GMS GUARDRAIL MINI SPACER RELEASABLE FASTENER:
IMPROVING PERFORMANCE AND RELIABILITY OF CONVENTIONAL
STRONG-POST GUARDRAIL

by

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ABSTRACT

This paper describes the theory, development, and testing of a significantly improved strong post W-Beam guardrail called the GMS Guardrail. A new approach to addressing the primary strong post guardrail failure modes of pocketing, vaulting, and hard wheel snagging is introduced and discussed. Only the mounting fastener is changed to implement performance and reliability benefits in conventional strong post guardrails. This robust releasable fastener is interchangeably called a “Gregory Mini Spacer” or simply a “Mini Spacer”. Improvements are attained without requiring the alteration of rail height, weakening of conventional steel posts, alteration of end anchors, use of backup plates, deeper blockouts- or even any blockouts at all, while eliminating any need for moving guardrail splices away from posts- since moving splices requires using altered guardrail panels (with more slots) as well as end adapters to enable use of some end terminals. Splices may be placed at posts without compromising either release or performance. Sources of variability in release behavior are substantially eliminated in order to suppress specific guardrail failure modes. Extraneous forces are also addressed by the improved fastener. Installation is more consistent and less sensitive to minor misalignments between the posts and the guardrail. Economic benefits include the use of unaltered, un-weakened, conventional posts and guardrail panels (no added slots or end adapters) by this new guardrail. This is both innovative and pragmatic, since these kinds of new inventory items represent a significant added burden to State DOT’s that must stock them. Crash testing results at 6 ft 3 inch post spacing confirm the new guardrail’s ability to contain heavier, high center-of-gravity light trucks at nominal conventional top of rail heights of 27 inches and 31 inches. Specific Mini Spacer technology breakthroughs are highlighted that enable it to be used as a direct upgrade of existing conventional guardrails. The Mini Spacer succeeds in leveraging ground-breaking research results in addressing decades-old problems.

INTRODUCTION

The present paper describes how conventional strong post guardrail may be significantly simplified and improved to perform beyond its present level of capability to enable this valuable and relatively effective guardrail to meet ever-increasing performance standards. This paper is divided into three parts for the sake of clarity in presenting the subject matter. Part I is a fundamental review of specific conventional strong post guardrail failure modes and how they directly relate to inherent variability in their release mechanism. It examines the sources, mechanisms, and consequences of variability from theoretical, practical, and hardware perspectives. Part II presents a new robust releasable fastener called the “Mini Spacer”, and includes crash testing results that confirm the new guardrail system’s ability to contain heavier, high center-of-gravity light trucks at a nominal conventional top of rail heights of 27 and 31 inches. Finally, Part III highlights various Mini Spacer technology breakthroughs that contribute toward improved guardrail performance and reliability made possible by this simple yet innovative and sophisticated releasable fastener.
PART I. STRONG POST GUARDRAIL OPERATION

ASSESSMENT OF CONVENTIONAL STRONG POST GUARDAIL

Strong Post W-beam guardrail represents the very backbone of the Highway Safety Infrastructure of the National Highway System (NHS) (1). Transportation Agencies have expended great resources to assure that all longitudinal barriers meet the safety performance evaluation guidelines contained in NCHRP Report 350 (2). This has meant using 8 inch deep blockouts in strong post guardrail systems. Blockouts were originally introduced as a spacer to reduce wheel snagging (3). However, the benefits of the blockout as a spacer are somewhat questionable at best, since the maximum dynamic deflection of a typical strong post system with blockouts is around 40 inches. This basically means that in order for a blockout to very significantly and consistently address wheel snagging by acting as a spacer, the blockout should ideally be as much as 40 inches deep, not 6 inches or even 8 inches or more.

