ENERGY ABSORBING POST FOR ROADSIDE SAFETY DEVICES

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ABSTRACT
An energy-absorbing post for absorbing the impact energy of an errant vehicle wherein the impact energy is absorbed by out-of-plane deformation in the material of the post. Out-of-plane deformation is provided by utilizing a through-bolt extending through a splice connection between upper and lower posts sections. Alternatively, out-of-plane deformation is provided by leaving an axial gap on a splice bolts. For terminal applications, a single through-bolt is utilized to allow the upper post section to pivot during end on impacts. Bolt tear out facilitators, including stress concentrators and pre-buckles, or an angled through-bolt decrease any initially high tear-out forces. Direct out-of-plane deformation is provided by extending a tab from a splice plate and connecting the tab to the post, by forming one or more slots in an upstream lateral face of the post and directly welding a splice plate near the slots, or by connecting a bent over splice plate on opposing planar sides thereof to facilitate out-of-plane deformation in a weldment area between the plate and the post.
Fig. 4

Fig. 5
ENERGY ABSORBING POST FOR ROADSIDE SAFETY DEVICES

FIELD OF THE INVENTION

[0001] The present invention relates in general to roadside safety devices and more specifically to mounting posts for roadside safety devices. In particular, the present invention relates to improved energy-absorbing breakaway posts for roadside safety devices, such as guardrail, guardrail terminals, and crash cushions, mounted in a foundation of rigid or semi-rigid earthen or artificial materials.

BACKGROUND

[0002] Many highway agencies across the nation have begun to use barrier layers, such as Portland cement or asphaltic mow strips, to prevent the growth of vegetation under roadside safety devices such as guardrail. Mow strips consist of a narrow strip of pavement placed under the length of a guardrail to limit the growth of vegetation. When Portland cement concrete is used, the guardrail is normally erected first and the concrete is poured around the mounting posts and under the barrier. Alternatively, the guardrail posts may be driven though an asphalt pavement barrier layer laid and compacted in the area of the guardrail. Although mow strips effectively eliminate the growth of vegetation, they also have a profoundly negative impact on the safety performance of roadside safety devices such as W-beam guardrails.

[0003] Guardrail posts are normally embedded vertically in soil at a depth that allows the post to rotate laterally upon the impact of an errant vehicle on the face of the guardrail. The guardrail is attached to the post by a bolt placed in a slot in the W-beam element which allows the guardrail to detach from the post when it begins to rotate laterally. Typically, the posts will absorb lateral forces in the neighborhood of 10 kips before rotating in the soil for 1.25 to 1.5 feet in order to absorb approximately 12.5 to 15 kip-ft. The lateral rotation of mounting posts in soil is one of the primary and intended mechanisms by which guardrails dissipate the energy of an impacting vehicle.

[0004] When a guardrail post is installed in a rigid foundation, such as a mow strip, the base of the post is prevented from rotating in the soil. Thus, wooden guardrail posts placed in a rigid foundation fracture quickly upon impact without absorbing significant amounts of energy. When wide-flange steel beam posts are placed in a rigid foundation, the post often fails in an unstable manner due to lateral torsional buckling. Initially, high lateral forces of 12 kips or more are generated before a steel post begins to yield. After only a short lateral deflection, a steel post begins to rotate due to lateral torsional buckling, which causes the post to twist until it is loaded about the weak axis. When the post twists until it is loaded about the weak axis, the resistance force drops dramatically and the energy dissipated by the post is greatly reduced. The twisting motion also causes the bolt between the post and the guardrail to slide along the W-beam until it contacts the end of the slot in the guardrail. When the bolt reaches the end of the slot, pullout is inhibited which can cause the guardrail to be pulled below the impacting vehicle with the lateral rotation of the post and thus degrade safety performance of the guardrail.

[0005] Full-scale crash testing and accident records indicate that W-beam guardrails installed in rigid foundations are not capable of meeting current safety performance evaluation criteria. (See, e.g., U.S. Dept. of Transp., Federal Highway Admin., Memo No. HSA-10/B64-B (Mar. 10, 2004).) Testing has also shown that this problem is not alleviated by using conventional breakaway guardrail posts that do not absorb energy during fracture. When guardrail posts fail quickly without absorbing sufficient energy, the W-beam guardrail often ruptures and the impacting vehicle is thereby allowed to penetrate through the barrier. Currently, most highway agencies resolve this problem by leaving open areas or cutouts in the mow strips in the area around the posts. Cutouts can defeat the purpose of the mow strip by allowing vegetation to grow up in the area around the posts. Some states attempt to resolve this problem by specifying that the cutout area around posts should be filled with a very low strength grout. However, low strength grouts are difficult to obtain in the field because most construction materials are specified by a minimum strength rather than a maximum allowable strength. Accordingly, the grouts actually used in cutouts are often found to be much stronger than the specified minimum strength and the effectiveness of the guardrail can therefore be seriously compromised. In addition, the installation of mow strip cutouts, whether open or grout-filled, increases the labor associated with the construction of a mow strip and thereby also increases overall costs.

[0006] Cold winter weather in northern climates may also present difficulties for roadside safety devices. In these climates, the soil may freeze during the winter to a depth of one foot or more. This type of frozen ground condition can result in the creation of a rigid foundation similar to a concrete mow strip. Unfortunately, there is no known post foundation treatment that mitigates the safety degradation associated with a rigid foundation caused by frozen soil.

