Performance of Weathered Steel Guardrail in NC

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16. Abstract

Weathered steel beam guardrail is a popular alternative to galvanized steel guardrail as an aesthetic solution that blends in with the surrounding natural environment. A research study from New Hampshire found that weathered steel guardrail deteriorated quicker than galvanized steel guardrail leaving erratic motorists without a safe roadside barrier. Weather conditions and de-icing chemicals play an obvious role in the deterioration of guardrail. These weather conditions vary across geographical regions, raising the question whether the New Hampshire findings are applicable to North Carolina locations. Nonetheless, the New Hampshire study is being recommended by the Federal Highway Administration for adoption across the country. Some North Carolina weathered steel guardrail installations from the 1980s and 1990s have provided a significant length of service; leading many to believe the findings from New Hampshire might not apply to other states with less severe weather conditions. Eliminating a potential guardrail treatment based on a non-comparable study location is not good engineering practice. Since weathered steel is more aesthetically pleasing and a preferable alternative in many natural environments, this study measures the rate of deterioration under North Carolina specific conditions. The study findings will be valuable to guide further guardrail installation and replacement decisions in North Carolina.

The team did not find any trends of deteriorating thickness as a function of guardrail age (oldest installation is almost 30 years old), elevation (highest average installation elevation is 4,200 feet), and AADT (highest traffic is 27,000 vehicles per day). The structural analysis therefore suggests no concerns of using weathered steel beam guardrail in the state of North Carolina. Collision analysis found that weathered steel beam guardrail collisions did not result in more severe collisions than galvanized steel guardrail, and that the severity of collisions decreased over the study period.

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EXECUTIVE SUMMARY

Weathered steel beam guardrail is a popular alternative to galvanized steel guardrail as an aesthetic solution that blends in with the surrounding natural environment. A research study from New Hampshire found that weathered steel guardrail deteriorated quicker than galvanized steel guardrail leaving erratic motorists without a safe roadside barrier. Weather conditions and de-icing chemicals play an obvious role in the deterioration of guardrail. These weather conditions vary across geographical regions, raising the question whether the New Hampshire findings are applicable to North Carolina locations. Nonetheless, the New Hampshire study is being recommended by the Federal Highway Administration for adoption across the country. Some North Carolina weathered steel guardrail installations from the 1980s and 1990s have provided a significant length of service; leading many to believe the findings from New Hampshire might not apply to other states with less severe weather conditions. Eliminating a potential guardrail treatment based on a non-comparable study location is not good engineering practice. Since weathered steel is more aesthetically pleasing and a preferable alternative in many natural environments, this study measures the rate of deterioration in North Carolina specific conditions, and supplements those findings with collision data analyzed over the life of the guardrail treatment. The study findings will be valuable to guide further guardrail installation and replacement decisions in North Carolina.

The research did not find any trends of deteriorating thickness as a function of guardrail age (oldest installation is almost 30 years old), elevation (highest average installation elevation is 4,200 feet), and AADT (highest traffic is 27,000 vehicles per day). The structural analysis therefore suggests no concerns of using WSB guardrail in the state of North Carolina. The findings from this research project differ significantly from the findings of a study which found that WSBG performed inadequately in New Hampshire. The routes with significant lengths of WSBG were located in western NC with low ADTs which led to low sample sizes for the collision data. Sample sizes were only sufficient enough to statistically analyze percent injury (K+A+B+C) collisions while combining each of the three sites. Statistical testing showed that there is a significant difference between the severity rates of WSBG and GSG installations, with WSBG experiencing a lower percentage of injury collisions than GSG. Only two WSBG and three GSG incapacitating crashes (K+A) took place over the entire analysis period, with both observed fatalities occurring on GSG sites. The lack of available sample sizes for incapacitating crashes further emphasizes that both guardrail types are likely adequate for redirecting traffic safely as intended to protect motorists from the severe terrain or objects behind the guardrail.

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1. INTRODUCTION

Efficient use of resources within the North Carolina Department of Transportation (NCDOT) is an important topic as budgets become tighter and staff availability becomes limited. The use of weathered steel beam guardrail (WSBG) has provided motorists of North Carolina with the dual benefit of a protective and aesthetic barrier. The primary use of WSBG is to protect errant motorists from a more dangerous roadside hazard behind the guardrail. As a secondary benefit, WSBG provides a more appealing aesthetic environment than traditional galvanized steel guardrail (GSG), particularly along roadways that pass through National Forests (Exhibit 1).

Exhibit 1. WSBG Installation in National Forest (Photo by J. Findley)

1.1. Problem Definition and Need

WSBG has been used across North Carolina for many years as both a protective and aesthetic barrier, and as a viable alternative to GSG. However, the inadequate performance of WSBG in a recent study performed in the state of New Hampshire has raised concern about the quality of the material at all installations (Perkins 2004). In response to the study in New Hampshire, an NCDOT memorandum on June 6, 2006 advised the Project Development and Environmental Branch to discontinue the usage of WSBG (NCDOT 2006) following this federal recommendation. However, the weather conditions are much different in New Hampshire than in North Carolina along with the corresponding de-icing frequency and quantity. For instance, the average annual snowfall in Asheville, NC is 15.2 inches compared to 63.8 inches in Concord, NH and 260.6 inches in Mt. Washington, NH (NOAA 2011). Counties in North Carolina's coastal and piedmont regions have even lower annual snowfall rates than mountainous counties.

Exhibit 2 shows the average annual snowfall accumulation of cities in New Hampshire and North Carolina, where data was available.

Exhibit 2. Average Annual Snowfall Accumulation in NC and NH

City, State	Annual Snowfall Accumulation (in)
Asheville, NC	15.2
Cape Hatteras, NC	1.9
Charlotte, NC	5.5
Greensboro/Winston-Salem/High Point, NC	9.1
Raleigh, NC	7.5
Wilmington, NC	2.0
Concord, NH	63.8
Mt. Washington, NH	260.6

Source: NOAA 2011

Exhibit 3 provides a visual display of the annual snowfall accumulation during 2009 across North Carolina, while Exhibit 4 provides the same information for New Hampshire. The piedmont and coastal areas of North Carolina experienced average snowfall accumulations of 0 to 15 inches, while the majority of locations in the mountains of North Carolina experienced 15 to 45 inches of snowfall accumulation. The majority of locations shown in New Hampshire saw 60 to 150 inches of snowfall accumulation.

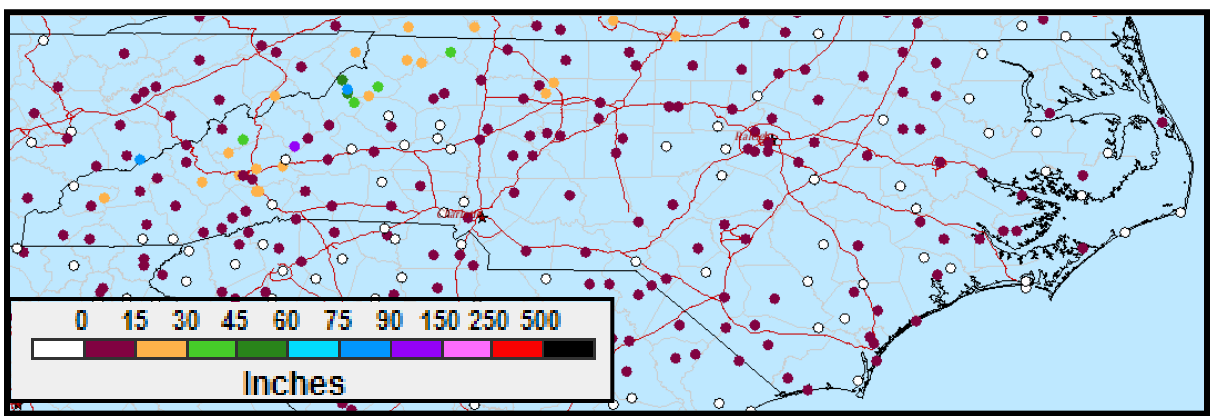


Exhibit 3. Annual Snowfall Accumulation in North Carolina for 2009 (NOAA 2009)

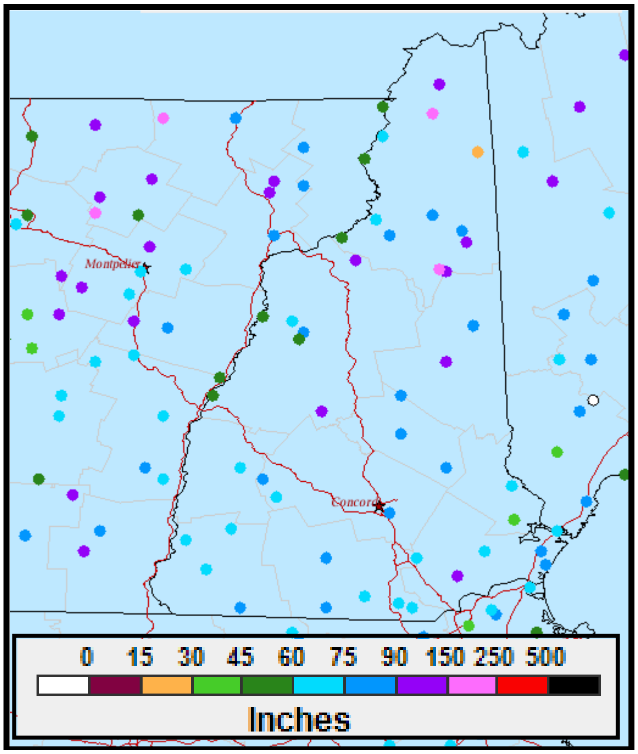


Exhibit 4. Annual Snowfall Accumulation in New Hampshire for 2009 (NOAA 2009)

The many existing miles of WSBG currently in service in North Carolina needed to be studied to assess their condition as they age and are exposed to weather and de-icing chemicals. Also, no affordable and durable alternative to the aesthetic WSBG is currently available. The use of painted galvanized steel beam guardrail in place of WSBG is more expensive and can experience chips in the paint during installation due to deformation of the guardrail when attaching to posts and other spans of guardrail. In this research, WSBG installations were studied to determine their operational and safety performance under North Carolina specific weather conditions and maintenance practices.

