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Evaluation of Attachments to Concrete Barrier Systems to Deter Pedestrians—Volume 1: Technical Report

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Cooperative Research Program

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COLLEGE STATION, TEXAS

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16. Abstract

Concrete rigid barriers are used in medians to separate traffic and on the roadside to shield hazards from motorists and motorists from hazards. These barriers need to demonstrate crashworthiness through full-scale testing per the American Association of State Highway and Transportation Officials *Manual for Assessing Safety Hardware* (*MASH*).

Attachments may be deployed on top of concrete barriers for various reasons, including deterring pedestrians from crossing highways. Such hardware attachments, however, have not been investigated to *MASH* standards. It is believed that impacting vehicles will likely interact with hardware attached to concrete barriers.

In this study, researchers conducted a literature review and surveys of Texas Department of Transportation districts and other transportation agencies to help identify existing technologies that can be mounted to concrete barriers to deter pedestrians from crossing roadways; evaluated their impact performance through engineering analysis and finite element simulations; and verified *MASH* Test Level 3 and Test Level 4 impact performance of the top-rated attachment systems through full-scale crash testing. Based on the results, this report provides valuable information for selection and implementation of attachments on top of barriers to deter pedestrians from crossing highways.

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EVALUATION OF ATTACHMENTS TO CONCRETE BARRIER SYSTEMS TO DETER PEDESTRIANS—VOLUME 1: TECHNICAL REPORT

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

Chapter 1. INTRODUCTION

Concrete rigid barriers are used in medians to separate traffic and on the roadside to shield hazards from motorists and motorists from hazards. These barriers need to demonstrate crashworthiness through full-scale testing per the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*).

Attachments may be deployed on top of concrete barriers for various reasons, including deterring pedestrians from crossing highways. Such hardware attachments, however, have not been investigated to *MASH* standards. Previous crash tests under *MASH* high-speed impact conditions highlighted the propensity for vehicles to climb and intrude into the area where these attachments might be deployed. Therefore, it is believed that impacting vehicles will likely interact with hardware attached to concrete barriers.

Texas A&M Transportation Institute (TTI) researchers conducted an extensive literature review and completed surveys with Texas Department of Transportation (TxDOT) districts and other transportation agencies to identify existing implementation guidelines and practices for concrete barrier attachments used to deter pedestrians. The team identified existing technologies that can be mounted to concrete barriers and evaluated their impact performance through engineering analysis and finite element simulations. The researchers then verified *MASH* Test Level 3 (TL-3) and Test Level 4 (TL-4) impact performance of the top-rated attachment systems through full-scale crash testing. Based on the results, this report provides valuable information for selection and implementation of attachments on top of barriers to deter pedestrians from crossing highways.

Chapter 2. LITERATURE REVIEW

According to the Insurance Institute for Highway Safety (IIHS), an increasing number of pedestrians are dying on freeways and interstates due to a lack of proper infrastructure for safe crossing (*1*, *2*). A 2019 IIHS report revealed that a 60 percent rise in pedestrian fatalities on highways was recorded in the last decade, even higher than the 53 percent rise in pedestrian deaths on all roads since 2009 (*1*).

The IIHS report investigated 2,518 traffic fatalities on controlled-access freeways and interstates between 2015 and 2017 (*1*). Forty-two percent of those were crashes that happened when pedestrians tried to cross the multilane corridors. Eighty-one percent of the deaths were in urban areas, with 58 percent located on stretches of roadway between residential and commercial areas. The report suggested strategies that could reduce pedestrian fatalities nationwide, such as building pedestrian overpass/underpass structures and providing alternative and safe means for pedestrians to travel between residential and commercial areas.

In line with the nationwide increase, Texas has also seen rising pedestrian fatalities on highways. Table 2.1 depicts the number of pedestrian-related crashes on I-35 in Austin between 2015 and the beginning of 2019 (*3*).

Table 2.1. Number of Pedestrian-Related Crashes on I-35, Austin (*3*).

Year	Fatal Crashes	Injury Crashes	Total Crashes
2015	3	4	7
2016	8	7	15
2017	3	5	8
2018	7	4	11
2019 (until 02/15/19)	3	0	3

As shown in Table 2.1, 44 pedestrian crashes happened along I-35 in the five-year span, and 24 of those were fatal.

To reduce the increasing number of pedestrian fatalities and injuries on I-35 and other high-traffic pedestrian areas and construction zones, TxDOT launched the Be Safe Be Seen initiative in November 2017 (*3*). As part of the initiative program, 26 "No Pedestrian Crossing" signs were installed on barriers along the I-35 frontage roads and main lanes at 51st Street (*3*). This countermeasure, however, is passive, leaving the decision of whether to cross up to the individual. There is no physical constraint to impede the crossing.

Attachments may be deployed on top of concrete barriers to physically deter pedestrians from crossing highways. The following section provides a summary of concrete barrier attachments that have been used for roadside safety applications.

2.1. CONCRETE BARRIER ATTACHMENTS

Attachments for roadside safety applications are primarily intended to help reduce accidents between different vehicles and between vehicles and pedestrians. For instance, attachments can provide physical protection or glare protection to help promote safety.

For instance, Figure 2.1 and Figure 2.2 show a chain-link system attached on the top of a portable concrete barrier that can be used to provide physical protection to pedestrians and bicyclists while still providing the visibility necessary for drivers to remain alert and be prepared to engage in defensive driving techniques. The system can be attached on either the top or the side of the concrete barrier. Figure 2.3 shows two barrier examples with chain-link systems attached on the side of the concrete barrier rather than at the top.

In contrast, glare screens can be attached to concrete barriers to shield drivers from the headlights of oncoming traffic on a highway. Glare screens, which are made of materials such as concrete, metal mesh, fabric, etc., can serve a dual purpose by also physically deterring pedestrians from crossing highways. Figure 2.4 shows a modular glare screen made of plastic on top of a concrete barrier. Figure 2.5 shows a fabric screen on top of a concrete barrier with additional signs to deter pedestrians from crossing.

Concrete glare screens are usually opaque and possess greater strength and durability, and thus potential lower maintenance costs, than metal mesh screens. The disadvantages of concrete glare screens include higher initial cost and lack of visibility at larger angles to the traffic flow. One solution to the opaqueness is to provide vertical slots to allow drivers to view oncoming traffic. Another important shortcoming of a concrete glare screen is that it cannot be used where other kinds of median barriers (such as guardrails) are used. Figure 2.6 shows a TTI drawing of the side view of a concrete barrier with a concrete glare screen. Figure 2.7 shows the pre-impact image of the concrete glare screen and concrete barrier. Figure 2.8 shows the concrete glare screen with vertical slots.

Figure 2.1. Chain-Link System for Concrete Barriers (*4*).

Figure 2.2. Chain-Link System for Concrete Barriers in Minneapolis (*5*).

a b

Figure 2.3. TxDOT Chain-Link Fence Supported by Weak Post prior to Testing.

Figure 2.4. Modular Glare Screen (*6*).

Figure 2.5. Barrier with Sign and Attachment (*7*).

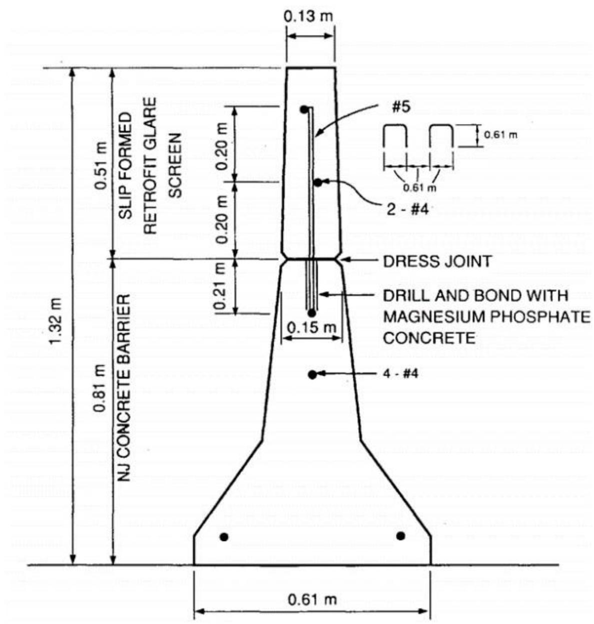


Figure 2.6. Reinforced Concrete Glare Screen.

Figure 2.7. Concrete Median Barrier Retrofitted with Concrete Glare Screen.

Figure 2.8. Modified Concrete Glare Screen (*8*).

Another commonly used material for glare screens is plastic. Figure 2.9 shows a combination glare screen pedestrian fence (CGSPF) that uses recycled plastic sheets and is easily installed on a concrete barrier (*8*). Due to the inherent characteristics of plastic, it is expected that maintenance costs for these systems will be significantly reduced compared to other designs. In addition, the CGSPF is lightweight, low cost, and easy to attach. Furthermore, the color and texture can be modified for aesthetic and safety purposes (e.g., as a median delineator), and the use of recycled material is environmentally responsive.

Figure 2.9. Prototype of Side-Mount CGSPF Using Recycled Plastics (*8*).

Attachments to concrete barriers can also be used for bridge rail applications. Figure 2.10 shows a chain-link system attached on top of a bridge rail to prevent people from falling off the bridge. As shown in the figure, the system is attached at the back of the barrier and can even be attached on top of the barrier.

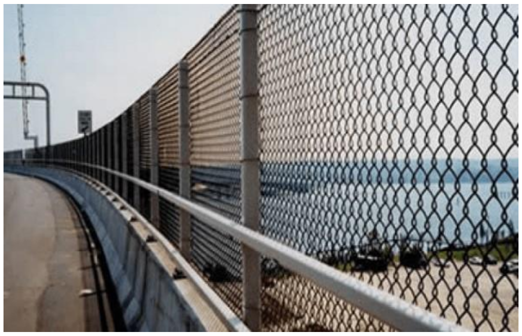


Figure 2.10. Chain-Link Installed on Top of Concrete Bridge Rail (*4*).

Figure 2.11 shows a special pedestrian fence used in Mesquite and Garland, Texas, respectively. The steel fence structures are installed on top of the bridge rails for pedestrian safety on the bridge.

a. Mesquite, TX

b. Garland, TX

Figure 2.11. Special Pedestrian Fence (*9*).

Figure 2.12 shows another example of an ornamental pedestrian fence on a bridge rail.

Figure 2.12. Ornamental Pedestrian Bridge Railing (*10*).

Figure 2.13 shows a wall installed on top of a concrete bridge rail for the purpose of noise reduction in Shanghai, China.

Figure 2.13. Bridge Rail Wall Installation for Noise Reduction in China (*11*).

2.2. CONCLUSION

This chapter provided a summary of literature review findings on existing concrete barrier attachments used to deter pedestrians from crossing highways. While some of these attachments are used primarily for other purposes, such as glare prevention, they can also be used to promote pedestrian safety. The literature review findings were used—in combination with the survey findings discussed in the next chapter—to identify existing systems for impact performance testing.

Chapter 3. SURVEY OF STATES

After conducting a thorough literature review, TTI researchers completed a survey with various state departments of transportation (DOTs), AASHTO, and the Federal Highway Administration (FHWA) to gather information on existing concrete barrier attachments used to deter pedestrians from crossing highways. This chapter presents the feedback received. All responses are presented verbatim.

The survey asked questions related to agencies' experiences with pedestrians crossing highways, implemented solutions, and efficacy of implemented solutions.