[0007] There currently exist designs for energy absorbing breakaway posts, such as those described in U.S. Pat. No. 6,254,063 (hereby incorporated by reference). These designs generally utilize two post sections joined together by an energy-absorbing splice and are designed such that the upper post section is intended to break away from the lower section at a predetermined impact force. The energy absorbing post splice is typically created by utilizing cable restraint systems, bending of metal tabs, and/or bolts placed in slotted splice plates. These designs have been shown to absorb significant amounts of energy. However, the cost and/or reliability of these designs is believed to be a concern. Cable restraint designs rely on energy dissipation associated with the friction of a cable slipping through a cable clamp. Similarly, bolts placed in slotted splice plates rely on energy dissipation through friction between the bolt head and the splice plate. Energy dissipation systems that rely on friction can be sensitive to even a minor variance in installation details, such as the application of improper torque when tightening the splice or cable clamp bolts. In addition, the reliability of friction-based systems can also be adversely affected by corrosion of the friction components. Systems utilizing metal tabs that dissipate impact energy by bending are generally more reliable and less susceptible to corrosion, but the energy absorption capacity of these systems is lower and their fabrication cost is higher.

SUMMARY OF THE INVENTION

[0008] In view of the foregoing and other considerations relevant in the field, the present invention represents an
improvement over conventional breakaway guardrail posts to increase energy absorption and thereby allow guardrails and other roadside safety devices to provide adequate safety performance even when installed in a rigid foundation. Further, the present invention provides an effective solution to the problems associated with rigid post foundations created by both concrete mow strips and frozen soils. These and other characteristics of the present invention are achieved by enhancing energy absorption in breakaway posts by facilitating bolt tear-out and the creation of out-of-plane stresses in the connection area of the upper and lower post sections.

[0009] In general, a lower post section is mounted in a foundation. An upper post section is vertically aligned and spliced or welded to the lower post section. The upper post section has a generally flat lateral side facing the anticipated direction of a lateral impact. When the upper post section is struck by an errant vehicle, impact energy is absorbed either by bolt tear-out in the connection, or by direct Mode 3 out-of-plane tearing in the splice plate or lateral face of the upper or lower post section.

[0010] Several preferred embodiments are described in more detail below, including the following:

[0011] Several embodiments utilize a through bolt extending through a splice connection between the upper post section and the lower post section. The through bolt preferably includes a head facing the anticipated direction of a lateral impact and a fastener opposing the bolt head. At least one splice section created by the through bolt does not include additional compressive fasteners that restrict out-of-plane deformation between the underlying splice plate and the post flange. During an impact, energy is absorbed by bolt tear-out of the flange material. By utilizing the through bolt, as opposed to two or more standard compressive fasteners, the through bolt will produce energy absorbing tear-out even when located at greater distances from the edge of the post section.

[0012] Several additional embodiments utilize tear-out facilitators to reduce initially high forces required to initiate bolt tear-out. Examples of facilitators described in more detail below include a saw cut located at the edge of the bolt hole in the material undergoing tear-out, as well as an out-of-plane pre-buckle formed in the edge of the bolt hole in the material undergoing tear-out. In other embodiments, initially high bolt tear-out forces may be reduced by renting the through bolt at a non-perpendicular angle with respect to the material undergoing tear-out. Two or more of the tear-out facilitators may be combined to even further reduce initially high tear-out forces.

[0013] The embodiments with a through bolt may also be utilized in terminal applications by using a single through bolt to connect the splice between the upper and lower post sections. By using a single through bolt, the upper post section is allowed to pivot freely during an end on impact while still absorbing impact energy during a lateral impact. To provide added stability in these applications, additional splice fasteners may be utilized by mounting the additional fasteners closer to the edge of the upper or lower post section, by removing post material near the other fasteners to similarly decrease the edge distance, or by removing a vertical slot of post material extending from the edge of the bolt hole to (or near to) the edge of the post.

[0014] In an alternative embodiment, bolt tear-out may be facilitated even without utilizing a through bolt by locating a soft or compressible gasket under the head or nut of a splice bolt. Here, upon impact, the compressible gasket material permits angular deflection of the bolt in the hole and thereby reduces the energy required to initiate and sustain bolt tear-out as a means for energy absorption.

[0015] Still other embodiments absorb impact energy by direct Mode 3 out-of-plane tearing in the splice plate or lateral face of the upper or lower post section. Here, energy absorption by direct Mode 3 out-of-plane tearing in the splice plate may be accomplished by extending a tab cut out or formed from a portion of the splice plate near the abutting ends of the post sections. One end of the splice plate is rigidly attached to the upper or lower post section by conventional means. The end of the tab is rigidly attached to the other post section such that deflection of the upper post section during an impact absorbs energy by out-of-plane tearing in the splice plate near the tab extension.

[0016] Alternatively, direct Mode 3 out-of-plane tearing in the lateral face of the upper or lower post section may be accomplished by forming slots in the lateral face of the upper or lower post section. One end of the splice plate is rigidly attached to the upper or lower post section by conventional means. The other end of the splice plate is welded or attached to the lateral face of the other post section adjacent to the slots. On a lateral impact, angular deflection of the upper post section causes direct out-of-plane tearing in the lateral face of the post at or near the slots.

[0017] Still other embodiments provide energy absorption by direct out-of-plane tearing in a weld area between the splice plate and the upper or lower post section. One end portion of the splice plate is rigidly attached to the upper or lower post section by conventional means. The other end portion of the splice plate is bent over on itself and its back side is welded by one or more vertically oriented welds to the other post section. In this manner, the upper and lower post sections are joined by opposing planar sides of the splice plate. Upon impact, angular deflection of the upper post section causes direct out-of-plane loading of the weld material between the back side of the splice plate and the underlying lateral post face.

