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GUIDELINES FOR ATTACHMENTS TO BRIDGE RAILS AND MEDIAN BARRIERS

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16. Abstract (Limit: 200 words)

Highway agencies are often presented with the need to add attachments of various configurations to the top or backside of crashworthy traffic barriers. Although, the National Cooperative Highway Research Program (NCHRP) Report No. 350 offers guidance for the safety performance evaluation of traffic barriers, it offers no guidance toward the evaluation of attachments on or near these barriers. The objective of the research project was to collect crash test data relating to bridge rails and median barriers, to collect information about common attachments to traffic barriers, and to evaluate this information for the purpose of developing guidelines for the design and placement of traffic barrier attachments.

A comprehensive review of full-scale crash testing of bridge rails and median barriers was conducted in order to establish Zones of Intrusion (ZOI's) for traffic barriers. The primary goal of this review was to identify the extent that a pickup or single-unit truck intrudes over the top of a traffic barrier during a vehicular impact. A field site investigation was undertaken to determine the types of devices commonly attached to traffic barriers. The field survey also categorized the traffic barriers which contained attachments. Finally, based on the combined results from the crash test review and the field investigation, recommendations for the placement and design of attachments are made.

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1 INTRODUCTION

1.1 Problem Statement

Very often, it is convenient or necessary to add attachments of various configurations to crashworthy traffic barriers. The Federal Highway Administration's (FHWA's) policy for the National Highway System (NHS) requires full-scale crash testing of all roadside safety devices. Although, National Cooperative Highway Research Program (NCHRP) Report No. 350 (1) offers guidance for the safety performance evaluation of traffic barriers, it offers no guidance toward the evaluation of attachments on or near these barriers. Secondary devices attached to, or in close proximity behind, an approved traffic barrier remains an unaddressed issue. Several questions need to be considered: first, what is the clear zone around a traffic barrier required to eliminate vehicle impact with an attachment; second, what safety hazards do attachments within this clear zone pose; and third, what potential design modifications could be incorporated to make these attachments safe when placed in this clear zone.

1.2 Background

Highway agencies are often presented with a need to add attachments, such as pedestrian and bicycle railings, highway signage, glare screening fences, and luminaire poles, to the top or backside faces of successfully crash-tested traffic barriers. It is not practical to conduct full-scale crash tests for all attachments typically used on or adjacent to these barriers. Presently, highway agencies must evaluate proposed attachments based on the available information, but to date there has been limited guidance for evaluation of the potential implications of placing an attachment on or adjacent to a crashworthy barrier.

The hazard associated with traffic barrier attachments is primarily related to the mounting location and the rigidity of the attachment. Hardware mounted in a location that can not be struck by vehicles impacting the barrier obviously pose little safety hazard. Hardware mounted on or adjacent to a barrier that will potentially be impacted must be evaluated in terms of potential hazards to the impacting vehicle, as well as the potential of hazardous debris.

1.3 Objective

The objective of this research study was to develop guidelines for the placement and design of traffic barriers attachments by collecting and analyzing crash test data of bridge rails and median barriers and information on common traffic barrier attachments on the roadways.

1.4 Scope

The research objective was to be achieved by performing several tasks. First, full-scale crash test results from a variety of traffic barrier classes, impacted with both pickup trucks and single-unit trucks, were analyzed in order to identify zones where rigid traffic barrier attachments would pose little or no hazard to impacting vehicles. The lateral penetration of vehicle components above and beyond the front face of each traffic barrier was carefully evaluated in order to establish intrusion limits for each barrier class. Next, a field investigation was undertaken to identify and document the devices that are commonly attached to traffic barriers. Finally, acceptable mounting areas for barrier attachments were identified and general recommendations for the placement and design of these attachments were developed.

2 ZONES OF INTRUSION

2.1 Research Method

A comprehensive review of full-scale crash testing of bridge rails and median barriers was conducted in order to establish Zones of Intrusion (ZOI) for traffic barriers. These ZOI represent the intrusion of various vehicular components in an envelope around the barriers. Whenever possible, high-speed films from the crash tests were obtained, and a film analyzer was used to identify the measured distances. When the high-speed film could not be obtained, time-sequential photographs or video tapes of the crash tests were used to make distance estimations. Using dimensions of the barrier or other items in the pictures, an approximate scale could be determined in order to estimate the amount of vehicle intrusion over the top of the barrier. Generally, the bridge rails and median barriers studied were very stiff, and the barrier deflections observed were negligible. However, where significant deflection did occur, the intrusions were estimated from the original location of the barrier's front face. Definition of the ZOI and analysis of the integrity of various vehicular components involved will ultimately form the basis for determining the potential influence of various appurtenances.

NCHRP Report No. 350 defines several test levels prescribing test conditions appropriate for a range of highway types, traffic volumes, and other parameters. Test Levels 1 and 2 (TL-1 and TL-2) are intended for low-speed and/or low-volume roads, while TL-3 through TL-6 are intended for high-speed facilities with increasingly higher traffic and truck volumes. Test Level 1 traffic barriers are designed for operating speeds in the range of 50 to 60 km/hr (31.1 to 37.3 mph). Because the risk of serious injury caused by attachments to the top or back of a rigid traffic barrier is greatly reduced with low impact speeds, TL-1 traffic barriers were not included in this study.

Similarly, TL-5 and TL-6 barriers are used only for very specific situations, and little work has been done developing these barriers. Therefore, these barriers were also not considered in this study.

TL-2 traffic barriers are generally considered to be adequate for roadways with operating speeds in the 70 to 80 km/hr (43.5 to 49.7 mph) range. Although many roadways with operating speeds in this range were found to have traffic barrier attachments, almost all of these situations involved either concrete barriers or combination concrete/steel railings. Therefore, only concrete or combination concrete/steel bridge railings were included in the analysis for TL-2. It should also be noted that some TL-2 barriers are only 508-mm (20 in.) tall (3, 4) and allow small cars to extend over the top of a TL-2 barrier, but the extent of small car intrusion is much less than that for pickup trucks. Therefore, evaluation of these TL-2 barriers was limited to crash tests using ¾-ton pickup trucks.

TL-3 is described as the basic test level for high-speed highways with operating speeds of 80 to 120 km/hr (49.7 to 74.6 mph). Full-scale crash testing has not identified any significant problem associated with small cars extending over or behind a bridge rail or median barrier. Therefore, for TL-3, the study was limited to the pickup truck crash tests. Although many roadside safety devices are designed only to meet TL-3, the added severity of trucks running off of a bridge or through the median and the risk of a vehicle falling on traffic at grade separations is taken into consideration in the design of bridge rails. Therefore, bridge rails are frequently designed to meet the TL-4 safety performance criteria. This test level requires testing with a small car, a ¾-ton pickup truck, and a single-unit truck. As mentioned previously, the intrusion of small cars was not a concern. Therefore, for this study only pickup truck and single-unit truck impacts were evaluated.

Many bridge rails have gained NCHRP Report No. 350 qualification based on earlier testing under the American Association of State Highway and Transportation Official's (AASHTO's) *Guide Specifications for Bridge Railings* (5). The primary difference between the *Guide Specifications for Bridge Railings* and NCHRP Report No. 350 is that the earlier guidelines recommended a 2,449-kg (5,400-lb) pickup truck impacting at a speed of 96.6 km/hr (60.0 mph) and at an angle of 20 degrees, while the current guidelines recommend a 2,000-kg (4,409-lb) pickup truck impacting at a speed of 100.0 km/hr (62.1 mph) and at an angle of 25 degrees. FHWA concluded that the performance levels and test levels were sufficiently similar to grandfather all bridge rails tested under AASHTO's *Guide Specifications for Bridge Railings* to be acceptable under NCHRP Report No. 350. The NCHRP Report No. 350 pickup truck test provides a 33.8 % increase in impact severity from that provided with AASHTO's Performance Level 2 (PL-2) pickup truck impact. Therefore, under AASHTO's *Guide Specifications for Bridge Railings* test conditions of reduced impact angle and speed as well as increased pickup truck weight may reduce the intrusion distances of the pickup truck over the top of some bridge rails from what would have been observed under NCHRP Report No. 350 crash testing.

2.2 Determination of ZOI

A wide variety of traffic barrier classes were reviewed, which included sloped-faced concrete parapets (e.g., New Jersey, Single Slope, F-shape, and open concrete rail), vertical-faced concrete parapets (e.g., vertical wall and open concrete rail), selected steel corrugated rails (e.g., W-beam and thrie beam), steel tubular rails, steel tubular rails on curbs, combination concrete and steel tube railings, and timber bridge rails. Crash test data was available for each barrier class although many of the barrier classes were represented by only one design, as shown in Tables 1 through 5. Barrier heights examined varied from a low of 508 mm (20 in.) for the Low-Profile Portable Concrete

Table 1. Intrusion Extent Results from Crash Test Reviews

Barrier Class	Barrier Name	Barrier Height (mm)	Test Level Equivalence	Vehicle	Maximum Significant Intrusion (mm)[1]		Vehicle Component
Concrete with Sloped Face	762-mm (30-in.) New Jersey Safety Shape	762	TL-4	small car	152		hood/fender
				pickup	203		hood/fender
				single-unit truck	2591	upper	leading box corner
					2743	lower	front fender
	Single Slope Concrete Bridge Rail	813	TL-4	pickup	305		hood/fender
				single-unit truck	NA	upper	Unable to determine
					711	lower	hood/fender
	813-mm (32-in.) F-Shape Bridge Rail	813	TL-4	small car	51		hood/fender
				pickup	203		hood/fender
				single-unit truck	1219	upper	leading box corner
					406	lower	fender
	813-mm (32-in.) New Jersey Safety Shape Bridge Rail	813	TL-4	pickup	229		hood/fender
				single-unit truck	2438	upper	leading box corner
					1219	lower	cab corner
	1067-mm (42-in.) F-Shape Bridge Railing	1067	TL-5	tractor trailer	1219		leading trailer corner
	Natchez Trace Parkway Bridge Rail	826	TL-2	small car	51		hood/fender
				pickup	305		hood/fender
	Federal Lands Modified Kansas Corral Bridge Rail	686	TL-2	small car	51		car side
				pickup	127		hood/fender

[1] May not be the maximum overall intrusion since that could include intrusion extent of mirrors or sideswipe action of the rear truck body which were considered less significant hazards. "Upper" refers to the top edge of the single-unit truck box, while "lower" refers to top of the barrier.

Table 2. Intrusion Extent Results from Crash Test Reviews (continued)

Barrier Class	Barrier Name	Barrier Height (mm)	Test Level Equivalence	Vehicle	Maximum Significant Intrusion (mm)[1]		Vehicle Component
Concrete with Sloped Face	813-mm (32-in.) New Jersey Safety Shape Bridge Rail	813	TL-3	pickup	457		hood/fender
	Low Profile Portable Concrete Barrier	508	TL-2	small car	305		hood/fender
				pickup	711		hood/fender
Concrete with Vertical Face	Nebraska Open Concrete Bridge Railing (AASHTO Bridge Guide Specifications)	737	TL-4	pickup	406		hood/fender
				pickup	356		hood/fender
				single-unit truck	1321	upper	leading box corner
					610	lower	fender/leading box corner
				single-unit truck	889	upper	leading box corner
					457	lower	leading box corner
	Texas Type T411 Bridge Rail	813	TL-3	pickup	610		hood/fender
	813-mm (32-in.) Vertical Wall	813	TL-4	small car	203		hood
				pickup	381		hood/fender
				single-unit truck	762	upper	leading box corner
					381	lower	fender
	1067-mm (42-in.) Concrete Parapet	1067	TL-5	tractor trailer	1372		leading upper trailer corner
	Nebraska Open Concrete Bridge Rail (NCHRP 230)	737	TL-2	pickup	305		hood/fender
				pickup	305		hood/fender

[1] May not be the maximum overall intrusion since that could include intrusion extent of mirrors or sideswipe action of the rear truck body which were considered less significant hazards. “Upper” refers to the top edge of the single-unit truck box, while “lower” refers to top of the barrier.

Table 3. Intrusion Extent Results from Crash Test Reviews (continued)

Barrier Class	Barrier Name	Barrier Height (mm)	Test Level Equivalence	Vehicle	Maximum Significant Intrusion (mm)[1]		Vehicle Component
Steel Tubular Rails	Texas Type T6 Bridge Rail	705	TL-3	pickup	762		hood/fender
	California Type 115 Bridge Rail	762	TL-3	small car	305		hood
				pickup	762		hood/fender
	Illinois Side-Mounted Bridge Rail	813	TL-4	small car	0		none
				pickup	330		hood/fender
				single-unit truck	1422	upper	leading box corner
					330	lower	front fender
	Steel Bridge Rail with Tube Rail System for Transverse Decks	914	TL-4	pickup	533		hood/fender
				single-unit truck	2032	upper	leading box corner
					762	lower	leading box corner
Steel Tubular Rails on Curbs	Illinois 2399 Bridge Rail	813	TL-4	small car	152		hood
				pickup	279		fender
				single-unit truck	1702	upper	leading box corner
					406	lower	fender
	NETC Bridge Rail, Curb Mounted	864	TL-4	small car	76		hood
				pickup	305		hood/fender
				single-unit truck	1448	upper	leading box corner
					381	lower	leading box corner

[1] May not be the maximum overall intrusion since that could include intrusion extent of mirrors or sideswipe action of the rear truck body which were considered less significant hazards. "Upper" refers to the top edge of the single-unit truck box, while "lower" refers to top of the barrier.

Table 4. Intrusion Extent Results from Crash Test Reviews (continued)

Barrier Class	Barrier Name	Barrier Height (mm)	Test Level Equivalence	Vehicle	Maximum Significant Intrusion (mm)[1]		Vehicle Component
Concrete/Steel Combination Bridge Rails	Minnesota Combination Bridge Rail	889	TL-4	small car	0		none
				pickup	610		hood
				single-unit truck	1321	upper	leading box corner
					762	lower	front fender
	BR27C Bridge Railing on Deck	1067	TL-4	small car	0		none
				pickup	254		hood
				single-unit truck	610	upper	front box corner
					610	lower	front fender
	BR27D Bridge Railing on Deck	1067	TL-2	small car	0		none
				pickup	178		hood
Concrete/ Concrete Combination Rail	Texas T5 Modified Bridge Rail	2286	TL-6	tanker	102		barrier displacement only
Flexible Bridge Railings	Oregon Side Mounted Bridge Railing	686	TL-2	small car	152		hood
				pickup	457		hood/fender (330 mm rail defl.)
	California Thrie Beam Bridge Rail	813	TL-2	small car	152		car side
				pickup	533		hood/fender
	TBC-8000 Bridge Rail for Longitudinal Decks	845	TL-4	single-unit truck	1219	upper	leading box corner
					508	lower	leading box corner

[1] May not be the maximum overall intrusion since that could include intrusion extent of mirrors or sideswipe action of the rear truck body which were considered less significant hazards. "Upper" refers to the top edge of the single-unit truck box, while "lower" refers to top of the barrier.

