applicable Tests[a]
Structural Adequacy	A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	10, 11, 12, 20, 21, 22, 35, 36, 37, 38
	B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	60, 61, 70, 71, 80, 81
	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	30, 31, 32, 33, 34, 39, 40, 41, 42, 43, 44, 50, 51, 52, 53

[a] Test numbers refer to last two digits in Test Designation for each Test Level unless otherwise noted.

TABLE 5.1. *(Continued)*

<table>
<tr><th>Evaluation Factors</th><th colspan="3">Evaluation Criteria</th><th>Applicable Tests[a]</th></tr>
<tr><td rowspan="13">Occupant Risk</td><td colspan="3">D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted. See discussion in Section 5.3 and Appendix E.</td><td>All</td></tr>
<tr><td colspan="3">E. Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.</td><td>70, 71</td></tr>
<tr><td colspan="3">F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.</td><td>All except those listed in Criterion G.</td></tr>
<tr><td colspan="3">G. It is preferable, although not essential, that the vehicle remain upright during and after collision.</td><td>12, 22, 30[b], 31[b], 32[b], 33[b], 34[b], 35[b], 36[b], 37[b], 38[b], 39[b], 40[b], 41[b], 42[b], 43[b], 44[b]</td></tr>
<tr><td colspan="3">H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:
Occupant Impact Velocity Limits (m/s)</td><td></td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td><td></td></tr>
<tr><td>Longitudinal and Lateral</td><td>9</td><td>12</td><td>10, 20, 30, 31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 80, 81</td></tr>
<tr><td>Longitudinal</td><td>3</td><td>5</td><td>60, 61, 70, 71</td></tr>
<tr><td colspan="3">I. Occupant ridedown accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:
Occupant Ridedown Acceleration Limits (G's)</td><td></td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td><td></td></tr>
<tr><td>Longitudinal and Lateral</td><td>15</td><td>20</td><td>10, 20, 30, 31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81</td></tr>
<tr><td colspan="3">J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.</td><td>10, 20, 30, 31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81</td></tr>
</table>

[a] Test numbers refer to last two digits in Test Designation for each Test Level unless otherwise noted.
[b] For Test Level 1 only.

TABLE 5.1. *(Continued)*

Evaluation Factors	Evaluation Criteria	Applicable Tests*
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	All
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction (see Appendix A, Section A5.3 for calculation procedure) should not exceed 20 G's.	11, 21, 35, 37, 38, 39
	M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	10, 11, 12, 20, 21, 22, 35, 36, 37, 38, 39
	N. Vehicle trajectory behind the test article is acceptable.	30, 31, 32, 33, 34, 39, 42, 43, 44, 60, 61, 70, 71, 80, 81

* Test numbers refer to last two digits in Test Designation for each Test Level unless otherwise noted.

Recommended limits for occupant impact velocity and ridedown acceleration are given in Table 5.1. Note that two values are given for each parameter, a "preferred" limit and a "maximum" limit. As implied, it is desirable that the occupant risk indices not exceed the preferred values, and it is recommended that they not exceed the maximum values. Reference should be made to Appendix A, Section A5.3, for the rationale used in selecting these values. Establishment of absolute occupant risk limits is a policy decision and accordingly must be made by the user agency responsible for the implementation of the recommendations contained herein.

As indicated in Table 5.1, if a dummy is to be used to supplement the assessment of occupant risk, it is recommended the Hybrid III dummy be used. However, note that the Hybrid III dummy is valid for *frontal or head-on impacts* only, that is, those in which dummy movement is essentially parallel to the longitudinal vehicular axis (x-axis, as shown in Figure 4.6). Specifications, calibration, and instrumentation of the Hybrid III dummy should be in accordance with Part 572, Subpart E, Title 49 of the *Code of Federal Regulations*, Chapter V (10-1-88 Edition). Response data should conform to Part 571.208, Title 49 of the CFR, Chapter V (10-1-88 Edition). There is no dummy capable of accurately simulating the kinetics and kinematics of an occupant for oblique movements, that is, those in which occupant movement has both x and y components. Oblique occupant movement typically occurs when the vehicle is redirected away from the feature being impacted, such as a longitudinal barrier.

Although not required, testing agencies are encouraged to calculate and report the Theoretical Head Impact Velocity (THIV), the Post-Impact Head Deceleration (PHD), and the Acceleration Severity Index (ASI), as described in Appendix F. The THIV, PHD, and the ASI have been adopted by the European Committee for Standardization (CEN) (*77*) as measures of occupant risks. At some time in the future, it is expected that the U.S. and CEN will develop common impact performance standards for highway features. By calculating and reporting the THIV, PHD, and the ASI, a database will be developed from which comparisons can be made relative to the flail space model and from which decisions can be made as to appropriate measures of occupant risk.

5.4 POST-IMPACT VEHICULAR TRAJECTORY

Vehicular trajectory hazard is a measure of the potential of the post-impact trajectory of the vehicle to cause a subsequent multivehicle accident, thereby subjecting occupants of other vehicles to undue hazard or to subject the occupants of the impacting vehicle to secondary collisions with other fixed objects. As indicated in Table 5.1, it is preferable that the vehicle trajectory and final stopping position intrude a minimum distance, if at all, into adjacent or opposing traffic lanes. Criterion "L" is included to limit pocketing or snagging of the vehicle and the post-impact consequences of excessive pocketing or snagging, such as a high vehicular exit angle or spin-out of the vehicle. It is preferable that the vehicle be smoothly redirected (for redirective devices), and this is typically indicated when the exit angle is less than 60 percent of the impact angle. Acceptable post-impact behavior may also be achieved if the vehicle is decelerated to a stop while vehicular-barrier contact is maintained, provided all other relevant criteria of Table 5.1 are satisfied. Note that if the barrier is within a lane width of adjacent traffic, the slowed or stopped vehicle may pose risks to oncoming motorists. As

DATE: ______________ TEST NO.: ______________

TRACTOR:

VIN NO.: ______________ MAKE: ______________ MODEL: ______________

YEAR: ______________ ODOMETER: ______________

TRAILER:

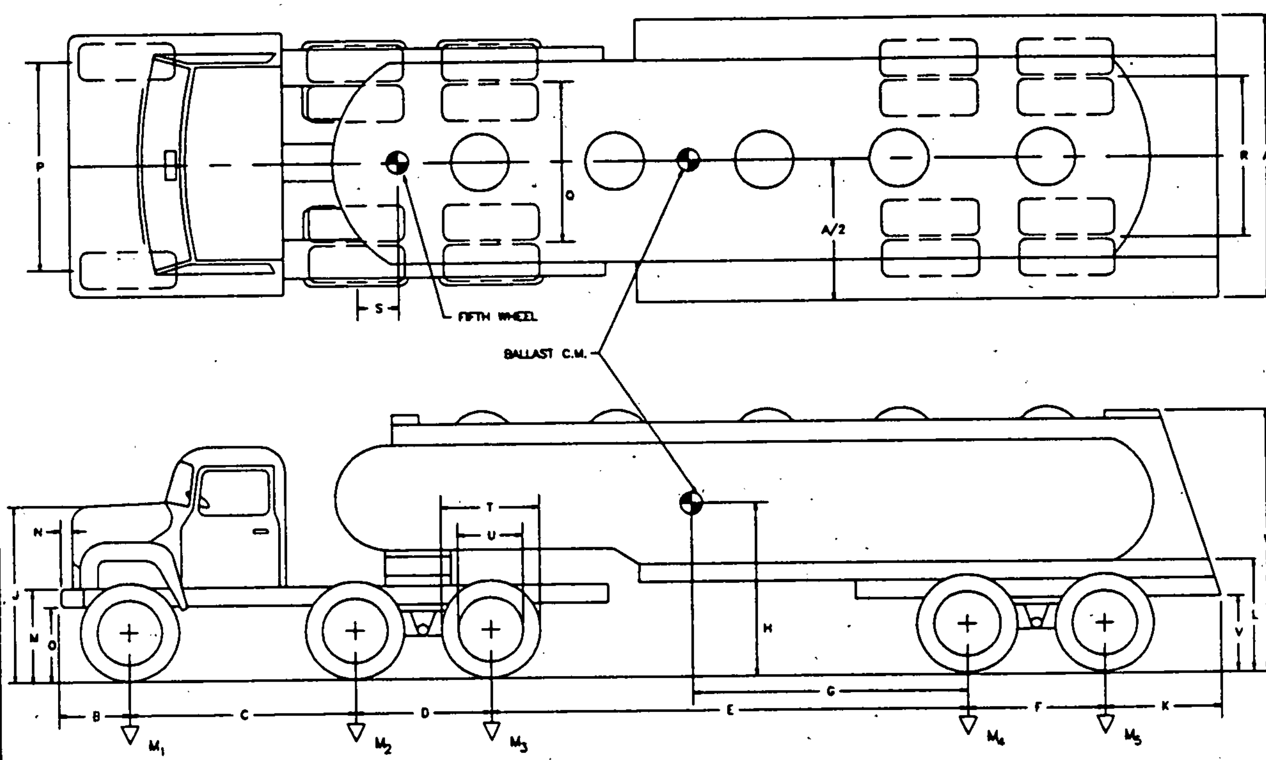
VIN NO.: ______________ MAKE: ______________ MODEL: ______________

YEAR: ______________

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

____

____



GEOMETRY – CM

A ____	D ____	G ____	K ____	N ____	Q ____	T ____
B ____	E ____	H ____	L ____	O ____	R ____	U ____
C ____	F ____	J ____	M ____	P ____	S ____	V ____
W ____						

MASS – Kg	CURB	TEST INERTIAL	GROSS STATIC
M_1	____	____	____
M_2	____	____	____
M_3	____	____	____
M_4	____	____	____
M_5	____	____	____
M_T	____	____	____

Figure 4.5. 36000T parameters.

