AASHTO – FHWA

Task Force on ET-Plus 4” Dimensions

March 11, 2015

AASHTO & FHWA Task Force – ET-Plus 4" Device Dimensions

Purpose

The American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) assembled a task force to answer the following questions:

- Is there any evidence that there are multiple versions of the ET-Plus 4" guardrail end terminals on the roadways?

  For the remainder of this report the term 'ET-Plus device' will mean the ET-Plus guardrail end terminal with a 4" feeder channel.

- Are the ET-Plus devices that were crash tested at Southwest Research Institute (SwRI) between Dec. 2014 and Jan. 2015 representative of the ET-Plus devices installed on the roadways?
- Do any of the variations in the dimensions either individually or in concert with another dimension cause a concern regarding the performance of the ET-Plus device?

During the task force's deliberations, a fourth question was raised based on allegations by Dr. Dean Sicking that the tests did not apply worst-case test conditions to the device:

- Did the crash tests conducted at SwRI between Dec. 2014 and Jan. 2015 apply worst-case test conditions to the ET-Plus device itself?

The Dimensions

Concerns have been raised around two specific dimensions of the ET-Plus device:

- the height of the guide channel as it enters the extruder head (the part of the device that flattens the W-beam so it can be deflected) – for the remainder of this report this dimension is called the *guide chute exit height (outside).*
- the gap through which the W-beam is flattened and extruded – this dimension is called the *exit gap*.

These two dimensions are shown on the diagram on the next page.

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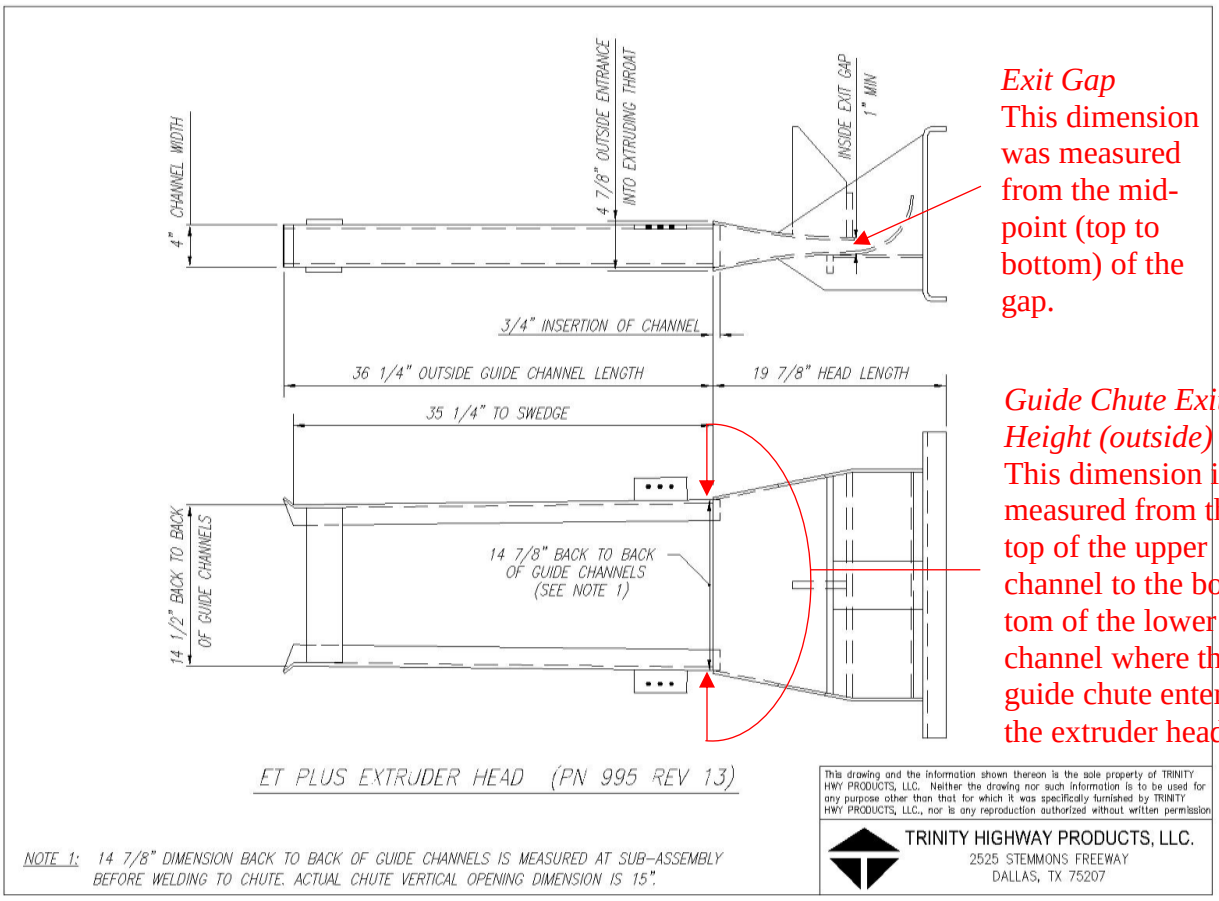

Exit Gap
This dimension was measured from the mid-point (top to bottom) of the gap.

