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Guidebook for Use of Pinned-Down Temporary Concrete Barriers in Limited Space Applications

by

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16. Abstract

A pinned-down temporary concrete barrier system was developed at Texas A&M Transportation Institute (TTI) under the Roadside Safety Research Program Pooled Fund study. This involved an extensive design and crash testing program that was carried out over various task orders, collectively leading to seven full-scale vehicle crash tests. This design and testing effort provides a pinned down temporary concrete barrier system that can be placed on concrete and asphalt, along with its transitions from free-standing to pinned, and from pinned to rigid barrier systems. Since this research was performed under many task orders that were carried out since 2007, the results of the crash tests are documented in several independent reports. This makes it difficult for a user agency to glean all the test results and develop a comprehensive design standard of an anchored barrier system.

This guidebook provides summarized information on the pinned-down barrier design, its applications on concrete and asphalt, and various transition to free-standing and rigid barriers. Key design details and test results have been summarized in this guidebook. Some general guidance on implementation of the pinned-down barrier system is also provided. References to the detailed project reports and test results have been provided to enable a reader to acquire more information if desired.

It is anticipated that this guide will promote the use of the pinned-down temporary concrete barrier system by making it easier for user agencies to develop their design standards related to restrained barrier applications.

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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 yard	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 1000 L 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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		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	fl 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 (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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INTRODUCTION AND BACKGROUND

Texas A&M Transportation Institute (TTI) has developed a pinned-down, temporary concrete barrier system for limited space applications after going through an extensive design and crash testing program under the Roadside Safety Research Program Pooled Fund [Study No. TPF-5(114)]. This work has been performed over various task orders, which have collectively led to seven full-scale vehicle crash tests and several component-level pendulum impact, static loading, and dynamic pull tests. The results of these tests have led to the development of a pinned down barrier system that can be placed on concrete and asphalt, along with its transitions from free-standing to pinned, and from pinned to rigid barrier systems.

This research was performed under many task orders that were carried out since 2007 based on the availability of funds and the results of a prioritization process among the pooled-fund states. Information from various project reports is difficult to glean and use for developing a comprehensive design standard of an anchored barrier system for work zones.

OBJECTIVE AND SCOPE

The objective of this guidebook is to present comprehensive information on the pinned-down barrier design, its applications, various transition designs, and to provide general guidance on implementation issues that have been addressed by TTI researchers in the past.

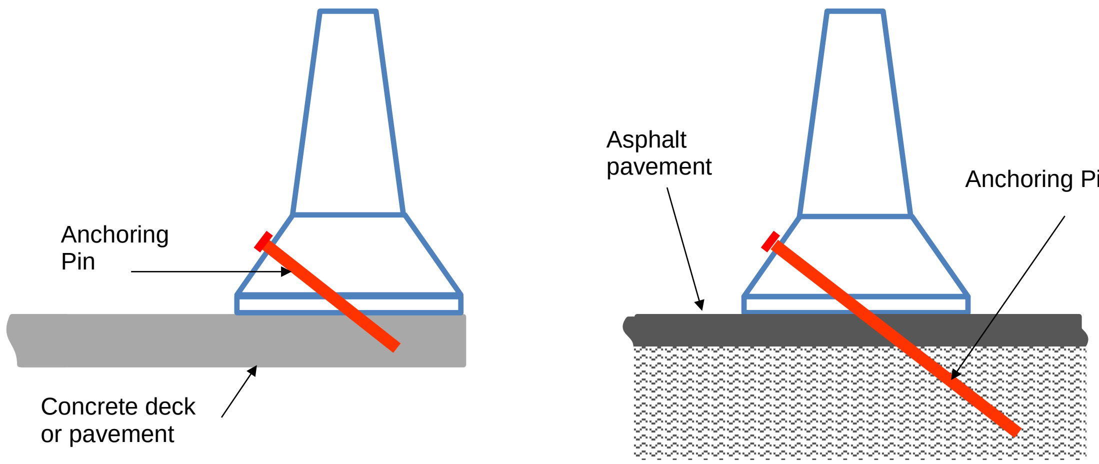
The objective of this guidebook is not to present detailed results of various tests that have been performed in the past. References to the detailed project reports and test results have been provided to enable a reader to acquire more information if desired.

It is anticipated that this guide will promote the use of the pinned-down barrier system by making it easy for user agencies in developing their design standards related to restrained barrier applications.

ANCHORING DESIGN CONCEPT

The temporary concrete barrier design used in this research was the Oregon Department of Transportation's F-shape pin-and-loop barrier that has been tested in the free-standing condition under National Cooperative Highway Research Report (NCHRP) *Report 350* test level 3 criteria. *(1, 2)* Several minor modifications were made to the reinforcement of the barrier to make it more suitable for anchoring. Design details of the barrier used in the new testing will be presented later.

The restrained temporary concrete barrier design developed uses standard 32-inch tall F-shape barrier profile. Adjacent barrier segments are connected using a pin-and-loop type connection. The barrier segments are restrained using a simple pinned-down anchoring mechanism as shown in Figure 1. Inclined holes are cast into the toe of the concrete barrier segments. These holes start from the traffic face of the barrier and exit near the bottom centerline of the barrier segment. Once the barrier is placed on site, a drill machine is used to continue the inclined holes a certain distance into the underlying concrete or asphalt. Steel pins are then installed in the inclined holes, passing though the barrier and into the underlying concrete or asphalt pavement. This locks the barrier in place by restraining its lateral deflection or rotation due to a vehicle impact. Longer anchoring pins are used for barriers placed on asphalt, as shown in Figure 1. This design can be installed on concrete bridge decks or pavements that are minimum 7 inches thick. On asphalt, the barrier can be installed on asphalt pavements that are minimum 4 inches thick.



Placement on concrete (min. 7-inch thk.)

Placement on asphalt (min. 4-inch thk.)

Figure 1. Anchoring mechanism of the pinned-down temporary concrete barrier system.

Inside each barrier segment, a diagonal U-bar passes around the diagonal hole that hosts the anchoring pin, as shown in Figure 2. This U-bar reinforces the concrete around the hole and prevents the anchoring pin from disengaging from the barrier segment if concrete fails in the vicinity of the hole.

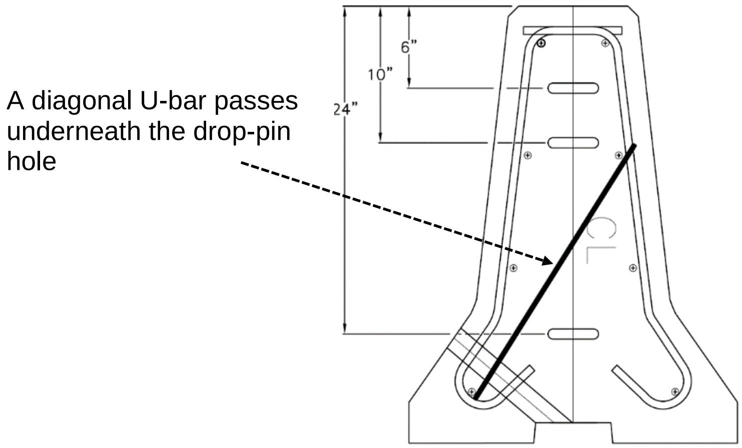


Figure 2. Reinforcement of the temporary concrete barrier with a diagonal U-bar.

ADVANTAGES OF THE PINNED-DOWN DESIGN

The pinned-down barrier system is relatively easier to install, inspect, and relocate in a construction zone with limited space. This method does not require through-the-deck bolting or other extensive restraining methods that are difficult to install in the field. Restraining the barrier segments with steel pins does not result in excessive damage to the underlying concrete or asphalt pavement. It is also relatively easy to remove the pinning restraint for relocating the barrier.

Pins installed in concrete can easily be removed by hand to unpin the barrier. Pins installed in asphalt can be pulled out using a forklift. In case of a vehicle impact, most pins can still be pulled out as described. Some of the pins may deform extensively and can be removed using a cutting torch. This procedure, however, is needed for a small number of pins. In the crash tests performed to evaluate the dynamic performance of the pinned barrier systems, only two pins were deformed enough that could only be removed by cutting.

Another advantage of the pinned-down barrier system is that its transitions to free-standing and rigid barrier systems have been developed using the same concrete barrier segment and barrier connection design. This eliminates the need to maintain inventory of additional transition hardware.

CONCRETE BARRIER DESIGN

The pinned down anchored barrier testing was performed using precast F-shape concrete barrier segments that were 12 ft-6 inch long. Other segment lengths can also be used with this design, as will be discussed later. This anchoring design is for barrier segments that have the standard “F” profile and are 32 inches tall, 24 inches wide at the base, and 9½ inches wide at the top.

Horizontal barrier reinforcement consists of eight #4 bars spaced along the height of the barrier within the vertical reinforcement. Vertical barrier reinforcement consists of rebar stirrups of #4 bars spaced 18 inches on centers. These vertical bars are bent to conform to the F-shape barrier profile and to provide sufficient concrete cover for the faces of the barrier and the drainage scupper at the base of the barrier. For the last two vertical stirrup bars adjacent to the ends of the barrier segments, the spacing is reduced to 17⅞ inches and 7⅞ inches, respectively.

Adjacent precast barrier segments are connected using a pin-and-loop type connection. The loops are made of ¾-inch diameter round stock steel. The outer diameter of the loops is 3½ inches and they extend 2 inches outside the end of the barrier segment. The barrier connection is comprised of two sets of three loops. When installed, the distance between adjacent barrier segments is ¼ inch. A 1-inch diameter, 30-inch long connecting pin is inserted between the loops to establish the connection. A 2-inch diameter and ¼-inch thick washer is welded ¾ inch from the top of the connecting pin. The pin is held in place by resting the washer on insets built into the faces of adjacent barriers.

Three 1⅞-inch wide and 4-inch long slotted holes, inclined 40 degrees from the ground, are cast into the toe of each precast barrier segment. These slotted holes start from the traffic face of the barrier and exit near its bottom centerline. Two of the slotted holes are positioned 16 inches away from each end of the barrier segment and are used for anchoring the barrier to the underlying concrete pavement. The third slotted hole is positioned in the middle of the barrier segment.

Inside the F-shape barrier segments, a 22-inch long U-shaped #4 bar is diagonally placed at the location of each slotted hole. The U-shaped bar surrounds the slot to reinforce the concrete around it and to resist pullout of the anchoring pin in the event of concrete failure in the vicinity of the slotted hole.

Details of the 12.5-ft concrete barriers used in this design are presented in Figure 3 to Figure 7.