The introduction of blockouts actually created a less than fully reliable release-triggering mechanism by which guardrail releases from a post during a crash event. Release is vital to guardrail system safety and performance. When peak release triggering forces are too high, or when no release occurs at all, (1) hard wheel snagging, (2) vehicle vaulting, or (3) pocketing, may occur, which are three primary failure modes of strong post guardrail systems with blockouts. However, the release-triggering mechanism of blockouts is quite sensitive to many installation and component variables that may combine, interact, and even compound together in unpredictable ways.

In strong post systems the release-triggering mechanism for wood or plastic blockouts generally consists of bending the long post bolt as the blockout pivots on the face of the post due to guardrail axial forces, thereby shortening the bolt length, which causes the bolt head to be pulled through the post bolt slot of the guardrail to accomplish release. Bending of the bolt is aided by the mechanical advantage of the blockout depth acting as a long lever arm, with the fulcrum being the pivot point on the back face of the blockout, and the shorter arm of the lever being the back face segment of the blockout between the pivot point and the bolt as shown in Figure 1 for W6x8.5 steel posts. This mechanism is similar for wood posts, except that bending of the long bolt may be further impeded due to increased constraint related to the length of post bolt that is held relatively straight inside of the wood post.
FIGURE 1a Various lever arms and pivot points activate release of modified G4(1S) conventional guardrail with blockouts

FIGURE 1b Guardrail release has generally required post bolt pull-through.

<table>
<thead>
<tr>
<th>Slot Location</th>
<th>Splice?</th>
<th>Force (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle</td>
<td>N</td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>9,200</td>
</tr>
<tr>
<td>Edge</td>
<td>N</td>
<td>6,500</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>14,500</td>
</tr>
</tbody>
</table>

source: Plaxico, WPI. No Block Behind Slot
Much Higher Loads Expected With Block (support & clamping loads)
Release Addresses Failure Modes

Release alleviates wheel snagging as follows. The wheel is more easily able to overcome the (lower) peak wheel contact forces associated with a post that is supported only at one end (i.e. by soil embedment at the lower end and no support at the released top end) rather than the much higher peak contact forces associated with a post that remains unreleased from the guardrail, thus being supported at two ends. Release alleviates vehicle vaulting by releasing the guardrail rather than letting it be pulled to the ground by a falling post, which if permitted, lets the vehicle over the rail. Pocketing occurs when the guardrail is not released from a post, and a segment of guardrail becomes trapped between the vehicle and the post.

The use of deeper blockouts increases the moment arm (the blockout depth), which increases the mechanical advantage, thereby facilitating release. This explains some release-related improvements of 8 inch deep blockouts over 6 inch deep blockouts. However, these improvements due to blockout depth come at a price. First, increased blockout depth results in greater twisting forces on the post. This promotes lateral-torsional buckling instability of the post that may significantly degrade the structural performance of the post. Second, the effective strength of the soil embedment may be compromised by complex torsion loads in ways that are not uniform or consistent, thereby introducing additional variability into the overall system. But this is only part of the picture. A release problem inherent in blockouts of all depths is that the actual pivot point location of the blockout on the post may vary considerably, depending upon installation details such as bolt tightness that may easily change over time, or during vehicle impact, due to various crash-related forces.

Release Mechanism Variables Of Blockouts: A Closer Look

Reliable and consistent triggering of the release of guardrail from posts during a crash event is vital to proper guardrail system safety, performance, and strength, because excessive or inconsistent release forces may keep the guardrail system from functioning properly (4). Yet in present strong post W-beam guardrail systems, relatively unregulated release mechanism variables govern how the blockout triggers release via the pull-through of the post bolt head through the face of the guardrail at a post bolt slot. These variables may combine, interact, and compound, to cause a general lack of consistency. To make matters worse, some of these variables are quite sensitive to installation and crash details.