Guide Chute Exit Height (outside)
This dimension is measured from the top of the upper channel to the bottom of the lower channel where the guide chute enters the extruder head.

Dimension	Drawing Measurements	TTI Design Tolerances
Exit Gap (middle – inside)	1” minimum	1” minimum
Guide Chute Exit Height (outside)	14-7/8”	(+1/4, -1/8)
Guide Chute Entrance Height (outside)	14-1/2”	(+1/4, -1/4)
Channel Width (outside)	4” (Per ASTM A-6)	4” (Per ASTM A-6)
Outside Guide Channel Length	36-1/4”	(+1/2, -1/4)

The Data FHWA Collected

From November 12, 2014 through January 8, 2015, FHWA engineers collected measurement data on 1,048 ET-Plus devices in five States with a tape measure and a carpenter's rule as shown below. The number of FHWA personnel trained and collecting this data was limited to ensure consistency in how the devices were measured and how the data was recorded. The measurements were taken and recorded in 1/16 of an inch increments. Data was collected as shown below:

Illustration of primary measurements obtained.

Exit Gap (middle inside)

Guide Chute Exit Height (outside)

Channel Width

Where FHWA collected the data.

The ET-Plus device is manufactured in the United States in four locations around the country. There are two plants in Ohio, one in Texas, one in Utah, and one in South Carolina. FHWA collected measurements in States across the country that give a good representation across the nation and are in close geographic proximity to potential manufacturing locations.

States where data was collected	Number of devices measured	Potential Manufacturing Location
Arizona	100	Utah
California	221	Utah
Illinois	234	Ohio
South Carolina	238	South Carolina
Texas	255	Texas
Total	**1048**	

Maps showing where in the States the measurements were collected including specific information on location of the ET-Plus devices that were measured are included in the data released with this report.

To ensure that the measurements did not reflect particular groupings of ET-Plus devices, the engineers sought, to the extent feasible, to have a minimum of three miles between any ET-Plus devices on the same road.

Sample size, confidence level & confidence interval

The analysis involved a sampling of 1,048 ET-Plus devices across five States, 79 counties and approximately 10,000 miles of roadways that included Interstates, State and county roads. The measurement of specific dimensions on these ET-Plus devices provided information on the distribution of measurements for these dimensions and what percentage of the installations had dimensions within the design tolerances.

Using this sample and a binomial probability distribution [a binomial probability distribution is applied for situations where there are two potential outcomes – in this case, the measurement was either within the stated design tolerance or it wasn't], the confidence level for the ET Plus devices that would be within the design tolerances, as shown on the table on page two, was calculated.

The dimensions analyzed were the exit gap and the guide chute exit height (outside). The sample results yielded the following estimates of the percentage of ET-Plus devices that had these dimensions within the design tolerances:

- Exit Gap: 100 percent within design dimension. (0 out of 1,048 measurements were < 1")
- Guide Chute Exit Height (outside): 98.7 percent within design tolerances.

The 1,048 samples were used to estimate the percentage of installations within design tolerances for each measured dimension. As this sample is, for all practical purposes, a random sample, the percentages obtained from these measurements provide a 98% confidence level with a margin of error of 3 percent. In other words, the sample size provides a 98 percent confidence level that the measured dimensions in the sample are reflective of the percentages of actual dimensions of ET-Plus devices in service on the nation's roads.

For example, as noted above, the percentage of measurements of the guide chute exit height (outside) that was within the design tolerances is 98.7%. The confidence level and the confidence interval combined means that with 98% confidence the percentage of devices within the design tolerances at the guide chute exit height (outside) dimension, across the country, is equal to or greater than 95.7%.

Other data

One of the reports expressing concern with the potential for multiple versions of the ET-Plus device cited locations in Arizona where it was reported different dimensions were recorded: (http://www.bloomberg.com/news/articles/2014-12-12/guardrails-seen-as-killers-got-quiet-fix-inventor-says). FHWA asked for these measurements so they could be included in this analysis, but no data were provided. So FHWA went to Arizona and took measurements that FHWA believes included ET-Plus devices from the same area in Arizona that was included in that report.

A synopsis of the data

The full data set is available at http://fhwatest.fhwa.dot.gov/guardrailsafetytest/mtf.cfm. The table below summarizes the national data set.

