CRASH PERFORMANCE OF ENERGY-ABSORBING GUIDE RAIL TERMINALS

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ABSTRACT

Energy-absorbing guide rail terminals (EAGRTs) are a form of end treatment designed to absorb energy during a collision and prevent intrusion into the impacting vehicle. After several years of use in New Brunswick there is evidence to suggest these systems may not always perform as desired. This study was conducted to evaluate the real-world performance of EAGRT systems in collisions throughout the Province. A retrospective review of 103 collisions that occurred prior to the study was supplemented with an in-depth analysis and reconstruction of 18 collisions that occurred during the study period.

The study involved two EAGRT systems; the ET-Plus and the SKT-350. In New Brunswick between 2007 and 2010 80% of all EAGRT collisions in the study area were property-damage-only, 19% resulted in injuries, and there was one fatality. In most cases the EAGRT absorbed a significant amount of energy (an average of 315 KJ per crash); however, several observations were made. It was determined that not all EAGRT systems are being installed in accordance with the manufacturer’s guidelines. Intrusion of system components into the vehicle was documented in two collisions. It was also observed that many of the collision configurations were outside the boundaries defined by both the NCHRP Report 350 and MASH.

The major recommendations focused on installation and maintenance issues. The study also revealed areas in need of further research. These areas include the feasibility of using systems that maximize lateral offset to reduce snowplow damage, and whether an impact offset greater than one quarter would be more critical than an impact with only a quarter offset, which is currently used in the NCHRP Report 350 (and MASH) Test 3-30.

1 INTRODUCTION

EAGRTs are a relatively new technology that were developed within the past two decades by manufacturers in the southern United States. An EAGRT is designed primarily to absorb energy from a collision between a vehicle and the end of a guide rail. It is believed that EAGRTs are currently one of the better methods for treating guide rail ends; however, after several years of use in New Brunswick there is evidence to suggest that these systems may not always perform as well as desired. There are also concerns in areas that receive a lot of snowfall, such as New Brunswick, about the effect of snow accumulation around EAGRT systems. It is unclear whether snow should be cleared from around the systems during the winter or whether it should be allowed to accumulate. It is best that these questions are answered sooner rather than later as EAGRT use continues to increase throughout New Brunswick as a result of the Province's commitment toward the continuing development of its high-speed divided arterial network.

2 STUDY BACKGROUND

The primary goal of this study was to evaluate the effectiveness of EAGRTs during real-world collisions in New Brunswick. Two main tasks were performed during the study; a retrospective review and detailed analyses of collisions. The retrospective review involved a manual search of archived collision documents obtained from two road authorities, MRDC and Brun-Way, who maintain and operate sections of the Trans-Canada Highway in New Brunswick. The retrospective review provided a general baseline of information including collision frequency and collision severity. The detailed collision analyses involved a more in-depth reconstruction of eighteen collisions that were sampled during the study period. Each analysis included information about the type of EAGRT and breakaway posts that were used, and whether or not all components were properly installed prior to the crash. The vehicle damage was assessed and occupant injury information was obtained for each occupant. A reconstruction of each crash was performed, which included estimated vehicle approach speeds and angles. The results were compared to the NCHRP Report 350 testing standards.

Each collision sampled during the study occurred on one of four sections of divided, four-lane, controlled access arterial highway with a design speed of 120 km/h. The majority of the collisions occurred on the Trans-Canada Highway (Route 2) that travels through New Brunswick. The study area included a total of approximately 480 km of highway.

3 LITERATURE REVIEW

An EAGRT typically consists of a terminal head, breakaway posts, a cable anchor, a ground strut and sections of W-beam guide rail. The terminal head is mounted on the end of the guide rail with the rail positioned into a feeder chute located at the neck of the terminal head. When struck by a vehicle, the terminal head moves along the guide rail, forcing the rail into the feeder chute. When the guide rail reaches the end of the feeder chute, it is bent or flattened and forced through an opening at the side of the terminal head. The movement of the terminal head along the guide rail causes the breakaway posts to topple. Both the extrusion of the guide rail and the toppling of the breakaway posts absorb energy from the collision. This decreases the severity of the collision and brings the vehicle to a more controlled stop *(1).*

There are currently two types of EAGRTs used in New Brunswick: the ET-Plus and the SKT-350. There are two obvious differences between the two systems. The ET-Plus has a tall and narrow terminal head, while the SKT-350 has a square terminal head. Secondly, guide rail extruded through the ET-Plus is completely flattened, while guide rail extruded through the SKT-350 has a kinked appearance, as shown in Figure 1.