3.1. EXPERIENCES WITH PEDESTRIANS CROSSING HIGH-SPEED HIGHWAYS

State DOTs were asked whether they had experienced any issues related to pedestrians crossing high-speed highways. A number of states—Alaska (AL), Arkansas (AK), Arizona (AR), Delaware (DE), Florida (FL), Illinois (IL), Indiana (IN), Massachusetts (MA), Missouri (MO), Montana (MT), North Carolina (NC), Nebraska (NE), New Hampshire (NH), New Jersey (NJ), New Mexico (NM), New York (NY), South Carolina (SC), Washington (WA), and California (CA)—answered yes.

According to the survey's logic, answering "yes" presented three more questions to the respondents. One question asked about the types of roadways where the agency had experienced issues with pedestrians crossing. The answers were "Freeway," "Expressway," "Conventional Divided Highway," or "Other."

Table 3.1 summarizes the responses from state DOTs who had experienced issues with pedestrians crossing roadways: nine state DOTs reported pedestrians crossing freeways, three reported pedestrians crossing expressways, and seven reported pedestrians crossing a conventional divided highway. MO and IL experienced issues with all three types of roadways. Most DOTs experienced issues with only one type of roadway.

Table 3.1. Types of Roadways with Pedestrian Crossing Issues Reported by State DOTs.

Type of Roadway	Agency
Freeway (9)	AK, AR, IL, MA, MT, MO, NM, NY, WA
Expressway (3)	IL, MO, NY
Conventional Divided Highway (7)	AL, DE, FL, IL, MO, NJ, WA
Other (8)	AL, IN, MO, NC, NE, NH, WI, SC
Verbatim Responses to “Other”	AL: Flush median also. IN: Conventional, non-divided, multilane. MO: Unsure of the frequency for each category, but fatalities have occurred. NC: Our experience in the Western Region has mostly been with pedestrians crossing 5 lane and 4 lane undivided roadways but recently a pedestrian safety situation developed on a recently widened divided roadway that was converted to an expressway. A study is underway to try to determine possible countermeasures. WI: We haven't experienced issues with people crossing high speed roadways. We receive requests to install pedestrian crossing 5 mph roadways which may be two lane as well as divided highways. Often adjacent development have destinations where people want/need to cross. Sometimes requests include shared-use paths crossing midblock. SC: As mentioned in Q1, frequency appears to be low in controlled access corridors.

Table 3.2 summarizes the types of solutions applied to deter pedestrians from crossing high-speed roadways. Seven state DOTs reported using attachments on top of barriers, and three state DOTs reported installing warning signs. Fifteen state DOTs reported other solutions. Some states, such as MO, DE, and WI, use more than one solution to deter pedestrians from crossing the highways.

Table 3.2. Types of Solutions Used by State DOTs to Deter Pedestrians from Crossing Highways.

Type of Solution	Agency
Using attachments on top of the barrier (7)	AK, FL, MA, MO, NJ, NY, WI
Installing warning signs (3)	DE, IN, NY
Educating the public (3)	AL, DE, MO
Painting some prevention signs on the barrier face	
No solution/system available (1)	WY
Other (14)	AL, AR, AK, IL, IN, MT, MO, NC, NE, NH, NJ, SC, WA, WI
Verbatim Responses to "Other"	AL: In the flush median, installed raised separators and well marked crosswalks and ped signals. AR: Police write tickets. AK: Stiffened ROW fencing. IL: In some of the tight ROW areas, IDOT has noise barrier or fence very close to the barrier, but it is unusual for the ROW to be co-located with a crash barrier. Taller barrier, but people still has climbed this. Some sort of pedestrian fence on the barrier has also been installed. IN: The long term solution involves installing a traffic signal with marked crosswalks at an intersection proximate to where the crossings are occurring. Currently there is no provisions for ped movements. MT: Installed pedestrian bridge in one location and converted an abandoned rail line to an underpass at another location. MO: One instance of chain link fence installed, but it is not a MoDOT. NC: 5 lane roadway. Installed signs to direct pedestrian traffic to only cross at marked crosswalks. Installed new signal with pedestrian crosswalks and signalization. NE: ROW fence. NJ: Our agency allow the uses of chain link fence mounted on top of median concrete barrier on a case by case basis and as a last resort where unlawful pedestrian crossing is an ongoing patterned problem. SC: Control access fencing (and repairs to them) in problem areas. No experience with this issue in rigid barrier locations, however, our state has adopted a 56" tall single slope barrier as our typical median barrier for other reason. This likely would be a strong deterrent to the survey topic as well. WA: Fencing to prevent entry (limited access). WI: Desirably attaching fence to backside of barrier or installing fence between two concrete barrier. Increase concrete barrier height.

Most of the state DOTs did not conduct specific studies to determine the efficiency of the solution/system for deterring pedestrians, as shown in Table 3.3. Even for the states that answered yes, the investigation is still ongoing, as per their verbatim responses.

Table 3.3. Studies Conducted by State DOTs to Determine the Efficiency of the Solution for Deterring Pedestrians.

Answer	Agency
No (15)	AL, AK, AR, DE, FL, IL, IN, MA, MO, NE, NH, NJ, NY, SC, WA
Yes (2)	MO, NC
N/A (7)	TN, MI, ND, NH, OH, WY, WI
Verbatim Responses to "No"	AL: Installation is recent enough to not have good after installation data. AK: System is 1 yr old, pretty new. Under HSIP program Schedule is for postconstruction crash review in a few years. IN: Solution was not to deter but to accommodate since the facility is not access controlled and there is a distinct pedestrian demand. NJ: I am not aware of any study. However, because chain link fencing, viewed from an angle, can reduce sight distance, our design standard require that the chain link fence must stop at a minimum of 300 feet in advance of the intersections. There are cases where pedestrians use this unprotected gap for unlawful crossings.
Verbatim Responses to "Yes"	MO: The pedestrian bridge sees a significant amount to pedestrian traffic. A post-construction study has not been completed. NC: A study is underway for the forementioned expressway (Q2-1-2). Our observations of the 5 lane roadway where signs and a traffic signal were installed has shown that the majority of pedestrians are not complying with the signs and continue to cross midblock.

3.2. ATTACHMENTS TO LONGITUDINAL ROADSIDE SAFETY HARDWARE

Next, agencies were asked whether they install attachments to longitudinal roadside safety hardware (such as concrete barriers or guardrails) for specific purposes. Table 3.4 summarizes the responses. Six states specified installing attachments to longitudinal roadside safety hardware for pedestrian crossing prevention, and 13 states use such hardware for glare prevention. Seven states reported using longitudinal roadside safety hardware for other purposes. A few states, such as NJ, have attachments for both pedestrian crossing prevention and glare prevention.

Table 3.4. Longitudinal Roadside Safety Hardware Attachment Type/Purpose for State DOTs.

Attachment Type/Purpose	Agency
Pedestrian Crossing Prevention (6)	AK, MA, MI, ND, NJ, NY
Glare Prevention (13)	AL, AR, FL, IL, MO, NE, NM, NH, NJ, NY, SC, TN, WI
Animal Crossing Prevention	
Nosie Reduction	
We do not have any attachment systems (6)	DE, IA, MD, MT, OH, WA
N/A (no reply)	NM, WV
Other purpose (7)	AL, FL, IL, IN, NC, NY, SC
Verbatim responses for "Other purpose"	AL: We have installed median glare screen paddles, but are not satisfied with their durability. Mostly an existing concrete median barrier height is extended with concrete. FL: Chain-Link Fence Attached to Concrete Barrier. FDOT does not have additional attachments for guardrail. IL: IDOT deploys glare screen, and infrequently attaches signs to concrete barrier. IDOT glare screen may be permanent concrete, or commercially available modular systems. IN: Bridge rail pedestrian fence. SC: Under NCHRP Report 350 barriers, we have a concrete glare screen addition for retrofitting Jersey Barriers, but the glare screen does not act as a barrier extension for vehicle impacts. Proprietary metal glare screens have been discontinued because of the extensive maintenance issues they introduce. For MASH, we use a monolithic barrier to achieve 56" height without additional retrofits. Noise barriers used on the roadside are not yet integrated into barrier designs (SCDOT requires seismic designs on the noise barrier in some parts of our state.) These noise barriers are not pedestrian restrictive. Control access fencing is used near the edge or ROW for both animal and human access control. NY: We do not have standard treatments. NC: There is a section of freeway in the Raleigh area that has a chain link fence to prevent peds crossing. It is there to prevent pedestrians from dropping off between two bridges. An example location is on I-440 at Yadkin Dr. in Raleigh.

3.3. ATTACHMENTS FOR PEDESTRIAN CROSSING PREVENTION

Table 3.5 summarizes the questions and answers for the state DOTs who indicated installing attachments for pedestrian crossing prevention. It appears that none of the six responding states have investigated the crashworthiness of their pedestrian crossing prevention attachment system. NJ is the only state that has the attachment included in its design standard, while AK, MA, and ND include their system in nonstandard documents. Only MI and AK shared a copy of their standards with the researchers. AK has not conducted any study regarding the implementation of an attachment for pedestrian prevention; however, respondents said that a steel system tends to work well for deterring crossings.

Table 3.5. Questions and Answers on Pedestrian Crossing Prevention.

Question	Answer	Agency
Q1. Has the crashworthiness of the attachment system for pedestrian crossing prevention been investigated?	No	AK: Although fencing was bolted atop a crashworthy concrete barrier system. MA, NY
	Yes	
	I am not aware of	MI, ND, NJ
Q2. Is the attachment system for pedestrian crossing prevention included?	Your design standard	MI NJ: The attachment system (chain link fence mounted on top of median concrete barrier) is in our Roadway Design Manual.
	Nonstandard documents	AK, MA, ND NY: In a very few project documents.
Q3. Can you share a copy of documents related to pedestrian crossing prevention?	Yes	MI, AK
	NA	MA, ND, NJ NY: Not at this time, as the projects which used the measures will require time to identify.
Q4. Has any study been conducted regarding the implementation of the attachment system for pedestrian crossing prevention?	No	MA, MI, NJ, NY ND: Unaware of any study. Railing went in after pedestrians were observed crossing in multiple locations not marked as such.
	Yes	AK: Study—No, Performance—Yes, the steel system appears to be effective as a deterrent- as first indicator-fence vandalism has stopped. A previous aluminum installation was in place only a few months and was heavily vandalized to allow crossing.

3.4. ATTACHMENTS FOR GLARE PREVENTION

Table 3.6 summarizes questions and answers for the state DOTs who indicated installing attachments for glare prevention. Seven states have not conducted any investigation of the crashworthiness of such attachments. Three states have investigated crashworthiness, and three states were not aware of this topic. Some states have included a glare prevention attachment system in their design standard, but most include their systems in nonstandard documents. FL shared a link to its standard.

Table 3.6. Questions and Answers on Glare Prevention.