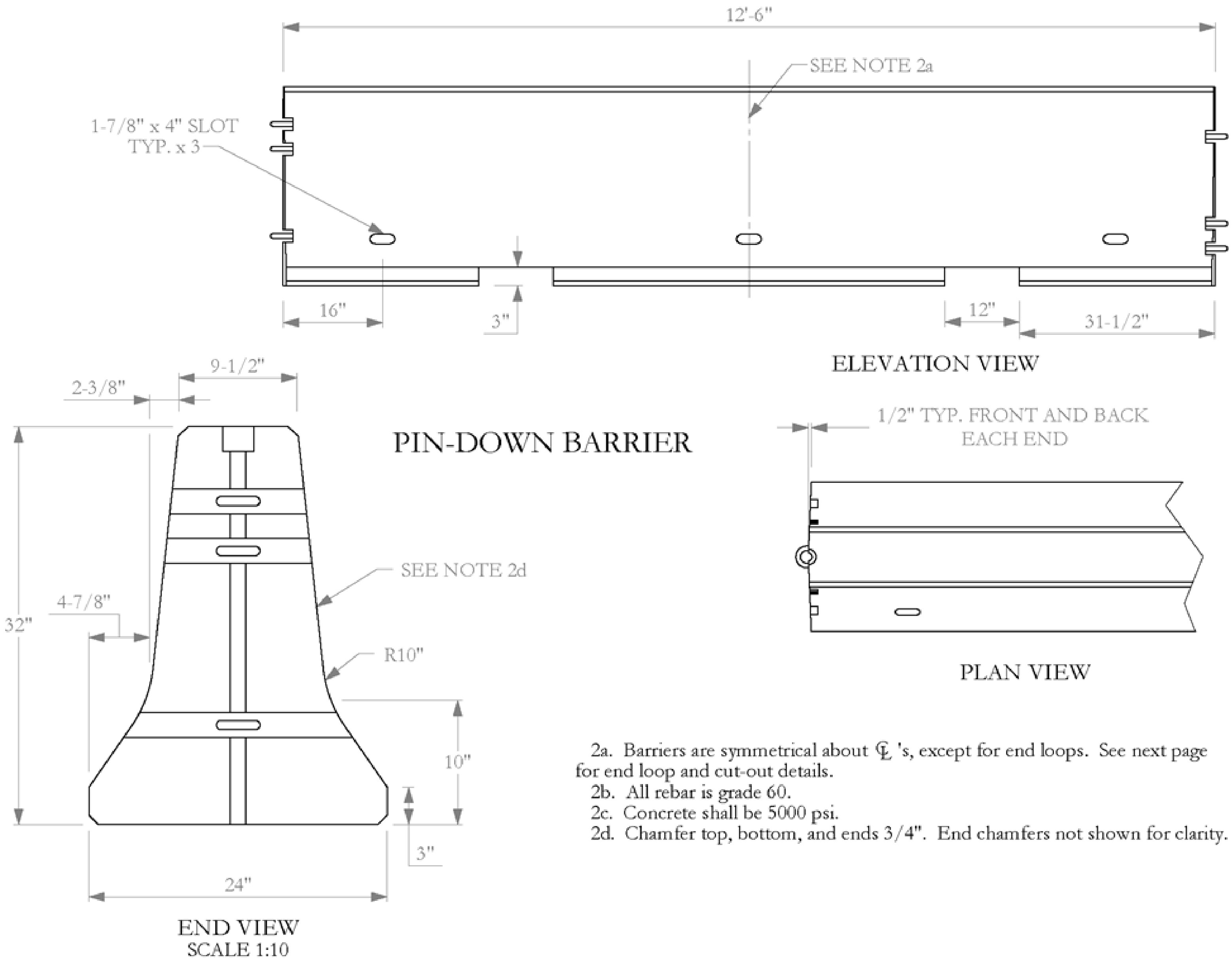
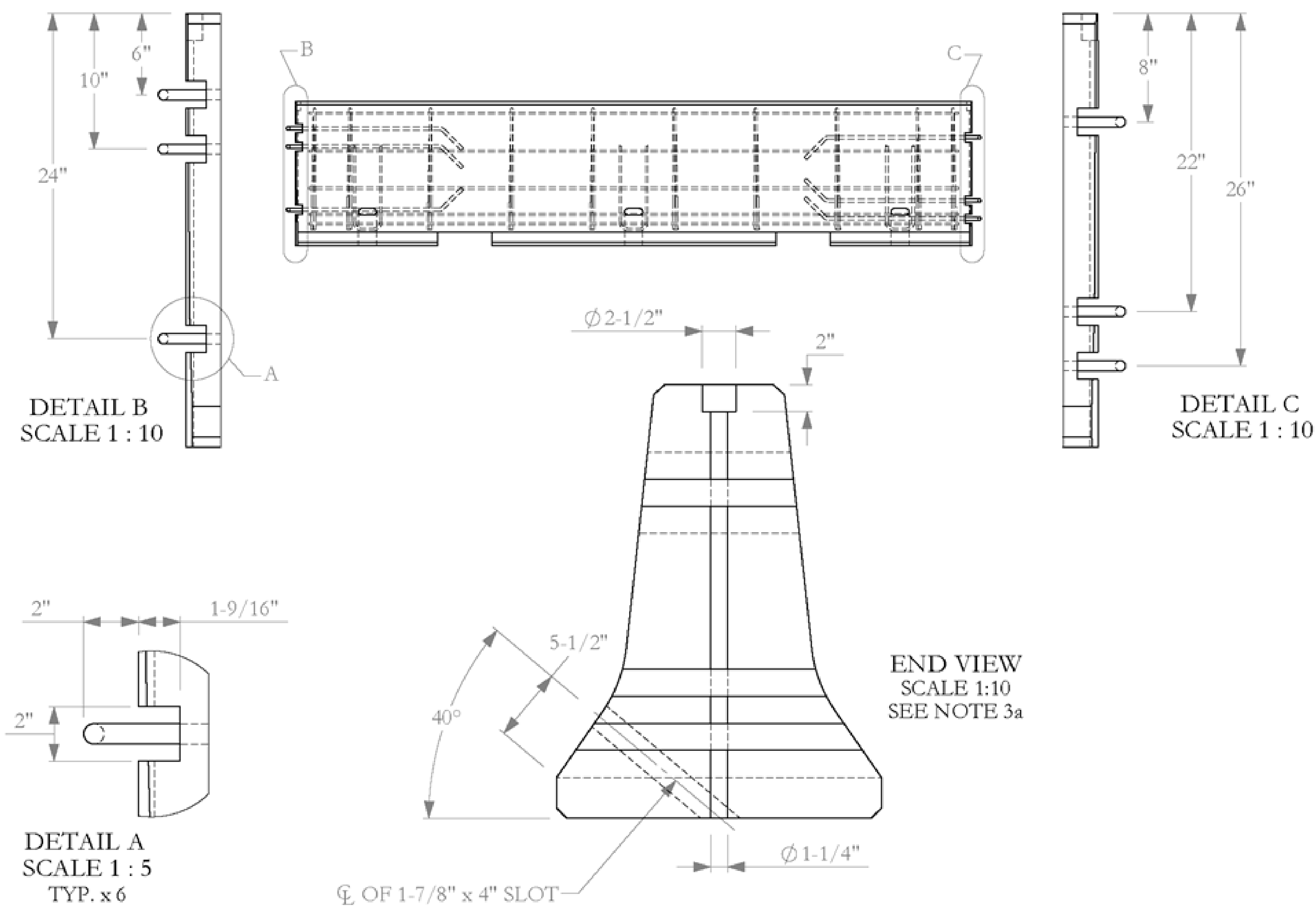
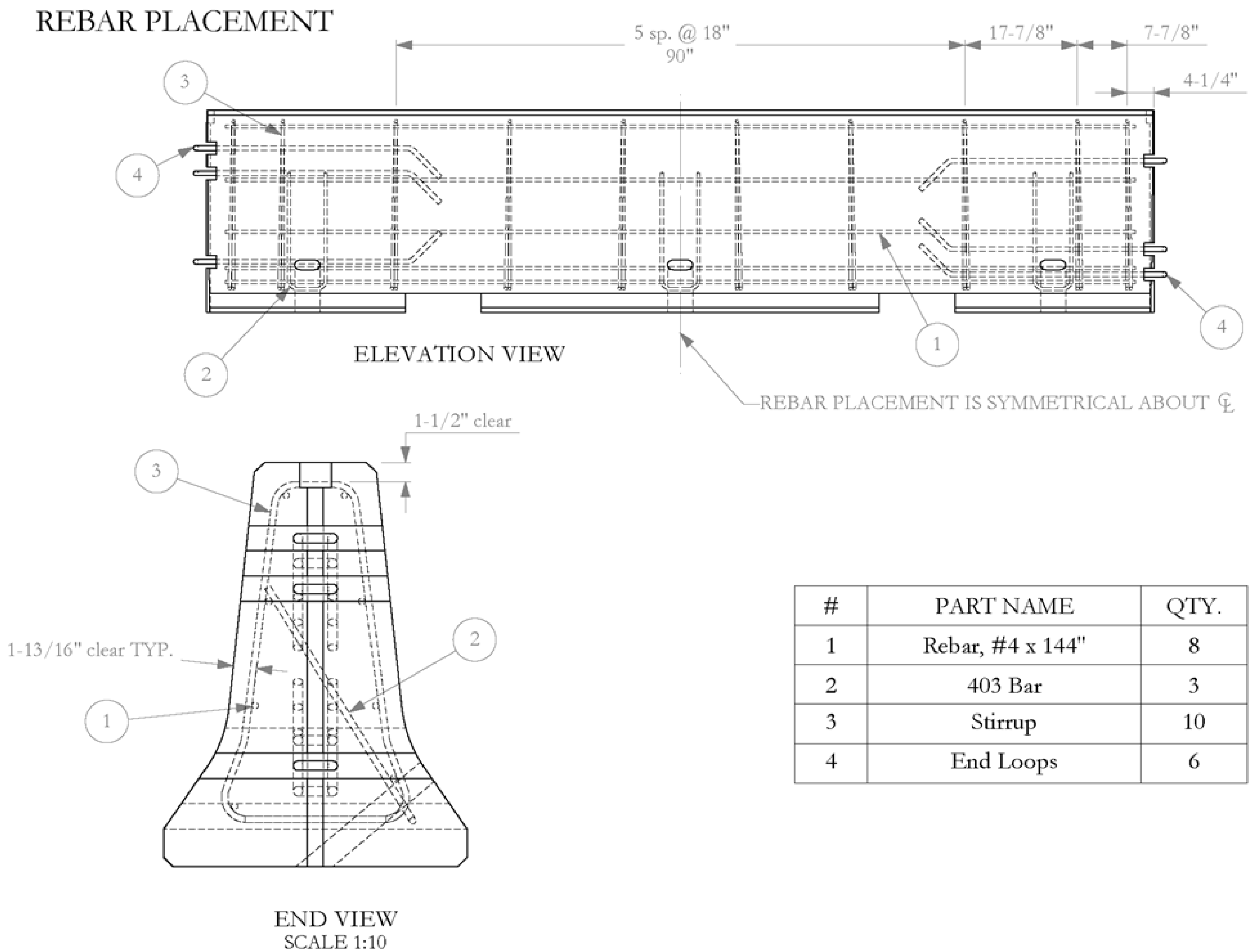


Figure 3. Design details of the pinned-down temporary concrete barrier segment.



3a. Rebar and End Loops not shown in End View for clarity.

Figure 4. Design details of the pinned-down temporary concrete barrier segment (continued).



#	PART NAME	QTY.
1	Rebar, #4 x 144"	8
2	403 Bar	3
3	Stirrup	10
4	End Loops	6

Figure 5. Design details of the pinned-down temporary concrete barrier segment (continued).