ET-Plus before collision **ET-Plus after collision**

SKT-350 before collision **SKT-350 after collision**

FIGURE 1: ET-Plus and SKT-350 before and after impact

NCHRP Report 350 Tests For Redirective Crash Cushions

Before an EAGRT can be used on a highway, it must pass all seven NCHRP Report 350 tests for gating terminals and crash cushions. There are three test levels; 1, 2 and 3. Test level 3 is designed for speeds of 100 km/h. There are seven applicable tests, which include tests 30, 31, 32, 33, 34, 35, and 39. Each test is explained in detail in section 3.2.2 of NCHRP Report 350 *(2).*

MASH (NCHRP Project 22-14(2))

In 2002 NCHRP Project 22-14(2) was undertaken to provide an update to NCHRP Report 350. Part of this project included the development of the AASHTO *Manual for Assessing Safety*

Hardware (MASH) in 2009, which contains the updated test procedures used for evaluating new roadside devices *(3).* MASH applies only to new roadside devices that have not been previously evaluated. All EAGRT collisions investigated in this study were compared only to NCHRP Report 350 because this was the current standard in place when these systems were installed; however, the updated MASH test procedures were considered for discussion.

EAGRT Collision Reconstruction Procedure

In 2005 Coon and Reid of the University of Nebraska-Lincoln published a report titled *Reconstruction techniques for energy-absorbing guardrail end terminals (1)*. This procedure was used in this study to calculate a minimum vehicle speed at impact for each of the detailed collision analyses.

In their paper, Coon and Reid warn that this reconstruction procedure is based on an ideally functioning EAGRT, where the guide rail feeds freely through the extruder of the terminal head and the guide rail does not become kinked at any location. They state that force levels will increase significantly if a guide rail jams in the feeder chute, resulting in energy dissipation through guide rail posts and the guide rail beam itself. They also state that significant variations in the force levels were found for the ET2000 family. According to Coon and Reid, this method should be limited to impacts where there is no jamming with ‘gating’ of the EAGRT.

After careful considering of the limitations expressed by the authors it was concluded that this technique could still be used in determining a minimum impact speed even though in many of the collisions the guide rail did become jammed or kinked in one or more locations. It is important to understand that the purpose of these calculations was not to determine the exact speed of each vehicle at impact, but rather to provide a minimum possible impact speed for each crash. An estimate of the minimum speed required to extrude the rail, even while ignoring any additional damage to the system, can help provide an indication of the crash severity. This is especially useful when there are no other means to establish the speed of the vehicle at impact.

In their paper Coon and Reid state that a force between 46.7 KN and 67.6 KN is required to extrude guide rail through the SKT-350. They did not provide corresponding information for the ET-Plus. The manufacturer of the ET-Plus system, Trinity Industries, was contacted for information regarding the force required to extrude guide rail through the ET-Plus. They provided a range of 45 – 55 KN (*4*). For this study the average force from each range was chosen as a reasonable estimated. A force of 50 KN was used for all ET-Plus collisions and a force of 57 KN was used for all SKT-350 collisions.

4 RETROSPECTIVE REVIEW

The retrospective review involved a manual search of archived collision data obtained from MRDC and Brun-Way. An attempt was made to collect as much data as possible from both sources; however, as expected the quantity and quality of the data diminished with age. No data were found for 2001 or 2002, when only the MRDC section of the highway was in operation. The earliest data collected from MRDC were for the year 2003, while the earliest data available from Brun-Way were for the year 2005. The final year of data collection for the retrospective review was 2010.

EAGRTs that were damaged by snowplows were excluded from this study. The collisions sampled as part of the detailed collision analyses have also been included with the retrospective review in order to provide continuity in the time series frequencies that are presented.

EAGRT Collision Frequency

The data in Figure 2 indicate the breakdown of collisions by source and year. The lower frequencies of EAGRT collisions observed at the start of the study period can be explained by two reasons. First, fewer crash records were available for the earlier years of the study, resulting in fewer EAGRT collisions being recorded for those years. Secondly, Brun-Way's section of highway was not fully completed until the fall of 2007, meaning there were fewer EAGRTs available to be struck during the first 5 years of the study. The first full year of service for the entire study area was 2008.