Table 5. Intrusion Extent Results from Crash Test Reviews (continued)

Barrier Class	Barrier Name	Barrier Height (mm)	Test Level Equivalence	Vehicle	Maximum Significant Intrusion (mm) [1]		Vehicle Component
Flexible Rails on Curb	Delaware Retrofit Bridge Railing	804	TL-4	single-unit truck	1524	upper	leading box corner
					660	lower	front fender
Timber Bridge Rails	GC-8000 Bridge Rail for Longitudinal Decks	838	TL-4	pickup	610		hood/fender
				single-unit truck	1270	upper	leading box corner
					610	lower	front fender/box corner
	Wood Bridge Rail with Curb System for Transverse Decks	838	TL-4	pickup	533		hood/fender
				single-unit truck	1778	upper	leading box corner
					762	lower	leading box corner

[1] May not be the maximum overall intrusion since that could include intrusion extent of mirrors or sideswipe action of the rear truck body which were considered less significant hazards. “Upper” refers to the top edge of the single-unit truck box, while “lower” refers to top of the barrier.

Barrier (3, 4) to a high of 1,067 mm (42 in.) for the BR27C (6) and the BR27D (7) bridge rails. A detailed listing of the crash test data which was evaluated is found in Appendix A with the corresponding references listed in Appendix B.

The crash test analysis initially attempted to identify the maximum intrusion of any portion of a test vehicle beyond the top-front corner of the barrier. This intrusion definition was later deemed to be inappropriate when it was determined that the maximum intrusion was sometimes controlled by the test vehicle's exterior mirrors. Since mirror supports are generally designed to bend or fracture at very low loads, snagging of a mirror on a barrier attachment was not considered to represent a significant risk for occupant injury. Therefore, the focus of determining the vehicle components intruding into the area behind the traffic barrier's top-front corner was redirected to better identify the structural portions of test vehicles that should be considered when defining the ZOI.

One potential safety hazard associated with traffic barrier attachments is the possibility of vehicles snagging sufficiently to produce high decelerations for the occupants. Large attachments have the potential to remain rigid during an impact, and if a sufficient portion of an impacting vehicle strikes the device, unacceptably high deceleration forces could result. Even devices that fail or yield can decelerate the vehicle significantly before failing. For this study, full-scale crash testing will not be performed and hard numbers for vehicle deceleration will not be generated. Therefore, engineering judgement must be applied to estimate this potential.

Occupant compartment intrusion and deformation is a concern for traffic barrier attachments under two scenarios: (1) a vehicle component is driven into the occupant compartment due to impact with the attachment; or (2) the attachment itself intrudes into or deforms the occupant compartment.

The best example of the first case is where a pickup truck hood strikes an exposed barrier attachment and is driven into the vehicle's windshield, as shown in Figure 1 (18). On the other hand, occupant compartment deformation may be a greater problem associated with traffic barrier attachments than occupant compartment intrusion. A possible example of the second case is where the occupant compartment comes into direct contact with the barrier attachment, such as when the cab of a single-unit truck leans over a barrier to the extent that a vertical pole contacts the windshield and deforms the cab and glass. The roll motion behavior of a single-unit truck that could produce the previously mentioned scenario is shown in Figure 2.

Although bridge rails and median barriers generally do not pose debris problems, many attachments could become detached when struck by an errant vehicle. For attachments mounted on top of a bridge rail but toward the back side or behind the barrier, the trajectory of any debris should not pose a significant hazard to vehicles on the bridge itself. One concern for debris associated with this type of barrier/attachment installation is that it would fall on traffic and/or pedestrians below the barrier if located at a grade separation. For attachments on top of the traffic barrier close to the front face, the possibility of a debris trajectory that would pose a hazard to traffic on the bridge must be considered. Finally, for attachments on median barriers, the previous hazards must be considered, as well as the potential hazard the debris would pose to oncoming traffic from the other side of the median separation.

2.2.1 Test Level 2

The ZOI for TL-2 barriers is defined by an impact with a ¾-ton pickup truck at a speed of 70 km/hr (43.5 mph) and at an angle of 25 degrees. This vehicle's maximum intrusion was found to occur near the impact point where the lower portion of the vehicle crushed inward sufficiently to

Figure 1. Vehicle Hood Snagging

Figure 2. Single-Unit Truck Roll Motion Behavior

allow the hood and the top of the fender to extend over the top of the barrier. For TL-2, there were five applicable crash tests for use in the evaluation, most involving barriers in the 686 to 813-mm (27 to 32-in.) height range. For tests of standard height barriers, the maximum intrusion was found to be near 305 mm (12 in.) (8). However, one test was conducted on a 508-mm (20-in.) high barrier which resulted in an intrusion of 711 mm (28 in.) (3, 4). Based on this limited data, the ZOI for TL-2 barriers was defined to be 305 mm (12 in.) for barriers 686-mm (27-in.) high or taller and 711 mm (28 in.) for all shorter barriers, as shown in Figure 3.

2.2.2 Test Level 3

Since the TL-3 and TL-4 ¾-ton pickup truck test conditions are the same and TL-4 traffic barriers are often incorporated in areas where TL-3 traffic barriers are acceptable, the pickup truck tests on TL-4 barriers were also used in the process of identifying ZOI's for TL-3 barriers. A review of nineteen pickup truck tests revealed that, with very few exceptions, the vehicle's impacting corner intruded the largest extent over the rail. The bumper and front fender of the truck were normally crushed under, and the hood and upper portions of the fender were observed to extend over the top of the barrier. Thus, the greatest extent of intrusion generally occurs early in the impact event while the vehicle's velocity is very high and its trajectory is still into the barrier. As the vehicle is redirected, it sometimes exhibits some roll toward the barrier. For most of the tests studied, this roll action is insufficient to cause the top of the cab to significantly extend over the barrier. As the impact progresses, the rear of the truck then encounters the traditional "tail slap" into the barrier, and some intrusion of the rear bumper and fender sometimes occurs when the back of the truck rides up over the top of the barrier. The intrusion of the vehicle's rear end over the barrier would result in a sideswipe impact that would not be expected to be as severe as the snagging impacts that would occur at the front of the truck.

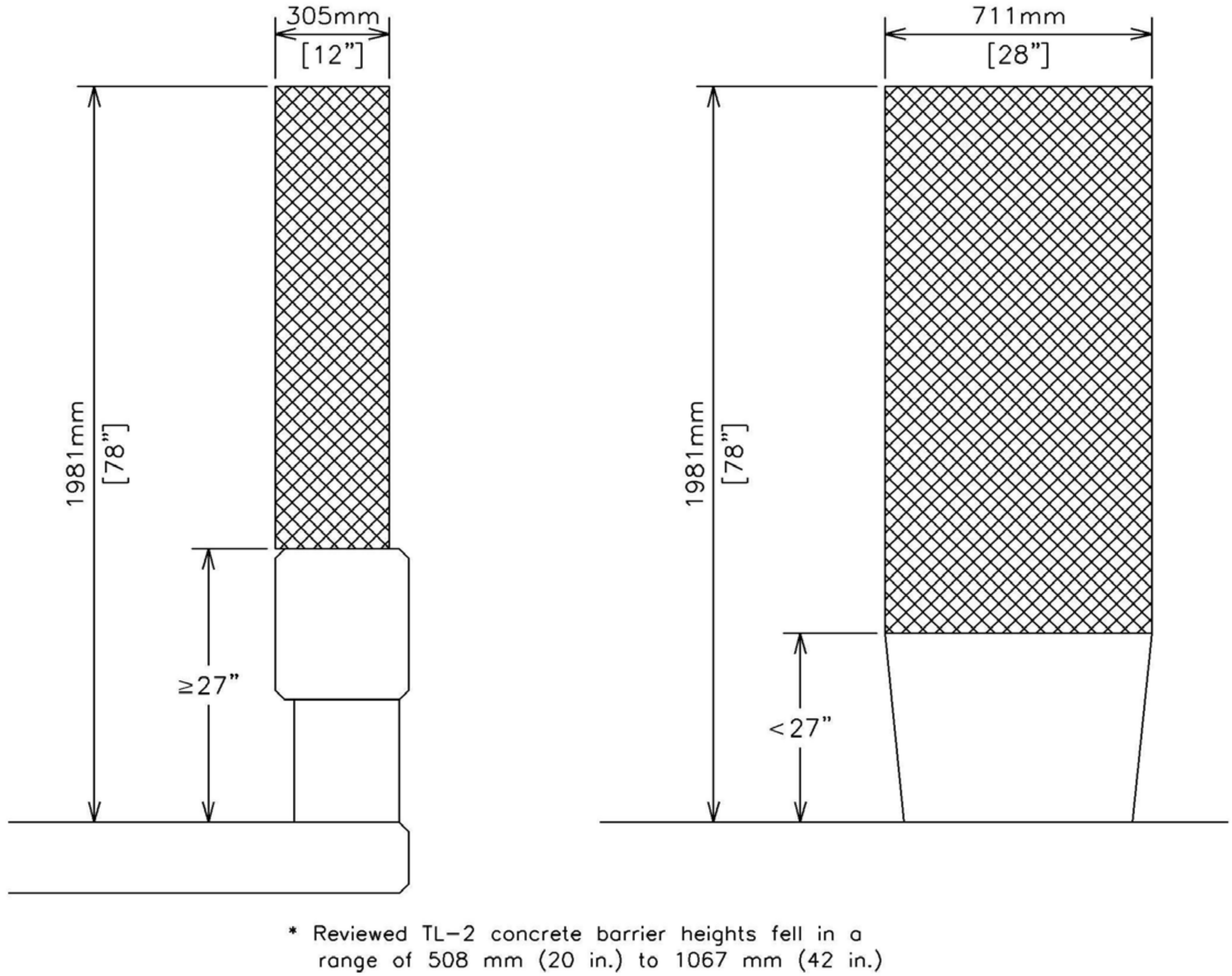


Figure 3. Intrusion Zones for Tall TL-2 Barriers ≥ 27 inches and for Short TL-2 Barriers < 27 inches

Barrier height was initially thought to be the variable that would relate best to the intrusion extent. Examination of the intrusion data in comparison to only the barrier height did not reveal this relationship. This finding was attributed to the fact that almost all traffic barriers included in the study had heights within a relatively narrow range from 705 mm (27.75 in.) (9) to 1,067 mm (42 in.) (6). Further, the taller barriers generally incorporated sloped concrete faces that tended to lift up the front of the pickup truck, thereby reducing their effective height.

For steel tubular rail systems, the extent of intrusion was affected by the lack or presence of a curb. Therefore, steel tubular rails were divided into two subclasses: (1) steel tubular rails on 152-mm (6-in.) curbs or greater, and (2) steel tubular rails not on curbs or on curbs less than 152 mm (6 in.) high.

The ZOI was found to be more closely related to the barrier class. Based on the size of the intrusion zone, the traffic barrier classes were combined into three groups. Group one included sloped-faced concrete barriers and steel tubular rails on 152-mm (6-in.) curbs or greater, and their ZOI extends 457 mm (18 in.) back from the front face of the barrier, as shown in Figure 4. The second barrier group included combination concrete and steel rails, vertical-faced concrete barriers, and all timber rails reviewed, and their ZOI extend 610 mm (24 in.) back from the front face of the barrier, as shown in Figure 5. Group three included steel tubular rails not on curbs or on curbs less than 152 mm (6 in.) high, and their ZOI extends back 762 mm (30 in.) from the front face of the barrier, as shown in Figure 6.

2.2.3 Test Level 4

Single-unit truck tests were found to exhibit greater variation in vehicle behavior than that observed for the pickup truck tests. Upon impact with the barrier, the test vehicle's front suspension