Exhibit 5 shows examples of WSBG installations that have been in service for approximately 15 years in Graham County, NC on the Cherohala Skyway (NC 143). Exhibit 6 shows an example of WSBG installed in New Hampshire between ten and twenty years old. Notice the amount of deterioration of the guardrail and accumulation of snow in Exhibit 6.

State policies have been dictated by a study in a distinctively different weather condition from North Carolina. This research will provide decision makers in NCDOT with data from North Carolina on the structural and safety performance of WSBG over different geographical and climatic conditions. The results of this research therefore represent a more recent and more representative evaluation of WSBG in the state of North Carolina that can help inform future policy decisions.


Exhibit 5. Weathered Steel Beam Guardrail Installation on NC 143 (Photos by D. Findley)


Exhibit 6. Weathered Steel Beam Guardrail Installation in New Hampshire (Perkins 2004)

1.2. Research Objectives

The aim of this research was to determine how WSBG has performed under North Carolina conditions, so that the NCDOT can make more informed installation and replacement decisions. The specific objectives were to:

- Compile an inventory of locations of WSBG in NC
- Compile an inventory of location of GSG in similar locations as WSBG for safety comparison
- Collect crash data at selected WSBG and GSG locations
- Observe and document the condition of WSBG in NC
- Observe and document the variations of WSBG among NC specific weather conditions, elevation, and de-icing activities
- Compare the current condition of the WSBG in the study to initial installation characteristics and summarize its performance
- Evaluate WSBG safety performance relative to similar GSG installations
- Document the operational and safety findings of WSBG in NC

2. LITERATURE REVIEW

2.1. Introduction

The following subsections detail a survey of state transportation agencies on the state of the practice with respect to WSBG, structural considerations for W-Beam guardrail, and collision severity of W-Beam guardrail. The first subsection deals specifically with WSBG, while the remaining subsections contain some material which are more general and can apply to multiple types of W-Beam guardrail, including WSBG.

2.2. Survey of State Transportation Agencies

The New Hampshire Department of Transportation surveyed other states on their use of WSBG (NHDOT 1999). In their survey, the researchers found that half of the forty respondents use WSBG and that two of the respondents had discontinued its use due to corrosion issues.

This research team contacted each transportation agency in the United States as an update to the NHDOT survey which was ten years old at the time of the survey. The research team inquired about the presence, quantity, use, and experience of WSBG in each jurisdiction. Among the 36 responding state agencies, 21 agencies have installations of WSBG in their jurisdictions and 15 do not have WSBG installations. Many of the agencies did not have detailed inventories of their WSBG installations, but those who provided information about the approximate quantity of WSBG include: Delaware (50 locations), Maine (1/2 mile since 2008), Maryland (210 miles), Oregon (50 miles), Utah (18 miles), West Virginia (39 miles), and Washington (380 miles).

The findings from the survey of state transportation agencies include:

- Many states responded that they allow the use of WSBG in specialized areas only, particularly natural areas.
- Three states responded that they have used WSBG in the past, but have discontinued the use of WSBG because of concerns over its structural integrity, cost, or availability.
- Public perception about WSBG can either be positive (aesthetically pleasing) or negative (unaesthetic, poor maintenance practices).
- Use of WSBG in an area requires stockpiling extra guardrail to replace damaged sections. If WSBG isn't available to replace a damaged section of existing WSBG, the replacement with a GSG section can be less than ideal from an aesthetics perspective.
- Several respondents noted that they have no concerns with WSBG beyond what is expected of any guardrail (environmental conditions and frequency of deicing chemical use affects all types of guardrail). The expected design lifespan of WSBG installations are being exceeded in numerous states.
- The hardware (nuts and bolts) are difficult to remove when replacing damaged sections, which makes repairs more time consuming and expensive.
- Low volume roads (which are the predominant locations of WSBG) are less likely to get excessive amounts of deicing chemical use because of the low volumes.

- One respondent described that their state's policy only allows new WSBG installations in locations where the annual rain fall is less than eight inches.
- Alternative types of guardrail to replace WSBG reported by respondents include: painted guardrail, stained GSG, polyester coated GSG, powder coated, acid washed GSG, steel-backed timber guardrail, stainless steel or galvanized steel tube railing with reinforced concrete base, stained concrete, concrete with encouragement of lichen growth, and stone columns.

2.3. Structural Considerations for W-Beam Guardrail

The American Association of State Highway and Transportation Officials (AASHTO) specifies guidelines and tolerances for guardrails (2004). The specification which covers WSBG is Class A, Type IV with a thickness of 0.105 inches. The specification also calls for a tolerance under the specified thickness of 0.009 inches, with no limit for over thickness.

The Federal Highway Administration (FHWA) provides guidance on roadside hardware, including w-beam guardrail (2011). FHWA recommends that the use of WSBG should be limited due to its proximity to the path of travel which can introduce water and chemicals sprayed from passing vehicles. The water and chemicals can degrade the structural integrity of the WSBG. FHWA recommends that agencies using WSBG should carry out frequent inspections and have a replacement schedule.

NCDOT has established guidelines on the condition assessment on W-beam guardrail in the *Maintenance Condition Survey Manual* (NCDOT 2008). The manual explains the risk of non-functioning guardrails which can be more hazardous to a driver than the roadside hazard it was meant to protect. Severely damaged guardrail should be repaired immediately, while moderately damaged, but still functional guardrail can be scheduled for future repair in coordination with other improvements. The threshold condition for guardrail repairs occurs when the guardrail is not functioning as designed or has been damaged. A damaged guardrail is defined as a rail beam which is dislocated by 18 inches, severed, or has three or more broken posts.

NCHRP Report 656 developed criteria for evaluating the need for guardrail replacement based on insufficient performance from damages (Gabler 2010). The researchers identified section loss as the quantitative repair criterion for any structural corrosion causing deterioration. However, the researchers were unable to test all of the proposed repair guidelines, including section loss. Therefore, the repair guidelines tests that were conducted could be used to infer the performance of other damage modes. Guardrail with section loss damage is expected to behave in a similar manner to guardrail which has a hole or tear.

Three levels of priority for guardrail replacement were designated in the guidelines (Gabler 2010):

- High priority, which indicates damage where the crash performance of the barrier has been compromised to such a degree that a second impact to the damaged barrier would result in unacceptable vehicle and/or barrier performance. This would include vehicle penetration of the barrier (via rail rupture, vehicle override, or vehicle underride) and vehicle rollover.

- Medium priority indicates damage where the crash performance of the barrier has likely been compromised to some degree but the damage is less likely to result in unacceptable vehicle and/or barrier performance than high-priority damage.
- Low Priority: Indicates damage where the crash performance of the barrier is indistinguishable from the undamaged condition.

The report specified three damage types which are expected to behave in a similar manner to guardrail with a section loss, including (Gabler 2010):

- Non-manufactured holes (such as holes caused by a collision, lug-nuts, or rusted-through):
  - More than two holes less than 1 inch in height in a 12.5' long rail (high priority)
  - Any holes greater than 1 inch in size (high priority)
  - Any hole which intersects either the top or bottom edge of the rail (high priority)
  - One or two holes less than 1 inch in height in a 12.5' long rail (medium priority)
- Vertical tear
  - Any length vertical (transverse) tear (high priority)
- Horizontal tear
  - Horizontal (longitudinal) tear greater than 12 inches long and greater than 0.5 inches wide (medium priority)

A study by the New Hampshire Department of Transportation Bureau of Materials and Research found that WSBG performed inadequately in New Hampshire (Perkins 2004). The methodology defined inadequate performance when a 10% or greater section loss occurred when compared to original thickness. After 10 to 15 years in service, the study found a 25% failure rate at mid-span locations, and a 50% failure rate at lap connections. For locations with 15 to 20 years of service, the mid-span failure rate was 25% and the lap connection failure rate was 71%. The researchers also recommended using zinc inserts in sections of WSBG which overlap (typically at locations where the beams are connected to the posts). These findings raised concern about the quality of the material at all installations and NCDOT responded to the study with a memorandum on June 6, 2006 that advised the Project Development and Environmental Branch to discontinue the usage of WSBG (NCDOT 2006). However, the weather conditions are much different in New Hampshire than in North Carolina, along with the corresponding de-icing frequency and quantity. The decision to discontinue the use of a roadside barrier with many miles of installation in the state should be based on comparable data in that state. This research project provides valuable data on how WSBG performs under North Carolina specific conditions.

2.4. Collision Severity of W-Beam Guardrail

A meta-analysis of 32 studies of roadside barriers found that guardrails reduce the severity of collisions at both new installations and replacements of old installations (Elvik 1995). The risk of a collision including a fatality is reduced by 45% and the risk of a collision involving an injury is reduced by 50%.

A study of barrier collisions in North Carolina, shown in Exhibit 7, found that for all types of barriers on all types of routes, 3% of collisions were fatal or involved an incapacitating injury and 72% were property damage only (Ray et al. 2003). The strong post w-beam guardrail with a steel post, which is a similar design to the WSBG included in this study, had a fatal and incapacitating injury percentage of 4% and 65% property damage only collisions.

Exhibit 7. Percentage of Severity of Barrier Collisions in NC in 1995 (Ray et al. 2003)

Severity	Interstate Routes	US Routes	State Routes	Strong Post (Steel) W-Beam Guardrail	All Routes and Guardrail Types
A+K	3	7	0	4	3
B+C	22	29	30	31	25
PDO	75	64	70	65	72
Total	100	100	100	100	100

3. SITE CONSIDERATIONS

The research team contacted each Division and District Engineer in North Carolina to identify WSBG locations across the state. The research team located and documented numerous locations of WSBG guardrail as shown in Exhibit 8. Each of the 25 locations were visited by the research team to investigate their structural and roadway characteristics. Appendix A contains photographs of installation locations.