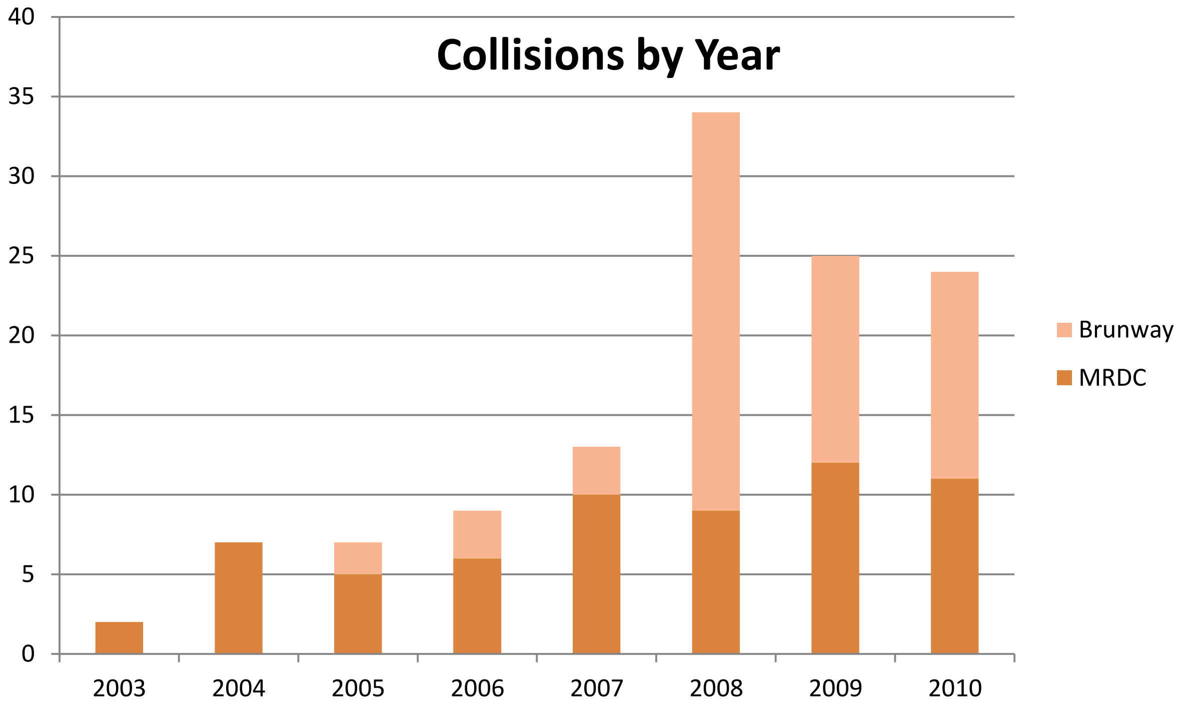

FIGURE 2: Collision Frequency by Year

The data in Figure 3 represent EAGRT collision frequencies sorted by month for both MRDC and Brun-Way. Seventeen collisions occurred in December, more than any other month, while September experienced the fewest collisions with only five.