For example, the forces that are associated with release mechanism operation (see Figure 1) may vary by as much as a hundred percent or more from a desired optimal value, since these forces depend upon widely variable factors associated with the release mechanism and how it operates. These factors include:
(1) the direction of the applied forces, since the post bolt is not installed symmetrically with respect to the central axis of the post,

(2) whether the post bolt happens to have been installed on the upstream flange or the downstream flange of the post during installation,

(3) actual bolt yield strength, which is only regulated as a minimum in specifications,

(4) actual guardrail beam yield strength, which is only regulated as a minimum in specifications (and may vary by 40 percent) and thickness,

(5) bolt tightness,

(6) initial position of the bolt head relative to the long axis of the post bolt slot,

(7) possible snagging of the post bolt head on one end of the slot during release due to the position of the post bolt head along the slot (this may also result in no release at all),

(8) number of plies of guardrail at a post that the bolt head has to be pulled through- i.e. splice or non-splice.

Consider the following example. When a guardrail post bolt is near one end of a post bolt slot of the guardrail, the bolt pull-through force required to accomplish release may be about 63 percent higher than when the bolt is more nearly centered in the slot, as shown in Figure 1. This is for a single ply of guardrail (i.e. at a post where there is no splice present). At a post where there is a splice present, there are two plies of guardrail, and the release force may be around 350 percent higher as compared with a bolt more nearly centered in the slot of a single ply. Furthermore, even when the post bolt is optimally and consistently installed near the middle of the slot, it often moves to one end of the slot due to the vehicle tugging on the guardrail during a crash. Sometimes the bolt may snag very hard on one end of the slot, such that virtually no release is possible- especially if two plies of guardrail are present, such as at a splice. This is true even if the blockout is made deeper, which means that deeper blockouts should not be considered to be a completely satisfactory solution to the problem of providing reliable and consistent release.
PART II. MINI SPACER RELEASABLE FASTENER

RELEASE MECHANISM OVERVIEW

Consider what happens when the release mechanism is changed from the kinematically (i.e. motion) operated release mechanism of conventional strong post guardrail with blockouts, to one that responds simply to a threshold force at a post to accomplish release. A novel and dramatic uncoupling is brought about by providing a separate deformable fastener element that is not easily affected by other system variations as it accomplishes its release function. The resulting performance and reliability improvements may be dramatic as well. In fact, there is a complete (and quantifiable) redefinition of the list of variables affecting release. These are now very different and far fewer in number. The great significance of this is that the new (far more simple and reliable) conventional guardrail system is more robust than the previous conventional guardrail in that specific failure modes are far more effectively suppressed.

By replacing the release mechanism of blockout kinematics with the far more simple and reliable release mechanism of force thresholds to accomplish release, the Mini Spacer not only improves the release mechanism, but also redefines the role that release may play in increasing guardrail performance. It does this by literally eliminating the blockout pivot (on the post) with long post bolt bending and post bolt slot deformation as the release mechanism. Having accomplished this “uncoupling” of blockouts from the release function, there is no longer any reason not to use any blockout depth desired, or simply no blockout at all. Additional benefits include the following. Guardrail thickness may now be increased by 25 percent (from 12 to 10 gage) or more without compromising release or guardrail performance, since such modifications no longer introduce the detrimental release variations that they once did. In this way, as fewer and fewer variables directly affect release, the reliability and robustness of the guardrail barrier are greatly increased. This is particularly important from the perspective that some dimensional and material property variations are unavoidable in these kinds of products.

Addressing Guardrail Failure Modes

The Mini Spacer introduces significant improvements to guardrail by systematically addressing specific conditions that lead to common guardrail failure modes. This represents the first time that a release mechanism has been scientifically and systematically designed for strong post guardrail, in terms of being able to comprehensively quantify and implement specific targets regarding greater simplicity, reliability, robustness, and repeatable performance for unaltered conventional posts and unaltered guardrail panels (i.e. extra slots). The Mini Spacer release mechanism (see Figure 2) is in fact the only release mechanism for strong post guardrail that does not rely upon deforming the post bolt slot in order to accomplish release of the guardrail.
Uncoupling Release Activation From Kinematic Motion

Uncoupling the release of the guardrail from a post, from the complex and vulnerable kinematics of motion of blockouts on posts, and replacing this less reliable (and less repeatable) mechanism with one that responds instead to force-threshold values, rather than kinematics is a key improvement. This is because we may predict (even from basic force-impulse relations) that certain force levels may consistently be exceeded, and we may do this with far greater confidence than we may predict the local kinematical details near the top end of a post (that itself may move according to the nonlinear kinematics of lateral-torsion buckling that may change, subject to the sequence of applied loads at a particular post), that may vary quite a bit along a guardrail installation.