Exhibit 8. WSBG Installations in North Carolina

Route	Installation Year	Linear Miles of WSBG	County
NC 215	2010	16.6	Transylvania
NC 143 – Cherohala Skyway*	1994	16.5	Graham
US 74 / NC 19*	2001	7.0	Swain/Macon
US 64 / NC 28 – Franklin Road*	2001	6.1	Macon
SR 1159 – Santeetlah Road*	1988	5.8	Graham
US 276*	2003	9.3	Transylvania/Haywood
NC107 (South of Cashiers)	2002	3.0	Jackson
NC 143 – Snowbird Road	1994	1.3	Graham
NC 49	2000	1.2	Davidson
IBM Drive	1997	0.8	Mecklenburg
NC107 (at WCU entrance)	1982	0.8	Jackson
Greenfield Parkway	1990	0.7	Wake
SR 5017 - Henson Forest Drive	2005	0.6	Guilford
National Service Road	2004	0.5	Guilford
SR 1001 - Fallston - Waco Road	2007	0.2	Cleveland
NC 150	2004	0.2	Iredell
SR 2044 - Ligon Mill Road	2005	0.2	Wake
US 17	2005	0.1	Pender
NC 700 - Meadow Road	2008	0.1	Rockingham
SR1527 - Richmond Hill Rd	2003	0.1	Yadkin
US264A - Raleigh Road	2006	0.1	Wilson
NC 194	2000	0.1	Watauga
NC 194	1994	< 0.1	Watauga
NC 18	1997	< 0.1	Allegheny
US 64 / US 74A - Memorial Highway	2001	< 0.1	Rutherford
	Total	**71.3**	**Miles**

**** Denotes locations considered for collision analysis***

Exhibit 9 shows the cumulative linear miles of WSBG which have been installed in North Carolina between 1982 and 2010. Three years (1994, 2001, and 2010) experienced installations of greater than 10 miles of WSBG, while many other years had installations of shorter sections of WSBG. The spread of WSBG installations over the past thirty years is beneficial for this study to observe the effect of age, in addition to other factors, on WSBG.

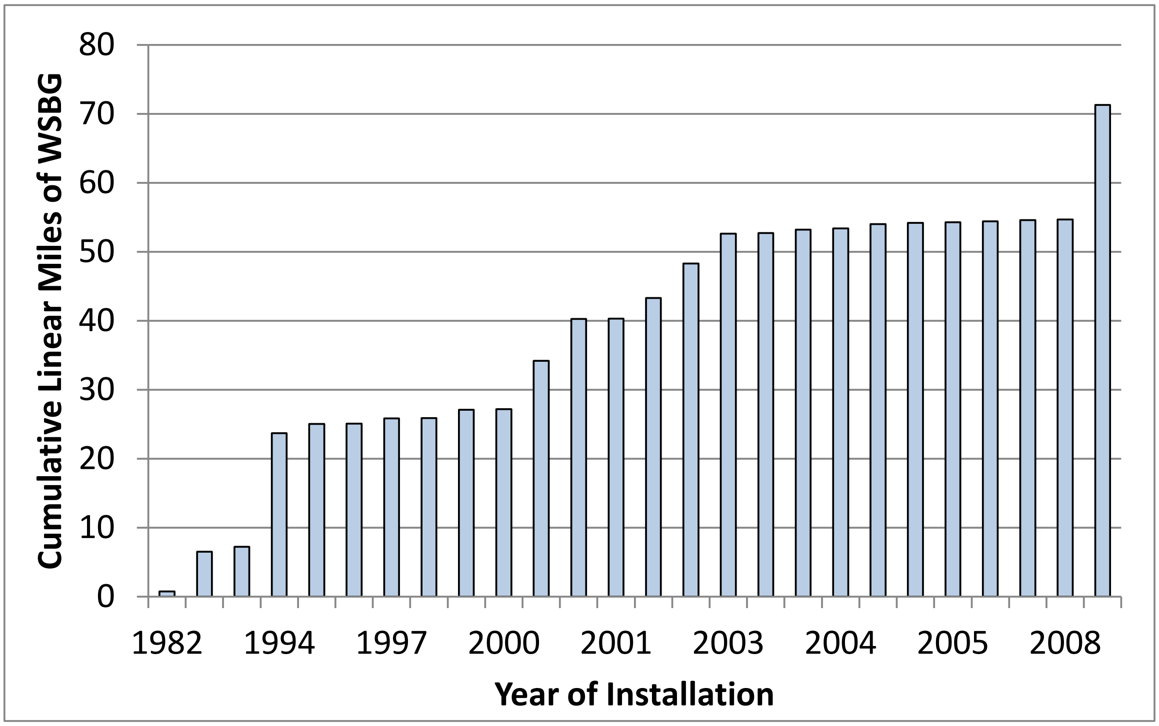


Exhibit 9. Cumulative Linear Miles of WSBG Installations in North Carolina

Because of the nature of collision sample sizes, WSBG sites of sufficient length and history were selected for safety evaluation. Following project objectives, a minimum of four WSBG segments could be selected for crash analysis; however, sample size was an important consideration for statistical significance in the overall safety findings. For consistency in the collision analysis, the research team references WSBG installations as "treatment sites."

Initially, the research team identified five routes that contained WSBG of sufficient length with legitimate crash samples. These sites were selected for data extraction and looked at more closely. The five initial WSBG routes of interest are provided in Exhibit 10 below. Each of the treatment sites chosen for crash analysis were in the western portion of the state, where all of the extended corridor installations of WSBG were located. An investigation of WSBG in the mountainous region of NC theoretically represents the worst conditions for guardrail, because of heavier annual snow fall averages. The team did not intentionally choose sites in the western portion of the state, but WSBG is more commonly used along the mountainous routes of NC for aesthetic reasons. The other sites across the state were shorter length installations with little, if any, collision history. The mountainous WSBG sites have a much longer history of collisions, as well as linear miles of this form of guardrail.

Exhibit 10. Weathered Steel Beam Guardrail Route Descriptions

Site	Location	Initial Collision Report Date	Route Length (mi)	Annual AADT	County
1T	NC 143 (Cherohala Skyway) - Tennessee State Line to Secondary Route 1159	1/1/1995	17.8	500	Graham
2T	Secondary Route 1159 - NC 143 (Cherohala Skyway) to the end of the Route	1/1/1990	7.0	<100	Graham
3T	US 276 - US 64/NC 280 (Asheville Hwy) to SR 1817	1/1/2004	32.9	300	Tran-sylvania
4T	US 74/NC 19 - US 129 to NC 28	1/1/2001	14.1	3,700	Swain/ Macon
5T	US 64/NC 28 - SR 1517/ 1518 to SR 1547	1/1/2002	5.0	2,700	Macon

In addition to WSBG installations, a list of comparable GSG locations was established for safety evaluation purposes. For consistency in the collision analysis, the research team references GSG installations as "comparison sites." Comparison sites are provided below in Exhibit 11. Note that site numbers for the comparison and treatment sites correspond (i.e. Site 1T corresponds with Site 1C).

Exhibit 11: Galvanized Steel Guardrail Route Descriptions

Site	Location	Initial Collision Report Date	Route Length (mi)	Annual AADT	County
1C	SR 1127/1134 (Joyce Kilmer Rd) - Santeetlah Rd to US 129-Tapoco Rd	1/1/1990	6.00	200	Graham
2C	NC 143 - Santeetlah Rd to US 129	1/1/1990	11.86	3,900	Graham
3C	NC 215 (Lake Logan Rd) - Blue Ridge Parkway (Transylvania County Line) to SR 1111 (Lake Logan Rd)	1/1/1990	15.14	940	Haywood
4C	US 129 (Tallulah Rd) - US 19/74 (Cherokee County) to SR 1260 (Airport Rd, Graham County)	1/1/1990	10.28	2,500	Graham
5C	US 64/NC 28 - Hiland Park Ln to NC 106 (Franklin Rd)	1/1/1990	16.45	2700	Macon

Comparison sites are used to account for any seasonality or historical effects that take place during the long evaluation period. Comparison sites had to be outfitted with GSG and were selected primarily based on geographic proximity to the treatment sites. The comparison routes were then evaluated to ensure that each contained similar roadway characteristics; including number of lanes, horizontal curvature, environmental characteristics, and whether the route was predominantly urban or rural.

After an initial assessment of the site attributes and collision data, two of the five treatment sites (and their respective comparison sites) were eliminated from the collision analysis. First, the NC 143 (Cherohala Skyway) treatment site is a very popular motorcycle route connecting Robbinsville, NC with Tellico Plains, TN on NC 143 and TN 165. The popularity of this skyway, specifically to motorcycling enthusiasts, led to an over representation of that vehicle type in the collision reports, particularly along the treatment route that extended from the TN state line to Santeetlah Road (SR 1159). The crash reports for this treatment site contained 297 total collisions, with 276 (93.24%) of these incidents involving motorcycles. Of the 297 total collisions, 130 of these involved a guardrail being struck and 125 (96.15%) of the guardrail related incidents involved a motorcycle. The comparison site was much less severe; however, of the 566 reported collisions 109 (19.26%) involved motorcycles. Because motorcycle collision severity with guardrails of any type is almost always extremely severe, and not the fault of the guardrail type installed along the facility, this treatment site could not be used to determine if WSBG caused higher severity collisions. The second site, Santeetlah Road (SR 1159), that began at NC143 was excluded due to a lack of any practical sample size to make the statistical analysis reasonably significant.

4. STRUCTURAL DATA

The collection of structural data involved inspecting and measuring the thickness of the guardrail which have been exposed to various climates, altitudes, de-icing activities, and offset location. The research team took five measurements on the top and bottom of each span of guardrail studied. A minimum of 20 measurements were taken at each location. Along longer roadway sections containing WSBG, measurements were taken every mile, provided a vehicle could be safely parked for safe data collection. Guardrail spans were measured in tangent sections of the roadway to avoid the potentially higher crash curve locations that might have been replaced by newer guardrail.