Question	Answer	Agency
Q1. Has the crashworthiness of the attachment system for glare prevention been investigated?	No	MO, NH, NM SC: We do not expect the glare screen to add any impact resistance, and it does take substantial damage when impacted by TL5 vehicles. If another state has a crash tested (and no amage/durable) glare screen retrofit, we would be very interested in those details. NY, FL, IL: IDOT has not crash tested our permanent concrete glare screen system to my knowledge.
	Yes	NE, TN WI: There are two systems I am aware of. One is small plastic panels installed on top of the barrier. The other is a system that Trinity developed. I cannot find the name of the product.
	I am not aware of	AL, AR, NJ: I am not aware of any study. See the responses for Q2-3 regarding the efficiently of the system.
Q2. Is the attachment system for glare prevention included?	Your design standard	FL: OPAQUE VISUAL BARRIER. IL: Permanent concrete glare screens are IDOT Standard 638101. Modular glare screens are per manufacturer's standard. NM: Yes, specification section 630. SC: 805-895-51 (retrofit at bridge piers) 805-899-M1 monolithic retrofit if Jersey barrier is damaged). Archived 2015 Standard 805-895-00 shows the concrete glare screen retrofit detail.
	Nonstandard documents	AL, AR, TN (currently do not use), NJ, NH, NY,
	No answer	NE, WI
Q3. Can you share a copy of documents related to glare prevention?	Yes	FL: https://fdotwww.blob.core.windows.net/sitefinity/docs/default source/design/standardplans/2022/idx/521010.pdf
	Other	AL: We have Plasticade Modular Glare Screen and Screensafe Highway Glare Screen on our approved products list. Installation would be per manufacturer's requirements. AR: We haven't used these in a long while. A quick search did not turn up the requested documents. If you need these, please let me know, and I will find them. NY: Will take time to locate the projects/plans. SC: The 2015 drawing is no longer current but may be used for repairs of damaged glare screen. I've also attached a photo of different types of damage of glare screen & Jersey Barrier as well as view of repair of the more extensively damaged section. I uploaded before I realized only one file could be attached. Will email other files. TN: Currently not using the attachment.
	No answer	IL, NJ, NH, NM, WI
Q4. Has any study been conducted regarding the implementation of the attachment system for glare prevention?	No	NE, NM
	No survey	AL, AR, FL, IL, MO, NH, NJ, NY, SC, TN, WI

3.5. ATTACHMENTS FOR OTHER PURPOSES

Table 3.7 indicates that only FL appears to have an ongoing effort to investigate the crashworthiness of attachments to concrete barriers. IL, IN, and SC include the related attachments in their design standards. Nine states have conducted some form of study for the implementation of the attachments for other systems.

Table 3.7. Questions and Answers on Other Purposes.

Question	Answer	Agency
Q1. Has the crashworthiness of the attachment system for other purposes been investigated?	No	IL, IN, SC
	Yes	FL: Ongoing Investigation
	I am not aware of	AL, NC: Unsure
	No answer	NY
Q2. Is the attachment system for other purposes included in…	Your design standard	IL: Permanent concrete glare screens are IDOT Standard 638101. Modular glare screens are per manufacturer's standard. IN: Typical applications for bride railing pedestrian fence are discussed in Section 404-4.05 of the Indiana Design Manual. SC: Current and archived drawings. FL
	Nonstandard documents	AL
	Both in standard and nonstandard documents	NC: Will have to check with our Standards group.
	No answer	NY
Q3. Can you share a copy of documents related to (other purpose)?	Yes	FL: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/2022/idx/550-010.pdf https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/2022/idx/550-013.pdf IN: https://www.in.gov/dot/div/contracts/standards/drawings/sep20/e/700e/e700 combined pdfs/E706-BRPF.pdf NC
	No answer	AL, NY
Q4. Has any study been conducted regarding the implementation of the attachment system for (other purpose)?	No answer (14)	AL, AR, DE, FL, IL, MA, MI, ND, NH, NJ, NY, OH, WI, WV
	No	MO: Unfortunately, MoDOT has very little on this topic. MT, NE, WY
	Yes (9)	AK, MD, IA, IN, NC, NM, SC, TN, WA
	More information of Yes	AK: HSIP nomination included in earlier response; photos available upon request to Mary McRae, mary.mcrae@alaska.gov, 907-465-1222. Please refer to this survey and the HSIP program number 14CN13 Ped Safety Fence Seward Highway in request. MD: If pedestrians are an issue, our approach is to use chain link fence along the ROW line. IA: As noted in Q2-1, we have not experienced issues with pedestrians regularly attempting to cross high speed roadways. IN: Based on a quick search of bid records it looks like over the past three years INDOT has used bridge railing pedestrian fence on 10 construction contracts but the typical application is on a bridge replacement where the existing bridge had a pedestrian fence.

Question	Answer	Agency
		NC: I will be out of town until December 9th or 10th so I wanted to go ahead and fill out the survey even though I do have all the documentation to provide at this time. I can get you something later. SC: Standard Drawing Page is here: https://www.scdot.org/business/standard-drawings.aspx Rigid Barrier standards are drawing number 805-8* to see archived 2015 standard, clear search fields and set status to "Zarchive Book". TN: Preventing human entering the ROW is the key. Recommend installing ROW fence. WA: The primary issue reported is people cutting fences or otherwise entering limited access on high-speed urban facilities, and then entering or crossing the traveled way where they are prohibited.

3.6. ADDITIONAL INFORMATION SHARED BY AGENCY

Table 3.8 summarizes the list of attachments used on barriers in six states. Four states (AL, MI, FL, and IN) have pedestrian crossing prevention fences, and three states (FL, SC, and CA) have glare prevention screens. These attachments are installed either on top or on back of the barrier. AL uses a steel-frame fence, which is different from the chain-link fence installed by other states.

Table 3.8. Summary of Attachments Used on Barriers in Six States.

Attachment	States	Type of Barrier Installed	Installation Position	Height from the Top of the Barrier
Steel-Frame Pedestrian Fence	AL	Concrete Median	Top	6 ft 3 in
Chain-Link Fence	MI	Concrete Barrier	Back	7 ft 9.5 in or 7 ft
Chain-Link Fence	MI	Concrete Barrier	Top	7 ft or 8 ft
Chain-Link Fence	FL	Concrete Bridge Rail	Back	6 ft
Chain-Link Fence	FL	Concrete Bridge Rail	Top	6 ft
Chain-Link Fence	IN	Concrete Bridge Rail	Top	6 ft
Opaque Visual Barrier (concrete)	FL	Concrete Median	Top	1 ft 10 in or 2 ft 4 in
Concrete Barrier Wall	SC	Concrete Median	Top	unclear
Plywood Barrier	CA	Concrete Median	Top	2 ft

3.7. CONCLUSION

This chapter presented the state-level survey results regarding the experiences of various states with pedestrians crossing high-speed roadways. Survey results showed that freeways, expressways, and divided highways are the most common roadways on which states face an issue with pedestrians crossing. Some of the states use barrier attachments to deter pedestrians from crossing, while others use warning signs. Some other solutions are issuing citations or installing right-of-way fencing. Results also showed that most of the responding states have not investigated whether the implemented solutions are efficient.

Moreover, while the results showed that states commonly use pedestrian prevention and glare prevention attachments, most do not have any specific attachments. Out of those that have used pedestrian attachments, none have investigated the system's crashworthiness or conducted an implementation study. The same is true for the states that have used attachments for glare prevention.

A similar survey was conducted with Texas state districts, and the results are presented in the next chapter.

Chapter 4. SURVEY OF TEXAS DISTRICTS

This chapter presents the survey results for the Texas state districts. Similar questions as those presented in Chapter 3 were included in the Texas survey. All results are presented verbatim.

4.1. EXPERIENCES WITH PEDESTRIANS CROSSING HIGH-SPEED HIGHWAYS

Ten answers were collected from TxDOT districts. Eight districts experienced issues related to pedestrians crossing high-speed highways, as summarized in Table 4.1.

Table 4.1. TxDOT District Experiences with Pedestrians Crossing High-Speed Highways.

Responses	TxDOT District
Yes (8)	Abilene, Austin, Lufkin, Liberty, Odessa Fort Worth: We have identified these corridors and are taking steps to improve safety. Waco: Pedestrian fatalities and near miss incidents on I-35 in Waco and Bellmead. Beaumont: History of US69 near FM365 in Port Arthur. and US69 in Beaumont Near Dowlen Rd.
No (1)	

Table 4.2 shows the breakdown of roadway types that TxDOT districts reported as experiencing issues with pedestrians crossing. Austin reported freeways, expressways, and conventional divided highways as the roadways with pedestrian crossing issues. Seven districts reported freeways having the majority of issues.

Table 4.2. Types of Roadways with Pedestrian Crossing Issues Reported by TxDOT Districts.

Roadway Type	TxDOT District
Freeway (7)	Abilene, Austin, Fort Worth, Beaumont, Liberty, Odessa, Waco
Expressway (3)	Austin, Beaumont, Liberty
Conventional Divided Highway (6)	Austin, Beaumont, Fort Worth, Lufkin, Liberty, Odessa
Other (4)	Abilene, Beaumont, Liberty Waco: I-35 8 lane Interstate with frontage roads.

The types of solutions adopted by TxDOT districts to deter pedestrians crossing the highways are shown in Table 4.3. Installing warning signs and educating the public were the most common solutions, while installing attachments on top of a barrier was only reported by Austin.

Table 4.3. Types of Solutions Used by TxDOT Districts to Deter Pedestrians from Crossing.

Type of Solution	TxDOT District
Using attachments on top of the barrier (1)	Austin
Installing warning signs (5)	Austin, Beaumont, Fort Worth, Liberty, Waco
Educating the public (6)	Abilene, Austin, Beaumont, Fort Worth, Lufkin, Liberty
Painting some prevention signs on the barrier face (2)	Austin, Waco
Other (4)	Abilene, Beaumont, Odessa, Waco
N/A	Lufkin
Verbatim responses to "Other"	Abilene: Installed 54" CTB in median as part of a widening project. Beaumont: Upcoming project to install... GAWK screens. Odessa: We do not have any current systems in place to deter pedestrian crossings. We have installed a fence on top of a bridge rail as a requirement from UPRR crossing their tracks to keep people from jumping from bridge onto the tracks. Waco: We have researched top extensions but have not yet installed or selected any.

Table 4.4 shows the breakdown of TxDOT district responses regarding studies to determine the efficiency of their solutions for deterring pedestrians. Only two districts—Austin and Liberty—had conducted a study.

Table 4.4. Studies Conducted by TxDOT Districts to Determine the Efficiency of Adopted Solutions to Deter Pedestrians from Crossing Highways.

Answer	TxDOT District
No (6)	Abilene, Austin, Beaumont, Lufkin, Odessa, Waco
Yes (2)	Austin, Liberty
N/A (or no answer) (2)	Fort Worth, Lufkin
Verbatim responses to "No"	Austin: I am not aware of a study. The standard was provided by Traffic Division to be implemented in Austin. Abilene: The barrier was necessary as part of a freeway widening, and we chose 54" CTB for cross median crash protection, and the increased height as a deterrent to pedestrian crossings. Waco: Beyond just talking to a few vendors and Traffic Safety Division employees we have not conducted any research or study. Beaumont: Not officially or systematically.
Verbatim responses to "Yes"	Liberty: I participate in reviews for fatalities that occur on highways under my responsibility. We evaluate typical measures that we can take to mitigate issues that may have contributed. Typically with adjusted and re-freshed signage and striping and other typical Traffic Control measures. At times we consider other engineering countermeasures, as is called for. Austin: We did research on many of our corridors to install items we felt would be beneficial and also reviewed accident data to try and focus on the areas that had the higher frequency.

4.2. ATTACHMENTS TO LONGITUDINAL ROADSIDE SAFETY HARDWARE

Table 4.5 shows the longitudinal roadside safety hardware types/purposes reported by TxDOT districts. Only a couple of districts, namely Austin and Waco, have more than one type of attachment for longitudinal roadside hardware. No districts have attachments for animal crossing and noise reduction. Three districts reported having no attachment system for longitudinal hardware.