		Exit Gap (middle - inside)	Channel Width (outside)	Channel Width (inside)	Guide Chute Entrance Height (outside)	Guide Chute Exit Height (outside)	Outside Guide Channel Length	Head Width	Head Height
Design Dimensions	Design Values	1.00	4.00	3.50	14.500	14.875	36.25	15.00	28.00
	Tolerance	n/a	4.00	3.50	0.250	0.25/-0.125	0.5/-0.25	n/a	n/a
	Upper Value	n/a	n/a	n/a	14.750	15.125	36.75	n/a	n/a
	Lower Value	1.00	n/a	n/a	14.250	14.750	36.00	n/a	n/a
National 1048	Max	1.75	4.13	3.63	15.00	15.31	36.63	15.75	28.50
	Min	1.00	3.94	3.00	14.06	14.56	35.00	14.75	27.50
	Avg	1.16	4.00	3.46	14.51	15.01	35.98	15.04	28.01
	Std. Dev.	0.09	0.01	0.10	0.11	0.07	0.18	0.09	0.07
	Median	1.13	4.00	3.50	14.50	15.00	36.00	15.00	28.00
	No. Above Tolerance	n/a	n/a	n/a	10	10	0	n/a	n/a
	No. Below Tolerance	0	n/a	n/a	8	4	179	n/a	n/a
	Pct out of Tolerance	0	n/a	n/a	1.7	1.3	17.1	n/a	n/a

Note: All measurements are in inches.

The upper and lower values for the tolerance of the channel width dimensions for both inside and outside are listed as n/a (not applicable) as these guide channel dimensions are not a result of Trinity's manufacturing process. The guide channels are ASTM A-6 standard specification materials purchased as built and used in the assembly of the ET-Plus device. The head dimension tolerances are listed as n/a as the dimensions of the impact plate were.

South Carolina DOT had accurate records of when and where roadside safety hardware was installed on its road network. This afforded the opportunity to look specifically at ET-Plus devices that were installed after 2012 and to compare the measurements from those ET-Plus devices to others in South Carolina and across the nation. The engineers taking the measurements in South Carolina also made a qualitative assessment of the condition of the ET-Plus devices and the sample reflected terminals that appeared to be newer, e.g., shiny zinc, than those that had been on the roadway longer. This level of detailed information regarding installation was not available for the other States.

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The table below provides a comparison of the dimensions of the ET-Plus devices installed in South Carolina in 2012 or later to the dimensions of the devices found nationally. All measurements in inches.