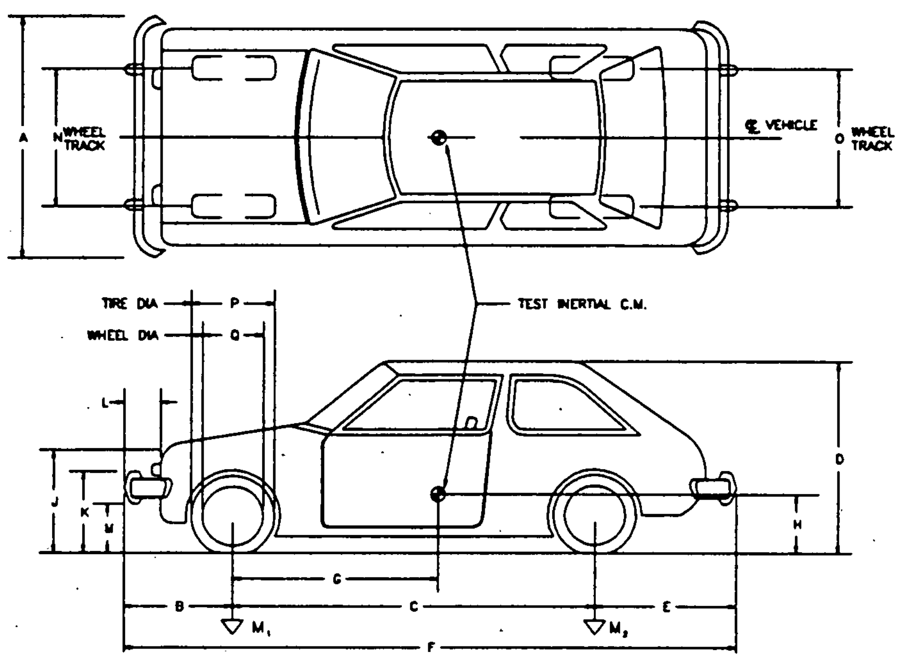
DATE: ____ TEST NO.: ____ VIN NO.: ____ MAKE: ____

MODEL: ____ YEAR: ____ ODOMETER: ____ TIRE SIZE: ____

TIRE INFLATION PRESSURE: ____

MASS DISTRIBUTION (kg) LF ____ RF ____ LR ____ RR ____

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: ____

ENGINE CID: ____

TRANSMISSION TYPE:

— AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ____

MASS: ____

SEAT POSITION: ____

GEOMETRY – (cm)

A ____	D ____	G ____	K ____	N ____	Q ____
B ____	E ____	H ____	L ____	O ____	
C ____	F ____	J ____	M ____	P ____	

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1			
M_2			
M_T			

Figure 4.1. 700C and 820C parameters.

DATE: ______ TEST NO.: ______ VIN NO.: ______ MAKE: ______

MODEL: ______ YEAR: ______ ODOMETER: ______ GVW: ______

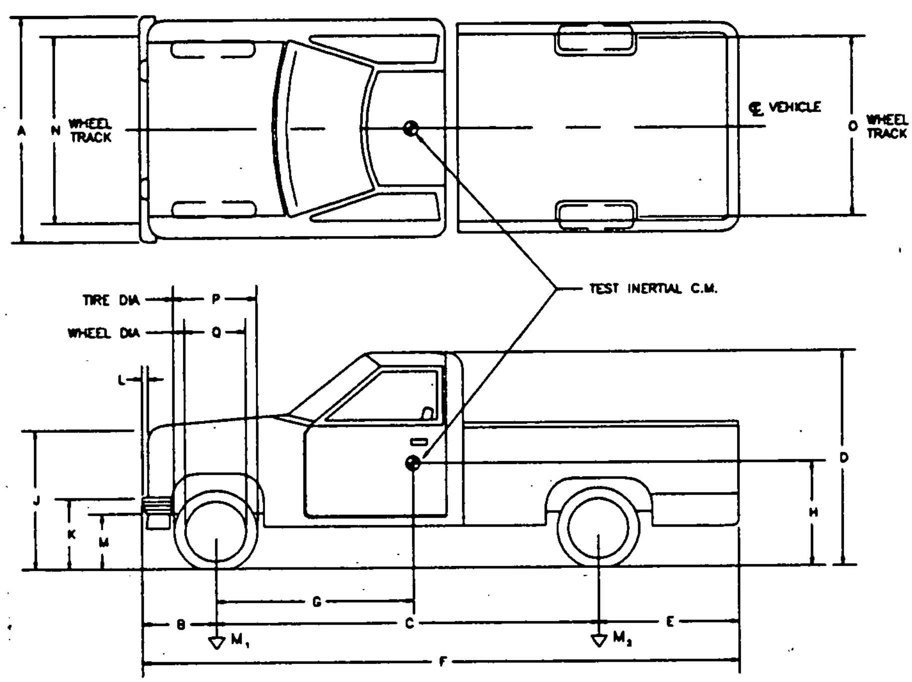
TIRE SIZE: ______ TIRE INFLATION PRESSURE: ______ TREAD TYPE: ______

MASS DISTRIBUTION (kg) LF ______ RF ______ LR ______ RR ______

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

______

______



ENGINE TYPE: ______

ENGINE CID: ______

TRANSMISSION TYPE:

— AUTO

— MANUAL

OPTIONAL EQUIPMENT:

______

______

______

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (cm)

A ______ D ______ G ______ K ______ N ______ Q ______

B ______ E ______ H ______ L ______ O ______

C ______ F ______ J ______ M ______ P ______

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1			
M_2			
M_T			

Figure 4.2. 2000P parameters.

DATE: ____________ TEST NO.: ____________ VIN NO.: ____________ MAKE: ____________

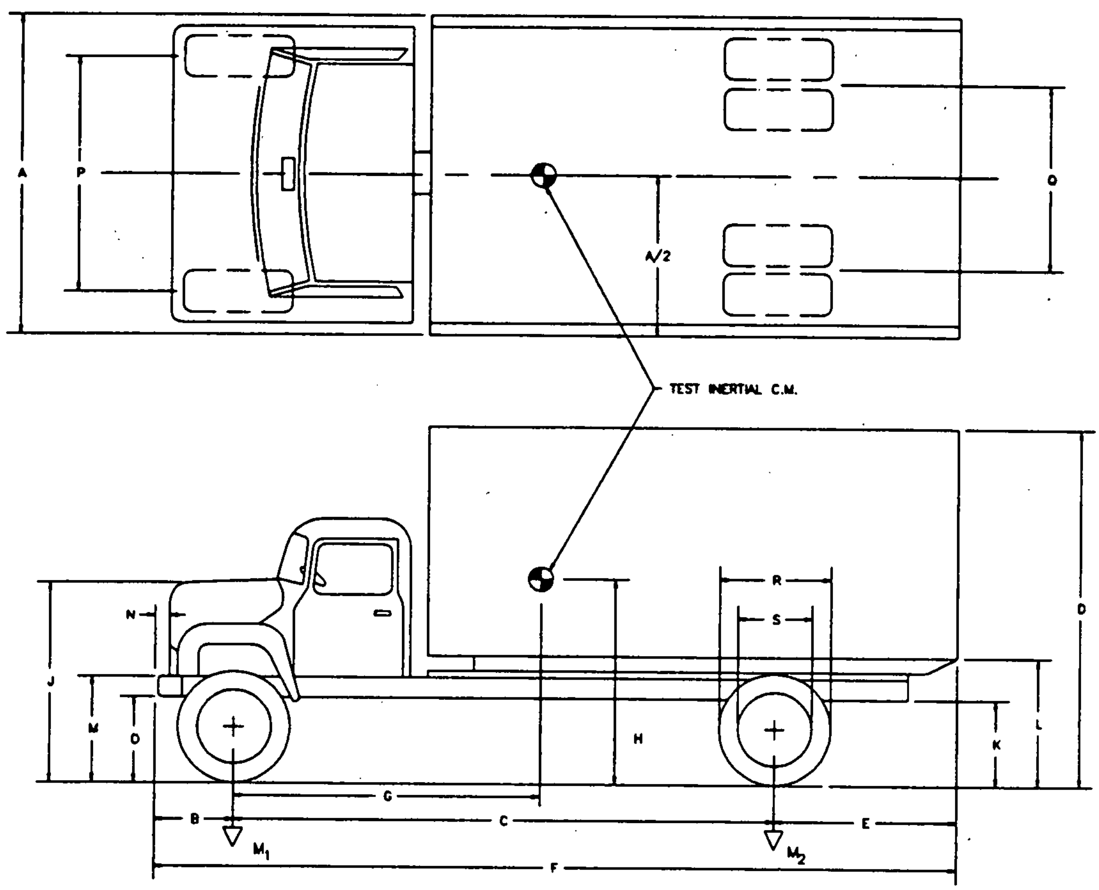
MODEL: ____________ YEAR: ____________ ODOMETER: ____________ TIRE SIZE: ____________

MASS DISTRIBUTION (kg) LF________ RF________ LR________ RR________

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

____

____



GEOMETRY – (cm)

A________	D________	G________	K________	N________	Q________
B________	E________	H________	L________	O________	R________
C________	F________	J________	M________	P________	S________

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	________	________	________
M_2	________	________	________
M_T	________	________	________

Figure 4.3. 8000S parameters.

DATE: ____________ TEST NO.: ____________

TRACTOR:

VIN NO.: ____________ MAKE: ____________ MODEL: ____________

YEAR: ____________ ODOMETER: ____________

TRAILER:

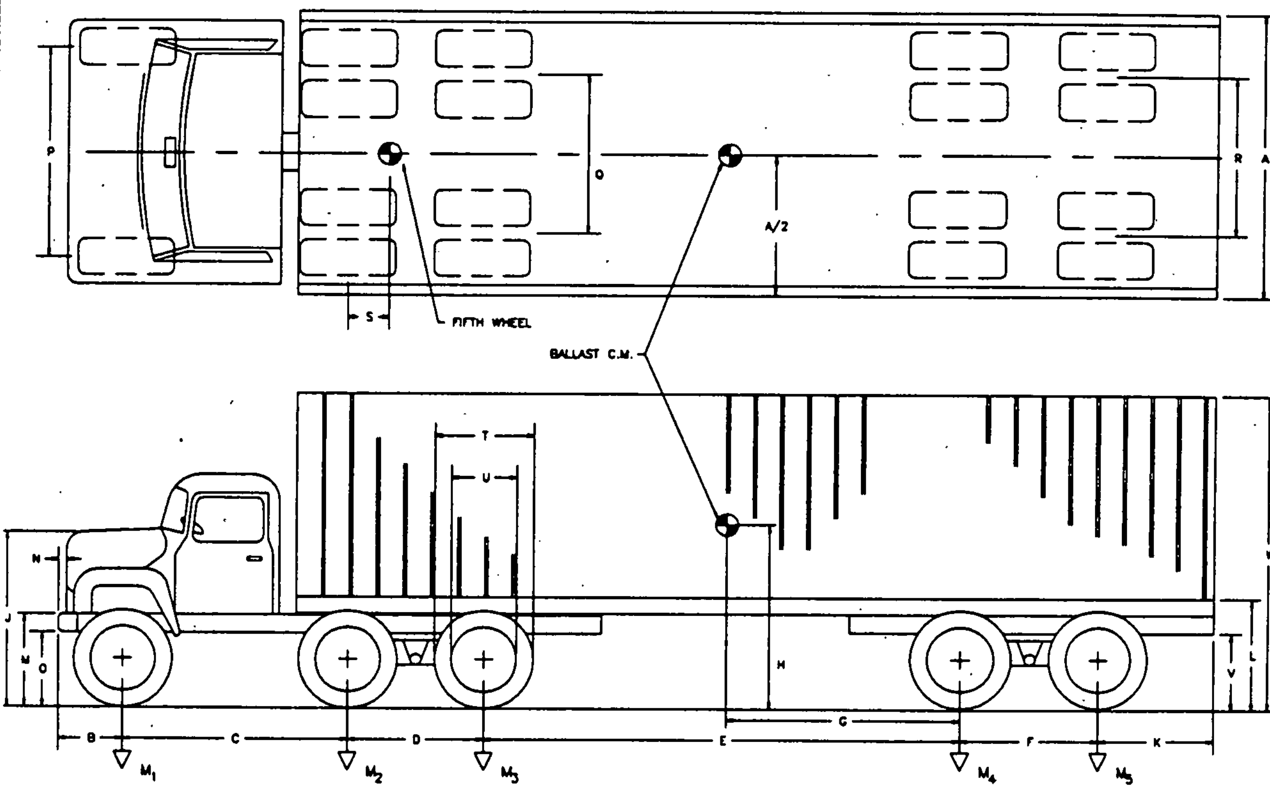
VIN NO.: ____________ MAKE: ____________ MODEL: ____________

YEAR: ____________

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

____

____



GEOMETRY – (cm)

A ____	D ____	G ____	K ____	N ____	Q ____	T ____
B ____	E ____	H ____	L ____	O ____	R ____	U ____
C ____	F ____	J ____	M ____	P ____	S ____	V ____
W ____						

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	____	____	____
M_2	____	____	____
M_3	____	____	____
M_4	____	____	____
M_5	____	____	____
M_T	____	____	____

Figure 4.4. 36000V parameters.

