

# **SYNTHESIS OF CRASH TESTED PRECAST CONCRETE BARRIER DESIGNS AND ANCHORING SYSTEMS**

*Requested by:*

American Association of State Highway  
and Transportation Officials (AASHTO)

Technical Committee on Roadside safety

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#### Arkansas

TC-4	Temporary Precast Barrier
TC-5	Temporary Precast Barrier

<b><u>State</u></b>	<b><u>Drawing Number</u></b>	<b><u>Drawing Title</u></b>
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Colorado		
	M-606-14 Sheets 1-3	Precast Type 7 Concrete Barrier
Connecticut		
	821-A	Precast Concrete Barrier Curb
	HW-822-01	Temporary Precast Concrete Barrier Curb
Delaware		Permits any approved NCHRP 350 concrete barrier for temporary use
Florida		
	412 Sheets 1-5	Low Profile Barrier
	414 Sheets 1-15	Type K Temporary Concrete Barrier System
Georgia		
	4961	Details of Precast Temporary Barriers
Hawaii		
	00 Sheets 1-2	Portable Concrete Barrier
Idaho		
	G-2-A-1 Sheets 1-2	20' Concrete Barrier
	G-2-A-2 Sheets 1-2	10' Concrete Barrier
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	E 801-TCCB-01	Temporary Concrete Barrier Dimensions
	E 801-TCCB-02	Temporary Concrete Barrier Details
	E 801-TCCB-03	Temporary Concrete Barrier Double Taper End Section
	E 801-TCCB-04	Temporary Concrete Barrier Anchorage
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	RD622C	Temporary Concrete Safety Barrier Type F 3 Anchorage at Expansion Jt
	RD622D	Temporary Concrete Safety Barrier Type F 3 Transition Layouts

<b><u>State</u></b>	<b><u>Drawing Number</u></b>	<b><u>Drawing Title</u></b>
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	RMB-006-09	Concrete Median Barrier Precast (Permanent)
	RMB-053	Concrete Median Barrier Precast (Permanent) (50" Tall Wall)
	RMB-115-08	Concrete Median Wall Type 9T (Temporary)
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		Temporary Precast Barrier F Shape
<b>Maine</b>		
	526 (01) to (04)	Temporary Concrete Barrier
<b>Maryland</b>		
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	MD 104.01-51	Precast Temporary 32-in F Shape Concrete Traffic Barrier Terminal End Left Side Approach Details
	MD 104.01-52	Precast Temporary 32-in F Shape Concrete Traffic Barrier Terminal End Left Side Approach Details
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	MD 104.01-54	Precast Temporary 32-in F Shape Concrete Traffic Barrier (Pin and Loop Joint)
	MD 104.01-55	Precast Temporary 32-in F Shape Concrete Traffic Barrier Transition Right Side Approach
	MD 104.01-56	Approach Plate for Precast Temporary 32-in F Shape Concrete Traffic Barrier for Transition Right Side
	MD 104.01-57	Precast Temporary 32-in F Shape Concrete Traffic Barrier Transition Left Side Approach
	MD 104.01-58	Approach Plate for Precast Temporary 32-in F Shape Concrete Traffic Barrier for Transition Left Side
	MD 104.01-61	Traffic Barrier W Beam Anchorage at Precast Temporary 32-in F Shape Concrete Traffic Barrier Terminal End
	MD 104.01-62	Traffic Barrier W Beam Median Barrier Anchorage at Precast Temporary 32-in F Shape Concrete Traffic Barrier Terminal End
	M(5.09)-83-143 Sh1-4	Temporary Precast Single Face F-Type Concrete Barrier
	M(8.01)-83-153	Detail of Temporary Slab Underpinning During Stage Construction
	M(5.10)-84-158 Sh1-4	Temporary Precast Double Face F-Type Concrete Barrier



<b><u>State</u></b>	<b><u>Drawing Number</u></b>	<b><u>Drawing Title</u></b>
Massachusetts		
	M/E 403.1 to 403.3	Precast Portable Concrete Barrier
Michigan		
	R-52-E Sheets 1-6	Temporary Concrete Barrier
Minnesota		
	8337B Sheets 1-2	Temporary Portable Precast Concrete Barrier Type "F"
Mississippi		
	MB-2A Sheet No 205	Median Barrier Concrete (Precast)
Missouri		
	617.20C Sheets 1-6	Temporary Concrete Traffic Barrier Type F
Montana		
	606-60	Concrete Barrier Rail
	606-62	Concrete Barrier Rail Anchors
	606-64	Tall Concrete Barrier Rail
	606-66	Concrete Barrier Rail Transition
	606-68	Concrete Barrier Rail Terminal Section (One-Way Departure)
Nebraska		
	8700 1 E 03 Sheets 1-2	Concrete Protection Barrier Special Plan C
Nevada		
	R-8.7.1 (502)	Portable Precast Concrete Barrier Rail
New Hampshire		
	GR-6	Precast Concrete Barrier 42" F-Shape (Double-Faced) Precast Concrete Barrier 1070mm F-Shape (Double-Faced) Precast Concrete Median Barrier (Single Slope)
New Jersey		
	CD-159-3	Construction Barrier Curb, Type 1
	CD-159-4	Construction Barrier Curb, Type 4 (Alternate A)
	CD-159-5	Construction Barrier Curb, Type 4 (Alternate B)
New Mexico		
	606-20-1/5	Temporary Pre-Cast Concrete Wall Barrier
	606-20-2/5	Temporary Pre-Cast Concrete Wall Barrier Details
	606-20-3/5	Concrete Wall Barrier Anchoring Details
New York		
	M606-21R1	Precast Concrete Barrier
	M619-70	Work Zone Traffic Control Temporary Concrete Barrier
	M619-71	Work Zone Traffic Control Temporary Concrete Barrier – Tapered End
North Carolina		
	1170D01 Sheets 1-4	Portable Concrete Barrier

<b><u>State</u></b>	<b><u>Drawing Number</u></b>	<b><u>Drawing Title</u></b>
North Dakota		
	D-704-51	Portable Precast Concrete Median Barrier (Temporary Usage)
Ohio		
	RM-4.1 Sheets 1-2	50" Portable Concrete Barrier
	RM-4.2 Sheets 1-2	32" Portable Concrete Barrier
	PCB-91	Portable Concrete Barrier Details
	PCB-DD	Portable Concrete Barrier Installation Guidelines
Oklahoma		
	TCS12-1A 01E T-512AE	Precast Concrete Median Barrier (Portable Type)
	TCS12-1B 00E T-512BE	Precast Concrete Median Barrier (Portable Type) Reinforcing /Connection Steel and Glare Screen Precast Concrete Median Barrier
	PBM-2 01E R-126AE	Precast Median Barrier
Oregon		
	RD500	Precast Concrete Barrier Pin and Loop Assembly
	RD515	Median Barrier Anchoring Details
	RD516	Securing Concrete Barrier to Roadway
	RD545	Precast Tall (42") Concrete Barrier
Pennsylvania		
	RC-57M Sheets 1-8	Concrete Median Barrier
	RC-58M Sheets 1-5	Single Face Concrete Barrier
Rhode Island		
	40.5.0	Unanchored Precast Concrete Barrier for Temporary Traffic Control
	40.1.0	Doubled-Faced Precast Median Barrier
	40.2.0	Single-Faced Precast Median Barrier
	40.2.1	Single-Faced Precast Median Barrier
	40.4.0	Precast Median Barrier for Light Standard
South Carolina		
	605-205-01	Temporary Concrete Barrier Safety Shape J-J Hook
	605-205-02 Sheets 1-2	Temporary Concrete Barrier Safety Shape J-J Hook
	605-205-03	Temporary Concrete Barrier Safety Shape Anchorage Adhesive Bond J-J Hook
	605-205-04	Temporary Concrete Barrier Safety Shape Anchorage Bolt Through J-J Hook
	605-210-01	Temporary Concrete Barrier Safety Shape Pin Connection North Carolina Design
	605-210-02	Temporary Concrete Barrier Safety Shape Reinforcement North Carolina Design
South Dakota		
	628.10 Sheets 1-2	Movable F Shape Concrete Barriers (Interior Section)
	628.11 Sheets 1-2	Movable F Shape Concrete Barriers (End Section)

<b><u>State</u></b>	<b><u>Drawing Number</u></b>	<b><u>Drawing Title</u></b>
Tennessee		
	T-PBR-1	Interconnected Portable Barrier Rail
Texas		
	CBR(P&P) -04	Concrete Barrier Rail (Portable and Precast)
	CSB(1) -04	Concrete Safety Barrier (F-Shape) Reinforcement for Precast and Cast-in-Place Barrier (Type 1)
	CSB(2) -04	Concrete Safety Barrier (F-Shape) Joint Types for Precast Barriers
	CSB(3) -04	Concrete Safety Barrier (F-Shape) Precast and Cast-in-Place (Bridge)
	CSB(4) -04	Concrete Safety Barrier (F-Shape) Precast Pinned Barrier
	CSB(8) -04	Concrete Safety Barrier (F-Shape) Reinforcement for (10 Foot) Barrier- (Type 4)
	PCTB(1 to 3) -04	Precast Concrete Traffic Barrier Type 2 Single Slope Concrete Barrier Precast Pinned Barrier
Utah		
	BA 1A and 1B	Precast Concrete Full Barrier Standard Section (New Jersey Shape)
	BA 1C	Precast Concrete Barrier Terminal for Speeds $\leq$ 40mph (NJ Shape)
	BA 1D	Precast Concrete Full Section Median Installation (New Jersey Shape)
	BA 1E	Precast Concrete Full Section Shoulder Applications (New Jersey Shape)
	BA 3B	Precast Concrete Constant Slope Transition Section for Crash Cushion and W-Beam Guardrail
Vermont		
	G-18	Precast Concrete Temporary Traffic Barrier
Virginia		
	105 512 501.45 & .46	Precast Traffic Barrier Service Concrete
	105 501.50	Precast Concrete Median Barrier 12 Ft. Terminal Section
	105 502 501.51 & .52	Traffic Barrier Service Concrete Parapet (Single Face) (For Temporary Installation on Bridge Deck Exterior)
	105 512 501.53 to .54A	Traffic Barrier Service Concrete Parapet (Double Face) (For Temporary Installation on Bridge Deck Exterior)
	501.59 to 501.61	Precast Concrete Median Barrier Positive Connection Options
	501.62 & 501.63	Butting Traffic Barrier Service to Single Face Parapet Service
Washington		
	C-8 Sheets 1-2	Concrete Barrier Type 2
	C-8a	Concrete Barrier Type 4 and Transition Section
	C-8e	Precast Concrete Barrier Anchor – Type 3 (Permanent)
	K-80.35-00	Temporary Conc. Barrier Anchoring
	K-80.37-00	Temporary Conc. Barrier Anchoring – Narrow
	TB-1	Precast Concrete Barrier Type 2 with Scupper
	TB-5	Concrete Barrier Type 5
	TB-23	Type 2 to Single Slope Transition
	C-13 Sheets 1-3	Single Slope Concrete Barrier (Precast)

<u>State</u>	<u>Drawing Number</u>	<u>Drawing Title</u>
Washington		
	C-13b	Single Slope Concrete Barrier (Precast) Vertical Back
	C-16a	Traffic Barrier Shoulder Widening – For Shoulders 8 ft and wider
	C-16b	Traffic Barrier Shoulder Widening – For Shoulders less than 8 ft wide
West Virginia		
	GR13	Temporary Concrete Barrier
Wisconsin		
	S.D.D. 14B 22-4a	Concrete Barrier Single-Faced (With Anchorage)
	S.D.D. 14B 7-11a-d	Concrete Barrier Temporary Precast, 12'-6"
	S.D.D. 14B 7-11e-f	Concrete Barrier Temporary Precast, 10'-0"
Wyoming		Permits any approved NCHRP 350 concrete barrier for temporary use

## Chapter 1

### Introduction

#### Problem statement

There are many different designs for precast concrete barriers (PCB) that have been developed and crash tested in accordance with National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features (1)*. These barriers differ in shape, height, width, length, reinforcement, and connection design. There are also many different anchoring methods that have been developed to reduce the deflection of these systems. As new crash test criteria for longitudinal barriers are being implemented some new testing of these barriers will be needed. To make better decisions on what designs should be considered for further testing, it would be very helpful to compile the information on the barriers, anchored and unanchored, that have been tested in accordance with NCHRP Report 350 and then summarize this information in a report.

#### Objective

The objective of this study is to compile data on all known testing of precast concrete barriers, including anchoring methods and other methods of reducing barrier deflection such as wedges, additional stiffening, key in with the asphalt, etc.

#### Tasks

Accomplishment of the project objective required the following tasks:

Task 1. Conduct an email survey of the states to identify the PCB design features approved for the states including types of anchoring methods for roadway and bridge systems and to identify which systems are most prevalently used. Identify whether the systems with anchoring methods have been tested to the NCHRP Report 350 crash test criteria. For all identified systems, request electronic "pdf" or "dgn" design drawings and information or obtain from State Highway agencies' websites.

Task 2. Review the Federal Highway Administration (FHWA) crashworthiness acceptance files, the *Standardized Guide to Barrier Hardware* from Task Force 13 (2), the National Crash Analysis Center (NCAC) library, and any research publications that deal with the performance of PCBs to determine the extent of systems crash tested. Contact the major test houses to determine if additional testing has been conducted for PCB systems and anchoring methods.

Task 3. Synthesize the information identified in Task 1 and Task 2 above, noting the most commonly used design features and anchoring methods for roadway and bridges. Identify future research needs, including but not limited to, in-service evaluations and recommend further testing for commonly-used systems. Isolate similar design and anchorage features and note aspects that may need to be evaluated for in-service or crash testing evaluations.

Task 4. Prepare a draft final report that summarizes the design information, including plan sheets, and the crash test performance data. The report shall be prepared in a format that can be easily used to compare characteristics such as deflection, anchoring methods, barrier segment lengths, etc.

Task 5. Considering the project panel's comments, revise and submit the final report.

## **Report's organization**

The report first gives background information about precast concrete barriers and their various uses. Crash test guidelines from NCHRP Report 350 and the Manual for Assessing Safety Hardware (MASH) (3) are discussed as well as how FHWA and American Association of State Highway and Transportation Officials (AASHTO) have agreed to implement these guidelines. FHWA acceptance procedures for PCBs are presented, and the different PCB designs that have been accepted by FHWA are given.

Based on data obtained from a survey of state DOTs, the different PCB systems used in the USA were identified and compared by their characteristics. Barriers with identical or nearly identical geometric dimensions were grouped into "systems" named after the state primarily responsible for the barrier's development and testing. PCBs used for temporary applications, the most common use of PCBs, are described separately from those used in permanent installations. Both non-proprietary and proprietary PCBs are included.

Results of all crash tests of PCBs identified during the study are summarized by type of connection (pin and loop and other), anchorage (free standing and anchored), and type of usage (temporary and permanent). These crash test results are used to predict barrier performance since no states have conducted meaningful in-service performance studies of PCBs.

Each of the major design features: profile, length, connection, reinforcement, anchorage, and material are discussed separately. Drawings from the state DOTs are used to show the significant variations in PCB designs.

The findings of the study are synthesized and research needs are identified. Recommendations for future design, testing, and use of precast concrete barriers are presented.

The appendix contains PCB drawings from the states. Two states, Delaware and Wyoming, use any NCHRP Report 350 accepted PCB so no drawings are included for these states.

## Chapter 2

### Background

#### Uses of precast concrete barriers

The main use of precast concrete barriers is in work zone areas where they are used on a temporary basis to shield roadside hazards from motorists, to provide separation between opposing traffic streams, to channelize traffic, and/or to shield construction workers from vehicles. Some states also use precast concrete barriers for permanent installations as median barriers, roadside longitudinal barriers, and bridge railings.

In work zone areas PCBs are usually used free standing without any anchorage. However, if deflection is an issue because of restricted clear area behind the barrier or close-by hazards, various anchorage methods are used to reduce barrier movement during impacts. In most permanent installations anchorage is used to limit barrier movement.

The use of traffic barriers in work zones is discussed in detail in Chapter 9 of the *AASHTO Roadside Design Guide: (4)*

PCBs (portable concrete barriers) are free-standing, precast, concrete segments, 2.4m to 9m [8ft to 30ft] in length, with built-in connecting devices. Barrier weight varies from 600 kg/m to 750 kg/m [400 lb/ft to 500 lb/ft] depending on exact cross-section, geometry, and amount of reinforcement. The mass of individual segments can vary from 2,000 kg to 7,500 kg [4,500 lb to 16,500 lb], thus requiring heavy equipment for installation and removal. Adequate longitudinal reinforcement and positive connections ensure that the individual segments act as a smooth, continuous unit.

#### Types of precast concrete barriers

Precast concrete barriers (PCBs) are usually categorized by the shape of the barrier's profile. The three common PCB profiles in the United States are the New Jersey-shape, F-shape, and single-slope, also known as the constant-slope. These barrier profiles are shown in Figure 1.

In addition to profiles, PCBs differ from state to state in terms of segment length, segment connection, cross-section dimensions, reinforcement, and materials. This report will examine how these characteristics vary from state to state and will discuss how these differences affect barrier performance.

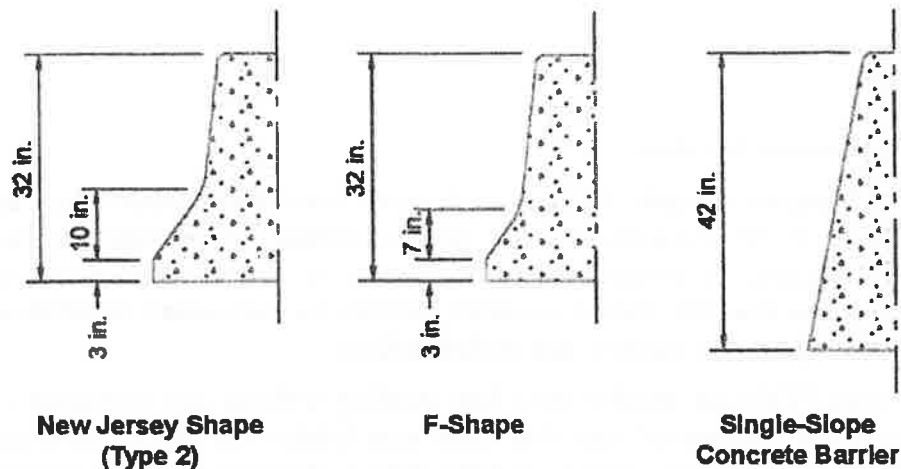


Figure 1 Comparison of precast concrete barrier profiles  
(Source: Washington DOT Design Manual M 22-01.04 (5) Page 710-21)

### Crash test guidelines for precast concrete barriers

Crash test guidelines for longitudinal barriers have evolved over the years. In 1980, NCHRP Report 230 (6), the first comprehensive guidelines, was published. In 1993 these guidelines were updated by NCHRP Report 350 and again in 2007 by NCHRP Project 22-14(2), *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. The results of this latest study are contained in AASHTO's *Manual for Assessing Safety Hardware* [MASH].

When the Federal Highway Administration decided to adopt NCHRP Report 350 guidelines for testing of safety hardware, questions arose relative to the use of existing barriers. Initially FHWA required all devices, both permanent and temporary, used on the National Highway System to meet these guidelines effective October 1, 1998. However, in July 1998, FHWA and AASHTO agreed on an implementation plan that included guidelines for portable concrete barriers. Under this plan existing portable concrete barriers could be used until October, 2000, but after that date barriers had to have an accepted connection design that transfers both moment and tension between segments. After October 1, 2002, new barriers used in work zones must meet NCHRP Report 350 guidelines, but existing barriers meeting the post-October 2000 requirements can continue to be used as long as they remain serviceable.

In June 2009, AASHTO adopted the *Manual for Assessing Safety Hardware* (MASH) and jointly agreed with FHWA on an implementation plan. Under this plan all safety equipment meeting NCHRP Report 350 guidelines can continue to be used and can be continued to be manufactured and installed. Any new safety hardware developed after 15 October 2009 will be tested using the MASH guidelines unless its development was underway on 15 October 2009 and its development is completed before January 2011. Safety hardware accepted under NCHRP 350 and tested unsuccessfully under MASH will be reviewed jointly by FHWA and AASHTO to determine a course of action.

### Crash test guidelines for precast concrete barriers – NCHRP Report 350

Precast concrete barriers are longitudinal barriers subject to the same crash test guidelines as used for semi-rigid and flexible barriers. NCHRP Report 350 provides for six different test



levels which require testing with typically two or more of the six test vehicles described in the report. Most precast concrete barriers have been tested at either Test-Level (TL) 3 or TL-4. The TL-3 tests include one with a small 820kg (1,800 lb) car to test for occupant risk and one with the 2000kg (4,400 lb) pickup truck to test for structural strength and vehicle stability. To be accepted at TL-4 an additional test using an 8000kg (17,600 lb) single-unit truck must be passed.

Precast concrete barriers need to be tested as configured in the length of need (LON) as well as in the transition configuration if they are to be connected with other types of barriers or bridge rails. This synthesis examines only the use of precast concrete barriers in the length of need and does not cover transitions or end treatments.

### Crash test guidelines for precast concrete barriers – MASH

The *Manual for Assessing Safety Hardware* follows an approach to crash testing that is similar to the one used in NCHRP Report 350. The most significant change from Report 350 is in the mass of the test vehicles. The small car has increased in mass to 1100kg (2,420 lb) and the pickup truck to 2270kg (5,000 lb) reflecting the larger vehicles now in the USA vehicle fleet. A major increase in the impact severity of the single-unit truck occurs in MASH due to the increased mass of the vehicle, 10,000kg (22,000 lb) and the increase in impact speed. Table 1 gives a comparison of the testing requirements for TL-3 and TL-4 for NCHRP Report 350 and MASH.

Table 1 – Comparison of crash test conditions for NCHRP Report 350 and MASH

Test Level	Test #	NCHRP Report 350 Impact Conditions				MASH Impact Conditions			
		Vehicle	Weight lb	Speed km/h (mph)	Angle deg	Vehicle	Weight lb	Speed km/h (mph)	Angle
3	3-10	820C	1,800	100 (62)	20	1100C	2,420	100 (62)	25
	3-11	2000P	4,400	100 (62)	25	2270P	5,000	100 (62)	25
4	4-10	820C	1,800	100 (62)	20	1100C	2,420	100 (62)	25
	4-11	2000P	4,400	100 (62)	25	2270P	5,000	100 (62)	25
	4-12	8000S	17,600	80 (50)	15	10000S	22,000	90 (56)	15

## Chapter 3

### **FHWA-accepted designs for precast concrete barriers**

#### **Federal Highway Administration barrier acceptance process**

The Federal Highway Administration reviews crash test results for highway safety hardware tested under NCHRP Report 350 or MASH. Manufacturers, state DOTs, and/or crash test houses submit documentation of crash tests performed on safety hardware to FHWA for its review. FHWA decides if the proper tests have been conducted, that the testing conditions were in agreement with the published guidelines, and reaches a determination of the crashworthiness of the safety hardware. Once FHWA is satisfied that the crashworthiness of the safety hardware has been properly documented, it issues an "acceptance letter" which is eventually published on its web site: ([http://safety.fhwa.dot.gov/roadway\\_dept/policy\\_guide/road\\_hardware/barriers/index.cfm](http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/barriers/index.cfm)).