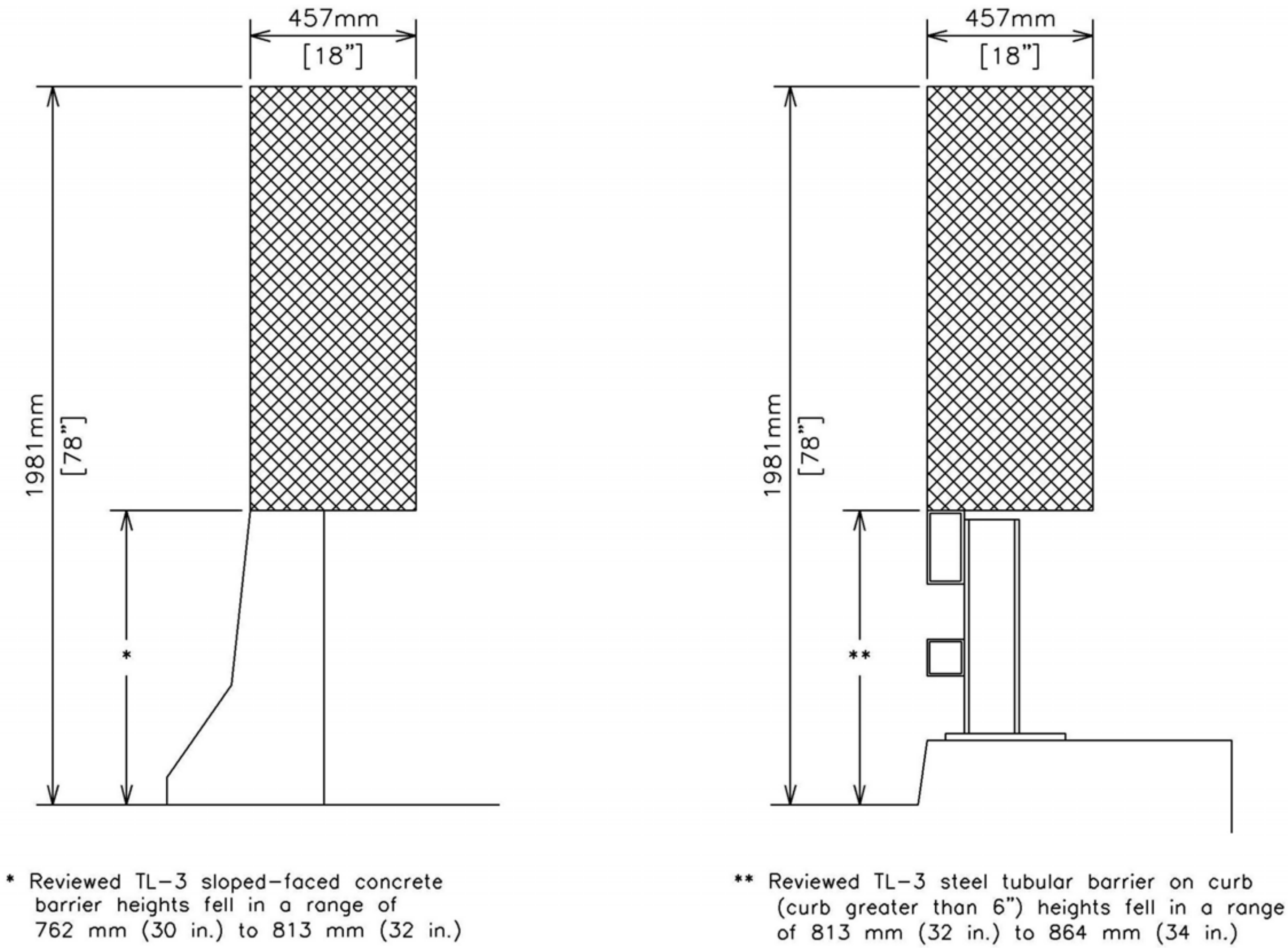
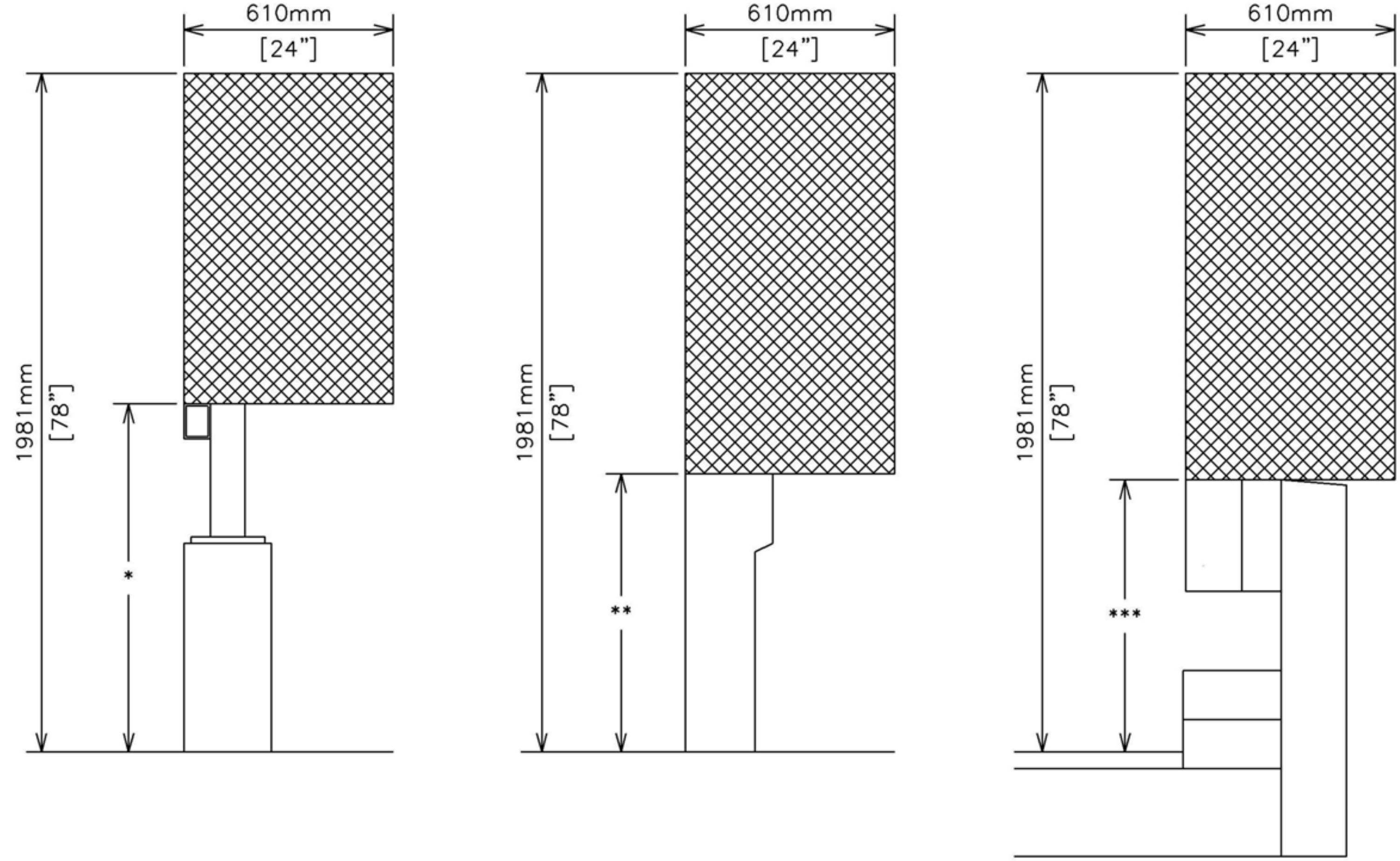


Figure 4. Intrusion Zones for TL-3 Concrete Barriers and Steel Tubular Rails on Curbs

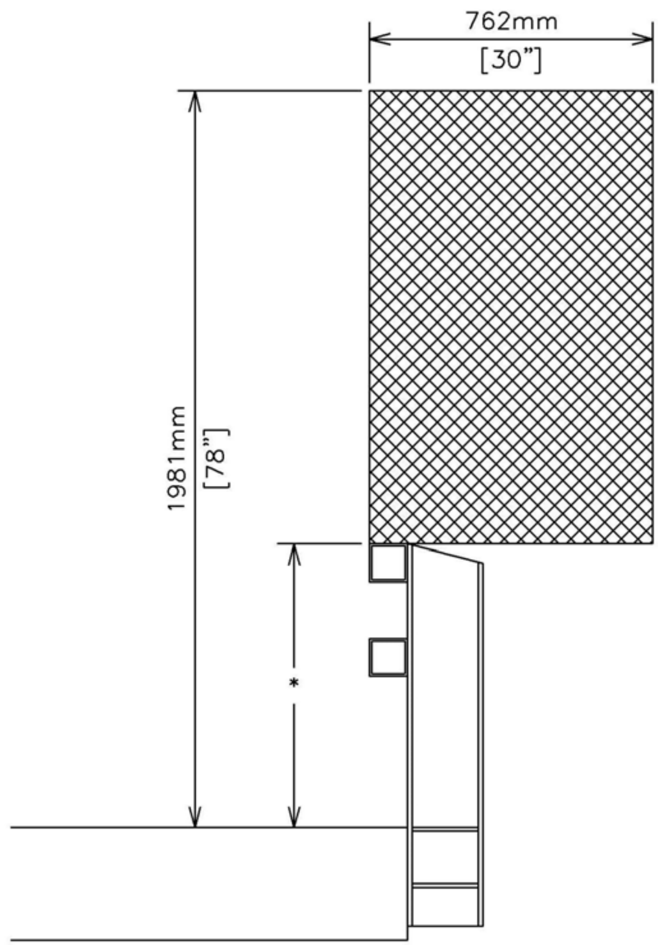


* Reviewed TL−3 combination barrier heights fell in a range of 889 mm (35 in.) to 1067 mm (42 in.)

** Reviewed TL−3 vertical concrete barrier heights fell in a range of 737 mm (29 in.) to 813 mm (32 in.)

*** The reviewed TL−4 timber barrier heights were 838 mm (33 in.)

Figure 5. Intrusion Zone for TL-3 Combination and Timber Barriers



* Reviewed TL−3 steel tubular barrier (no curb or curbs 152 mm or less) heights fell in a range of 705 mm (27.75 in.) to 914 mm (36 in.)

Figure 6. Intrusion Zones for TL-3 Steel Tubular Rails not on Curbs

was usually displaced laterally and longitudinally. During many of these tests, the front wheel on the impact side of the vehicle was pushed under the vehicle, often nearly to its centerline. Depending on the height of the barrier and the degree of wheel climb on the barrier's front face, the vehicle's front bumper would either crush or ride up over the top of the barrier. The test vehicle's front fender generally extended well over the top of the barrier, regardless of the action of the bumper and front tire. As the test vehicle was redirected, the rear of the truck typically rotated around and slapped the barrier. Since the bottom of the truck's cargo box was always higher than the top of the barrier, the rear wheels contacted the barrier instead of the cargo box or frame. The high lateral load on the rear wheels caused both the truck's cab and its cargo box to roll toward the barrier and generally extend well beyond the front face of the barrier. The extent of roll associated with the truck box and cab was found to vary significantly. Sometimes the two rolled approximately the same amount, while in other cases, the cargo box roll was much greater than that of the cab.

Much of the variation in vehicle behavior can be attributed to the torsional rigidity of the truck frame as well as the strength of the cargo box/frame connection. A stiff frame with a good connection would cause the truck cab and cargo box to roll simultaneously. In this case, the windshield and the top of the cab would usually extend well past the front face of the barrier. This behavior exposes the upper corner of the truck cab to an impact with barrier attachments. The cab roll also lowers the height of the truck cab to a level where shorter attachments may impact and penetrate it. A more flexible truck frame or a weak cargo box/frame connection allows the cargo box to roll more than the truck cab. In this case, the truck cab generally did not extend far beyond the front face of the barrier. Regardless of the behavior of the truck cab, the cargo boxes were observed to extend well beyond the barrier's front face. The primary difference between the cab and cargo box intrusions was the height at which it occurred. Maximum intrusion of the cargo box generally occurred at a point well above the top of the barrier, while the truck cab generally intruded near the top of the barrier. Some cargo boxes were observed to actually roll over the barrier sufficiently to extend behind the back and below the top of the barrier. It was determined that a distance of 229 mm (9 in.) would account for this behavior exhibited by a majority of the trucks.

Two tests on New Jersey Safety Shaped barriers, one with a 762-mm (30-in.) height (10, 11) and the other with an 813-mm (32-in.) height (12), exhibited behavior that was unlike the other TL-4 single-unit truck tests, both resulted in higher intrusion numbers. The cabs of these trucks rode up and over the top of the bridge rail, and for the 762-mm (30-in.) barrier, nearly the entire cab was over and beyond the barrier. It is believed that this behavior is particular to the New Jersey Safety Shape constructed at these heights. It was difficult to include the data from these tests in the determination of the ZOI for TL-4 since this would have resulted in an extremely large ZOI when most of the test results did not exhibit this, but this behavior should be noted. Therefore, these two particular barriers were excluded from the TL-4 ZOI determination.

It should be noted that several test vehicles experienced extreme penetrations caused by the vehicle running off the end of the barrier due to insufficient barrier length. Consequently, the cargo box experienced excessive roll (6, 13) and these tests were not included in the ZOI determination. However, while in contact with these barriers, the vehicle intrusion was consistent with the other tests used in the ZOI determination. Therefore, the maximum intrusion data for these tests was taken during barrier contact.

TL-4 barriers tend to be rigid and have a minimum height of 737 mm (29 in.) (14, 15) in order to redirect trucks. Also, most TL-4 barriers are 1,067 mm (42 in.) or less in height (6) since they are not tested with tractor-trailer trucks. Therefore, since TL-4 barriers have little height variation, it is not surprising that all of the TL-4 barriers exhibited similar intrusion numbers. Therefore, only one ZOI was defined for TL-4 barriers. The TL-4 ZOI was much wider at the top where the cargo box extended significantly past the front face of the barrier. Near the top of the barrier, the ZOI for the single-unit trucks was similar in extent to that of the pickup trucks in the TL-3 analysis. Since there was some variation in the height of the test vehicle's cargo box, the height of the upper intrusion region was standardized to represent most single-unit truck impacts. The bottom of the intrusion region was placed 229 mm (9 in.) below the top of the barrier, and the top of the region was placed 3.05 m (10 ft) above the roadway surface, as shown in Figure 7.

The risk of occupant injury associated with a truck cab snagging on a traffic barrier attachment is significantly greater than that associated with the snagging of the cargo box. The maximum extent of the TL-4 ZOI pertains to the cargo box intrusion, which runs from a point at barrier height and 864 mm (34 in.) behind the front face of the barrier to a point 3.05 m (10 ft) above the roadway surface and 2,032 mm (80 in.) back from the front face of the barrier. The truck cab ZOI extends 864 mm (34 in.) back from the front face of the barrier and from the top of the barrier up to 2.44 m (8 ft) above the roadway surface, as shown in Figure 7.

As noted previously, the tests involving the 762-mm (30-in.) and 813-mm (32-in.) New Jersey barriers were neglected in determining the ZOI for TL-4 barriers. Therefore, caution should be taken when using these barriers.