Exhibit 12. Measurement of Top (left) and Bottom (right) Edge (Photos by J. Findley)

4.1. Methodology

The method used by the research team for analyzing the structural adequacy of the guardrail is a measurement of the thickness of the guardrail. Similar to the New Hampshire study, a micrometer was used to measure the thickness of the guardrail in the field. This was later compared to the known thickness when leaving the factory. The micrometer used for this study was a Starrett® Number 210 Point Micrometer with a resolution of 0.001". Each of the 25 known WSBG sites in North Carolina was visited and measurements were taken of the guardrail. Appendix B contains a sample field data collection sheet used by the research team. Trend analysis was used to gauge the structural performance of the WSBG over time. The research team also analyzed the data based on the AADT and elevations of the WSBG installations.

4.2. Results

This section presents the analysis of the structural integrity of the analyzed WSBG sites in North Carolina. The principal measure of effectiveness for this analysis is the measured thickness of the WSBG installations. No impact or crash testing was performed through this research. AASHTO (2004) offers specifications for new WSBG, where a Class A, Type IV WSBG should have a base thickness of 0.105 inches, with a tolerance of 0.009 inches below the base thickness. This research assumes this lower tolerance as the threshold for whether or not WSBG section loss is within the allowable range. In other words, a thickness of 0.096 inches or above is considered to meet specifications. A thickness measurement below 0.096 inches is considered below specifications.

4.2.1. Top and Bottom Measurements

Thickness measurements were taken at the top and bottom of each WSBG section. The research hypothesized that there might be a difference in section loss for the top and bottom portions of the guardrail, since weather impacts, snow, and splatter from passing vehicles do not accumulate evenly across the guardrail.

From the field measurements, the team found that the mean difference in thickness between top and bottom measurement for the same guardrail section was -0.0005 inches, with the negative number indicating a slightly thicker cross-section at the bottom. This difference is very close to zero, and a 95% confidence interval on this difference ranges from -0.0077 to 0.0086, which includes zero. It was concluded that no statistical difference exists between top and bottom thickness measurements at the WSBG sections. Consequently, all top and bottom measurements were combined for the subsequent analysis. The resulting data set represents 2,020 data points, where each data point represents an individual thickness measurement. These data points can be aggregated to a total of 202 guardrail sections (10 measurement per section), distributed across the 25 test corridors or segments.

4.2.2. Site Average Results

With the decision to combine all WSBG thickness measurements into an overall dataset, the research team explored the question of section loss for each test site. For this analysis step, all measurements were combined for each of 25 test sites. The analysis included calculating the average and standard deviation of the field-measured WSBG thickness. From these, the team calculated the 95% confidence interval. A site was considered to still meet AASHTO standard, if that 95% confidence interval did not include a thickness of 0.096 inches. Results are given in Exhibit 13.

The results in Exhibit 13 are ordered by year of installation with the oldest WSBG installation in the state of North Carolina shown at the top of the table. For each site, the table shows general site characteristics including route name and county, installation year, linear miles of WSBG installed, the average elevation for the site, the average annual snowfall, and the Average Annual Daily Traffic (AADT). The table then shows the descriptive statistics for the thickness measurements taken in this research. The data include sample size, average thickness, standard deviation of thickness measurements, and the upper and lower bound of the 95% confidence interval.

Exhibit 13. WSBG Structural Analysis Summary

Site ID	Route (County)	Install Year	Linear Miles of WSBG	Average Elevation (ft)	Average Snowfall 2008-2010 (in)	AADT (vehicles per day)	Thickness Measurements: Number of Obs.	Average Thickness (in)	Std. Dev. (in)	95% Confidence Interval: Lower	Upper
1	NC107 (Jackson)	1982	0.8	2,000	6	18,000	60	0.105	0.003	0.104	0.105
2	SR 1159 (Graham)	1988	5.8	2,500	19	<100	90	0.102	0.004	0.101	0.103
3	Greenfield Parkway (Wake)	1990	0.7	300	4	3,500	100	0.100	0.003	0.099	0.100
4	NC 143 – Cherohala (Graham)	1994	16.5	4,200	13	500	120	0.103	0.003	0.103	0.104
5	NC 143 – Snowbird Rd (Graham)	1994	1.3	1,900	13	2,100	40	0.103	0.002	0.102	0.104
6	NC 194 (Watauga)	1994	< 0.1	2,600	32	700	60	0.107	0.004	0.106	0.108
7	IBM Drive (Mecklenburg)	1997	0.8	700	6	13,000	70	0.109	0.005	0.107	0.110
8	NC 18 (Allegheny)	1997	< 0.1	2,800	10	1,000	60	0.101	0.004	0.100	0.102
9	NC 194 (Watauga)	2000	0.1	2,600	32	700	50	0.105	0.003	0.104	0.106
10	NC 49 (Davidson)	2000	1.2	500	1	5,000	120	0.105	0.003	0.104	0.105
11	US 64 / NC 28 (Macon)	2001	6.1	3,200	7	2,700	60	0.103	0.003	0.102	0.104
12	US 64 / US 74A (Rutherford)	2001	< 0.1	300	5	3,800	60	0.104	0.004	0.103	0.105
13	US 74 / NC 19 (Swain/Macon)	2001	7.0	1,800	13	3,700	100	0.103	0.002	0.102	0.103
14	NC107 (Jackson)	2002	3.0	3,100	6	700	50	0.102	0.001	0.102	0.102
15	SR1527 (Yadkin)	2003	0.1	700	16	400	80	0.103	0.003	0.103	0.104
16	US 276 (Transylvania/Haywood)	2003	9.3	3,500	25	300	180	0.103	0.002	0.103	0.103
17	National Service Road (Guilford)	2004	0.5	800	12	500	40	0.103	0.003	0.102	0.104
18	NC 150 (Iredell)	2004	0.2	700	6	13,000	40	0.103	0.003	0.102	0.104
19	SR 2044 (Wake)	2005	0.2	200	7	4,100	50	0.101	0.002	0.101	0.102
20	SR 5017 (Guilford)	2005	0.6	700	16	500	120	0.104	0.002	0.103	0.104
21	US 17 (Pender)	2005	0.1	<100	<1	27,000	60	0.101	0.002	0.101	0.102
22	US264A (Wilson)	2006	0.1	<100	9	6,000	30	0.104	0.002	0.103	0.105
23	SR 1001 (Cleveland)	2007	0.2	800	9	1,700	100	0.102	0.002	0.101	0.102
24	NC 700 (Rockingham)	2008	0.1	400	13	9,100	20	0.103	0.002	0.102	0.104
25	NC 215 (Transylvania)	2010	16.6	3,400	11	1,000	260	0.103	0.002	0.102	0.103
All Observations			71.3	1,900	12	3,600	2,020	0.103	0.003	0.103	0.103

Results in Exhibit 13 show that the lower AASHTO threshold of 0.096 inches lies outside the 95% confidence interval for all 25 sites. In other words, each of the 25 sites, on average, meets AASHTO specifications. Visual inspection of all sites further showed that no significant structural defects were identified, other than those caused by vehicular collisions. Representative photographs of sites are given in Appendix A.

The resulting confidence bounds are shown in graphical form in Exhibit 14. The exhibit shows the average thickness and error bars showing the 95%confidence interval for each site ordered by installation year (same order as Exhibit 13). Note that the y-axis starts at a thickness of 0.08 inches to more clearly show the confidence interval relative to the AASHTO threshold of 0.096 inches, which is shown as a solid black line. Exhibit 15 and Exhibit 16 show the same data, but arranged in order of increasing elevation, and increasing AADT, respectively. The latter two exhibits were created to test for a trend in thickness as a function of these two site characteristics.

Exhibit 14. Average Thickness (inches) by Installation Year

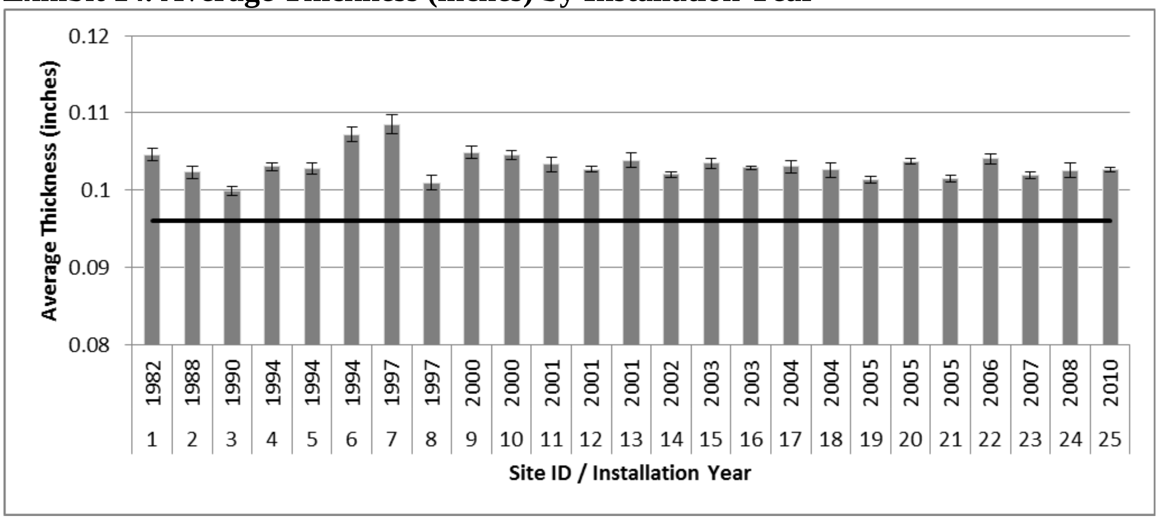


Exhibit 15. Average Thickness (inches) by Elevation (feet)