Having done this, it is now possible to precisely prescribe which loads do and do not activate release. For example, it is desirable for the release mechanism to resist vertical guardrail loads in order to maintain the guardrail height during a vehicle impact. The Mini Spacer accomplishes this by incorporating a pathway for vertical loads to bypass (i.e. go around) the release mechanism and the bolt, thereby protecting both. This capability is also quite useful in addressing miscellaneous loads such as snow loads that might otherwise damage the mounting fastener or cause premature release of the guardrail.

Figure 2a. The Mini Spacer Is Simple And Robust.
FIGURE 2b  Mini Spacer parts interface to perform multiple functions.

FIGURE 2c  The Mini Spacer releases without slot deformation or complex kinematics.
Uncoupling Release From Guardrail Panel Material Properties

Uncoupling release of the guardrail from a post, from the material properties of the guardrail panel and from the guardrail panel thickness are key capabilities. The Mini Spacer is the only known release mechanism for strong post guardrail that does not rely upon deforming the guardrail post bolt slot in order to accomplish release of the guardrail, as shown in Figure 2c. The importance of achieving this uncoupling is due to the fact that guardrail panel material property specifications are based upon a minimum yield strength of 50 ksi, whereas actual yield strengths in the field may be as high as 69 or 70 ksi. This may result in as much as a 40% change in the release load for a single ply of guardrail at a post. This variation may be further compounded by other related variables such as guardrail panel thickness variations of a single ply, or more importantly, due to having two plies at a post such as occurs when splices are placed at posts. Still other compounding variations are presented below.

Uncoupling Release From Bolt Material Properties

The Mini Spacer uncouples release from bolt yield strength because it does not rely upon deforming (bending) the post bolt to pull the bolt head through the slot of the guardrail panel in order to accomplish release of the guardrail. This is important because post bolt steels are typically specified in terms of minimum strength values, meaning that actual bolt strengths may vary by as much as 30% above minimum required values.

Uncoupling Release From Bolt Head Position In Slot

Uncoupling release from bolt pull-through reduces variability, since bolt pull-through may vary by as much as 60 percent or more depending upon whether the post bolt happens to pull though near the center of the slot, or near the edge of the slot. Note that the guardrail slot may move relative to the post bolt during a crash event, making any attempts to install the post bolt precisely near the center of the slot a futile exercise.

Uncoupling Release From Installation Variables

Another area of improvement is to uncouple the release mechanism from other basic installation variables. This includes long post bolt tightness, and even which side of the post the long post bolt happens to be installed on (upstream or downstream), which affects release by changing the length of the shorter lever arm of the blockout as it pivots on the face of the post.
BARRIER INSTALLATION CONSIDERATIONS

Barrier Height

Wheel snagging is related to barrier height in several ways. First, wheel snagging has the potential to increase the amount of roll induced in pickup trucks during a crash event—particularly when more than a single post is snagged. It is generally accepted that by raising the barrier mounting height, this effect is somewhat diminished by directly reducing the distance between the vehicle center of gravity and the guardrail contact points along the vehicle. Thus, increasing rail height is generally considered to be beneficial. The caveat has been that this is achievable as long as release loads are simultaneously reduced, such as by moving the splices between posts (5, 6, 7), rather than at posts. This is because raising the rail height increases the distance along the post between the mounting height and the wheel contact height, thereby generally increasing the wheel forces required to accomplish release at the mounting point. The Mini Spacer addresses this difficult trade-off situation by releasing at a selected load level that accommodates variations in rail height.