[0018] In any of the embodiments absorbing energy by direct Mode 3 tearing, the generation of out-of-plane forces may be facilitated by locating a small spacer between the splice plate and lateral post face. In this manner, a small out-of-plane angle is formed between the splice plate and the lateral post face such that even initial forces are directed out-of-plane.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The foregoing and other features and aspects of the present invention are best understood with reference to the following detailed description of particular embodiments of the invention, as read in conjunction with and in light of the accompanying drawings, wherein:

[0020] FIG. 1 is a partial side view of a flange with splice bolts for joining post sections.

[0021] FIG. 2 is a top plan view of a spliced connection common among the prior art.
FIG. 3 is a top plan view of a spliced connection utilizing through bolts in accordance with several embodiments of present invention.

FIGS. 4 and 5 plot force versus deflection during an impact on the energy absorbing posts in accordance with the several embodiments of present invention.

FIG. 6A is a partial side view of a flange section with saw cut tear-out facilitators.

FIG. 6B is a partial perspective view of a post section with a partially deformed saw cut tear-out facilitator.

FIG. 7 is a partial perspective view of a post section with a pre-buckle tear-out facilitator.

FIG. 8 is a partial perspective view of a post section with a combined pre-buckle and saw cut tear-out facilitator.

FIG. 9 is a partial side view of a splice connection utilizing an angled through bolt in accordance with an embodiment of the present invention.

FIGS. 10A-C are partial cut-away side views of alternative through bolt embodiments of the present invention.

FIGS. 11A and 11B are partial side views of an alternative embodiment of the present invention utilizing a compressible gasket to facilitate angular displacement of splice bolts.

FIGS. 12A and 12B are alternative side views of an embodiment of the present invention adapted for terminal applications.

FIGS. 13A-C are side views of an additional embodiment of the present invention adapted for terminal applications.

FIGS. 14A-D are alternative side views of an embodiment of the present invention adapted for absorbing impact energy by direct tear-out in the splice plate.

FIGS. 15A and 15B are alternative side views of an additional embodiment of the present invention adapted for absorbing impact energy by direct tear-out in the post flange.

FIG. 15C is a perspective view of the embodiment shown in FIGS. 15A and 15B.

FIGS. 16A-C are alternative side views of a further embodiment of the present invention adapted for absorbing impact energy by direct tear-out in a welded area between the splice plate and post flange.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Refer now to the drawings in which the depicted elements are not necessarily shown to scale and like or similar elements are designated by the same reference numeral throughout the several views.

In several embodiments, the present invention utilizes bolt tear-out as a mechanism for energy absorption. Bolt tear-out normally occurs when there is insufficient material between the edge of a bolt hole and the edge of a metal plate. In this situation, in-plane shear stresses produced by the bolt bearing on the plate material exceed the capacity of the metal and the plate fails in a double Mode-II fracture. Traditional structural design guidelines recommend that bolt tear-out can be prevented by increasing the bolt edge distance (the distance from the bolt hole to the margin or edge of the bolted material) to at least 1.5 times the bolt diameter. (See Shigley, J. E. & Mischke, C. R., Mechanical Engineering Design 360 (5th ed.) (1989) noting that failure due to tear-out “may usually be neglected” with large edge distances.) As shown in FIG. 1, when a bolt 10 with a lateral side 12 is forced laterally into the edge of a hole 20 in a steel flange plate 30, the flange material is loaded in a Mode 2, in-plane shear condition. As is generally understood, Mode 1 fracture is associated with tension stresses, Mode 2 fracture is associated with in-plane shear failure and Mode 3 fracture arises from out-of-plane shear stresses in the plate material.

With a large edge distance d, the material resistance is sufficient to prevent the bolt 10 from tearing out from the material of flange plate 30 due to Mode 2 fracture. In this case, the bolt 10 tears out from the material of flange plate 30 when two cracks develop in the margin material of flange 30 (as indicated by arrows 13 on each side of the bolt 10) and eventually a small piece of the material forming flange 30 is torn out. On the other hand, buckling in the material of flange 30 allows the material of flange 30 to deform out-of-plane and become loaded in Mode 3, out-of-plane shear.

As shown in FIG. 2, when short bolts 10 are used in a post splice, as common among prior devices, the material forming flange 30 is clamped in plane between the bolt head 14 and the nut 16 so as to generate a high resistance to local out-of-plane buckling. In these prior systems, the potential for energy absorption by bolt tear-out is thereby greatly restricted.

FIG. 3 illustrates a cross-section view of an embodiment of the present invention wherein the breakaway post is depicted as having an I-beam cross-section. As should be understood by those skilled in the field with reference to this specification, other beam sections could be employed, e.g., round or box-beam, so long as the beam section forms generally opposing vertical walls of metal material (typically steel) with a definite wall thickness between the exterior surface of the post and its interior surface, here flange back side 50.

As shown in FIG. 3, when a through-bolt 40 is used in a post splice in accordance with the present invention, the flange back side 50 is not restrained in plane by the through-bolt 40. In this embodiment, through-bolt 40 is a generally cylindrical rod member extending through the post which does not include a fastener (e.g., a threaded nut) compressing the flange back side 50. Accordingly, local out-of-plane buckling of the material forming flange 30 is uninhibited. Further, as the material of the post flange 30 begins to buckle, the post rotates laterally and the through-bolt 40 thus begins to displace at a non-perpendicular angle to the flange 30, thereby accentuating the out-of-plane shear loading. As a result, bolt tear-out can occur, even with large edge distances d, provided that through-bolts 40 are employed for the splice such that the flange back side 50 is unrestrained.