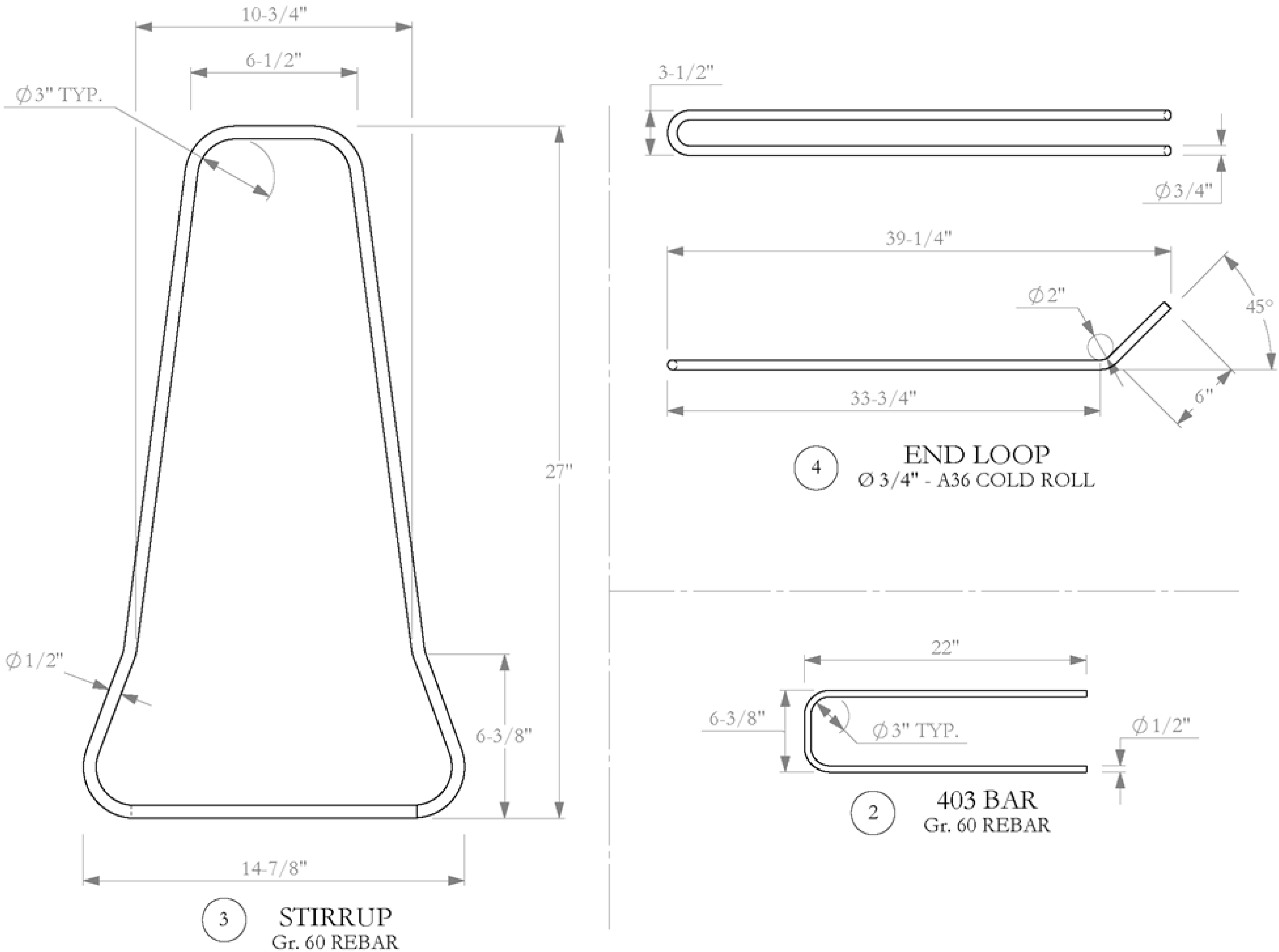
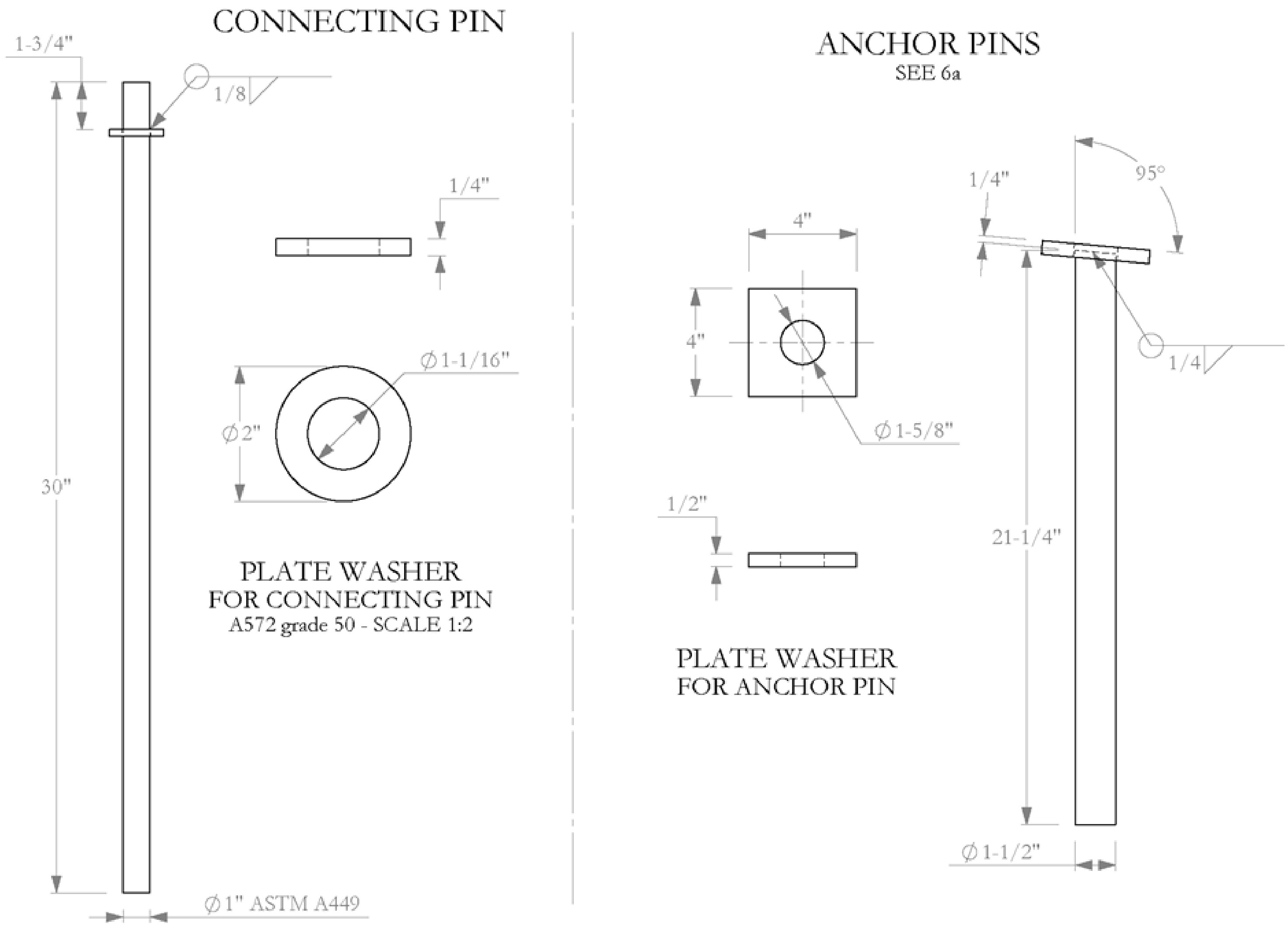


Figure 6. Design details of the pinned-down temporary concrete barrier segment (continued).



6a. All material for Anchor Pins is ASTM A36.

Figure 7. Design details of the pinned-down temporary concrete barrier segment (continued).

PINNING ON CONCRETE

For pinning on a concrete pavement or deck, the precast segments are anchored to the underlying concrete pavement or deck using two 1½-inch diameter steel pins per barrier segment.

Once the precast barrier segments are positioned in place, the slotted holes near each end of the portable concrete barrier segment are used as a guide to drill a hole in the underlying concrete pavement. These holes are drilled using a 1¾-inch diameter drill bit. After the holes are drilled, a 1½-inch diameter, 21⅜-inch long anchoring pin is passed through each of the slotted holes in the barrier (except the middle slots) and into the concrete pavement. Thus, each barrier segment is anchored to the ground with two pins.

The top of each anchoring pin has a ½-inch thick, 4-inch × 4-inch ASTM A36 steel plate cover welded to it. The plate covers are welded at a 5-degree angle from the vertical so that they matched the profile of the barrier's toe when installed. Details of the anchoring pin are shown in Figure 7.

The 21⅜-inch long anchoring pins reach a vertical depth of 6¼ inches in the concrete deck or pavement, as shown in Figure 8. Thus this system can be used with a concrete deck or pavement that is at least 7 inches thick.

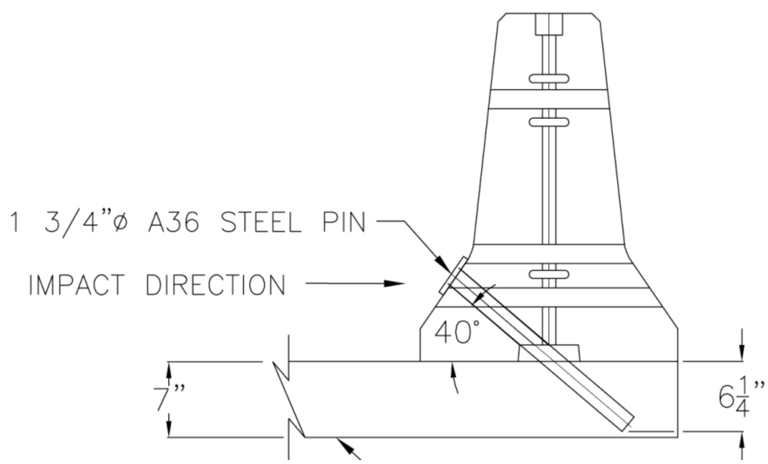


Figure 8. Pinning of temporary concrete barrier on concrete deck or pavement.

PINNING ON ASPHALT

For pinning on asphalt, the 12.5-ft precast segments are anchored to the underlying asphalt pavement using three 1½-inch diameter steel pins per barrier segment. The underlying pavement is required to be at least 4 inches thick as shown in Figure 9.