Post Optimization

Some researchers have proposed significant improvements to strong post guardrails by modifying line posts in various ways (8, 9). No changes to posts are required in the present guardrail. This is because the behavior of posts during vehicle impacts is optimized without any alteration of the posts, thus enabling the use of unmodified conventional posts. This is accomplished by adequately establishing the release load within a known and desirable range. With this appropriate release established, the guardrail is able to maintain its height during contact with the vehicle by preventing the post from pulling down the rail as the post rotates in the soil during lateral deflection of the guardrail. Moreover, in the GMS Guardrail a beneficial response related to section properties of the post in combination with appropriate release loads enables the post to move out of the way of the approaching vehicle. The significance of this “new” capability is that entrapment of the guardrail section between the post and the vehicle (sometimes related to pocketing) is avoided, thereby eliminating the need for backup plates at posts.

Roadway Width

The Mini Spacer release system is designed to work with blockouts of any depth, such as may be desired at curbs (10), or with no blockouts at all. One obvious advantage of not requiring blockouts is to effectively increase roadway width. Another advantage is to reduce nuisance damage by providing wider effective margins along the shoulders of roadways to provide more space in which vehicles may maneuver.
Backup Plates

No backup plates are required in the present guardrail. With adequate release loads, the high peak loads that have been associated with the release mechanisms of previous guardrails are avoided. The “W” shape of the guardrail cross-section is generally maintained, making backup plates unnecessary, since the guardrail is no longer pounded flat at posts by high peak loads.

Splice Location

Even though splices of the new guardrail system may be placed either at or between posts without affecting performance, placing them at posts is selected (see Figures 3 and 5) in order to avoid the need for adding extra slots to conventional guardrail panels to accommodate placement of splices between posts, as well as avoiding additional parts such as special new guardrail adapters that may be required to interface with some end terminals.

FULL-SCALE CRASH TESTING

The purpose of the present full-scale crash testing program was to evaluate the impact performance of the new guardrail according to specifications for Test Level 3 (TL-3) of NCHRP Report 350 (3) and its update.

Barrier Height

The system was tested at nominal conventional top of rail heights of 27 inches as well as at 31 inches with the 2270P pickup truck at Test Level 3 in order to demonstrate adequate performance at conventional rail height as well as at 31 inches.

Barrier Impact Conditions

Test 3-10 of NCHRP Report 350 specifies an 1800 lb car impacting at a speed of 62 mph and an angle of 20 degrees, and Test 3-11, which specifies a 4400 lb pickup truck impacting at a speed of 62 mph and an angle of 25 degrees. Because of the update to NCHRP Report 350 that proposes a heavier pickup truck weighing 5000 lb to be impacted at a speed of 62.5 mph and an angle of 25, degrees, the heavier pickup truck was selected for the present test program in lieu of the 4400 lb pickup truck, since it represents a more demanding test. The heavier pickup truck has a higher center of gravity than pickup trucks specified under NCHRP Report 350. Thus, the test is considered to be more challenging based upon both weight and center of gravity considerations.

The proposed update to NCHRP Report 350 will possibly specify a 2400 lb car impacting at
a speed of 62.5 mph and an angle of 25 degrees. Based upon observations of previous test results, it was decided to use the lighter car of NCHRP Report 350 Test 3-10 rather than the heavier car of the proposed update to NCHRP Report 350, because this test was considered to be as severe in terms of occupant risk and wheel snagging considerations. With this, it was also decided to run the small car test using a double-faced W-Beam guardrail, as shown in Figure 5, rather than a single faced W-Beam guardrail as shown in Figure 3. This was selected in order to clearly demonstrate that occupant risk and wheel snagging would be acceptable even for this extreme case where each post is attached to guardrail on both sides of each post, i.e. using two Mini Spacers at each post. This W-Beam configuration corresponds to a median installation.