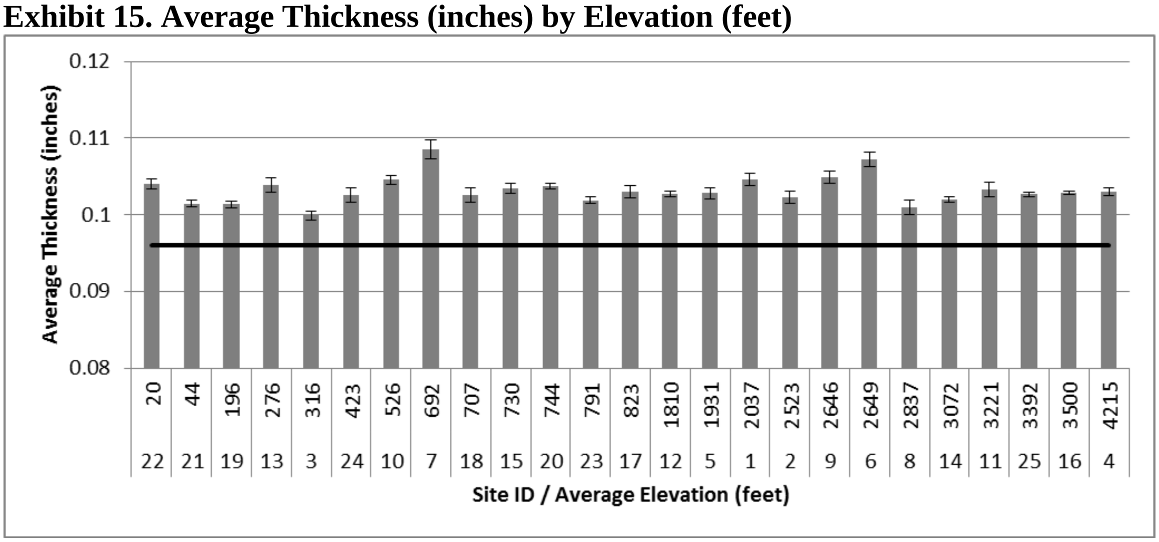
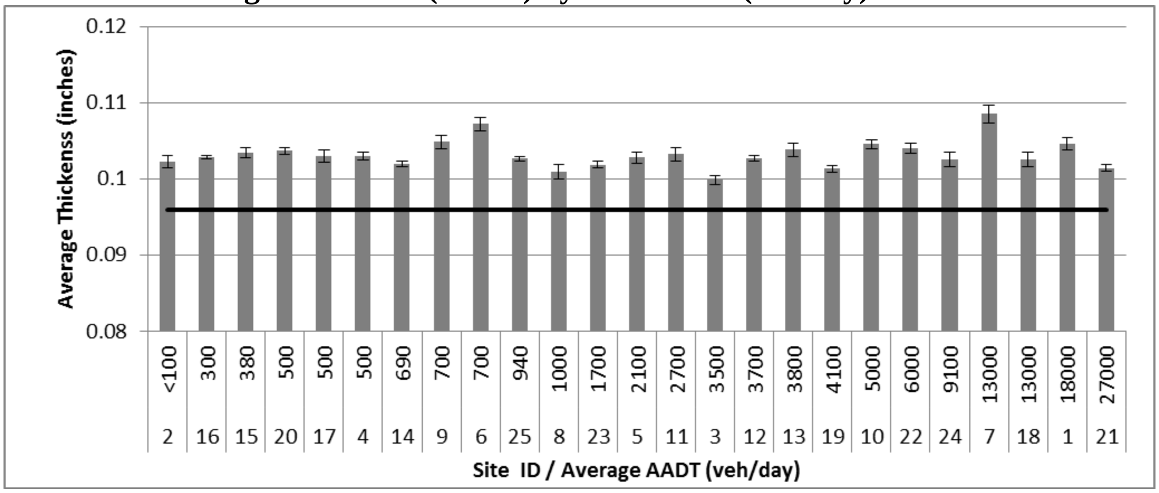


Exhibit 16. Average Thickness (inches) by Site AADT (veh/day)



The charts in Exhibit 14, Exhibit 15, and Exhibit 16 expectedly confirm that all site averages are above the AASHTO minimum thickness specifications, as are all 95% confidence limits. A further investigation of trends by installation year, elevation, or AADT does not suggest a relationship between these characteristics and a significant average section loss. In the following, the analysis will take a closer look at the individual measurements to get a sense of the distribution of the raw measurements (all 2020 data points).

4.2.3. Raw Data Results

This section repeats the analysis in the previous section, but uses all 2,020 raw data points, rather than site averages. While the team believes that the average performance presented in Section 4.2.2. is the more important one in terms of judging WSBG thickness, there is merit in investigating trends in the raw data as well. Exhibit 17, Exhibit 18, and Exhibit 19 present scatter plots of average WSBG thickness (in inches) as a function of installation year, elevation (feet), and AADT (veh/day) consistent with the previous section.

Exhibit 17. Raw Data of Thickness (inches) by Installation Year

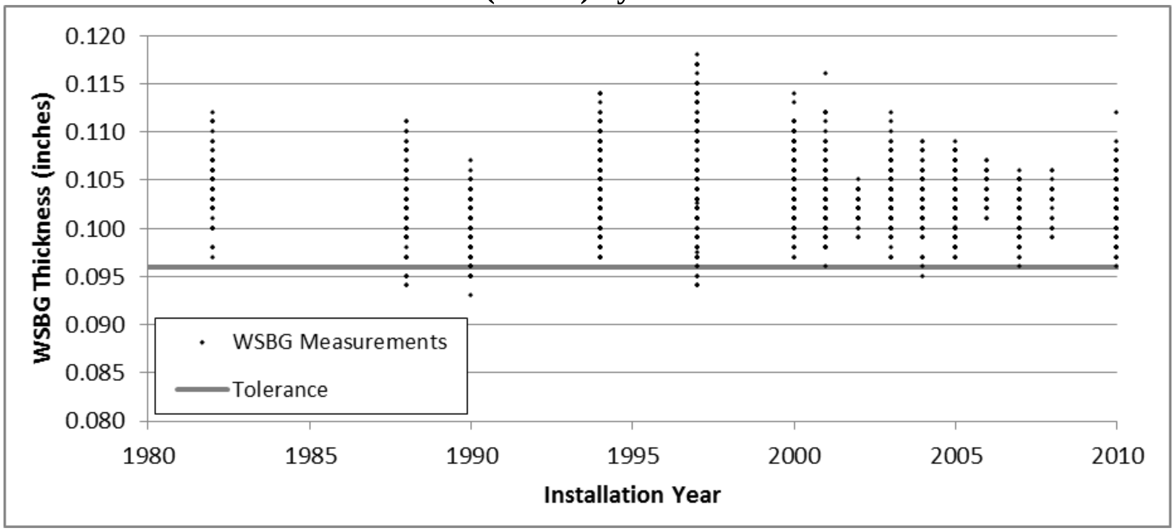


Exhibit 18. Raw Data of Thickness (inches) by Elevation (feet)

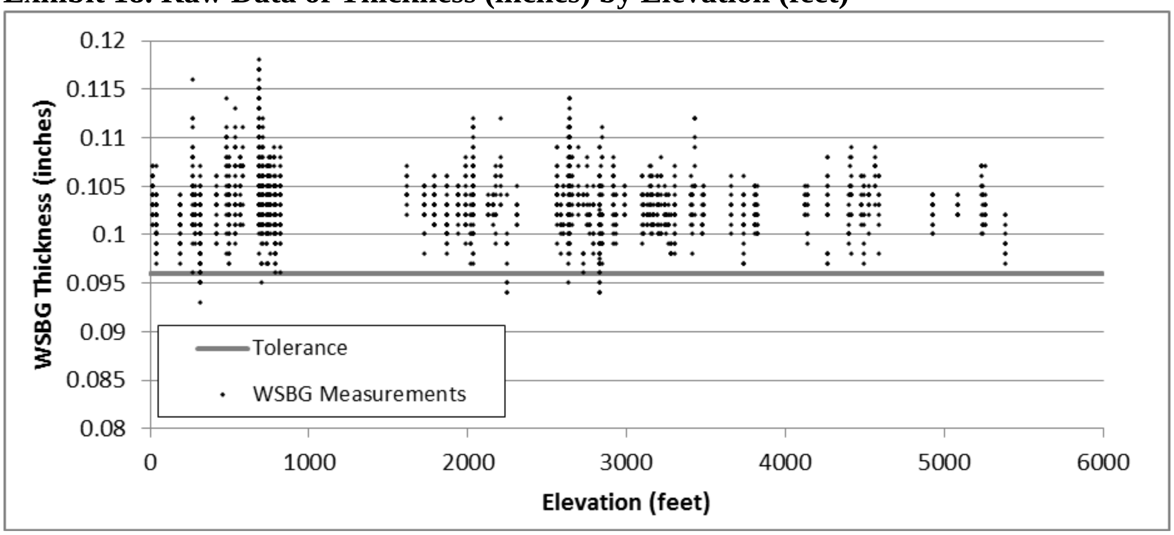
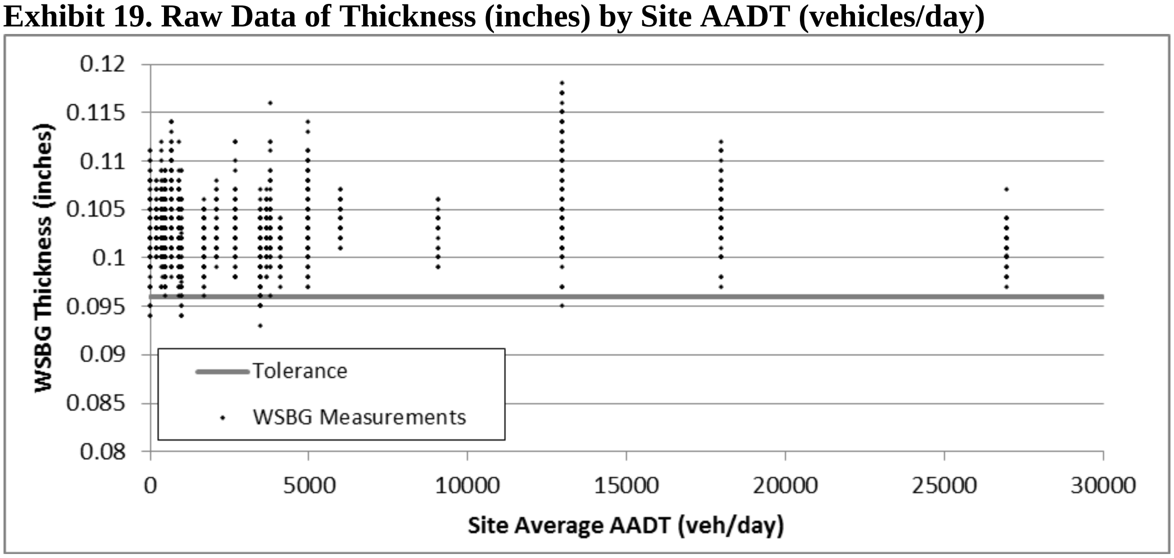


Exhibit 19. Raw Data of Thickness (inches) by Site AADT (vehicles/day)



The scatter plots in Exhibit 17, Exhibit 18, and Exhibit 19 confirm that the vast majority of individual measurements are located above the AASHTO minimum specifications. A look at the range of observations only shows a few isolated measurements that fall below that minimum. These will be discussed further below. Consistent with the conclusion reached in the previous section, the raw data do not suggest any sort of trend as a function of the three site characteristics. The team initially hypothesized that guardrail thickness would decrease with higher age (earlier installation year), greater elevation (more snow and de-icing activities), and greater AADT (more splatter, higher likelihood of de-icing treatments). None of these hypotheses were supported by the data. The team also looked at interaction effects of high-elevation roads with high AADT, which would be the routes most likely to experience heavy de-icing treatments and harsher climates. However, these interaction tests also did not show any noteworthy trends.