FIGS. 4 and 5 provide the results of dynamic testing of breakaway posts joined by a splice in accordance
with an embodiment of the present invention using through-bolts 40 positioned at two edge distances. Deflection of the upper post section is indicated on the x-axis (in inches). Post load is indicated by the y-axis (in 1000 pound units). From this it can be seen that the lateral force required to initiate tear-out is much greater than the force required to sustain tear-out. This initially high force is required to initiate buckling of the material forming flange 30 prior to the onset of tear-out. It can also be seen that the amount of post deflection at the point of final fracture increases as the edge distance (distance d in FIG. 3) increases. The area under the force-deflection curves, i.e., the energy absorbed by the post, also increases as the bolt edge distance increases. However, when the edge distance (distance d in FIG. 3) exceeds 5 inches, resistance to tear-out can become too great and the post can fail in other modes. It should also be understood that, with reference again to FIG. 3, a splice utilizing through-bolts 40 provides the most reliable energy dissipation characteristics when the bolt head 14 is placed on the front or tension side of the post such that the threaded portion of the through-bolt 40 does not interfere with the bolt tear-out process.

Local buckling of the material surrounding the through bolt helps to initiate Mode-III tearing of the plate material used in the splice. Although classical solutions can be used to predict local buckling of metal plates, these analysis techniques are not readily applicable to the dynamic loading conditions associated with the present invention. However, dynamic testing of a large number of bolted splice configurations has shown that the tear-out initiation forces are at least equal to the force required to yield all of the material below the through bolt and create slip planes on each side of the bolt as approximated below.

$$F_y = \sigma_y \left( d_b + \frac{4t^2}{\sqrt{3}} \right)$$

where:

- $F_y$ = Minimum force required to initiate plate tear-out
- $\sigma_y$ = Plate yield strength
- $t$ = Plate thickness
- $d_b$ = Bolt diameter

The shear strength of the through bolt must be sufficient to initiate the tear-out process. The strength of the through bolt can be approximated by,

$$F_s = \frac{\tau_s d_b}{\sqrt{3}}$$

where:

- $F_s$ = Bolt shear strength
- $\tau_s$ = Ultimate strength of bolt material
- $A_b$ = Area of bolt in the shear plane

Accordingly, in order to initiate tear-out, the relationship between the size and strength of the bolt and the thickness and strength of the plate material must be such that,

$$\frac{\pi d_b \sigma_y}{4\sqrt{3}} \geq \sigma_y \left( d_b + \frac{4t^2}{\sqrt{3}} \right)$$

In the equations above, it should be noted that as the bolt diameter is reduced, both the tear-out initiation force and bolt strength diminish. However, the reduction in bolt strength is directly related to the square of its diameter. Accordingly, bolt strength tends to decrease much more rapidly.

Larger diameter through-bolts 40 produce higher tear-out forces and higher post energy absorption, but the deflection of the post at failure is not significantly affected by the bolt size, but rather is controlled primarily by the post edge distance d. As bolt size increases, the resistance to bolt tear-out can become so large that the post fails in other modes, such as fracture through the flange 30. Also, smaller diameter through-bolts 40 may not have sufficient shear capacity to produce long tear-out distances because the bolt itself tends to fracture in shear before sufficient force is generated in the material of flange 30. While through bolts 40 have been illustrated throughout the figures, it should be understood that other elongate rod members could be used instead.

It has been found that Grade 5 through-bolts 40 with diameters between 3/8 inch and 1 inch appear to provide the optimal behavior and produce consistent energy dissipation through tear-out. Higher grade through-bolts 40 with smaller diameters may also be able to provide adequate shear capacity to facilitate energy dissipation through tear-out. Optimally, the threaded portion of the bolt is kept out of the shear plane (i.e., oriented on the back of the post) to improve the reliability of energy absorbing posts with long tear-out distances. Here, in some instances the bolts themselves can fracture in two pieces due to stress concentrations in the threaded portion of the bolts located on the back side of the post and thus greatly restrict energy dissipation.

Ideally, an energy absorbing post in accordance with the present invention will exhibit little or no plastic deformation until the lateral load reaches a desired level, typically 10 to 12 kips. The ideal post would then sustain the initial force until it reaches the desired deflection limit, when the post would finally fracture completely. As shown in FIGS. 4 and 5, long through-bolts 40 (e.g., FIG. 3) do not achieve this ideal behavior because the forces required to initiate tear-out are much higher than the force required to sustain the process. As discussed below, this undesirably high initial tear-out force can be reduced by one or a combination of several methods, including stress concentrators to facilitate tear-out, dimples located in the post flange to serve as pre-buckles, and by using through-bolts 40 that form a non-perpendicular angle with respect to the flange 30.

As shown in FIG. 6A, a saw cut 100 or other stress concentrator can be placed on the edge of the hole 20 in the post flange 30. Alternative stress concentrators might include a v-cut or a square-shaped hole 20 (not shown). As
indicated in FIG. 6B, the stress concentrator allows the material forming the post flange 30 to deform at lower initial bolt shear loads in order to produce out-of-plane deformations. These out-of-plane deformations allow the material of the flange 30 to be loaded in a Mode-3 fracture condition to initiate tear-out. The initial deformation of the post, facilitated by the stress concentrator, also allows the through-bolt 40 to become angled relative to the post flange 30, which further facilitates tear-out.