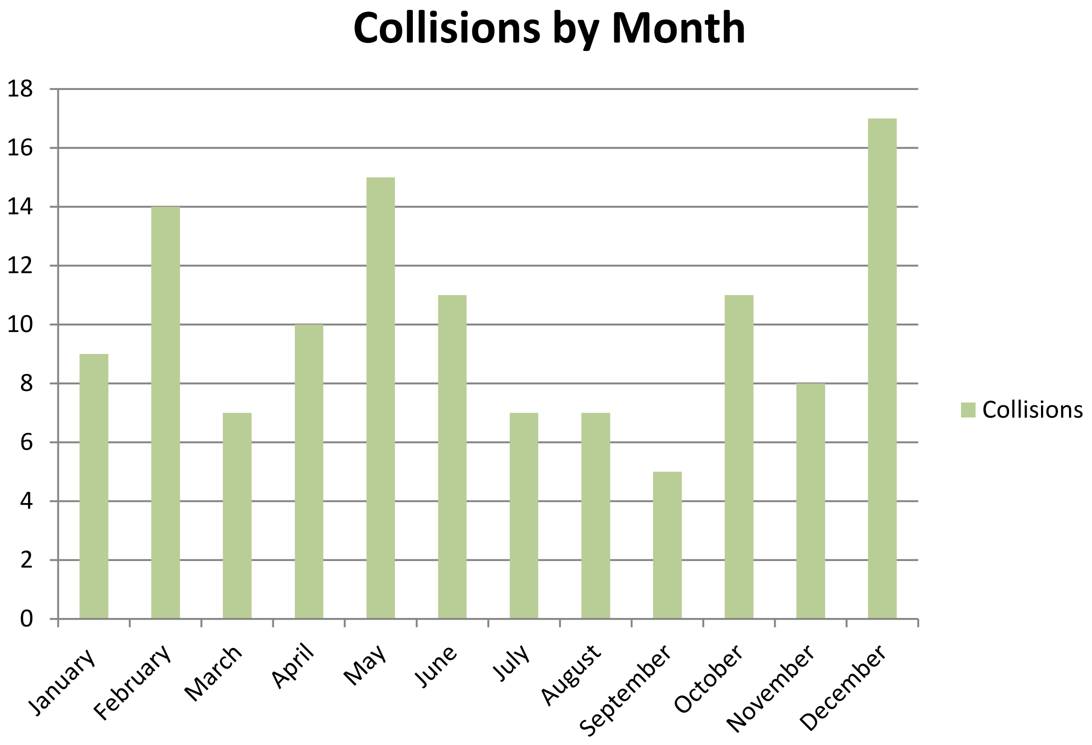

FIGURE 3: Collision Frequency by Month

EAGRT Collision Severity

The data in Table 1 are sorted by injury severity and year. Injury severity data were missing for many of the collisions that occurred prior to 2007.

TABLE 1: EAGRT Collision Severity

Severity	2003	2004	2005	2006	2007	2008	2009	2010	Total
PDO	-	-	2	5	12	26	20	19	84
Injury	-	-	-	1	1	7	5	5	19
Fatality	-	-	-	-	0	1	0	0	1
Unknown	2	7	5	3	0	0	0	0	17

- represents data that are incomplete or unavailable

The collision severity data indicate that between 2007 and 2010 when the injury severity was known for every collision, 80% of all EAGRT collisions were property damage only (PDO), nearly 19% resulted in injuries, while only one EAGRT collision resulted in a fatality.

Collision Frequency by Shoulder Location

Each EAGRT is installed on either the left (median) or right shoulder of the highway. The data in Table 2 represent the EAGRT collisions sorted according to shoulder location. No shoulder location data were available for crashes that occurred in 2003 and 2004 and very little data were available for those that occurred in 2005 and 2006.

TABLE 2: Collision Frequency by Shoulder Location

Shoulder	2003	2004	2005	2006	2007	2008	2009	2010	Total
Right	0	0	3	4	7	11	15	5	45
Left	0	0	0	4	6	23	10	19	62
Unknown	2	7	4	1	0	0	0	0	14

The data in Table 2 indicate that nearly 58% of the collisions whose locations were known occurred on the left shoulder of the highway. Traffic volumes are low on these facilities, which cause the majority of traffic to travel in the right travel lane and use the left travel lane only when passing slower-moving vehicles; therefore, it would be expected that more EAGRT collisions would occur on the right shoulder. This is not the case. The data indicate that some of the EAGRT collisions that would be expected to occur on the right shoulder are prevented by the use of rumble strips. In New Brunswick rumble strips are currently only used along the right shoulder. The data support the argument that rumble strips should be used on both sides of the highway.

EAGRT Performance Affected by Snow

Snow removal protocol around EAGRTs is a topic that has been under debate for many years. Some jurisdictions completely remove snow from around the EAGRT; some remove snow from the front of the terminal head only; while others do not remove any snow, allowing it to accumulate around the terminal head. The current practice in New Brunswick is to allow snow to accumulate around EAGRTs; however, actual practices vary around the province depending on which jurisdiction is clearing the snow *(5).*

The retrospective review provided evidence of at least one collision in 2009 that was affected by a heavy accumulation of snow behind the terminal head. The snow had been cleared from the front of this EAGRT, exposing the terminal head, but had been left to accumulate behind the guide rail and terminal head. When the EAGRT was struck the snow prevented the guide rail from extruding through the terminal head. The guide rail jammed, causing the terminal head to swing upward as demonstrated in Figure 4. The terminal head was not able to absorb energy as designed. This caused the vehicle to decelerate suddenly. There were three occupants in the vehicle and all were transported to hospital with injuries.