The team ultimately took a closer look at the few individual WSBG thickness measurements that fell below the AASHTO specifications. It showed that individual measurements from four sites showed some thickness values below 0.096 inches:

- Site 2: SR 1159 (Graham County), five out of 90 measurements below threshold (5.6%)
- Site 3: Greenfield Parkway (Wake County), eight out of 100 measurements below threshold (8%)
- Site 8: NC18 (Allegheny County), five out of 60 measurements below threshold (8.3%)
- Site 18: NC150 (Iredell County), one out of 40 measurements below threshold (2.5%)

In all cases, these below-threshold measurements were distributed across multiple measured sections. As a result, individual section average (10 measurements) at any site did not fall below AASHTO specifications. The team concludes that these measurements were outlier observations that are most likely attributable to random variation in the WSBG material, or spots that have been compromised by debris or other impacts.

5. COLLISION DATA

The collision data collection effort was very data intensive. Research team members examined individual crash reports (and associated sketches of the collisions) looking for single vehicle crashes that struck the guardrail in a run-off-road collision. Looking only at guardrail related crashes significantly reduced the sample size of available collisions; however, this research is not interested in other collision types since they are not affected by the guardrail.

Collision data for this project was obtained through coordination with the NCDOT to obtain crash reports for the specified routes of interest over the entire period of performance that WSBG was installed. Comparable GSG site data were collected during the same time periods for comparison purposes. Crash data was collected from the installation date of WSBG at a particular site through July 31, 2010. The matched comparison sites contained the same time frame of data for comparison purposes. It is important to note that a crash could have reported more than one injury severity. To avoid bias in the collision data set, only the most severe injury was used in the analysis for a single crash.

The crash reports supplied by NCDOT included a number of contributory factors regarding incidents, as well as characteristics of the section of roadway that they occurred. The most important fields of the report for this study were accident severity, object struck, and the type of vehicle.

The driver and passenger injury codes are very important for collision studies. The most common coding scheme for the extent of injuries incurred by motorists in a crash is the "FABCO" or "KABCO" scale, which includes five categories:

1. F (fatality) or K (killed): The person died within 30 days of the collision as a direct result of injuries received during the collision.
2. A: The person experienced serious, incapacitating, nonfatal injuries during the collision. Broken bones, massive losses of blood, or more serious injuries are rated A.
3. B: The person experienced a visible, but not serious or incapacitating injury, during the collision.
4. C: The person complained of pain or momentary loss of consciousness due to an injury during the collision, but no visible sign of injury was evident to the investigator.
5. O: No injury, which includes "PDO-Property Damage Only" collisions. These can be significantly underreported since they are often handled between the drivers of the vehicles (or by the driver striking the obstacle) without the assistance of the police.

With guardrail related collisions parsed out of the full data set, the team looked at each of the three individual sites analyzed under this effort to try and ascertain if problems with the guardrail exist at an individual site. It should be noted that sample sizes at some individual sites may be very small, so results should be read in light of the sample sizes.

To help counter this concern, the research team will also look at the overall findings to increase the total sample size, and thus the significance of the findings.

5.1. Validating Comparison Sites

A comparison group of GSG installations was used to evaluate background trends in collisions that may have impacted the WSBG data overtime. This method is preferable because it helps account for many of the problems associated with typical safety evaluations; namely historical effects, traffic volume, seasonality, speed limits, and time.

Typically, comparisons sites are validated by calculating an odd's ratio for each treatment/comparison site group. The collision data utilized for this test is data collected prior to the installation of the treatment in question, in this case WSBG. This is typically done for an analysis of a treatment that is installed as a collision countermeasure, so a before condition should actually exist along the treatment site being analyzed to conduct an odd's ratio test. However, for this particular study, two of the three studied treatment sites were newly constructed roadways where WSBG was installed from day one, and was not necessarily a collision countermeasure installed in place of the existing guardrail for the purpose of reducing collisions.

Therefore, the research team has no formal method for determining if comparison sites were similar. Based on a comparison of site characteristics, traffic volumes, and collision trends, the team assumed that the three sites under analysis have valid comparison sites primarily based on local knowledge from team members, as well as NCDOT personnel. Each site was located in a rural area and located in the general proximity of its paired treatment site. Additional evidence is provided in Exhibit 20, below. Traffic volumes at each of the treatment/comparison groups are fairly consistent, each having very low average daily traffic (ADT) estimates. Other important factors provide additional reasons for making the groupings. First, the average elevation for each group is similar. Second, the distance between the comparison treatment groups is short. This means that similar temperature and weather patterns should have existed at each of the sites over long periods of time. Last, guardrail related crashes tend to happen more frequently in curve sections. The curves per mile for the comparison/treatment groups are fairly consistent, with GSG sites typically having more per mile than their partner WSBG sites.

Exhibit 20. WSBG and GSG Site Characteristics

Route	Guardrail Type	ADT (vpd)	Vehicle Exposure (MVMT)	Length (Miles)	Elevation (feet)	Distance from Treatment Site (miles)	Curves Per Mile
US 276	WSBG	300	40	32.9	3,500	n/a	4
NC 215	GSG	940	35	15.1	3,400	2.8	6
US 74 / NC 19	WSBG	3,700	178	14.1	1,800	n/a	1
US 129	GSG	2,500	196	10.3	2,500	0.0	2
US 64 / NC 28	WSBG	2,700	138	5.0	2,100	n/a	3
US 64	GSG	2,700	657	9.5	3,000	1.0	6

5.2. Analysis Methodology

The research team focused on the evaluation of injury severity when analyzing collisions. Injury severity is used in lieu of total collisions or collision type because guardrail is not installed as a collision countermeasure, but is instead installed to reduce the likelihood of a serious injury, such as run-off road collisions in rural two-lane settings with steep embankments (the focus of the sites being studied in this effort). Initially, the team desired to look at incapacitating injuries and fatal collisions (i.e. the most severe collisions); however, as will be shown later, there was insufficient data to analyze these severe collisions by themselves.

The treatment and comparison sites were evaluated using two subsets of collision data involving guardrail; percentage of injuries and the percentage of fatal and incapacitating injuries. The sample size of crashes was low, causing sporadic spikes or lulls in the datasets over time. Therefore, the team decided to normalize, or smooth, the data sets using a three-year binning method. Crash data were combined yearly for the next consecutive three-year period (i.e. 2002-2004, 2003-2005, etc.). The safety analysis focused on the *percentage of injury crashes* in these periods, rather than pure crash frequencies. Crash frequencies generally do not account for many of the different attributes between the two sites and can bias the analysis by exaggerating results.

For example, at *treatment site* A, let's assume the total number of guardrail related collisions for two consecutive years was 100 each year. Assume 10 and 20 of those collisions were classified as injuries during those same two years, or a 10% increase in collisions. At *comparison site A*, let's assume the total number of guardrail related collisions for two consecutive years was 100 and 120 (i.e. not equal). Assume 10 and 20 of those collisions were also classified as injuries during that two year period, or an 8.3% increase in collisions. If using crash frequency only, one could assume that there was no difference between the treatment and comparison group (i.e. both comparison and treatment sites increased by a frequency of 10 collisions); however, the percentages tell the story more accurately.

The equations for both injury and incapacitating percentages based on the injury severity scale (KABCO) are provided below:

because there is no evidence to assume that the treatment would increase or decrease collisions. The null and alternative hypotheses are shown below:

$$H_o: P_c = P_t$$
$$H_a: P_c \neq P_t$$

A z-score was calculated for each paired treatment/comparison using injury severity (KABC and KA) for every site and year the treatment was in place, as well as totals for all years and all sites. The method for determining the respective z-score was:

5.3.1. US 276 and NC 215

The treatment route for this paired analysis included the section of US 276 from US 64/NC 280 (Asheville Hwy) in Transylvania County to SR 1817 (Pigeon Gap Rd) in Haywood County. The installation of WSBG took place in early 2004 and had 13 total guardrail related incidents that occurred over that span. The comparison route in this pair included the section of NC 215 (Lake Logan Rd) from the Blue Ridge Parkway (Transylvania County Line) to SR 1111 (Lake Logan Rd). The route consisted of 6 total guardrail related incidents that occurred over that span. Collision data were available going back to the initial installation date of the WSBG. As noted earlier, the data were binned into three-year time spans to help normalize the data over time. Exhibit 21 provides an overview of the binned data with severities, percent injured, and percent incapacitating injuries.