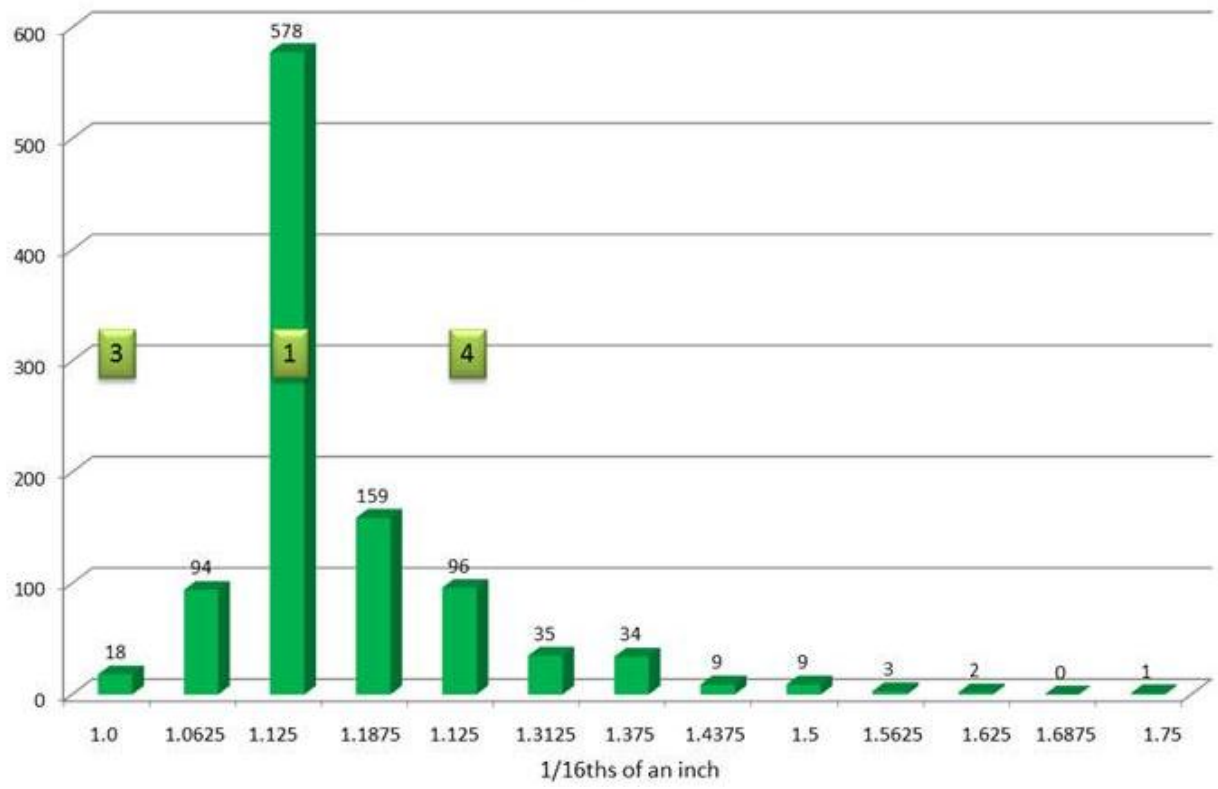
		Exit Gap (middle - inside)	Channel Width (outside)	Channel Width (inside)	Guide Chute Entrance Height (outside)	Guide Chute Exit Height (outside)	Outside Guide Channel Length	Head Width	Head Height
Design Dimensions	Design Values	1.00	4.00	3.50	14.500	14.875	36.25	15.00	28.00
	Tolerance	n/a	4.00	3.50	0.250	0.25/-0.125	0.5/-0.25	n/a	n/a
	Upper Value	n/a	n/a	n/a	14.750	15.125	36.75	n/a	n/a
	Lower Value	1.00	n/a	n/a	14.250	14.750	36.00	n/a	n/a
National 1048	Max	1.75	4.13	3.63	15.00	15.31	36.63	15.75	28.50
	Min	1.00	3.94	3.00	14.06	14.56	35.00	14.75	27.50
	Avg	1.16	4.00	3.46	14.51	15.01	35.98	15.04	28.01
	Std. Dev.	0.09	0.01	0.10	0.11	0.07	0.18	0.09	0.07
	Median	1.13	4.00	3.50	14.50	15.00	36.00	15.00	28.00
	No. Above Tolerance	n/a	n/a	n/a	10	10	0	n/a	n/a
	No. Below Tolerance	0	n/a	n/a	8	4	179	n/a	n/a
	Pct out of Tolerance	0	n/a	n/a	1.7	1.3	17.1	n/a	n/a
South Carolina 108 2012 or Later	Max	1.31	4.00	3.50	14.88	15.13	36.50	15.25	28.25
	Min	1.00	4.00	3.50	14.25	14.63	35.00	15.00	28.00
	Avg	1.14	4.00	3.50	14.47	15.01	36.01	15.02	28.00
	Std. Dev.	0.04	0.00	0.00	0.16	0.07	0.22	0.05	0.02
	Median	1.13	4.00	3.50	14.44	15.00	36.00	15.00	28.00
	No. Above Tolerance	n/a	n/a	n/a	1	0	0	n/a	n/a
	No. Below Tolerance	0	n/a	n/a	0	1	9	n/a	n/a
	Pct out of Tolerance	0	n/a	n/a	0.9	0.9	8.3	n/a	n/a

The table below provides a comparison of ET-Plus devices installed in South Carolina after 2012 compared to a random sample of devices in South Carolina. All measurements in inches.

		Exit Gap (middle - inside)	Channel Width (outside)	Channel Width (inside)	Guide Chute Entrance Height (outside)	Guide Chute Exit Height (outside)	Outside Guide Channel Length	Head Width	Head Height
South Carolina 130 Random Sample	Max	1.38	4.00	3.50	15.00	15.13	36.50	15.25	28.25
	Min	1.06	4.00	3.50	14.25	14.75	35.25	14.88	27.88
	Avg	1.15	4.00	3.50	14.54	15.02	35.99	15.06	28.02
	Std. Dev.	0.06	0.00	0.00	0.16	0.06	0.23	0.09	0.06
	Median	1.13	4.00	3.50	14.50	15.00	36.00	15.00	28.00
	No. Above Tolerance	n/a	n/a	n/a	3	0	0	n/a	n/a
	No. Below Tolerance	0	n/a	n/a	0	0	27	n/a	n/a
	Pct out of Tolerance	0	n/a	n/a	2.3	0.0	20.8	n/a	n/a
South Carolina 108 2012 or Later	Max	1.31	4.00	3.50	14.88	15.13	36.50	15.25	28.25
	Min	1.00	4.00	3.50	14.25	14.63	35.00	15.00	28.00
	Avg	1.14	4.00	3.50	14.47	15.01	36.01	15.02	28.00
	Std. Dev.	0.04	0.00	0.00	0.16	0.07	0.22	0.05	0.02
	Median	1.13	4.00	3.50	14.44	15.00	36.00	15.00	28.00
	No. Above Tolerance	n/a	n/a	n/a	1	0	0	n/a	n/a
	No. Below Tolerance	0	n/a	n/a	0	1	9	n/a	n/a
	Pct out of Tolerance	0	n/a	n/a	0.9	0.9	8.3	n/a	n/a