FIGURE 4: Terminal head kinked upward adjacent to snowbank (Source: Brun-Way, 2009)

5 DETAILED COLLISION ANALYSES

There were eighteen collisions included in the detailed reconstruction analyses. All collisions occurred between April 2009 and December 2010. The data in Table 3 describe the type of vehicle, EAGRT, and injury outcome of each crash.

TABLE 3: Summary of Detailed Collisions

Vehicle	EAGRT Type	Injury Severity
1990 Mazda B2200	SKT-350	PDO
1993 Ford Topaz	ET-Plus	PDO
2000 Ford Focus	ET-Plus	Injury
2001 Chevrolet Impala	ET-Plus	PDO
2001 Chrysler Neon	ET-Plus	PDO
2001 Dodge Caravan	ET-Plus	Injury
2001 Mazda Protege	ET-Plus	PDO
2002 Nissan Altima	ET-Plus	PDO
2002 Toyota Corolla	ET-Plus	PDO
2003 Ford Windstar	SKT-350	PDO
2003 Mazda Protege5	SKT-350	PDO
2003 Nissan Pathfinder	SKT-350	Injury
2006 Volkswagen Jetta	ET-Plus	PDO
2007 Chevrolet Cobalt	ET-Plus	Injury
2007 Chrysler 300	ET-Plus	PDO
2007 Ford Ranger	ET-Plus	PDO
2007 Kia Rio5	ET-Plus	PDO
2009 Ford Escape	ET-Plus	Injury

The data in Table 3 reflect that the ET-Plus system is used more frequently in New Brunswick than the SKT-350 system. The detailed collision study included thirteen PDO collisions, five injury-producing collisions, and no fatal collisions. The injuries were all minor and ranged from contusions and lacerations to temporary loss of consciousness.

Table 4 contains data about each EAGRT system including the type of breakaway posts used, the number of posts broken during each crash, the distance the terminal head was offset laterally from the rest of the guide rail, the height of the guide rail, and the length of extruded and damaged guide rail.

TABLE 4: EAGRT Characteristics

Collision	Breakaway Post Type	Posts Damaged	Height to Centre of Guide Rail (cm)	Length of Extruded Guide Rail (m)	Length of Damaged Guide Rail (m)	Offset at Terminal Head (cm)
B2200 vs. SKT-350	HBA	5	53	7.21	7.21	8
Topaz vs. ET-Plus	HBA	2	42	2.67	4.12	15
Focus vs. ET-Plus	HBA	5	55	5.40	9.70	20
Impala vs. ET-Plus	CRT	5	53	3.80	5.80	0
Neon vs. ET-Plus	CRT	6	55	11.00	11.00	0
Caravan vs. ET-Plus	HBA	4	55	5.06	7.60	25
Protege vs. ET-Plus	HBA	2	56	2.90	2.90	0
Altima vs. ET-Plus	CRT	9	53	5.20	15.80	10
Corolla vs. ET-Plus	Plug Welded	4	51	6.90	7.62	20
Windstar vs. SKT-350	Plug Welded	7	50	8.40	9.80	25
Protege5 vs. SKT-350	Plug Welded	5	54	4.50	7.90	15
Pathfinder vs. SKT-350	Plug Welded	7	45	7.10	13.30	10
Jetta vs. ET-Plus	HBA	4	56	6.50	9.50	0
Cobalt vs. ET-Plus	HBA	5	57	3.60	7.85	20
300 vs. ET-Plus	HBA	8	52	11.10	15.24	15
Ranger vs. ET-Plus	CRT	6	52	4.30	9.60	20
Rio5 vs. ET-Plus	CRT	7	55	9.85	13.34	10
Escape vs. ET-Plus	HBA	7	63	4.10	12.00	0

Nine of the EAGRT systems were installed with Hinged Breakaway (HBA) posts, five systems were installed with Controlled Release Terminal (CRT) wood posts, four systems were installed with plug welded posts, while Steel Yielding Terminal Posts (SYTP), which are also used in New Brunswick, did not appear in the sample. Plug welded posts were installed on one ET-Plus system, even though these posts are only designed for the SKT-350 system.

The minimum number of posts broken in any collision was two, while the maximum number of posts broken was nine. The average crash resulted in five posts broken.

The minimum, average, and maximum measured heights from the shoulder to the centre of the guide rail beam were 42, 53, and 63 cm, respectively. According to the Roadside Design Guide (2006), the suggested height from the shoulder to the centreline of the guide rail is 55 cm *(6)*. The average guide rail height on all installations was close to the recommended height; however, some of the installations varied from the recommended height by as much as 13 cm.