APPENDIX B

Survey of State Departments of Transportation

A questionnaire was mailed to each of the 50 state departments of transportation (DOTs) in late May 1995. In early July the states that had not replied were called and new questionnaires were sent in several cases. By early August, 39 responses had been received. The information from these 39 questionnaires was supplemented by roadside safety data that had been collected by Bucknell University researchers from state DOTs during 1994 and 1995. The survey that was sent to the states is reproduced in this appendix. The responses to the survey are summarized in Appendix C.

NCHRP Synthesis of Highway Practice
A Survey of Guardrail and Median Barrier Usage and Warrants
Spring 1995

1. **General Information:**

(a) Agency ______

(b) Responder ______

(c) Title ______

(d) Telephone Number ______

(e) FAX Number ______

(f) Address ______

______

2. **Request for Printed Information on Guardrails & Median Barriers**

Please include with your completed questionnaire any of the following items that have been produced by or for your agency.

- Warrants for guardrails, roadside barriers, and median barriers
- Written standards or guidelines for placement of roadside and median barriers (not standard drawings)
- Criteria used in selecting the appropriate barrier type for given conditions
- In-service reports on guardrails, roadside barriers or median barriers
- Life cycle and/or maintenance cost studies for any type of barrier
- Summaries of installation costs for barriers
- Inventory data on existing guardrails and median barriers
- Results of any barrier crash tests conducted for your agency
- Analyses of accident severity and barrier type
- Research reports on the design, installation, maintenance, and/or performance of highway barrier systems

3. **Instructions for Table 1 - Common Uses of Guardrails**

Type of Guardrail - Detailed descriptions and diagrams are shown on attached Figure 1.

Post Material - A separate row is given for wood and steel for guardrails used with both types of posts.

Post X-Section - For each type of guardrail used in your state, please indicate the post cross-section used, e.g., 6 by 8, S3 x 5.7, W6 x 8.5, etc.

Amount of Usage - For each type of guardrail used in your state, please indicate the percentage (on a linear-foot basis) of each type <u>currently</u> being installed in your state. If percentages are unknown, please estimate using the following codes:

A - Over 90%	E - 5% to 14%
B - 60% to 90%	F - Less than 5%
C - 30% to 59%	N - Never Used
D - 15% to 29%	P - No longer installed, but used in the Past

Common Applications - For each type of guardrail used in your state, please indicate the applications for which the guardrail is generally used by using the following codes:

C - <u>C</u>ommonly used
R - <u>R</u>arely used
N - <u>N</u>ever used

For Guardrails types NOT used in your state, please leave this section blank.

4. **Instructions for Table 2 - Guardrail Installation Costs and Characteristics**

Installation Cost - Please provide a range for typical installation costs per linear foot (LF) for each of the guardrails used. Exclude the cost of terminals and crash cushions.

Guardrail Height - For all barrier types please indicate the height to the top of the barrier rail, beam, or cable. For cable systems indicate the height of the lowest cable and for beam barriers indicate the height of the bottom of the barrier (beam or rub rail).

Standard Post Spacing - Indicate the normal spacing between posts (centerline to centerline) and the minimum required clear area behind the barrier. If your standards also specify a "desirable" clear area behind the barrier, please give that value too.

Minimum Post Spacing - If your standards permit closer post spacing to increase stiffness and decrease deflection, indicate the minimum spacing that you use and the associated minimum clear area behind the barrier.

5. **Instructions for Table 3 - Guardrail Transitions Used**

For each type of guardrail used in your state, please indicate for which other barriers, transitions are used in your state by using the following codes:

C - <u>C</u>ommonly used
R - <u>R</u>arely used
N - <u>N</u>ever used

For Guardrails types NOT used in your state, please leave this section blank.

6. **Instructions for Table 4 - Common Uses of Median Barriers**

Type of Median Barrier - Detailed descriptions and diagrams are shown on attached Figure 2.

Post Material - Indicate the type of material (wood or steel) used for the barrier posts.

Post/Barrier X-Section - For each type of median barrier used in your state, please indicate the post or barrier cross-section used, e.g., 6 by 8, S3 x 5.7, W6 x 8.5, etc.

Barrier Height - For all barrier types used please indicate the height to the top of the barrier, rail, beam, or cable. If more than one height of concrete barrier is used, please list separately.

Amount of Usage - For each type of median barrier used in your state, please indicate the percentage (on a linear-foot basis) of each type currently being installed in your state. If percentages are unknown, please estimate using the following codes:

A - Over 90%	E - 5% to 14%
B - 60% to 90%	F - Less than 5%
C - 30% to 59%	N - Never Used
D - 15% to 29%	P - No longer installed, but used in the Past

Common Applications - For each type of median barrier used in your state, please indicate the applications for which the median barrier is generally used by using the following codes:

C - Commonly used
R - Rarely used
N - Never used

For Median Barrier types NOT used in your state, please leave this section blank.

Acceptable Median Width - Indicate the range of median widths where each type of barrier is generally used. Give the minimum width permitted for the barrier and the maximum median width where the specified barrier type is normally used.

Installation Cost - Please provide a range for typical installation costs per linear foot (LF) for each of the median barrier used.

7. Instructions for Table 5 - Repair & Maintenance Costs of Guardrails and Median Barriers

Type of Barrier - Detailed descriptions and diagrams are shown on attached Figures 1 & 2. Use the left side of the table for cost values for guardrails and the right side for median barrier costs.

Post Material - A separate row is given for wood and steel for barriers used with both types of posts

Routine Maintenance Cost - Please provide a range for the annual cost per linear foot (LF) to maintain guardrails/median barriers exclusive of accident damage repairs.

Repair Cost Per Accident - Please provide a range for the cost to repair a guardrail/median barrier after an accident. Consider the "Low Range" as a minor accident, "Median" as an average accident, and "High Range" as a severe accident. Please include material, labor, and traffic maintenance costs in your estimates.

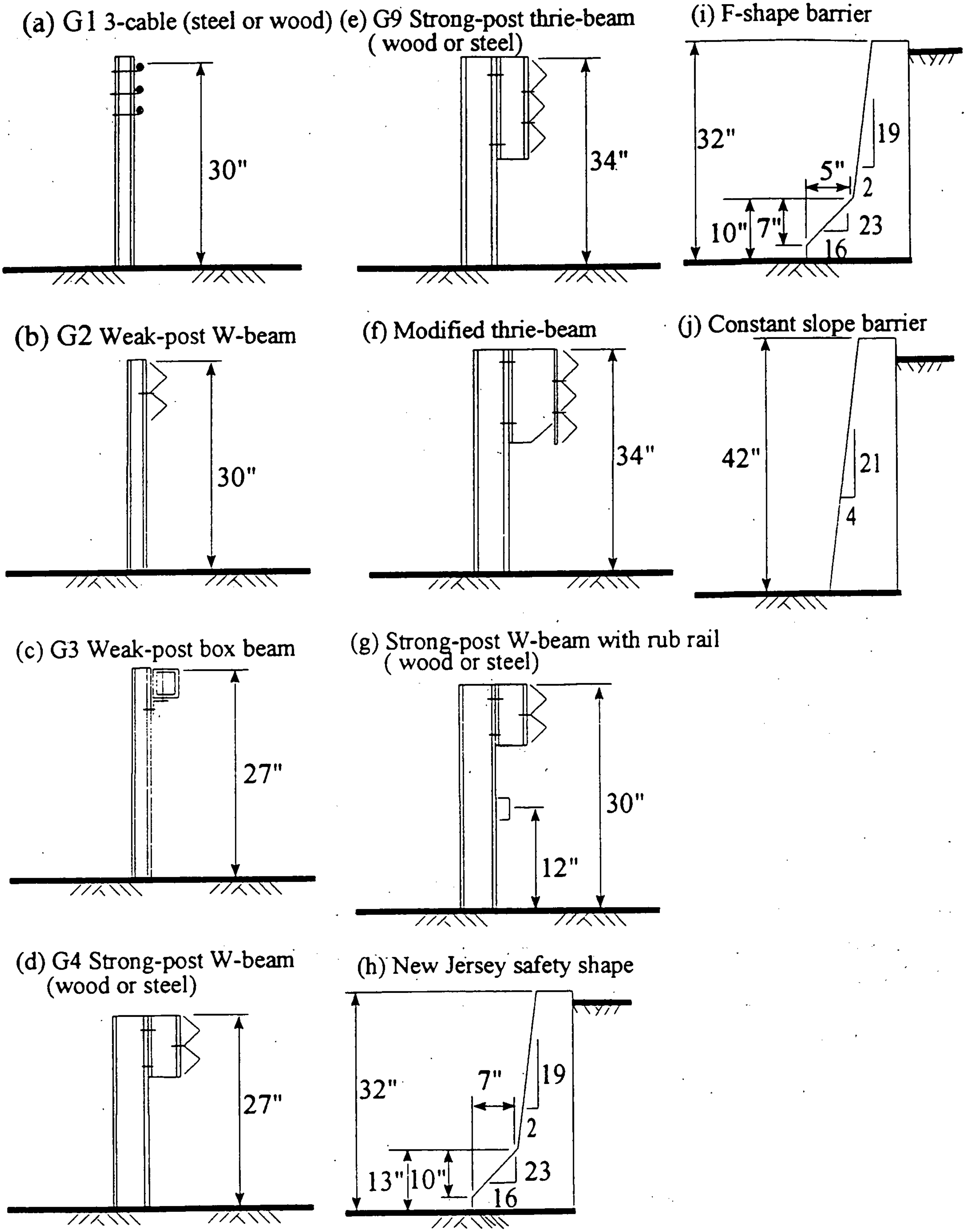


Figure 1: Guardrail Systems.