Table 4.5. Longitudinal Roadside Safety Hardware Attachment Type/Purpose for TxDOT Districts.

Attachment Type/Purpose	TxDOT District
Pedestrian crossing prevention (3)	Austin, Fort Worth, Waco
Glare prevention (3)	Austin, Abilene, Waco
Animal crossing prevention	
Nosie reduction	
We do not have any attachment systems (3)	Beaumont, Lufkin, Liberty
Other purposes (2)	Liberty: Nothing that is specifically installed to prevent pedestrian or other crossings. Items are typically installed to protect against fixed object hazards. Odessa: Fence attached to bridge rail for UPRR overpass crossing the railroad tracks.

4.3. INVESTIGATIONS OF CRASHWORTHINESS OF SYSTEMS

Table 4.6 shows the breakdown of responses to additional questions for the TxDOT districts. Questions focused on investigations into the crashworthiness of implemented attachment systems. Only Austin has investigated the crashworthiness of the attachments used for pedestrian crossing and glare prevention. Austin and Waco include the details of their attachment systems in both standard and nonstandard documents, while Odessa and Abilene include related details in nonstandard documents only. Moreover, Austin is the only district that has conducted any study on the implementation of pedestrian crossing prevention systems.

Table 4.6. Questions and Answers on Investigations into the Crashworthiness of Attachment Systems.

Question	Answer	TxDOT District
Q1. Has the crashworthiness of the attachment system for (…) been investigated?	No (2)	Waco (for pedestrian crossing prevention) Odessa (for fence attached to bridge rail for UPRR overpass crossing the railroad tracks)
	Yes (1)	Austin (for pedestrian crossing prevention): Anything we implement must be tested & approved by the Department. However, I have not personally reviewed the information for the pedestrian barrier. Austin (for glare prevention) Austin (for pedestrian crossing prevention): I believe so but would encourage additional confirmation.
	I am not aware of (2)	Abilene (for glare prevention) Fort Worth (for pedestrian crossing prevention)
	N/A (or not displayed to the respondent) (3)	Beaumont, Liberty, Lufkin
Q2. Is the attachment system for (…) included in … your design standard	Nonstandard documents (2)	Abilene (for glare prevention) Odessa (for fence attached to bridge rail for UPRR overpass crossing the railroad tracks)
	Both in standard and nonstandard documents (2)	Austin (for pedestrian crossing prevention) Austin (for glare prevention) Waco (for pedestrian crossing prevention)
	No answer (1)	Fort Worth
	N/A (or not displayed to the respondent) (3)	Beaumont, Lufkin, Liberty
Q3. Can you share a copy of documents related to (…)?	Yes	Austin (for pedestrian crossing prevention): I would have to provide the information from the plan set but do not currently have them available. Please contact me at Omar.X.DeLeon@txdot.gov so I can provide the information directly. Austin (for glare prevention): https://www.txdot.gov/inside-txdot/division/design/cad-disclaimer.html Austin (for pedestrian crossing prevention): Attached are specs, details, and CO showing plan sheets with limits of installation. GAWK Screen.zip Odessa (for fence attached to bridge rail for UPRR overpass crossing the railroad tracks): 0906-06-045-0413.tif
	Other	Abilene (for glare prevention): The barrier and glare screen attachment were designed by the Design and Bridge Divisions. We don't have any documentation in the district. Waco (for pedestrian crossing prevention): We do not have any to share currently.
	No answer	Fort Worth
	N/A (or not displayed to the respondent)	Beaumont, Lufkin, Liberty

Question	Answer	TxDOT District
Q4. Did you conduct any study regarding the implementation of the attachment system for pedestrian crossing prevention?	No	Austin: We are currently monitoring the segment for accidents and will continue this for the life of the barrier. Austin: I am not aware of any after studies performed to date. My personal observations are that since installation we have experienced one pedestrian fatality on I-35 within the limits of installation. I wish I was exaggerating, prior to installation we experienced a fatality monthly of a pedestrian crossing I-35 in the limits. Installation was completed in May 2020 I believe.
Q5. Is there any other information you would like to share with the researchers?	No answer	Austin, Beaumont, Fort Worth, Liberty, Lufkin, Odessa
	Other	Austin: We implement these typically in construction work zones where the inside shoulder is reduced and in places where vertical or horizontal curves along with headlight glare could impact the drivers. Abilene: The use of the 54" barrier has been a significant deterrent since it was installed in 2007. There has only been 1 fatality in 2020 since installation. Prior to barrier installation, there were numerous fatalities in a 6–8-year span. Lufkin: Our pedestrians' fatalities are related to pedestrian walking along the side of the roadway. Waco: I believe a standard approach for use statewide in Texas should be investigated and put in our design standards. I understand that some products are proprietary, but notwithstanding that, having a standard approach is something we need to investigate for uniformity and recognition by the public. Also need to consider signage or preemptive devices to stop a pedestrian from attempting to cross a highway and find they cannot mount the center barrier because then you just have a stranded pedestrian in a precarious position that may be prone to making a poor decision to relieve themselves of the situation, they are in.

4.4. CONCLUSION

This chapter presented the survey results related to Texas district experiences with pedestrians crossing high-speed roadways. Survey results showed that freeways, expressways, and divided highways were the most common roadways facing issues. Some of the common solutions used included painting warning signs and educating the public to deter pedestrians from crossing. Results also showed that most of the districts have not investigated the efficiency of implemented solutions.

Moreover, results showed that districts commonly use pedestrian crossing and glare prevention attachments, but many of them do not have any specific attachments. Of those that have used pedestrian or glare prevention attachments, most have not investigated the system's crashworthiness or conducted an implementation study.

Based on findings from the literature review and surveys, the researchers proposed some potential options for testing, as discussed in the next chapter.

Chapter 5. SYSTEM PRIORITIZATION AND TESTING PLAN

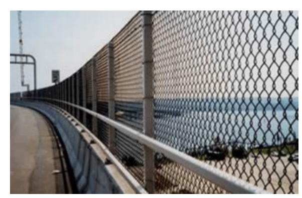
This chapter presents a list of design options of various attachment systems to concrete barriers for deterring pedestrians from crossing highways, along with the final testing plan.

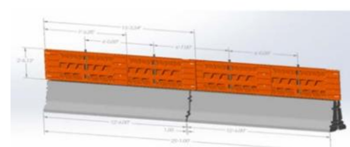
5.1. POTENTIAL OPTIONS

Table 5.1 lists the various attachment system options with anticipated advantages and disadvantages, including any perceived performance benefits and application limitations. The designs have been tailored to account for AASHTO *MASH* TL-3 and TL-4 barrier design requirements, as requested by TxDOT.

The researchers developed the list of proposed attachment system design options based on the results of both the literature review and the surveys, with a specific focus on the project objectives of deterring pedestrians and meeting AASHTO *MASH* requirements.

Table 5.1. Proposed Design Options for Attachment Systems on Concrete Barriers for Deterring Pedestrians from Crossing Highways.

Attachment System Description	Advantages/Disadvantages	Image
Structural Steel Fence—Attached at the top or back of the barrier with a proposed height range of 6 ft	Advantages: • Easy attachment • Sustain wind loads Disadvantages: • Shy distance if installed with taller height • No available test regarding its crashworthiness • Limited glare screening	 (*12*)
Chain-Link Fence—Attached at the top or back of the barrier with a proposed height range of 6 ft	Advantages: • Range of height options available • Easy attachment • Sustain wind loads • *MASH* compliant Disadvantages: • Shy distance if installed with taller height • Limited glare screening	 (*10*)
Screen-Safe® Glare Screen Safety Shield—Attached at the top of the barrier	Advantages: • Lightweight • Powder-coated galvanized steel • Provides glare screening • Resists salts, chlorides, and corrosion • Easy installation and repair Disadvantages: • Narrow range of height • Shy distance if installed with taller height • Installed on top of barrier only • No available test regarding its crashworthiness	 (*13*)

Attachment System Description	Advantages/Disadvantages	Image
Concrete Wall Extension—Attached at the top of the barrier with 2 ft design	Advantages: • Durable, low-maintenance solution • Provides glare screening • Can be provided from off-the-shelf materials Disadvantages: • Narrow range of height • Shy distance if installed with taller height • Possible effect of wind load if solid wall • Difficult to make a connection to the existing barrier • No available test regarding its crashworthiness for *MASH*	
Armorcast® Gawk Screen—Attached at the top of the barrier with height of 2 ft	Advantages: • Lightweight (polyethylene) • Provides glare screening • Resists salts, chlorides, and corrosion • Easy installation and repair Disadvantages: • Limited range of height • No available test regarding its crashworthiness • Shy distance if installed with taller height	7  (*7*)
Arrow Glare Screen—Attached at the top of the barrier with height of 2 ft	Advantages: • Lightweight (plastic) • Provides glare screening • Easy installation and repair Disadvantages: • Limited range of height • No available test regarding its crashworthiness • Shy distance if installed with taller height • Possible effect of wind load if solid wall	 (*14*)
Combination Glare Screen Pedestrian Fence—Attached at the top of the barrier with possible height of 2 ft or more	Advantages: • Good range of heights • Could be made of different materials—plastic or metal • Provides glare screening • Low cost • Easy to connect to existing barriers Disadvantages: • Shy distance if installed with taller height • Possible risk of debris during a vehicle impact • Possible effect of wind load if solid sheet • No available test regarding its crashworthiness	 (*8*)

Attachment System Description	Advantages/Disadvantages	Image
54-inch-tall concrete barrier—New installation	Advantages: • Durable, low-maintenance solution • Tested successfully for *MASH* TL 5-2 • Provides glare screening • Can be provided from off-the-shelf materials Disadvantages: • Limited range of height • Only for new installations/projects	 (*15*)
Modular glare screen—Attached at the top of the barrier with 18, 24, or 30 inches	Advantages: • Lightweight (durable, impact-resistant, polymeric materials) • Provides glare screening • Resists salts, chlorides, and corrosion • Easy installation and repair Disadvantages: • Limited range of height • Installed on top of barrier only • No available test regarding its crashworthiness	 (*6*)

5.2. SYSTEM PRIORITIZATION AND TESTING PLAN

Next, the project panel members selected the systems to be investigated from the proposed solutions listed in Table 5.1. When prioritizing the systems, the panel considered various factors, including system height, visibility through the system, maintenance, cost, repairs, applicability, and advantages and disadvantages. Three systems were chosen, as shown in Table 5.2.