Test Installation

The test installation for evaluation of the new guardrail system consisted of 12.5-ft long 12-gauge W-beam rail elements supported on 6-ft long W6x8.5 steel posts embedded in standard strong soil and spaced 6 ft-3 inches on center. The nominal height to the top edge of the W-beam is provided in Table 1. The W-beam rail elements were mounted to the posts using Mini Spacers. All splices were located at posts. No backup plates or blockouts were used at any posts in these “bare bones” tests.

FIGURE 3 Test installation for test 3-11 included splices at unaltered conventional posts with no backup plates at any posts.
Each end of the system was terminated with modified Type T Anchors (foundation tube option), without blockouts, and without struts between posts. The length of the longitudinal barrier, including the end anchors was 187.5 feet.

**Test Results**

A summary of the results of the three tests run on the new strong-post, reduced offset guardrail system is presented in Table 1. In all tests, the Mini Spacers performed as designed, and the vehicles were successfully contained and redirected in a stable manner. Damage to the guardrail installation and vehicle are shown in Figures 4 and 5. There was no occupant compartment deformation in each test, indicating that vehicle impact forces were adequately managed by the new release mechanism. The posts moved out of the way to avoid excessive guardrail damage due to the guardrail being trapped between a post and the impacting vehicle. In addition, as shown up close in Figure 6, the posts folded over in a very stable fashion, without the need for weakening holes in the conventional W6x8.5 steel posts.

![FIGURE 4 Barrier damage and vehicle damage of test 3-11 at 31 inch top of rail height (top photos) and 27 5/8 inch top of rail height (bottom photos)](image_url)
FIGURE 5a  Test installation for test 3-10.

FIGURE 5b  Barrier damage of test 3-10.
FIGURE 6  Extracted posts displayed uniform hinging behavior of posts in Test 3-10 without any need for weakening holes.
### TABLE 1 Crash Test Results

<table>
<thead>
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<th>Test Designation</th>
<th>Modified Test 3-11</th>
<th>Modified Test 3-11</th>
<th>Test 3-10</th>
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<tbody>
<tr>
<td><strong>Test Article (top of rail height, in.)</strong></td>
<td>Single-Face W-Beam (31)</td>
<td>Single-Face W-Beam (27 5/8)</td>
<td>Double-Face W-Beam (31)</td>
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<td>820C</td>
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<td>Speed (mph) / Angle (deg)</td>
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<td>Impact Velocity (ft (m/s))</td>
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<td><strong>Test Article Deflections (ft)</strong></td>
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<td><strong>Post-Impact Behavior (in 1.0 sec)</strong></td>
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<td>Max. Yaw Angle (deg)</td>
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<td><strong>Test Assessment</strong></td>
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PART III. TECHNOLOGY INNOVATIONS

The Mini Spacer is the result of years of research directed at identifying economical and practical, yet simple and versatile avenues toward upgrading and improving existing conventional guardrail barriers. These research results underpin a simple yet sophisticated releasable mounting fastener having sufficient versatility to enable it to be used as a direct upgrade of existing conventional guardrails. The Mini Spacer succeeds in leveraging ground-breaking research results in addressing decades-old problems. It provides a viable pathway toward adapting conventional guardrail barriers to a variety of evolving geographical and roadway demands as represented in increasingly stringent testing standards. This research was uniquely focused in that it was guided from the outset by the fact that the three primary failure modes of guardrail are directly related to improper release.

Release Before Crush

The concept of release before crush uses existing cross-sectional properties of conventional W6x8.5 steel posts to accomplish a novel orchestration that effectively manages forces, timing, and motion between the guardrail and posts that reduces crushing and cutting of guardrail between a post and an impacting vehicle. This results in the “W” shape of W-Beam guardrail panel being substantially maintained during a crash event, thereby making backup plates unnecessary.

With proper release and new technical insights, hidden potential of unmodified conventional W6x8.5 steel posts is unleashed, thus enabling revolutionary improvements in the behavior of these posts that actively prevents a specific sequence of events that may cause guardrail failure. A significant problem in conventional guardrail has been that vehicles tend to crush (or “pound flat”) the trapped guardrail section against unreleased posts; thereby twisting, damaging and sometimes cutting the trapped rail in a “scissors action”. This is a widely recognized failure mechanism associated with the pocketing failure mode.