Alternatively, as shown in FIG. 7, a dimple 110 or other out-of-plane deformation may be placed at the bottom of the hole 20 in the post flange 30 to serve as a pre-buckle for reducing the otherwise high forces associated with initiating local buckling of the post. The dimple 110 provides an out-of-plane deformation to facilitate generation of Mode 3 shear stresses in the material of flange 30 as soon as the post becomes loaded. These out-of-plane shear stresses reduce the lateral forces required to initiate tear-out in the flange 30 and thereby facilitate more effective energy absorption.

As shown in FIG. 8, a combination of a saw cut 100 or other stress concentrator and a pre-buckle such as dimple 110 can be used in conjunction to further reduce the forces required to initiate tear-out. A saw cut 100 can be placed below the through-bolt 40 (not shown) and a small out-of-plane deformation, such as dimple 110, can be formed at the to of the saw cut 100. This double initiator embodiment further assures that out-of-plane shear stresses will be applied to the post flange 30 immediately and that a crack will facilitate better energy dissipation and lower stress levels. In similar fashion, one or more of the facilitators can be combined in any of the alternative through-bolt embodiments described below.

In yet another alternative embodiment of the present invention, as shown in FIG. 9, the through-bolt 40 (or other rod member) can be placed at an acute angle $\alpha$ relative to the post flange 30 to also produce out-of-plane shear stresses in the post flange 30. As shown in the embodiment of FIG. 9, the through-bolts 40 can be placed at an angle $\alpha$ of approximately 80 degrees relative to the post flange 30 by cutting holes 20 located 1 inch higher in the rear flange 30 than the holes 20 in the front flange 30. Thus, installing the through-bolt 40 at an acute angle $\alpha$ can also facilitate tear-out and a more effective energy absorption. As would be recognized by persons skilled in the art with reference to this specification, the facilitators described in connection with FIGS. 6A, 6B, and 7 could also be combined with the angled-through-bolts embodiment of FIG. 9 to even further facilitate tear-out.

In FIGS. 3 and 6-9, splice plate 60 is shown as attached outside the flange 30 and, accordingly, bolt tear-out occurs in the material of the flange 30. Here, tear-out is facilitated, even with large edge distances d (see FIG. 1) because the through-bolt 40 does not restrain the material of flange 30 against out-of-plane deformations. Accordingly, those of ordinary skill in the field with reference to this specification would recognize that alternative configurations may facilitate tear-out in the material forming other components of the present invention. FIGS. 10A through 10C depict examples of other such configurations. As shown in FIG. 10A, tear-out may be facilitated in splice plate 60 by locating splice plates 60 on the back side 50 of flange 30 and using through-bolt 40 to permit out-of-plane deformations in splice plate 60. Further, as shown in FIG. 10B, splice plate 60 may be omitted entirely to facilitate tear-out in the material of flange 30 in the upper post section by employing an upper post section with a flange separation distance slightly less than the flange separation distance of the lower post section, such that the flange 30 of the lower post section overlaps the flange 30 of the upper post section. Similarly, as shown in FIG. 10C, splice plates 60 may be omitted to facilitate tear-out in the material of flange 30 in the lower post section by employing a lower post section with a flange separation distance slightly less than the flange separation distance of the upper post section, such that the flange 30 of the upper post section overlaps the flange 30 of the upper post section. So long as through-bolt 40 does not also include structure such as nuts 16 restraining out-of-plane deformation in both upper and lower post sections (e.g., FIG. 2), tear-out will be facilitated to provide enhanced energy absorption of the breakaway post.

Alternatively, as shown in FIG. 11A, a soft compressible washer or gasket 70 may be placed between the nut 16 on bolt 10 and the material of flange 30, or as shown in FIG. 11B, the compressible gasket 70 may be placed between the head 14 of bolt 10 and the material forming flange 30. In these embodiments, bolt 10 need not extend through the entire connection because the compressible gasket 70 permits local buckling of the flange material and angular displacement of the bolt 10 to facilitate the generation of out-of-plane stresses and bolt tear-out in the material of flange 30. This design relies primarily on the use of a bolt 10 that is too long to allow the clamping of the plates between the head 14 and the nut 16. When lateral loads are applied to the post, such a longer bolt 10 rotates until the bottom of the bolt head 14 and the top of the nut 16 contact the splice plate and post flange respectively. Ideally, the bolt 10 and compressible material of gasket 70 will be sized to allow the bolt 10 to rotate sufficiently to provide out-of-plane shear stresses to be applied to the material of flange 30. Further note that the compressible material of gasket 70 is primarily recommended to eliminate post vibration which could occur with an overly long splice bolt 10. Hence, the gasket 70 could be omitted entirely without adversely affecting the safety performance of the energy absorbing post.

As would be appreciated by persons of ordinary skill in the field, guardrail posts used for mounting end terminals or crash cushions should break easily during end-on impacts. The present invention includes embodiments adapted for use in these end-on impact applications. For example, while side-impact applications might ordinarily utilize a plurality of through-bolts 40, alternatively, as shown in FIG. 12, the present invention is readily adapted for terminal applications by utilizing a single through-bolt 40 to form the splice between the two breakaway post sections. In this embodiment, the attachment between the guardrail and the guardrail post maintains the post in an upright position until the post is struck by the terminal (generally by the impact head) during a head-on collision. Thereafter, the single through-bolt 40 provides a pivot to facilitate angular deflection of the upper post section. Full-scale crash testing has shown that a design utilizing a single through-bolt 40 in accordance with this alternative embodiment provides both adequate energy dissipation during lateral redirection impacts and also performs well during end-on impacts. The embodiment utilizing a single through-
bolt 40 should also improve the performance of guardrail line posts by reducing the effects of a wheel snagging on a post. Wheel snagging has been shown to produce heavy damage to the front suspensions of light trucks, which can lead to vehicle rollovers during guardrail impacts. The single through-bolt 40 embodiment of the present invention eliminates this problem by allowing the post to rotate when it is struck by a vehicle’s wheel, thereby greatly reducing both vehicle loading and suspension damage.