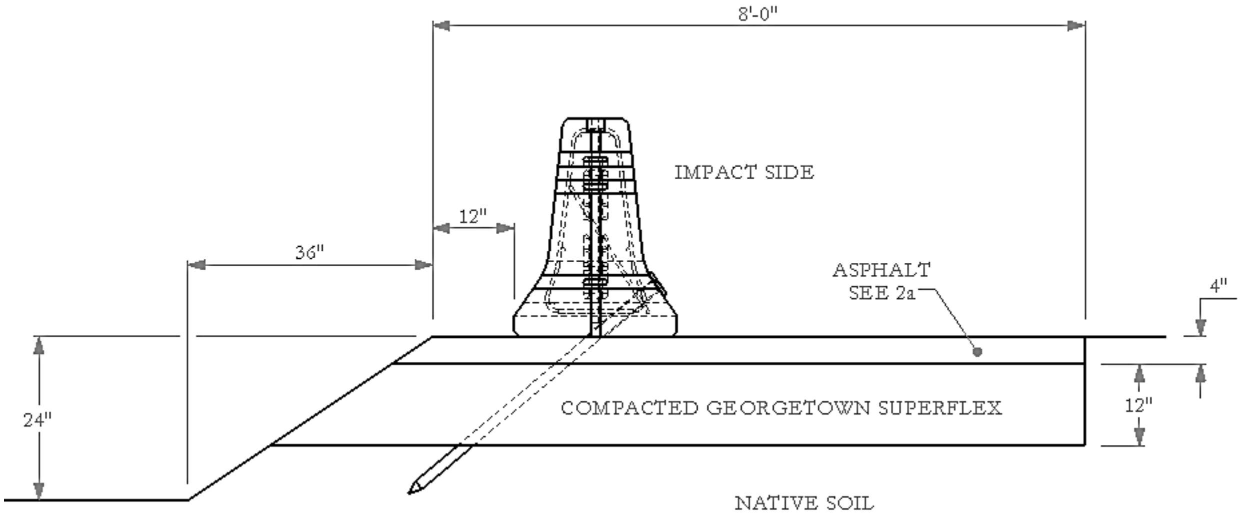


Figure 9. Pinning of temporary concrete barrier on asphalt pavement.

If the barrier segments are pinned adjacent to a slope, there should be a minimum 12-inch offset from the break point of the slope. The pinned down barriers have been tested adjacent to a 1V:1.5H slope and should not be place adjacent to steeper slopes without further evaluation through testing or simulation. In the test performed to evaluate the pinned barrier on asphalt, the asphalt pad was constructed on a 12 inch thick layer of crushed limestone road base (Type A, Grade 1), which was compacted to 95 percent of standard proctor density (more discussion on soil type presented later). A layer of asphalt binder (CSS-1H tack coat binder) was sprayed at the interface between the asphalt and soil surfaces. The asphalt used was hot mixed Type D with reclaimed asphalt pavement (RAP).

PIN INSTALLATION

To install the anchoring pins, once the barriers are positioned in place, the slotted holes in the barrier segments are used as a guide to drill pilot holes in the underlying asphalt and soil base. The pilot holes can be drilled using a 1½-inch diameter drill bit. After each pilot hole is drilled, a 1½-inch diameter, 48-inch long anchoring pin is passed through the slotted hole in the barrier and driven into the asphalt-soil base. Thus, each barrier segment is anchored to the ground with three pins. The anchoring pin is fabricated with a 2-inch tip. The top of each anchoring pin has a ½-inch thick, 4-inch × 4-inch A36 plate cover welded to it. The plate covers are welded at a 5 degree angle from the vertical so that they matched the profile of the barrier's toe when installed. Details of the anchoring pins are shown in Figure 10.

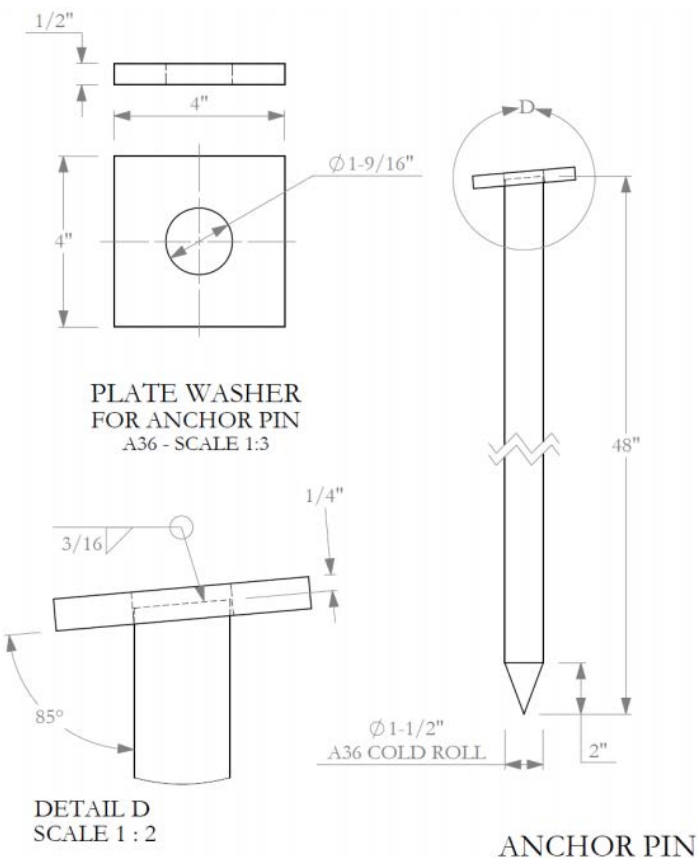


Figure 10. Anchoring pin details for installation on asphalt pavement.

MATERIALS

All rebar reinforcement is specified to grade 60 steel material. The loops for the connecting pin, the anchoring pins, and the washers welded on top of the anchoring pins are specified to be A36 steel. The connecting pin between adjacent barrier segments is specified to be A572 grade 50 steel. The specified compressive strength of the concrete for the barrier segments is 5000 psi.

CRASH TEST PERFORMANCE – PINNED ON CONCRETE

A crash test was performed in accordance with *NCHRP Report 350* testing criteria to evaluate the crash safety performance of the pinned-down barrier installed on concrete. *(2)* *NCHRP Report 350* was the prevalent roadside safety hardware evaluation criteria at the time when this test was performed. All subsequent design and testing of the pinned-down barrier system was performed using the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) evaluation criteria. *(3)* At the time of this writing, the Pooled Fund has funded a follow up Task Order to perform this test under *MASH* evaluation criteria. Following is the summary of the crash test performed.

The test installation was 100-ft long and was comprised of eight 12.5-ft F-shape barrier segments. *(4)* The barrier was installed flushed to the edge of an unreinforced concrete pavement as shown in Figure 11.

Crash Test

A 2000P vehicle (i.e. a 4,400-lb pickup truck), traveling at an impact speed of 62.7 mi/h, impacted the barrier at an angle of 25.4 degrees. The barrier successfully contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation.

Maximum dynamic and static deflections of the barrier during the test were 11.5 inches and 5.8 inches, respectively. Although the barrier sustained some damage that would require repair, there were no detached elements, fragments, or other debris to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area. The damage to the barrier is shown in Figure 12.

The drop pins adjacent to the impact joint were deformed as shown in the Figure 13, but none of the pins pulled out of the concrete pavement due to the impact. Other than the drop-pins adjacent to the impact joint, none of the pins were deformed. There was no significant damage caused to the unreinforced concrete pavement due to the impact. The damage to the drilled holes in the concrete pavement near the joint of impact is shown in the Figure 14.

Maximum occupant compartment deformation of the vehicle was 1.1 inches. The vehicle remained upright during and after the collision event. Maximum vehicle roll angle was 41 degrees. Occupant risk factors were within the limits specified in *NCHRP Report 350*. The maximum occupant impact velocity (OIV) was 20.3 ft/s and the maximum ride-down acceleration was 6.4 g.

The 12.5-ft pinned F-shape temporary barrier performed acceptably according to the requirements of *NCHRP Report 350*.

The concrete barrier design used in this first test was slightly different than described previously. Instead of the inclined 1⅞-inch wide and 4-inch long slotted holes, it had 1⅞-inch diameter holes. These were changed to slotted holes in later tests to allow some longitudinal field tolerance for installing anchoring pins on reinforced bridge decks. This change however had no significant impact on the performance of the barrier.

Figure 11. Test installation of the pinned-down barrier on concrete.

Figure 12. Barrier deflection and damage after the crash test.

Figure 13. Anchoring pins after the test.

Figure 14. Holes in the underlying concrete pavement after the test.

CRASH TEST PERFORMANCE – PINNED ON ASPHALT

Due to the differences in the material strength of the concrete and asphalt pavements, the pinned-down barrier was evaluated for the placement on asphalt. When placed on asphalt, some key design differences in comparison to placement on concrete are as follows.

- A minimum asphalt thickness of 4 inches is required for pinning on asphalt. The underlying roadbase or soil should be well compacted to allow construction and compaction of the asphalt pad on top.
- For pinning the barrier on asphalt, three pins are used for each 12.5-ft barrier segment as opposed to two pins per segment used for pinning on concrete.
- The installation pinned on concrete can be installed at the edge of a concrete pavement or deck with no offset. However, when pinned on asphalt adjacent to a steep slope, there needs to be a minimum 1-ft offset from the slope.
- When installed on asphalt, the length of the steel pins is longer than the installation on concrete.

Crash Test

A 151-ft test installation comprising of 12 barrier segments, connected using pin-and-loop connections, was built for *MASH* test level 3 testing. The barrier was placed adjacent to a 1.5H:1V slope at a lateral offset of 1 ft. from the slope break point. The barrier was anchored using three 1½-inch diameter steel pins per barrier segment. Photos of the test installation are shown in Figure 15 and Figure 16. Detailed drawings of the test installation and crash testing results are available in the full report. *(5)* A summary of the results is presented next.

MASH test 3-11 was performed with a 2005 Dodge Ram 1500 pickup impacting the barrier at an impact speed and angle of 62.2 mi/h and 24.8 degrees, respectively. The pinned-down barrier contained and redirected the test vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 17.8 inches. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was ¾ inch in the lateral area across the cab at passenger hip height. The pickup truck remained upright during and after the collision event. Maximum roll and pitch angles were 17 and 20 degrees, respectively. The occupant risk factors were below the preferred values specified in *MASH*. The pinned down anchored barrier design met *MASH* test level 3 criteria.

Damage to the barrier is shown in Figure 17 and Figure 18. Most of the barrier segments were undamaged and could be reused. Maximum damage to the barrier system occurred at the joint of vehicle impact as shown in the figure. The maximum dynamic and static deflections of the barrier system were 17.8 inches and 17 inches, respectively.

Figure 15. Pinned barrier installation on 4-inch asphalt past adjacent to a roadside slope.

Figure 16. Test installation before test.

Figure 17. Pinned barrier installed on asphalt after *MASH* test 3-11.

Figure 18. Barrier deflection and damage after full-scale crash testing.

TRANSITIONS

Several transitions were developed to connect the pinned-down concrete barrier system to free-standing and rigid barrier systems. These transitions were developed for the temporary concrete barrier placed on concrete and asphalt. While the key design features of the transitions are the same, there are some minor differences when placed on concrete versus asphalt (discussed later).

For all transition designs, same barrier segment design and connection details were used. Thus a key advantage of using this system is that only one barrier design needs to be maintained in the inventory. Same concrete barrier segment can be used for free-standing, pinned, or transition applications.

Details of the transition design and results of the full scale testing are presented next.