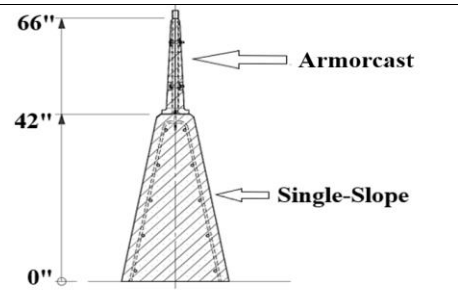
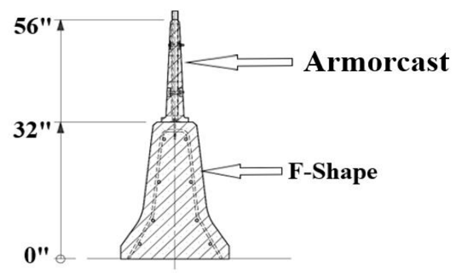
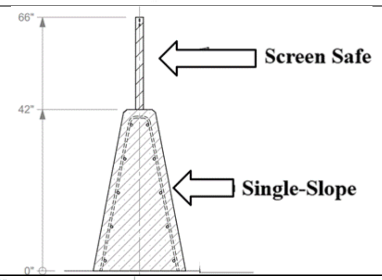
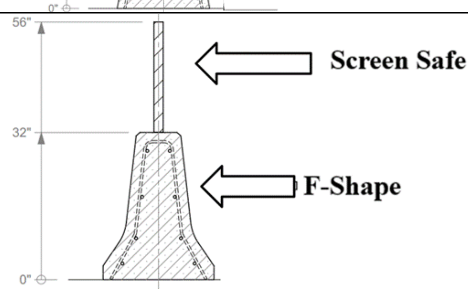
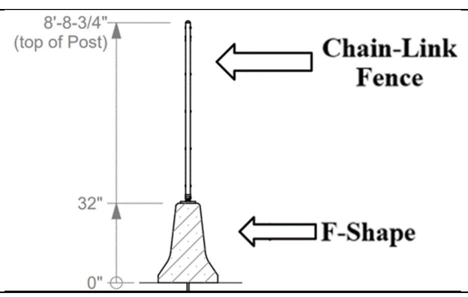
Table 5.2. Prioritized Systems for Testing.

System No.	Name	Image
1.	Armorcast® Gawk Screen	 (*7*)
2.	Screen-Safe® Glare Screen Safety Shield	 (*13*)
3.	Chain-Link Fence	 (*10*)

Table 5.3 provides a description of the attachments chosen for final testing. For each one, a specific length of need was proposed to make sure that the behavior of the vehicle, interaction

with the system, and stability during the impact event were properly captured. In addition, the critical impact points were identified. More information is presented in the following chapters.

Table 5.3. Attachments for Final Testing.

Attachment System	Test Level	Image	Characteristics
Armorcast® Gawk Screen	4-12		Speed: 56 mph Angle: 15° Vehicle Type: 22,046-lb Single-Unit Truck Dummy: Yes Barrier Type: 42-inch Single-Slope
	3-11		Speed: 62.2 mph Angle: 25° Vehicle Type: 5,000-lb Pickup Truck Dummy: Yes Barrier Type: 32-inch F-Shape
Screen-Safe®	4-12		Speed: 56 mph Angle: 15° Vehicle Type: 22,046-lb Single-Unit Truck Dummy: Yes Barrier Type: 42-inch Single-Slope
	3-11		Speed: 62.2 mph Angle: 25° Vehicle Type: 5,000-lb Pickup Truck Dummy: Yes Barrier Type: 32-inch F-Shape
Chain-Link Fence	3-11		Speed: 62.2 mph Angle: 25° Vehicle Type: 5,000-lb Pickup Truck Dummy: Yes Barrier Type: 32-inch F-Shape

Chapter 6. FULL-SCALE CRASH TESTING SUMMARY

The researchers conducted full-scale crash testing to verify the crashworthiness of the prioritized system attachments at high-speed TL-3 and TL-4 *MASH* impact conditions. Details on the conducted full-scale crash testing are reported in a separate volume (*16*). Specifically, the crash tests for the attachments on the single-slope concrete median barrier were performed in accordance with *MASH* TL-4, and the crash tests for the attachments on the F-shape concrete median barrier were performed in accordance with *MASH* TL-3.

6.1. SYSTEM DETAILS

Three attachments, coupled with two concrete barrier types, were investigated, for a total of five tested systems:

- Armorcast® gawk screen on 42-inch single-slope barrier—*MASH* Test 4-12.
- Screen-Safe® glare screen on 42-inch single-slope barrier—*MASH* Test 4-12.
- Armorcast® gawk screen on 32-inch F-shape barrier—*MASH* Test 3-11.
- Screen-Safe® glare screen on 32-inch F-shape barrier—*MASH* Test 3-11.
- Chain-link fence on 32-inch F-shape barrier—*MASH* Test 3-11.

The Armorcast® gawk screen on 42-inch single-slope barrier installation consisted of a 100-ft-long section of a cast-in-place single-slope concrete median barrier, with 20 sections of Armorcast® gawk screen panels mounted on top starting 23 inches from the upstream end of the concrete. The single-slope barrier was 42 inches tall, 24 inches wide at its base, and sloped symmetrically upward on both sides for a final width of 8 inches at the top of the barrier. The gawk screen panels were 63 inches long with a 6-inch overlap; thus, each individual panel spanned 57 inches. The panels were 24 inches tall and had a 6-inch wide, 1-inch-tall base that sloped up on both sides for a final width of 2 inches at the top of the screen. The screens had two 9⁄16-inch slots spaced vertically on one end and two 9⁄16-inch holes spaced vertically on the opposite end to bolt the screens end to end on top of the single-slope barrier. Each screen was fixed to the barrier by being placed over a 26-inch-tall post that was anchored to the top of the concrete barrier. The posts were centered on their respective screens, and a hitch pin attached to a chain welded to the inside of the post was inserted into a ¼-inch through hole in order to keep the screens from being easily removed from the posts.

The Armorcast® gawk screen on 32-inch F-shape barrier installation consisted of a 100-ft-long section of a cast-in-place F-shape concrete median barrier, with a 79-ft 9-inch section of Armorcast® gawk screen panels mounted on top starting from the upstream end of the F-shape barrier. The F-shape barrier was 32 inches tall, 24 inches wide at its base, and sloped upward on both sides for a final width of 9½ inches at the top of the barrier.

The Screen-Safe® glare screen on 42-inch single-slope barrier installation consisted of a 100-ft-long section of a cast-in-place single-slope concrete median barrier, with an 81-ft 3-inch section of Screen-Safe® glare screen and work-zone safety shield mounted on top, starting approximately 112 inches from the upstream end of the single-slope barrier. The single-slope barrier was 42 inches tall, 24 inches wide at its base, and sloped symmetrically upward on both sides for a final width of 8 inches at the top of the barrier. The Screen-Safe® glare screen was split into two sections. The upstream section was 25 ft long, and the downstream section was

50 ft long. Each end of the screen was anchored with a 6-ft 7-inch long anchor cable attached from the top of the end posts to an eyebolt anchored to the top of the single-slope barrier. The glare screen was a double-reverse corrugated steel screen fabric that stood 24 inches above the top of the single-slope barrier and was affixed to the barrier by threaded 26-inch-long post bolts that were screwed into wedge anchors installed in the top of the concrete barriers.

The Screen-Safe® glare screen on 32-inch F-shape barrier installation consisted of a 100-ft-long section of a cast-in-place F-shape concrete barrier, with an 81-ft 6½-inch section of Screen-Safe® glare screen and work-zone safety shield mounted on top starting approximately 90 inches from the upstream end of the F-shape barrier. The F-shape barrier was 32 inches tall, 24 inches wide at its base, and sloped upward on both sides for a final width of 9½ inches at the top of the barrier.

The chain-link fence on 32-inch F-shape barrier installation consisted of a 100-ft-long section of a cast-in-place F-shape concrete barrier, with an 80-ft-long section of chain-link fence mounted on top and approximately centered on the F-shape barrier. The F-shape barrier was 32 inches tall, 24 inches wide at its base, and sloped upward on both sides for a final width of 9½ inches at the top of the barrier. The chain-link fence was 72 inches tall and was secured to the posts, which were spaced at 96 inches. The posts were affixed to the barrier by threaded ⅝-inch diameter rods secured in the concrete with epoxy.

The following section provides a summary of the conducted crash testing and the results.

6.2. SUMMARY OF RESULTS

Figure 6.1 through Figure 6.5 present summaries of the full-scale crash test results.

0.000 s

0.100 s

0.200 s

0.300 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 4-12
TTI Project No.	440822-01-1
Test Date	2022-04-29
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Armorcast® Gawk Screen on Single-Slope Barrier
Length	100 ft
Key Materials	42-inch tall single-slope barrier, 24-inch × 120-inch gawk screens, 26-inch tall 1-inch schedule 40 pipe posts
Soil Type and Condition	Concrete, damp
TEST VEHICLE	
Type/Designation	10000S
Year, Make and Model	2008 Sterling
Curb Weight (lb)	14,690
Inertial Weight (lb)	22,430
Dummy (lb)	N/A
Gross Static (lb)	22,430
IMPACT CONDITIONS	
Impact Speed (mi/h)	56.7
Impact Angle (deg)	15
Impact Location	70.4 inches upstream from the center of post 6
Impact Severity (kip-ft)	161.5
EXIT CONDITIONS	
Exit Speed (mi/h)	N/A
Trajectory/Heading Angle (deg)	Along barrier
Exit Box Criteria	N/A
Stopping Distance	242 ft downstream of impact point 5 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	Concrete Barrier at 0 inches
Permanent (inches)	Concrete Barrier at 0 inches
Working Width/Height (inches)	129.9/27.7
VEHICLE DAMAGE	
VDS	11LFQ5
CDC	11FLEW6
Max Ext. Deformation	15 inches
Max. Occupant Compartment Deformation	No Occupant Compartment Deformation

OCCUPANT RISK VALUES

Long. OIV (ft/s)	7.5	Long. Ridedown (g)	4.8	Max. 50-ms Long. (g)	−2.2	Max. Roll (deg)	24
Lat. OIV (ft/s)	11.2	Lat. Ridedown (g)	6.1	Max. 50-ms Lat. (g)	2.9	Max. Pitch (deg)	6
THIV (m/s)	4.1	ASI	0.4	Max. 50-ms Vert. (g)	3.0	Max. Yaw (deg)	19

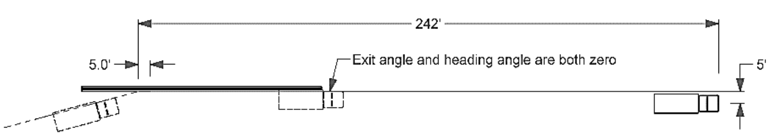


Figure 6.1. Summary of Results for *MASH* Test 4-12 on Armorcast® Gawk Screen on Single-Slope Barrier.

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Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 4-12
TTI Project No.	440822-01-2
Test Date	2022-06-01
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Screen-Safe® Glare Screen on Single-Slope Barrier
Length	100 ft
Key Materials	42-inch tall single-slope concrete barrier, 24-inch tall double-reverse corrugated steel, and 26-inch long ¾-inch post bolts
Soil Type and Condition	Concrete, damp
TEST VEHICLE	
Type/Designation	10000S
Year, Make and Model	2011 Freightliner M2
Curb Weight (lb)	13,110
Inertial Weight (lb)	22,210
Dummy (lb)	N/A
Gross Static (lb)	22,210
IMPACT CONDITIONS	
Impact Speed (mi/h)	56.7
Impact Angle (deg)	15.2
Impact Location	64.6 inches upstream from the centerline of joint between posts 5 and 6
Impact Severity (kip-ft)	164.1
EXIT CONDITIONS	
Exit Speed (mi/h)	Not measurable
Trajectory/Heading Angle (deg)	Along barrier
Exit Box Criteria	N/A
Stopping Distance	333 ft downstream of impact point 21 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	Not measurable
Permanent (inches)	20.5
Working Width/Height (inches)	69/136.6
VEHICLE DAMAGE	
VDS	01RFQ2
CDC	01FREN3
Max. Ext. Deformation	12 inches
Max. Occupant Compartment Deformation	3.5 inches in the right front floor pan

OCCUPANT RISK VALUES							
Long. OIV (ft/s)	6.3	Long. Ridedown (g)	4.2	Max. 50-ms Long. (g)	−2.1	Max. Roll (deg)	23
Lat. OIV (ft/s)	10.4	Lat. Ridedown (g)	10.7	Max. 50-ms Lat. (g)	−5.0	Max. Pitch (deg)	25
THIV (m/s)	3.8	ASI	0.6	Max. 50-ms Vert. (g)	−3.1	Max. Yaw (deg)	53

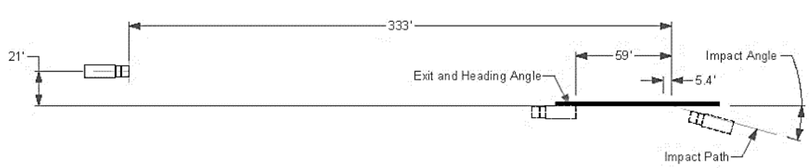

Figure 6.2. Summary of Results for *MASH* Test 4-12 on Screen-Safe® Glare Screen on Single-Slope Barrier.