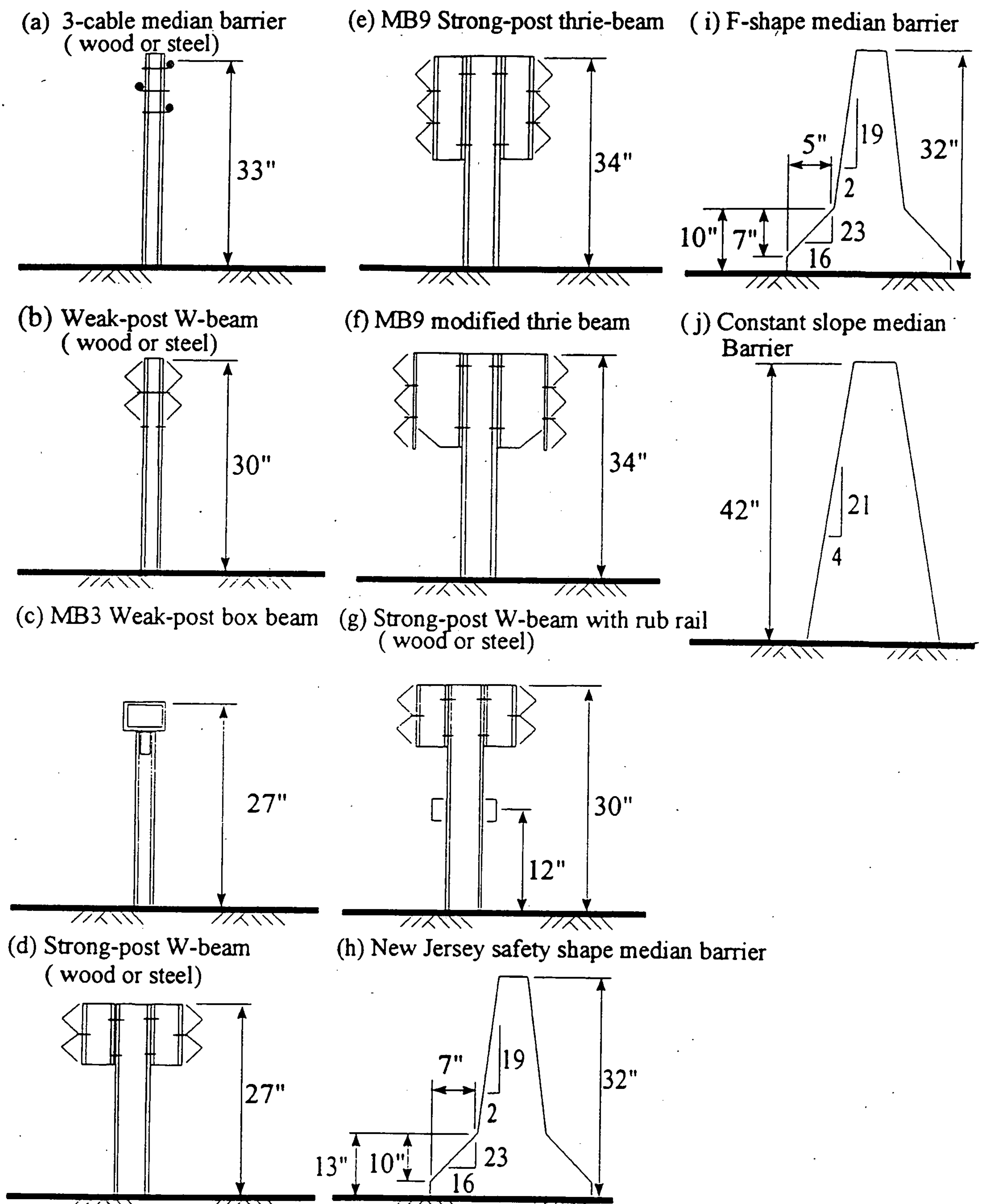


Figure 2: Median Barrier Systems.

Table 1 - Common Uses of Guardrails (See Instructions)

				Indicate Common Applications for Each Type of Guardrail											
Type of Guardrail	**Post Material**	**Post X-Section**	**Amount of Usage**	Embankments	Bridge Piers etc.	Headwall Culverts etc.	Rocks & Boulders	Sign & Luminaire Supports	Trees	Utility Poles	Ditches	Bodies of Water	Bike & Pedestrian Facilities	Other	Other
Weak-Post Systems															
Cable (3 ropes)	**Steel**														
"	**Wood**														
W-Beam	**Steel**														
Box Beam	**Steel**														
Thrie Beam	**Steel**														
Strong-Post Systems															
W-Beam	**Wood**														
"	**Steel**														
W-Beam with Rub Rail	**Wood**														
"	**Steel**														
Thrie Beam	**Wood**														
"	**Steel**														
Modified Thrie Beam	**Steel**														
Concrete Roadside Barriers															
Safety Shape	[redacted]														
F-Shape															
Constant Slope															
Other (Please Describe)															

Table 2 - Installation Costs and Characteristics of Guardrails (See Instructions)

		Installation Cost $/LF			Guardrail Height (inches)		Standard Post Spacing			Minimum Post Spacing	
Type of Guardrail	Post Material	Low Range	Median	High Range	Bottom Rail/Cable	Top Rail/Cable	Spacing (Ft)	Minimum Clear Area	Desirable Clear Area	Spacing (Ft)	Minimum Clear Area
Weak-Post Systems											
Cable (3 ropes)	Steel										
"	Wood										
W-Beam	Steel										
Box Beam	Steel										
Thrie Beam	Steel										
Strong-Post Systems											
W-Beam	Wood										
"	Steel										
W-Beam with Rub Rail	Wood										
"	Steel										
Thrie Beam	Wood										
"	Steel										
Modified Thrie Beam	Steel										
Concrete Roadside Barriers											
Safety Shape											
F-Shape											
Constant Slope											
Other (Please Describe)											

Table 3 - Guardrail Transitions Used (See Instructions)

		Indicate Guardrail Transitions Used (C - commonly used; R - Rarely Used; N - Never Used)														
		Weak Post Systems					Strong-Post Systems							Concrete Barriers		
Type of Guardrail	Post Material	Cable (3 ropes)		W-Beam	Box Beam	Thrie Beam	W-Beam		W-Beam with Rub Rail		Thrie Beam		Modified Thrie	Safety Shape	F-Shape	Constant Slope
Weak-Post Systems		Steel	Wood	Steel	Steel	Steel	Wood	Steel	Wood	Steel	Wood	Steel	Steel			
Cable (3 ropes)	Steel															
"	Wood															
W-Beam	Steel															
Box Beam	Steel															
Thrie Beam	Steel															
Strong-Post Systems																
W-Beam	Wood															
"	Steel															
W-Beam with Rub Rail	Wood															
"	Steel															
Thrie Beam	Wood															
"	Steel															
Modified Thrie Beam	Steel															
Concrete Roadside Barriers																
Safety Shape																
F-Shape																
Constant Slope																
Other																
Bridge Railings																
Concrete Piers, etc.																

Table 4 - Common Uses of Median Barriers (See Instructions)

Type of Median Barrier	Post Material	Post/Barrier X-Section	Barrier Height (in)	Amount of Usage	Indicate Common Applications for Each Type of Median Barrier					Acceptable Median Width		Installation Cost $/LF		
					Prevent Cross-overs	Bridge Piers etc.	Sign & Luminaire Supports	Openings Between Bridges	Other	Minimum Allowable (ft)	Practical Maximum (ft)	Low Range	Median	High Range
Weak-Post Systems														
Cable (3 ropes)														
W-Beam	Steel													
Box Beam	Steel													
Thrie Beam	Steel													
Strong-Post Systems														
W-Beam														
W-Beam with Rub Rail														
Thrie Beam														
Modified Thrie Beam	Steel													
Concrete Barriers														
Safety Shape			32 in											
"														
F-Shape														
Constant Slope														
Earth Barrier														
Innovative Types (Please Describe)														

Table 5 - Repair & Maintenance Costs of Guardrails and Median Barriers

		Guardrail Costs						Median Barrier Costs					
		Routine Maintenance Cost ($/Year/LF)			Repair Costs Per Accident ($)			Routine Maintenance Cost ($/Year/LF)			Repair Costs Per Accident ($)		
Type of Barrier	Post Material	Low Range	Median	High Range	Low Range	Median	High Range	Low Range	Median	High Range	Low Range	Median	High Range
Weak-Post Systems													
Cable (3 ropes)	Steel												
"	Wood												
W-Beam	Steel												
Box Beam	Steel												
Thrie Beam	Steel												
Strong-Post Systems													
W-Beam	Wood												
"	Steel												
W-Beam with Rub Rail	Wood												
"	Steel												
Thrie Beam	Wood												
"	Steel												
Modified Thrie Beam	Steel												
Concrete Barriers													
Safety Shape													
F-Shape													
Constant Slope													
Other (Please Describe)													

Special Uses and Conditions for Guardrail and Median Barriers

Please answer the following questions by **circling** "yes" or "no" and providing the additional information when applicable. If your state has any written standards, policies, or warrants addressing any of the conditions discussed in this section, please attach.

Yes No Are crashworthy terminals used at driveways and field openings?
What types? ______

Yes No Do you use longer posts when the guardrail is close to a slope break-point?
If yes, (a) what is the normal post embedment depth? ______; (b) how far from the break-point are longer posts used? ______; (c) how much deeper is the embedment depth near the break-point? ______.

Yes No In your standards is there a guardrail option that you use in aesthetically sensitive areas?
What guardrail system is used? ______

Yes No In your standards is there a median barrier option for use in aesthetically sensitive areas?
What median barrier system is used? ______

Yes No Are curbs used in conjunction with guardrails and median barriers?
If yes, what barrier and curb combinations are used? ______

Yes No Are dikes and berms used in conjunction with guardrails and median barriers?
If yes, what barrier and dike/berm combinations are used? ______

Yes No Are there guardrail and median barrier alternatives for use in poor soil conditions? Are longer posts used? ______ Are soil plates used? ______ What circumstances consitute poor soil conditions? ______

Yes No Are there guardrail and median barrier alternatives for use where bedrock is close to the surface? Please describe. ______

Yes No Are longitudinal barriers reset after pavement overlays to maintain the same barrier height? What criteria are used to determine if resetting is needed? ______

Yes No Are curved guardrails used at intersecting roadways? What is the minimum guardrail radius that can be used? ______ Are guardrail anchors used in the curved segment? ______

Yes No Are there guardrail/median barrier options for use in areas prone to blowing and drifting snow and/or sand? What guardrail/median barrier systems are used?
______
What conditions must be present to warrant a special barrier in drift-prone areas?
______

Yes No Are removable barrier sections used in median gaps? What type of system is used?
______

Yes No Are posts sometimes omitted when spanning drainage inlets or small culverts? How long may the gap be ? ______

Yes No In your standards is there a connection detail for a guardrail spanning a box culvert? Is the post attached to the top of the culvert? ______ Is the post buried in the fill above the culvert? ______ Is a post skipped to span the culvert? ______ Is another method used? ______

Yes No Are median barriers used in conjunction with median plantings? What combinations are used? ______

Guardrail and Median Barrier Maintenance

Yes No Is guardrail and median barrier maintenance done solely by state crews?