2.3 Test Level Selection

Due to cost, consistency, and aesthetic considerations, traffic barriers tested at high test levels are often used on low-speed and low-volume roadways. Thus, the test level at which a given

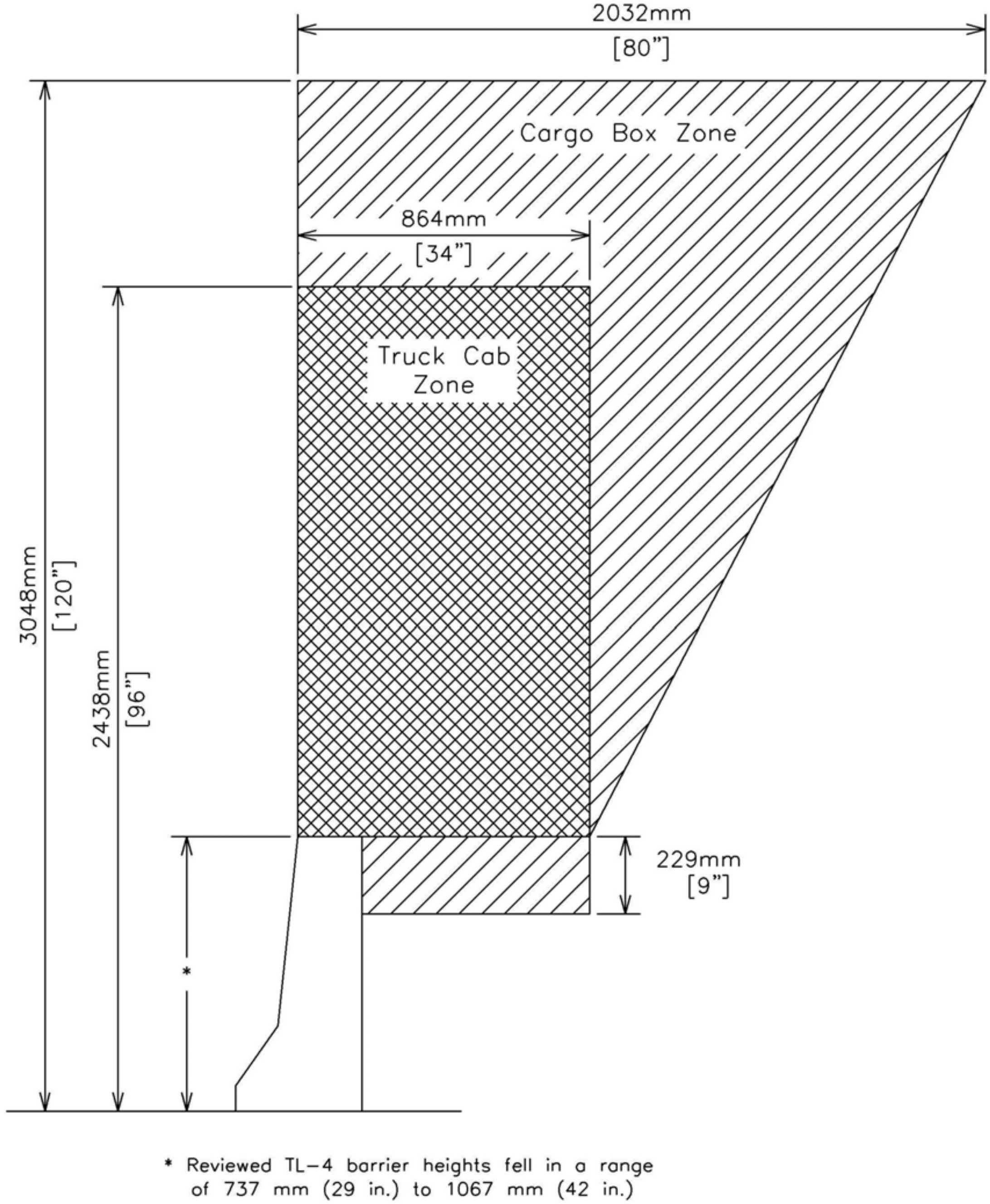


Figure 7. Intrusion Zones for TL-4 Barriers

barrier was tested for acceptance under NCHRP Report No. 350 is not an appropriate criteria for determining the ZOI to be applied. The most recent evaluation of appropriate bridge railing performance levels was conducted under NCHRP Project 22-8 (16). This study examined the bridge rail selection procedures and recommended some significant changes to the guidelines found in AASHTO's *Guide Specifications for Bridge Railing* (5). FHWA has made the determination that PL-1 can be considered equivalent to TL-2, and a PL-2 barrier is approximately equivalent to a TL-4 design. Hence, these guidelines do not include a category for TL-3. Eliminating TL-3 from the guideline selection process would mean that TL-2 would be expanded to include larger traffic volumes and higher design speeds, and TL-4 would be expanded to include lower traffic volumes and design speeds.

Preliminary guidance for barrier use in TL-2 and TL-3 applications is being developed under NCHRP Project 22-12 (17). These guidelines indicate that TL-2 systems appear to be appropriate for highways with speed limits as high as 96.6 km/hr (60 mph) when the traffic volume is low. Under high traffic volume conditions, these preliminary guidelines indicate that TL-3 barriers are appropriate at speed limits as low as 56.3 km/hr (35 mph). These barrier selection guidelines can be used to provide general guidance for traffic conditions considered appropriate for TL-2 applications.

Using the guidance found in NCHRP Project 22-12, the guidelines formulated in NCHRP Project 22-8 were reanalyzed in order to generate general guidance for traffic conditions where the various barrier test levels could be considered appropriate. To include TL-3 systems, engineering judgement was applied to the NCHRP Project 22-8 guidance, and Figure 8 was created and should only be considered interim guidance until more definitive guidelines are developed.

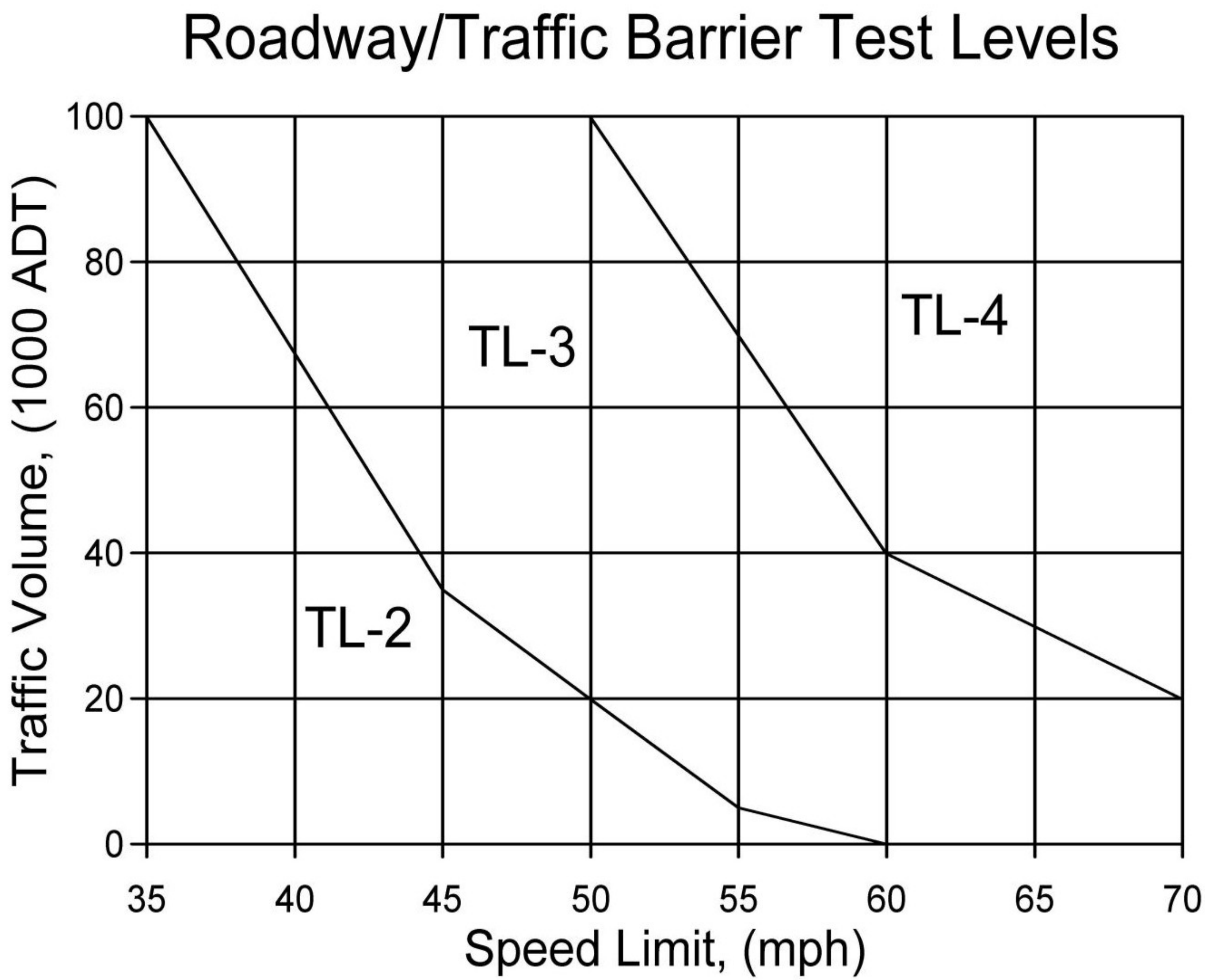


Figure 8. Roadway/Traffic Barrier Test Levels

3 CURRENT ATTACHMENTS TO TRAFFIC BARRIERS

3.1 Field Site Investigation

Design of traffic barrier attachments tend to be handled on a case-by-case basis as the need arises. As a result, standard highway and bridge plans offer little information on the types of attachments or their connection methods. Therefore, a field site investigation was conducted to determine common traffic barrier attachments. Telephone surveys of several states indicated that barrier attachments were much more common in urban areas where barriers are involved with grade separations rather than on rural highways where they are used to traverse terrain discontinuities.

The field survey, which entailed photographing a representative sample of traffic barrier attachments, focused on urban areas in Minnesota, Nebraska, Iowa, Kansas, Missouri, and South Dakota. Cities included in the field survey were: Omaha and Lincoln, Nebraska; Sioux Falls, South Dakota; Minneapolis/St. Paul, Minnesota; Des Moines, Iowa; Kansas City, Missouri; and Kansas City, Kansas. In order to determine locations of traffic barrier attachments, city engineers were contacted before and during the field survey.

Highway functional class and speed helped determine which roadways to investigate. Since FHWA requires that safety features used on the NHS meet the NCHRP Report No. 350 impact performance criteria, the field survey focused mainly on NHS roadways. However, highway engineers are frequently asked to provide barrier attachments on low-speed or low-volume facilities that are not commonly included in the NHS. Even though barrier attachments are also implemented on roadways with posted speeds of 64.4 km/hr (40 mph) or less, it was estimated that the risk of serious accidents on these facilities was greatly reduced. Therefore, the field survey was limited to roadways with posted speed limits greater than 64.4 km/hr (40 mph). Finally, it should be noted that some low-volume roadways were also included in the survey.

3.2 Traffic Barrier Types

The field survey categorized the traffic barriers which the attachments were connected was completed. Most of the traffic barriers with attachments were constructed from concrete and therefore essentially rigid. This finding was not unusual since wind loads on the attachments are expected to deliver high anchor forces to the barrier, and these forces are best supported by concrete barriers and pedestals.

3.3 Attachment Types

More than 125 traffic barrier attachments, such as delineators, luminaries, overhead sign support structures, signs, pedestrian and bicycle railings, sound walls, fences, and glare screens, were identified in the field review. The wide variety of barrier attachments makes individual treatment of each device impractical. Therefore, these attachments were grouped according to their size and method of connection to the barrier. The eight general attachment types are shown in Figures 9 through 16 and include:

(1) luminaire supports mounted on top of the traffic barrier,
(2) luminaire supports mounted behind the traffic barrier,
(3) signs for traffic on grade-separated intersecting roadways,
(4) large single support signs and overhead sign support structures,
(5) medium to small signs,
(6) fences and screens,
(7) pedestrian/bicycle railings, and
(8) miscellaneous attachments or fixed objects adjacent to parapets.

Luminaire supports were by far the most numerous of the attachments found in the field. These supports were either mounted on top of the barrier or on an extension behind the traffic barrier. Signs for traffic passing under the structure on grade-separated intersecting roadways generally involved very large informational signs consisting of large panels with a significant number of wind beams to support the portion that extends above the top of the traffic barrier. Large single support signs and large overhead sign support structures span the roadways. The size of small to medium signs range from a mile marker to a 1.22-m x 1.83-m (4-ft x 6-ft) regulatory or warning sign. Fences and screens are continuous obstacles with periodic posts and longitudinal railings or metal fabrics. Pedestrian/bicycle railings are used to provide further separation between walkways and the traveled-way and are often attached to the top of traffic barriers generally lower than the recommended minimum heights for pedestrian/bicycle railings. Miscellaneous attachments, including small delineators, entrance ramp meter signals, old bridge rail installations behind retrofit new rails, and decorative concrete spires, do not easily fit in with the other attachment types.

Figure 9. Luminaire Supports Mounted on Top of the Traffic Barrier

Figure 10. Luminaire Supports Mounted Behind the Traffic Barrier

Figure 11. Signs for Traffic on Grade-separated Intersecting Roadways

Figure 12. Large Single Support Signs and Overhead Sign Support Structures

Figure 13. Medium to Small Signs

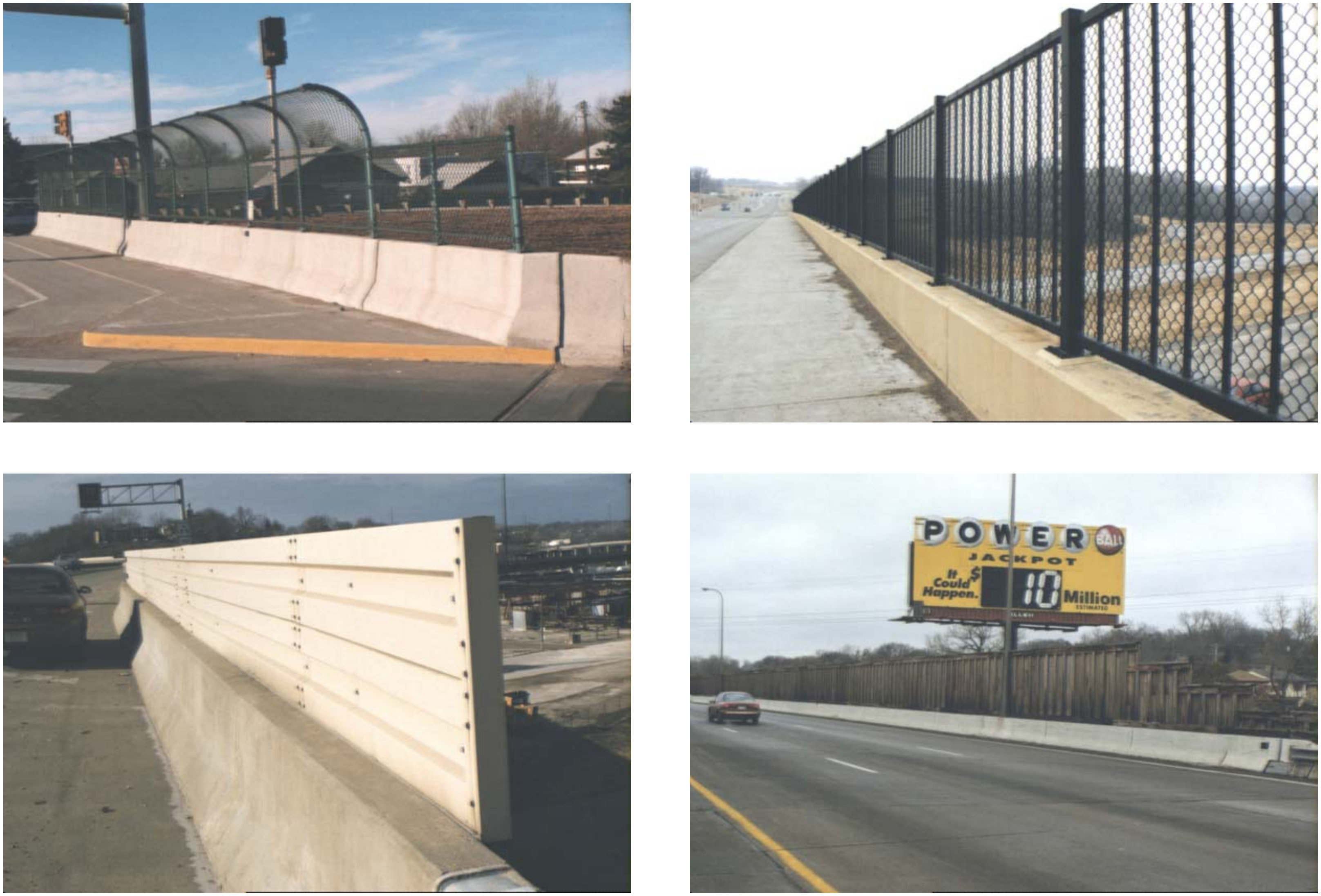


Figure 14. Fences and Screens

Figure 15. Pedestrian/Bicycle Railings

Figure 16. Miscellaneous Attachments or Fixed Objects Adjacent to Parapets

4 EVALUATION OF BARRIER ATTACHMENTS

In reviewing the general attachment types, each attachment was further classified according to its geometry and potential to cause a safety hazard to both occupants and bystanders. Each attachment was found to either be a single, individual entity (e.g., luminaire supports, sign support poles, and other structural devices) or to span the entire length of the traffic barrier (e.g., pedestrian rails, screens, and fences). Therefore, each attachment was classified as either a discrete or continuous attachment.