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Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	440822-01-3
Test Date	2022-04-19
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Armorcast® Gawk Screen on F-Shape Barrier
Length	100 ft
Key Materials	32-inch tall F-shape barrier, 24-inch × 120-inch gawk screens, 26-inch tall 1-inch schedule 40 pipe posts
Soil Type and Condition	Concrete, damp
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2017 RAM 1500
Curb Weight (lb)	5040
Inertial Weight (lb)	5025
Dummy (lb)	165
Gross Static (lb)	5190
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.8
Impact Angle (deg)	24.6
Impact Location	45.2 inches upstream from the centerline of post 4
Impact Severity (kip-ft)	114.8
EXIT CONDITIONS	
Exit Speed (mi/h)	52.7
Trajectory/Heading Angle (deg)	1/8
Exit Box Criteria	Crossed 76 ft downstream from loss of contact
Stopping Distance	184 ft downstream of impact point 32 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	16.5
Permanent (inches)	8.5
Working Width/Height (inches)	29.5/56.0
VEHICLE DAMAGE	
VDS	01LFQ6
CDC	01FLEW4
Max. Ext. Deformation	12 inches
Max. Occupant Compartment Deformation	2 inches in the toe pan

OCCUPANT RISK VALUES

Long. OIV (ft/s)	20.1	Long. Ridedown (g)	3.1	Max. 50-ms Long. (g)	−9.7	Max. Roll (deg)	27
Lat. OIV (ft/s)	30.4	Lat. Ridedown (g)	13.5	Max. 50-ms Lat. (g)	16.6	Max. Pitch (deg)	17
THIV (m/s)	11.3	ASI	2.2	Max. 50-ms Vert. (g)	3.6	Max Yaw (deg)	145

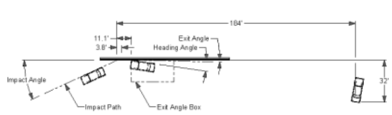

Figure 6.3. Summary of Results for *MASH* Test 3-11 on Armorcast® Gawk Screen on F-Shape Barrier.

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Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	440822-01-4
Test Date	2022-05-17
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Screen-Safe® Glare Screen on F-Shape Barrier
Length	100 ft
Key Materials	32-inch tall F-shape barrier, 24-inch × 120-inch glare screens, 26-inch tall 1-inch schedule 40 pipe posts
Soil Type and Condition	Concrete, damp
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2017 RAM 1500
Curb Weight (lb)	5080
Inertial Weight (lb)	5060
Dummy (lb)	165
Gross Static (lb)	5225
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.3
Impact Angle (deg)	24.5
Impact Location	41.4 inches upstream from the centerline of the screen joint (between posts 6 and 7)
Impact Severity (kip-ft)	112.9
EXIT CONDITIONS	
Exit Speed (mi/h)	47.8
Trajectory/Heading Angle (deg)	2/9
Exit Box Criteria	Crossed 79 ft downstream from loss of contact
Stopping Distance	195 ft downstream of impact point 8 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	24
Permanent (inches)	21
Working Width/Height (inches)	36/56
VEHICLE DAMAGE	
VDS	01RFQ4
CDC	01FREW3
Max. Ext. Deformation	14 inches
Max. Occupant Compartment Deformation	7 inches in the toe pan

OCCUPANT RISK VALUES

Long. OIV (ft/s)	21.6	Long. Ridedown (g)	3.3	Max. 50-ms Long. (g)	−10.5	Max. Roll (deg)	39
Lat. OIV (ft/s)	25.4	Lat. Ridedown (g)	7.2	Max. 50-ms Lat. (g)	−14.0	Max. Pitch (deg)	12
THIV (m/s)	10.3	ASI	1.9	Max. 50-ms Vert. (g)	4.0	Max. Yaw (deg)	48

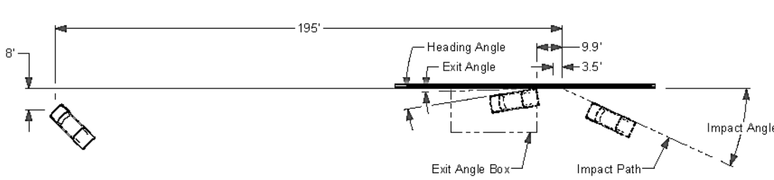

Figure 6.4. Summary of Results for *MASH* Test 3-11 on Screen-Safe® Glare Screen on F-Shape Barrier.

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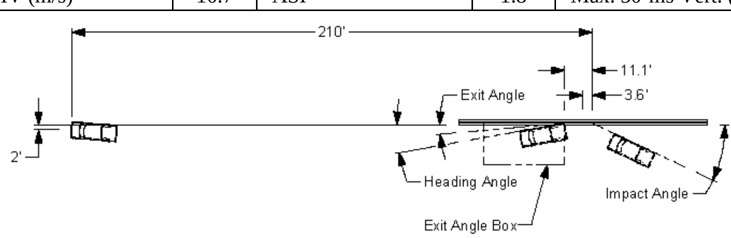
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	440822-01-5
Test Date	2022-08-04
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Chain-Link Fence on F-Shape Barrier
Length	100 ft
Key Materials	32-inch tall F-shape barrier, 72-inch tall chain-link fence
Soil Type and Condition	Concrete, damp
TEST VEHICLE	
Type/Designation	2270 P
Year, Make and Model	2016 RAM 1500
Curb Weight (lb)	5066
Inertial Weight (lb)	5065
Dummy (lb)	165
Gross Static (lb)	5230
IMPACT CONDITIONS	
Impact Speed (mi/h)	61.0
Impact Angle (deg)	25.0
Impact Location	42 inches upstream from the centerline of post 6
Impact Severity (kip-ft)	112.5
EXIT CONDITIONS	
Exit Speed (mi/h)	48.3
Trajectory/Heading Angle (deg)	3/10
Exit Box Criteria	Crossed 75 ft downstream from loss of contact
Stopping Distance	210 ft downstream of impact point 2 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	28.6
Permanent (inches)	7.3
Working Width/Height (inches)	41.4/103.8
VEHICLE DAMAGE	
VDS	01RFQ4
CDC	01FREW3
Max. Ext. Deformation	10.5 inches
Max. Occupant Compartment Deformation	5 inches in the right foot well

OCCUPANT RISK VALUES

Long. OIV (ft/s)	23.1	Long. Ridedown (g)	4.2	Max. 50-ms Long. (g)	−11.2	Max. Roll (deg)	23
Lat. OIV (ft/s)	25.8	Lat. Ridedown (g)	5.7	Max. 50-ms Lat. (g)	−14.3	Max. Pitch (deg)	8
THIV (m/s)	10.7	ASI	1.8	Max. 50-ms Vert. (g)	3.4	Max. Yaw (deg)	41



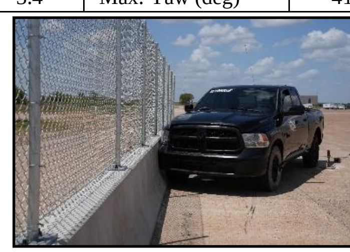


Figure 6.5. Summary of Results for *MASH* Test 3-11 on Chain-Link Fence on F-Shape Barrier.

6.3. CONCLUSION

The crash tests for the attachments on the single-slope concrete median barrier were performed in accordance with *MASH* TL-4, and the crash tests for the attachments on the F-shape concrete median barrier were performed in accordance with *MASH* TL-3. All the evaluated attachments on concrete barriers met the performance criteria for *MASH* longitudinal barriers for their respective tests.

Chapter 7. CONCLUSIONS AND FUTURE RESEARCH

Concrete rigid barriers are used in medians to separate traffic and on the roadside to shield hazards from motorists and motorists from hazards. Attachments may be deployed on top of concrete barriers for various reasons, including deterring pedestrians from crossing highways. Such hardware attachments, however, have not been investigated to *MASH* standards.

Researchers conducted an extensive literature review and completed surveys with TxDOT districts and other transportation agencies to identify existing implementation guidelines and practices for attachments to concrete barriers to deter pedestrians. Survey participants were asked questions related to their experiences with pedestrians crossing highways, implemented solutions, and efficacy of implemented solutions. Survey results showed that freeways, expressways, and divided highways were the most common roadways facing related issues.

For state DOTs, some use top-mounted attachments to deter pedestrians from crossing, while others use warning signs. Other solutions used are issuing citations or installing right-of-way fencing. Results also showed that most of the responding states have not investigated the efficiency of implemented solutions.

For Texas districts, many commonly use pedestrian crossing and glare prevention attachments but do not have specific attachments. Of those that have used pedestrian or glare prevention attachments, most have not investigated the system crashworthiness or conducted an implementation study.

Based on findings from the literature review and surveys, researchers prioritized existing attachment systems and then conducted full-scale crash testing to verify the crashworthiness of the system attachments at high-speed TL-3 and TL-4 *MASH* impact conditions. The crash tests for the attachments on the single-slope concrete median barrier were performed in accordance with TL-4, and the crash tests for the attachments on the F-shape concrete median barrier were performed in accordance with TL-3. All the evaluated attachments on concrete barriers met the performance criteria for *MASH* longitudinal barriers for their respective tests.

While the crashworthiness of the prioritized attachments was investigated through full-scale crash testing, the researchers recommend execution of an implementation study to verify the efficacy of attachment systems used to deter pedestrians from crossing highways. The implementation study could also be utilized to understand potential needs and setbacks related to repairs when such systems are struck in real-world crashes.

The researchers also suggest the potential development of future research studies involving low-speed applications for urban environments. While the systems investigated in this research can be implemented in urban, low-speed areas, there might be a need to investigate the design and crashworthiness for attachments to other types of barriers, including the low-profile concrete barrier system, which is only 20 inches tall—significantly lower than the 32-inch and 42-inch concrete barriers utilized in this project.

An additional potential need for future research is the design and investigation of the crashworthiness of non-redirective systems that might be placed on the roadside with the specific purpose of deterring pedestrians from crossing. Based on survey feedback from TxDOT districts, there is interest in understanding the crashworthiness of systems such as chain-link fences mounted on the side of the roadway to deter pedestrians from crossing. Although there have been some studies investigating the crashworthiness of a chain-link fence mounted on top of concrete barriers, a chain-link system's crashworthiness has never been evaluated as a non-redirective system at low-speed applications.