[0064] Alternatively, as shown in FIGS. 13A-C, two through-bolts 40 can be used in a breakaway guardrail post for terminal applications if the flange material below the upstream bolt 40U has a low tear-out distance d, and therefore a lower resistance to tear-out during end-on impacts. To create such a low tear-out distance d, the material of flange 30 below the upstream bolt 40U can be removed (FIG. 13A), or a slot 120 may be placed below the upstream bolt 40U (FIG. 13B). In this embodiment, the tear-out distance d for the upstream bolt is reduced to allow the post to easily breakaway during end-on impacts with the terminal. If a slot 120 is placed in the flange 30, the slot could even be extended all of the way from the bolt to the edge of flange 30, as indicated in order to even further reduce the fracture energy associated with an end-on impact. Those of ordinary skill in the field would recognize, with reference to this specification, that other alternative locations for bolt 40U may be selected to reduce its associated edge distance d. For example, as shown in FIG. 13C, the upstream bolt 40U may be placed much lower on the post flange 30 in order to similarly reduce the tear-out distance d. Also facilitators such as those described in connection with FIGS. 6A, 6B, and 7 can be employed in the terminal embodiment of FIGS. 13A-C. Alternatively, additional fasteners could be employed to close the splice connection between the upper and lower post sections, and thereby add nominal stability to the post, (e.g., small shear pins, not shown) so long as the force required to shear such fasteners does not adversely affect the ability of the post to easily rotate during an end impact, and the force required to shear or tear-out such fasteners does not adversely affect the lateral energy-absorbing characteristics of the invention during a lateral impact.

[0065] As shown in FIGS. 14A-F, another alternative embodiment of the present invention involves loading the splice plate 60 or the flange 30 of the post to allow direct Mode 3 out-of-plane tearing of the splice plate. FIGS. 14A-F demonstrate mechanisms for loading the post splice plate and the post flange in Mode 3 out-of-plane shearing when a lateral load is applied to the top of the post. Although these figures show specific examples for loading the splice plate 60 or post flange 30 to facilitate tearing, a person of ordinary skill in the field with reference to this specification would be able to substitute alternate structures for loading the splice plate 60 or the post flange 30 in order to allow direct Mode 3 out-of-plane tearing of the splice plate.

[0066] Referring to FIGS. 14A-D, there is shown an embodiment of the present invention for loading the splice plate 60 to facilitate out-of-plane tearing. In this embodiment, a tab 130 is cut in the splice plate 60 and the tab 130 is thereafter bent outward by 90 degrees or more. The front flange 30 of the upper portion of the post is then welded to the tab 130. Those of ordinary skill should recognize that the weld 132 between the tab 130 and the post flange 30 must be of sufficient strength to propagate the out-of-plane crack in the splice plate 60. Here, a wider tab (indicated as width w in FIG. 14B) will provide a greater weld length without greatly increasing the forces required to propagate the cracks. A conventional splice plate 60 may be welded (as shown in FIG. 14C) or bolted (not shown) to the back of the upper and lower post sections. As would be understood by persons skilled in the art with reference to this specification, in any of the embodiments shown in FIGS. 14A-D, the conventional splice plate 60 located on the back of the upper and lower post sections may be omitted simply by welding the lower post section to the upper post section along a line 136 between the upper and lower post sections (as shown in FIG. 14D).

[0067] When a lateral load is applied to the top of the post in the embodiment of FIGS. 14A-D, the front flange 30 is placed in tension. The tension load is transmitted into the tab 130 in the splice plate 60. As the tab 130 is pulled upward, an out-of-plane tearing stress is applied to the base of the tab 130 and it begins to tear away as shown in FIG. 14D. Here, the saw cuts or stamping process used to form the tab 130 generate points of high stress concentration that will quickly lead to the formation of a crack in the material of splice plate 60. The force-deflection behavior of this embodiment is controlled by the fracture resistance of the splice plate 60. Fracture resistance is related to the strain energy release rate and the thickness of the material forming splice plate 60. Classical fracture mechanics can be used to aid in the selection of the material and thickness of the splice plate 60. It should be noted that, due to the existence of the tear formed by the saw cut or stamping process used to form the tab 130, crack initiation does not produce potentially undesirable large initial post loads. Further, crack propagation occurs at a relatively constant force. Thus, in this embodiment, energy absorption by out-of-plane tearing produces relatively flat force-deflection behavior until the crack propagates through the top of the splice plate 60 and thereafter the upper post will easily deflect laterally about the rear splice plate 60.

[0068] FIGS. 15A-C illustrate a similar embodiment that produces out-of-plane tearing in the post flange 30. In this embodiment, a small generally horizontal slot 140 is created in the post (e.g., punched out of the flange 30) and the splice plate 60 is welded to the flange 30, just below slot 140. When tensile loads are applied to the post flange 30, the misalignment between the post flange 30 and the splice plate 60 thereby causes a moment to be applied to the flange 30 just below the slot 140. This moment produces out-of-plane deformation that creates out-of-plane tearing stresses at the ends of the slot 140 and eventually leads to Mode 3 tearing of the post flange 30. In this embodiment, vertical slots 142 may be added to facilitate initial out-of-plane deformation of the flange 30 and initiate the Mode 3 tearing. As would be recognized by persons of ordinary skill with reference to this specification, this embodiment is merely another example of various involving out-of-plane tearing of the post flange 30 or splice plate 60.