TRANSITION FROM FREE-STANDING TO PINNED-DOWN BARRIER

Two similar transition designs were developed to connect the pinned-down barrier to free-standing barrier system. One of these was developed for the pinned-down barrier placed on concrete, and the other one was developed for the pinned-down barrier pinned on asphalt. Both of these transitions were tested in accordance with *MASH* test level 3 criteria, using the F-shape pinned-down TCB design described earlier.

Transition Concept

The transition comprised of a single F-shape barrier segment that connected the freestanding and the pinned-down barrier segments, as shown in Figure 19. The design of the transition segment was kept the same as the fully pinned and free-standing segments. Only one pin was used in the transition segment to pin it to the underlying surface near the anchored barrier end of the installation. The transition for anchored barrier placed on asphalt is the same as the transition on concrete, except that it uses the longer anchoring pin, as shown in Figure 19.

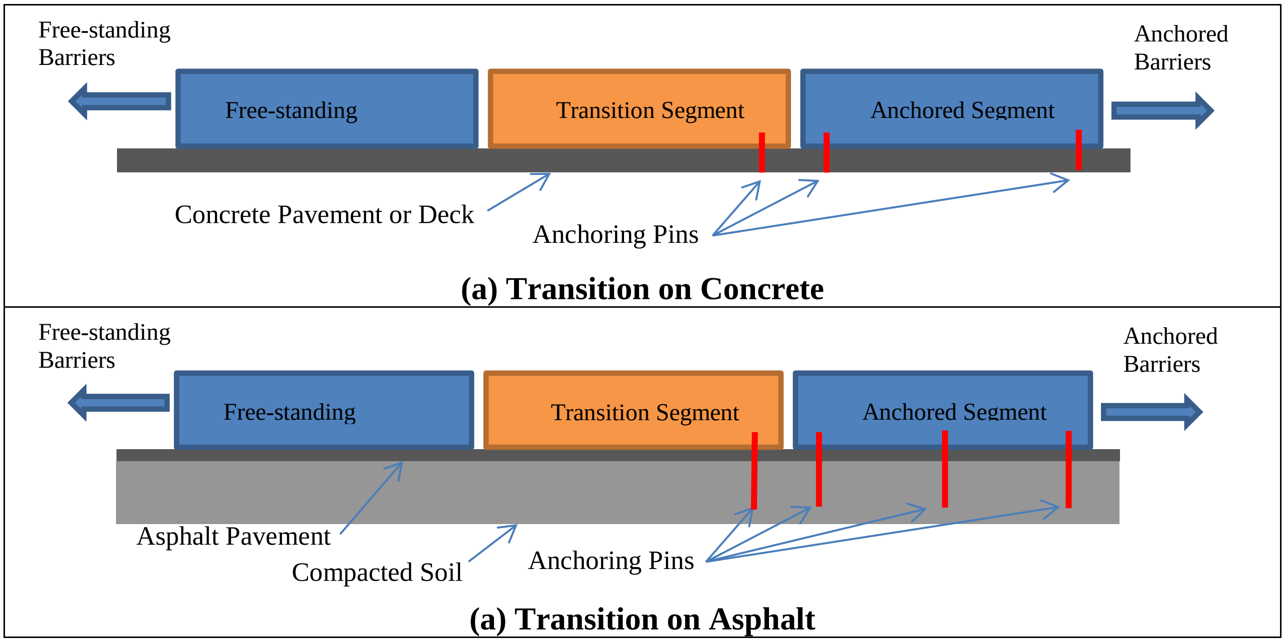


Figure 19. Transition from free-standing to pinned down barrier installed on (a) concrete and (b) asphalt.

Crash Test of Transition Pinned on Concrete

Test 3-21 of *MASH* (5000-lb pickup, 62 mi/h, 25 degrees) was performed to evaluate the performance of the transition design on concrete. Test installation setup and photos are shown in Figure 20. Detailed drawings of the test installation and crash testing results are available in the full report. *(6)* A summary of the results is presented next.

The overall length of the test installation was 201 ft-3 inches. The installation was comprised of sixteen 12 ft-6 inches long precast concrete barrier segments that were 32 inches tall and had the standard “F” profile. The first eight segments (1 to 8) were freestanding and were not anchored to the underlying concrete pavement. Barrier segment 9 was pinned to the underlying concrete pavement using a single 1½ inch diameter steel pin near the downstream end of the segment. Segments 12 through 16 were pinned using two 1½-inch diameter steel pins per barrier segment. The barriers were placed on an unreinforced concrete pavement that was nominally 6 to 8 inches thick.

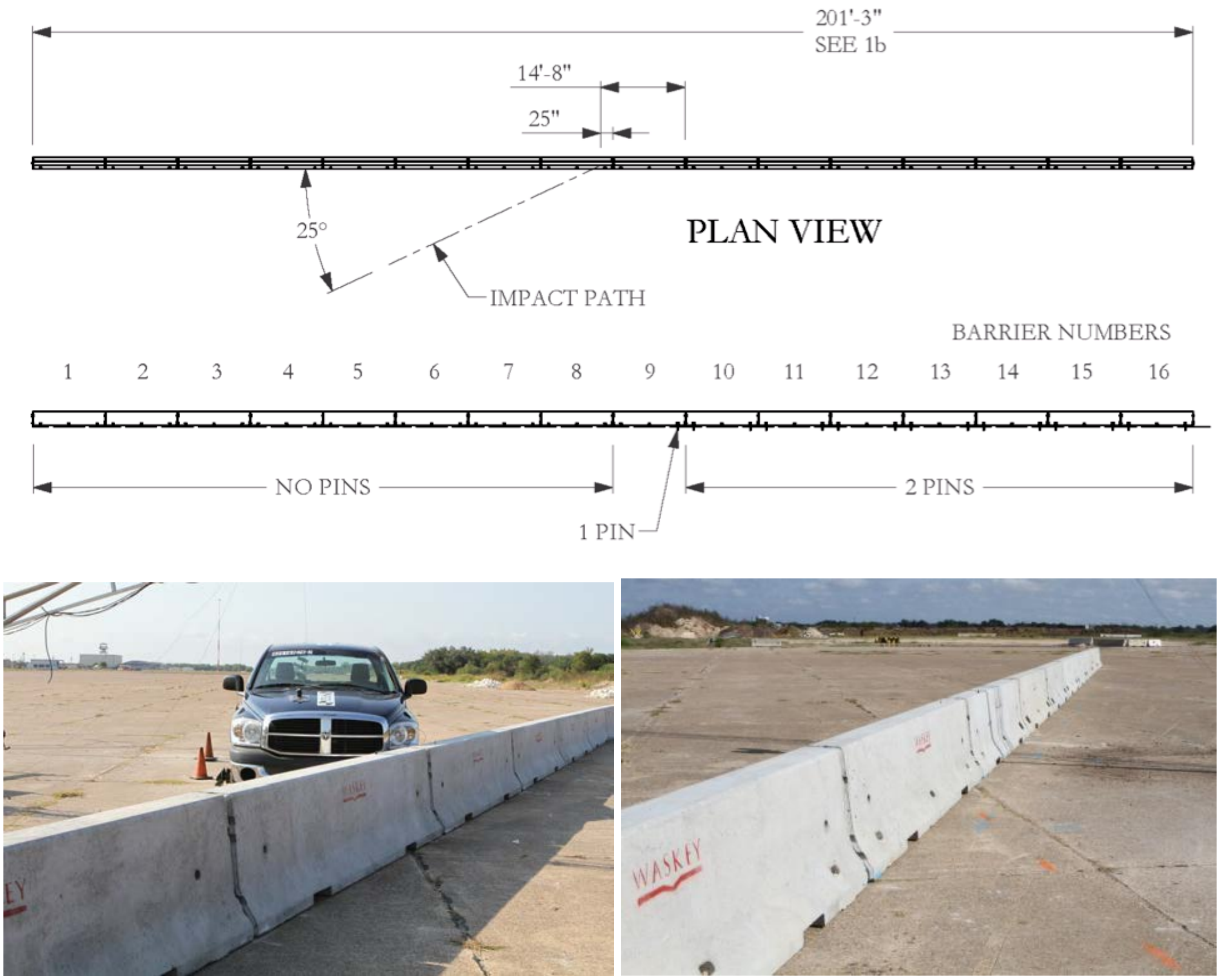


Figure 20. Test installation of free-standing to pinned-down concrete barrier transition installed on concrete pavement.

The detailed design of the precast F-shape barrier segments, the connection between adjacent segments, and the drop pins used to anchor the pinned-down barrier segments were the same as described for the test with the pinned-down TCB system. The change in the barrier design was that the 1⅞-inch diameter inclined holes used to pass the drop pins were changed to 1⅞-inch wide and 4-inch long slotted holes. The inclined holes/slots are used as guides to drill a hole in the underlying concrete deck or pavement for receiving the drop pin. The slotted holes provide some longitudinal tolerance for installation of the anchoring pins on reinforced concrete decks where it can help in missing a rebar.

Figure 21 shows the deflection of the barrier due to the vehicle impact. Moderate concrete damage occurred at the adjacent ends of segments 8 and 9, and significant damage occurred to the adjacent ends of barrier segments 9 and 10. Other than these segments, no damage occurred in concrete barrier segments.

(Installation After Test)

(Joint 8-9)

(Joint 9-10)

Figure 21. Test installation after crash testing.