Yes No Solely by private contractors?

Yes No Or by a combination of state and private forces?

Yes No Does your state have a separate budget for guardrail/median barrier maintenance? What is an estimate of your agency's annual expenditures on maintenance of guardrails and median barriers? ______
What percentage (%) of these expenditures are for repairs? ______

Yes No Does your state have a policy or guidelines on how quickly damaged barriers should be repaired? If so, please describe. ______

Yes No Do you attempt to collect barrier repair costs from the responsible driver or driver's insurance company? Comments? ______

Yes No Is life-cyle cost (installation plus maint/repair) considered in barrier type selection?

Yes No In your state are you allowed to consider life cycle costs in engineering decisions?

APPENDIX C

Summary of Survey Responses

A survey was mailed to each of the 50 state departments of transportation (DOTs) in late May 1995. In early July the states that had not replied were called and new questionnaires were sent in several cases. By early August, 39 responses had been received. The information from these 39 questionnaires was supplemented by roadside safety data that had been collected by Bucknell University researchers from state DOTs during 1994 and 1995. A summary of the responses to the verbal questions included in the survey are included in this appendix. In addition to information about guardrail and median barrier usage, installation and maintenance costs, and design details, the survey recipients were asked to answer 36 questions relating to a variety of guardrail and median barrier issues. Each question is listed in this appendix with the percentage of yes answers, no answers, and no response answers. Survey recipients could also write in comments or explanations, and these are also summarized with each question. Where a comment was written on the survey form, the comment has been included in a table after the question in this appendix. The table identifies the state where the comment originated. Not all survey respondents provided comments to all questions, so the number of entries in each table varies. Summaries of the information obtained from the tabular questions in the survey were presented in the tables and figures in earlier chapters of this report. The survey form that was sent to the states is included in Appendix B.

SPECIAL USES AND CONDITIONS FOR GUARDRAILS AND MEDIAN BARRIERS

1. Are crashworthy terminals used at driveways and field openings? If yes, what percentage of the time? What types?

Yes: 73% No: 25% No Response: 3%

State	% of Time	Comments
AL	100*	BCT, MELT, ET-2000 *Whenever guardrail is required in the area of the driveway
AR		Driveways moved outside limits of guardrail
CA	100	Mostly BCT
CO	100	The standard treatment is a BCT, see attachment #1
CT	75	Turned down, weak post and attenuators have been used; phasing in MELT systems
DE		At new installations
GA	100	MELT type
HI	5	Inertial barrier systems and GREAT
IA	2-3	Low speed anchor system as detailed in FHWA technical advisory T5040.32
ID	90	BCT, then MELT, now SRT
IL	100	BCT unless guardrail is wrapped around radius
KS		Crashworthy terminals used where exposed to approach traffic. Curved section is used when required for length of need
ME	50	BCT's
MO		Not very often - type will be of a proprietary nature and alternates will be offered and left to contractor. Previously it would have been a BCT
MT	100	MELT
NC	100	MELT
NE	Unknown	MELT
NH	100	MELT and Curved Guardrail with CRT posts
NJ	100	ELT, ET-2000, CRT
NM	10	Type B, curved W-beam, GRATE
NV	90	Mod. eccentric loader terminals
OH		Guardrail is flared around radius of drive apron
OR	Wherever feasible	Whatever fits the situation - if a terminal won't work radius guardrail is used
SC	75	
TX	5	
VT	50	BCT
WA	100	Weak-post intersection design, BCT
WI	20	Breakaway Cable Terminal
WY	95	Corr beam radius, WYBET(Box beam)

Do you use longer posts when the guardrail is close to a slope break-point? If yes, (a) what is the normal post embedment depth? (b) how far from the break-point are longer posts used? (c) how much deeper is the embedment depth near the break-point?

Yes: 65% No: 33% No Response: 3%

State	(a) Depth	(b) Distance	(c) Depth	Comments
AL				Require slope break to be back of the guardrail
AR	1,117	<610	51	
CA	1,676	< 914	610	
CO	1,117	< 610	1,422	
CT	1,219	305	305	
DE				We require proper embankment width
FL				Florida standard has extra length (1,981mm); normal embedment 1,270mm; minimum embedment 914mm on slope at break point
GA	305	1,117	305	
HI	1,575	<610		
ID	1,016	< 610	1,422	
IL			2,058	
KS	1,295	0	457	
ME	1,117	305	305	
MN	914	305-610	0	
MO	1,117	610	229	
MS	1,143	0	610	
MT	914	< 610	813	
NC	1,143	0-610	305	
ND	1,117	610	305	
NE	1,066-1,143	305	305	
NH	1,422		305	On all slopes steeper than 4:1 because we don't have 610mm from post to break-point
NJ	1,095	610	1,219	
NM	1;117	<610	610	
NV	1,219	1,219	610	
OH	1,041		610	If breakpoint is closer than 610mm measured from face of guardrail,
OR	1,829			1,829mm long posts are standard. Longer posts are used on a case-by-case basis.
PA	1,066	152	305	
VT	1,219	<914	305	
WA		varies		We use 2,667mm and 3,353mm posts depending on the placement relative to the slope and the slope steepness
WI	1,066	*	0	* If breakpoint is in front of the post, longer posts are required to assure 1,067mm minimum embedment

3. If you use a weak-post system, (a.) are post spacings decreased when placed near the top of a steep slope? (b.) when placed on a sharp curve or ramp? Please elaborate.

a. **Yes:** 5% **No:** 40% **No Response:** 55%

b. **Yes:** 10% **No:** 30% **No Response:** 60%

State	*Comments*
CT	Not used on radius of less than 15.24m - strong post system recommended
MT	Cable guardrail
NE	Weak-post systems used on Cable only
NC	Use weak post rail in medians only
ND	We increase the number of anchors needed for 3-cable guardrail. We only use 3-cable guardrail for weak post systems
SD	4.877m for 8 degrees or less, 3.658m for above 8 degrees to 13 degrees- G1 system
WA	Cable barrier spacings are reduced on curves R=33.53m - 66.75m spacing = 1.829m, e=67.06m - 213.06m spacing = 3.648m
WI	3-cable wood post system is not used on curves sharper than 4 deg.

4. Do you decrease post spacing if a fixed object has a breakaway support? How much?

Yes: 8% **No:** 83% **No Response:** 10%

State	*Comments*
CA	If breakaway, guardrail is not used
CO	CDOT uses either a 1.905m spacing or a 3.810m spacing depending on design speed
GA	Breakaway supports do not warrant guardrail
HI	953mm
MS	Do not use where object is breakaway
NE	Designers do not routinely change spacing. Standards have considered this technique.
NJ	953mm or 476mm depending upon offset distance
NV	953mm
OH	Guardrail is not required for a breakaway support
OR	We maintain 1.524m distance from face of rail to object
WY	Place fixed object outside max deflection of rail

5. Do you have a minimum shoulder width requirement for guardrail? What is it?

Yes: 58% **No:** 40% **No Response:** 3%

State	*Minimum shoulder width requirement*
AR	Width of shoulder plus 1,676mm
CO	1,219mm with a desirable 610mm offset, see attachment #2
CT	1,219mm
DE	610mm
FL	(min. shoulder +610mm) ; freeways 3,658mm, arterials 3,048mm, collectors 3,048mm'
GA	Useable shoulder width plus 610mm
HI	610mm
IA	10' - with or without guardrail
ID	1,727mm
ME	610mm
MT	.6 m
NE	0
NC	1,219mm to face - 2,134mm total
NH	1,219mm
NM	generally 610mm
NV	610mm
OH	Minimum shoulder "clearance" for guardrail or barriers is 1,219mm from traveled way. Type of facility and traffic volumes may increase this "minimum".
OR	1,219mm.
PA	839mm
SD	914mm
VA	2,134mm
WA	For new construction/reconstruction: 610mm shy if shoulder is <2,438mm , no additional shy required for 3e projects or for shoulder => 2,438mm
WI	610mm

6. Do you have a minimum shoulder width requirement for median barriers? What is it?
Yes: 55% **No:** 40% **No Response:** 5%

State	*Minimum shoulder width requirement*
CA	610mm
CT	610mm
DE	1,219mm
FL	freeway 3,658mm; standard shoulder width applies to other facilities
GA	With double face guardrail, useable shoulder width plus 610mm
HI	610mm
IA	1,829mm - with or without guardrail
ID	2,032mm
KS	610mm recommended shy distance
MD	610mm
MT	.6 m
NB	0
NC	1,219mm
NH	1,219mm
NM	generally 610mm
NV	610mm
OH	Minimum shoulder "clearance" for guardrail or barriers is 1,219mm from traveled way. Type of
OR	1,219mm
PA	610mm
VA	1,219mm
WA	610mm shy distance
WI	1,829mm

7. Do you have a minimum shoulder width requirement for concrete median barriers? What is it?
Yes: 58% **No:** 38% **No Response:** 5%

State	*Minimum shoulder width*
AR	Width of shoulder plus width of barrier
CA	610 mm
CT	1,829 mm
DE	610 mm
FL	Standard shoulder width without barrier same as with barrier
GA	3,658 mm desirable or as attainable
HI	305 mm
IA	3,048 mm - with or without guardrail
ID	1,473 mm
KS	610 mm recommended shy distance
MD	4;267 mm
MT	0.6 m

7. Continued

State	*Comments*
NC	1,219 mm
NE	0
NH	1,219 mm
NM	generally 610 mm
NV	610 mm
OH	Minimum shoulder "clearance" for guardrail or barriers is 1,219mm from traveled way. Type of
OR	1,219 mm
VA	1,219 mm
WA	610 mm shy distance
WI	1,829 mm

8. Do you take special delineation measures when the guardrail or median barrier is close to the roadway? If yes, please elaborate.
Yes: 45% **No:** 53% **No Response:** 3%

State	*Comments*
CA	Reflectors on barriers
CT	Reflecting delineators at less than 1,829mm from edge of shoulder
FL	Reflective markers at spacing (S) for barrier offset (D); when 305mm<=D<1,219mm then S=12.2m;
GA	Reflectorize washers in valley of guardrail beam
HI	Added raised pavement markers to supplement edgeline
IA	When rail on the shoulder, use D-1W delineators 183m in front
ID	Install delineator reflectors on the guardrail
MN	Usually use reflectors
MO	Use reflectors of guardrail and barrier, see STD 606.00 & 617.00
MS	On construction projects, barrier is temporialy close - add delineators
NC	We delineate in all cases
ND	We delineate all guardrail.
NM	Always use retroreflective markers on barrier
OH	Barrier reflectors are used
OR	For temp barrier,reflectors on 7.62m centers
PA	Delineators are either top or side or mounted on concrete median barriers
SC	reflectors
SD	Add delineators to face of rail for winding roads in hilly terrain
UT	610mm offset min, from shoulder to face barrier
WA	When placed immediately adjacent to traveled lane, delineate at 40' spacings
WY	Generally, don't place it that close