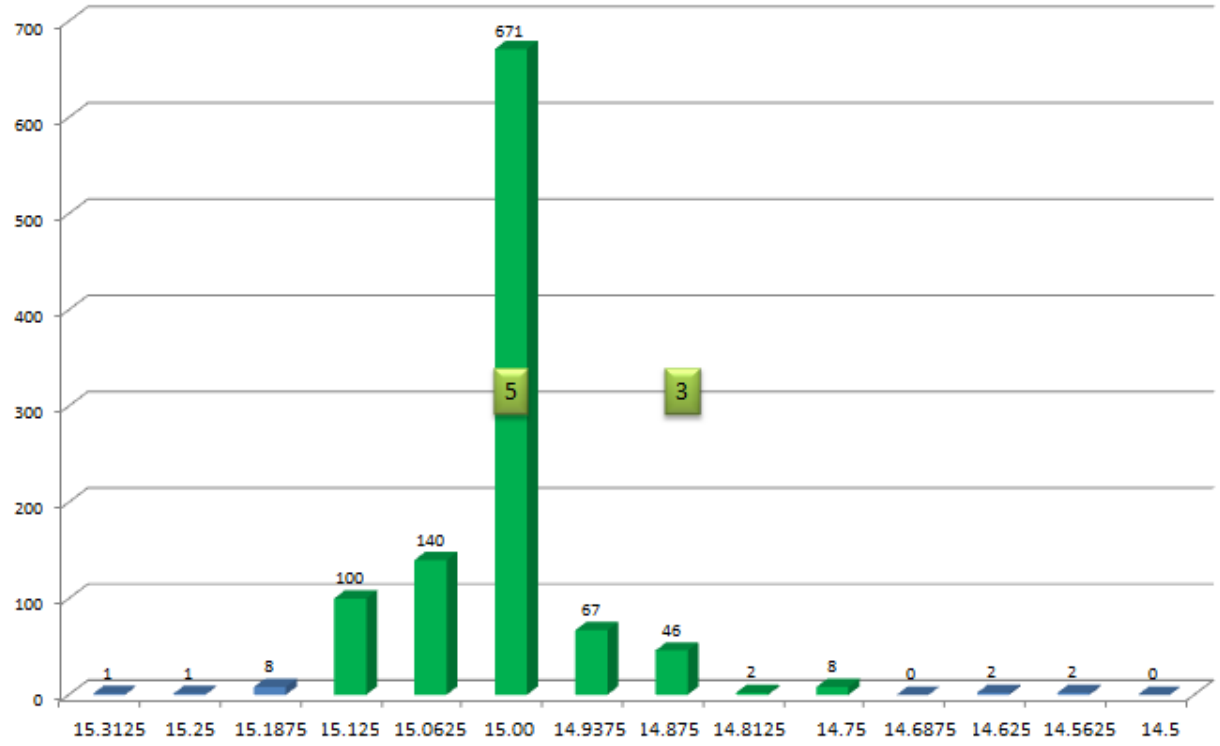
Exit Gap

The design dimension for the exit gap is a minimum of one inch. There were no measurements of the exit gap of less than one inch. The national average for the exit gap was 1.16 inches, the median was 1.13 inches, and the standard deviation was 0.09 inches. The graph below shows the national distribution of exit gap dimensions. As noted earlier, the measurements in the report are in 1/16" increments, which is why the graph below shows there is a distribution of measurements around a gap measurement of 1.125 inches and not the statistical average. The measurement data shows that all measurements of the exit gap over 1.375 inches were found in California and Arizona; ET-Plus devices which were presumably shipped from the Utah manufacturing facility. The ET-Plus device that showed an exit gap of 1.75" had scuff marks on the interior of the device indicating it may have been impacted and reused. The potential for reuse of the ET-Plus device is addressed in the documentation provided with its purchase and is at the discretion of the purchaser. The boxes at the 300 line in the graph below represent the measurements of the ET-Plus devices that were crash tested at SwRI between Dec 2014 and Jan 2015. The dimensions used for the reference boxes in the graph below are the measurements taken of the ET-Plus devices at the CalTrans facility prior to shipment to SwRI for testing. This was done to compare measurements taken with comparable methods. While there are 1,048 ET-Plus samples in the data collected, there are 10 devices where the exit gap is listed as 'n/a' or not applicable due to guardrail in the exit gap. All other measurements for these samples are included in the data, but there are only 1038 exit gap measurements in the data set.