4.1 Discrete Attachments

The discrete attachments were further subdivided based on general geometry, structure, connection to the barrier, as well as the estimated severity of impact with the attachment. These three basic categories are rigid, breakaway and non-rigid.

4.1.1 Rigid

The rigid category is defined as any large, structurally-stiff, and rigidly connected devices. These attachments would be expected to impart significant loads on impacting vehicle when ZOI impacts occur and have the potential to cause severe vehicle snagging and occupant compartment deformation.

Based on roll behavior noted in some of the single-unit truck cabs in TL-4 testing and the fact that in some tests most of the cab extended over the railing, the concern for these trucks is that the occupant compartment will impact the attachments directly and deformation and/or intrusion will result. Since the cargo box of a single-unit truck can extend significant distances beyond the front face of a traffic barrier, severe snagging between the cargo box and a structurally-stiff attachment could also exist. This snagging could generate high deceleration forces on the truck and possibly injure the vehicle's occupants.

Occupant compartment deformation and intrusion are the major concerns for the TL-3 pickup trucks. The hood and fender components of a pickup truck are most likely to intrude over the barrier and potentially cause significant snagging. Even though the snagging could cause high deceleration forces or unstable vehicle behavior such that it rolls, it is believed to be unlikely that a significant portion of the truck components will interact with the rigid attachment to produce occupant compartment deformation and/or intrusion and is not seen as a concern. It should be noted that there is always the potential for this intrusion to create contact between the vehicle components and the attachment resulting in occupant compartment penetration.

Occupant compartment deformation and intrusion concerns may be reduced by the lower speeds of TL-2, but not sufficiently to exclude the hazard completely. In a couple of cases, larger vehicle intrusion was shown with low-height TL-2 rails that are discussed within this report. The height of these two rails was low enough that barrier contact was mostly limited to the vehicle tires. The front end of the truck, from the bumper upward, intruded over the barrier, and the vehicle experienced significant roll. Therefore, snag and high decelerations along with deformation of and intrusion into the occupant compartment are concerns.

Not much can be done to rigid discrete attachments to improve their safety performance when placed in the ZOI. The only practical recommendation that can be made for rigid discrete attachments is that they must be moved out of the ZOI until such time as the risks can be more adequately assessed through full-scale crash testing.

4.1.2 Breakaway

The breakaway category is defined for attachments which utilize mechanisms to weaken the connection to the barrier. In general, these breakaway devices have been tested with respect to frontal impacts when they are located on the ground surface near the travelway. Since these attachments are generally designed to be activated by a full-frontal vehicle impact, they require relatively high forces to activate the breakaway mechanism. Impacts by the front hood or fender of a pickup truck or the front cab of a single-unit truck would either require significant deformations before, or not be sufficiently rigid, to activate these breakaway mechanisms. Therefore, vehicle snagging on these hardware items is believed to be a potentially serious problem. Secondly, if the breakaway mechanism is activated, these large devices have the potential for creating debris problems.

Occupant compartment deformation and intrusion is quite likely for all ZOI impact conditions. Even though the breakaway mechanism may be activated at TL-4 conditions, the truck cab impacting the attachment still poses a hazard when considering the force needed to activate the mechanism. The high mass of the single-unit truck should help reduce the potential for snagging and high deceleration forces. For this reason, these attachments have the potential to be considered safe for the truck's cargo-box ZOI at TL-4 impact conditions. On the other hand, it appears to be quite unlikely that an impact with a pickup truck hood and/or fender at TL-2 and TL-3 conditions will approach the forces needed to activate the breakaway mechanism. Therefore, for these impact conditions, breakaway discrete attachments should be treated in the same manner as rigid attachments.

Debris concerns for breakaway discrete attachments are very similar to those of rigid attachments. If proper care is taken when placing these attachments, the debris hazard may be mitigated. Proper placement of breakaway discrete attachments is the only solution in order to address the hazard concerns of their safety performance related to occupant compartment intrusion.

Therefore, breakaway discrete attachments should be placed outside the single-unit truck cab TL-4 ZOI and in a location where debris is not projected upon traffic or pedestrians. In terms of breakaway performance related to the ZOI for the TL-4 truck box, individual devices will have to be considered separately.

4.1.3 Non-Rigid

The non-rigid category is defined as small, non-structural devices which contain minimal connections to the barriers and includes light-gauge steel and aluminum posts and reflectors. These attachments are not believed to pose a serious snagging problem since they are expected to fail or deform at relatively low loads. However, these attachments could still pose a serious risk to motorists if the occupant compartment contacts the attachment directly. Similarly, since these attachments are expected to become detached from a traffic barrier when impacted by an errant vehicle, they do pose a significant potential for creating debris that could fall below the bridge, on a pedestrian walkway, on the traffic side of the barrier, or into oncoming traffic behind a median barrier.

In terms of occupant compartment deformation and intrusion, location of the attachment forms the basis for evaluation. In considering all of the test levels, if the attachment is within the ZOI then the propensity for the attachment to become dislodged or to deform and contact the occupant compartment must be considered. This consideration is especially important for attachments weakly mounted at heights where the detached elements could impact the windshield of the vehicle. Attachments which are mounted outside the ZOI, but which have elements within the ZOI require consideration as well. This situation could potentially lead to impact of some portion of the attachment with the occupant compartment while the attachment is still fixed to the barrier.

The possibility of a debris being a hazard on bridges with vehicular or pedestrian traffic below needs to be considered. Similarly for non-rigid discrete attachments on median barriers, the potential debris hazard posed to oncoming traffic is a concern. Attachments in these locations should be designed to minimize or eliminate debris and its associated hazard.

4.2 Continuous Attachments

The performance of continuous attachments such as fences, noise walls, and pedestrian/bicycle railings that intrude on the ZOI for a particular barrier is dependent on a number of attachment features. These features include: post location and stiffness; geometry, continuity and tensile capacity of the longitudinal elements; transitions at the ends of the attachment; and proximity to pedestrians or vehicles that may be effected by debris.

As previously discussed, snagging on the posts may lead to occupant compartment intrusion, deformation, and potentially excessive decelerations when a stiff structural vehicle component contacts a strong post. In considering ZOI criteria, examples of railing systems as depicted in Figure 15 may have a propensity to snag the protruding hood of the impacting vehicle. Many of these installations involve stiff vertical posts mounted between the top of the concrete barrier and the longitudinal rail element. In many cases, the longitudinal elements are either structurally inadequate or inappropriately placed to prevent snagging on the posts. Crash testing has shown that when posts are mounted 178 mm (7 in.) behind the front face of a relatively rigid railing, the risk of snagging is greatly reduced (19). However, offsetting the posts of these attachments to the back of the rail does not eliminate these concerns. Designing open railings for these locations can be accomplished if post breakaway is considered. A combination pedestrian/bicycle rail system (19), as shown in Figure 17, utilized breakaway vertical posts to satisfy the safety performance criteria at both TL-3 and TL-4.

Figure 17. Minnesota Bridge Rail Breakaway Posts

For installations where the longitudinal structure (i.e. rails) of the attachment shields the posts, it is critical that this structure have adequate continuity and tensile capacity to prevent vehicular impact with the posts. As shown in Figure 18, the apparently continuous wall section had inadequate capacity to redirect the impacting vehicle. As shown in this example, there is no connection between adjacent wall panels in this system, but this performance is also replicated in systems where the longitudinal elements do not have sufficient bending strength to prevent bending (pocketing) adjacent to the posts. This situation is obviously exacerbated by stiff posts.

To date, there has been limited evaluation of transitions in height of attachments adjacent to the ends of the attachment. As shown in Figure 15, attachments typically transition from the end of the bridge rail section. Prudent design criteria involving installation in the ZOI is similar to considerations previously discussed, i.e. having posts that will breakaway allowing the system to deflect. Previous testing has shown that tapers of 8:1 or greater are advisable for concrete barrier end treatments (18). This recommendation for non-breakaway rail mounted to the top of the barrier is appropriate if the attachment design takes snag potential into consideration.

Finally, the potential implications of debris from impacts on these systems must be considered. This topic has been discussed at length in previous sections, and the considerations are the same in considering continuous attachments. Both the proximity of other pedestrian and vehicle traffic and the potential for elements of the attachment to become dislodged must be considered.

Figure 18. Failure of a Smooth Continuous Attachment

5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary

A review of crash tests was conducted on currently acceptable bridge rails and median barriers. The findings, as presented in Tables 1 through 5, were used to determine the extent of intrusion of impacting vehicles over the barriers. Based on this review, ZOI's were established at the test levels appropriate for this study and provided in the current NCHRP Report No. 350 guidelines. Three test levels were studied – TL-2, TL-3, and TL-4.

Next, a field investigation was conducted to determine the types of traffic barrier attachments currently in place. The attachments were classified as to the level of hazard they were believed to present. Finally, recommendations for placement and/or design of the attachments were made based on the combined results from the crash test review and the field investigation.

5.2 Conclusions

The goal of this research was to provide quantitative definition on how far behind and above a barrier a designer needs to place attachments and to make some general suggestions on how to design attachments to eliminate safety concerns. A large variety of attachments are currently in use on bridge rails and median barriers and very often the design of these attachments is handled on a case-by-case basis. Variations in bridge structure and deck design, roadway characteristics around the median barriers and bridges, and the type of traffic barrier itself, have implications to the attachment design. Using the intrusion around a barrier as the basis for the design provides an approach to generalize design of attachments based on a limited number of full-scale crash evaluations.

5.3 Recommendations

The design characteristics suggested, allowing attachments to be placed within a given ZOI, are based on the best available engineering judgement. To date, there are only a few tests of actual barrier attachments on which to base this judgement. Further research and testing to determine whether the design suggestions produce the desired effects is needed. One instance, where this testing would be necessary, is if an attachment was to be placed in a manner not in accordance with the guidelines presented herein. Therefore, it is recommended that the impact performance of an attachment and its placement that does not follow these guidelines can only be verified through the use of full-scale crash testing. Furthermore, testing of a select subset of barrier attachments could provide an understanding that would potentially aid in the development of design standards that could be applied to other attachments.

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7 APPENDICES

APPENDIX A

Vehicle Intrusion Data from Traffic Barrier Crash Tests

Table A-1. Crash Test Impact Conditions Summary

Sloped Faced Concrete Parapets

Vehicle / Impact Conditions		CS1 30" NJ	CS2 32" SS	CS3 32" F-shape	CS4 32" NJ	CS5 42" F-shape	CS6 27" open beam & post	CS7 32.5" open beam & post	CS8 32" NJ
820C	TL-2						C	C	
	TL-3,4	C		C					
2000P	sub TL-2						P	P	
	TL-2								
	sub TL-3,4	P	P	P	P				
	TL-3,4								P
8000S	TL-4	S	S	S	S				
36000V	TL-5					V			
36000T	TL-6								

Notes:
(1) "sub TL-2" and "sub TL-3,4" for the 2000P vehicle refer to older testing standards that do not match current NCHRP Report 350 impact conditions.
(2) 820C, 2000P, etc. are vehicle designations as used in NCHRP Report 350.