9. In your standards is there a guardrail option that you use in aesthetically sensitive areas? What guardrail system is used?
Yes: 30% **No:** 68% **No Response:** 3%

State	Comments
CO	This has been somewhat of a problem
CT	Box beam - A study of steel backed wooden rail on metal posts is being conducted
ID	W-beam with wood posts
IL	Case by case use color coated guardrail
MD	Polyester coated W-beam
ME	core 10 steel (Rusty)
MT	weathered steel
NC	Have used weathering steel - Special Detail
NH	Corrosion Resistant Steel in National Forest areas
NM	weathered guardrail
OR	Steel backed timber guard rail
PA	Rustic steel
SD	Self weathering steel
VT	Weathering w/beam w/woodposts
WA	Weathering steel (W-beam)
WY	Usually corr beam with Curion steel

10. In your standards is there a median barrier option for use in aesthetically sensitive areas? What median barrier system is used?
Yes: 13% **No:** 83% **No Response:** 5%

State	Comments
CO	This has been somewhat of a problem
ID	W-beam with wood posts
IL	Case by case use textured surface
MD	Polyester coated W-beam, Exposed Aggregate
ME	Core 10 steel (Rusty)
NM	pigmented CWB
WA	Weathering steel (W-beam)

11. Do you adjust the guardrail height if sight distance is restricted by the barrier? Please list any unique methods of addressing this concern.
Yes: 0% **No:** 93% **No Response:** 8%

State	Comments
ID	But we might adjust the offset.
NE	Move guardrail away from the line of sight, if possible
NM	No- we may move its location relative to edge of roadway
OH	Guardrail location may be adjusted, but not height
PA	Use 813mm and 1,270mm barriers

12. Are curbs used in conjunction with guardrails and median barriers? If yes, what barrier and curb combinations are used?
Yes: 78% **No:** 23% **No Response:** 0%

State	Comments
CA	W-beam guardrail with curb and sidewalk
CO	A bituminous curb is used with W-beam
CT	Not recommended but strong and weak post may be used at curbs - 1,829mm must be added to clear
DE	102mm max. height curb
FL	Guardrail flush with curb face and CWB with spec. transition and CWB set back 305mm from curb
GA	102mm high mountable curb w/ "T" beam guardrail
HI	W beam guardrail and 152mm high curb
IA	W-beam flush w/ curb line. Generally discourage this combination but in special cases may use W-
ID	203mm curbs located behind the rail faces
IL	0-305mm behind curb - 152mm barrier curb, 305mm-3,048mm behind curb - 51mm mountable curb
KS	102mm curb w/nested thrie beam at bridge approach. Laid down curb or gutter section may be used at
LA	Sometimes we use 102mm mountable
MD	Normally 203mm concrete curb with W-beam barrier
ME	Bituminous curb may be used w/ single rail beam GR
MN	Plate beam guardrails and 102mm curb
MO	Guardrail with 102mm barrier curb, see STD 606.00
MT	Generally, roadside barriers are not placed in conjunction with curbs. However, if necessary, the face
NC	With guardrail only - 762mm guard and gutter
ND	We reduce curbs to 76mm in height
NE	$\leq$ 102mm curb used w/ safety thrie and cable with face of rail at face of curb
NH	102mm high curb at face of guardrail for drainage purposes
NJ	G4 Strong post w-beam with rubrail, curb height variers from 102mm to 203mm
OH	Type G4 (fig. 1) with 102mm or 152mm high curb on highspeed roads (over 40 mpg) as long as curb is
OR	102mm drainage curb is used with guard rail
SC	Mountable bituminous curb
SD	W & Thrie beam over 152mm barrier and 102mm mountable-barrier curb removed when barrier leaves
TX	Round post blocked out to face of curb
UT	Guardrail transition to structure parapet
VA	Strongpost guardrail with face of rail aligned with face of mountable curb
WA	Max of 102mm curb lined up with face of W-beam
WI	G4 Strong Post with curb (102mm to 152mm height) located at or behind face of rail

13. Are dikes and berms used in conjunction with guardrails and median barriers? If yes, what barrier and dike/berm combinations are used?
Yes: 28% **No:** 73% **No Response:** 0%

State	*Comments*
CA	102mm dike or mountable under w-beam guardrail
CT	Rare - may be used to develop a cut slope anchorage or to bury concrete barrier terminal
FL	Standard W-beam guardrail (normally located at right of way or at berm of parallel canal.)
ID	We terminate concrete guardrail in 914mm minimum high, 3.96m wide earth berm
MO	Embedded end, see STD 606.00
NC	Combination earth berm & paved shoulder
NJ	G4 strong post w-beam with rubrail, 102mm high berm at slope
OR	Earth mound end treatment is used
PA	about 1,524mm high at obstructions
VA	We use a mountable curb as dike under guardrail for high fills
WA	Concrete barrier beam used as end treatment for concrete barrier (as per roadside design guide)

14. Are there guardrail and median barrier alternatives for use in poor soil conditions? Are longer posts used? Are soil plates used? Other alternatives? What circumstances constitute poor soil conditions?
Yes: 15% **No:** 85% **No Response:** 0%

State	*Long Posts Used?*	*Soil Plates Used?*	*Alternatives*	*Circumstances that constitute poor soi conditions*
CA	Y	N		Low R values or sandy-unstable soil
FL	Y	Y	soil plates only rarely	Generally muck, occasionally sugar sand
HI	Y			sand
KS			Guardrails are typically installed in fill sections which have adequate material and construction controls to eliminate this concern	
MO		Y		Soil condition is not considered, soil plates used on BCT post tubes, see STD 606.00
NC	Y	N		
NE				No poor soil conditions in NE
NM				We very rarely have poor soil conditions
SC	Y			Marsh and swamp
VT	Y			

15. Are there guardrail and median barrier alternatives for use where bedrock is close to the surface? Please describe.
Yes: 33% **No:** 68% **No Response:** 0%

State	*Comments*
AR	Embedment of post in rock to 610mm min & backfilled w/Class A or S concrete 457mm min width
CA	Usually use concrete rail with spread footings in these locations or concrete footing around posts
DE	Would be rigid barrier in this situation
FL	No standard details. Shallow holes and groutsite specific
GA	Shorter post in concrete block
HI	Post hole drilled prior to post installation
IA	Guardrail uses steel posts
KS	Where guardrail is required the post holes are bored into the rock and backfilled with soil
MO	Yes, for post embedment, STD 606.00
MT	Pre-drilling may be required
ND	We have no bedrock conditions, have depth restrictions at box culverts. At these locations we provide
NJ	Circular holes drilled into bedrock to allow full length post. After post is installed, hole is backfilled
SC	Plate attached to bottom of post and bolted to rock
VA	Soil plate eliminated for cable and weakpost rail. Hole drilled or excavated in rock for post.

16. Are longitudinal barriers reset after pavement overlays to maintain the same barrier height? What criteria are used to determine if resetting is needed?
Yes: 83% **No:** 10% **No Response:** 8%

State	*Comments*
AL	51mm-76mm variations from standard
AR	AASHTO roadside design guide
CA	If height from roadway surface to top of barrier is decreased to less than 737mm
CO	Wood/Steel posts have 2 post holes 76mm apart to adjust for overlays. Our criteria is 686mm +/-
CT	Reset if height is outside of range: 3 cable - 559mm-762mm, strong post W - 610mm - 762mm, weak
DE	Standard guardrail height +/- 76mm
FL	Reset if shoulder reworked that modifies shoulder final elevation.
GA	Sometimes if overlay cannot be tapered down enough
HI	76mm maximum
IA	686mm-635mm height: Don't raise rail. 610mm height: raise blockout and rail. Under 610mm
ID	Reset guardrail when it is below standard height (Necessary on most overlay projects)
IL	+/- 76mm from standard height

16. Continued

State	Comments
KS	Barriers are typically reset on 3R projects but not maintenance (1R) overlays. A deviation of +-76mm
LA	Barrier will be redone
ME	686mm to top of rail
MN	Reset if the overlay thickness is >76mm
MO	If overlay is > 76mm. then barrier is reset
MT	If barrier is within 76mm of standard height, it is not reset
NC	If height is 76mm below normal
ND	If guardrail is +/- 25mm from standard height.
NE	Height measurements, reset to current requirements
NJ	When height to top of w-beam is reduced to 610mm and 737mm to top of Jersey barrier
NM	Maintain 813mm height to top of rail
NV	Below 584mm
OH	When top of guardrail is less than 635mm, or top of concrete barrier is less than 737mm
OK	711mm +/- 25mm
OR	AASHTO min's
PA	635mm
SD	Not as a practice- try to maintain 0-76mm deviation- looked at on project to project
TX	If effective height of barrier is more that 76mm lower
VA	If reduction of barrier hgt. from design is >76mm
WA	Must be reset if height is reduced below 610mm
WI	thin acceptable height is 610mm, however rail height must be raised to 686mm on STHs with 3000
WY	76mm of mounting height

17. Are curved guardrails used at intersecting roadways? What is the minimum guardrail radius that can be used? Are guardrail anchors used in the curved segment?
Yes: 90% **No:** 10% **No Response:** 0%

State	Minimum Radius(mm)	Anchors Used in curved segment?
AL	6,096	Y
CO	2,590	Y
CT	15,240	N
DE	2,590	N
FL	2,438	Y
GA	4,572	Y
HI	6,096	
IA	2,438	N
ID	2,590	N
IL	4,572	N
KS	2,438	
LA	2,438	Y

17. Continued

State	Minimum Radius (mm)	Anchors Used in curved segment?
MD	7,620	N
ME		N
MN	2,590	N
MO	6,096	Y
MS	7,620	
MT	2,590	Y
NC	6,096	N
ND	2,590	N
NE	2,438	Y
NH	2,590	N
NJ		N
NM	6,096	N
NV	15,240	N
OH	1,524	N
OK	2,438	Y
OR	1,524	N
PA	6,096 /3,048	Y
SC		N
TX	4,572	Y
VA	6,096	N
VT	4,877	Y
WA	1,524	Y
WI	9,140	Y

18. Are there guardrail/median barrier options for use in areas prone to blowing and drifting snow and/or sand? What guardrail/median barrier systems are used? What conditions must be present to warrant a special barrier in drift-prone areas?
Yes: 25% **No:** 73% **No Response:** 3%

State	Barrier systems used	Conditions
CO		Would like to get more information on this
FL	Double faced W-beam or double faced thrie beam (sand in Florida only)	Beach front generally without dune protection and repeated seasonal drift
MD	W-beam in lieu of all others	
MN	3-cable is often used in such areas	
MT	Cable guardrail is generally used where snow drifting is prevalent	
NE	Cable rail is used as last resort, if deflection is appropriate	Past experience no other practical remedy
NM	If possible, eliminate hazard to eliminate need for barrier. (Through use of R/W snowfence)	
OR	Rectangular washer added to back of post	