The length of extruded guide rail was the most important measurement in estimating the amount of energy absorbed by the EAGRT system and it provided a means of quantifying the benefit of each EAGRT. The minimum, average, and maximum lengths of extruded guide rail were 2.67 m, 6.09 m, and 11.1 m, respectively.

The length of damaged guide rail was also measured. Damaged guide rail included the length of extruded guide rail, as well as any additional sections of guide rail that were kinked or bent. In collisions where the guide rail was not kinked or bent the length of extruded guide rail was the same as the length of damaged guide rail. The minimum, average, and maximum lengths of damaged guide rail were 2.90 m, 9.46 m, and 15.8 m, respectively.

The manufacturers of the ET-Plus and SKT-350 permit them to be installed with a maximum flare of 25:1 from the edge of the roadway. This means that the terminal head of an 8-post EAGRT system that is 15.24 m (50’ 0”) long can be offset from the rest of the guide rail by a maximum of 60 cm (2’ 0”). Five of the EAGRT systems were installed parallel to the roadway with zero offset. The average offset was 12 cm, while the maximum offset was 25 cm, which is less than half of the maximum allowable offset.

The EAGRT in Figure 5 was included in this study and was installed with a minimal offset of 15 cm, resulting in a flare of 100:1. There is nothing technically wrong with this installation; however, the installation does not take advantage of the maximum flare allowed by the manufacturer. In contrast, it is important to ensure an EAGRT system is not installed with too much flare. Figure 6 is an example of an EAGRT system installed with a 10:1 flare, which is more than allowed by the manufacturer. The EAGRT in Figure 6 was located in another province and was not part of this study.

FIGURE 5: EAGRT installed with 100:1 flare

FIGURE 6: EAGRT installed with 10:1 flare

Intrusion into occupant compartment

One of the main objectives of an EAGRT system is to prevent the guide rail from intruding into the occupant compartment of an impacting vehicle. Three of the eighteen collisions in the sample resulted in intrusion into the occupant compartment. These three vehicles were the Altima, the Cobalt, and the Ranger. Each collision involved the ET-Plus system and none of these systems had any incorrect installation issues that would have affected the performance of the EAGRT.

The Cobalt was impacted on its side, causing the terminal head to intrude directly into the rear occupant compartment. The Ranger was also impacted on its side, causing the lower portion of the door to intrude into the occupant compartment. The Altima was initially impacted on its left front corner, causing the vehicle to rotate into the guide rail. A kinked section of the guide rail then intruded through the front passenger window. Figure 7 demonstrates the extent of damage and intrusion into each vehicle.

Right rear seat of Cobalt **Right side of Ranger**

Edited photo demonstrating position of Altima at FRP

FIGURE 7: Examples of intrusion into occupant compartment

The guide rail became kinked in all three of these collisions. Kinking of the guide rail is something that occurs often during EAGRT impacts and is unavoidable in many instances due to rotation of the vehicle. NCHRP 350 allows kinking of the guide rail during its crash tests, provided that no part of the guide rail or EAGRT intrudes or penetrates, or shows potential for intruding or penetrating, into the vehicle (*2*, *7*). In fifteen of the eighteen collisions studied at least one section of the guide rail became kinked during the crash. The Altima demonstrated that the guide rail does have the potential to kink and enter the occupant compartment during a head-on impact; however, this was not a common occurrence throughout the study.

Vehicle rollovers

One of the goals of an EAGRT system is to prevent vehicle rollovers, which occur frequently with buried-end guide rails. Three of the eighteen collisions in this study resulted in a vehicle rollover (Escape, Focus, Protege5). The rollovers typically occurred after the vehicles had lost a substantial amount of their speed. The EAGRT systems involved in two of these collisions were properly installed; however, the ET-Plus that was struck by the Escape had an HBA post that was installed backwards. This prevented the post from toppling properly, causing it to remain partially upright. This post likely contributed to the rollover, as the Escape overturned after travelling over the post.

EAGRT Installation Problems

It was determined that three of the eighteen EAGRT systems had not been installed properly according to manufacturer specifications. The ET-Plus that was struck by the Corolla was installed with plug welded posts, which are only designed for the SKT-350. The ground strut on this system was also designed only for the SKT-350. The ET-Plus that was struck by the Cobalt had two HBA posts installed 180° backwards (these posts were not actually contacted during the collision), while the ET-Plus that was struck by the Escape had one HBA post installed backwards. This post was contacted during the collision.