For most highway safety hardware the review process is conducted by the FHWA Office of Safety Road Departure group in Washington, D.C. However, for precast concrete barriers, regional FHWA offices sometimes do the review. Acceptance letters written by regional offices are not published on the FHWA web site.

It is not necessary for states to have an FHWA acceptance for a successfully-tested system as long as the crash tests for the system were conducted per NCHRP Report 350 or MASH by an accredited laboratory. Some states rely on crash test reports or FHWA acceptance letters for systems that are similar (but not necessarily identical) to their barriers for their crashworthiness documentation.

#### **Published acceptance letters**

Table 2 lists the FHWA acceptance letters listed on the FHWA website. Details on the systems covered by these letters as well as information on the crash tests are given later in the report.

#### **Regional FHWA offices' acceptance letters**

In some cases acceptance letters for PCBs are issued by the regional FHWA offices. These letters do not get published on the FHWA website. These letters are typically based on an assessment of the similarity between the barrier being reviewed and one that has been crash tested successfully.

Since it is difficult to find these letters, it is possible that there may be additional acceptance letters for PCBs that have not been identified by this research project. Table 3 lists FHWA acceptance letters issued by regional offices for precast concrete barriers.

Table 2 FHWA acceptance letters for precast concrete barriers

Code	Manufacturer	Date	Test Level	Shape	Segment Length ft (m)	Test Length ft (m)	Anchor	Connect
B-5	L.B. Foster	1989	PL-2	NJ	15/20 (4.6/6)	125 (38.1)	Yes	None
B-5a	Kelken Cons	1996	TL-4	F	20 (6.1)	Not tested	Yes	Re-bar
B-41	U Nebraska	1997	TL-3	F	12.5 (3.8)	267 (81.5)	No	P&L
B-42	Rockingham	1997	TL-3	F	12 (3.7)	156 (47.6)	No	T-LOK
B-42a	Rockingham	2009	TL-3	F	18 (5.5)	Not tested	No	T-LOK
B-52	Easi-Set Ind	1999	TL-3	NJ	12 (3.7)	192 (58.6)	No	JJ hook
B-52a	Easi-Set Ind	2000	TL-3	F/NJ	20 (6.1)	Not tested	No	JJ hook
B-54	VA DOT	1999	TL-3	F	20 (6.1)	142 (43.3)	No	P&L
B-61	Caltrans	1999	TL-3	NJ	20 (6.1)	160 (48.8)	Yes	P&L
B-62	Gunnar	1999	TL-3	Vert	19.7 (6.0)	Not given	No	Pin/Plate
B-63	Barrier Systems	2000	TL-3	T	3.3 (1.0)	246 (75.0)	No	Pin/Plate
B-67	GA DOT	2000	TL-3	NJ	9.8 (3.0)	181 (55.3)	No	P&L
B-69b	Barrier Systems	2005	TL-3	T	3.3 (1.0)	243 (74.0)	Backup	Pin/Plate
B-70	ID DOT	2000	TL-3	NJ	20 (6.1)	240 (73.2)	No	P&L
B-79	Penn DOT	2000	TL-3	F	12 (3.6)	192 (58.6)	No	Plate
B-84	IN DOT	2002	TL-3	F	10 (3.0)	259 (79.0)	No	P&L
B-86	OR DOT	2001	TL-3	F	12.5 (3.8)	199 (60.8)	No	P&L
B-86a	OR DOT	2001	TL-4	F tall	10 (3.0)	Not given	No	C-chan&P
B-90	Caltrans	2001	TL-3	SS	13.1 (4.0)	157 (48.0)	No	Pin/Plate
B-93	OH DOT	2002	TL-3	NJ	10 (3.0)	244 (76.0)	No	P&L
B-94	NY DOT	2002	TL-3	NJ	20 (6.1)	200 (61.0)	No	H-beam
B-98	NC DOT	2002	TL-3	NJ	10 (3.0)	200 (61.0)	No	P&L
B-102	John Carlo	2002	TL-3	NJ	20 (6.1)	200 (61.0)	No	T-pin&L
B-115	U Florida	2003	TL-2	Vert	12 (3.7)	180 (55.0)	No	Bolt/Pin
B-122	MidwestRSF	2003	TL-3	F	12.5 (3.8)	204 (62.2)	Yes	P&L
B-149	Battelle Inst	2006	TL-3	NJ tall	12 (3.7)	200 (61.0)	No	P&L
B-164	Barrier Conn	2007	TL-3	F	10/20 (3/6.1)	Not tested	No	P&L
B-169	Easi-Set Ind	2008	TL-3	NJ mod	20 (6.1)	Not tested	No	JJ hook
B-171	CO DOT	2008	TL-3	F mod	12.5 (3.8)	Not tested	No	P&L
B-180	MidwestRSF	2008	TL-3	F	12.5 (3.8)	204 (62.3)	Yes	P&L
B-190	Bexar Conc	2009	TL-3	F	30 (9.1)	240 (73.1)	No	Bolts

Table 3 Non-published FHWA acceptance letters for precast concrete barriers

FHWA Region	Requester	Date	Test Level	Shape	Segment Length ft (m)	Comparison System	Anchor	Connect
AZ	AZ DOT	2002	NS	NS	20 (6.1)	OR & VA	No	P&L
KY	KY TC	1999	NS	NS	NS	IA	No	P&L
MI	Kerkstra Precast	2007	TL-3	NJ	NS	EASI-SET Ind JJ Hooks	No	NS
TN	TN DOT	2002	TL-3	NJ	NS	OH	No	P&L

NS – Not specified in the acceptance letter

## Chapter 4

### Survey of States

An important part of the study was to survey the state DOTs to determine their experience with precast concrete barriers. A list of the TRB representatives for the states was obtained and each TRB representative was contacted to get the names of the people who were best positioned to respond to the inquiries about PCBs. E-mail was the primary means of communication and most TRB reps were very helpful. All but one TRB rep responded.

The initial e-mail contact with each state requested the following information:

- 1) Precast concrete barrier designs approved for use in your state for roadway and bridge systems,
- 2) Details on the anchoring and connection designs of these barriers including “pdf” or “dgn” design drawings,
- 3) Data on crash tests conducted on these systems by your organization or by others if known,
- 4) Data on the extend of use (number of barriers in use or in storage) of the barriers,
- 5) Information on the in-service performance of the barriers, and
- 6) Information on your state’s process for adding new barriers to your list of approved systems.

If the designated state representatives were not responsive, additional e-mails were sent, followed by telephone calls if necessary. Information for unresponsive states was obtained from the states’ websites. In the end, only Rhode Island and West Virginia chose not to participate in the study.

The information obtained through this survey is the basis for most of what is presented in this report. Survey information was supplemented with information from the literature search, discussions with researchers at the major crash testing facilities, and information obtained from state DOT websites.

## Chapter 5

### Usage of precast concrete barriers

Precast concrete barriers are used primarily for temporary applications in work zones and other areas for traffic channelization and hazard shielding. Some states use precast concrete barriers in permanent applications on bridges and highways.

#### Precast concrete barriers used in temporary applications

By far the most common use of PCBs is in work zones. These barriers are usually 32 in (813mm) high, have either the NJ or F-shape profile, and are unanchored. These barriers come in different lengths with 12.5 ft (3.8m) being the most popular, followed by 10 ft (3.0m) and 20 ft (6.1m). A few states use barriers of other lengths with 30 ft (9.1m) being the longest.

All but four states use some type of a pin and loop (P&L) connection for their barriers. These connections vary in the number of loops, the size and material of the loops, the diameter of the connection pin, and the presence or absence of a restraining nut or bolt at the bottom of the connection pin.

Table 4 gives a summary of the different systems used in the USA for 32-in (813mm) high temporary PCB. The most popular system is the Kansas (a.k.a., Iowa) F-shape barrier which was developed by the Midwest Roadside Safety Facility through a pooled fund project. Over the years the design of the barrier has been modified to improve its performance. Currently nine states use this non-proprietary barrier. The Oregon F-shape and Idaho NJ-shape barriers are close behind with six states using each of these barriers. Adding in the Ohio NJ-shape barrier, which is used by four states, half of the fifty states use these four barrier systems. Two states, Delaware and Wyoming, reported that they accept any barrier that meets NCHRP Report 350 crash test requirements. Cross-sections for the four most commonly used PCBs are shown in Figure 2.

Other states have developed and crash tested PCBs, but each of these barriers is used by four or fewer states. Among these barriers, Georgia, Indiana, Montana, Nebraska, North Carolina, Virginia, and Washington State use pin and loop connections. The New York barrier uses an H-beam to connect adjoining barriers and the Texas barrier employs bolts crossing in an "X" configuration. Pennsylvania is the only state that still uses a barrier that does not have a connection which transfers both moment and tension between segments. Its connection consists of a steel plate that slides into grooves in the adjacent barrier segments.

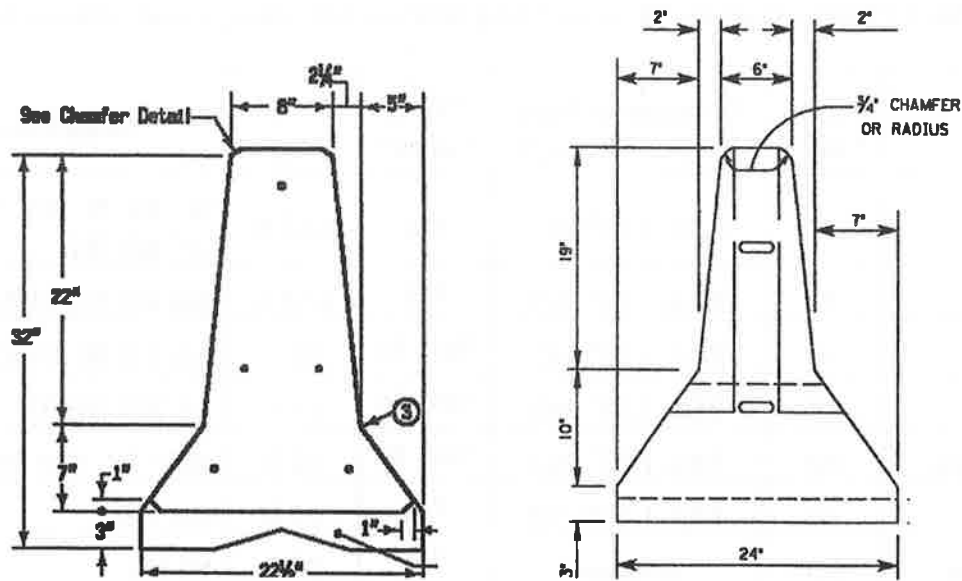
Based on the information that could be obtained from the DOTs, it appears that Connecticut, Maine, Massachusetts, Michigan, Rhode Island, Vermont, and West Virginia are still using PCBs that do not meet NCHRP Report 350 requirements. Because of difficulties in getting responses from these states it is possible that one or more of these states may have received an acceptance letter from an FHWA regional office. No information was found to indicate that New Hampshire uses any 32-in (813mm) high temporary PCBs.

Table 4 Systems used for 32-in (813mm) temporary median precast concrete barriers

System	Barrier Profile	Connection Type Pin $\phi$ , # of Loops	Crash Tested?	Tested Length	States Using It	#
Kansas (Iowa)	F	P&L 1.25" 2x3	Yes	12.5 ft	FL IA IL KS MN MO OK SD WI	9
Oregon	F	P&L 1.00" 2x3	Yes	12.5 ft	AK AZ CO* LA NV OR	6
Idaho	NJ	P&L 1.25" 2x2	Yes - M	20 ft	AR CA HI ID KY* UT*	6
Ohio	NJ	P&L 1.25" 2x2	Yes - M	10 ft	AL MS OH TN	4
N. Carolina	NJ	P&L 1.25" 2x3	Yes - M	10 ft	MA* NC NM SC	4
Georgia	NJ	P&L 1.25" 2x2	Yes	10 ft	GA ND	2
New York	NJ	H-beam	Yes	20 ft	NJ NY	2
Indiana	F	P&L 1.25" 2x2	Yes	10 ft	IN MD*	2
Nebraska	F	P&L 1.25" 2x2	Yes - M	12.5 ft	NE	1
Virginia	F	P&L 1.25" 2x2	Yes	20 ft	VA	1
Washington	NJ	P&L 1.00" 2x2	Yes - M	12.5 ft	WA	1
Pennsylvania	F	Plate (no tension)	Yes - M	12 ft	PA	1
Texas X-Bolt	F	X-bolts	Yes	10,30 ft	TX	1
Montana	NJ	P&L 1.25" 3x2	Yes	10 ft	MT	1
	NJ	P&L 1.00" 2x2	No	10-12 ft	RI VT WV	3
	NJ	P&L 1.00" 2x2	No	20 ft	CT	1
	NJ	P&L 1.25" 2x2	Yes-Fail	10 ft	MI	1
	NJ	P&L 0.94" 2x2	No	10 ft	ME	1
Any NCHRP 350					DE WY	2
		Does not use 32-in high PCBs			NH	1

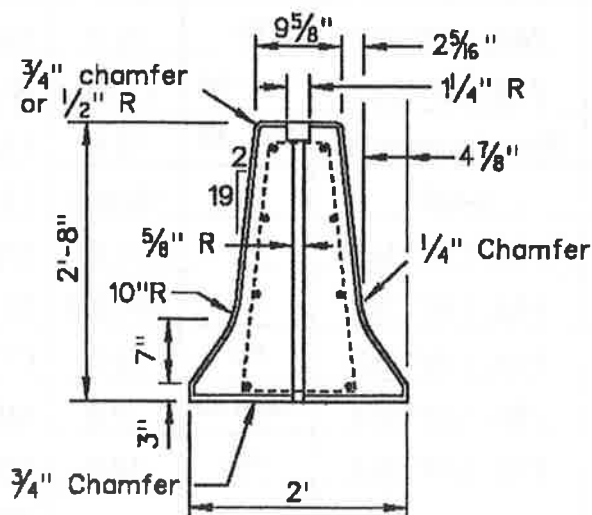
\* Uses a modification of the crash-tested system

M – marginal performance in crash test



Kansas F-Shape

Ohio and Idaho New Jersey-shape



Oregon F-Shape

Figure 2 Cross-sections for the four most commonly used PCBs

Sources: Iowa DOT RE-71, Alabama DOT GTE-629, Nevada R-8.7.1

### Proprietary designs

A small number of proprietary PCBs are available. Each of these barriers employs a unique type of connection upon which its patent is based. The system most mentioned in the material received from the DOTs is the JJ-Hooks system (Easi-Set Industries) which can be used on both F-shape and NJ-shape barriers. The connection consists of a J-shape steel plate cast into each barrier end which interlocks with the "J" hook of the adjoining barrier.



Another proprietary system mentioned in a small number of DOT specifications is the T-LOC system (Rockingham Precast). This connection for F-shape barriers consists of a "T" shaped steel plate cast into one end of each barrier segment which slides into a steel tube cast in the end of the adjoining barrier.

In March 2009, Bexar Concrete Works in Texas received an FHWA acceptance letter for its Quick-Bolt Connection which was crash tested using the new MASH guidelines. The 30-ft (9.1m) long F-shape barrier has two PVC pipes cast horizontally into each end. Behind each PVC pipe is a 3-in (76mm) diameter by 12-in (305mm) long "retraction" cavity that allows the two threaded bolts to move for ease of installation. Vertical "hand" holes allow access to the bolts so that connection nuts can be threaded onto the bolts.

### **Other Designs**

Alaska, Colorado and Maryland reported using one-sided F-shaped pin and loop PCBs for temporary uses. Alaska's and Maryland's barriers are 32 in (813mm) high and Colorado's is 34 in (864mm) high.

Florida has a low-profile temporary roadside PCB that was developed by the University of Florida which retains proprietary rights to the product. It has been crash tested to TL-2 and has an 18-in (457mm) high near-vertical traffic face with a double-bolt connection that allows for installations on curves of 66 ft (20.1m) radius or greater. Texas also uses a low-profile temporary PCB for highways with posted speeds of 45 mph (73 km/h) or less. The 20-in (508mm) high barrier has a trapezoidal cross-section with a 26-in (660mm) base and a 28-in (711mm) top. The 20-ft (6.1m) long barriers are connected with two bolts.

A number of states use temporary PCBs that are higher than the typical 32 in (813mm). These barriers range from 42 in (1067mm) in height to 50 in (1270mm) and have either an F-shape, NJ-shape or single slope (SS) profile. Table 5 presents a summary of the tall temporary barriers identified in the study.

### **Precast concrete barriers used in permanent applications**

According to the survey of states, six use PCBs for permanent installations on shoulders, in medians, and around bridge piers. Seven states specifically indicated that they do not use PCBs for permanent applications, and the remaining states provided information only on uses of PCBs for temporary applications. Profiles for PCBs used in permanent installations are either NJ, F, or single slope. These barriers are typically "keyed" by pavement to provide anchorage and reduced deflections from impacts.

Connecticut uses 32-in (813mm) high, 20-ft (6.1m) long NJ-shape PCB for permanent applications. Figure 3 shows cross-sections for the permanent median barrier and the permanent shoulder barrier. These barriers are embedded a minimum of 10 in (254mm) below the top of pavement, and two 1-in (25mm) diameter 18-in (457mm) long dowel bars are used in the connections between barrier segments. The median barrier is composed of two single-faced barriers with gravel fill in between the two units.

Table 5 Tall temporary precast concrete barriers

State	Type	Profile	Lengths	Heights	Tested?	Connection
New Hampshire	Median	F	10/20 ft	48 in	No	I-beam
North Carolina	Median	F	12.5 ft	42 in	TL-4	P&L 2 x 4
Oregon	Median	F	12.5 ft	42 in	TL-4	P&L 2 x 4
Pennsylvania	Median	F	12-30 ft	50 in	No	Plate
Idaho	Median	NJ	10 ft	46 in	No	P&L 2 x 3
Montana	Median	NJ	10 ft	46 in	No	P&L 2 x 3
Ohio	Median	NJ	12-14 ft	50 in	TL-3	P&L 3,2,3
New Hampshire	Median	SS	10/20 ft	48 in	No	I-beam
Texas	Median	SS	30 ft	42,48,54 in	Yes	Rebar grid
Washington	Median	SS	20 ft	42,48,54 in	Yes	Rebar grid
Oregon	Single Face	F	12.5 ft	42 in	TL-4	P&L 2 x 4
Pennsylvania	Single Face	F	12-30 ft	41 in	No	Plate
Washington	Single Face	SS	20 ft	42, 48 in	No	Rebar grid

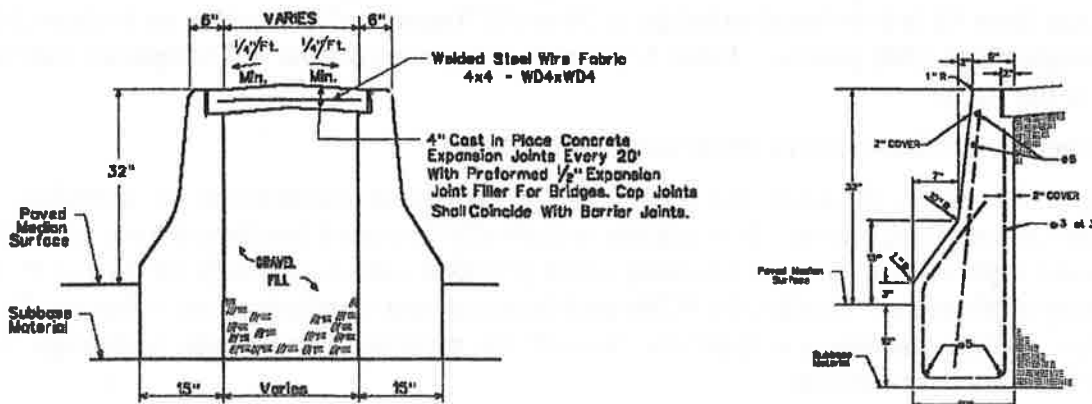


Figure 3 Connecticut permanent 32-in (813mm) NJ-shape barrier  
(Source: Connecticut DOT 821-A)

Kentucky uses PCBs for two different height permanent barriers, 32-in (813mm) and 50-in (1270mm). The 32-in (813mm) high barrier is 30 ft (9.1m) long and uses three dowels in the connection between segments. It can be constructed in three sizes: 9-in (229mm) wide top with 27-in (686mm) wide base, 12-in (305mm) top with 30-in (762mm) base, or a 14-in (229mm) top with 32-in (813mm) base. The 50-in (1270mm) high barrier is 20 ft (6.1m) long, uses six dowels in its connection and is available in two sizes as indicated in Figure 4. These barriers are keyed into the pavement a minimum of 3 in (76mm).

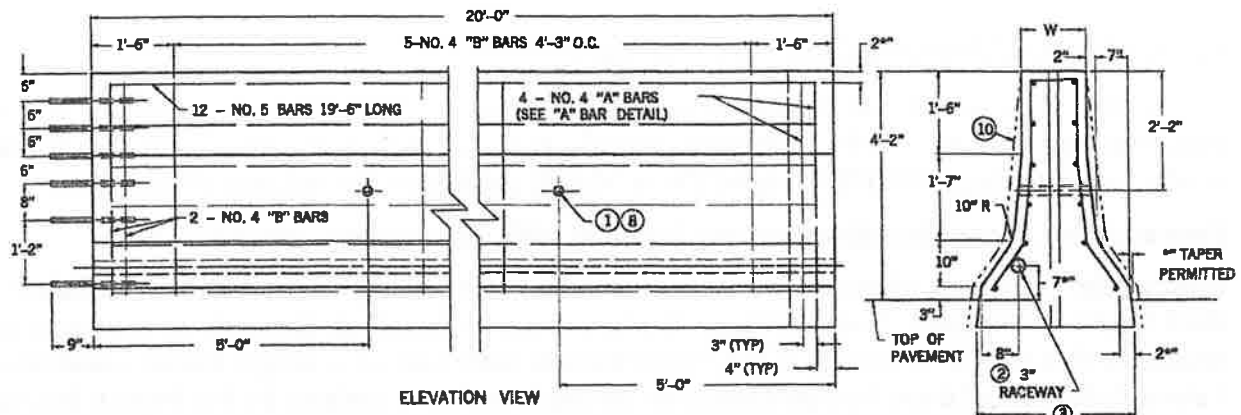


Figure 4 Kentucky 50-in (1270mm) permanent NJ-shape barrier  
(Source: Kentucky Transportation Cabinet RBM-053)

Oklahoma uses 42-in (1067mm) high PCBs for permanent median barriers. These barriers are F-shape and must be a minimum of 10 ft (3.0m) in length. When used with new pavement they are embedded 9 in (229mm) below the top of pavement to reduce deflection. On existing pavements dowel pins are used to anchor the barrier as shown in Figure 5. This figure also shows the tongue and groove connection used between barrier segments.