Guide Chute Exit Height (outside)

As described in Note 1 in the drawing of the ET-Plus device on page 2, the guide chute sub assembly has a drawing dimension of 14 7/8" prior to its insertion into the extruder head. The extruder head vertical opening is 15" and the 14 7/8" dimension of the guide chute subassembly is fitted into this opening and then the two subassemblies are welded together. The design tolerance for the guide chute exit height is +1/4" and -1/8"; per TTI, this tolerance is applicable to the finished dimension for this opening - 15 1/8" to 14 ¾". The national average for the guide chute exit height (outside) was 15.01 inches, the median was 15 inches, and the standard deviation was .07 inches. The graph below shows the national distribution of the guide chute exit height (outside) dimensions. The boxes at the 300 line in the graph below represent the measurements of the ET-Plus devices that were crash tested at SwRI between Dec 2014 and Jan 2015. The dimensions used for the reference boxes in the graph below represent measurements taken of the ET-Plus devices at the CalTrans facility prior to shipment to SwRI for testing. This was done to compare measurements taken with comparable methods.



Other dimensions

As noted above and contained in the data, measurements were taken of dimensions other than the exit gap and the guide chute exit height (outside). While these measurements have not been the focus of any allegations, the measurement data does point to some variations in these dimensions.

The guide chute entrance height (outside), where the guard rail first enters the guide channel of the ET-Plus device, had measurements beyond the design tolerances. The guide channel length also had measurements beyond the design tolerances, predominantly in the California measurements. The locations of the ET-Plus devices with dimensions beyond the design tolerances suggest that there are potentially manufacturing variances in the different manufacturing facilities. These data do not suggest a systemic variation in dimensions across the country.

The dimensions were compared and correlated to each other to determine if there was any relationship between dimensional variations. That is, did a variation in the guide chute exit height (outside) dimension in either direction correlate to a corresponding variation in the exit gap dimension? A pivot table showing this relationship is contained later in this report. The data align around the average dimensions and supports the conclusion that the data do not show a systemic variation in the dimensions that would indicate there are multiple ET-Plus devices on the roadways.

Conclusions

Is there any evidence that there are multiple versions of the ET-Plus 4" guardrail end terminals on the roadways?

No. The task force found that while there are variances around the design dimensions, there is no evidence in the data that there are multiple versions of the ET-Plus device. When the data from the ET-Plus devices installed on South Carolina roads in 2012 or later were compared with other data from South Carolina and with the national data, there was no evidence that the dimensions of those ET-Plus devices were statistically different.

Are the devices that were crash tested at SwRI between Dec. 2014 and Jan. 2015 representative of the devices installed on the roadways?

Yes. The dimensions of the ET-Plus devices that were crash tested at the SwRI between Dec. 2014 and Jan. 2015 are representative of the ET-Plus devices measured on the roadways. The table below compares the crash tested ET-Plus devices to the national sample.

	Exit Gap (middle - inside)		Channel Width (outside)		Guide Chute Exit Height (outside)	
	Test Samp.	National	Test Samp.	National	Test Samp.	National
Avg	1.14	1.16	4.00	4.00	14.95	15.01
Median	1.19	1.13	4.00	4.00	15.00	15.00

The two graphs that show the national distribution of exit gap and guide chute exit height (outside) dimensions also compare the dimensions of the crash tested ET-Plus devices to the national sample.

Do any of the variations in the dimensions either individually or in concert with another dimension cause a concern regarding the performance of the ET-Plus device?

The test criteria in both NCHRP 350 and MASH state that the test article 'should be constructed and erected in a manner representative of in-service installations and should conform to specifications and drawings of the manufacturer or designer.' As all eight devices crash tested at SwRI between Dec 2014 and Jan 2015 were within the design tolerances of the ET-Plus device, the task force decided that the performance of device when within design tolerances was addressed by the crash test results.

The task force could not determine, based on the data or material it reviewed, whether or not dimensional variances beyond the design tolerances, either individually or in combination, would affect the performance of the ET-Plus device. For example, the task force could not determine if an additional 1/8" in the length of the guide channel, or a guide chute entrance height (outside) dimension of 1/8" beyond the design tolerance would affect the performance of the device.

Did the crash tests conducted at SwRI between Dec. 2014 and Jan. 2015 apply worst-case test conditions to the device itself?

NCHRP-350 does not apply worst-case testing conditions to the test article. NCHRP-350 section 2.3 addresses the requirements for the test article – the device itself. In this section it states 'The test article should be constructed and erected in a manner representative of in-service installations and should conform to specifications and drawings of the manufacturer or designer.' In the eight crash tests conducted at SwRI, the devices that were tested met the criteria for the devices as called for in NCHRP 350; the ET-Plus devices were within the stated design tolerances of the device and are representative of in-service installations.

NCHRP-350 addresses the concept of worst-case test conditions in the sections that address the *types of tests* to be conducted - specifically in sections 3.2.2.3 and 3.4.1. In Section 3.2.2.3 it states: 'If the feature [this term, in this context, refers to the centerline of the system being tested] will typically be used in various orientations, *worst-case test conditions should be selected within the recommended test matrices*.' In Section 3.4.1 it states: 'To the extent possible, the initial impact point for a redirective device should be selected to establish a *worst-case testing condition, that is, the critical impact point (CIP) or the point with the greatest potential for causing failure of the test*, whether this be by excessive wheel snag, excessive pocketing, or structural failure of the device.' The application of worst-case testing conditions in NCHRP 350 is to the *types of tests* that are conducted, not to the device itself. The interpretation and application of worst-case test conditions to the devices themselves or any of their multiple dimensions has not been applied to any device tested under NCHRP 350 guidelines.