Finally, the researchers recommend the development of future research and testing to determine the crashworthiness of attachments implemented on top of post-and-beam guardrail systems as pedestrian crossing deterrents. A semi-flexible system would allow considerable lateral deflection during vehicle impact. Therefore, the interaction between the impacting vehicle and the system's attachment is expected to potentially be more critical in terms of system crashworthiness due to potential vehicle instability and occupant compartment deformations/intrusions.

Chapter 8. IMPLEMENTATION

The researchers conducted full-scale crash testing to verify the crashworthiness of prioritized system attachments when impacted at high-speed TL-3 and TL-4 *MASH* impact conditions. Table 8.1 summarizes the investigated systems, the testing characteristics used to evaluate each system's crashworthiness, and the performance evaluation results.

Table 8.1. Systems Evaluated through Crash Testing.

System	Representative Photo	Impact Conditions	Performance Evaluation
Armorcast® Gawk Screen on 42" Single-Slope Barrier		• *MASH* Test 4-12 • 56-mph impact speed • 15-deg orientation angle • Single-unit truck	Pass
Screen-Safe® Glare Screen on 42" Single-Slope Barrier		• *MASH* Test 4-12 • 56-mph impact speed • 15-deg orientation angle • Single-unit truck	Pass
Armorcast® Gawk Screen on 32" F-Shape Barrier		• *MASH* Test 3-11 • 62-mph impact speed • 25-deg orientation angle • Pickup truck	Pass
Screen-Safe® Glare Screen on 32" F-Shape Barrier		• *MASH* Test 3-11 • 62-mph impact speed • 25-deg orientation angle • Pickup truck	Pass
Chain-Link Fence on 32" F-Shape Barrier		• *MASH* Test 3-11 • 62-mph impact speed • 25-deg orientation angle • Pickup truck	Pass

All the evaluated attachments on concrete barriers met the performance criteria for *MASH* longitudinal barriers for their respective tests.

The *MASH* matrix for TL-4 evaluation includes three different tests:

- *MASH* Test 4-10: passenger car, 62 mph, 25-degree orientation angle.
- *MASH* Test 4-11: pickup truck, 62 mph, 25-degree orientation angle.
- *MASH* Test 4-12: single-unit truck, 56 mph, 15-degree orientation angle.

When investigating the crashworthiness of both the Armorcast® gawk screen and the Screen-Safe® glare screen on top of the 42-inch single-slope barrier, *MASH* Test 4-12 was prioritized based on the project objective and available funds. *MASH* Tests 4-11 and 4-10 were not conducted on the system. The 42-inch single-slope barrier has been demonstrated to be a crashworthy system at *MASH* -10 and -11 impact conditions. Since it is expected that both passenger cars and pickup trucks will have minimal to no interaction with the attachments on top of the concrete barrier, the 4-10 and 4-11 tests were considered unnecessary to verify the system's crashworthiness with the 42-inch-tall single-slope barrier.

The *MASH* matrix for TL-3 evaluation includes two tests:

- *MASH* Test 3-10: passenger car, 62 mph, 25-degree orientation angle.
- *MASH* Test 3-11: pickup truck, 62 mph, 25-degree orientation angle.

When investigating the crashworthiness of both the Armorcast® gawk screen and the Screen-Safe® glare screen on top of the 32-inch single-slope barrier, *MASH* Test 3-11 was prioritized based on the project objective and available funds. *MASH* Test 3-10 was not conducted on the system. The 32-inch F-shape barrier has been demonstrated to be a crashworthy system at *MASH* -10 impact conditions. Since it is expected that passenger cars will have no interaction with the attachments on top of the concrete barrier, the 3-10 test was considered unnecessary to verify the system's crashworthiness with the 32-inch-tall F-shape barrier.

Table 8.2 provides a description of the post-impact debris for the Armorcast® gawk screen on top of the 42-inch single-slope barrier along with the damage to the installation. There was no dynamic/permanent deflection of the single-slope barrier.

Table 8.3 provides a description of the post-impact debris for the Armorcast® gawk screen on top of the 32-inch F-shape barrier along with the damage to the installation. There was a 16.5-inch dynamic deflection of the screen on the field side of the barrier.

Table 8.4 provides a description of the post-impact debris for the Screen-Safe® glare screen on top of the 42-inch single-slope barrier along with the damage to the installation. There was around 20 inches of permanent deflection of the screen on the field side of the barrier.

Table 8.5 provides a description of the post-impact debris for the Screen-Safe® glare screen on top of the 32-inch F-shape barrier along with the damage to the installation. There was around 21 inches of permanent deflection of the screen on the field side of the barrier and 24 inches of dynamic deflection.

Table 8.6 provides a description of the post-impact debris for the chain-link fence on top of the 32-inch F-shape barrier along with the damage to the installation. There was around

28.6 inches of dynamic deflection of the fence on the field side of the barrier and 7.3 inches of permanent deflection.

Table 8.2. Post-Impact Debris Information for Armorcast® Gawk Screen on 42-inch Median Single-Slope Barrier.

System Description	Image
Debris Pattern	 a. Debris pattern on the opposite side of the impact of the system.  b. Debris pattern on the impact side after hitting the system.  c. Side view of the debris pattern on the impact side of the system.  d. Closer view of the debris on the impact side of the system.
Damage to the Installation	1. Scuffing and gouging at impact on the concrete barrier. 2. Panels 6–20 were removed from the parapet. 3. Panels 6 and 7 landed behind the parapet, and other panels landed from 195 to 240 ft downstream.
Permanent Deflection	0 inches at the concrete barrier.
Dynamic Deflection	0 inches at the concrete barrier, and the screen released from barrier.
Working Width	The screen panels at 10.8 ft, at a height of 27.7 inches.

Table 8.3. Post-Impact Debris Information for Armorcast® Gawk Screen on 32-inch Median F-Shape Barrier.

System Description	Image
Debris Pattern	 a. Debris pattern with the lateral deformation after impacting the system.  b. Debris pattern on the impact side after hitting the system.  c. Front view of the debris pattern with the lateral after impacting the system.  d. Top view of the debris after impacting the system.
Damage to the Installation	1. Scuffing and gouging at impact on the concrete barrier. 2. Screen 4 was damaged and had a vertical tear at its post. 3. Screens 3, 4, and 5 posts and baseplates were bent.
Permanent Deflection	The screen at 8.5 inches toward the field side, 5 inches upstream of post 4.
Dynamic Deflection	The screen at 16.5 inches toward field side.
Working Width	Barrier attachment at 29.5 inches, at a height of 56 inches.

Table 8.4. Post-Impact Debris Information for Screen-Safe® Glare Screen on 42-inch Median Single-Slope Barrier.

System Description	Image
Debris Pattern	 a. Debris pattern with the lateral deformation after impacting the system.  b. Debris pattern opposite to the impact side after hitting the system.  c. Debris pattern from the opposite side of the impact.  d. Side view of the debris pattern after impacting the system.
Damage to the Installation	1. Scuffing and gouging at the impact location and along the barrier for the duration of contact. 2. The screen was bunched up and severely deformed at post 8, with slight damage to the screen at posts 4 and 9 and post 14 having its anchor insert pulled loose from the barrier. 3. Posts 5 and 6, 7, 8, 9, 10, 11, 12, 13, and 15 had a 26-degree lean, 46-degree lean, 83-degree lean, 45-degree lean, 38-degree lean, 37-degree lean, 43-degree lean, 39-degree lean, and 36-degree lean, respectively, all from vertical. 4. Posts 1 through 3 and 16 were all undamaged.
Permanent Deflection	The fence at 20.5 inches toward field side, 20 inches downstream of post 9.
Dynamic Deflection	Not measurable (view obscured by box truck).
Working Width	The box truck at 69 inches, at a height of 136.6 inches.

Table 8.5. Post-Impact Debris Information for Safe-Screen® Glare Screen on 32-inch Median F-Shape Barrier.

System Description	Image
Debris Pattern	 a. Debris pattern with the lateral deformation from the opposite side of the impact.  b. Debris pattern from the impact side after hitting the system.  c. Front view of the debris pattern from the impact side of the system.  d. Side view of the debris after impacting the system.
Damage to the Installation	1. Scuffing and gouging at the impact location and along the barrier for the duration of contact. 2. The glare screen was deformed, and several post bolts were bent toward the field side. 3. Post 5 had a 10-degree lean from vertical, posts 6 and 7 had a 63-degree lean, post 8 had a 45-degree lean, and post 9 had an 11-degree lean.
Permanent Deflection	The screen at 21 inches toward field side at the joint of posts 6 and 7.
Dynamic Deflection	The screen at 24 inches toward field side.
Working Width	The barrier attachment 36 inches, at a height of 56 inches.

Table 8.6. Post-Impact Debris Information for Chain-Link Fence on 32-inch Median F-Shape Barrier.

System Description	Image	
Debris Pattern	 a. Debris pattern from the impact side of the system.	 b. Debris pattern from the opposite side of the impact.
	 c. Front view of the debris pattern from the opposite side of impact.	 d. Side view of the debris pattern after impacting the system.
Damage to the Installation	1. Scuffing and gouging at the impact location on the contact barrier. 2. The chain link was pulled loose from the bottom wire from post 5 to post 7, and the chain link was pushed up 10 inches and back 12 inches just upstream of post 6. 3. Post 6 was bent at 20 inches from the bottom, and the weld securing the pipe to the base plate failed ¾ of the way around the pipe.	
Permanent Deflection	The fence at 7.3 inches toward field side, at post 6.	
Dynamic Deflection	The fence at 28.6 inches toward field side.	
Working Width	The fence at 41.4 inches, at a height of 103.8 inches.	

The reported debris patterns from the crash testing impacts can be utilized to make decisions regarding implementation of the evaluated barrier attachments on roadways based on the roadway geometry characteristics (such as existence of emergency lanes next to the implemented system, which would create a buffer to the travel lane when including lateral distance from potential debris patterns).

In accordance with the project's scope, the research team prepared an estimate for the value of research (VoR) associated with the research products delivered for this project. The benefit areas deemed relevant and identified in the project agreement for the purpose of establishing the VoR encompass both qualitative and economic areas. Information regarding the VoR is contained in the Appendix of this report.