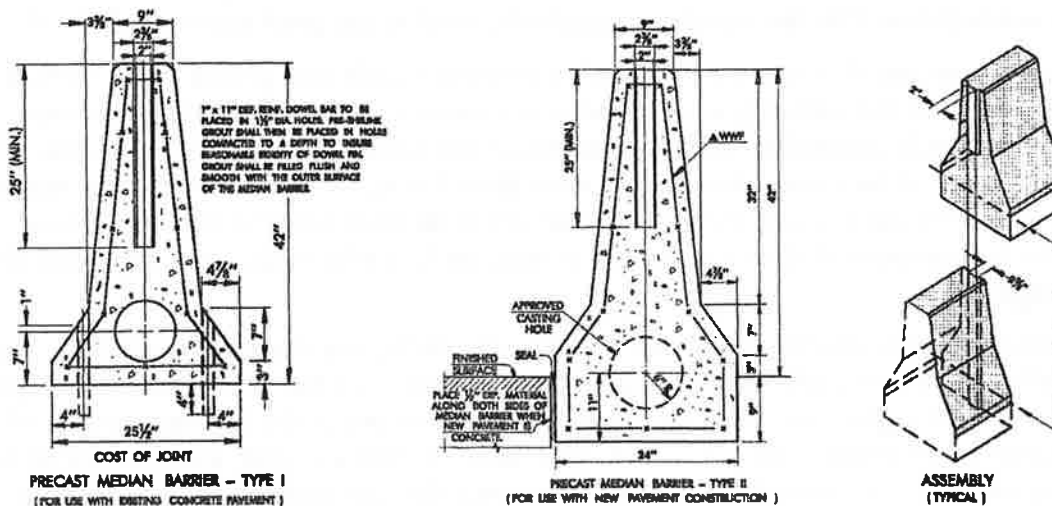


Figure 5 Oklahoma 42-in (1067mm) F-shape permanent barrier  
(Source: Oklahoma DOT PMB-2 01E R-126AE)

## Chapter 6

### Crash Tests of Precast Concrete Barriers

Information on crash tests of precast concrete barriers was obtained from a number of sources including state DOTs, FHWA, research reports, and the testing houses. Only crash tests conducted according to NCHRP Report 350 or MASH guidelines are included in this report.

#### **Free-standing (unanchored) temporary barriers with pin and loop connections**

Most of the crash tests identified were conducted on free-standing barriers without restraints to limit lateral deflection. Some of these barriers were anchored at the ends to represent the resistance that would be present if the tested barriers were part of a longer barrier installation. Lateral deflection of these barriers caused by the crash impact is resisted by the friction between the barrier and the ground/pavement and the mass of the interconnected barrier segments. The success of the crash test is highly dependent on the performance of the connections between the barrier segments.

Table 6 presents results for eighteen crash tests conducted on 32-in (813mm) PCBs with pin and loop connections. The systems are identified by the state for which the barrier was created, and if an FHWA acceptance letter has been published, its code is shown. All of the crash tests in Table 6 were conducted at NCHRP Report 350 test level 3 except for two tests on the Kansas barrier which were conducted with the larger pickup required under MASH guidelines (M09). A "marginal" result indicates that the vehicle roll angle observed in the crash test exceeded 45°.

The crash tests are arranged in order of increasing segment length and profile type, F-shape or New Jersey-shape. The pin and loop connection is described by the number of connections, the number of loops in each connection, and the diameter of the connecting pin. For example, a 2 x 3 connection consists of two connection points with three loops, two from one barrier segment and the third loop from the adjacent barrier segment that is inserted between the other two loops. A 3 x 2 connection consists of three connection points, each of which has two loops, one from each barrier segment.

Of the eighteen crash tests described in Table 6, only eight (44%) are classified as "pass." Three of the tests failed to meet NCHRP Report 350 criteria, and seven of the tests produced marginal results because of roll angles exceeding 45 degrees. Only three out of the ten tests conducted on NJ-shaped barriers performed well, and these tests were on barriers that were heavier or had improved connections. For example, the 10-ft (3.0m) long Georgia barrier has a top width of 12 in (305mm) compared to the conventional 6 in (152mm) width. The 10-ft (3.0m) long Montana barrier has three loop connections rather than two, and the 20-ft (6.1m) long Idaho barrier is longer than all of the other NJ-shape barriers. Even the Idaho barrier had marginal performance when the pin was bolted at the bottom.

Five of eight (63%) of the F-shape barrier crash tests had good results. The three tests that were marginal or failed all had only 2 x 2 loop connections and the minimum cross-section [8 in (203mm) top width].

To generalize from these crash tests results, F-shape barriers tend to perform better than NJ-shape barriers, large cross-section barriers perform better than smaller barriers, and three-loop connections are generally better than two-loop connections. The data are not sufficient to determine if longer barrier segments perform better than shorter length segments.

**Table 6 Crash test results for unanchored temporary 32-in (813mm) PCBs  
with pin and loop connections**

System	FHWA Letter	Test	Results	Roll deg	Pitch deg	Defl ft	Profile	Length ft	Top in	Connect	Pin $\phi$ in
Indiana	B-84	TL3	Pass	5	20	5.3	F	10	10	2 x 2	1.25
Oregon	B-86	TL3	Pass	15		2.5	F	12.5	9.5	2 x 3	1.00
Nebraska	B-41	TL3	Marginal	49	33	3.8	F	12.5	8	2 x 2	1.25
Kansas		TL3	Override	48		3.3	F	12.5	8	2 x 2	1.25
Kansas		TL3	Marginal	49		3.8	F	12.5	8	2 x 2	1.25
Kansas		M09 TL3	Pass	40	-30	4.7	F	12.5	8	2 x 3	1.25
Kansas		M09 TL3	Pass	-24	-13	6.6	F	12.5	8	2 x 3	1.25
Virginia	B-54	TL3	Pass	12	9	6.0	F	20	9	2 x 2	1.25
Georgia	B-57	TL3	Pass	38	9	6.3	NJ	10	12	2 x 2	1.25
Idaho		TL3	Override	35	-19	5.2	NJ	10	6	2 x 2	1.00
Idaho		TL3	Rupture	-63	-27	10	NJ	10	6	2 x 2	1.00
Ohio	B-93	TL3	Marginal	46		5.5	NJ	10	6	2 x 2	1.25
NC	B-98	TL3	Marginal	48		5.0	NJ	10	6	2 x 3	1.25
MT		TL3	Pass	38	10	4.2	NJ*	10	6	3 x 2	1.25
WA		TL3	Marginal	52	-12	4.5	NJ	12.5	6	2 x 2	1.00
WA		TL3	Marginal	59	-22	4.1	NJ	12.5	6	2 x 2	1.25
Idaho	B-70	TL3	Marginal	-53	16	3.3	NJ	20	6	2 x 2	1.25
Idaho	B-70	TL3	Pass	23	28	3.6	NJ	20	6	2 x 2	1.25

\* Profile is a modification of the New Jersey shape

### **Tall temporary barriers with pin and loop connections**

Only three crash tests of tall, pin and loop PCBs were identified, and these tests are described in Table 7. The Oregon 42-in (1067mm) barrier was tested successfully under both TL-3 and TL-4 conditions. The Ohio 50-in (1270mm) barrier was tested successfully under TL-3 conditions.

No crash tests for anchored tall PCBs with pin and loop connections were found. Oregon indicates that it does anchor its 42-in (1067mm) barrier while Ohio does not allow its 50-in (1270mm) barrier to be anchored to bridge decks.

Idaho and Montana have 10-ft (3.0m) long NJ-shape 46-in (1168mm) high pin and loop barriers, but no crash test data for these barriers was located. Neither Idaho nor Montana indicates that their tall barriers are used in anchored conditions.

Table 7 Crash test results for tall PCBs with pin and loop connections

System	FHWA Letter	Test	Results	Roll deg	Pitch deg	Defl ft	Profile	Length ft	Top in	Connect	Pin $\phi$ in
Oregon 42-in	B-86A	TL3	Pass	16	23	2.7	F	10	9	2 x 4	1.25
Oregon 42-in	B-86A	TL4	Pass	-10	8	2.7	F	10	9	2 x 4	1.25
Ohio 50-in	B-149	TL3	Pass	16	-10	5.2	NJ	12	6	3,2,3	1.25

#### Anchored temporary barriers with pin and loop connections

Few of the pin & loop temporary PCBs have been crashed tested under anchored conditions. Of the eleven different pin and loop systems shown in Table 6, crash test data for these systems under anchored conditions could be found for only four: Kansas, K-Rail (Idaho), Oregon, and Washington. The crash test of the anchored Washington PCB was not successful. All of the other seven systems, except for the Georgia barrier, are used with anchors when conditions require lower deflections.

Table 8 provides data on the crash tests for pin and loop PCBs under anchored conditions. The various anchoring techniques used are discussed later in the report. Anchored barriers require greater reinforcement steel because of the greater forces exerted on the barrier in the vicinity of the anchors. Reinforcement of PCBs is discussed in a separate section of the report.

Table 8 Crash test results - anchored temporary 32-in (813mm) PCBs with pin & loop connections

System	FHWA Letter	Test	Results	Roll deg	Pitch deg	Defl ft	Profile	Len ft	Top in	Anchor	Connect	Pin $\phi$ in
Kansas	B-122	TL3	Pass	34	high	0.9	F	12.5	8	3 vert bolts	2x3	1.25
Kansas	B-180	TL3	Pass	38	22	1.8	F	12.5	8	3 vert pins	2x3	1.25
Kansas		TL3	Pass	10	10	3.1	F	12.5	8	Strap	2x2	1.25
Oregon		TL3	Pass	41	-13	3.1	F	12.5	9.5	2 ang pins	2x3	1.00
WashDOT		TL3	Rolled	49		3.8	NJ	12.5	6	2 ang pins	2x2	1.00
K-Rail	B-61	TL3	Pass	30	9	0.9	NJ	20	6	4 vert bolts	2x2	1.25
NJ Half-section		TL3	Rolled	90	-10	0.4	NJ	7.4	9	6 vert bolts	2x3	1.25

### Temporary barriers without pin and loop connections

A few states have 32-in (813mm) temporary PCBs that do not use a pin and loop connection, and all of the proprietary PCBs use a different type of connection. Table 9 gives data on crash tests for these barriers.

Table 9 Crash test results for temporary 32-in (813mm) PCBs without pin and loop connections

System	FHWA Letter	Test	Results	Roll deg	Pitch deg	Defl ft	Pro-file	Len ft	Top in	Anchor/Stiffener	Connection
Texas X-bolt		TL3	Pass	-30	-20	2.3	F	10	9.5	None	X-bolt
PennDOT	B-79	TL3	Marginal	-19	16	8.4	F	12	9	None	Plate
T-LOK	B-42	TL3	Pass	34	15	4.1	F	12	9	None	T-LOK
Quick Bolt	B-190	M09 TL3	Pass	-17	-13	2.6	F	30	9.5	None	Quick Bolt
GPLINK	B-62	TL3	Pass	36	25	1.3	Vert	20	9.5	None	Pin & Plate
CCBWS	B-102	TL3	Marginal	44	5	7.5	NJ	20	10	None	Mod P&L
Texas X-bolt		TL3	Pass	-23	-18	1.6	F	30	9.5	None	X-bolt
Texas X-bolt		TL3	Pass 6:1 slope	-40	-13	1.1	F	30	9.5	None	X-bolt
Montana		TL3	Pass	35	-13	3.6	NJ	10	6	None	Lapped splice
JJ-Hooks	B-52	TL3	Pass	25	13	4.3	NJ	12	6	None	JJ-Hooks
New York	B-94	TL3	Pass	19	51	4.1	NJ	20	6	None	H-section
New York		M09 TL3	Pass	-11	-11	2.3	NJ	20	6	Box Beam	H-section
New York		M09 TL3	Pass w/ joint separation	30	-24	5.4	NJ	20	6	4 vert pins, ½ of units	H-section
Kansas FRP Deck		M09 TL3	Pass	23		0.4	SS	15.3	9	8 bolts	X-bolt

The Pennsylvania barrier is the only one in use today that does not have a connection that transfers tensile forces between barrier segments. It was crash tested in 1999, and an FHWA acceptance letter was issued even though the barrier broke apart completely during the test. The pickup truck was successfully redirected during the test, but because of the inability of the plate connection to transfer tension, the barrier separated at the joint closest to the point of impact. The FHWA-AASHTO implementation agreement associated with NCHRP Report 350 requires

that after October 2002, barrier connection designs must transfer both moment and tension between segments.

The Texas X-bolt PCB has been tested extensively. Three crash tests are shown in table 9, but additional tests were conducted during its development. The 30-ft (9.1m) length barrier has been tested on flat ground (7) and on a 1V:6H slope (8) with reported deflections of 1.6 ft (0.5m) and 1.1 ft (0.3m), respectively. The 10-ft length barrier (9) had a deflection of 2.3 ft (0.7m). These deflections are the lowest of any unanchored PCBs.

The New York barrier uses an H-beam as its connection. It has been crash tested freestanding, stiffened with a backup box beam (10), and anchored with vertical pins (11). The two recent tests were conducted according to MASH guidelines. In the test with the anchored system, one of the joints failed which allowed an increase in deflection to 5.4 ft (1.6m).

A new PCB for Fiber Reinforced Plastic (FRP) composite bridge decks has been developed at the Midwest Roadside Safety Facility for Kansas DOT (12). It was crash tested successfully according to MASH guidelines in March 2009. It is a 32-in (813mm) high, 15 ft 4-in (4.67m) long single sloped barrier which is bolted to the bridge deck with 8 bolts per segment. The detailed report on this barrier is not yet available.

Montana DOT has crash tested successfully a 10 ft (3.0m) PCB with a lapped splice connection. This barrier is not currently in use.

Several proprietary PCBs have been crash tested successfully to TL3. Details on these crash tests are given in Table 9. Of these systems, the JJ-Hooks (Easi-Set Industries), is the one that is most commonly used. At least eleven states allow this barrier to be used. The JJ-Hooks connection may be used with either NJ-shape or F-shape barriers. The "hooks" are formed in the shape of a "J" from 0.4-in (10mm) thick steel plates which are connected through the barrier by three 1-in (25mm) diameter reinforcing rods. The "JJ" hooks from adjacent segments interconnect. (13)

Other proprietary systems include T-LOK (Rockingham Precast), GPLINK (Gunnar Prefab AB), Cabled Concrete Barrier Wall System (CCBWS) (John Carlo, Inc.), and Quick-Bolt Connection (Bexar Concrete Works I, Ltd). The T-LOK barrier is a 12-ft (3.7m) long, 31.9 in (810mm) high F-shape barrier. One end of each segment has an integral "T" shaped steel plate cast into the concrete and the opposite end contains a slotted steel tube. The segments are connected by lifting one segment and sliding its extending "T" plate into the slotted tube on the adjoining segment. (14)

The GPLINK system was developed and crash tested in Sweden. The segments are 19.7 ft (6.0m) long and 34.25 in (870mm) high. The width of the barrier is 9.5 in (240mm) except for the bottom 3.9 in (100mm) and the top 2.8 in (70mm) which are both tapered. The bottom width is 17.3 in (440mm). Adjacent segments are connected with 26.8 in (680mm) long, 0.87 in (22mm) diameter steel rods inserted through steel plates cast into each barrier segment. (15)

The Cabled Concrete Barrier Wall System consists of 20-ft (6.1m) long NJ-shape barriers 32 in (810mm) high with widths of 28 in (711mm) at the base and 10 in (254mm) at the top. Each segment contains two ¾-in (19mm) diameter steel cables with double factory-installed crimps used to form a loop at each end. The cables are placed through 2-in (51mm) diameter PVC sleeves in the center of the barrier 9 in (229mm) from the top and 7 in (178mm) from the bottom of the barrier. Adjacent segments are connected with two 32-in (813mm) long, 1.25-in (32mm)



diameter steel pins which have T-shaped handles on the top and are unrestrained at the bottom. (16)

The F-shape concrete traffic barrier with the Quick-Bolt Connection is 30 ft (9.1m) long, 32 in (813mm) high, 24 in (610mm) wide at the base and 9.5 in (241mm) wide at the top. Ten-in (254mm) long sections of 1.5-in (38mm) diameter PVC pipe are cast horizontally into the ends of each segment to provide access for feeding a threaded rod from one segment into the adjacent segment and securing the nuts and washers on the rod. A 3-in (76mm) diameter, 12-in (305mm) long bolt retraction cavity extends from the hand hole farther into the barrier. Two “hairpin” shaped bars extend horizontally along the top and bottom of the PVC sleeve, hand hole, and bolt retraction cavity. The barrier segments are connected with two 7/8-in (22mm) diameter, 23 in (584mm) long steel rods. (17)

### **Permanent precast concrete barriers**

No crash tests of precast barriers used in permanent applications were found. The general assumption is that if a temporary PCB design performs well in a crash test then a permanent barrier with similar design features will also perform well. Another often-heard comment is that the design has been in use for years without any significant problems.

Many of the permanent PCB designs use dowels or other connections that do not transfer tension between barrier segments. New portable, i.e., temporary precast concrete barriers, must have a connection that transfers tension after October, 2002. However, it appears that this requirement does not apply to PCBs used in permanent applications.

## Chapter 7

### Performance of Precast Concrete Barriers

Precast concrete barriers are used in work zone areas on a temporary basis to shield roadside hazards from motorists, to provide separation between opposing traffic streams, to channelize traffic, and to shield construction workers from vehicles. PCBs are also used by some states in permanent installations as median barriers, roadside longitudinal barriers, and bridge railings.

NCHRP Report 350 and MASH guidelines are used to assess the crashworthiness of roadside safety features including precast concrete barriers. These guidelines evaluate how well safety features perform when impacted under specified conditions from the viewpoint of the impacting vehicle and its occupants. These guidelines do not specifically address the safety of construction workers who typically are located behind the barriers although data on barrier deflection during crash tests does provide useful information to help assess worker safety.

The performance of PCBs must be evaluated from the viewpoints of both the motorist and the construction worker. To date crash tests have been the primary means of evaluating barrier performance. NCHRP Report 350 and MASH both say that performance should also be evaluated through in-service studies since crash tests cannot cover all of the possible impact scenarios that occur in the field. As part of the survey for this study, each state was asked to provide information on in-service evaluations of PCBs. No state was able to provide a structured study of PCB in-service performance. A common response to this request for information was "We haven't heard of any problems so they seem to be working fine."

#### PCB performance from the motorist's viewpoint

The primary crash test (3-11) specified in NCHRP Report 350 and MASH used to evaluate PCB crashworthiness has a pickup truck impacting the barrier at a 25° angle at 62 mph (100 km/h). For temporary applications of PCBs in construction zones, this test represents an extreme condition because of reduced speed limits and narrower roadways that make high speed-sharp angle impacts less likely than on the open highway. Thus, one could argue that the marginal performance observed in many of the crash tests, particularly ones with the NJ-shape, may not be a problem since it is very unlikely that 25° crashes at 62 mph (100 km/h) will occur. But without good in-service performance data this question cannot be answered.

A sufficient number of crash tests of PCBs have been conducted to begin to give some insight on design aspects of PCBs that affect performance in crashes. How this information can be used to improve PCB performance is discussed later in the report.

A few crash tests have been conducted with the larger 5,000 lb (2270 kg) pickup truck required in the new MASH guidelines. Early indications are that the larger vehicle is more stable in PCB crashes than the NCHRP Report 350 4,400 lb (2000 kg) pickup, but that barrier deflections are greater due to the increased mass of the MASH vehicle. From a motorist's viewpoint the improvement in vehicle stability is a plus.

Crash tests of PCBs with small cars are rare. The vehicle used to test for occupant risk in MASH, 2,200 lb (1100kg) passenger car, is significantly larger than the 1,800 lb (820kg) vehicle used in NCHRP Report 350 crash tests. The greater mass of the MASH vehicle should help stability and lower occupant risk. However, at the time that this report is being written, the small Smart car is

being introduced into the US market. If this vehicle becomes a significant portion of the US fleet, its compatibility with PCBs should be evaluated.

PCBs that have passed NCHRP Report 350 TL-3 crash tests should perform adequately from a motorist's viewpoint. Some barrier designs perform better than others, and improvements in barrier design can be made to enhance barrier performance. However, it should be noted that some states are using PCBs that have not been crash tested successfully under NCHRP Report 350.

#### **PCB performance from the construction worker's viewpoint**

NCHRP Report 350, MASH, and FHWA acceptance letters do not consider the safety of people who might be working behind PCBs. An example is the Pennsylvania temporary precast barrier that passed NCHRP Report 350 TL-3 and received an acceptance letter from FHWA even though the barrier broke apart completely during the crash test. The pickup truck was safely redirected, but the welfare of any workers who might have been behind the barrier when it deflected 8.4 ft (2.6m) was not considered. Other PCBs have received passing marks on crash tests even when barriers have separated or deflected large distances.

Dynamic deflections of 4 to 6 ft (1.2 to 1.8m) are common in TL-3 crash tests of unanchored PCBs. These distances need to be incorporated into clearance requirements for work zones behind the barriers. Barriers should not be placed where expected impact deflections will infringe on areas where people are working or where roadside hazards exist.

Many states specify the minimum clearance required behind a barrier. For states that allow anchoring of PCBs these minimum clearances are usually the threshold for when anchoring is required. Clearances can also be used for workers located behind barriers. Table 10 presents a comparison of specified minimum clearances and observed deflections in the TL-3 pickup crash test for states for which the information could be found.

In many cases the specified clearance requirement is less than the deflection that was observed in the crash test for the state's barrier. There is no consistency in required clearances between the states even for states using the same barrier.

Deflection limits for temporary concrete barriers were studied by Sicking, Reid and Polivka (18). They concluded that acceptable barrier deflection depends on the barrier's application. In cases where the barrier will be used on the edge of a bridge deck, the design deflections should be set to contain more than 95% of crashes. In all other applications a criterion in which 85% of crashes are contained should be sufficient. In the case of construction workers, the researchers indicated that the amount of time that workers are immediately behind the barrier is relatively limited and since the impacting vehicle is redirected long before the barrier reaches its maximum deflection, it would not contact the workers. If the workers happened to be close to the barrier, the barrier would slide into them at a very low speed. For the Iowa (Kansas) barrier the 95% deflection limit is the dynamic deflection observed in the 3-11 crash test, 3.8 ft (1.2m), and the 85% deflection limit is 2 ft (0.6m).

Flying debris from vehicular impacts with PCBs is another concern for worker safety. Figure 6 shows an after-impact photograph of a Kansas barrier impacted with a 5,000-lb (2270kg) pickup truck in a 3-11 crash test. The test was considered a success and the report states "There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic." (19, p 30) However, as seen in the photograph, certainly there were fragments that showed potential for penetrating into the area

behind the barrier where people could have been working. Nothing in the current crash test criteria for PCBs addresses the safety of people who might be working behind the barrier.