Exhibit 21. Collision Statistics for US 276 and NC 215 Comparison Group

Weathered Steel Beam Guardrail							
US 276 Route							
Time Period	K	A	B	C	PDO	% K + A + B + C	% K + A
2004-2006	0	0	3	0	4	43%	0%
2005-2007	0	0	3	0	4	43%	0%
2006-2008	0	0	2	0	6	25%	0%
2007-2008	0	0	2	0	4	33%	0%
2008-2010	0	0	0	0	3	0%	0%
Total (2004-2010)	0	0	5	0	8	38%	0%
Galvanized Steel Guardrail							
NC 215 Route							
Time Period	K	A	B	C	PDO	% K + A + B + C	% K + A
2004-2006	0	0	1	1	2	50%	0%
2005-2007	0	0	0	1	3	25%	0%
2006-2008	0	0	0	0	2	0%	0%
2007-2008	0	0	0	0	1	0%	0%
2008-2010	0	0	0	0	1	0%	0%
Total (2004-2010)	0	0	1	1	4	33%	0%

Given the low sample sizes, statistical testing was not used to draw detailed conclusions about WSBG versus GSG. However, a couple observations can be made about the data. First, no incapacitating injuries have been reported at either site for a period of seven years (2004-2010), which in itself is a positive finding. Second, the low sample of injury and incapacitating crashes provides evidence that very few guardrail crashes are serious enough to report, and when they are reported both types of guardrail appear to be doing a sufficient job redirecting traffic safely. Last, the percent of injury collisions between WSBG and GSG are fairly consistent given the lack of available data to draw observations.

5.3.2.US 74/NC 19 and US 129 Comparison Group

The treatment route in this comparison group included the section of US 74/NC 19 from US 129 in Macon County to NC 28 in Swain County. WSBG was installed in late 2001; therefore, we requested all collision data beginning January 2002. In that nine year time period, a total of 34 WSBG crashes took place. The comparison route in this paired group included the section of US 129-Tallulah Road from US 19/74 in Macon County to SR 1260 (Airport Road) in Graham County. NCDOT supplied data as early as 1990; however, to coincide with the treatment site, only data starting in January 2002 was analyzed. The GSG route consisted of 27 total guardrail related incidents that occurred over that span. Exhibit 22 provides an overview of the 3-year binned data with crash severities, percent injured, and percent incapacitating injuries.

Exhibit 22. Collision Statistics for US 74/NC19 and US 129 Comparison Group

Weathered Steel Beam Guardrail							
US 74 / NC 19 Route							
Time Period	K	A	B	C	PDO	% K + A + B + C	% K + A
2002-2004	0	1	0	1	5	29%	14%
2003-2005	0	1	0	0	7	13%	13%
2004-2006	0	1	0	1	8	20%	10%
2005-2007	0	0	0	2	7	22%	0%
2006-2008	0	0	1	2	9	25%	0%
2007-2008	0	0	2	2	17	19%	0%
2008-2010	0	0	2	1	15	17%	0%
Total (2002-2010)	0	1	2	4	27	21%	3%

Galvanized Steel Guardrail							
US 129 Route							
Time Period	K	A	B	C	PDO	% K + A + B + C	% K + A
2002-2004	1	1	0	0	2	50%	50%
2003-2005	1	1	1	0	3	50%	33%
2004-2006	0	1	1	0	5	29%	14%
2005-2007	0	1	2	1	5	50%	10%
2006-2008	0	1	1	1	6	40%	10%
2007-2008	0	1	1	3	7	46%	8%
2008-2010	0	1	1	2	9	31%	8%
Total (2002-2010)	1	3	3	4	16	41%	15%

As before, analyzing this site alone using statistical methods was not feasible due to lack of available crashes per year. A couple very general observations can be made. First, no fatal collisions occurred along the WSBG site over the nine year period, and only one (2004) severe (Type A) crash occurred, which means very few serious guardrail related crashes have been reported along the treatment site. Last, although sample sizes are small, the percent of injury collisions at the treatment site appear to be less than the GSG comparison site during every time period analyzed.

5.3.3. US 64 Comparison Group

The treatment route in this comparison group included the section of US 64/NC 28 from SR 1517-SR 1518 (Bethel Church Rd) to SR 1547 (Webmont Rd). The WSBG was installed in 2001; therefore, crash data was obtained from January 2002 and consisted of 15 total guardrail related incidents that occurred over that time span. The comparison route in this paired group included the section of US 64/NC 28 from Hiland Park Lane to NC 106-Franklin Rd. NCDOT supplied data as early as 1990; however, to coincide with the treatment site, only crash data starting in January 2002 was analyzed. The comparison route consisted of 28 total guardrail related incidents that occurred over that time span. Exhibit 23 provides an overview of the 3-year binned data with crash severities, percent injured, and percent incapacitating injuries.

Exhibit 23. Collision Statistics for US 64 and US 64 Comparison Group

Weathered Steel Beam Guardrail							
US 64 Route							
Time Period	K	A	B	C	PDO	% K + A + B + C	% K + A
2002-2004	0	1	2	4	2	78%	11%
2003-2005	0	0	2	2	1	83%	0%
2004-2006	0	0	1	1	0	100%	0%
2005-2007	0	0	0	0	1	0%	0%
2006-2008	0	0	1	0	3	25%	0%
2007-2008	0	0	1	1	4	33%	0%
2008-2010	0	0	1	1	3	40%	0%
Total (2002-2010)	0	1	3	5	6	60%	7%

Galvanized Steel Guardrail							
US 64 Route							
Time Period	K	A	B	C	PDO	% K + A + B + C	% K + A
2002-2004	0	0	2	2	7	36%	0%
2003-2005	0	0	3	2	5	50%	0%
2004-2006	0	0	1	0	3	40%	0%
2005-2007	0	0	1	0	4	20%	0%
2006-2008	0	0	0	1	8	11%	0%
2007-2009	0	0	0	2	8	33%	0%
2008-2010	0	0	0	2	8	33%	0%
Total (2002-2010)	0	0	3	6	19	32%	0%

Again, analyzing this site by itself using statistical methods was not feasible due to insufficient sample size. Generally speaking, only one serious incapacitating injury (Type A) was reported along the WSBG treatment site, and none were reported at the

GSG site. Given the low number or guardrail related collisions at both sites, one could ascertain that guardrail at both sites appears to provide adequate safety along each route. Last, although sample sizes are very low, the section of WSBG appears to have a higher percentage of injury related collisions compared to its comparison GSG site.

5.3.4. Total WSBG Installations

Data for each of the three sites previously discussed were aggregated and analyzed jointly to achieve larger sample sizes. Two of the sites installed WSBG during 2001, while the other site installed WSBG during 2003. It was important to analyze the collision data using the same start dates; therefore, the data was all normalized to time t=0. Three year bins were still used as discussed in previous sections. The aggregated treatment data consisted of 123 total guardrail related incidents, 62 at WSBG sites and 61 at GSG sites. It is important to remember that the collisions reported below are normalized over a three-year period to smooth the effects of small crash data sets.

Exhibit 24 provides an overview of the seven three-year time periods by collision severity, percent injury collisions, and percent incapacitating collisions. Sample sizes were only sufficient to statistically analyze percent injury collisions using a z-test.

Exhibit 24. Collision Statistics for All WSBG and GSG Sites

Weathered Steel Beam Guardrail							
Total (All Sites)							
Time Period (yrs)	K	A	B	C	PDO	% A + B + C + K	% K + A
1 – 3	0	2	5	5	11	52%	9%
2 – 4	0	1	5	2	12	40%	5%
3 – 5	0	1	3	2	14	30%	5%
4 – 6	0	0	2	2	12	25%	0%
5 – 7	0	0	2	2	15	21%	0%
6 – 8	0	0	8	3	21	28%	0%
7 – 9	0	0	3	2	18	22%	0%
Total (1 – 9)	0	2	10	9	41	34%	3%

Galvanized Steel Guardrail							
Total (All Sites)							
Time Period (yrs)	K	A	B	C	PDO	% A + B + C + K	% K + A
1 - 3	1	1	3	3	11	42%	11%
2 - 4	1	1	4	3	11	45%	10%
3 - 5	0	1	2	0	10	29%	8%
4 - 6	0	1	3	1	10	38%	6%
5 - 7	0	1	1	2	15	25%	5%
6 - 8	0	1	2	6	19	40%	3%
7 - 9	0	1	1	4	17	32%	4%
Total (1 – 9)	1	3	7	11	39	36%	7%

In all but two time periods (t = 2-4 and 5-7)), using a 95% confidence interval, the null hypothesis was rejected that $P_c = P_t$. When looking at the total injury collisions combined over all time periods, the null hypothesis was also rejected that the two proportions of injury crashes at WSBG and GSG (34% vs. 36%, respectively) sites were the same.

Exhibit 25 provides a visual comparison of the WSBG and GSG grouped sites. The graph provides further evidence that the null hypothesis was rejected during t = 1-3 and t= 3-5 because the percentage of GSG injury collisions were lower, while time periods t = 4-6, 7-8, and 8-9 rejected the null hypothesis because the percentage of WSBG injury collisions were lower. Time periods t = 2-4 and 5-7 confirmed the null hypothesis, shown by the two data points so closely related on the graph. As noted earlier in Exhibit 24, and now shown graphically below, the overall hypotheses was rejected that the two proportions were equal, the proportion of injury collisions (overall) were lower for WSBG versus GSG.