REFERENCES

1. J. Wang and J. B. Cicchino. 2019. *Fatal pedestrian crashes on interstates and other freeways in the United States*. Insurance Institute for Highway Safety.
2. IIHS. 2018. Study highlights rising pedestrian deaths, points toward solutions. Accessed February 23, 2020. https://www.iihs.org/news/detail/study-highlights-rising-pedestrian-deaths-points-toward-solutions
3. Amy Denney. 2019. TxDOT is encouraging people to "Stay Alive, Don't Cross I-35" in Austin. *Impact Community Newspaper*. Accessed February 23, 2020. https://communityimpact.com/austin/transportation/2019/02/15/txdot-is-encouraging-people-to-stay-alive-dont-cross-i-35-in-austin/
4. Chain Link Fence Manufacturers Institute. Infrastructure security fencing system. Accessed November 11, 2022. https://chainlinkinfo.org/infrastructure-security-fencing-system/
5. Amy Fortli. 2018. Super Bowl brings massive security resources to Minneapolis. Accessed November 11, 2022. https://apnews.com/article/nfl-football-super-bowl-fencing-football-north-america-c10beefba5644b0ea234c7fb59ce16c8
6. Coral Sales Co. Vlatir Glare Screen. Accessed November 11, 2022. http://www.coralsales.com/products/highwayproducts/specialtyproducts/glarescreen/
7. Ian Oldman. 2020. TxDOT installing barriers along I-35 in North Austin to prevent pedestrian fatalities. Accessed November 11, 2022. https://communityimpact.com/austin/northwest-austin/transportation/2020/03/10/txdot-installing-barriers-along-i-35-in-north-austin-to-prevent-pedestrian-fatalities/
8. M. Ala Saadeghvaziri and W. R. Spillers. 2003. *Combination glare screen pedestrian fence for center barrier*. New Jersey Institute of Technology. Accessed November 11, 2022. https://web.njit.edu/~ala/Projects/GlareScreen/Final_Report_GS.pdf
9. GSI. Steel pedestrian rail projects. Accessed November 11, 2022. https://www.gsihighway.com/steel-pedestrian-rail-projects
10. Ameristar. Aegis II Xtreme. Accessed November 11, 2022. https://www.ameristarfence.com/en/products/fence-systems/aegis2-xtreme-pedestrian-bridge-railing/
11. Xia Yun. 2020. During the morning rush hour, the person who actually rode the battery car on the inner ring elevated has been punished. Accessed November 11, 2022. http://newsxmwb.xinmin.cn/shanghaitan/2020/06/10/31743579.html
12. Almec Fencing. 2021. Palisade fencing and gates installed for Capital Roofing, Longport Industrial Estate. Accessed November 10, 2021. https://www.almecfencing.co.uk/blogs/news/palisade-fencing-and-gates-installed-for-capital-roofing-longport-industrial-estate.
13. Transpo. Screen-Safe® Glare Screen Safety Shield. Accessed November 10, 2022. https://www.transpo.com/roads-highways/safety-products/highway-glare-screen-screen-safe.
14. Freeway Screens LLC. Temporary Glare Screen—Arrow Glare Screen 4766. Accessed November 10, 2022. https://freewayscreens.com/product/arrow-glare-screen-4766/.

15. Nauman M. Sheikh, James C. Kovar, Sofokli Cakalli, Wanda L. Menges, Glenn E. Schroeder, and Darrell L. Kuhn. 2019. *Analysis of 54-Inch-Tall Single Slope Concrete Barrier on a Structurally Independent Foundation*. Texas A&M Transportation Institute.
16. Chiara Silvestri-Dobrovolny, Roger P. Bligh, Maysam Kiani, Aniruddha Zalani, William J. L. Schroeder, and Darrell L. Kuhn. 2022. *Evaluation of Attachments to Concrete Barrier Systems to Deter Pedestrians—Volume 2: Crash Report*. Texas A&M Transportation Institute.

APPENDIX. VALUE OF RESEARCH

A.1. INTRODUCTION

In accordance with the scope of TxDOT Project 0-7082, Survey Development and Prioritization of Existing Technologies for Further Investigation, the TTI researchers prepared an estimate for the VoR associated with the research products delivered for this project.

The benefit areas deemed relevant and identified in the project agreement for the purpose of establishing the VoR encompassed both qualitative and economic areas. The benefit areas identified for this project are summarized in Table A.1.

Table A.1. Selected Benefit Areas for Project 0-7082.

Selected	Functional Area	QUAL	ECON	Both	TxDOT	State	Both
X	System Reliability		X		X		
X	Level of Knowledge	X			X		
X	Quality of Life	X			X		
X	Engineering Design Improvement			X			X
X	Safety			X			X

A.2. QUALITATIVE BENEFIT AREAS

A.2.1. Level of Knowledge

Based on findings from the research and surveys conducted as a part of the project, solutions to existing issues related to pedestrians crossing highways are limited. The surveys included various questions designed to help researchers understand how imperative the issue of unwanted pedestrian crossings is and to determine what types of roadways are most critical. Findings showed that many states have experienced issues and currently have very limited sources to deter pedestrians from crossing highways. One of the primary outcomes of the project will be to provide a list of solutions that can be implemented as needed in various highway conditions.

A.2.2. Quality of Life

With the application of attachments on existing roadside safety hardware to deter pedestrians from crossing highways, there will be a significant reduction in deaths and injuries. Implementing attachments on existing roadside hardware will help to improve road safety, which will improve quality of life. Reduction in deaths will be a big step in achieving the Sustainable Development Goal of reduced deaths by 2030 (*1*). Improved road safety promotes healthy living and wellbeing. The project outcome will address road safety, one of the core aspects of the Social Progress Index that measures human wellbeing (*1*).

A.3. QUALITATIVE AND ECONOMIC BENEFIT AREAS

A.3.1. Safety

IIHS reported in December 2019 that more pedestrians are dying on freeways and interstates due to the lack of proper infrastructure for safe crossing. The IIHS report also revealed that there has been a 60 percent rise in pedestrian fatalities, which is 50 percent higher than in 2009 (*2*). Moreover, there were 2,518 traffic fatalities on freeways and interstates between 2015 and 2017, out of which 42 percent occurred due to pedestrian crossings. Moreover, between 2009 and 2020, more than 100,000 miles were added on highways, and studies have shown an increase in pedestrian deaths.

One outcome of this project is to provide a list of existing systems that can be used as attachments on top of existing concrete barriers to deter pedestrians from crossing expressways and interstates.

A.3.2. Engineering Design Improvement

Additionally, the research team also conducted a survey to determine whether different states had any existing solutions to prevent unwanted crossings. Only a handful of states had used any attachments, and those that did had not evaluated the crashworthiness compatibility of the systems. This project not only proposed various attachment options but also investigated the crashworthiness compatibility of those systems based on *MASH* design impact conditions through computer analysis and full-scale crash testing to verify the safety of current vehicles with the attachment systems.

A.4. SYSTEM RELIABILITY

One measure of the VoR is the economic benefits that can potentially be realized with implementation of the project products. The economic benefit is safety related and expressed in terms of lives saved and associated societal cost of the tragic losses that can be averted by deterring pedestrians from attempting to cross multilane freeways.

The Centers for Disease Control and Prevention estimates that the total societal cost of highway crashes in Texas is over $5.7 billion per year (*3*). With reference to the Crash Records Information System (CRIS), there were 4,487 traffic-related fatalities in Texas in 2021 (*4*). Of those, 823 (18 percent) were pedestrian fatalities. More specific to this project, there were at least 37 fatalities and an additional 22 serious injuries in 2021 that can be attributed to a pedestrian being struck by a vehicle in the main lanes of traffic while attempting to cross an interstate, freeway, or expressway at an unauthorized location. This number is based on the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) variable with values of “Crossing an Expressway,” “Dart-Out,” and “Dash” (*5*). There were an additional 17 pedestrian fatalities and 16 pedestrian serious injuries coded as “Standing in Roadway” that could also be attributable to attempted pedestrian crossings (*5*). The year 2021 is the first year that the PBCAT variable is reported.

Concrete median barriers are used to separate opposing lanes of traffic and prevent head-on, cross-median crashes. An unauthorized pedestrian crossing involves crossing multiple lanes in each direction of travel as well as the concrete median barrier at the center of the highway. The products evaluated under this project are intended to increase the effective height of a concrete median barrier and, thereby, deter pedestrians from attempting to cross the divided highway. Thus, the primary safety and economic benefit derived from the use of the pedestrian deterrent systems is a reduction in pedestrian crash frequency.

It is conservatively estimated that implementation of the pedestrian deterrent systems will reduce the pedestrian fatalities and serious injuries associated with attempts to cross divided highways at unauthorized locations by 30 percent. Based on the 2021 crash data described above, this equates to 11.1 fatalities and 6.6 serious injuries per year.

A 2015 report published by the National Highway Traffic Safety Administration entitled *The Economic and Societal Impact of Motor Vehicle Crashes* indicates that the economic cost to society of each fatality in a fatal crash is $1.4 million (*6*). The economic cost of a serious injury crash (average cost of MAIS 3-5) is approximately $526,000. Thus, application of the pedestrian deterrents can be estimated to have an economic safety benefit of 11.1 fatalities/year × $1.4 million/fatality + 6.6 serious injuries/year × $526,000/serious injury = $19 million/year.

Figure A.1 presents a summary of the VoR calculations for this project.

- Project Budget: $436,762.
- Project Duration: 2.3 years.
- Expected Value per Year: $19,000,000.
- Expected Value Duration: 20 years.
- Total Savings: $170,563,238.
- Net Present Value: $140,172,346.
- Payback Period: 0.022987.
- Cost Benefit Ratio ($1: $): $321.

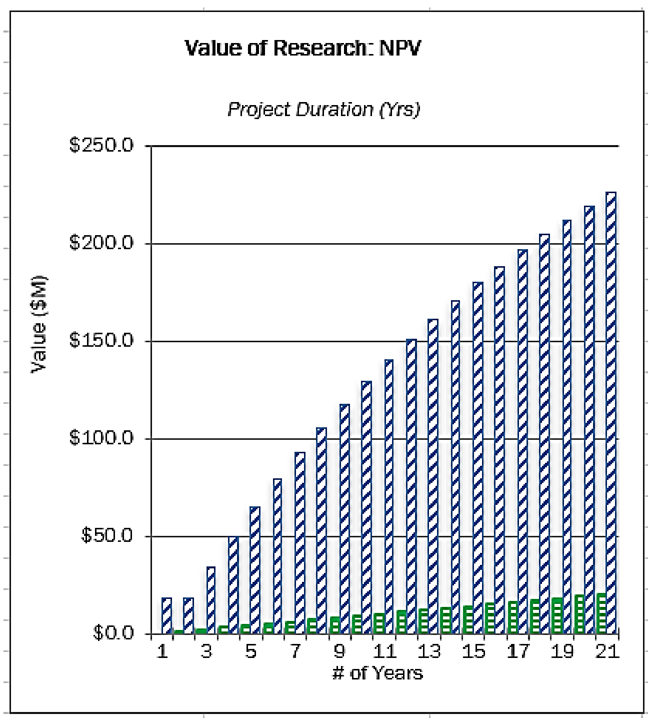


Figure A.1. Summary of VoR Calculations for Project 0-7082.

A.5. REFERENCES

1. Nneka Henry. 2022. This is how road safety affects your quality of life. Accessed December 2, 2022. https://www.weforum.org/agenda/2022/04/how-to-tackle-the-road-safety-crisis/
2. J. Wang and J. B. Cicchino. 2019. *Fatal pedestrian crashes on interstates and other freeways in the United States*. Insurance Institute for Highway Safety.
3. TxDOT. 2022. Texas motor vehicle traffic crash facts, 2020. Accessed December 2, 2022. https://ftp.txdot.gov/pub/txdot-info/trf/crash_statistics/2020/01.pdf
4. TxDOT. Welcome to the TxDOT Crash Query Tool. Accessed December 2, 2022. https://cris.dot.state.tx.us/public/Query/app/home
5. David L. Harkey, Sean Tsai, Libby Thomas, and William W. Hunte. 2006. *PBCAT: Pedestrian and Bicycle Crash Analysis Tool*. Accessed December 2, 2022. https://www.fhwa.dot.gov/publications/research/safety/pedbike/06089/06089.pdf
6. L. J. Blincoe, T. R. Miller, E. Zaloshnja, and B. A. Lawrence. 2015. *The economic and societal impact of motor vehicle crashes, 2010* (Revised). National Highway Traffic Safety Administration.