Table 10 Comparison of clearance requirements and observed crash test deflections

State	Barrier Design	Clearance Requirement ft (m)	Observed Deflection ft (m)		State	Barrier Design	Clearance Requirement ft (m)	Observed Deflection ft (m)
GA	GA	6.0 (1.8)	6.3 (1.9)		MT	MT	6.5 (2.0)	4.2 (1.3)
ND	GA	2.0* (0.6)	6.3 (1.9)		NC	NC	3.1 (0.9)	5.0 (1.5)
CA	ID	2.0 (0.6)	3.6 (1.1)		NM	NC	5.0 (1.5)	5.0 (1.5)
HI	ID	3.3 (1.0)	3.6 (1.1)		NE	NE	2.0 (0.6)	3.8 (1.2)
ID, KY, UT	ID	3.0 (0.9)	3.6 (1.1)		AL	OH	5.0 (1.5)	5.5 (1.7)
IN	IN	5.0 (1.5)	5.3 (1.6)		OH	OH	3.7 (1.1)	5.5 (1.7)
MD	IN	4.0 (1.2)	5.3 (1.6)		TN	OH	4.0 (1.2)	5.5 (1.7)
FL, WI	KS	4.0 (1.2) H 2.0 (0.6) L	3.8 (1.2)		AK CO	OR	3.0 (0.9) 4.0 (1.2)	2.5 (0.8)
KS, OK	KS	2.0 (0.6)	3.8 (1.2)		TX	TX	2.0 (0.6)	2.3 (0.7)
MO	KS	4.0 (1.2) B 2.0 (0.6) R	3.8 (1.2)		NV	OR	4.0 (1.2) B 3.0 (0.9) R	2.5 (0.8)
MI	MI	4.0 (1.2)	N.A.		VA	VA	6.0 (1.8)	6.0 (1.8)

\* Requirement is under review, H – speeds  $\geq 50$  mph, L – speeds  $\leq 45$  mph, B – on bridges, R – on roadways

It should be noted that “the center of gravity of 686 mm (27 in.) of the pickup [involved in the crash test of the barrier shown in Figure 6] was determined to be at the low end of the c.g. height range of the large passenger vehicle class (i.e., light trucks) currently on the roadways. Consequently, this vehicle was judged to not be an accurate representation of the light trucks on the roadways ...” (19, p 31), thus this test did not meet official MASH criteria.

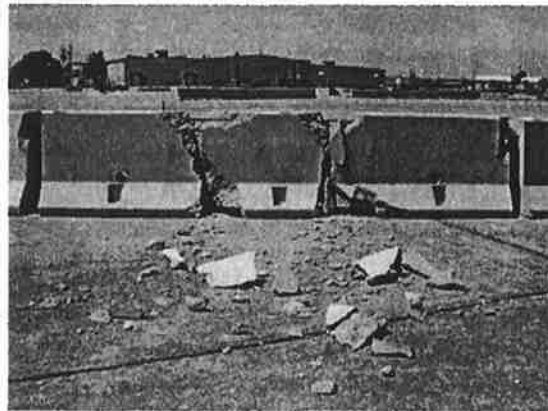


Figure 6 Debris on the backside of a barrier after a crash test  
Source: MwRSF Report TRP-03-173-06 (19)

## Chapter 8

### Discussion of PCB Design Features

The major features of precast concrete barriers that affect its performance include the profile of the barrier facing the traffic; the length of the barrier segments; the type of connection used to join adjacent segments; the way that the barrier is anchored or stiffened; the amount, size, and pattern of the reinforcing steel; and the properties of the concrete and steel materials used in the barrier. It is important to note that each of these elements contributes to the performance of the barrier system individually and interactively with the other elements of the barrier “system.” Each of these features is discussed below.

#### Profile and cross-section

The traffic-side profile of a precast concrete barrier is an important determinant of the barrier’s performance. Longitudinal barriers are designed to contain and redirect impacting vehicles in a stable and safe manner. These barriers need to perform well for a wide range of vehicle types and sizes for crashes at various speeds and impact angles. Today’s precast concrete barriers have one of three profiles: New Jersey, F-shape, or single slope (a.k.a., constant slope) as shown previously in Figure 1.

The New Jersey profile gets its name from the state that conducted the experimental work that led to this “optimal” shape that has been in use for about fifty years. While California installed its first concrete median barriers in 1946 on the Grapevine Grade, it was New Jersey that made the effort to refine the barrier’s design. The first New Jersey barrier was installed in 1949 on the Judgetown Mountain section of U.S. Route 22. It had a 30 in (762mm) wide base and was 19 in (483mm) tall of which 3 in (76mm) was below the pavement surface. In-service evaluations resulted in several increases in the barrier’s height to prevent overrides. By 1959 the 32 in (813mm) high barrier was being used. (20)

Research in the 1970s at Southwest Research Institute (21) examined a number of different shapes for concrete barriers which resulted in the creation of the F-shape barrier, which received its name from the letter associated with its 6<sup>th</sup> order in the alphabetical list of barrier shapes studied. The most significant difference between these two profiles is that the break between the lower and upper slopes of the barrier face occurs 3 in (76mm) higher for the New Jersey shape, at 13 in (330mm) versus 10 in (254mm) for the F-shape.

The New Jersey and F-shape profiles, often called “safety shapes,” were developed to minimize vehicle damage in low-angle impacts. The design minimizes sheet metal damage by allowing the vehicle’s tires to ride up the sloped face of the barrier tilting the vehicle away from the barrier’s face. As the vehicle rides up the barrier it is redirected back onto the roadway. The trick is to allow sufficient ride up to cause redirection, but not too much to cause the vehicle to yaw, pitch, or roll excessively. (22)

Crash tests, simulations, and in-service evaluations have shown in steep-angle crashes the tendency for small vehicles to ride up the face of these barriers far enough to cause vehicle instability and the chance for a rollover. A study conducted by the Texas Transportation Institute (TTI) investigated rollovers caused by concrete safety-shaped barriers. (23) The study examined the extent and severity of these overturn crashes, the causes for them, and proposed potential countermeasures to reduce concrete-barrier rollovers. Simulation was used to evaluate three

potential countermeasures: F-shape, constant slope, and vertical wall barriers. The results indicated that for rollovers, the F-shape barrier offers little improvement over the NJ-shape barrier. The vertical wall barrier showed the greatest potential to reduce rollovers, but at a cost of significant increases in lateral accelerations that could result in the contact of the occupant's head with the barrier during the crash. The constant slope barrier showed promise as a compromise solution.

At the time of this rollover study another group of TTI researchers were in the process of developing a single-slope concrete median barrier. The main objective of this project was to develop a barrier shape that could handle pavement overlays without compromising barrier performance. (24) Because of the shape of the NJ- and F-shaped barriers, the profile encountered by a colliding vehicle is changed with each pavement overlay. However, with a constant-slope barrier there is no change in profile with pavement overlays, only a decrease in the effective height of the barrier. Simulations were used to optimize the slope of the barrier to reduce rollover potential. The final design was a 42 in (1067mm) high barrier with a 10.8° slope. A series of NCHRP Report 230 crash tests were conducted with two different types of connections representing use as a temporary barrier and as a permanent barrier.

Height is an important component of barrier profile that affects barrier performance and cost. The "standard" height for TL-3 barriers is now 32 in (813mm) although a few states have designs that vary slightly from the standard. Indiana's F-shape barrier is 31 in (787mm) high while Colorado's F-shape barrier is 34 in (864mm). Maine's NJ-shape barrier is 31.5 in (800mm) high while Rhode Island's is 33 in (838mm).

Higher performance PCBs meeting TL-4 and TL-5 requirements have been developed. These barriers must be taller than the TL-3 barriers to contain the larger test vehicles. Tall barriers range in height from 42 in (1067mm) to 50 in (1270mm). Table 5 provides details on available tall barriers.

Variations in cross-sections of PCBs exist. For example, the two most common F-shape designs are the Kansas and Oregon systems. Kansas barriers have a base width of 22.5 in (572mm) and a top width of 8 in (203mm) while the Oregon barrier has a 24 in (610mm) base and a 9.5 in (241mm) top width. The larger cross-section of the Oregon barrier makes it 50% heavier per unit length than the Kansas barrier. The top width of F-shape barriers used by other states ranges from 9 in (229mm) to 10 in (254mm).

The standard NJ-shape barrier has a base width of 24 in (610mm) and a top width of 6 in (152mm). Maine's barrier varies from these dimensions slightly, probably because of its use of metric units. Its barrier has a base width of 23.6 in (600mm) and a top width of 5.9 in (150mm). Kentucky and Tennessee use a large NJ-shape barrier with a base of 27 in (686mm) and a top width of 9 in (229mm).

The largest cross-section PCB is used by Georgia and North Dakota. This NJ-shape barrier has a base width of 30 in (762mm) and a top width of 12 in (305mm). It is interesting that the most massive PCB also had the largest dynamic deflection observed in the NCHRP Report 350 TL-3 crash tests. Georgia's barrier had a deflection of 6.3 ft (1.9m) while the much lighter Kansas barrier had a deflection of 3.8 ft (1.2m). Segment length may have been a factor since the Georgia barrier is only 10 ft (3.0m) long while the Kansas barrier is 12.5 ft (3.8m) long.

An FHWA-sponsored study of portable concrete barrier profiles, lengths, and connections was conducted by the National Crash Analysis Center (NCAC) at the George Washington University (25). Finite element (FE) analyses were performed to determine the expected safety performance of a variety of hypothetical PCB designs. The FE models, validated using data from previous crash tests, were used to simulate NCHRP Report 350 test 3-11 for the different barrier designs.

Five different shapes (F, NJ, single slope, vertical, and inverted) were simulated in both a narrow width and a wide width. Four barrier segment lengths; 6 ft (1.8m), 10 ft (3.0m), 12 ft (3.7m), and 20 ft (6.1m), were compared. Two different barrier gap separations were compared. The “open” gap had a separation of 3.1 in (80mm) between the ends of the barrier and the “closed” gap design had no separation. Two different barrier connections were used in the analyses. The “close hook” configuration, similar to what is used by most states, separated adjacent loops by 1.6 in (40mm) and the pairs of loops by 16.9 in (430mm). The “far hook” design separated adjacent loops by 4.7 in (120mm) and pairs of loops by 10.6 in (270mm). Altogether 160 different PCB designs were simulated.

Results of the analyses can be seen in Figure 7. The ten different profiles are shown along the left side of the figure with a separate row for each of the two hook designs. Across the top of the figure the four barrier lengths are shown with a separate column for the two gap designs, open and closed. Cells that are colored green indicate simulations where all crash test criteria were met and cells in red indicate cases where the simulations resulted in at least one of the NCHRP Report 350 3-11 criteria not being met.

The F-shape narrow configuration [base 22.4 in (570mm) and top 7.9 in (200mm)] with a “close hook” design produced successful simulations for all of the segment lengths and gap combinations. Similarly the New Jersey narrow configuration [base 24.0 in (610mm) and top 6.0 in (152mm)] with an “open hook” design produced successful simulations for all of the segment lengths and gap combinations.

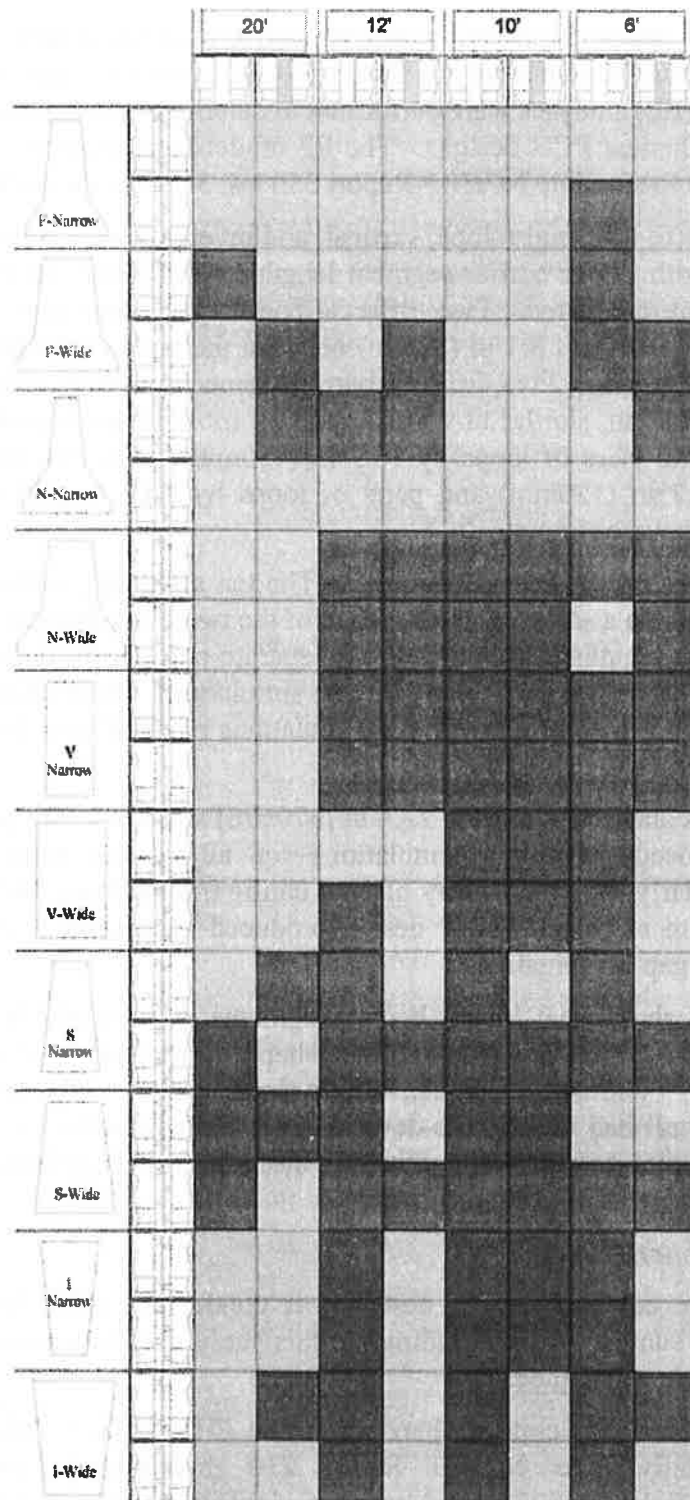
In general the study shows that longer barrier segments, particularly the 20 ft (6.1m) length, performed better than shorter lengths. The NJ-shape barriers showed a greater tendency for producing rollovers. While the vertical, single-slope, and inverted shapes produced lower rotation angles, they all had higher ride-down accelerations than the F- and NJ-shape barriers. This study indicates that current F-shape barrier designs should perform well relative to other possible PCB profiles.

### **Aesthetic concrete barriers**

A study of aesthetic concrete barrier design was conducted under NCHRP 22-19 by TTI. NCHRP Report 554 summarizes the findings of this study, but the concrete barriers considered were cast-in-place rather than precast.

There is one precast aesthetic concrete barrier that has FHWA TL-3 acceptance although it has been crash tested only under NCHRP Report 230 guidelines. According to an FHWA Memorandum dated 9 April 2003 from Michael S. Griffith, the Pre-cast Concrete Guardwall is considered to have met NCHRP Report 350 TL-3 evaluation criteria. (26)

This barrier, shown in Figure 8, has an inverted “T” cross-section, and the 10 ft (3.0m) long segments are ship-lapped at each end. The barrier is 39.6 in (1007mm) high with a base width of 42.1 in (1070mm) and a top width of 26 in (660mm). The surface of the barrier can be tailored in color and pattern to blend in with the surrounding landscape. (27)



**Green** cells indicate simulations where all crash test criteria were met and **Red** cells indicate cases where the simulations resulted in at least one of the NCHRP Report 350 3-11 criteria not being met.

Figure 7 Parametric analysis of PCB configurations  
Source: National Crash Analysis Center (25)



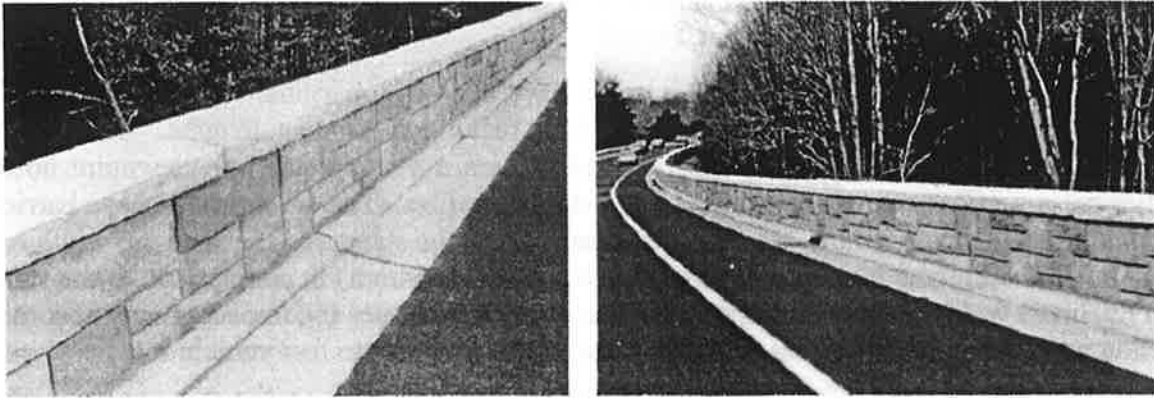


Figure 8 Pre-cast Concrete Guardwall  
Source: MwRSF Report TRP-03-197-07 (26)

### Length

Precast concrete barriers range in length from 10 ft (3.0m) to 30 ft (9.1m). Shorter length barriers are easier to transport and handle because of their lower weight, and they can be used on sharper horizontal curves than the longer ones. Longer barriers have fewer segment connections for a given length, which can shorten the time for installation and removal and reduces the number of potential snag points.

Longer barriers have more mass which should help to reduce dynamic deflections in impacts, particularly if the barrier is not anchored. However, research conducted at TTI in the late 1970s found that deflection was lowest for segment lengths of either 10 ft (3.0m) or 30 ft (9.1m) and was greatest for 20 ft (6.1m) segments (28). This phenomenon is explained by the conflicting influences of moment capacity and friction. The frictional resistance to deflection increases with segment length and for long segments of 20 to 30 ft (6.1 to 9.1m) the influence of barrier energy absorption attributable to friction becomes dominant. On the other hand, for short segments more impact energy is absorbed through joint rotation than by friction. The amount of energy absorbed through joint rotation increases with the moment capacity of the connections.

For a constant amount of joint rotation, lateral deflection of the barrier increases directly with segment length, e.g., as segment length goes from 10 to 20 ft (3.0 to 6.1m) the lateral deflection will double. With a short segment length of 10 ft (3.0m) joint rotation is high because little of the impact energy is being absorbed by friction. However, even though the barrier rotates a relatively large amount, the lateral deflection is small because the segment length is short. As segment length is increased to 20 ft (6.1m) the energy absorbed by friction increases, but the decrease in the energy that must be absorbed by joint rotation is not enough to compensate for the increase in lateral deflection caused by the longer segment. For segments longer than 20 ft (6.1m) the increase in energy absorbed by friction is sufficient to compensate for the increase deflection caused by the longer segment length which leads to an overall decrease in lateral deflection. The optimum length of the barrier segment to minimize lateral deflection is therefore a function of the moment capacity of the connection and the friction between the barrier and the roadway/shoulder.

Marzougui et al (29) performed friction tests with concrete barriers on asphalt, concrete, and gravel pavements. They found that the dynamic coefficient of friction between the barrier and pavement was 0.2 and was consistent for varying speeds and directions of movement (lateral and

longitudinal). However, the static coefficient of friction varied widely from 0.4 to 1.2 for the different cases investigated.

Most of the crash tests of 10 ft (3.0m) barriers have had only marginal results because of high vehicle instability, and some states are switching to longer segment lengths. The two 10-ft (3.0m) barriers that performed well in crash tests from a vehicle stability viewpoint both had heftier cross-sections than the typical NJ and F-shape profiles. The Georgia NJ-shape barrier has a top width of 12 in (305mm), which is twice as wide as the standard NJ-shape top width of 6 in (152mm). The Indiana F-shape has a top width of 10 in (254mm) in comparison to the standard 8 in (203mm) width. The greater mass of these barriers increases the impact energy absorbed by friction which should lead to less rotation of the barrier and thus to less vehicle roll.

The two most popular barriers, the Kansas and Oregon F-shape, are 12.5 ft (3.8m) in length. The Idaho barrier, currently used by 6 states, is 20 ft (6.1m) long. The only 30-ft (9.1m) PCBs that have been crash tested are the Texas X-bolt barrier and the Quick-bolt proprietary system.

The Kansas F-shape barrier is being developed by the Midwest Roadside Safety Facility (MwRSF) through a pooled fund project initially supported by Iowa, Kansas, Minnesota, Missouri, Nebraska, and South Dakota. The 12.5 ft (3.8m) segment length for the Kansas barrier was selected in the mid 1990s based primarily on the TTI research findings (30) described earlier. MwRSF listed the three reasons for selecting this segment length:

1. It provides an increased capability over 20 ft (6.1m) segment lengths for limiting lateral barrier deflections,
2. It should be easier to handle for temporary uses than longer segment barriers, and
3. It provides a 30% increase in weight over the 10 ft (3.0m) long NJ safety shape but maintains contractors' ability to lift and install the barrier with current equipment. (30)

Some states allow the use of barriers of more than one length. Typically only the shortest length barrier will be crash tested on the assumption that longer length barriers of the same design will perform at least as well as the shorter length barrier.

A short, 8 ft (2.4m) version of the standard 20 ft (6.1m) New York PCB was crash tested under NCHRP Report 230 conditions. While the observed dynamic deflections were slightly lower with the shorter version, the vehicle instability was significantly higher. In one of the three crash tests with the 8 ft (2.4m) barrier, the vehicle rolled over, and in the other two tests the vehicle roll angles were -64° and -42°. In a similar crash test with the 20 ft (6.1m) segment the vehicle roll angle was only -11°. (31)

Segment length is only one of the factors that affect PCB performance, and at this time there is no consensus on what the optimum segment length should be. Crash tests of existing barriers have not shown any consistent relationships between vehicle stability and barrier length nor between lateral deflection and barrier length. Most researchers feel that the connection between barrier segments has a larger influence on barrier performance than does segment length.

### **Connection**

A very important feature of precast concrete barriers is the connection between adjacent segments which is usually the weakest structural component of the barrier. The connection's primary function is to limit the movement and rotation of the barrier segments, but it also must be capable of absorbing some of the impact energy. To allow the individual segments to work

together as a system to contain and redirect the impacting vehicle, the connection needs to be capable of transferring tension and moment between adjacent segments.

Connection design directly affects the amount of dynamic deflection that occurs during impacts and indirectly affects the stability of the vehicle after impact. Since most PCBs are used for temporary applications, the ease of assembly and disassembly is an important consideration in connection design.

By far the most common type of PCB connection is the pin and loop which is used by 46 states. It consists of steel loops that extend from each end of a barrier segment at specific heights that allow loops from adjacent segments to align in a way that permits a pin to be dropped in place through the loops. Figure 9 shows the design used in Virginia for its FHWA-accepted 2 x 2 pin and loop connection.

Although the functions performed by PCB pin and loop connections are identical, a large number of different designs are used in the USA. The designs appear to be independent of barrier profile and vary by the number of loops, the shape of the loops, the type of material used to form the loops, the diameter and length of the connection pin, the method for securing the pin, and the method for anchoring the connection loops into the concrete and its reinforcement system.