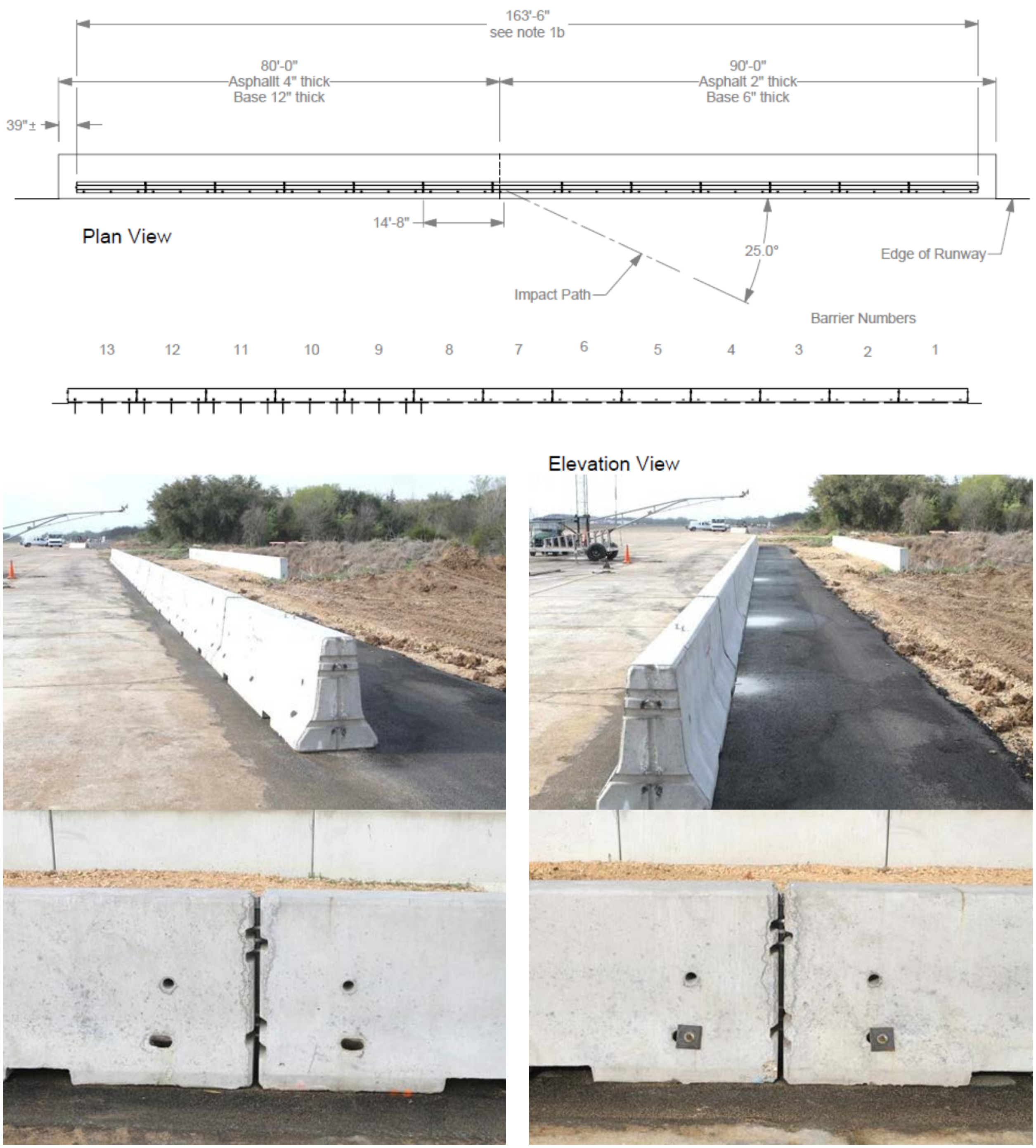
The maximum dynamic and permanent deflections were 3.9 ft and 3.7 ft, respectively. Maximum occupant compartment deformation was 1.5 inches in the lateral area across the cab at hip height. The occupant impact velocity in the longitudinal direction was 13.4 ft/s and the ridedown acceleration was 5.7 g. In the lateral direction, the occupant impact velocity was 19.4 ft/s and the ridedown acceleration was 13.3 g. All occupant risk values were within the *MASH* thresholds. The vehicle was redirected in a stable manner and the freestanding to pinned-down TCB transition design performed acceptably under *MASH* testing criteria. More details about the test installation and the crash testing can be found in the test report. *(6)*

Crash Test of Transition Pinned on Asphalt

Test 3-21 of *MASH* (5000-lb pickup, 62 mi/h, 25 degrees) was performed to evaluate the performance of the transition design on asphalt. Test installation setup and photos are shown in Figure 22. Detailed drawings of the test installation and crash testing results are available in the full report. *(7)* An overview of the test installation and a summary of the test results is presented next.

The overall length of the test installation was 163 ft-6 inches. The installation was comprised of thirteen 12 ft-6 inch long precast concrete barrier segments that were 32 inches tall and had the standard "F" profile. The first seven barrier segments (1 to 7) were free-standing and were not anchored to the underlying asphalt pavement. Barrier segment 8 was pinned to the underlying asphalt pavement using a single 1½ inch diameter, 48-inch long steel pin that passed through the inclined slotted hole near the downstream end of the segment. Segments 9 through 13 were pinned using three 1½-inch diameter, 48-inch long steel pins per barrier segment. These pins were passed through the inclined slotted holes in the barrier and driven into the asphalt-soil base. The anchoring pin was fabricated with a 2-inch long tapered tip.

The barriers were placed on flat level ground. The underlying ground was comprised of 170-ft long, and 8-ft wide asphalt pad constructed on top of a layer of crushed limestone road base (Type A, Grade 1), which was compacted to 95 percent of standard proctor density. The anchored barriers were pinned to a 4-inch thick asphalt layer (whose total length was 80 ft) on top of a 12-inch thick layer of crushed limestone road base, while the free standing barriers were positioned on a 2-inch thick asphalt layer (whose total length was 90 ft) on top of a 6-inch thick layer of crushed limestone road base. A layer of asphalt binder (CSS-1H tack coat binder) was sprayed at the interface between the asphalt and soil surfaces. The asphalt used was hot mixed Type D with reclaimed asphalt pavement (RAP).



Unpinned Pinned-Down

Figure 22. Test installation of transition from free standing to pinned-down temporary concrete barrier installed on asphalt pavement.

Damage to the barrier installation due to the test vehicle impact is shown in Figure 23. Minimal spalling of the concrete segments occurred at the joint between segments 7 and 8. Working width was 44.2 inches, and vehicle intrusion was 31.1 inches. Maximum dynamic deflection during the test was 34.2 inches and maximum permanent deformation was 33.0 inches.

Figure 23. Test installation after full-scale crash testing.

The transition from the free-standing F-shape barrier to pinned F-shape barrier placed on asphalt contained and redirected the test vehicle. The vehicle did not penetrate, underride, or override the installation. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. The test vehicle remained upright during and after the collision event. Occupant risk factors were within preferred limits specified in *MASH*. The transition design performed acceptably under *MASH* testing criteria. More details about the test installation and the crash testing can be found in the test report.

TRANSITION FROM PINNED-DOWN TO RIGID BARRIER

A transition design was developed to connect the pinned-down TCB to a rigid concrete barrier. The simplest case would have been to connect to a permanent F-shape rigid concrete barrier due the same height and profile as the pinned-down TCB. However, to allow greatest flexibility in the use of the pinned barrier system, a worse-case rigid barrier design was picked for designing the transition. This worst-case scenario was determined to be when the pinned-down 32-inch tall F-shape TCB is connected to a 42-inch tall rigid single slope barrier. This scenario presented the greatest potential for vehicle snagging for an errant vehicle. The transition was designed to allow a smooth transition in the barrier profile and height, along with the lateral stiffness of the two barrier systems. Since this transition design was developed for a worst-case scenario, it can be adapted to less critical connections scenarios with minor modifications. Examples of these scenarios are connecting the pinned-down TCB to a rigid F-shape or New Jersey barrier.

Design Details and Crash Test of Transition on Concrete

The transition was comprised of the pinned-down F-shape TCB placed adjacent to the 42-inch tall single slope barrier. To accommodate the 10-inch difference in barrier height while transitioning from the 32-inch tall F-shape barrier to the 42-inch tall single slope barrier, a cap with a tapered profile was bolted to the top of the F-shape and the single slope barriers. On the traffic side, a nested thrie beam cover was bolted to the F-shape concrete barrier segment and the rigid single slope barrier using the standard thrie beam end shoes. This cover was intended to provide a smoother transitioning surface during the change in the barrier profiles from F-shape to single slope. It was also used to establish a connection between the rigid and the pinned-down barriers. On the field side, a steel plate was bolted to the F-shape and the single slope barriers.

Test installation setup and photos are shown in Figure 24 for the pinned barrier installed on concrete. Detailed drawings of the test installation and crash testing results are available in the full report. *(8)* A summary of the results is presented next.

The overall length of the test installation was 104 ft-6 inches. The installation was comprised of seven 12 ft-6 inch long pinned-down TCB segments that had the standard “F” profile. The detailed design of the pinned-down segments, the connection between adjacent segments, and the drop pins used to anchor the pinned-down barrier segments were the same as in the test of free-standing to pinned-down transition. The downstream end of the pinned-down barrier installation was connected to a 16 ft long and 42 inches tall permanent single slope concrete barrier with an 11-degree slope of the barrier’s traffic-side face.

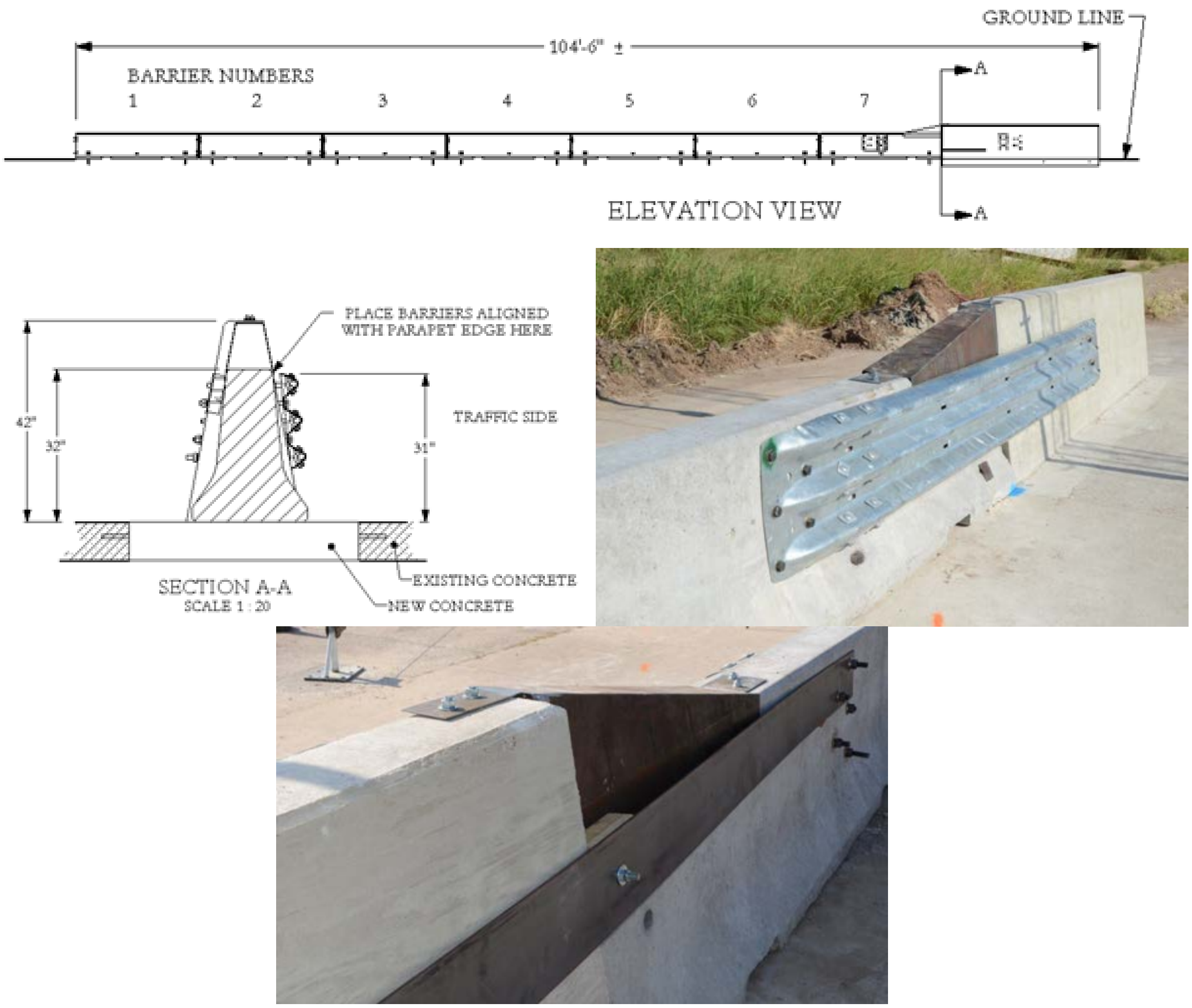


Figure 24. Design and test installation on transition from pinned-down to permanent concrete barrier.