18. Continued

State	Barrier systems used	Conditions
SD	Minimum W-beam and/or thrie beam transitions to 3	
WA	cable is available	none established
WI	GI 3-cable (wood)	Open fields adjacent to highway. Orientation
WY	Box Beam	Maintenance personnel recommendations

19. Are removable barrier sections used in median gaps? What type of system is used?
Yes: 15% No: 83% No Response: 3%

State	Comments
CA	Concrete , 610 - 3,048mm precast concrete panels
FL	Proposed (tentative): "Barrier Gate"
MD	Tapers on lowspeed and end treatment on high speed
NC	Double faced guardrail
NH	In gaps created for traffic control, portable NJ safety shape is used and relocated temporarily for
NJ	Barrier Gate by TRANSPO
NM	However we're investigating their possible uses
OR	Our stnd conc barrier is pin & loop, unanchored
PA	Concrete safety shape
TX	Very rare, have used Energy Absorption's barriergate

20. Do you have a special barrier design for sawtooth medians? If so please attach a cross-sectional view.
Yes: 18% No: 78% No Response: 5%

21. Are posts sometimes omitted when spanning drainage inlets or small culverts? How long may the gap be?
Yes: 50% No: 43% No Response: 8%

State	Comments
CA	5,715mm with nested guardrail design
DE	5,715mm with 2 sections of w-beam nested together
FL	Not normally, but 3,658mm permitted with nested beams
HI	3,810mm
IA	5,715mm as FHWA memornadum "W-Beam Guardrail Over Low Fill Culverts" 9/9/91
ID	5,715mm

21. Continued

State	Comments
KS	Maximum of one post may be eliminated
LA	5,994mm as crash tested
MD	Length of inlet or culvert
MO	Not presently
MT	Used frequently over low-fills; 2 nested W-beams - 3,810mm gap; 3 nested W-beams - 5,715mm gap
NC	5,715mm
NE	3,810mm with a nested beam section; special posts may be connected to the deck of larger concrete
NH	Double nested sections of guardrail installed if more than one post is omitted
NM	special footings are used
OR	5,715mm
PA	1,905mm
VA	5,715mm
VT	3,810mm
WA	5,715mm with nested W-beam across the gap
WI	1,905mm

22. In your standards is there a connection detail for a guardrail spanning a box culvert? Is the post attached to the top of the culvert? Is the post buried in the fill above the culvert? Is a post skipped to span the culvert? List any other method used?
Yes: 73% No: 28% No Response: 0%

State	Post attached to top	Post	Post	Comments
AL				Normally use concrete barrier rail across a culvert with
AR	Y	Y	N	
CA	Y			buried and skipped are options
CO	Y			
DE	N	Y	N	
FL	Y	Y	Y	posts are only rarely skipped
GA		Y	N	Post is either attached to plate on culvert or embeded in
HI	Y	N	Y	
IA	Y	Y	Y	5,715mm as FHWA memornadum "W-Beam Guardrail
ID	N	N	Y	Two sections of W-beam nested
KS	Y		N	*Buried used when fill depth is >940mm
LA	Y	Y	Y	
MD	N	Y	Y	Double thickness of W-beam sometimes used
ME	Y	Y	N	

22. Continued

State	*Post attached to top*	*Post*	*Post*	*Comments*
MN	Y	N	N	
MO			N	post attached to headwall, post buried depends upon fill
MS	Y		N	
MT				Concrete Barrier rail is generally used here
NC	Y	Y	Y	
ND	N	Y	N	We provide a concrete collar around post on top of box
NE	Y	Y	Y	One post may be skipped if nested rail is used. Otherwise
NH	Y	Y	Y	
NJ	Y	Y	N	Attachment designed on a project by project basis
NM	Y	Y	N	Special footing design may be used where cover over pipe
OH	Y	Y	N	
OK	Y	Y	N	
OR	Y		Y	
PA	Y			
SC	Y			
SD				Special designs when needed- have used post sleeves and
TX	Y			
UT	Y	Y	N	
VA		Y	Y	We have a special design to attach rail to box culvert in the
WA	Y	N	Y	5,715mm with nested W-beam across the gap
WI	Y	Y	N	Skipping a post and nesting two sections of w-beam to.

23. Are median barriers used in conjunction with median plantings? What combinations are used?
Yes: 20% No: 75% No Response: 5%

State	*Comments*
AL	Control the size, type, and location of median plantings such that they are crashworthy
CA	Thrie beam barriers on either side of plantings is the most common use
CO	This varies with the demands of the (typically) local agency's request. CDOT prefers to use a concrete
GA	Concrete barrier face each side w/ earth fill and planting in-between
HI	NJ safety shape with back filled dirt
NC	Use planters with concrete median barriers
NE	We don't plant in medians around guardrail; we guardrail a tree in the median if necessary.
NM	CWB
UT	Modified Jersey

24. Do use concrete median barriers? If so, what percentage (excluding temporary work zone barriers) are precast, slipformed, and cast-in-place?
Yes: 100% No: 0% No Response: 0%

State	*Precast*	*Slipformed*	*Cast-in-place*
AL		50%	50%
AR	0%	75%	25%
CA	5%	95%	
CO	< 5%	30 - 60 %	15 - 30%
CT	95%	0%	5%
DE	70%	10%	20%
GA	0%	90%	10%
HI			100%
IA	Not at present	Contractor's option	Contractor's option
ID	60%	20%	20%
IL	20%	20%	10%
LA	10%	50%	40%
MD	0%	75%	25%
ME	100%		
MN	0%	100%	0%
MO	0%	95%	5%
MS	<5%	>90%	<5%
MT	100%		
NC		75%	25%
ND	Y	Y	Y
NE	rarely	most	some
NH	100%		
NJ		10%	90%
NM	10%	60%	30%

24. Continued

State	Precast	Slipformed	Cast-in-place
NV	10%	90%	
OH	0%	95%	5%
OK	5%	80%	15%
OR	95%	2.5%	2.5%
PA	90%		
SC		90%	10%
TX	50%	10%	40%
UT	90%		
VT	100%		
WA	85%	15%	15%
WI	<1%	90%	9+
WY		75%	25%

25. Has your state approved any types of recycled materials for posts and/or blocks? If so, please elaborate.
Yes: 20% No: 75% **No Response:** 5%

State	Comments
FL	Block - recycled plastic; also, recycled rubber on certain secondary facilities
GA	Offset blocks of composite sawdust and plastic on a trial basis
IL	Currently evaluating
ME	Mobil Corp. Timbrex or similar material for blockouts
MN	Approved Timbrex for blockouts
NC	Timbrex offset blocks
NH	Allow the use of recycled plastic in the blocks
OH	Not yet, but some being considered
OR	We are reviewing one block, but not yet approved
PA	Wood and plastic composite offset block
VA	Yes, recycled materials such as Timbrex are allowed for blockouts
VT	Not to my knowledge
WA	Not aware of any that have been approved by FHWA

GUARDRAIL AND MEDIAN BARRIER MAINTENANCE

26. Is guardrail and median barrier maintenance done solely by state crews?
Yes: 45% **No:** 53% **No Response:** 3%

Solely by private contractors?
Yes: 3% **No:** 93% **No Response:** 5%

Or by combination of state and private forces?
Yes: 45 % **No:** 38 % **No Response:** 18 %

State	% State forces	% Private forces
AL	40	60
AR	75	25
CO	90	10
DE	70	30
FL	40	60
HI	50	50
IA	99	1
ME	50	50
NC	80	20
NH	95	5
NJ	25	75
NV	95	5
OH	65	35
PA	30	70
TX	50	50
VA	10	90

27. Does your state have a separate budget for guardrail/median barrier maintenance? What is an estimate of your agency's annual expenditures on maintenance of guardrails and median barriers?
Yes: 25 % No: 63 % No Response: 13 %

State	Response
AL	$1,100,000
CA	Guardrail - $3,942,890, Concrete Barrier - $1,776,557
DE	$180,000
FL	No, unable to break down, only lump sum figures provided
IA	$700,000
ID	$60,000
KS	$450,000
ME	$630,000
NC	$2,000,000
NH	$650,000
NJ	$1,700,000
NV	$350,000
OR	$615,000
UT	guardrail maint - $96,067, concrete barrier maint- $91,093
VA	$3,644,000
VT	$50,000
WA	$1,310,000
WI	$2,100,000

28. Are highway personnel routinely notified by police of significant accidents involving guardrail/median barriers?
Yes: 78% No: 15% No Response: 8%

State:	Comments:
AL	Accident data system provides notice through law enforcement accident reports.
NM	During construction, yes. Otherwise, department relies on annual accident reports.

29. Does your state have a policy or guidelines on how quickly damaged barriers should be repaired? If so, please describe.
Yes: 38% No: 50% No Response: 13%

State	Responses
CA	Repair should be made promptly if a traffic hazard exists or functional integrity is questionable. Damage not constituting a hazard should be repaired when scheduling permits.
FL	Completely inspected every two years
LA	We have a policy on all repairs but never done expeditiously.
MN	The next day on freeways, others depend on location and severity of damage
MO	As quickly as practical
NH	As soon as practicable, but with lower priority in winter if snow banks are established
NJ	As soon as notified
NM	Reasonable period of time
OK	As soon as possible
SD	Maintenance Policy- Initiate action within 24 hours- Commence repair within 48 hours. Some exclusions
VA	If emergency - within 24hrs
WA	Within 1 week
WY	Try to do as soon as possible

30. Do you attempt to collect barrier repair costs from the responsible driver or driver's insurance company? Comments?
Yes: 90% No: 0% No Response: 10%

State	Responses
CT	Difficult to collect if barrier is successful and vehicle can drive away
FL	On any component of the roadway by accident for reimbursement
IL	Our bureau of claims pursues all traceable claims
LA	If they can be identified
NE	Bill approximately $425,000; collect 90% of it
NH	Department will charge costs unless winter (ice) conditions prevail

31. Can your accident records system correlate accident severity with specific barrier type?
Yes: 15% No: 78% No Response: 8%

32. Is life-cycle cost (installation plus maint/repair) considered in barrier type selection?
Yes: 38% No: 58% No Response: 5%

33. In your state are you allowed to consider life cycle costs in engineering decisions?
Yes: 85% No: 13% No Response: 3%

CONCLUDING INFORMATION

34. What are the three (3) most critical research topics dealing with longitudinal highway barriers?

Below is a summary of the responses. The numbers indicate the frequency [illegible]ch particular response.