Researchers in the mid 1980s analyzed pin and loop designs (32). At that time, of the states using pin and loop connections, 27 agencies used pin and rebar, 14 used pin and wire rope, two used pin and eye bolt, and one used pin and plate. The researchers analyzed each of these connections and computed the structural capacities of the loops in terms of tension, shear, moment, and torsion. Based on their findings five recommendations were made:

1. Inserted loops are preferable to staggered loops in pin and loop connector design because of the inserted loops' resistance to torsional overturn of individual barrier segments.
2. Pins in pin and loop connectors should be anchored at both ends of the barrier segment. Only nut and washer anchoring will prevent pins from being bent out of the loop when the pin is loaded.
3. Because of its greater strength, wire rope is generally preferable to steel reinforcing bars for forming loops in pin and loop connectors.
4. States should use PCB connectors only if they have been structurally analyzed and successfully crash tested.
5. Connectors should be designed to match the strength of all components of the connector. (32, p103)

Subsequent to this study states have generally moved away from using rebar and wire rope for loops and now primarily use smooth steel bars which provide a strong, stiff connection that resists barrier rotation. Connectors used by thirty-four states employ inserted loops in which the loops from one barrier segment are surrounded by the loops from the other barrier segment. Only nine states still use "staggered" loops where the loops from one segment are each higher than the associated loop from the other segment. The use of nuts and washers to secure the bottom of the connection pin varies among the states as discussed below.

Figures 9, 10 and 11 show four different 2 x 2 pin and loop connections used by a number of states. All four designs use a 1.25-in (32 mm) diameter steel pin that is inserted through four overlapping loops (two from each barrier segment). The pins used in the Virginia (Figure 9) and

the Indiana (Figure 10 left) systems have nuts that secure the pin at each end. Both of these designs have “staggered” loops. The pin for the Ohio design (Figure 10 right) has a nut only at the bottom, and the pin for the Idaho design (Figure 11) has no nuts at all. These two connections have “inserted” loops.

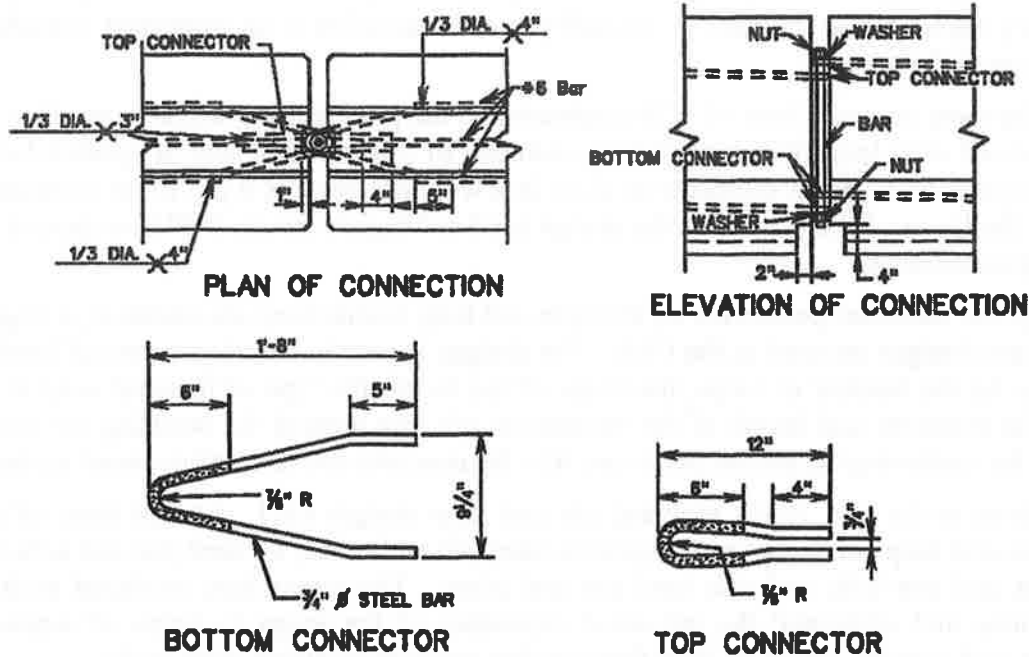


Figure 9 Virginia's 2 x 2 pin and loop connection

Source: VA DOT 501.46

The method for anchoring the loop steel into the concrete differs by system. The loops for the Virginia system are relatively short, 18 in (457mm) for the bottom and 12 in (305 mm) for the top, and are directly connected (welded) to longitudinal reinforcement bars. In the Indiana system the loop bars are approximately 6 ft (1.8m) long, and the bars from each end are overlapped longitudinally in the middle of the barrier. Ohio and Idaho use a similar design for their loop bars which is shown in the steel loop bar detail in the lower right corner of Figure 11.

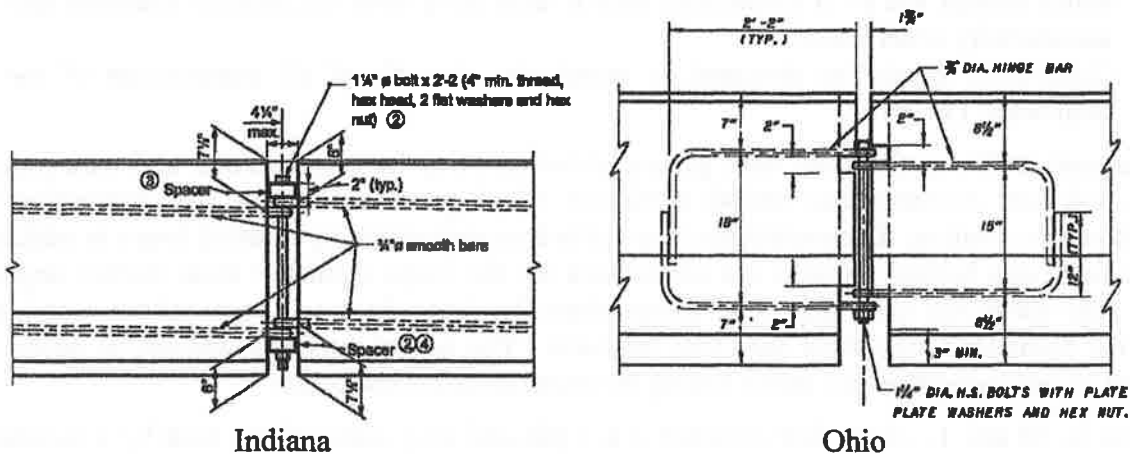


Figure 10 Comparison of 2 x 2 pin and loop connections – Indiana and Ohio

Sources: IN DOT 801-TCCB-02 and OH DOT PCB-91

The design for the Idaho pin and loop connection shown in Figure 11 is the result of developmental testing conducted at E-TECH in 1999 and 2000. The first design tested consisted of four (two per barrier)  $\frac{1}{2}$  in (12mm) diameter wire rope loops through which a 1 in (25mm) round steel bar 29.5 in (750mm) long was inserted. In the crash test the connection broke very quickly which allowed the vehicle to ramp over the barrier. In a follow up test the connection was strengthened by shortening the pin to 25 in (635mm) and adding washers and a hex nut to the bottom of the pin. In the second crash test slack developed in the wire rope connection which allowed the upper end of the downstream barrier segment to become exposed. The vehicle's tires contacted the exposed end, which caused the vehicle to ramp up and over the barrier. (33)

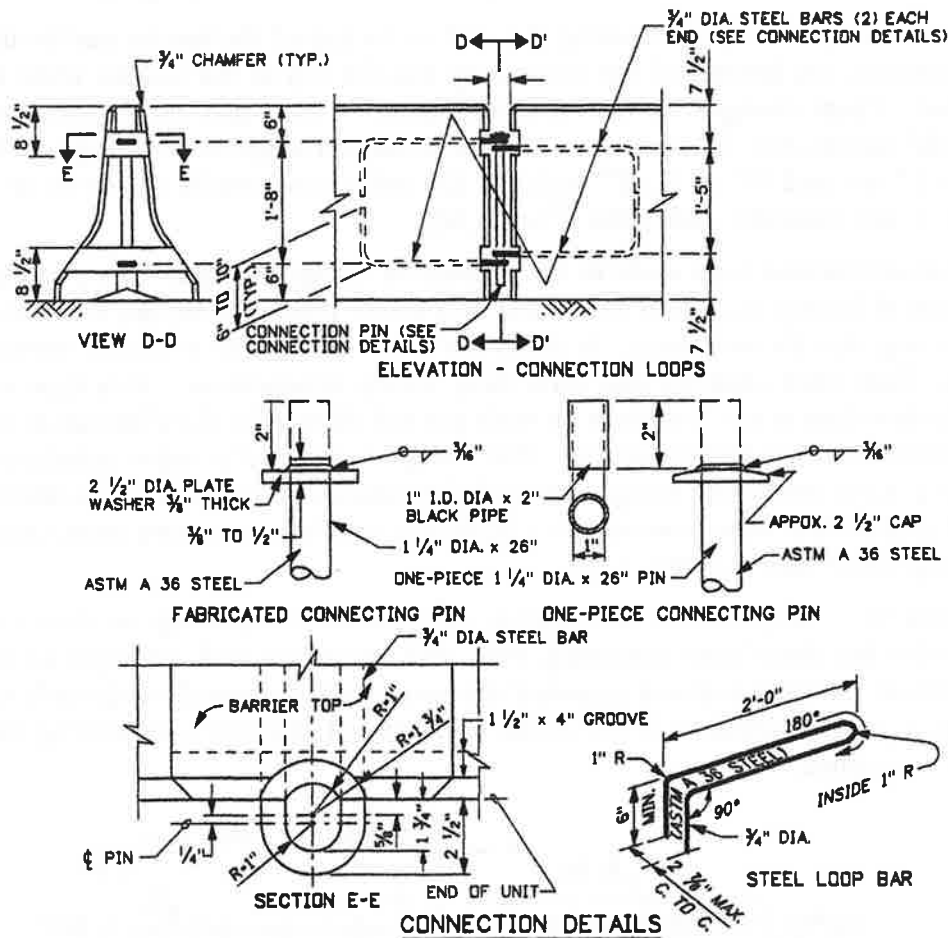


Figure 11 Idaho's 2 x 2 pin and loop connection  
Source: ID DOT G-2-A-1 sheet 1

In the third design the wire rope loops were replaced with  $\frac{3}{4}$  in (19mm) diameter solid steel bars. The 1 in (25mm) pin was replaced with a 1 1/4 in (32mm) diameter A307 hex bolt that was 25 in (638mm) long and had washers and a nut to secure the bottom of the pin. The crash test on this design was successful, but only marginally because of a -53° roll angle. The design was modified by removing the washers and nut from the bottom of the pin and using a 26 in (660mm) long pin. This time the crash test was also successful, and the roll angle was lowered to 23° (34). While the unsecured pin worked better than the bolted pin in these two crash tests, it is not known if the same results would occur if the crash tests were to be repeated.

The Kansas system, which is now the most widely used PCB design, has been under continuous development since 1995. The pin and loop connection was selected because prior research had shown that it was capable of providing the needed structural capacity, and it was approximately 50% less expensive than other available connections with comparable strength (30).

The first connection design for the Kansas F-shape barrier had a 2 x 2 pin and loop configuration with a 1 1/4 in (32mm) diameter pin that was secured at the bottom with a pin and cotter pin. The crash test of this design was unsuccessful because the left rear wheel of the vehicle contacted the ground behind the barrier. The cause of the failure was attributed to recessed areas located at the top of each barrier that weakened the pin and loop connection causing the rebar loops to deform significantly which in turn allowed excessive joint rotation and barrier uplift.

The design was modified by eliminating the void at the top of the barrier and by decreasing the clearance between the bottom of the lower loop and the top of the bottom plate to reduce pin deformations. These changes were sufficient to improve the crash test performance enough to meet NCHRP Report 350 TL-3 criteria. However, the roll angle did not improve from the first test (48° on 1<sup>st</sup> test and 49° on the 2<sup>nd</sup> test) and the deflection actually increased to 3.8 ft (1.2m) from 3.3 ft (1.0m) observed during the 1<sup>st</sup> test. (30)

Additional modifications were made to the connection design to improve its performance. For a while instead of having each loop composed of a single rebar, the design was changed to have three rebars together for each loop. In about 2001 the design was modified further to have six loops, three from each segment that form two, 3-loop connections. This type of connection provides double shear at two locations on each pin and allows for the elimination of the retainer bolt at the bottom on the connection pin. This change was part of a major redesign of the barrier to allow for a better anchoring design that could be used on bridges and on pavements. Features from the standard plans from Kansas, Iowa, Nebraska, and Missouri were incorporated as well as the 2 x 3 loop design from Oregon. (35)

Today the Kansas F-shape system still uses a 2 x 3 pin and loop design as shown in Figure 12. The connection has three loops extending from each segment's ends arranged so that two loops at the bottom of the right segment surround the single bottom loop from the left segment. The loops at the top are reversed with two loops from the left segment surrounding the single loop from the right segment.

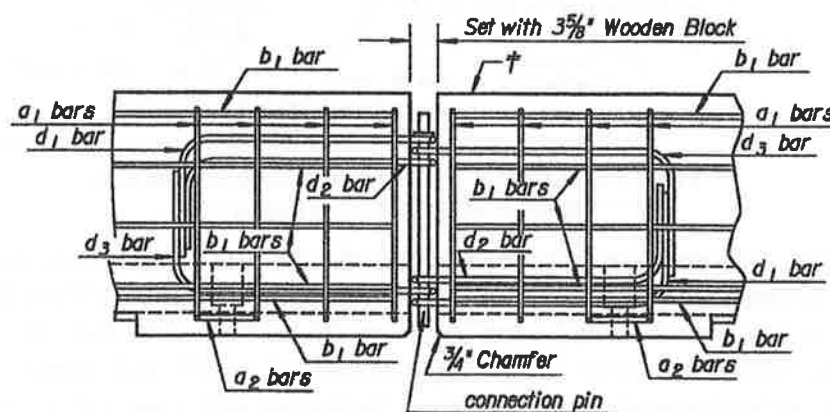


Figure 12 Kansas 2 x 3 pin and loop connection  
Source: KS DOT RD 622

The dynamic deflections observed in crash tests do not appear to be related to the number of loops in the connection. For 32-in (813mm) high unanchored PCBs crash tested according to NCHRP Report 350 Test 3-11, the dynamic deflections for successful tests have varied from 2.5 ft (0.8m) for the Oregon F-shape 2 x 3 pin and loop system (Figure 13) to 6.3 ft (1.9m) for the Georgia NJ-shape 2 x 2 pin and loop system. However the North Carolina NJ-shape 2 x 3 system had a deflection of 5.0 ft (1.5m) while the Idaho NJ-shape 2 x 2 system had a deflection of only 3.3 ft (1.0m).

Details of the Oregon system 2 x 3 pin and loop connection are shown in Figure 13. Oregon and Washington are the only two crash-tested systems still using a 1-in (25mm) diameter connection pin. The majority of the states use a 1.25 in (32mm) diameter pin. Connecticut, Rhode Island, Vermont, and West Virginia use 1-in (25mm) pins, but their systems have not been crash tested. Maine's PCB, which also has not been crash tested, uses a 0.94 in (24mm) diameter pin.

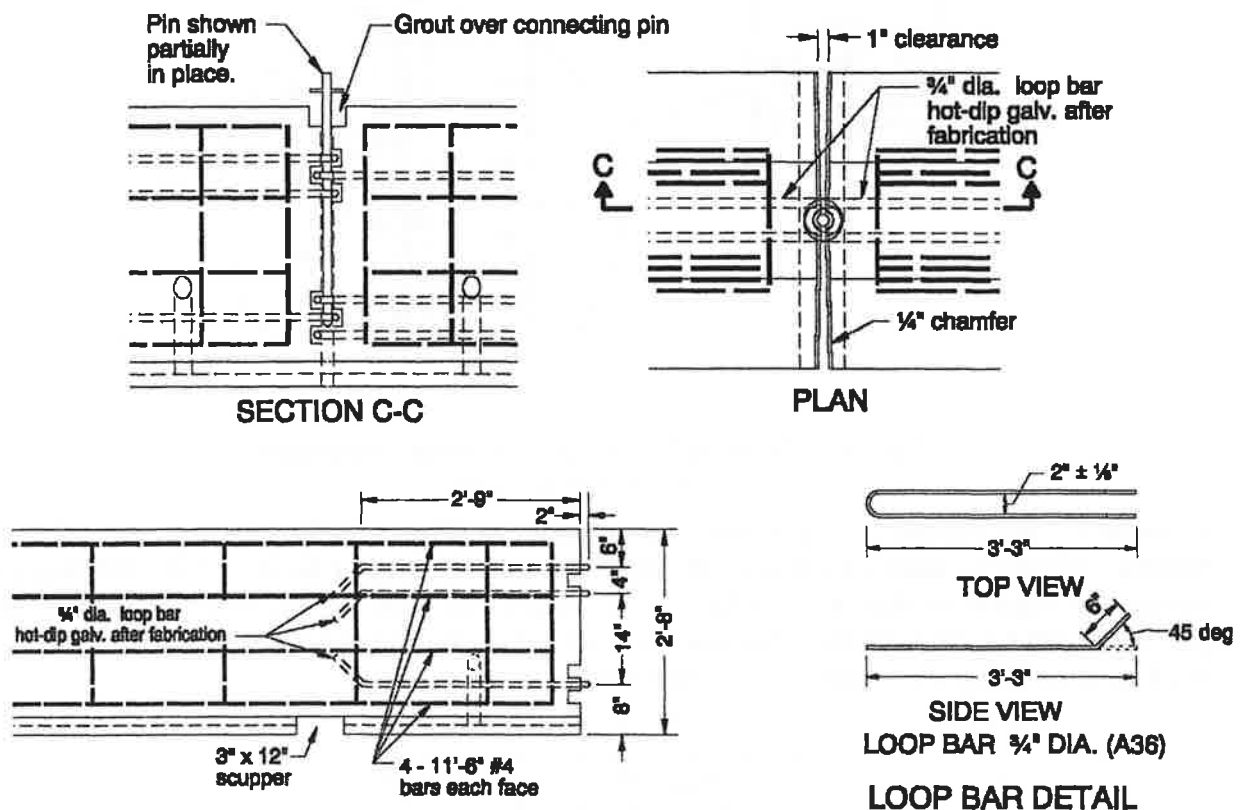


Figure 13 Oregon's 2 x 3 pin and loop connection  
Source: OR DOT RD-500

Montana has crash tested successfully a 3x2 pin and loop design (Figure 14). It is the only 32-in (813mm) barrier with a connection design that has three pairs of loops through which the pin passes.

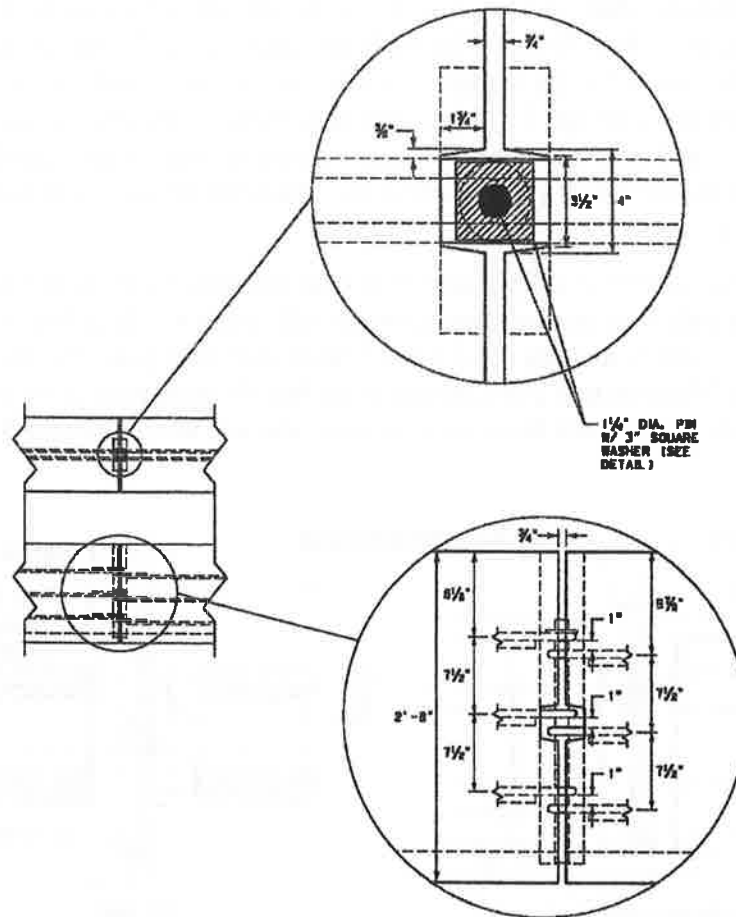


Figure 14 Montana's 3 x 2 pin and loop connection

Source: MT DOT 606-60

As expected tall barriers with pin and loop connections have more loops than 32-in (813mm) barriers. Figure 15 shows the 8-loop (4, 4) design used in Oregon for its 42-in (1067mm) tall barrier and Figure 16 shows the 8-loop (3, 2, 3) pin and loop design used for Ohio's 50-in (1270mm) tall NJ-shape PCB. Montana has a 46-in (1168mm) tall barrier that uses a 3 x 2 pin and loop connection similar to the one shown in Figure 14.