Verticle Faced Concrete Parapets

Vehicle / Impact Conditions		CV1 20" portable	CV2 29" open beam & post	CV3 32" open Astetic	CV4 32" Verticle	CV5 42" Verticle	CV6 29" open beam & post
820C	TL-2	C					
	TL-3,4				C		
2000P	sub TL-2	P					P1, P2
	TL-2						
	sub TL-3,4		P1, P2		P		
	TL-3,4			P (failed)			
8000S	TL-4		S1, S2		S		
36000V	TL-5					V	
36000T	TL-6						

Timber Systems

Vehicle / Impact Conditions		W1 33" GC-8000	W2 33" wood BR w/ curb
820C	TL-2		
	TL-3,4		
2000P	sub TL-2		
	TL-2		
	sub TL-3,4	P	
	TL-3,4		P
8000S	TL-4	S	S
36000V	TL-5		
36000T	TL-6		

Steel Tubular Rails

Vehicle / Impact Conditions		T1 27.75" T6	T2 30" Type 115	T3 32" Illinios side mounted	T4 36" steel tube & thrie BR	TC1 32" 2399	TC2 34" NETC
820C	TL-2						
	TL-3,4		C	C		C	C
2000P	sub TL-2						
	TL-2						
	sub TL-3,4		P	P		P	P
	TL-3,4	P			P		
8000S	TL-4			S	S	S	S
36000V	TL-5						
36000T	TL-6						

Combination Rails (concrete w/ concrete)

Vehicle / Impact Conditions		CCC1 90" T5 mod.
820C	TL-2	
	TL-3,4	
2000P	sub TL-2	
	TL-2	
	sub TL-3,4	
	TL-3,4	
8000S	TL-4	
36000V	TL-5	
36000T	TL-6	T

Combination Rails (concrete vert. w/ steel rails)

Vehicle / Impact Conditions		CSC1 35" Minnesota	CSC2 42" BR27C	CSC3 42" BR27D
820C	TL-2			
	TL-3,4	C	C	C
2000P	sub TL-2			P
	TL-2			
	sub TL-3,4		P	
	TL-3,4	P		
8000S	TL-4	S	S	
36000V	TL-5			
36000T	TL-6			

Flexible Bridge Rails (W and Thrie Beam)

Vehicle / Impact Conditions		F1 27" Oregon side mounted	F2 32" Cal TB	F3 33.25" TBC-8000	FC1 31.65" thrie
820C	TL-2	C	C		
	TL-3,4				
2000P	sub TL-2	P	P		
	TL-2				
	sub TL-3,4				
	TL-3,4				
8000S	TL-4			S	S
36000V	TL-5				
36000T	TL-6				

Table A-2. Vehicle Intrusion Data from Traffic Barrier Crash Tests

Rail, Height	Test Level (Appendix B Reference)	Vehicle	Top of Barrier Height weak structure	(in.)	strong structure low snag prob.	(in.)	strong structure high snag prob.	(in.)	High strong structure low snag prob.	(in.)	strong structure high snag prob	(in.)	Other Notes:
CS1	TL-4	C					hood/ fender	6					
30"	(B1 & B2)	P	mirror	6			hood/fender	8					
		S					fender	108			front box corner	102	front suspension removed allowed excessive override
CS2	TL-4	P					hood/fender	12					
32"	(B3 & B4)	S					hood/fender	28					53 degree box roll
CS3	TL-4	C	mirror	6			hood/fender	2					
32"	(B5)	P	mirror	10			hood/fender	8					
		S	mirror	18	rear box corner	8	fender	16	rear box corner	60	front box corner	48	31 degree roll
CS4	TL-4	P	mirror	12			hood/fender	9					
32"	(B5)	S					cab corner	48	rear box corner	18	front box corner	96	front suspension removed allowed excessive override
CS5	TL-5	V					front trailer corner	48					
42"	(B6)												
CS6	TL-2	C					car side	2					
27"	(B7)	P			rear corner	3	hood/fender	5					
CS7	TL-2	C					hood/fender	2					
32.5"	(B8)	P			box side	6	hood/fender	12					
CS8	TL-3	P	mirror	12			hood/fender	18					
32"	(B24)												
CV1	TL-2	C	mirror	12	rear fender	3	hood/fender	12					
20"	(B9 & B10)	P			rear bump/corner	14	hood/fender	28					
CV2	TL-4	P1	mirror	16	rear bump/corner	7	hood/fender	16					
29"	(B11 & B12)	P2					hood/fender	14					
		S1					fender/box corner	24	rear box corner	14	front box corner	52	
		S2					front box corner	18	rear box corner	24	front box corner	35	
CV3	TL-3	P	door frame/mirror	12			hood corner	24					
32"	(B13)												
CV4	TL-4	C					hood	8					
32"	(B5)	P			rear bump/corner	8	hood/fender	15					
		S	mirror assembly	18			fender	15	rear box corner	40	front box corner	30	max roll angle 17.6 degrees
CV5	TL-5	V					fender	27	rear trailer corn.	72	front trailer corn.	54	trailer max roll 39 degrees
42"	(B6)												
CV6	TL-2	P1			rear bumper	8	hood/fender	12					
29"	(B14)	P2					hood/fender	12					
T1	TL-3	P			rear corner	42	hood/fender	30					
27.75"	(B15)												
T2	TL-3	C					hood corner	12					
30"	(B16)	P			rear bump/corner	18	hood/fender	30					
T3	TL-4	C	mirror	8									
32"	(B17)	P	mirror	16			hood/fender	13					
		S					front fender	13	rear box corner	48	front box corner	56	max roll angle 53 degrees box intrusions may be low, pictures ended well before max roll angle time
T4	TL-4	P	door frame	12			hood/fender	21					
36"	(B25)	S					front box corner	34	rear box corner	70	front box corner	80	box shifted badly on truck frame, nearly came off, caused excessive roll
TC1	TL-4	C					hood	6					
32"	(B5)	P	mirror	17	side of box	4	fender	11					
		S			rear box corner	30	front fender	16	rear box corner	66	front box corner	40	max roll angle 23 degrees
TC2	TL-4	C					hood	3					
34"	(B18)	P	mirror	15	rear box corner	6	hood/fender	12					
		S					front box corner	15			front box corner	>40"	max roll angle 26 degrees
CSC1	TL-4	C											no intrusion
35"	(B19)	P					hood	24					
		S					front fender	30	rear box corner	58	front box corner	52	max roll angle 23 degrees
CSC2	TL-4	C											no intrusion
42"	(B17)	P					hood	10					
		S					front fender	24			front box corner	24	box intrusions may be low limited pictures, stopped early
CSC3	TL-2	C											no intrusion
42"	(B20)	P	mirror	10			hood	7					
CCC1	TL-6	T											no intrusion, 4" barrier displ.
90"	(B21)												
F1	TL-2	C					hood	6					
27"	(B20)	P			rear bump/corner	18	hood/fender	18					max rail deflection 13"
F2	TL-2	C					side of car	6					mostly rail deflection, 2" of car on rail
32"	(B16)	P			rear bump/corner	26	hood/fender	21					
F3	TL-4	S					front box corner	20	rear box corner	52	front box corner	48	
33.25"	(B22)												
FC1	TL-4	S					front fender	26	rear box corner	58	front box corner	60	
31.65"	(B23)												
W1	TL-4	P			rear bump/corner	18	hood/fender	24					
33"	(B22)	S	mirror assembly	36			frnt fend/box corn	24	rear box corner	48	front box corner	50	cab roll 23 degrees, box roll 31 degrees
W2	TL-4	P	door frame	10			hood/fender	21					
33"	(B25)	S					front box corner	30	rear box corner	63	front box corner	70	

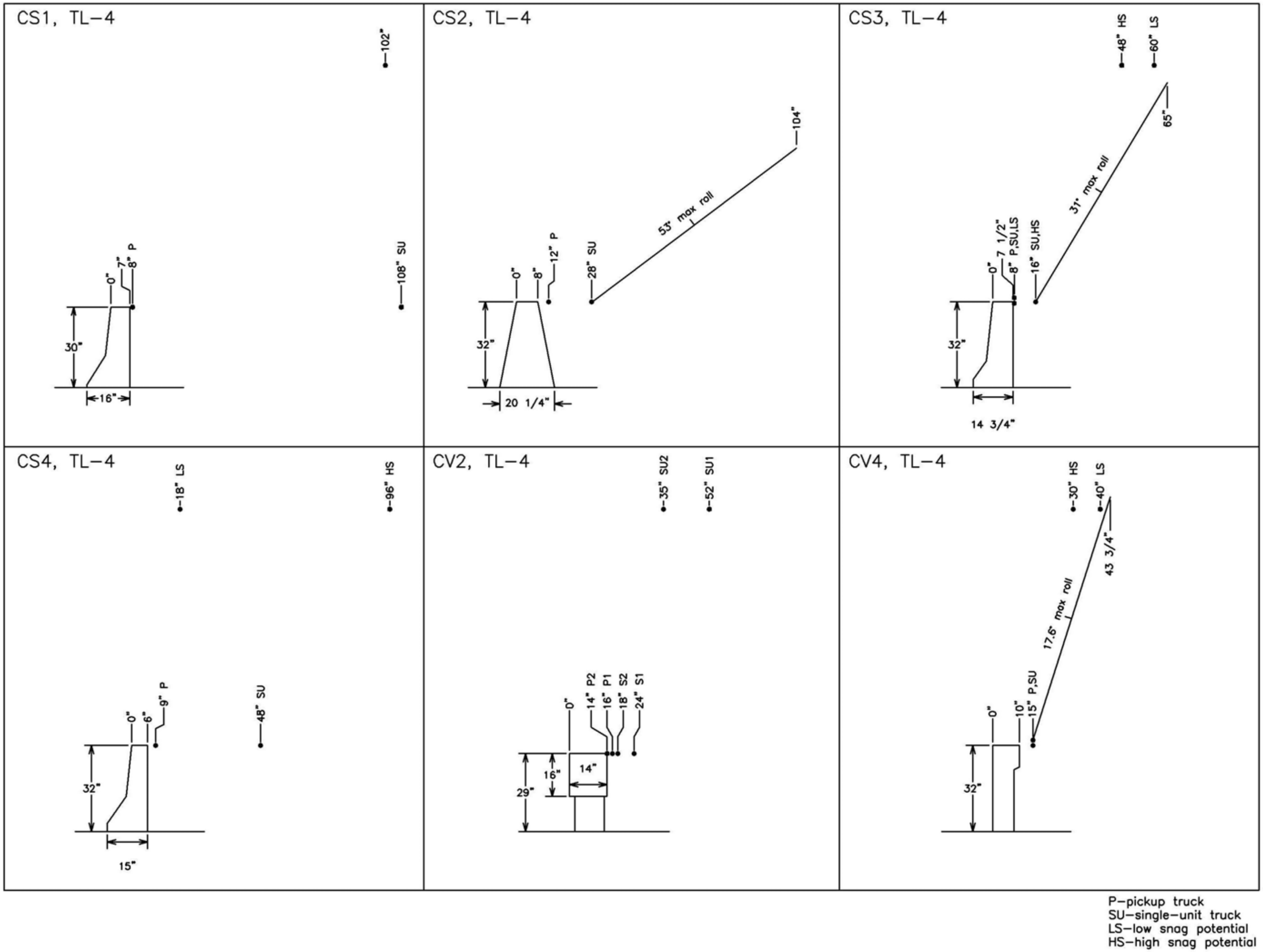

Figure A-1. Graphical Representation of Vehicle Intrusion Data from TL-4 Traffic Barrier Crash Tests

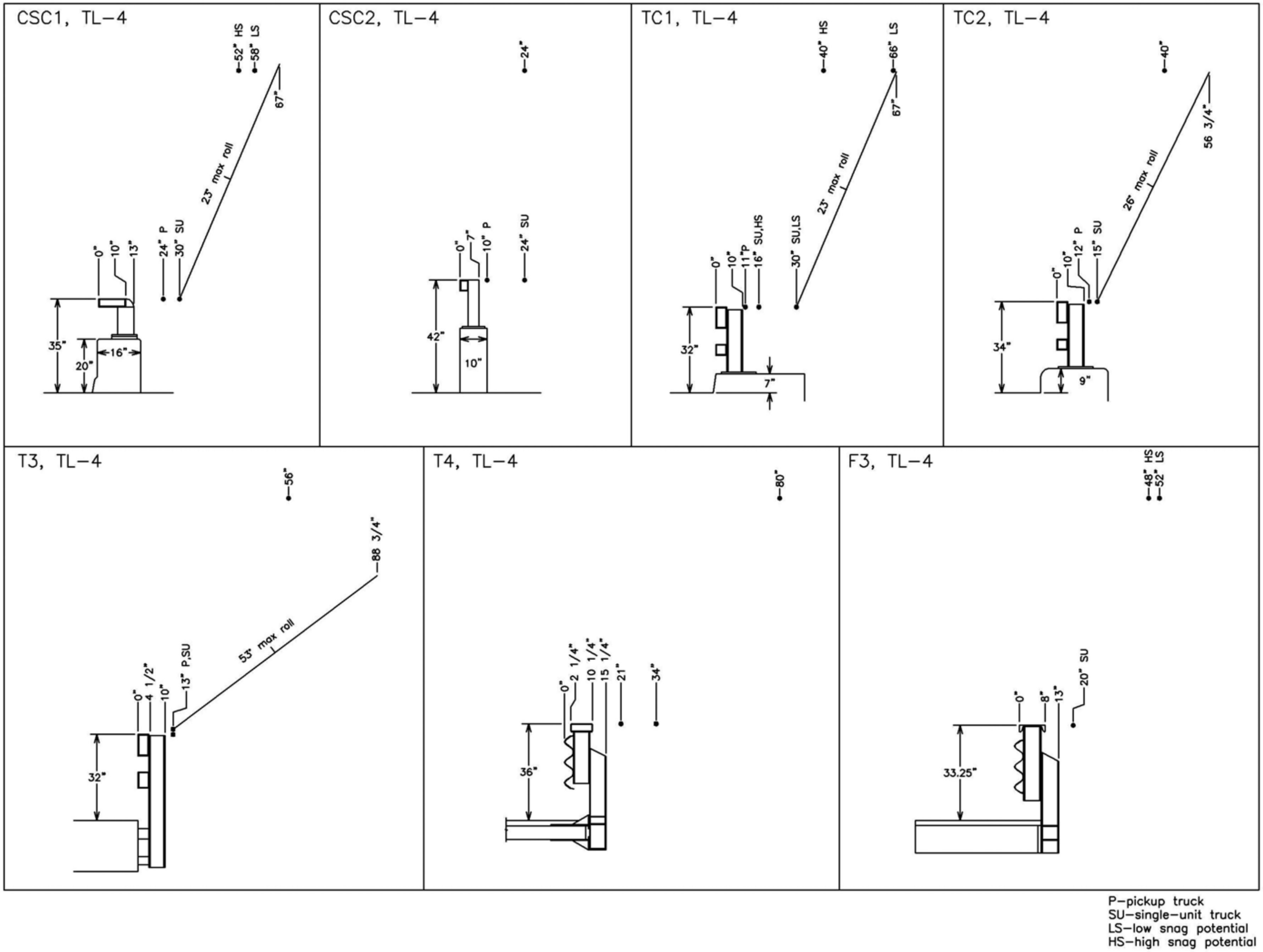

Figure A-2. Graphical Representation of Vehicle Intrusion Data from TL-4 Traffic Barrier Crash Tests