Windshield Damage

There were three instances during the study where the windshield of the impacting vehicle was struck by an exterior object other than the hood. These three vehicles were the Impala, the Neon, and the Rio5. The windshield of the Impala suffered the most damage and was actually punctured, as shown in Figure 8. All three collisions involved an ET-Plus system equipped with CRT wood posts. The damage was likely a result of contact with a CRT post, which typically break into two pieces when struck. This was not observed in any other collision involving HBA or plug welded posts because these types of posts are designed to remain attached to their ground anchors after impact, with the exception of the first post *(8, 9, 10).*

FIGURE 8: Punctured windshield of Impala

Energy Absorbed by the EAGRT

The total energy absorbed during each collision was estimated using Coon and Reid's reconstruction procedure and traditional collision reconstruction methods including slide-to-stop and rollover formulas, etc. The results are listed in Table 5 below. It is important to note that Coon and Reid's reconstruction procedure uses conservation of momentum and the initial impact between the vehicle and terminal head is considered perfectly plastic. This means that forces such as vehicle crush do not need to be explicitly calculated in the reconstruction procedure (*1*).

TABLE 5: Energy Absorbed During Each Collision

Collision	Energy absorbed by extrusion of guide rail (KJ)	Total collision energy (KJ)	Guide rail energy/collision energy (%)
B2200 vs. SKT-350	412	412	100*
Topaz vs. ET-Plus	134	163	82
Focus vs. ET-Plus	270	336	80
Impala vs. ET-Plus	190	554	34
Neon vs. ET-Plus	550	550	100*
Caravan vs. ET-Plus	253	314	81
Protege vs. ET-Plus	145	211	69
Altima vs. ET-Plus	260	317	82
Corolla vs. ET-Plus	345	420	82
Windstar vs. SKT-350	480	777	62
Protege5 vs. SKT-350	257	416	62
Pathfinder vs. SKT-350	406	892	46
Jetta vs. ET-Plus	325	425	76
Cobalt vs. ET-Plus	180	279	65
300 vs. ET-Plus	555	696	80
Ranger vs. ET-Plus	215	396	54
Rio5 vs. ET-Plus	493	608	81
Escape vs. ET-Plus	205	508	40
Average of all Collisions	**315**	**460**	**68**

** these ratios in reality are less than 100% because a small amount of the energy is absorbed by vehicle crush*

The total collision energy in column three is an estimate of the energy the vehicle had just prior to impacting the EAGRT. It includes the energy absorbed by the extrusion of the guide rail and toppling of posts (column two) and any additional energy that is lost during travel including tire friction, etc. For each collision the energy absorbed by the extrusion of the guide rail was expressed as a percentage of the total collision energy in an attempt to quantify the benefit of the EAGRT system. These results are presented in the fourth column of Table 5.

It should be noted that the energy absorbed by the extrusion of the guide rail does not always represent the energy absorbed by the EAGRT system. In cases where the guide rail becomes kinked there is additional energy absorbed by the EAGRT system which cannot be accounted for.

The data indicate that for each collision an average of 315 KJ of energy was absorbed through the process of guide rail extrusion, which represents nearly 70 % of the average total energy absorbed during each collision (460 KJ).

Comparison to NCHRP Report 350 Tests

The impact location, impact angle, and impact speed of each collision were estimated and compared to the various NCHRP Report 350 test configurations. The data are synthesized in Table 6. In cases where there was significant damage including kinking and buckling of the guide rail the minimum calculated impact speed (column 4) is likely significantly lower than the actual impact speed of the vehicle. In some cases additional data were available including driver statements or Event Data Recorder (EDR) data, which provides a more reliable impact speed (column 5).

The data indicate that one collision (Impala) was almost identical to an NCHRP Report 350 test, four collisions were similar to an NCHRP Report 350 test, while the remaining collisions were not similar to any of the tests.