[0069] FIGS. 16A-C illustrate another embodiment of the present invention in which energy is absorbed by direct out-of-plane tearing. In this embodiment, the top of the splice plate 60 is bent over on itself and its back side is welded directly to the upper or lower post section, or to an intermediate plate (not shown) attached to the upper or
lower post section. The welding process used can be either fillet welds on the edge of the splice plate or resistance seam welding to produce lines in the middle of the splice plate. In FIGS. 16A and 16B, splice plate 60 is shown removed from the post in order to indicate the general area where welding 150 fastens the bent over portion of the splice plate 60 to the post section. The other end of the splice plate 60 may be rigidly attached to the other post section by conventional means. Upon impact, a moment is applied to the upper post section as shown in FIG. 16C. The displacement of the upper post section causes direct out-of-plane tearing in the area of welding 150, thereby absorbing impact energy. Note that when fillet welds are used, the weld material is loaded in a conventional Mode III, out-of-plane tearing condition. However, when resistance welding is used, the out-of-plane loading actually produces Mode I crack-opening loading condition on the weldment. In either case, out-of-plane loading of the weld material allows the post to efficiently dissipate impact energy.

[0070] FIG. 16C further illustrates the use of a small spacer 160 placed between the post section and splice plate 60 in the embodiment of FIGS. 16A and 16B. The use of spacer 160 facilitates the generation of immediate out-of-plane stresses by creating an angle between the plane of the splice plate 60 and the area where it is attached to the upper or lower post section. The use of such a spacer 160 thereby tends to decrease initially high loads in the force-deflection curve, such as shown in FIGS. 4 and 5. As would be recognized, spacer 160 may also be utilized in like manner between the splice plate 60 and the post section in the embodiments shown in FIGS. 15A-B.

[0071] From the foregoing detailed description of several specific embodiments of the present invention, it should be apparent that novel and non-obvious, energy-absorbing breakaway posts for use with various roadside safety devices, including those mounted in a rigid foundation, have herein been disclosed. Although specific embodiments of the invention have been disclosed in some detail, this has been done solely for the purposes of describing various features and aspects of the invention. Moreover, it is contemplated that various substitutions, alterations, and/or modifications may be made within the spirit and scope of the invention. Such may include but are not limited to the substitution of rods or other rigid elongate members for through-bolts, the substitution of splice plates integral with the upper or lower post section, or the substitution of splice plates located on the flange back side, as well as the implementation details known to those of skill in the art to which the present invention pertains. Accordingly, the scope of the invention is defined by the following appended claims.

We claim:

1. An energy absorbing post for roadside safety devices comprising:
   a lower post section for engaging a foundation upon which the roadside safety device is mounted;
   an upper post section for receiving the impact of an errant vehicle, the upper post section and the lower post section being generally vertically aligned;
   a splice connection formed between the lower and upper post sections; and
   a rod member extending laterally through holes in the splice connection, wherein the rod member includes at least one axial portion thereof that closes the splice connection without opposing compressive fasteners;

   wherein the material of the splice connection which surrounds said axial portion of the rod member has a thickness t and a plate yield strength σ_y, and the rod member has a diameter d, and an ultimate strength σ_u, each selected to satisfy the general relationship:

   $\frac{\pi d^2}{4} \geq \sigma_y \left( \frac{2t}{\sqrt{3}} \right)

   such that the energy of an errant vehicle impacting the upper post section may be absorbed by tear-out from the material of the splice connection.

2. The post of claim 1 wherein the edge distance extending from the outside edge of the material undergoing tear-out to the edge of the hole in said material is more than 1.5 times the diameter of the rod member.

3. The post of claim 1 or 2 wherein the rod member includes a distal end for receiving a fastener, the distal end being oriented away from the anticipated direction of a lateral impact.

4. An energy absorbing post for roadside safety devices comprising:
   a lower post section for engaging a foundation upon which the roadside safety device is mounted;
   an upper post section for receiving the impact of an errant vehicle, the upper post section and the lower post section being generally vertically aligned; and
   a means for attaching the lower post section to the upper post section and facilitating out-of-plane deformation in the post upon the impact of an errant vehicle on the upper post section;

   such that at least a portion of the energy of the errant vehicle is absorbed by the out-of-plane deformation.

5. The post of claim 4 wherein the means for attaching comprises a splice connection between the lower and upper post sections to facilitate out-of-plane deformation in the material of the splice connection.

6. The post of claim 5 wherein:
   the means for attaching comprises a rod member extending laterally through a hole in the splice connection, wherein the rod member closes at least one portion of the splice connection without opposing compressive fasteners; and
   the edge distance extending from an outside edge of the material undergoing tear-out to the hole in said material is more than 1.5 times the diameter of the rod member.

7. The post of claim 6 further including a stress concentrator located at the edge of the hole.

8. The post of claim 6 further including a pre-buckle formed in the edge of the hole.

9. The post of claim 6 further including a stress concentrator and a pre-buckle located at the edge of the hole.
10. The post of claim 6 wherein the rod member includes a distal end for receiving a fastener oriented away from the anticipated direction of a lateral impact.

11. The post of claim 6 wherein the rod member is oriented at an acute angle with respect to the post in a vertical plane extending in the anticipated direction of a lateral impact.