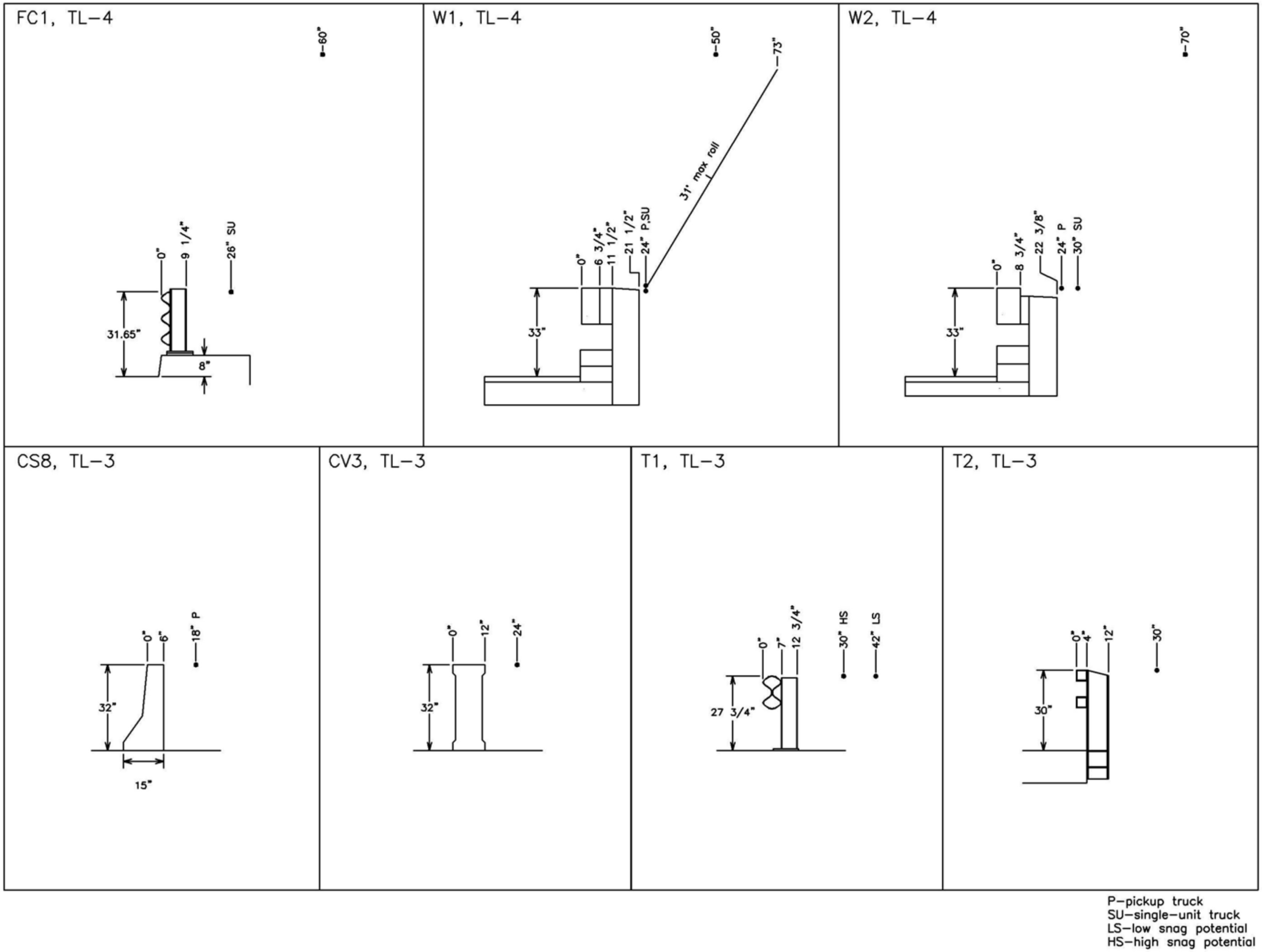

Figure A-3. Graphical Representation of Vehicle Intrusion Data from TL-4 and TL-3 Traffic Barrier Crash Tests

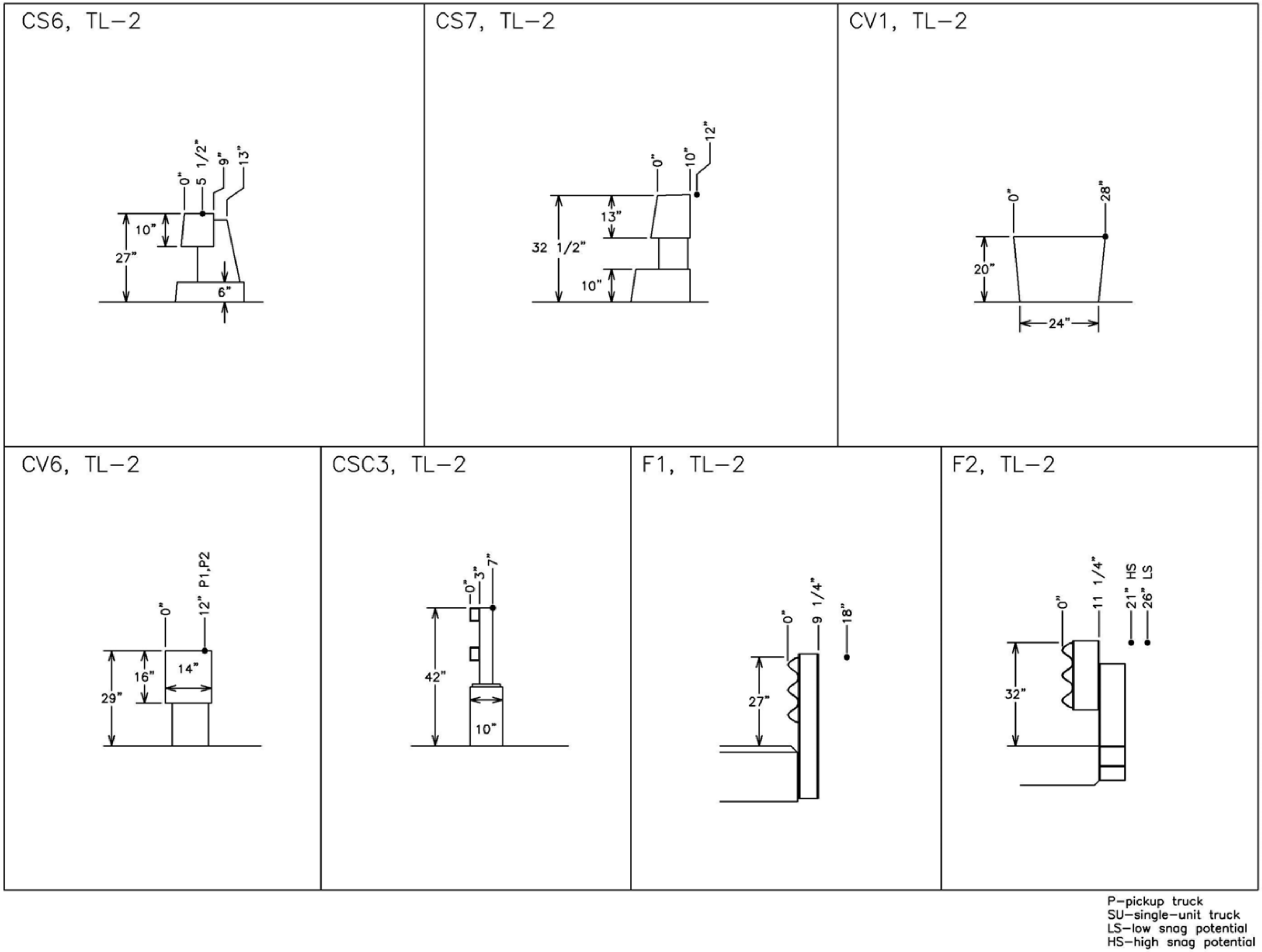

Figure A-4. Graphical Representation of Vehicle Intrusion Data from TL-2 Traffic Barrier Crash Tests

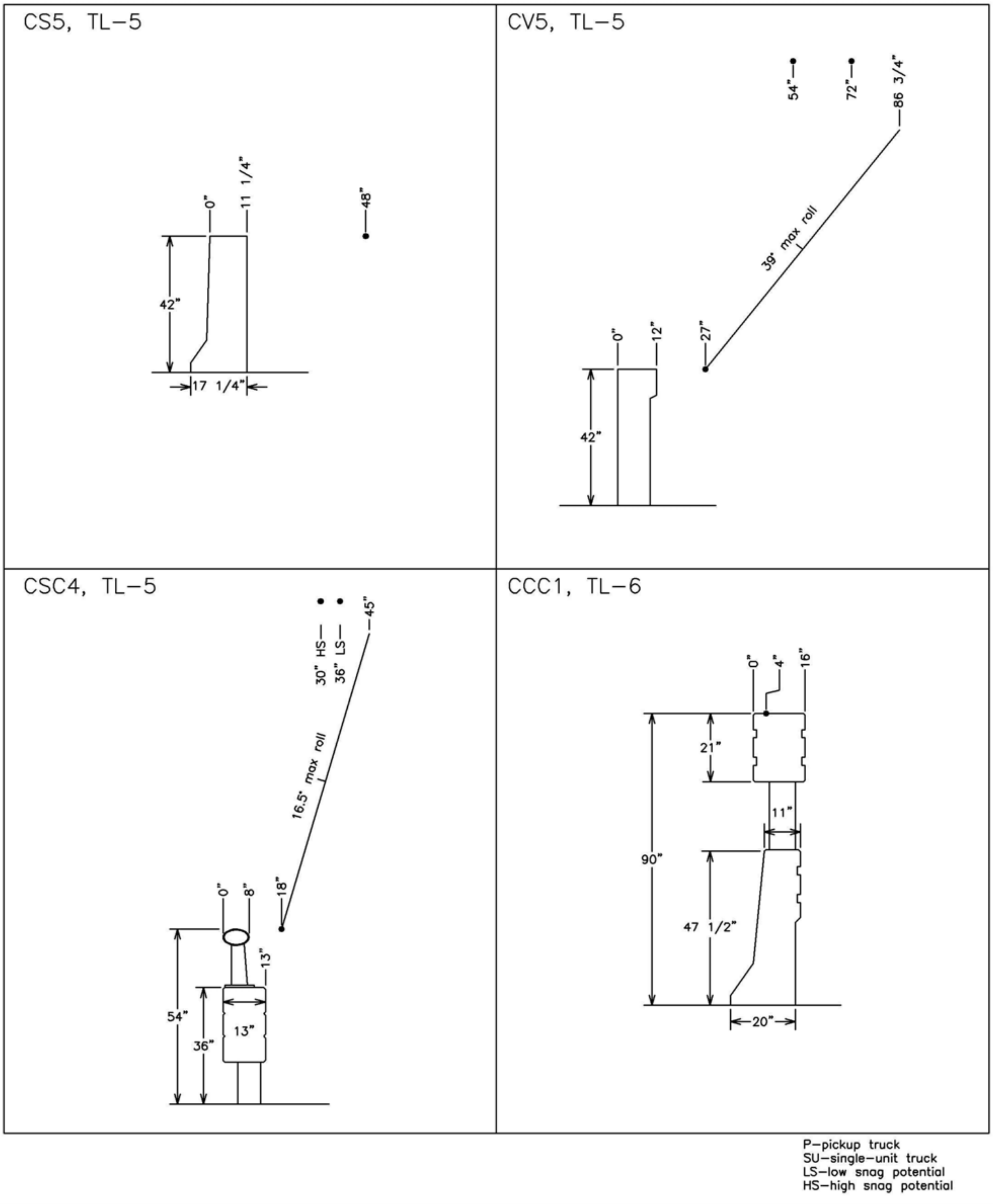

Figure A-5. Graphical Representation of Vehicle Intrusion Data from TL-5 and TL-6 Traffic Barrier Crash Tests

APPENDIX B

Traffic Barrier Test References

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APPENDIX C

Bridge Rail Attachment Field Review

Table C-1. Bridge Rail Attachment Field Review Summary

terms:

divided	separate paved roadways w/ grass/dirt median between (individual, separate bridges usually)
separated	continuous paved surface w/ median barrier
undivided	continuous paved surface w/ low raised concrete median
unseparated	continuous paved surface w/ opposing traffic adjacent, or parted by a middle turn lane
multilane	more than 4 lanes, # perhaps varying with exits and entrances to main road

Field Book Reference	Road	Speed (mph)	Impression of Traffic Vol.	Rail	New / Old construction	Hardware Item	Common or Rare	Other Speeds / Type Roads	Rail Face Offset	Mounted	Structure (of snag concern)
Omaha											
1	4 lane divided	65?	moderate	open concrete	new	Luminary Pole	common	yes	22"	blister low and behind rail	pole
2	4 lane divided	65	moderate	OCR post gaps filled	new	Luminary Pole Sign for Underpass Traffic	common common	yes yes	10.5" 24" ?	top of rail with widened section hangs off back of rail	pole and base steel I sections, medium
3	4 lane undivided	45-50?	heavy	a safety shape	medium	Fence	rare	no	back of rail top	deck behind rail	round tubular post, medium
4	4 lane undivided	55?	moderate	a safety shape	new	Luminary Pole	common	yes	13"	blister low and behind rail	pole
5	4 lane divided	55?	moderate	a safety shape	medium	Luminary Pole	common	yes	3"	top of rail with widened section	pole and base
6	4 lane undivided	45?	heavy	a safety shape	medium	Ped. Tube Railing Fence behind sidewalk	rare rare	no no	2.5" 36", at 99" high	top of rail sidewalk behind rail	square tube posts small and base top of fence posts curved to road
7	4 lane separate	55	heavy	safety shape CMB	old	Luminary Pole Signage Structure Support	common common	yes yes	pole in CMB middle base in middle CMB	top of CMB, in void for base CMB top widened to vert. face	pole large poles, and bases
8	multilane separate	60	heavy	safety shape CMB	old	Luminary Pole Sign Pole Delineator (mile marker)	common common common	yes yes no	pole in CMB middle base in middle CMB middle of CMB	top of CMB, in void for base CMB top widened to vert. face bolted into top	pole large poles and bases unistrut, base-unistrut on end
9	4 lane divided	55	moderate	a safety shape	old	Sign for Underpass Traffic	common	yes	width of rail top	backside of barrier, sticking up	steel I section, end of sign
10	4 lane undivided	45	light	OCR post gaps filled	new	Fence Luminary Pole	rare common	no yes	4"? 6"?	top of rail, toward back top of widened rail toward back	large round posts pole and base
11	4 lane separated	45	moderate	a safety shape	medium	Ped. Tube Railing	rare	no	nearly 0"	top of rail, as wide as top of rail	square tubular posts, medium sized
12	4 lane divided	60	moderate	OCR post gaps filled	medium	Sign for Underpass Traffic	common	yes	width of rail top	backside of barrier, sticking up	large I section, angle iron end
13	ramp one way 3 lane	60	heavy	a safety shape	new	Sign Sign for Underpass Traffic	rare common	no yes	6"? not much, but low	top of barrier, widened section hanging off back, attached top	very large pole and base tee sections, tapered on end
14	multilane separate	65	heavy	safety shape CMB	new	Delineator (mile marker) Small Reflector Sign (speed limit) Luminary Pole	common common common common	no no no yes	middle of CMB " " "	bolted into top " " top of CMB, in void for base	unistrut, base-unistrut on end light gage bent metal large I section only 2 bolts pole
Lincoln											
1	4 lane divided	65	moderate	concrete rail attached to bridge piers	new	Bridge Pier Treatment	common	no	8"	traffic side of bridge piers	square bridge piers
2	4 lane divided	60	heavy	vertical face	medium	Luminary Pole Sign	common common	yes yes	19.75" 23.75"	blister low and behind rail backside edge of bridge deck	pole smaller I sections, end of sign
3	2 lane unseparated 2 lane unseparated	45 45	heavy heavy	conc. / steel comb. a safety shape	old medium	Luminary Pole Luminary Pole	somewhat common rare	yes no	7" 8"	conc. top behind tube rail, on wide sect. recessed pocket in top and rear of barrier	pole pole
4	4 lane divided	60	heavy	OCR	new	Luminary Pole	common	yes	28.25"	blister low and behind rail	pole
Sioux Falls											
1	4 lane unseparated	35	light	a safety shape	new	Traffic Signal and Pole Luminary Pole	rare rare	no no	24.5" 28"	in dirt coming high up on back of wall in dirt coming high up on back of wall	pole and frangible base
2	4 lane undivided	35	heavy	a safety shape	medium	Fence	rare	no	curved top of rail stuck out 30" at 103" height	top of rail	ends of fence posts
3	4 lane unseparated	35	moderate	a safety shape	new	Ped. Tube Railing	common	no	not much, 2" max	top of rail	square steel tube posts, not large
4	4 lane separate	65	light	CMB (safety shape)	new	Bridge Pier Treatment Concrete Glare Screen Luminary Pole	rare rare common	no no no	2" max almost none almost none	top of CMB widened to a vertical face top of rail top of rail in gaps in glare screen	square pier sticking out from glare sc. none (except for gaps for poles) pole, base, ends of screen each side