Further, in the MASH guidelines, the application of worst-case test conditions and the need for manufacturers to identify 'critical dimensions' of the test article prior to conducting crash testing is not applied. MASH section 3.4.1 addresses the test article and it mirrors verbatim what is stated in NCHRP 350 - 'The test article should be constructed and erected in a manner representative of in-service installations and should conform to specifications and drawings of the manufacturer or designer.' MASH introduces an underlying philosophy of 'worst practical conditions' which is discussed and applied in section 2 'Test Matrices and Conditions' in the same way 'worst test conditions' are applied in NCHRP 350.

Nevertheless, the dimensions of the devices used for the most demanding of the tests, the head-on with the pick-up truck and the head-on offset with the small vehicle were reviewed. The dimensions for those crash tests are:

Guard-rail Height	Type	NCHRP 350 Test Designation	Exit Gap	Guide Chute Exit Height (outside)
27 ¾"	p/u head-on	3-31	1.089	14.9375
31"	p/u head-on	3-31	1.1145	15.0625
27 ¾"	small car head-on	3-30	1.1395	15.0625
31"	small car head-on	3-30	1.0495	15

The design dimension of the exit gap is a minimum of one inch. At the national level, the average dimension of the exit gap is 1.16" and the median dimension is 1.13". All of the dimensions of the exit gaps in the most demanding tests are below the average dimension of 1.16"and three of the four are below the median dimension of 1.13" with the exception of one of the exit gaps, which is one/one thousands of an inch larger.

The design dimension of the guide chute exit height (outside) is 14 7/8" and has design tolerances of +1/4" and –1/8". At the national level, the average dimension of the guide chute exit height (outside) is 15.01 and the median dimension is 15". All the dimensions of the guide chute exit height (outside) for the devices crash tested bracket the average, and median dimension by six hundredths of an inch on either side.