The connection loops on the downstream end of the pinned-down F-shape barrier segment placed adjacent to the permanent single slope barrier were cut off. This allowed placing the pinned-down F-shape barrier segment flush to the rigid single slope barrier. The connection between the F-shape barrier and the single slope barrier was established using nested 12-gauge thrie beam guardrails. At one end, the nested thrie beam guardrails were connected to the traffic-side face of the F-shape barrier segment, and at the other end, the guardrails were connected to the traffic-side face of the single slope barrier. The connection to the barrier was made using a 10-gauge thrie beam end-shoe and five ⅞-inch diameter, ASTM A325 bolts that passed through the cross-section of the barrier and were fastened using heavy hex nuts on the field side of the barriers.

On the field side of the barriers, a ¼-inch thick and 16.33 ft long ASTM A36 steel plate was fastened to barriers using the top two through-bolts used to connect the thrie beam end-shoes. An 8-inch × 8-inch × 2½-inch wood block spacer was attached to the ¼-inch steel plate near the end of the pinned-down F-shape segment placed adjacent to the single slope barrier. The wood block spacer was attached to the steel plate using a ⅝-inch diameter carriage bolt that was bolted with a hex nut on the field side of the steel plate. The ¼-inch steel plate and the wood spacer were used to reduce slack near the top of the F-shape and the single slope barrier profiles, thus providing additional resistance to the lateral roll of the pinned-down F-shape barrier during vehicle redirection.

A transition cap made of 1/8 inch thick ASTM A36 steel was attached to the top of the F-shape and single slope barriers. The transition cap ramped 10 inches over a length of 48 inches to transition from the 32-inch tall F-shape barrier to the 42-inch tall single slope barrier.

The 42-inch tall permanent single slope barrier was 16 ft long, 24 inches wide at the base, and 8 inches wide at the top. The barrier had an 11-degree slope of the traffic and field sides.

Test 3-21 of *MASH* (5000-lb pickup, 62 mi/h, 25 degrees) was performed to evaluate the performance of the transition design on concrete. The thrie beam guardrail element was deformed in the area of impact. Maximum permanent and dynamic deflections during the test were 2.5 inches and 5.7 inches, respectively. Barrier damage during the test is shown in Figure 25. The longitudinal OIV was 22.6 ft/s and the ridedown acceleration was 3.6 Gs. The lateral OIV was 28.2 ft/sand the ridedown acceleration was 10.4 Gs. The vehicle was successfully contained and redirected in smooth manner.

The performance of the transition was deemed acceptable under *MASH* testing criteria.

Figure 25. Transition test installation after crash testing.

Design Details and Crash Test of Transition on Asphalt

For the pinned-down barrier installed on asphalt transitioning to a rigid single slope concrete barrier, the details of the transition were the same as used with the pinned-down barrier installed on concrete. Previously discussed design differences between the TCB pinned on concrete versus TCB pinned on asphalt, such as the number of pins per segment, etc. were the primary differences between the two installations. Thus, for the transition of the pinned-down barrier installed on asphalt, three pins per segment were used. The pinned barrier was installed on 4-inch thick asphalt pad that was constructed over compacted crushed limestone roadbase. Similarly, the pins were longer compared to the barrier pinned on concrete.

Key details of the transition for pinned-down on asphalt to rigid single-slope barrier are presented in Figure 26. Figure 27 shows the test installation prior to testing. Detailed drawings of the test installation and crash testing results are available in the full report. *(9)*

In the test, the transition contained and redirected the test vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 4.0 inches. Damage to the test installation is shown in Figure 28. No detached elements, fragments, or other debris from the transition were present to penetrate or show potential for penetrating or present undue hazard to others in the area. The test vehicle remained upright during and after the collision. The transition from temporary concrete barrier pinned on asphalt to rigid concrete barrier performed acceptably according to the evaluation criteria for *MASH* Test 3-21.

In the two crash tests performed for the pinned-down to rigid barrier transition, a ¼-inch thick, 8-inch wide, and 16.33-ft long steel plate was bolted on the field side of the barrier using two of the bolts of the nested thrie beam end shoes. If desired, this steel plate may be replaced with a thrie beam or a W-beam section. Doing so does not reduce the strength or lateral stiffness of the transition connection. The W-beam or the thrie beam section replacing the field side plate can be attached using existing bolts, or additional epoxy anchor bolts. As in the crash tested design, the attachment at each end of the W-beam or the thrie beam section should be made with at least two bolts.

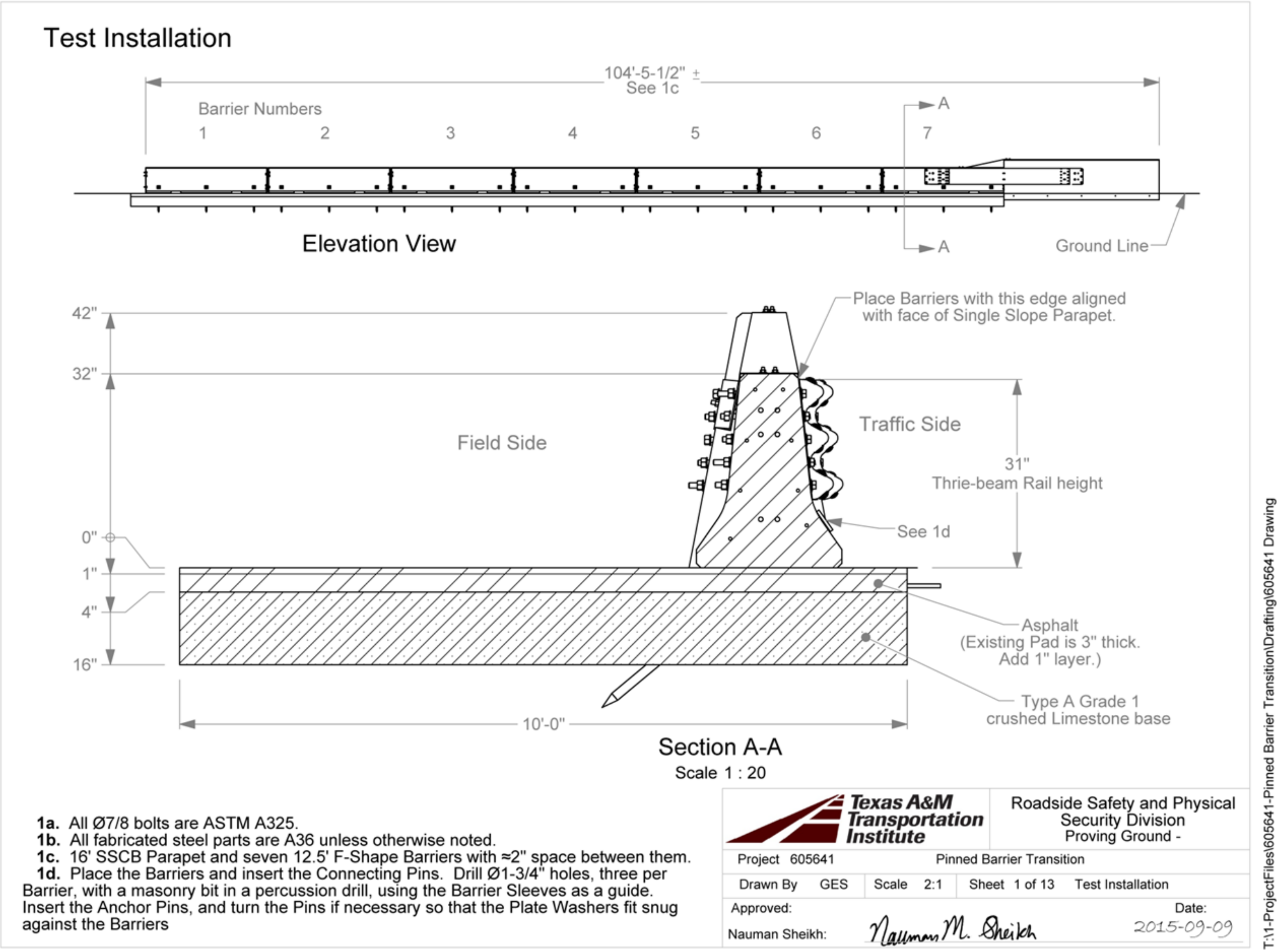


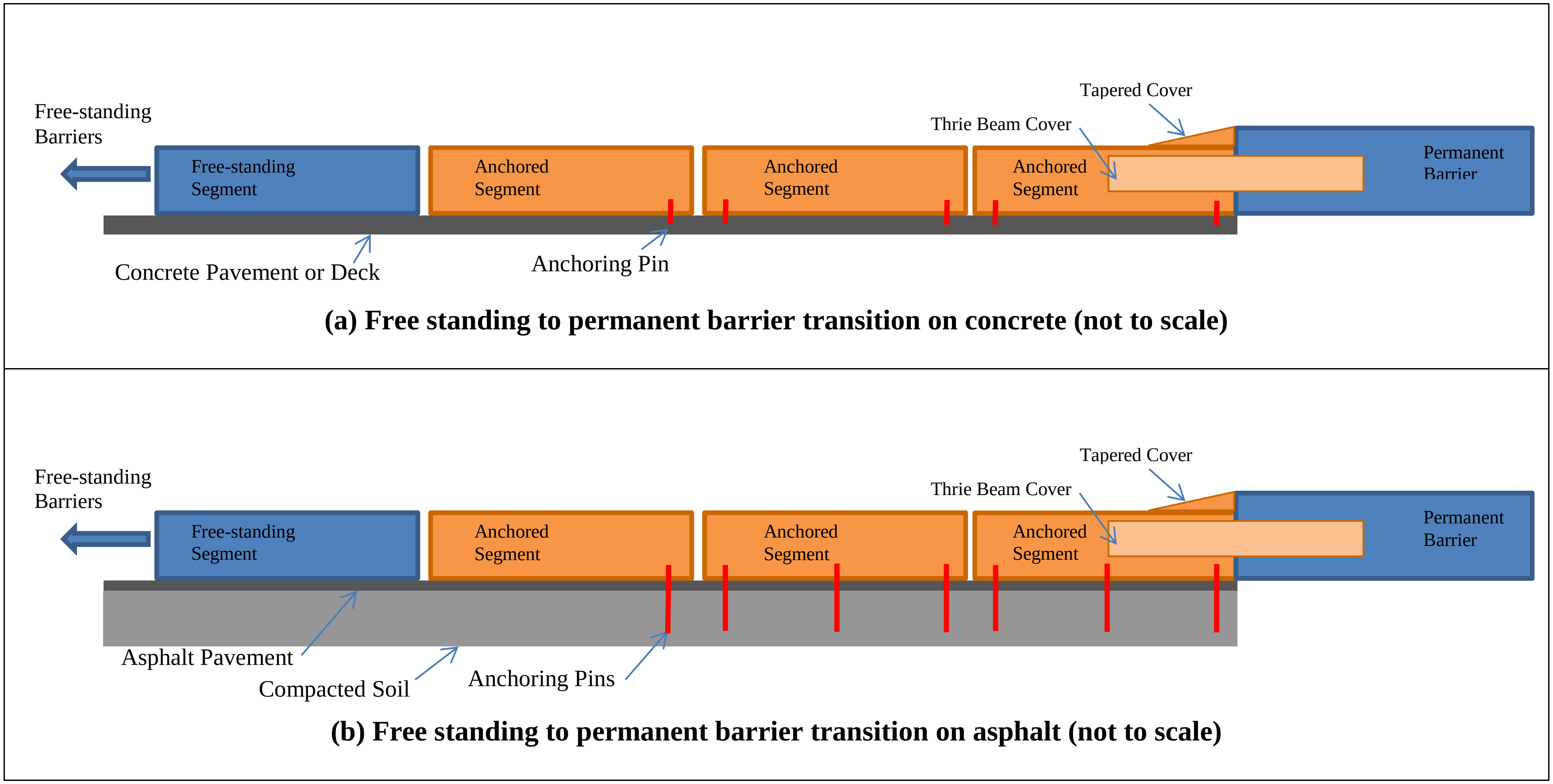
Figure 26. Design and layout of the transition from pinned-down to permanent concrete barrier.