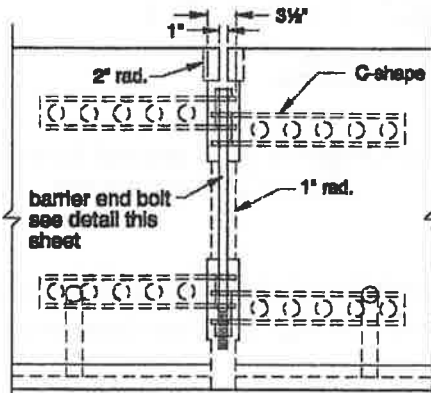
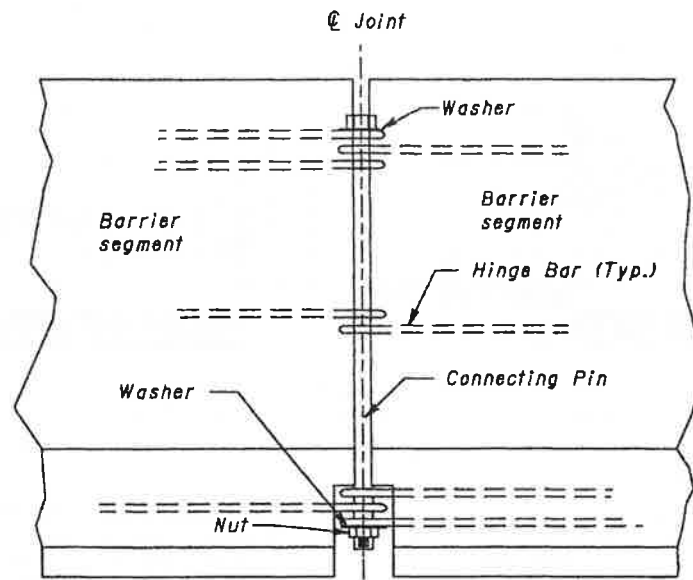


Figure 15 Oregon's 8-loop connection for its 42-in tall barrier

Source: OR DOT RD545





*Connecting Pin is a 1 1/4" [32] diameter by 43" [1190] Grade 5 galvanized high strength steel bolt, with 3" [75] of threads. (Each bolt passes through eight hinge bar loops - four on each segment.)*

*The assembly requires two F436 1 1/4" [32] flat washer with an ID of 1 3/8" [35] and an OD of 2.5" [64]. The thickness is 0.156" [4]. The flat washer is hot dipped galvanized.*

*The assembly also requires one 1 1/4" [32] -7 heavy hex nut. The nut is hot dipped galvanized and waxed and is categorized 2H/DH.*

#### CONNECTING PIN ASSEMBLY

Figure 16 Ohio's 8-loop connection for tall barriers

Source: OH DOT RM-4.1

While the pin and loop connection is by far the most popular design used for precast concrete barriers, several states and companies have developed and crash tested other types of connections. Texas has developed an F-shape PCB that uses an X-bolt connection in which two 7/8 in (22mm) diameter threaded bolts 29 in (737mm) long are used to secure the barrier segments as shown in Figure 17. The unanchored barrier has been crash tested with segment lengths of 10 ft (3.0m) and 30 ft (9.1m) which resulted in dynamic deflections of only 2.3 ft (0.7m) and 1.6 ft (0.5m), respectively. (7, 9)

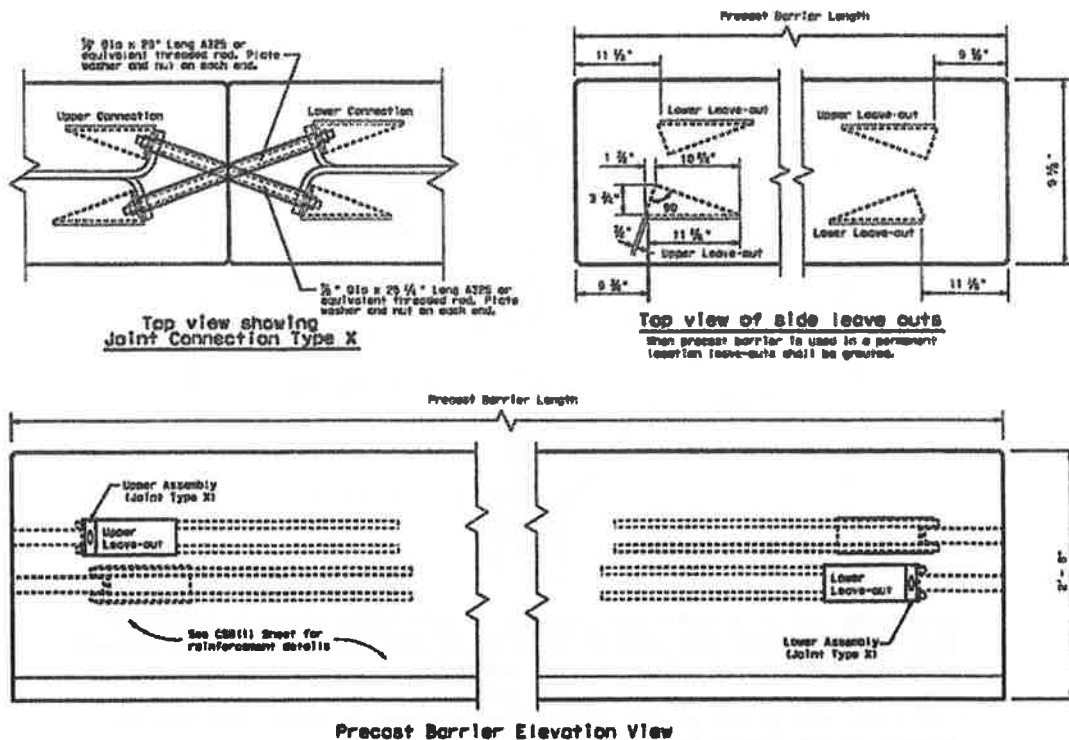


Figure 17 Texas X-bolt connection

Source: TX DOT CSB(2)-04

New York has developed a NJ-shape barrier that uses an H-shape connection key to transfer tension between barrier segments as shown in Figure 18. The 3.25 in (83mm) x 2 in (50mm) connection key slides down into openings at each end of the barrier. In an NCHRP Report 350 3-11 crash test with the barrier unanchored a dynamic deflection of 4.1 ft (1.3m) was observed. This barrier design is used also by New Jersey.

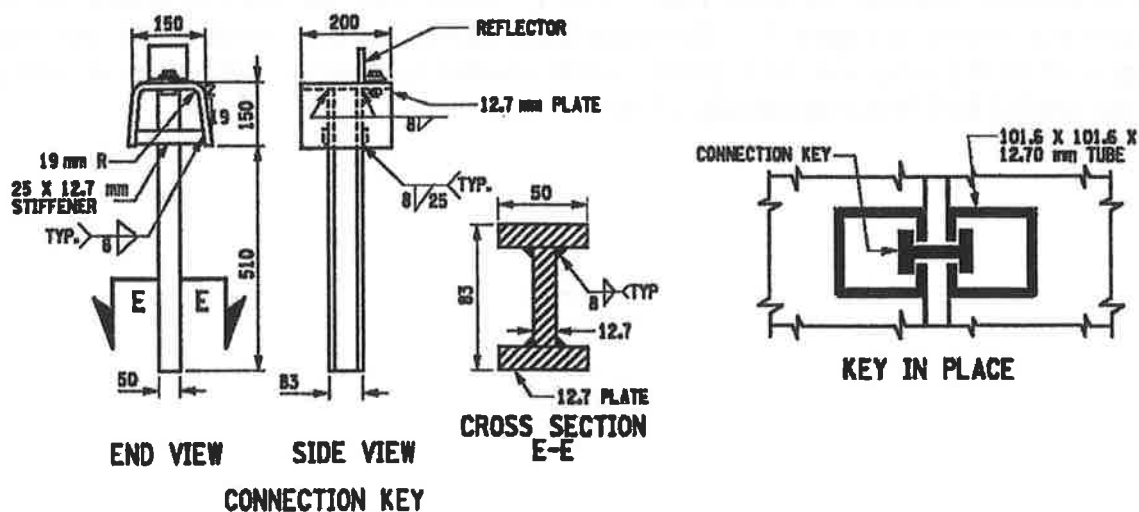


Figure 18 New York key connection

Source: NY DOT M 619-70

Pennsylvania is the only state that still uses a precast concrete barrier that is not capable of transferring tension between adjacent segments. Its F-shape barrier uses a steel plate that fits in vertical slots in the end of each barrier segment as shown in Figure 19. This barrier has been crash tested and was given an acceptance letter from FHWA even though the barrier connection at the point of impact separated completely in the crash test. The observed deflection was 8.4 ft (2.6m), but since the vehicle was contained and redirected, the test was considered a “success.”

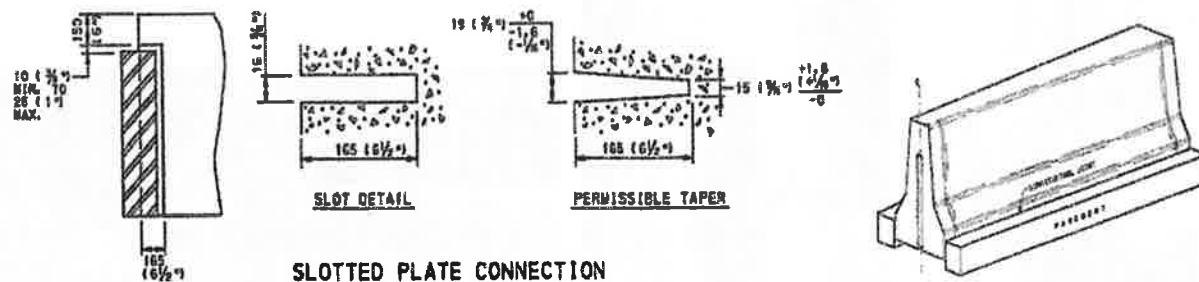


Figure 19 Pennsylvania's slotted plate connection

Source: PennDOT RC-57M sheets 3 and 4

A single slope PCB was developed in Texas in the late 1980s for Washington State. (36) For its connection a rebar grid is fitted into slots in the ends of the segments as shown in Figure 20. If the barrier is to be used in a permanent application, the areas around the rebar grid are filled with grout. The barrier was crash tested under NCHRP Report 230 guidelines successfully with no grout and the 30-ft (9.1m) segments deflected only 0.5 ft (0.2m). This barrier is used by Texas and Washington State with heights of 42 in (1067mm), 48 in (1219mm), or 54 in (1372mm).

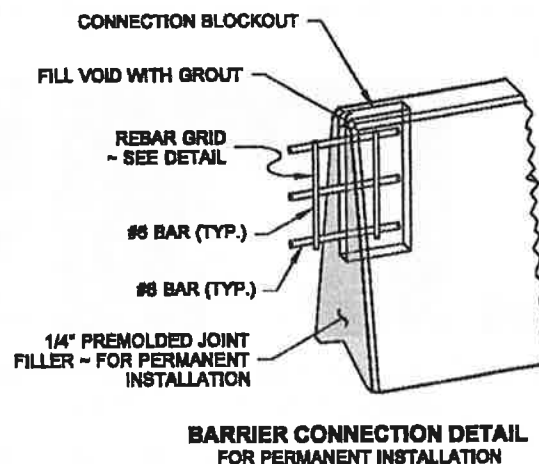


Figure 20 Washington State's rebar grid connection for its tall single slope barrier

Source: WS DOT C-13 sheet 1

In 2000 TTI evaluated the TxDOT Type 2 PCB with joint type A to see how it would perform under NCHRP Report 350 testing. (37) For the first crash test the steel bar grid in the TxDOT barrier was replaced with an 18 in (457mm) x 18 in (457mm) x 0.75 in (19mm) thick steel plate. The plate had 3 reinforcement bars welded to it to reduce play in the precast slots in the barrier.

The plate is shown in the left picture in Figure 21, and the slot is shown in the middle picture. Nothing was added to provide a way to transfer tension between barrier segments.

The results of the 3-11 crash test are shown in the right picture in Figure 21. Without a mechanism for transferring tension between the segments the system broke apart allowing a deflection of 9 ft (2.7m). However, the test met all NCHRP Report 350 criteria so it was considered to be a successful test.

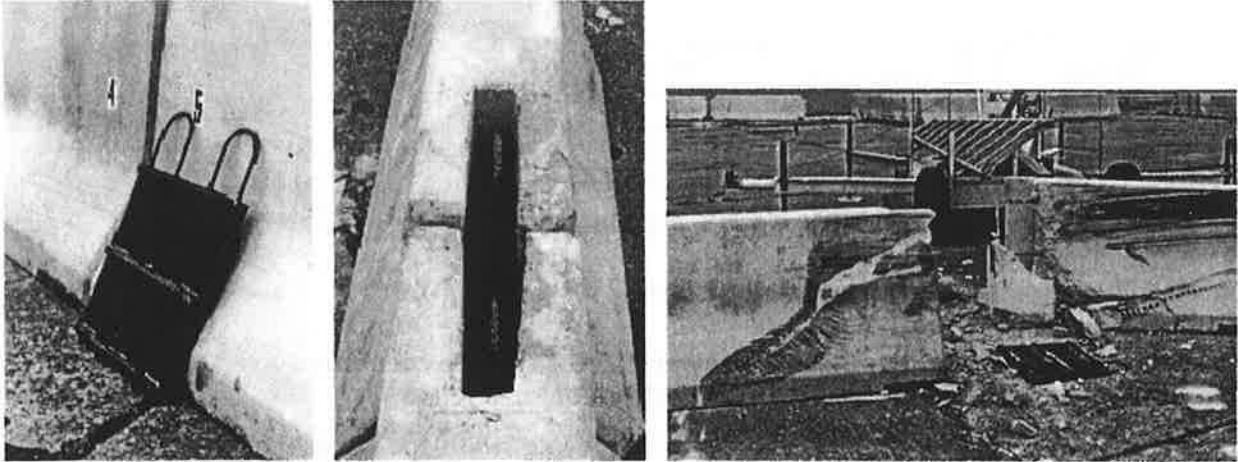


Figure 21 Texas Grid-Slot connection crash test results ()

Source: TTI Report 0-4162-1 (37)

In an attempt to reduce the deflection of the barrier the steel plate was replaced with a rebar grid with a “U-shaped” bar across the joint as shown in the left picture in Figure 22. This modification was not effective in transferring tension between the barrier segments, and the barrier once again separated as shown in the middle and right pictures in Figure 22. This test also met all NCHRP Report 350 criteria so it was considered to be a successful test despite a deflection of 12.4 ft (3.8m). (37)



Figure 22 Texas Grid-Slot with U-bar connection

Source: TTI Report 0-4162-1 (37)

A third attempt was made to reduce the deflection for the Texas Grid-Slot barrier. For this test the modified rebar grid was used again but without the “U-shaped” bar. To provide a mechanism for transferring tension between the barrier segments, 4-in (102mm) wide, 3/16 in (5mm) thick steel straps were placed across each joint on both sides of the barrier as shown in Figure 23. These 48 in (1219mm) long straps were anchored to the barrier. The results of the crash test are shown in the right picture in Figure 23. This time the barrier segments did not separate and deflection was reduced to 4 ft (1.2m). All NCHRP Report 350 Test 3-11 test

criteria were met. This series of three crash tests at TTI provides clear evidence that PCB connections must be able to transfer tension across segment joints.

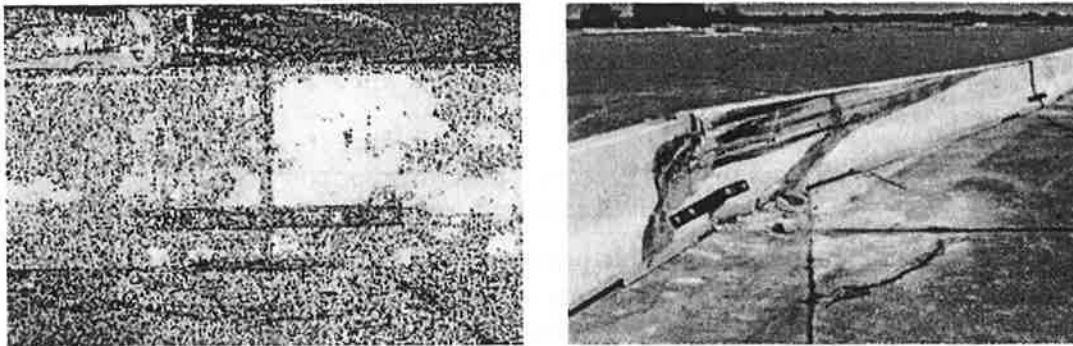


Figure 23 Texas Grid-Slot with joint bar  
Source: TTI Report 0-4162-1 (37)

A number of private companies have developed proprietary precast concrete barriers. The method for connecting the barriers is a major part of each company's patented design. A popular connection used by a number of states is the JJ Hooks design developed by Easi-Set Industries. As shown in Figure 24 J-shaped hooks protruding from each barrier end are interconnected to provide a joint capable of transferring tension between units. This type of connection has been accepted by FHWA and under NCHRP Report 350 3-11 test conditions it deflected 4.3 ft (1.3m).

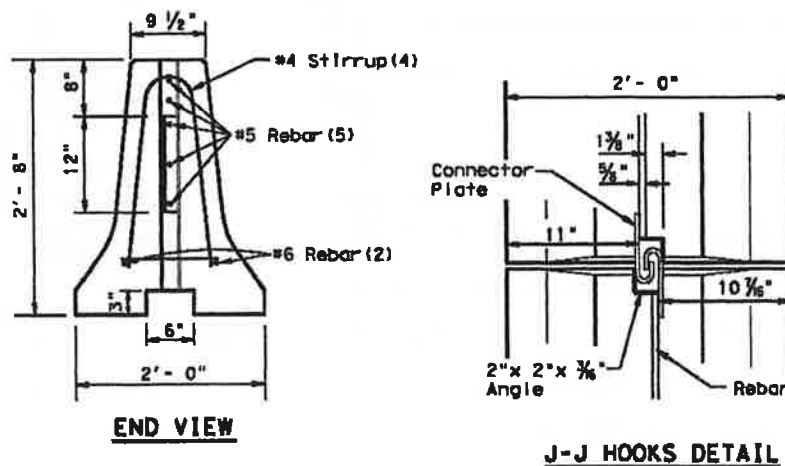


Figure 24 Easi-Set Industries' JJ Hooks proprietary connection  
Source: TX DOT CSB(2)-04

Another proprietary connection with an FHWA acceptance letter is the T-LOK system developed by Rockingham Precast. This connection is made by inserting a T-shaped bolt that protrudes from one end of each segment into a C-shaped slot in the end of the adjacent segment as shown in Figure 25. This barrier deflected 4.1 ft (1.2m) when it was crash tested under NCHRP Report 350 Test 3-11 conditions.

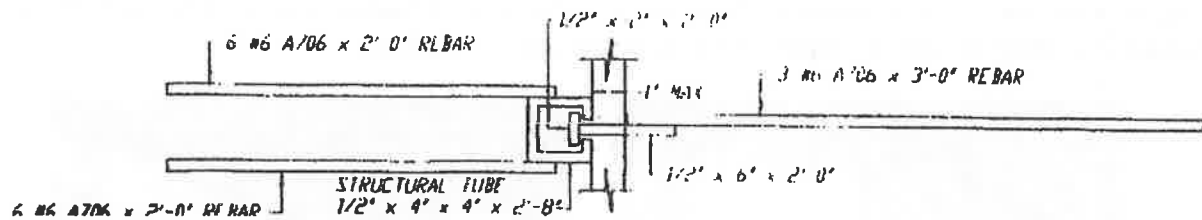


Figure 25 Rockingham Precast's T-LOK proprietary connection

Source: FHWA acceptance letter B-42 (14)

Barrier Systems has developed a moveable precast concrete barrier system that is composed of a number of 3.3 ft (1.0m) long barrier segments connected with a proprietary connection system. The connection (shown in Figure 26) is similar in concept to a pin and loop since a 1 1/8 in (29mm) diameter pin is inserted through 4 hinges, two from each barrier. Under NCHRP Report 350 Test 3-11 conditions this barrier deflected 4.4 ft (1.3m). (38)

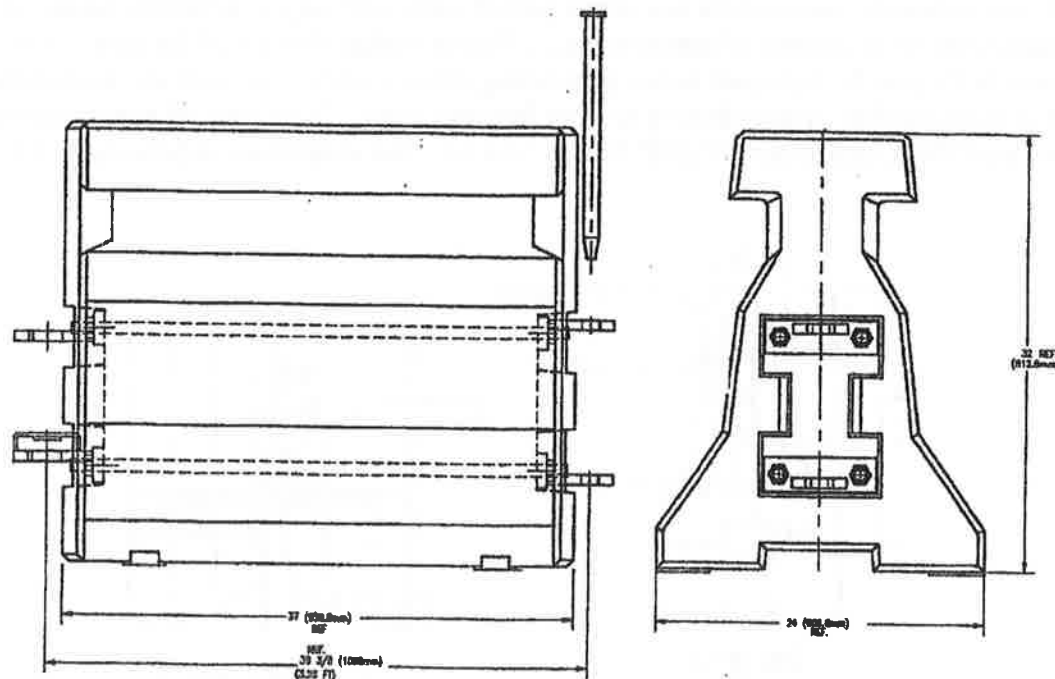


Figure 26 Barrier System's Quickchange Moveable Barrier connection

Source: FHWA acceptance letter B-63 (38)

A recently developed PCB connection is Bexar Concrete's Quickbolt system. In this system 30 ft (9.1m) F-shape barrier segments are connected with two 7/8 in (22mm) diameter bolts as shown in Figure 27. The bolts can be retracted into a cavity during placement. Hand holes allow access to the bolts so that nuts can be used to secure the connection. This barrier deflected 2.6 ft (0.8m) under MASH test 3-11 conditions. (17)

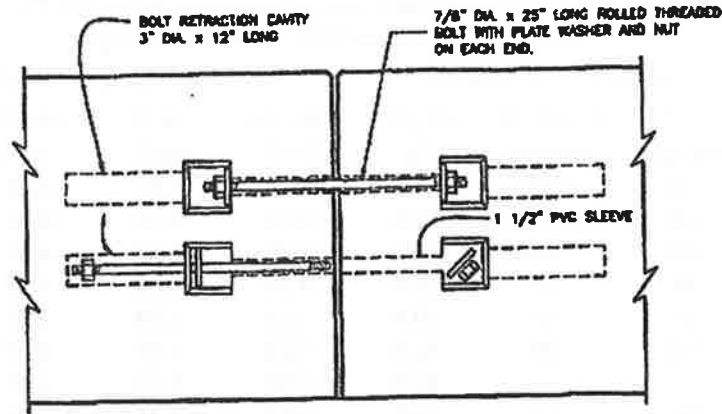


Figure 27 Bexar Concrete's Quick-Bolt proprietary connection  
Source: FHWA acceptance letter B-190 (17)

### Reinforcement

All PCBs include reinforcing steel to provide the strength needed to maintain the barrier's integrity during a crash. Reinforcement designs vary in pattern, quantity, and bar size among PCB systems as well as among states using the same PCB system. Horizontal longitudinal reinforcement is used to provide strength along the barrier's primary axis, and vertical "stirrups" are used to tie together the longitudinal reinforcement which helps to maintain the barrier's shape. Reinforcing steel is used in association with the inter-segment connections, and extra reinforcement is needed around anchors, lift points, and scuppers (openings through the bottom of the barrier to allow passage of water).

Many of the failures in crash tests have been attributed to inadequate reinforcement thus providing adequate reinforcement is important for good barrier performance. Reinforcement does increase barrier cost which implies that there may be an amount of reinforcement that maximizes the cost-effectiveness of a PCB design.

The unit amount of reinforcement steel used in PCBs, excluding extra steel for anchors, lift points, and scuppers, varies from 4.07 lb/LF (6.1 kg/m) in Rhode Island's design to 19.02 lb/LF (28.3 kg/m) in Montana's PCB. A state-by-state comparison of reinforcement quantities is given in Table 11. The data for this table was obtained from the standard drawings from each state and is presented separately for stirrups, longitudinal reinforcement, loop steel, and anchor reinforcement. New Hampshire is not included in the table because no standard height barrier is in use as far as could be determined. West Virginia is not shown because their standard drawing does not show any reinforcement in their PCB. Delaware and Wyoming are not included because they use any accepted PCB. Finally, Ohio is listed twice to show the difference in reinforcement between their design that uses rebars and the one that uses welded wire fabric (WWF). To convert lb/LF to kg/m multiple by 1.5.