Table C-2. Bridge Rail Attachment Field Review Summary (continued)

Minn. / St. Paul

Field Book Reference	Road	Speed (mph)	Impression of Traffic Vol.	Rail	New / Old construction	Hardware Item	Common or Rare	Other Speeds / Type Roads	Rail Face Offset	Mounted	Structure (of snag concern)
1	4 lane undivided	40	light	vert. parapet w/ sidewalk	medium	Fence	rare	no	8"?	top of rail, toward back	square steel tube posts, spindles
2	4 lane divided	60	heavy	conc. wall flush with pillars	old	Bridge Pier Treatment	common	yes	NA	wall in front of bridge piers	round bridge piers
3	4 lane divided	60	moderate	conc. vert. w/ plow curb	old	Luminary Pole	common	yes	23"	blister low and behind rail	pole (octagonal)
						Sign for Underpass Traffic	common	yes	26"	deck behind rail and bridge structure	medium I beam posts, small I long.
4	4 lane undivided	40	heavy	a safety shape	old	Pedestrian Protection Fence	rare	no	little	top of rail	large round posts, fence fabric
5	multilane divided	60	heavy	a safety shape	old	Luminary Pole	common	yes	0	top of rail flush	pole (oct.) , flared base
6	4 lane undivided	40	moderate	a safety shape	old	Steel tube rail w/o sidewalk	rare	no	2-3"?	top of rail 64" tall	steel tube posts, pickets
						Luminary Pole behind tube rail	rare	no	behind rail	top of wall, widened section	pole
				vert. behind sidewalk	old	Steel tube rail w/ sidewalk	rare	no	2-3"?	top of rail 104" tall w/ fence overlay	steel tube posts, pickets, fencing
						Luminary Pole behind tube rail	rare	no	behind rail	top of wall, widened section	pole
7	2 lane undivided	50	light	a safety shape	new	Sign	common	yes	width of wall top + 2"	backside of barrier, sticking up	round post
day 2											
1	multilane separated	60	heavy	CMB (safety shape)	medium	Glare Screen	common	yes	none	top of rail, weakish connection	ovular plastic vanes
						Luminary Pole	common	yes	none	top of rail amongst glare screen	pole, flared base
2	multilane separated	55	heavy	CMB (safety shape)	old	Luminary Pole	common on medians	yes	none	top of rail	pole, flared base
3	4 lane divided	55	heavy	a safety shape	medium	Mile Marker	common	yes	middle of barrier top	top of rail , small bolts through base plate	u-channel sign post w/ base plate
4	1 lane one way ramp	?	?	a safety shape	medium	Meter light	common	no	none	top of rail	pole, sign, traffic light
	various one ways	?	?	safety shapes	medium	Luminary Poles	common	yes	none	top of rail, widened section	pole, flared base
	1 lane one way ramp	?	light	a safety shape	medium	Meter light	common	no	1-2 feet?	ground behind rail	pole, sign, traffic light
	2 lane one way ramp	?	light	a safety shape	medium	Single support overhead sign	common	yes	3-4"?	top of rail, widened section	large pole, base
5	multilane separated	55	heavy	a safety shape	medium	Single support overhead sign	common	yes	3"?	top of wall, widened section	large pole, base
6	4 lane divided	55	heavy	Vert. concrete Parapet	old	Luminary Pole	common	yes	12-18"?	blister low and behind rail	pole (oct.)
7	4 lane seperated	45	moderate	old Combination rail	old	luminary pole	rare	no	none	on concrete, in gap in steel rails	pole, ends of steel rails
8	4 lane seperated	55	heavy	a safety shape	new	Sound barrier fence, wood	rare	no	6-8"?	backside of rail sticking up, resting on top	wood post protrude approx. 2"
						Luminary Pole in front of fence	rare	no	none	top of rail	pole, flared base
9	4 lane seperated/divided	55	heavy	a safety shape	new	Luminary Poles	common	yes	none	top of rail	pole , flared base
						Trees	rare	no	6-8 feet?	dirt fill between safety shape barriers	tree
10	2 lane unseparated	40	light	vert. parapet w/ sidewalk	old	tubular ped rail w/ fence overlay	rare	no	3-4"?	top of rail	square tubular posts, spindles
				a safety shape	old	tubular ped rail	rare	no	8-10"?	hanging off back of rail, bolted to top	square tubular posts, spindles
11	4 lane unseparated	40	heavy	vert parapet w/ sidewalk	old	pedestrian fence	rare	no	2"?	top of rail	round posts, fence fabric
						luminary pole	rare	no	none	top of rail	pole, flaerd base, fence posts sides
12	4 lane seperated	55	heavy	a safety shape	old	luminary pole	common	no	6-8"?	high blister behind rail	pole, frangible base
						Single support overhead sign	common	no	6-8"? base, pole more	high blister behind rail	pole, very large base plate
13	4 lane separated	55	heavy	a safety shape	old	fence	rare	no	2-3"?	top of rail	round fence posts, fence fabric
14	4 lane unseparated	45	moderate	vert. asthetic conc./steel	new	luminary pole on concrete posts	rare	no	none	top of conc. posts rising above rail	conc. posts, steel poles
15	1 lane one way ramp	?	heavy	a safety shape	new	curve delineator	common	no	pole, 6-8"?	back of rail sticking up	round post
16	too dark to see					Sound barrier fence, wood					
Pre Des Moines											
1	2 lane unseparated	45	light	a safety shape	new	pedstrian rail	rare	no	2-3"?	top of rail	round posts, medium
						luminary pole	common	yes	18-24"?	blister low and behind rail	pole
2	4 lane divided	65	moderate	vert. wall retrofit, big curb	old	old tube rail behind vert wall	common	no	12-18"?	curb behind rail	tubular rail, cast posts
3	4 lane divided	65	moderate	vert. wall retrofit, big curb	old	old tube rail, end concrete caps	common	no	12-18"?	curb behind rail	tube rail, cast posts, end conc. caps
4	multilane separated	65	heavy	bridge pier treatment	new	retro wall in front of old treat.	common	yes	6-8" to piers	NA	piers behind wall

Table C-3. Bridge Rail Attachment Field Review Summary (continued)

Des Moines

Field Book Reference	Road	Speed (mph)	Impression of Traffic Vol.	Rail	New / Old construction	Hardware Item	Common or Rare	Other Speeds / Type Roads	Rail Face Offset	Mounted	Structure (of snag concern)
1	4 lane divided	55	moderate	square tube on curb	medium	luminary pole	rare	no	34"	blister low and behind rail	pole
2	multilane divided	55?	heavy	vert, conc. parapet	old	luminary pole	common	yes	17.25"	blister low and behind rail	pole
3	4 lane undivided	40	heavy	vert. concrete	old	pedstrian rail	rare	no	none	top of rail	steel plate posts, small
4	multilane seperated	65	heavy	a safety shape	medium	luminary pole	common	yes	18-24"?	blister low and behind rail	pole
						signs for underpass traffic	common	no	12-18"?	backside of rail , sticking up	round tubular posts, end of sign
5	multilane seperated	65	heavy	CMB (safety shape)	medium	sign support structure	common	no	2-4"?	top middle, CMB flares keeps profile	large round posts, large base struct.
						bridge pier	common	no	6-8"?	down thru CMB which divides & flares	big square concrete pier
6	multilane seperated	65	heavy	CMB (safety shape)	medium	sign support structure	common	no	2-4"?	top middle, CMB flares keeps profile	large round posts, large base struct.
						small delineator	common	no	sticks off face 2-4"?	face of rail, near top	extruded odd shape channel, 1 bolt
7	multilane seperated	60	heavy	CMB (safety shape)	medium	sign post	common	no	2-3"?	top of rail middle	small round post
9	4 lane divided	55	moderate	vert wall in front of tube rail	old	luminary pole	common	no	30"	deck blister behind vert wall and tube rail	pole
10	4 lane undivided	50	heavy	a safety shape	new	luminary pole	common	yes	24-30"?	blister behind rail	pole, frangible base
				vert wall in front of tube rail	old	luminary pole	common	no	28-36"?	deck blister behind vert wall and tube rail	pole

Kansas City

Field Book Reference	Road	Speed (mph)	Impression of Traffic Vol.	Rail	New / Old construction	Hardware Item	Common or Rare	Other Speeds / Type Roads	Rail Face Offset	Mounted	Structure (of snag concern)
1	multilane seperated	65	moderate	segmented CMB	old	mile marker	common	no	1-2"?	top middle of CMB	unistrut post, larger unistrut base
				(safety shape)		small delineator	common	no	1-2"?	top midlle of CMB	thin bent plate L
						overhead sign support struct.	common	no	12-18"?	between divided and flared CBM	large round posts, large base flanges
2	multilane seperated	65	moderate	segmented CMB (SS)	old	single support large sign	common	no	6-12"?	between divided and flared CBM	large round post, raised grout pad
3	multilane divided	70	light	combination rail	old	phantom luminary pole	na	na	pole not there	blister top of conc, behind steel tube	pole
						single support large sign	common	yes	16-24"?	blister top of conc, behind steel tube	large pole
4	multilane separated	55	heavy	a safety shape, outer	old	sign support	rare	no	2-4"?	bridge superstructure behind rail	very large pole cut into rail
				SS, inside barrier	old	fence for gap between bridges	rare	no	?	top of rail	fence pole and fabric, base pad
				a safety shape, outer	old	luminary pole	rare	no	none	widened and raised wall section on top	raised conc, pole, base
				a safety shape, outer	old	speed limit sign	rare	no	1-2"?	top and back of rail sticking up	mounting L brackets, I-beam posts
5	2 or 3 lane one way ramp	65	moderate	vert wall comb. rail w/ curb	old	luminary pole on frangible base	rare	no		widened section at wall top, behind tube	pole, frangible base
						sign support large	common	no		bridge superstructure behind tube & wall	pole
						Bridge Pier for higher ramp	rare	no	19"	ground, doesn't touch ramp of intrest	round concrete pier, very large
6	4 lane divided	65	moderate	vert wall comb. rail w/ curb	old	signs for underpass traffic	common	yes	25.5"	backside of rail sticking up	I-beam posts small lat. channels, sign
7	multilane seperated	60	light	SS, may have been comb.	medium	luminary pole	common	yes	12"	widened and raised wall section on top	raised concrete, pole
8	multilane seperated	60	light	a safety shape	new	aluminum siding fence	rare	yes	6-8"? width rail top	backside of rail, sticking up	face solid, square tube posts
				a safety shape	new	large single support sign	common	yes		blister top of rail	pole, thick base plate
				a safety shape	new	small delineator	rare	no	3-4"?	top of wall	bent plate
				a safety shape	new	large sign like above	common	yes		blister top of rail, behind aluminum fence	pole
				a safety shape	new	mile marker	common	yes	1-2"?	top of wall, in front of aluminum fence	unistrut post, larger unistrut base
9	multilane seperated	65	moderate	a safety shape	medium	fence	rare	no	4-6"?	top of wall to back side	posts, fence fabric, base gusset
10	multilane seperated	45	light	astetic vert conc. w/ posts	new	decorative conc. spires	rare	no	76"	extension of bridge base structure	very large conc. column
						luminary poles	rare	no	11"	top of widened section of rail	pole, slightly raised mount platform
11	multilane divided	60	moderate	52" tall safety shape	old	fence	rare	no	little	posts cast into top of barrier	poles, fence fabric
12	multilane separated	65	moderate	52" CMB (safety shape)	medium	mile marker	common	yes	none	top of rail	unistrut post, larger unistrut base
						small delineator	common	yes	sticks off face 3-6"?	face opf rail, near top	short length of steel angle
						large single support sign	common	yes	6-8"?	atop flared CMB on raised conc. base	post, base, conc foundation
13	4 lane undivided	45	moderate	a safety shape	medium	sign for underpass traffic	common	yes	11.5"	backside of rail, sticking up	I-beam vert, extrude chan hor, sign
14	multilane separated	60	moderate	a safety shape	medium	luminary pole	rare in KC	no in KC	10"	blister low and behind rail	pole
15	various one way ramps	55-65	moderate	a safety shape	medium	luminary pole	common	yes		top of wall on widened section	pole, base
				retro vert, curb, front comb.	medium/old	luminary pole	rare	yes		top of old conc widened, behind steel rail	pole
16	4 lane seperated	45	light	a safety shape	medium	luminary pole	common	yes		top of widened and slightly raised section	pole, base, raised concrete
				safety shape combination	medium	luminary pole	common	yes		" (behind steel rail)	pole
				"		aluminum siding fence	rare	yes		back of rail, sticking up behind steel rail	face solid, square tube posts
17	multilane separated	55	heavy	retro vert, in front of comb.	old	luminary pole	common	yes		top of old conc widened, behind steel rail	pole
18	4 lane unseparated	40	light	SS in front of sidewalk	old	luminary pole	rare	no		top of wall widened section	pole, frangible base