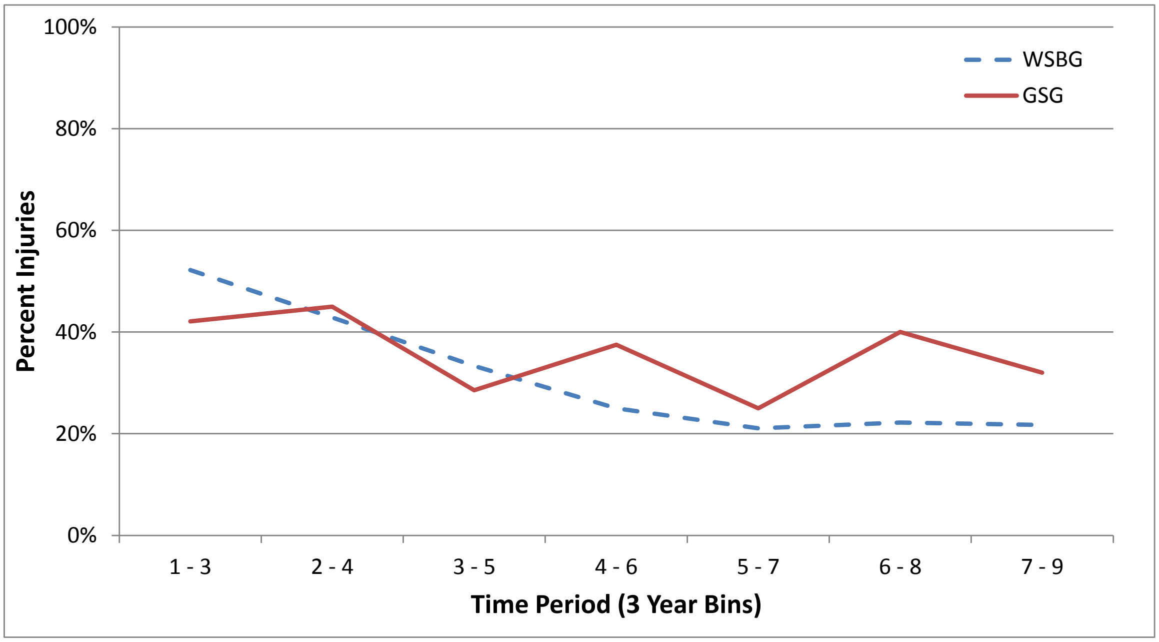


Exhibit 25. Percentage of Injuries (K, A, B, and C) for All Routes

Total incapacitating injuries were also tabulated across each of the three treatment/comparison groups. Sample sizes were very small and therefore impractical for statistical testing. A total of two WSBG and four GSG incapacitating crashes (KA) took place over the entire analysis period. The only fatality in the entire data set took place on a GSG site. The lack of available sample sizes for incapacitating crashes further emphasizes that both guardrail types are likely adequate for redirecting traffic safely as intended.

However, looking at the trends in Exhibit 25, it is evident that the percentage of injury crashes for WSBG appears to decrease over time, while the GSG crashes fluctuate about what appears to be a constant mean. While it should not be presumed here that WSBG installations grow safer over time, the important finding is that the percentage of injuries does not get worse. The finding of a stable (or potential decreasing) injury percentage over a period of 9 year (seven three-year bins) is noteworthy, and speaks towards a satisfactory performance of the WSBG installations. If a significant deterioration of WSBG structural integrity had taken place, the result would have been an increase in injury collisions over time as individual sections fail on impact. Overall, this safety analysis helps validate the findings of the structural performance in section 4, that the studied WSBG guardrail installations in North Carolina appear to be performing satisfactorily even after they have been installed for fifteen years or more.

6. FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The structural analysis found no evidence that existing WSBG installations in NC have deteriorated below the AASHTO minimum thickness specification of 0.096 inches. All of the 25 test sites showed 95% confidence intervals of measured thickness that were above that threshold, suggesting an overall WSBG performance that meet AASHTO specifications. The team further did not find any trends of deteriorating thickness as a function of guardrail age (oldest installation is 29 years), elevation (highest installation is 4,200 feet), and AADT (highest traffic is 27,000 vehicles per day). The structural analysis therefore suggests no concerns of using WSB guardrail in the state of North Carolina.

The routes with significant lengths of WSBG were located in western NC with low ADTs which led to low sample sizes for the collision data. Sample sizes were only sufficient enough to statistically analyze percent injury collisions while combining each of the three sites. Statistical testing showed that there is a significant difference between the severity rates of WSBG and GSG installations, with WSBG experiencing a lower percentage of injury collisions than GSG. Only two WSBG and four GSG incapacitating crashes (K or A) took place over the entire analysis period, with the lone fatality occurring on the GSG site. The lack of available sample sizes for incapacitating crashes further emphasizes that both guardrail types are likely adequate for redirecting traffic safely as intended to protect motorists from the severe terrain or objects behind the guardrail. In a long-term safety analysis, the percentage of injury collisions at the WSBG locations appeared to decrease over time. This supports the notion that the tested WSBG installations perform well even after long-term deployment (over 15 years), since a compromise in structural integrity presumably would have shown an increase in percent injury collisions with guardrail age.

The findings from this research project differ significantly from the findings of a study which found that WSBG performed inadequately in New Hampshire (Perkins 2004). The findings from New Hampshire raised concern about the quality of the material at all installations and NCDOT responded to the study with a memorandum on June 6, 2006 that advised the Project Development and Environmental Branch to discontinue the usage of WSBG (NCDOT 2006). However, this study found that the conditions in North Carolina (weather, de-icing, maintenance, etc.) do not appear to create the severe deterioration problems as found in New Hampshire. A similar research effort could be executed in future years (five or ten years) to include additional structural and collision data if necessary to follow the experience of North Carolina WSBG further along in time. But based on data at 25 guardrail sites across the state covering over 70 miles of linear installation and ranging in age from one year to almost thirty years old, the WSBG treatment appears to perform satisfactorily in North Carolina.

7. IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The analysis of WSBG performance in relation to time, weather conditions, elevation, and AADT provides valuable information to NCDOT. Over 70 miles of WSBG exist in North Carolina were studied to determine their current performance. The findings from this study could be used to determine whether WSBG should be replaced with standard galvanized steel beam guardrail. In addition, FHWA guidelines could be modified to include findings from this study in addition to the experience in New Hampshire. The research team will be available for presentations to relevant NCDOT personnel as requested by the steering and implementation committee.

This research result produces the justification for the continued use of WSBG in North Carolina. This research provides valuable information on two topics of WSBG for NCDOT:

1. To better understand the current operating status and condition of WSBG installations in North Carolina climate and de-icing conditions.
2. To make a judgment on future installations of WSBG based on North Carolina climate and de-icing conditions, not on New Hampshire conditions.

7.1. Research Products

The research products developed as a result of this research project are included in this report which documents the following research products that will be useful for NCDOT:

- Literature review of WSBG state of the practice across the nation
- Inventory of locations of WSBG in NC
- Manual field investigation procedure and data collection forms
- Structural condition of WSBG in NC
- Safety performance of WSBG in NC
- Variations of WSBG among NC specific weather conditions, elevation, and AADT

8. REFERENCES

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APPENDIX A: SITE PHOTOGRAPHS

NC 215 (Transylvania County)

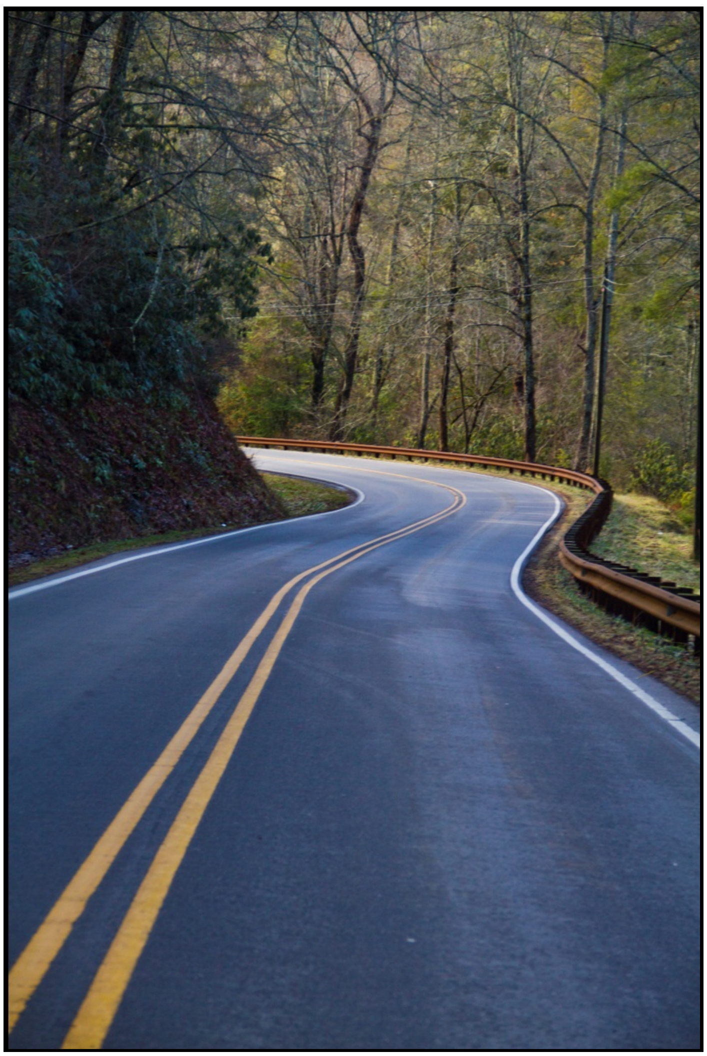
NC 143 – Cherohala Skyway (Cherohala Skyway)

US 74 / NC 19 (Swain/Macon Counties)

US 64 / NC 28 – Franklin Road (Macon County)

US 276 (Transylvania County)

NC 143 – Snowbird Road (Graham County)



NC49 (Davidson County)

IBM Drive (Mecklenburg County)

NC107 (Jackson County)

Greenfield Parkway (Wake County)

SR 5017 - Henson Forest Drive (Guilford County)

National Service Road (Guilford County)

SR 1001 - Fallston - Waco Road (Cleveland County)

NC 150 (Iredell County)

SR 2044 - Ligon Mill Road (Wake County)

US 17 (Pender County)

SR1527 - Richmond Hill Rd   (Yadkin County)

US264A - Raleigh Road (Wilson County)

NC 194 (Watauga County)

NC 18 (Allegheny County)

US 64 / US 74A - Memorial Highway (Rutherford County)

APPENDIX B: FIELD DATA COLLECTION SHEET

Route:	
Route Length Studied:	
Linear Miles of WSBG:	
Date / Analyst:	
Age of Guardrail:	
Starting Location:	
Land Use:	
Joint Observations:	
Streaking on Concrete:	

	Location	Elevation (feet)	Height (inches)	Offset (edgeline to face, in feet)	Shoulder Type	Post Type	Block Type	Heat Number	Top Thickness														
									1			2			3			4			5		
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	Location	Elevation (feet)	Height (inches)	Offset (edgeline to face, in feet)	Shoulder Type	Post Type	Block Type	Heat Number	Bottom Thickness														
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