Related to NCHRP Report 350 Guidelines
- 8 - Ability of existing barriers and end treatments to meet standards
- 6 - Development of longitudinal barriers that meet 350 criteria
- 5 - Development of end treatments that meet 350 criteria
- 1 - Cost-effective transitions from traffic barrier to bridge rail that meet 350 criteria
- 1 - Development of guidelines for applying the multiple test levels in NCHRP 350
- 1- The impact of NCHRP 350 pick-up truck as a test vehicle

Longitudinal Barriers
- 5 - Use of curbs in conjunction with barriers
- 2 - Determination of length of need
- 1 - Guardrail for urban settings
- 1 - Guardrail terminals at driveways/approaches
- 1 - Clear zone
- 1 - Effects of 8:1 versus 10:1 cross-slopes next to barrier, mounting height variations including on superelevated curves and other geometric effects of guardrail placement (including evaluation of flare rates on various guardrails)
- 1 - How to treat driveways/minor road intersections
- 1 - Esthetic treatment of barrier
- 1 - Longitudinal barrier treatment on embankment sections at ramp gore
- 1 - Development of warrants for roadside features

End Treatments
- 7 - End treatments
- 6 - Development of non-proprietary end treatments
- 4 - Development of lower cost end treatments
- 1 - Crashworthy end anchors
- 1 - End anchor designs for 3-cable guardrail systems
- 1 - Crashworthiness of existing end sections in use at different speeds
- 1 - Final settlement of the MELT vs. SRT controversy
- 1 - Quality Bull nose designs for rural intersections
- 1 - Attenuation at ends or breaks; alternatives, cost, effectiveness

Median Barriers
- 1 - Warranting criteria for tall (over 813mm high) median barriers
- 1 - Median barrier warrants, water filled barrier warrants
- 1 - Median barrier visibility
- 1 - Taller barrier as glare shield
- 1 - Guardrail at obstacles in medians
- 1 - Water filled barriers acceptable over 45 mph
- 1 - Innovative barrier requirement
- 1 - Median barrier system for less radii less than 15.24m

Accidents and Safety Aspects
- 1 - In depth severity vs system type study
- 1 - Severity vs cost for concrete shapes (F, NJ, Single Slope)
- 1 - Roll over accidents
- 1 - More forgiving systems
- 1 - Are existing guardrail designs compatible with today's traffic composition/wheelbase?
- 1 - Procedures for expediting police accident reporting
- 1 - Side angle impact criteria
- 1 - Risk factors of box beam and cable versus corrugated beam and concrete barrier
- 1 - Reducing "Secondary Accidents"
- 1 - Balancing SSD against barrier requirements

Maintenance Aspects
- 1 - How much can plate beam rail be damaged before repairs are needed
- 1 - Snow related problems - what works best for maintenance operations

Temporary Barriers
- 1 - Development of improved temporary concrete barriers
- 1 - High quality temporary barriers that are fast and user friendly

35. Which three (3) states do you consider the leaders in innovative cost-effective applications of longitudinal barriers?

14 - Texas	1 - Michigan	1 - Pennsylvania
9 - California	1 - Nebraska	1 - Washington
5 - New York	1 - Oregon	1 - Ontario
3 - Illinois		

36. Job titles and average years of experience of people responding to survey:

Number	Job Title	Average Years Experience
26	Roadway Design Engineer	20
4	Traffic Engineer	11
4	Standards Engineer	10
1	Maintenance Engineer	28
1	Construction Engineer	23
1	Bridge Engineer	20
1	Structural Engineer	14
1	Policy Engineer	--

	Shoulder Barrier Usage										
	W-Beam				*Cable*	*Concrete*			*Thrie Beam*		Box Beam
	Strong Post			*Weak Post*	*Weak Post*				*Strong Post*		
State	*Steel*	*Wood*	*Rub Rail*			*Safety Shape*	*Constant Slope*	*F-Shape*	*Steel*	*Wood*	
Alaska	U	U	U	N	F	U	X	X	P	P	X
Alabama	B	D	N	N	N	U	N	N	N	N	N
Arkansas	A	N	A	N	N	U	N	N	P	P	N
Arizona	U	U	U	N	N	N	U	X	P	P	X
California	F	A	N	N	N	U	N	N	P	P	N
Colorado	U	U	N	N	N	U	N	N	M	U	N
Connecticut	C	U	C	U	B	U	N	N	M	M	U
Delaware	A	F	N	N	N	U	N	F	P	P	N
Florida	C	C	F	N	N	U	N	B	U	U	N
Georgia	A	N	N	N	N	U	N	N	P	P	N
Hawaii	B	N	N	N	N	U	N	N	U	N	N
Iowa	F	B	N	N	F	U	F	N	M	M	N
Idaho	N	B	N	N	N	U	F	N	N	U	N
Illinois	E	U	N	N	N	U	N	N	N	N	N
Indiana	N	A	U	N	N	X	X	X	X	X	X
Kansas	C	C	F	N	N	U	N	N	U	U	N
Kentucky	X	X	U	N	N	X	X	X	N	N	X
Louisiana	D	B	N	N	N	U	N	N	U	U	N
Massachusetts	X	X	U	N	N	X	X	X	X	X	X
Maryland	A	N	N	N	N	U	N	N	N	U	N
Maine	A	F	N	N	F	U	N	N	U	N	N
Michigan	U	U	U	N	U	U	X	X	P	P	X
Minnesota	U	C	N	N	C	U	N	N	N	N	N
Missouri	A	A	N	N	F	N	N	N	U	N	N
Mississippi	A	U	U	N	N	U	N	N	P	P	N
Montana	U	B	N	N	E	U	N	N	P	P	U
North Carolina	U	U	N	U	F	U	N	N	P	P	N
North Dakota	U	U	N	N	C	N	N	N	P	P	N
Nebraska	E	E	N	N	C	U	U	N	U	U	N
New Hampshire	N	U	N	N	N	N	N	U	P	P	N
New Jersey	U	N	U	N	N	N	N	N	U	N	N
New Mexico	E	A	N	N	N	U	N	N	U	U	N
Nevada	F	F	N	N	N	U	N	F	U	U	N
New York	U	U	U	U	C	U	U	N	N	N	U
Ohio	A	U	N	N	N	U	F	N	U	U	N
Oklahoma	C	C	F	N	N	U	E	N	M	M	N
Oregon	E	A	E	N	N	N	E	A	N	U	N
Pennsylvania	B	U	N	U	N	U	D	N	N	N	N
Rhode Island	U	U	U	N	N	X	X	X	X	X	X
South Carolina	E	B	N	N	N	U	N	N	U	N	N
South Dakota	N	B	N	N	C	U	N	N	N	U	N
Tennessee	U	U	U	N	N	X	X	X	P	P	U
Texas	C	B	N	N	N	U	F	N	N	N	N
Utah	E	D	N	N	N	U	N	N	N	N	N
Virginia	B	D	N	U	F	U	N	N	N	N	N
Vermont	A	U	N	N	E	U	N	N	N	N	U
Washington	U	A	F	N	F	U	N	N	U	U	N
Wisconsin	N	B	N	N	F	U	N	N	N	U	N
West Virginia	U	U	U	N	N	X	X	X	X	X	X
Wyoming	U	B	N	N	N	U	N	N	P	P	U

Key:

A Over 90%	**E** 5% to 14%	
B 60% to 90%	**F** Less than 5%	**M** "Modified" barrier
C 30% to 59%	**U** Used, percentage unknow	**P** Used, post material unknown
D 15% to 29%	**N** Not used	**X** Data not available

State	Median Barrier Usage										
	Concrete			W-Beam				Thrie Beam		Box Beam	Cable
				Strong Post			*Weak Post*	*Strong Post*			
State	**Safety Shape**	**Constant Slope**	**F-Shape**	**Steel**	**Wood**	**Rub Rail**		**Steel**	**Wood**		
Alaska	U	X	X	X	X	X	N	P	P	U	X
Alabama	A	N	N	N	N	N	N	N	N	N	N
Arkansas	C	U	N	N	N	N	N	N	N	N	N
Arizona	U	X	X	U	U	X	N	P	P	X	N
California	C	U	N	N	N	U	N	C	U	N	N
Colorado	B	N	N	E	E	N	N	M	N	N	N
Connecticut	C	N	N	C	N	N	U	N	N	N	N
Delaware	X	X	U	X	X	X	N	N	N	N	N
Florida	U	N	U	U	U	N	N	N	N	N	N
Georgia	U	N	N	U	N	X	N	P	P	N	N
Hawaii	U	N	N	N	N	U	N	N	N	N	N
Iowa	A	N	N	N	N	N	N	N	U	N	N
Idaho	C	N	N	N	C	N	N	N	N	N	N
Illinois	B	N	N	D	N	N	N	N	N	N	N
Indiana	B	X	X	U	U	X	N	P	P	X	N
Kansas	C	N	U	N	N	U	N	N	N	U	N
Kentucky	U	U	N	N	N	X	N	N	N	X	N
Louisiana	U	N	N	N	N	N	N	U	U	N	N
Massachusetts	U	X	X	U	U	X	N	P	P	X	N
Maryland	F	N	N	A	N	N	N	N	N	N	N
Maine	A	N	N	A	N	N	N	N	N	N	N
Michigan	U	U	U	U	U	X	N	U	U	X	N
Minnesota	A	N	N	N	N	N	N	N	N	N	N
Missouri	C	U	N	F	N	N	N	N	N	N	N
Mississippi	E	N	N	U	U	X	N	P	P	N	N
Montana	A	N	N	N	N	N	N	N	N	N	N
North Carolina	U	N	N	U	U	X	U	N	N	N	U
North Dakota	U	N	N	N	N	N	N	N	N	U	N
Nebraska	U	N	N	U	U	N	N	N	U	N	U
New Hampshire	F	N	U	N	N	U	N	N	N	N	N
New Jersey	B	N	N	U	N	U	N	N	N	N	N
New Mexico	A	N	U	E	E	N	N	A	E	N	N
Nevada	A	N	U	N	N	N	N	N	N	N	N
New York	U	U	N	U	U	X	U	N	N	U	X
Ohio	B	U	N	F	F	N	N	N	N	N	N
Oklahoma	U	U	N	X	X	X	N	N	N	N	N
Oregon	U	U	U	N	N	U	N	N	N	N	N
Pennsylvania	A	U	N	E	N	N	U	N	N	N	N
Rhode Island	U	X	X	U	U	X	N	P	P	X	N
South Carolina	U	U	N	N	N	N	N	N	N	X	N
South Dakota	F	N	N	N	F	N	N	N	M	N	U
Tennessee	U	X	X	U	U	U	N	P	P	U	N
Texas	A	U	N	C	B	N	N	N	N	N	N
Utah	B	N	N	N	N	N	N	N	N	N	N
Virginia	U	N	N	U	U	N	U	N	N	N	N
Vermont	U	N	N	B	N	N	N	N	N	N	N
Washington	A	U	U	N	N	N	N	N	N	N	U
Wisconsin	C	N	U	N	N	U	N	N	U	N	N
West Virginia	U	X	X	U	U	X	N	P	P	X	X
Wyoming	C	U	N	N	N	N	N	N	N	U	N

Key:

A Over 90%
B 60% to 90%
C 30% to 59%
D 15% to 29%
E 5% to 14%
F Less than 5%
U Used, percentage unknown
N Not used
M "Modified" barrier
P Used, post material unknown
X Data not available

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