### Stirrups

Stirrups are vertical reinforcement bars usually in closed loops that are connected to the longitudinal reinforcement at intervals throughout a barrier's length. The stirrups help performance in three ways: they resist shear cracks by carrying vertical shear forces, they keep the concrete from bulging outward due to flexure, and they resist the buckling of the longitudinal bars from compressive forces.

Table 11 Amount of reinforcement steel for standard height PCBs by state  
Source: Individual state DOT standard drawings

State	Barrier Characteristics			Amount of Reinforcing Steel				
	X-section Design	Reinforce Design	Length ft	Stirrups Lb/ft	Long Lb/ft	Loops Lb/ft	Total Lb/ft	Anchors Lb/ft
Alabama	OH	OH	10.0	2.24	4.87	4.16	11.27	2.78
Alaska	OR	OR	12.5	3.05	5.06	4.81	12.92	
Arizona	OR	OR	12.5	3.05	5.06	4.81	12.92	
Arkansas	ID	ID	19.8	4.00	6.08	1.57	11.65	
California	ID	ID	19.8	2.88	6.08	1.57	10.53	
Colorado	OR	OR	12.5	4.82	7.90	4.99	17.71	0.52
Connecticut			20.0	2.93	7.18	1.30	11.41	
Florida	KS	KS	12.5	3.83	5.11	5.85	14.79	2.22
Georgia	GA	GA	10.0	4.29	3.91	4.03	12.23	
Hawaii	ID	ID	19.8	4.00	6.08	1.57	11.65	0.34
Idaho	ID	ID	19.8	4.00	6.08	1.57	11.65	0.34
Illinois	KS	KS/OR	12.5	4.33	4.29	4.81	13.43	0.84
Indiana	IN	IN	10.0	2.52		7.01	9.53	
Iowa	KS	KS	12.5	3.85	4.35	5.89	14.09	2.10
Kansas	KS	KS	12.5	3.85	7.11	5.89	16.85	2.10
Kentucky	ID *	ID *	19.8	1.64	8.22	5.05	14.91	
Louisiana	OR*	OR*	15.0	4.01	5.11	2.92	12.04	0.35
Maine			10.0	0.00	3.69	1.70	5.39	
Maryland	IN*	NC	12.0	1.83	1.26	1.67	4.76	
Massachusetts	NC	NC	10.0	1.82	1.27	6.16	9.25	
Michigan			10.0	1.81	4.95	0.46	7.22	
Minnesota	KS	KS	12.5	3.85	4.35	5.89	14.09	2.10
Mississippi	OH	OH *	10.0	2.72	3.15	5.41	11.28	
Missouri	KS	KS*	12.5	4.80	4.35	5.65	14.80	2.10
Montana		MT	10.0	5.35	6.69	6.98	19.02	
Nebraska	KS*	KS*	12.5	3.23	4.35	3.81	11.39	
Nevada	OR		12.5	4.10	5.14	4.81	14.05	0.52
New Jersey	NY	NY	20.0	1.31	5.76	0.30	7.07	
New Mexico	NC		10.0	0.30	1.45	9.96	11.71	2.20
New York	NY	NY	20.0	1.31	5.71	0.25	7.02	0.93
North Carolina	NC	NC	10.0	1.82	1.27	6.16	9.25	1.53
North Dakota	GA	GA	10.0	4.29	3.91	4.03	12.23	
Ohio	OH	OH	10.0	2.24	4.87	4.01	11.12	
Ohio	OH	OH-WWF	10.0	1.82	1.22	4.01	7.05	
Oklahoma	KS		12.5	3.23	4.35	5.89	13.47	2.10
Oregon	OR	OR	12.5	3.05	5.06	4.81	12.92	0.52
Pennsylvania	PA	PA	12.0	3.62	1.96		5.58	4.49
Rhode Island			10.0	0.00	0.00	4.07	4.07	
South Carolina	NC	NC	10.0	1.82	1.27	5.56	8.65	3.39
South Dakota	KS	KS	12.5	4.65	4.35	5.95	14.95	2.16
Tennessee	OH	OH*	10.0	2.94	3.96	3.77	10.67	3.06
Texas	TX	TX	30.0	8.87	8.23		17.10	0.58
Utah	ID	ID	19.8	4.00	6.08	1.57	11.65	0.70
Vermont			10.0	1.73	4.52	2.78	9.03	
Virginia	VA	VA	20.0	0.47	4.54	0.90	5.91	0.40
Washington	WA	WA	10.0	1.04	3.03	2.10	6.17	
Wisconsin	KS	KS	12.5	3.85	4.35	5.89	14.09	2.10



The number, size, and configuration of stirrups vary widely for PCBs. The Texas X-bolt PCB has the greatest amount of vertical reinforcement with 34 stirrups along its 30-ft (9.1m) length. These stirrups are composed of No. 5 (16) bars which are larger than the typical No 4 (13) bars used in stirrups. On average, the Texas X-bolt barrier has 8.9 lb of vertical reinforcement per linear foot (13.2 kg/m). In comparison, the Virginia PCB has only 3 stirrups composed of No. 4 (13) bars along its 20 ft (6.1m) length, which is an average of 0.5 lb of vertical reinforcement per linear foot (0.7 kg/m). The drawings for the Maine, Rhode Island, and West Virginia barriers do not show any vertical reinforcement.

Out of the thirty-nine states that use stirrups in their PCBs, twenty-seven use No. 4 (13) bars, nine use No. 5 (16) bars, and three use No.3 (10) bars. The three states that use the No. 3 (10) bars are Alabama, Ohio, and New Mexico. Of the states that use stirrups in their barriers, New Mexico uses the least amount of steel. Its barriers have only two stirrups composed of No. 3 (10) bars, which provide 0.3 lb/LF (0.4 kg/m) of vertical reinforcement.

Figure 28 compares the layouts for three states that have heavy vertical reinforcement in their barriers. The Texas design spaces the stirrups every 6 in (152mm) at the ends of the barrier and every 12 in (304mm) in the middle 20 ft (6.1m) of the barrier. The Oklahoma version of the Kansas system uses tight spacing at the ends, 6 in (152mm) and 8 in (203mm); and wider spacings in the middle, 21.5 in (546mm) and 31.5 in (800mm). The Nevada version of the Oregon system uses a uniform spacing of 18 in (456mm) except at the very end of the barrier where the spacing is 8.5 in (216mm). There is no information available to determine if these variations in stirrup placement affect barrier performance.



Figure 29 compares the designs for three states that have light vertical reinforcement in their barriers. Virginia provides only 3 stirrups over its barrier 20 ft (6.1m) length. Two are located approximately 1 ft (.3m) from each end and the other is at the midpoint of the barrier's length. The Washington State barrier has only two stirrups, located a minimum of 2 in (51mm) from each end of the barrier. Indiana uses a welded wire fabric in place of reinforcement bars. Maryland, Massachusetts, North Carolina, and South Carolina also use WWF for vertical reinforcement and a few other states allow it as an alternate to bars. No crash tests of barriers reinforced with WWF could be located, and concern about WWF in PCBs has been expressed.

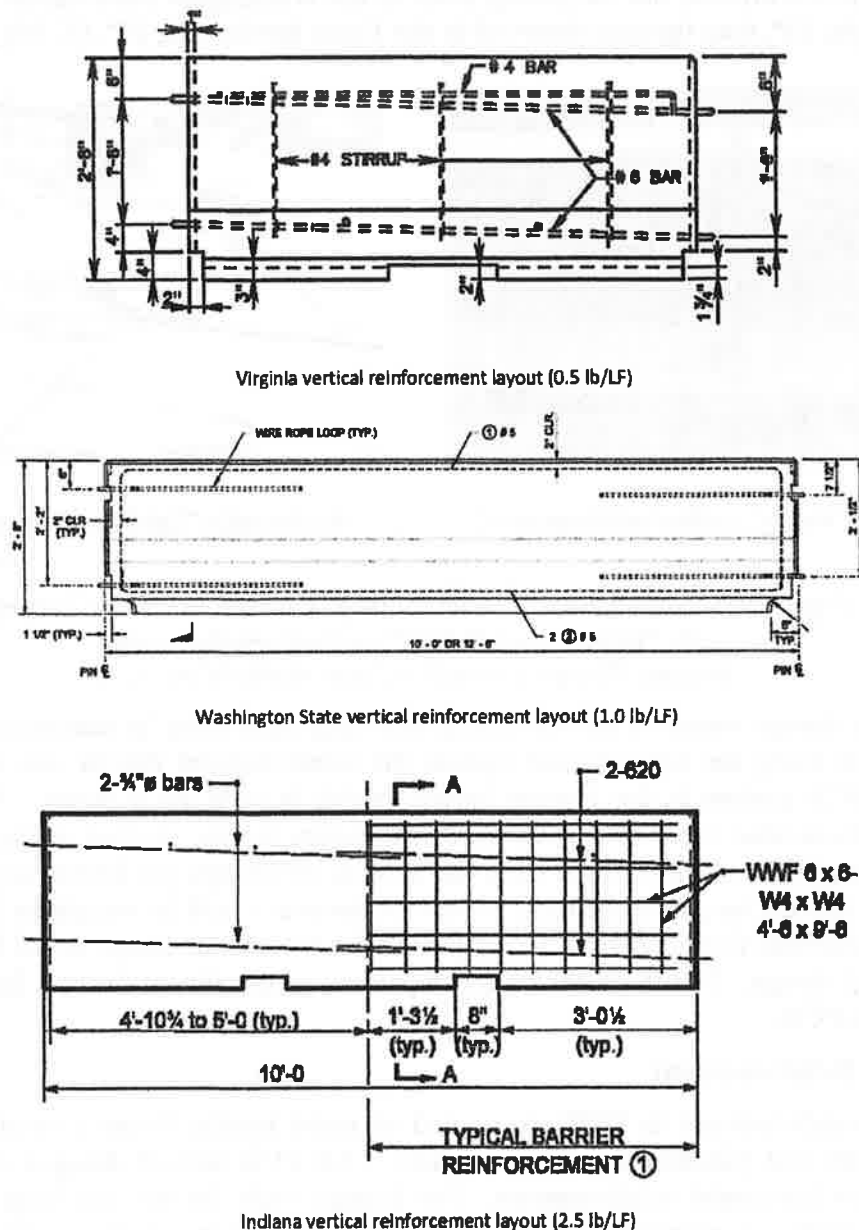
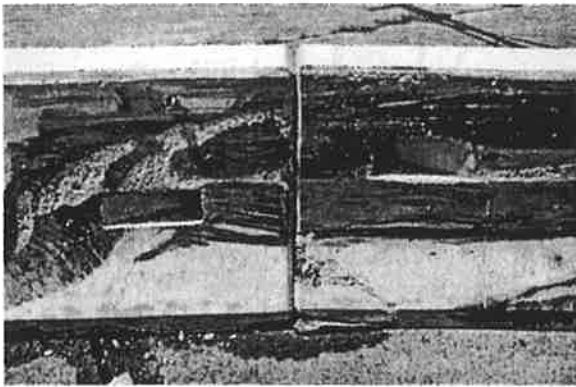
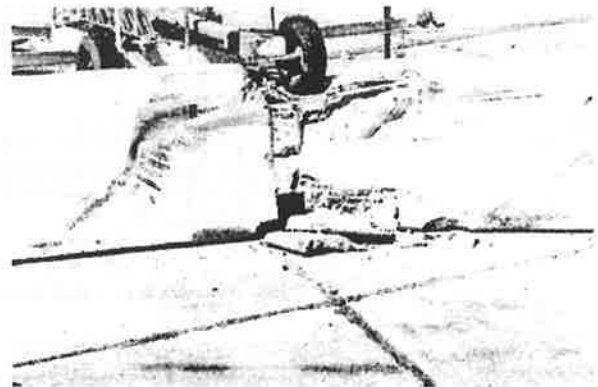


Figure 29 Comparison of layouts for "light" vertical reinforcement designs  
Sources: Virginia DOT 501.45, Washington State DOT C-8, Indiana DOT E801-TCCB-02

The lack of in-service performance data on PCBs makes it difficult to assess the impact of vertical reinforcement on barrier performance, but comparison of damaged barriers after crash tests can provide some insight. Figure 30 shows a comparison of two damaged barriers after NCHRP Report 350 TL-3 tests with a pickup truck. The barrier on the left is the Texas X-bolt PCB which has "heavy" vertical reinforcement, and the one on the right is the Washington State barrier which has "light" vertical reinforcement. The heavily reinforced barrier shows only minor cracking of the concrete at the joint near the impact point while the lightly reinforced barrier shows extensive damage to the barrier end. Both crash tests were deemed to have met the NCHRP Report 350 criteria, but the pickup truck in the Washington State barrier test had a much higher roll angle, 52°, than the one observed in the Texas barrier test, 23°. (7, 39)



Barrier with "Heavy" vertical reinforcement



Barrier with "Light" vertical reinforcement

Figure 30 Comparison of barrier damage after crash test for barriers with "Heavy" and "Light" vertical reinforcement

Sources: TTI reports 0-4162-3 (7) and 400091-WDT1 (39)

Reinforcement design seems to be something that each state likes to customize for its barrier. Even for states using the same barrier system the reinforcement details can vary. The most widely used PCB system is the Kansas barrier which is used by 9 states. A review of the drawings for these nine states found six different designs for the vertical stirrups. The designs differ in the size of the reinforcement bars, the number of stirrups per barrier segment, the shape of the stirrup, and the length of the bars. These differences result in variations in the amount of vertical reinforcement from 3.2 lb/LF (4.8 kg/m) in the Oklahoma design to 4.8 lb/LF (7.2 kg/m) in the Missouri design. Figure 31 shows a comparison of the stirrup designs for five states that use the Kansas PCB.

### Longitudinal Reinforcement

Longitudinal reinforcement in PCBs is needed to resist tensile forces exerted on the barrier during transport and placement and in impacts. All PCB barrier designs except for West Virginia's show horizontal reinforcement. For barriers with the pin and loop connection, the loop steel is usually incorporated with the longitudinal reinforcement. For comparison purposes, the steel used for loops is combined with the steel used for longitudinal reinforcement. The amount of longitudinal reinforcement (and loops) varies from 2.9 lb/LF (4.4 kg/m) in Maryland's PCB to 13.7 lb/LF (20.4 kg/m) in Montana's PCB. Maryland's PCB uses welded wire fabric for vertical reinforcement which also contributes to longitudinal reinforcement.

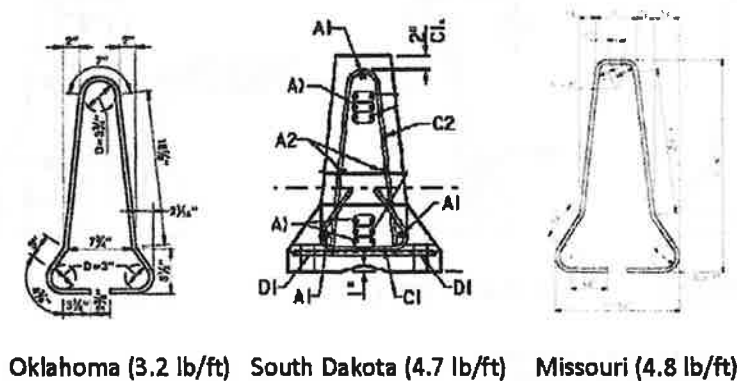
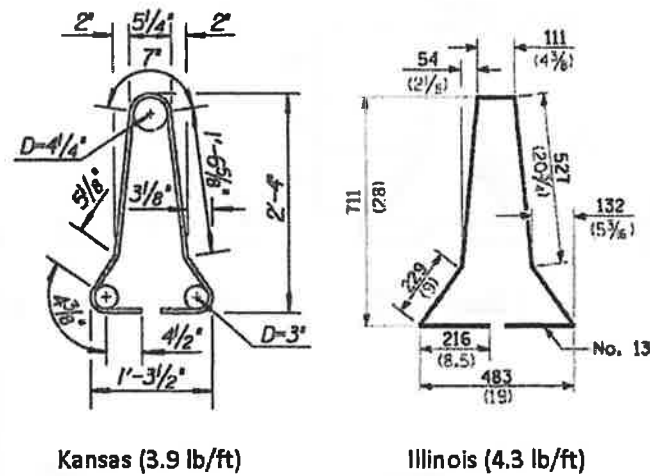


Figure 31 Comparison of stirrup designs for 5 states using the Kansas PCB

Sources: KS DOT RD 622, IL DOT 704001-04, OK DOT TCS 12-1B, SD DOT 628.10, MO DOT 617.20C

The states are evenly split on the size of bars used for longitudinal reinforcement. Excluding the steel used for the loops, sixteen states use No. 4 (13) bars, sixteen use No. 5 (16) bars, and eight use a combination of No.4 (13) and No. 5 (16) bars. Five states use No. 6 (19) bars for longitudinal reinforcement.

The number of longitudinal reinforcement bars (excluding loop steel) used varies from one to eight with fourteen states using four or fewer and thirty-one states using five or more. Figure 32 shows how various states place the longitudinal bars in their barriers. Eight states use 8 longitudinal bars, three states use 7 bars, seven use 6 bars, thirteen use 5 bars, three use 4 bars, four use 3 bars, six use 2 bars, and one uses 1 bar. Five of the states using 2 bars also use welded wire fabric. New Mexico, the state that uses only one longitudinal bar, also has four loop bars welded together that extend the full length of the barrier.

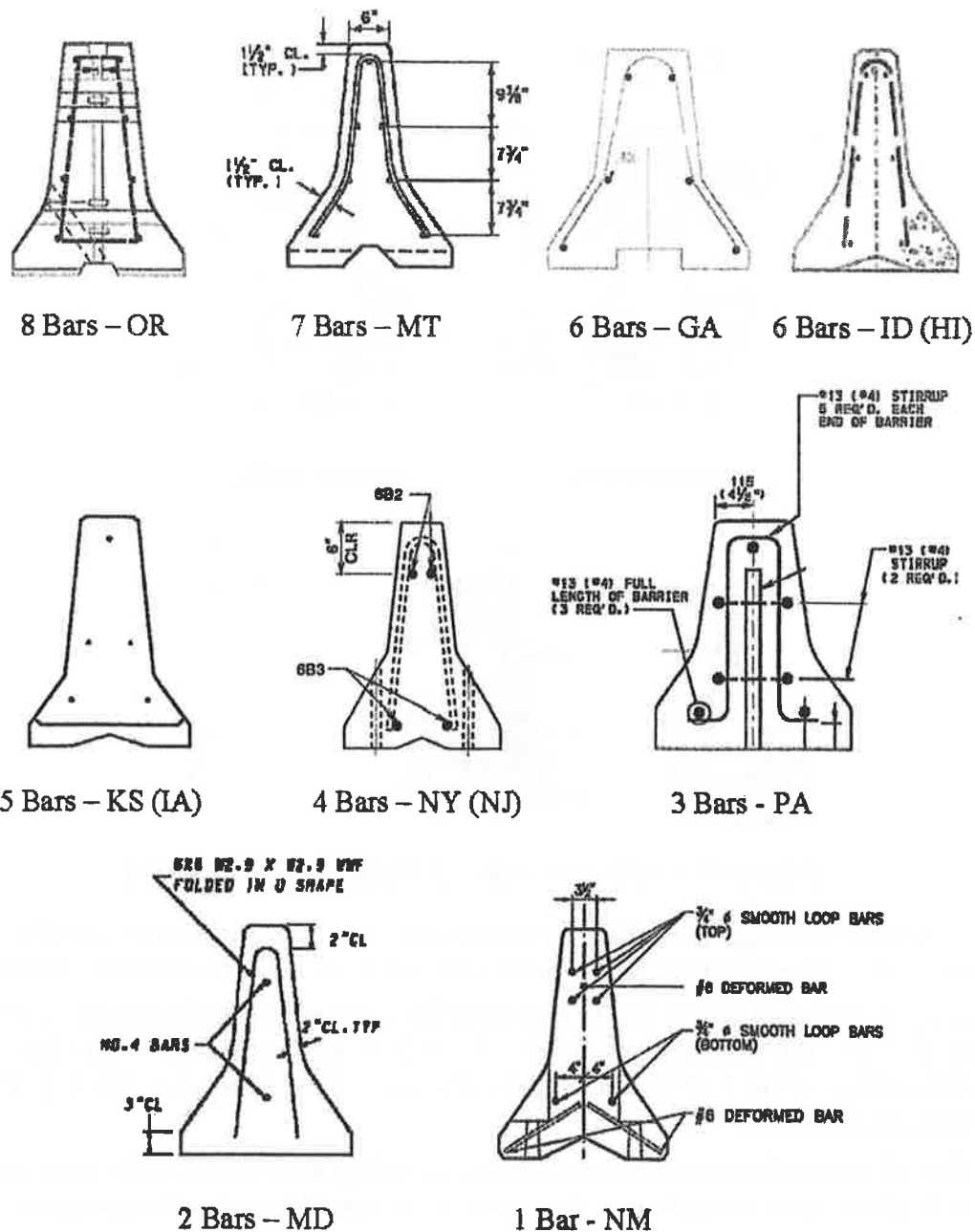


Figure 32 Comparison of longitudinal reinforcement designs

Sources: OR DOT RD 500, MT DOT 606-60, GA DOT 4961, HI DOT Portable Concrete Barrier Sheet 1, IA DOT RE-71, NJ DOT 16-146, PennDOT RC-57M, MD SHA 104.01-53, NM DOT 606-20-1/5

### Loop steel

The size of the loop steel is very important to barrier performance since the loops are what connect the barrier segments together to form a continuous barrier system. All but seven states use 3/4 in (19mm) diameter smooth rods or rebar for their loops. Five of the seven states that do not use 3/4 in (19mm) steel use 5/8 in (16mm) diameter smooth rods or rebar for their loops. The other two states, Washington and Michigan, use wire rope for their loops. Washington State uses

5/8 in (16mm) wire rope, and Michigan uses 1/2 in (13mm) wire rope. The Michigan barrier was crash tested, but it failed to meet NCHRP Report 350 criteria. It is in the process of retrofitting its barriers with 5/8 in (16mm) wire rope connection loops.

The three most popular PCB designs, Kansas, Oregon, and Idaho, use loop designs as shown in Figure 33. The Idaho design consists of two double loops (left side of diagram) while the Kansas and Oregon designs have a 2 x 3 design (right side of diagram). All of these designs use 3/4 in (19mm) smooth steel bars for the loops. Massachusetts, North Carolina, and South Carolina use a loop design similar to the Oregon design. The designs shown in Figure 33 are used by a total of twenty-four states.