Seventeen of the eighteen impact angles were within the specified range of 0 – 15° and many of the impact speeds were within 15 km/h of the 100 km/h test speed. The impact location was usually the limiting factor. Only four of the eighteen impacts occurred on the front bumper within one quarter of the vehicle's width from the centreline. Eleven of the impacts occurred on the left or right front corner of the vehicle, while the three remaining impacts occurred on either the side or rear of the vehicle. An impact to the left front corner for vehicles travelling onto the left shoulder or an impact to the right front corner for vehicles travelling onto the right shoulder were the most common impact configurations. These types of impact configurations often resulted in significant rotation of the vehicle. This was especially evident with the Caravan, 300, Escape, Protege5, Rio5, and Pathfinder. The data provide a good argument that an impact to the front corner of the vehicle (with an offset greater than one quarter of the vehicle's width) would create a more critical impact scenario than an impact with only a quarter offset. This brings to question whether the quarter offset used in NCHRP 350 (and MASH) Test 3-30 should be increased. This would result in the terminal head impacting closer to the front corner of the vehicle, which was more prevalent in this study and, arguably, the more critical impact configuration.

TABLE 6: Comparison to NCHRP Report 350 Test Parameters

Vehicle	Impact within 1/4 offset from centreline	Estimated Impact Angle (°)	Estimated Minimum Impact Speed (km/h)	Most Reliable Impact Speed (km/h)	Similar NCHRP Report 350 Test #
B2200	no	5	95	95	#30, with greater impact offset
Topaz	no	10	60	60	None
Focus	yes	5	87	120 (driver)	#31/32, with higher speed
Impala	yes	5	97	101 (EDR)	31/32
Neon	yes	0	110	110	#31, with higher speed
Caravan	no	5	69	69	None
Protege	no	12	64	110	None
Altima	no	10	77	115 (driver)	None
Corolla	no	0	100	100	#30, with greater impact offset
Windstar	no	-2	91	110 (driver)	None
Protege5	no	2	92	130 (driver)	None
Pathfinder	no	5	105	105	None
Jetta	yes	5	84	90 (driver)	None
Cobalt	no	10	76	100 (EDR)	None
300	no	1	102	118 (EDR)	None
Ranger	no	5	61	75 (driver)	None
Rio5	no	5	119	119	None
Escape	no	2	88	110 (driver)	None

6 CONCLUSIONS AND RECOMMENDATIONS

It was determined that fourteen of the eighteen collision configurations observed in this study did not match any of the NCHRP Report 350 test configurations. The most common, and arguably the most critical, impact configuration was an impact to the front corner of the vehicle. This represents an impact that is offset by more than the quarter offset that is currently used in NCHRP 350 (and MASH) Test 3-30. Further research is needed to investigate whether an impact offset greater than one quarter would, in fact, be more critical than an impact with only a quarter offset, especially given that the greater offset was much more prevalent in this study.

None of the EAGRTs included in the detailed analyses were installed with the maximum allowable offset (flare). Any new EAGRT systems used in Snowbelt regions that are installed at a new location or at an existing location to replace a damaged system should be installed with a flare of 25:1 from the edge of the road, when possible. This would be extremely helpful in reducing snowplow impacts in areas that receive heavy amounts of snowfall. It may also be beneficial to consider using other systems such as the Flared Energy-Absorbing Terminal (FLEAT) which can be installed with a larger flare than the ET-Plus and SKT-350 systems *(11)*. This would further reduce the probability of an impact with a snowplow.

The study provided evidence that clearing snow from the front of an EAGRT's terminal head while leaving it to accumulate behind the EAGRT system is not ideal. It appears that the best option is to allow the terminal head to become buried in the snow. This will reduce the amount of impacts to the terminal head and requires less effort for snow removal. If a road authority decides to clear the snow from the front of an EAGRT's terminal head, it should also be cleared from behind the EAGRT system to provide adequate space for the extruded guide rail to travel during a collision.

The HBA, plug welded, and CRT posts were all represented in the detailed analyses. There were data that suggested CRT posts may have made contact with and damaged the windshields on three of the vehicles in the study; however, there was not enough evidence to prove the damage was indeed caused by contact with the posts. The potential for CRT posts to act as a projectile during a crash is something that should be monitored in future studies.

Sections of guide rail often become kinked during EAGRT collisions, which was the case in fifteen of the eighteen collisions included in the detailed analyses. A kinked section of guide rail intruded into the occupant compartment of one of the vehicles, but did not result in any injuries. Intrusion of the guide rail into a vehicle's occupant compartment should be considered for future studies.

The eighteen EAGRT collisions resulted in three vehicle rollovers; however, all three rollovers occurred after the vehicles had lost much of their speed. Vehicle rollovers are another factor that should be included in future research.

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