Furthermore, as the released post moves out of the way it is also bending over, and by the time the vehicle wheel does reach the post, the wheel is able to overcome the post, since the post is no longer supported at its upper end by attachment to the guardrail. This movement consists of posts bending preferentially along their cross sectional “weak” direction- much faster than in their “strong” direction when subjected to bending loads having a relatively small offset from being aligned with the principal axis corresponding to the strong direction of the cross section. This effect is caused by a shift in the neutral axis (of bending) of the post. Conventional W6x8.5 steel posts always knew how to do this- they only required proper release to activate this capability in a useful way. Moreover, with appropriate release of the post, the vehicle is able to buckle contacted posts at the ground line (see Figure 6) without any need for weakening holes. In this way, the problem of hard wheel snagging is simultaneously addressed.
Self-Aligning/Positioning Fastener

The self-aligning fastener accommodates installation misalignments between posts and guardrail (see Figure 2), while facilitating precise placement and alignment of the fastener in the guardrail’s post bolt slot. The dome nut of the Mini Spacer fastener is slightly offset from the post, and is shaped to have the ability to pivot slightly at the mounting point. Yet the dome nut is also shaped to establish and maintain precise lateral positioning of the release mechanism in the post bolt slot that prevents release washers from snagging on the slot ends. This precise positioning is maintained even in the presence of extreme guardrail axial forces.

This addresses a significant problem of conventional strong post guardrail with blockouts, which has been that misalignments between the guardrail and post that occur during installation may not be adequately accommodated. This misalignment results in anomalous behavior, including affecting how blockouts pivot on a post to accomplish release. In addition, misalignments may encourage detrimental snagging of the post bolt head on the end of a slot, potentially leading to pocketing, vaulting, and hard wheel snagging failure modes.

Clamping Fastener

The clamping fastener stabilizes against extraneous forces, motion, and vibration that may damage guardrail during impact, even interfering with the release process itself. Thus, the clamping fastener generally improves the stable mounting and release of guardrail from a post.

One problem with conventional strong post guardrails has been that the blockouts do not properly secure the guardrail in position due to bolt tightness issues, since any attempts to tighten the 5/8 inch diameter button head bolts is thwarted as the weaker blockout will crack or deform as tightening is attempted. Further tightening simply deforms the slot of the guardrail, and may even result in release of the guardrail during installation. Beyond that, tightened bolts may actually prevent pivoting of the blockout, thus impeding release, thereby inducing failure modes related to pocketing, vaulting, and hard wheel snagging. The choices are thus quite simple: the guardrail post bolt is either left relatively loose, in which case the guardrail is improperly secured against extraneous loads that may interfere with release, or the guardrail bolt is tightened, in which case release may be compromised. Neither alternative is very appealing from a performance standpoint.

Hard Stop For Tightening Post Bolt

The Mini Spacer of the GMS guardrail is configured so that bolt tightness has no significant effect upon release, since as the bolt is tightened, a hard stop prevents over-tightening. This is accomplished without interfering with the release mechanism. As the bolt is tightened, the dome washer tightens and deforms against the dome nut until it reaches a point where no further movement is possible, yet a defined gap remains open between the dome washer and the release washers that corresponds closely to the guardrail panel thickness. In this way a
prescribed range of clamping loads may be consistently established during installation without activating the release mechanism. This is in contrast to conventional guardrail with 5/8 inch diameter button head bolts and blockouts of any depth, where over-tightening of the post bolt may deform the guardrail slot to cause release, particularly if the bolt head happens to be near the middle of the guardrail slot.

**Shock Absorber**

Clamping guardrail panels at each post reduces the effects of extraneous forces and vibration by limiting movement, thereby more effectively routing these forces into the ground via the post. In cases where these loads may become extremely large, a shock absorbing capability is present in the form of a crushable dome washer that reduces or attenuates peak loads that are most likely to damage the guardrail panel at a post. In this way these loads may be addressed in a controlled manner to avoid twisting the guardrail as the loads are directed along the most stable pathway possible, which is through the (central) mounting flange of the guardrail, through the posts, and into the ground.