Figure 27. Installation of transition from pinned-down to permanent single slope concrete barrier.

Figure 28. Test installation after full-scale crash testing.

TRANSITION FROM FREE-STANDING TO RIGID BARRIER

Transitions from free-standing to permanent barrier are shown in **Error! Reference source not found.**. Details are shown for barriers pinned to asphalt and to concrete. These transition details were developed using the results of the crash tests performed for free-standing to pinned-down barrier transition and for pinned-down to permanent barrier transition described previously.



(a) Free standing to permanent barrier transition on concrete (not to scale)

(b) Free standing to permanent barrier transition on asphalt (not to scale)

Figure 29. Transition from free standing temporary concrete barrier to permanent single slope barrier; (a) on concrete; (b) on asphalt.

TRANSITION TO RIGID BARRIERS OF OTHER TYPES

The crash test of the transition to permanent barrier used a 42-inch tall single slope barrier as the rigid concrete barrier. However, this transition design can also be used with other common rigid concrete barrier profiles, such as the New Jersey profile, F-shape profile, vertical wall, etc. When using a different rigid concrete barrier profile, the pinned-down F-shape barrier should be placed adjacent to the rigid barrier in a position that minimizes the potential for vehicle snagging. The nested thrie beam should then be used to provide a smooth transition surface over the pinned-down and rigid barrier interface, as tested herein with the single slope rigid concrete barrier. The steel transition cap used in this crash test for transitioning over the 10-inch difference in the barrier heights (i.e. from 32-inch F-shape to 42-inch single slope) can be modified to accommodate variations in heights of other rigid barrier types. So for instance, no transition cap will be required in transitioning from the 32-inch tall pinned-down F-shape to 32-inch tall rigid New Jersey or F-shape barriers. If however a 36-inch tall rigid barrier is used, the slope of the transition cap should be adjusted accordingly to accommodate the 4-inch height difference. In making modifications to the transition cap, the length of the transition cap should not be reduced.

USE IN MEDIANS

The pinned-down barrier design may be used in median applications (with the exception of transitions) by pinning the barrier on both sides with additional pins per segment. For barrier pinned on concrete, four pins would be needed per segment, two on each side of the barrier. Similarly, for barrier pinned on asphalt, six pins would be needed, three on each side of the barrier. It should be noted that all transitions of the pinned-down barrier were developed for roadside application. Pinning on both sides of the barrier, as in a median application, can change the strength characteristics of the transition significantly. Thus median applications are restricted to length-of-need sections of the pinned-down barrier until further testing.

A detail of the pinned-down barrier with slotted holes on both sides of the barrier was developed under the pooled fund program. Figure 30 shows the basic layout for this barrier segment and further design details can be downloaded from the Pooled Fund's website. *(10)* This detail allows for pinning the barrier on either side without the need of rotating the barrier segments if pinning is required on opposite sides. This design can also be used for median barrier applications described above where pinning is required on both sides.

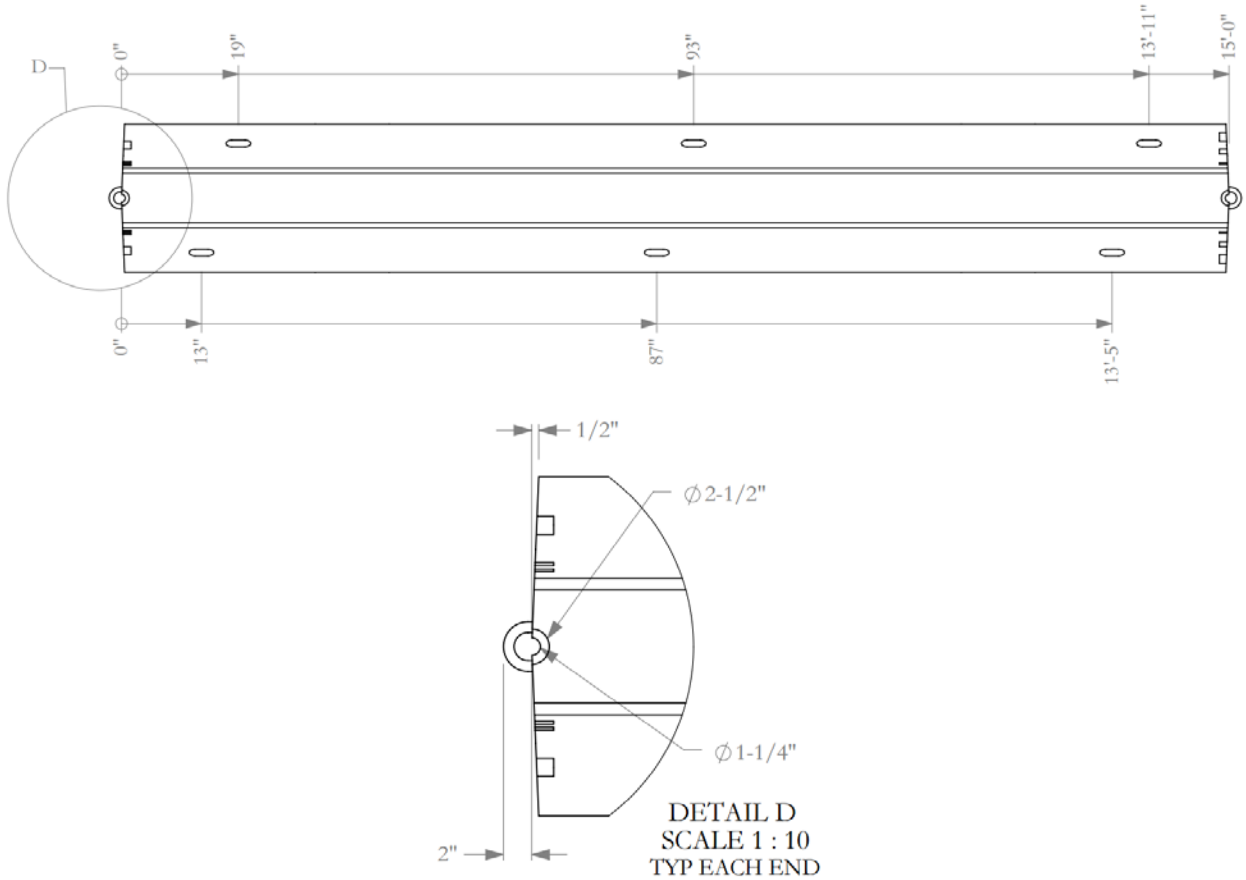


Figure 30. Design of the temporary concrete barrier with pinning holes on both sides.

VARIATION IN SEGMENT LENGTHS

The design of the pinned-down barrier was developed with a segment length of 12.5 ft as it was the most commonly used segment length among the pooled-fund states, and because it was the shortest segment length used by the states. This pinning scheme, however, can be used with larger segment lengths, such that on concrete, two (2) anchoring pins per segment are used for up to 15-ft segment length, and three (3) anchoring pins per segment are used for 20-ft long segments. When pinning on asphalt, three (3) anchoring pins per segment are used for up to 15-ft segment length, and four (4) anchoring pins per segment are used for 20-ft segments.

CONNECTION TYPE CHANGES

The pin-and-loop connection used for connecting adjacent barriers should be kept the same as used in the crash tests described herein. Use of a different connection can result in adverse performance of the design.

SUMMARY AND CONCLUSIONS

The pinned-down temporary concrete barrier system for limited space applications was developed under various projects funded by the roadside safety pooled fund program. The TCB system is easy to install, inspect, and remove or relocate. It minimizes damage to the underlying bridge deck or concrete pavements. The mechanism uses the pinned-down approach to restrain the barriers. Various transitions of the system for free-standing to pinned-down, and pinned-down to permanent barrier were developed for placement of the system on both concrete and asphalt.

For ease of implementation, this guidebook presents key design details of the barrier system and its transitions, summary of the crash testing performed, and results of those tests. These are also summarized in Table 1. Some issues related to implementation and use of the barrier system and its transitions are also discussed. For more information on each of the tests and design details, references are provided in this guidebook.

Table 1. Summary of various pinned-down barrier configurations tested and key test results.

Surface	System	Transition From	Transition To	Maximum Dynamic Deflection (in.)	Permanent Deflection (in.)	Key Features	Test Report(s)
Concrete (minimum 7-inch thick, reinforced or unreinfirced)	Pinned-Down F-shape TCB on Concrete	N/A	N/A	11.5	5.8	12.5-ft F-shape segments. Two pins per segment used for pinning. Minimum 7-inch concrete pavement or deck needed	405160-3
	Transition from Free-standing to Pinned TCB on Concrete	Free-standing F-shape TCB	Pinned-down F-shape TCB	46.8	44.4	One transition segment needed with only one pin.	405160-26
	Transition from F-shape TCB pinned on concrete to Permanent Single Slope Barrier	Pinned-down F-shape TCB on Concrete	42-inch Tall Rigid Single Slope Concrete Barrier	5.7	2.5	Connection with nested thrie beam cover on traffic side and a steel plate on back side of barrier. Vertical transition cap used for height difference	405160-34
Asphalt (minimum 4-inch thick)	Pinned-Down F-shape TCB on Asphalt	N/A	N/A	17.8	17	12.5-ft F-shape segments. Three pins per segment used for pinning. Minimum 4-inch asphalt thickness needed	405160-25-1
	Transition from Free-standing to Pinned TCB on Asphalt	Free-standing F-shape TCB	Pinned-down F-shape TCB	34.2	33	One transition segment needed with only one pin.	601651-1
	Transition from F-shape TCB pinned on asphalt to Permanent Single Slope Barrier	Pinned-down F-shape TCB on Asphalt	42-inch Tall Rigid Single Slope Concrete Barrier	4	1.5	Connection with nested thrie beam cover on traffic side and a steel plate on back side of barrier. Vertical transition cap used for height difference	605641-1

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