12. The post of claim 5 wherein the means for attaching comprises overlapping plates connected by a bolt, wherein the axial distance between the bolt head and nut substantially exceeds the thickness of the overlapping plates, such that angular deflection of the bolt during an impact facilitates out-of-plane deformation in one or more of the plates.

13. The post of claim 12 further including a compressible gasket positioned between the plates and the bolt head or nut.

14. The post of claim 6 wherein the rod is a single rod member such that the upper post section pivots on the rod member during an end on impact.

15. The post of claim 14 including a splice fastener positioned upstream from the rod member, wherein the edge distance for the upstream fastener is less than 1.5 times the diameter of the upstream fastener.

16. The post of claim 4 wherein the means for attaching comprises:

a splice plate oriented in the direction of a lateral impact; and

a tab extending from the splice plate and connected to the post such that impact energy may be absorbed by out-of-plane tearing in the area where tab extends from the splice plate.

17. The post of claim 4 wherein the means for attaching comprises:

a generally horizontal slot formed in a lateral portion of the post, the lateral portion facing the anticipated direction of impact; and

a splice plate rigidly connected near said slot such that impact energy may be absorbed by out-of-plane tearing in the lateral portion of the post.

18. The post of claim 17 further including one or more generally vertical slots adjacent to the generally horizontal slot, the generally vertical slots further facilitating out-of-plane tearing in the lateral portion of the post.

19. The post of claim 17 or 18 further including a spacer located between the splice plate and the post to further facilitate out-of-plane tearing.

20. The post of claim 4 wherein the means for attaching comprises a splice plate attached on a first planar side thereof to the upper or lower post section, the splice plate including a bent over portion welded on an opposing planar side to the other of the upper or lower post section, such that impact energy may be absorbed by out-of-plane loading of the weld material.

21. The post of claim 20 further including a spacer located between the splice plate and the post for further facilitating out-of-plane loading in the weld area.

22. An energy absorbing post for roadside safety devices comprising:

a lower post section for engaging a foundation upon which the roadside safety device is mounted; an upper post section for receiving the impact of an errant vehicle, the upper post section and the lower post section being generally vertically aligned;

a splice connection between the upper and lower posts sections, the splice connection including overlapping splice plates; and

a bolt connecting the overlapping splice plates, wherein the bolt forms an axial gap between the bolt head and nut, the gap exceeding the thickness of the overlapping splice plates;

wherein the axial gap permits angular deflection of the bolt during an impact to facilitate tear-out in one or more of the overlapping splice plates and thereby absorb at least a portion of the energy of an errant vehicle impacting the upper post section.

23. The post of claim 22 further including a compressible gasket positioned in the axial gap.

24. An energy absorbing post for roadside safety devices comprising:

a lower post section for engaging a foundation upon which the roadside safety device is mounted; an upper post section for receiving the impact of an errant vehicle, the upper post section and the lower post section being generally vertically aligned;

a splice connection between the lower and upper post sections, the splice connection including a splice plate rigidly attached to one of the upper or lower post sections; and

a tab extending from a portion of the splice plate, the tab being attached to the other of the upper or lower post sections;

such that the tab closes the splice connection, and the energy of an errant vehicle impacting the upper post section is absorbed by out-of-plane tearing in the material of the splice plate near where the tab extends therefrom.

25. The post of claim 24 wherein the splice plate is oriented facing the anticipated direction of a lateral impact.

26. The post of claim 25 wherein the tab is cut out from the material of the splice plate.

27. The post of claim 24 or 25 wherein the tab is welded to the upper or lower post section.

28. An energy absorbing post for roadside safety devices comprising:

a lower post section for engaging a foundation upon which the roadside safety device is mounted; an upper post section for receiving the impact of an errant vehicle, the upper post section and the lower post section being generally vertically aligned;

a splice connection between the lower and upper post sections, the splice connection including a splice plate facing a lateral impact and attached to the upper or lower post section; and

a generally horizontal slot formed in a portion of the other of the upper or lower post sections, the splice plate being rigidly attached to the post near said slot;
such the energy of an errant vehicle impacting the upper post section is absorbed by out-of-plane tearing in the material of the upper or lower post section near said slot.

29. The post of claim 28 wherein the splice plate is welded to the upper or lower post section near the generally horizontal slot.

30. The post of claim 28 or 29 further including one or more generally vertical slots adjacent to the generally horizontal slot, the generally vertical slots further facilitating out-of-plane tearing in the post.

31. The post of claim 28 or 29 further including a spacer located between the splice plate and the post to further facilitate out-of-plane tearing in the post.

32. The post of claim 29 further including:

one or more generally vertical slots adjacent to the generally horizontal slot; and

a spacer positioned between the splice plate and the post;

wherein the generally vertical slots and spacer further facilitate out-of-plane tearing in the post.

33. An energy absorbing post for roadside safety devices comprising:

a lower post section for engaging a foundation upon which the roadside safety device is mounted;

an upper post section for receiving the impact of an errant vehicle, the upper post section and the lower post section being generally vertically aligned;

a splice connection between the lower and upper post sections, the splice connection including a splice plate facing a lateral impact;

a first portion of the splice plate is rigidly attached on a first planar side to the upper or lower post section; and a second portion of the splice plate is side bent over and an opposing second planar side thereof is welded to the other of the upper or lower post sections;

such that impact energy of an errant vehicle is absorbed by out-of-plane tearing in the weld area.

34. The post of claim 33 wherein the welding includes one or more generally vertical welds.

35. The post of claim 33 or 34 further including a spacer located between the splice plate and the post to further facilitate out-of-plane tearing in the post area.

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