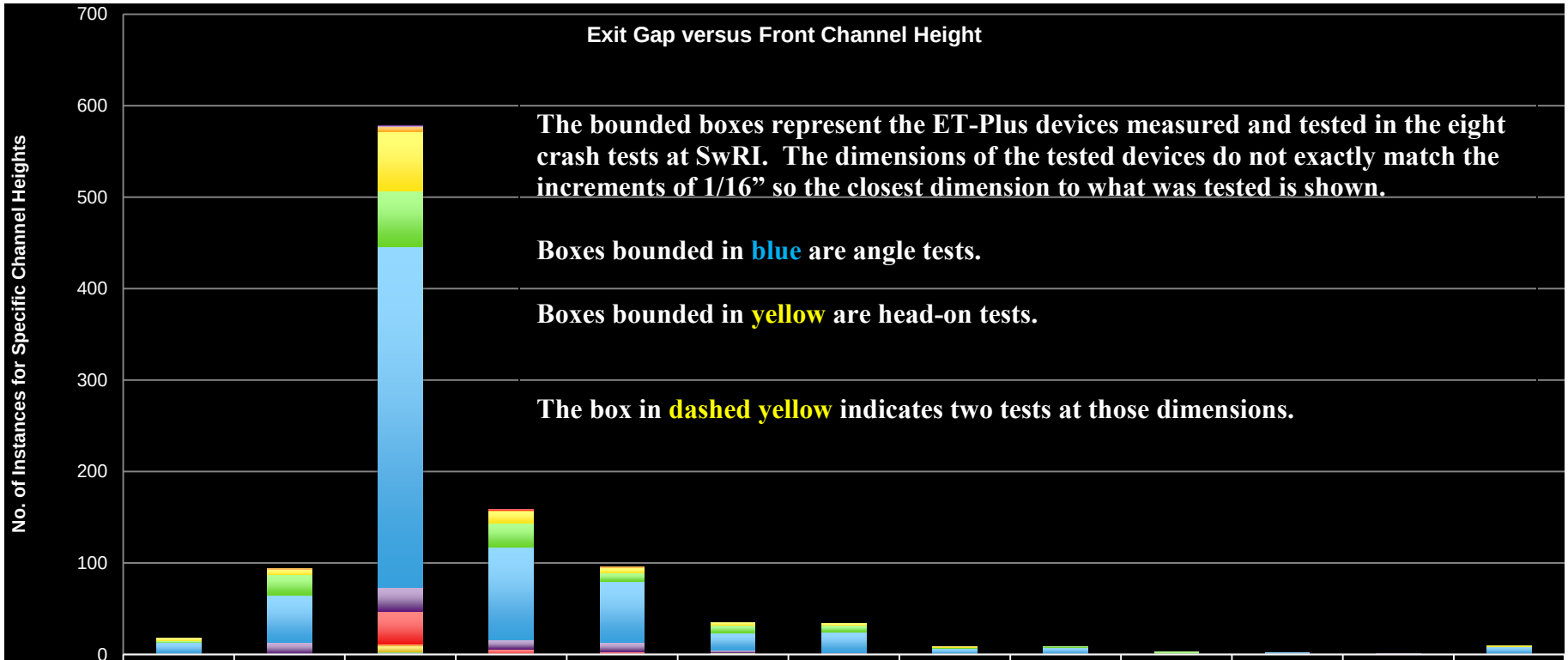
Observations

While the task force found the comparison of the more complete information from South Carolina sufficient to compare recent installations with the national sample, the task force found that having more complete manufacturing and installation information of the devices would have improved the understanding of the available data and could support in-service performance evaluations. The task force suggests that AASHTO's Technical Committee on Roadside Safety (TCRS) review and consider a method of identification for roadside safety hardware (e.g., RFID tags or stamping along the lines of AASHTO M-180) in the next update to the Manual for Assessing Safety Hardware (MASH).

Normally, the process of evaluating particular dimensions, or combinations of dimensions, is conducted during research and development for the device and culminates in a device that is crash tested against the applicable criteria. As noted above, the crash test criteria state that 'The test article should be constructed and erected in a manner representative of in-service installations and should conform to specifications and drawings of the manufacturer or designer.' The potential application of worst-case testing conditions to the roadside safety hardware being tested, versus the types of tests being conducted on the hardware, could entail multiple testing combinations of particular dimensions either individually or in combination, under different types of tests. This is an issue best reviewed by the Technical Committee on Roadside Safety as they consider the next update to the Manual for Assessing Safety Hardware (MASH).

As noted in NCHRP 350 and MASH, the test article should be constructed and erected in a manner representative of in-service installations and should conform to specifications and drawings

of the manufacturer or designer. So that buyers may determine the most appropriate means of ensuring that the devices they purchase are within the specifications identified by the manufacturer or designer, the Technical Committee on Roadside Safety should consider the extent to which the disclosure of these dimensions should be included in the documentation that is provided when the device is installed on the roadways.



	1	1.0625	1.125	1.1875	1.25	1.3125	1.375	1.4375	1.5	1.5625	1.625	1.75	na
15.3125			1										
15.25				1									
15.1875		1	5	1	1								
15.125	3	6	65	13	6	3	2	1					1
15.0625	2	22	61	27	9	8	7	1	1	2			
15	12	52	373	101	67	19	23	6	7	1	2		8
14.9375	1	12	26	10	10	3	1	1	1			1	1
14.875		1	36	6	3								
14.8125			1				1						
14.75			7			1							
14.625			1			1							
14.5625			2										

Pivot Table showing guide channel exit height (outside) dimensions compared to exit gap dimensions

AASHTO & FHWA Task Force – ET-Plus 4" Device Dimensions

Task Force Members

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Bill Wilson	Wyoming DOT *
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Kelly Hardy	AASHTO
Jim McDonnell	AASHTO
Eduardo Arispe	FHWA
Tony Furst	FHWA
Pat Hasson	FHWA

* Denotes membership on AASHTO's Technical Committee on Roadside Safety (TCRS)

Reference Documents

The data from the field measurements.

Joshua Harman's presentation from Jan. 2012 that presents his concerns regarding the dimensions of the ET-Plus.

Joshua Harman's court documents from May 2013 that presents his allegations regarding dimensions of the ET-Plus.

Dr. Sicking's email from Nov. 2014 that references an informal study he conducted on guide channel height dimensions (guide channel exit height (outside)) at the entrance to the extruder head.

Dr. Sicking's deposition in Sep. 2014 where he was questioned about that informal study.

Link to a Bloomberg News article that captures/synopsizes concerns that have been raised regarding multiple versions of the ET-Plus device.

John Durkos' email on the dimensions of the ET-Plus.

John Durkos' presentation on ET 2000 – ET-Plus head comparisons.

John Durkos' presentation on alleged ET-Plus guide chute exit height (outside) dimensions.

Brian Smith's affidavit from Feb. 2012 regarding exit gap dimensions of the ET-Plus.

Presentation on the re-inspection of the ET-Plus device in Laurel, CA with a 1.75" exit gap.

Three photos that were taken of the entrance to the extruder head that shows the guardrail relative to the dimension of the guide chute exit height. This was the device after crash test ET27-31 the head-on impact of the pickup truck at the guardrail height of 27 ¾". The exit gap for this test was 1.0890 and the guide chute exit height (outside) was 14.9375".