**Load Bypass**

The Mini Spacer includes provisions for some loads to bypass the release washers and the 5/16 inch diameter bolt, making it significantly more robust against damage to the bolt while enabling better management of various barrier loads associated with nuisance damage.

**SUMMARY AND CONCLUSIONS**

This paper focuses on reduced offset, strong post guardrail with increased capacity where the only required change to conventional hardware is the use of a new releasable guardrail mounting fastener called the Mini Spacer. The Mini Spacer release mechanism is presently the only comprehensive release mechanism for conventional strong post guardrail in that it no longer relies upon (significant variability associated with) deforming the post bolt slot in order to accomplish release of the guardrail. The tested guardrail barriers functioned adequately in addressing hard wheel snagging, pocketing, and vaulting without the use of any backup plates or blockouts at the posts, and without any need for placing the splices away from the posts. Since the Mini Spacer mounting fastener is the only new hardware item added to otherwise (unaltered) conventional posts and (unaltered) conventional guardrail, significant additional inventory and distribution costs associated with maintaining expanded hardware inventories are substantially eliminated in this economical, yet versatile and practical new guardrail. Costly installation or maintenance mistakes associated with confusing hardware alterations are also avoided. Further economies are enabled in eliminating blockouts, due to increases in roadway width as well as savings associated with storage and transportation of bulky hardware.
The GMS Guardrail is quite conventional, yet significantly improved. It is the only new guardrail that does not require splices to be placed between, rather than at posts (thus necessitating special adapters to terminate them). It is the only guardrail that requires neither backup plates nor blockouts, even though it is compatible with both. It is the only release mechanism in existence today that has effectively eliminated (variability associated with) snagging of the post bolt on the end of the guardrail slot during release and the only one where the post bolt has no contact at all with a guardrail panel during release. It is the only release mechanism incorporating a means by which vertical guardrail loads go around (i.e. bypass) the post bolt to protect it. It is the only mounting fastener with a built-in shock absorber capability to address peak loads. It is the only release mechanism with its own dedicated (deformable) release element to ensure repeatable and consistent release while accommodating a wide variety of barrier variations, such as being used with both strong and weak post guardrails. It is the only release mechanism that may effectively be used with 10 gage guardrail, while maintaining the same release loads. It is the only release mechanism where the release loads will not be significantly affected by changes in guardrail mounting height due for example, to roadway overlays. It is the only release mechanism to introduce a new technical understanding of managing and orchestrating unaltered conventional posts to improve performance. It is the only release mechanism incorporating means to effectively clamp the guardrail at a post to address extraneous loads and vibration. It is the only release mechanism to maintain precise positioning of the mounting fastener near the central portion of the guardrail slot to ensure consistent release. It is the only mounting fastener with the ability to pivot at a post to accommodate small misalignments between the guardrail and the post. It is the only mounting fastener having a hard stop feature that effectively uncouples bolt tightness from affecting the release load.

By providing substantially improved release of the post from the rail, the Mini Spacer mounting fastener enables the rail to maintain its height during vehicle engagement and redirection, while also maintaining deflection characteristics comparable to other strong-post guardrail systems.

The new reduced offset, strong-post W-beam guardrail system has met the impact performance requirements of *NCHRP Report 350*. It has demonstrated capability to successfully contain and redirect vehicles ranging from an 1800-lb passenger car to a 5000-lb pickup truck with a 28 inch high center of gravity. The system has been accepted by the Federal Highway Administration for use on the National Highway System.

Guardrail end terminals and bridge approach transitions designed to be compatible with conventional guardrail should perform acceptably with the new guardrail system without modification. FHWA acceptance has been granted for the use of various terminal configurations with the new guardrail system, and requests related to other longitudinal barrier system components are pending.
REFERENCES


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