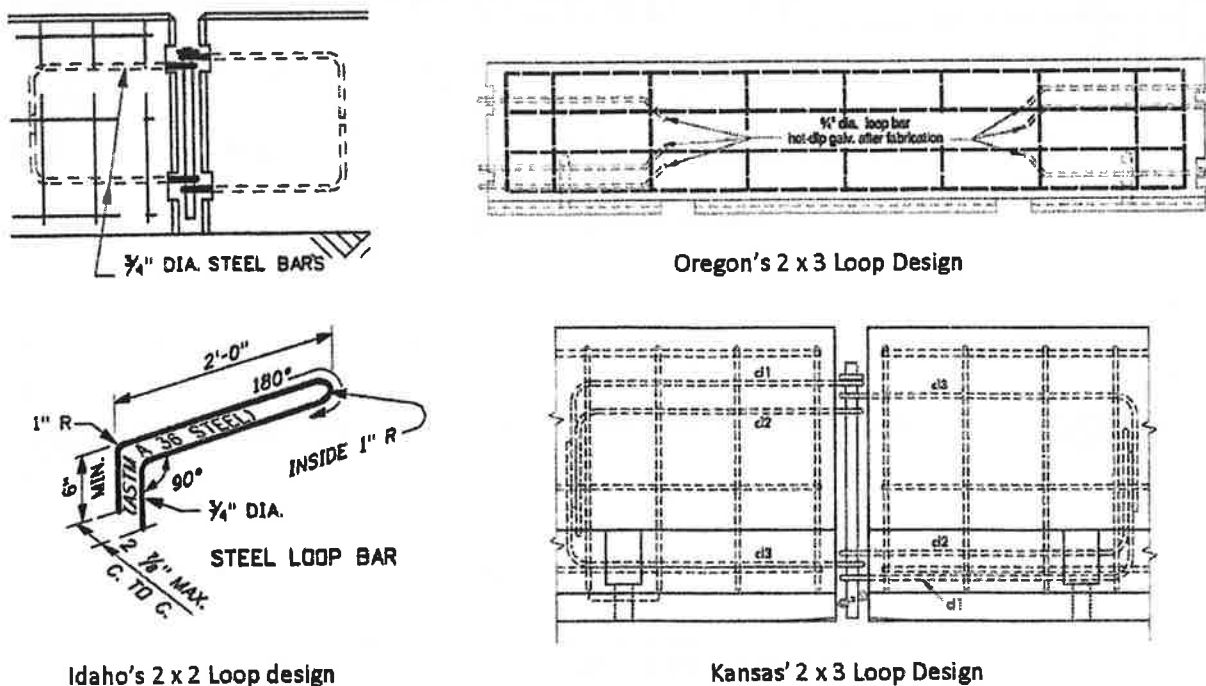
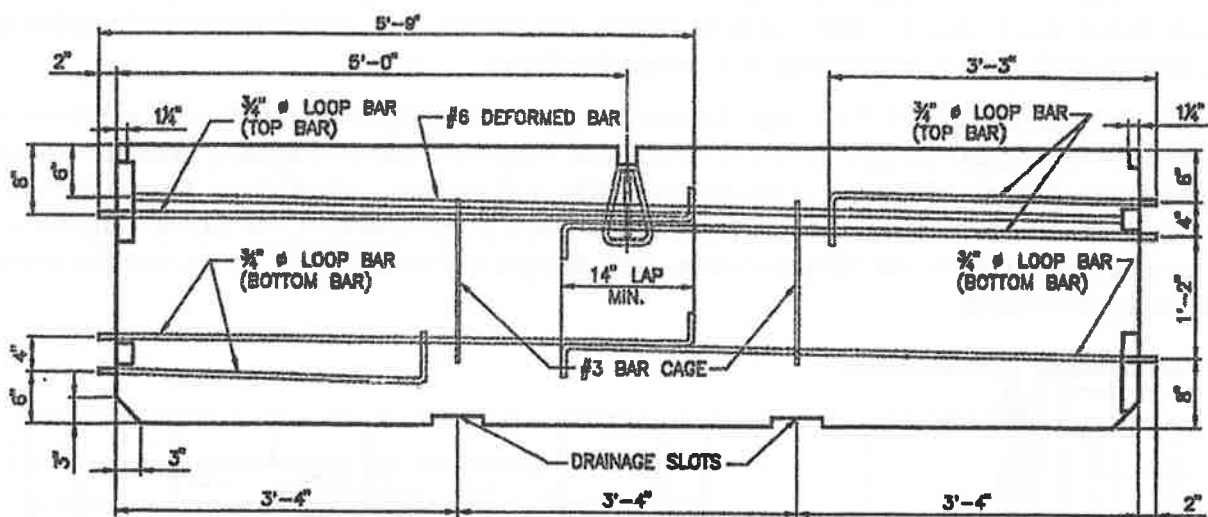


Figure 33 Most popular designs for loop steel  
Sources: ID DOT G-2-A-1, OR DOT RD 500, and OK DOT TCS 12-1A

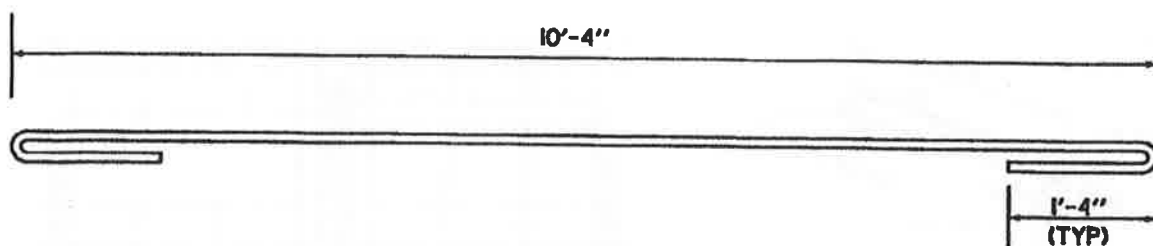
Figure 34 compares the most complex loop design (New Mexico) with the simplest loop design (Vermont). Each of Vermont's two loops is a No 5 (16) rebar that extends the length of the barrier. These bars are not connected to any of the other reinforcement in the barrier.

New Mexico's loop design is complex, and it includes approximately 67 ft (20.4m) of smooth 3/4 in (19mm) steel bars. In addition to providing the connections for the barrier, these bars provide most of the barrier's longitudinal reinforcement. The longer loop bars are interconnected with the two vertical stirrups (#3 BAR CAGE as shown in the diagram).

Other states have adopted different designs for their loops. The Montana design as shown in Figure 35 is a variation of the Oregon design in that the loop bars are not interconnected with the barrier's steel reinforcement system. The Montana system has three double loop connections while the Oregon system has two triple loop connections.



New Mexico's Loop Design



Vermont's Loop Design

Figure 34 Complex and simple loop designs

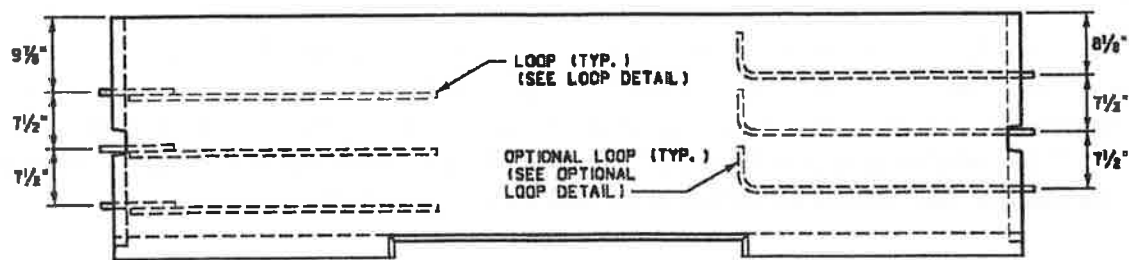
Sources: NM DOT 606-20-1/5 and VT DOT 618

Figure 35 also shows the Kentucky 2 x 2 loop design. Relatively short loop bars are welded to longitudinal rebars creating three (one at the top and two at the bottom) 3/4 in (19mm) horizontal bars that extend the length of the barrier. These bars supplement eight No.5 (16) horizontal rebars making Kentucky's barrier the second highest in the amount of longitudinal (including loop steel) reinforcement provided, 13.3 lb/LF (19.8 kg/m).

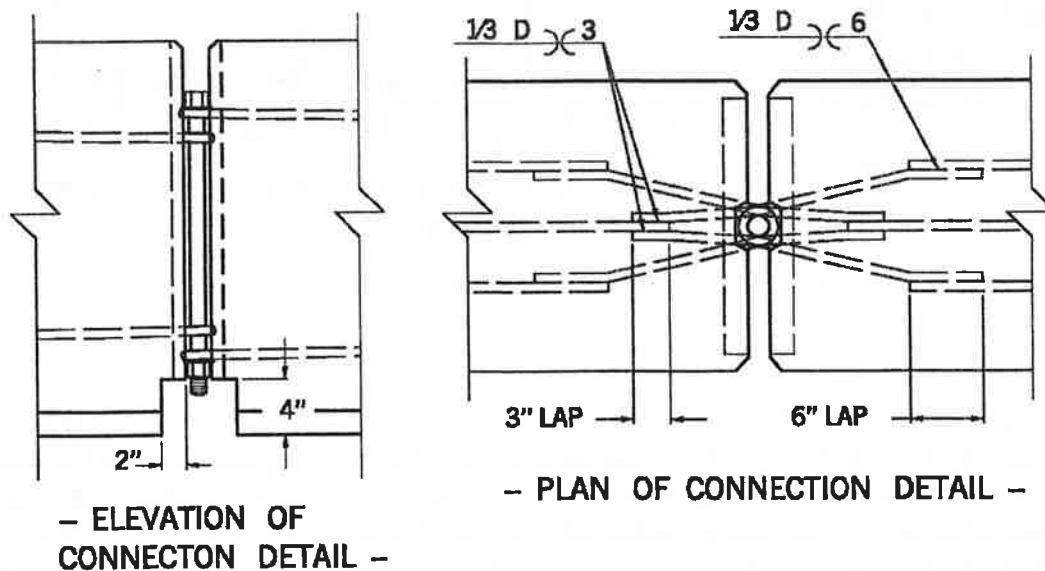
Georgia's loop design (Figure 35) consists of No. 5 (16) bars that are not interconnected with the barrier's reinforcement. Each of the eight loop bars is approximately 5 ft (1.5m) long.

Loop bars need to be strong enough to transfer tension between barriers without failing. Loop bar strength depends on its diameter, type of steel, and method for embedment into the concrete. Smooth 3/4 in (19mm) diameter steel loop bars are what most states are using and should provide the needed strength. Many different methods are being used to embed the loop bars into the concrete. Some of the designs connect the loop bars with the reinforcement steel and others do not. The variations in designs are too great to draw any conclusions.

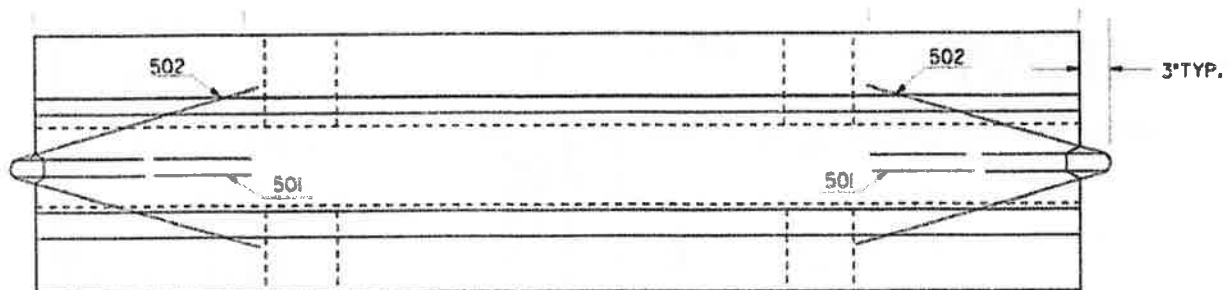




Montana's Loop Design



Kentucky's Loop Design



Georgia's Loop Design

Figure 35 Other loop designs

Sources: MT DOT 606-60, KY DOT RBM-115-08, and GA DOT 4961

### Reinforcement for scuppers, lift points, and anchors

In addition to the vertical and longitudinal reinforcement, barriers need reinforcement around anchor points and lift points. Some states also add reinforcement in the vicinity of scuppers, i.e., drainage passages.

## Scuppers

An example of reinforcement for scuppers is shown in Figure 36. In this design used by Idaho, three 6.5 ft (2.0m) long No. 5 (16) reinforcement bars (H-2 in Figure 36) are placed longitudinal above each scupper. Connected transversely to each end of the H-2 bars is an 18 in (457mm) long No. 4 (13) bar labeled as H-3 in Figure 36. The H-3 bars are also tied to the vertical stirrups located at each end of the scupper as shown in the end view in Figure 36.

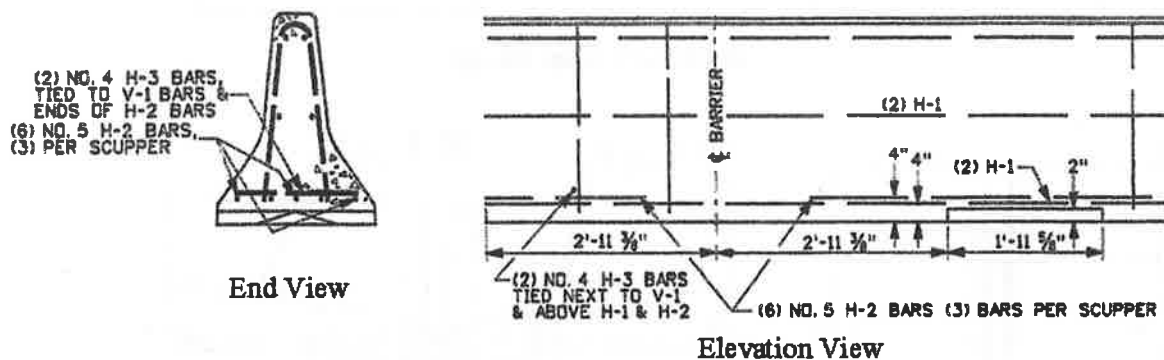
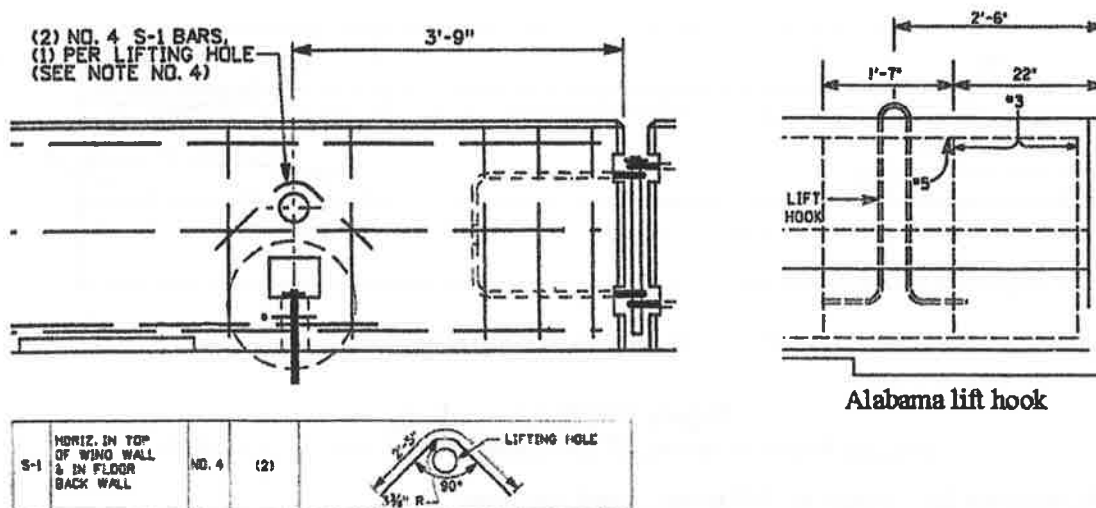


Figure 36 Scupper reinforcement design – Idaho

Source: Idaho DOT G-2-A-1 sheet 2

## Lift points

Reinforcement for lifting points is needed because of the external forces applied to the barrier during lifting operations. Two types of lifting devices are shown in Figure 37. On the left is Idaho's design for a lifting hole that has an angled No. 4 (6) reinforcement bar above each hole. On the right side of Figure 37 the lifting hook used in the Alabama barrier is shown. A No. 4 (6) reinforcement bar approximately 5.5 ft (1.7m) long is bent into the shape shown in the figure and place in the barrier so that the top 3 in (76mm) of the hook is exposed. Each barrier segment has two hooks.



Idaho lifting hole

Figure 37 Lifting reinforcement designs – Idaho and Alabama

Sources: Idaho DOT G-2-A-1 sheets 1 & 2 and Alabama DOT PNJB-629 Sheet 1

Florida's lifting sleeve design as shown in Figure 38 is similar to Idaho's except it has a 2 in (51mm) diameter sleeve instead of a 4 in (102mm) diameter sleeve used by Idaho. Also, the Florida lifting sleeve is located 6 in (152mm) closer than Idaho's sleeve to the end of the barrier. In addition to the lifting sleeve, Florida's PCB design calls for two lift/drain slots as shown in Figure 38.

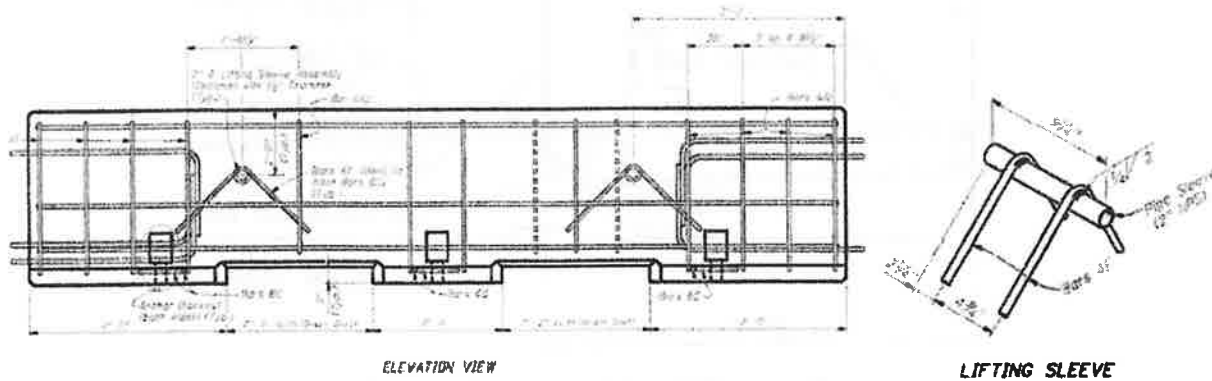


Figure 38 Florida's lifting sleeve  
Source: Florida DOT 414 sheet 2 of 15

Florida's PCB is accepted by FHWA under the Kansas acceptance letter B-122. Figure 39 shows the lift hole design for the Kansas barrier. Unlike Florida's design its lift hole is located within the end area of the barrier that is heavily reinforced by the loop bar steel and therefore does not require any additional reinforcement. It is located 2 ft (0.6m) from the barrier's end while Florida's lift sleeve is located 3.25 ft (1.0m) from the end. Figure 39 also shows the detailed design of the lifting slot for the Kansas barrier.

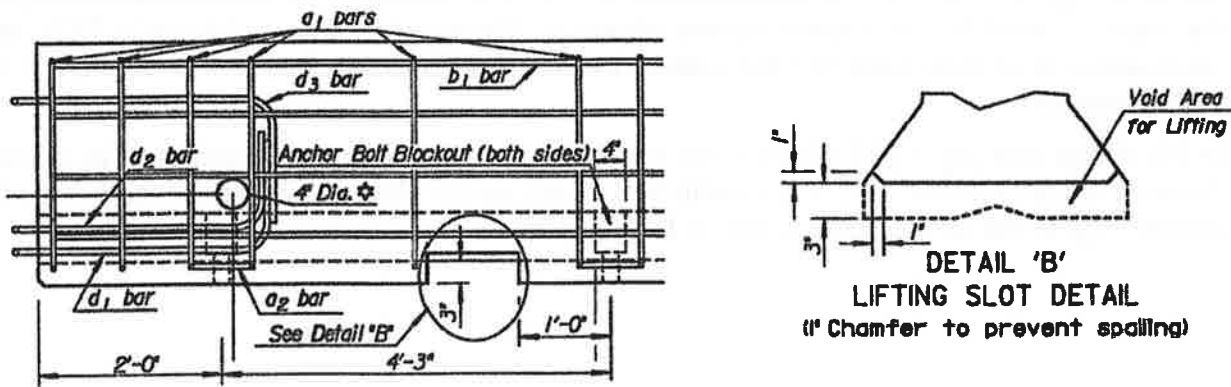


Figure 39 Kansas lift hole location and lifting slot detail  
Source: Kansas DOT RD 622

New Mexico uses a single lifting point in the center of the barrier. The 1 in (25mm) x 12 in (305mm) double flared loop is shown in Figure 40.

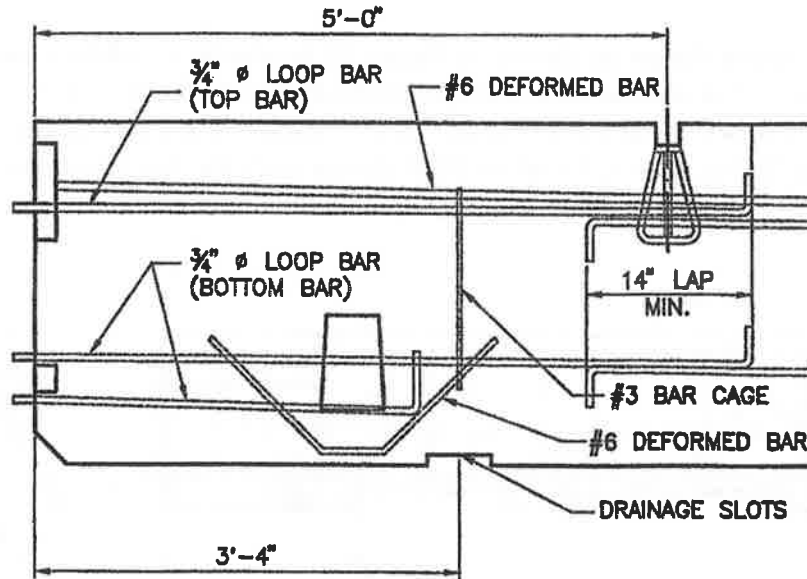


Figure 40 New Mexico's lifting coil  
Source: New Mexico DOT 606-20-1/5

### Anchor reinforcement

States use a variety of methods for providing reinforcement in the vicinity of anchor points. Anchor points experience large forces during impacts as the energy from the impact is transferred to the anchor through the concrete. Insufficient reinforcement around the anchor points can cause the concrete to break or spall.

A common method for reinforcement is to wrap reinforcement bars around the anchor sleeves as shown in Figure 41 for the Alabama rendition of the Ohio system. The reinforcement design is the same as used in the Kansas system shown in Figure 43. Thus, Alabama's PCB is a combination of features from the Ohio system, the one its FHWA acceptance is based on, and the Kansas system.

In this design two No. 6 (19) rebars in the horizontal plane are wrapped around the 2 in (51mm) diameter anchor sleeves. Since the centerline of the anchor sleeve is 3.5 in (89mm) from the outside edge of the barrier, a maximum of 1.75 in (45mm) of concrete covers the rebars.

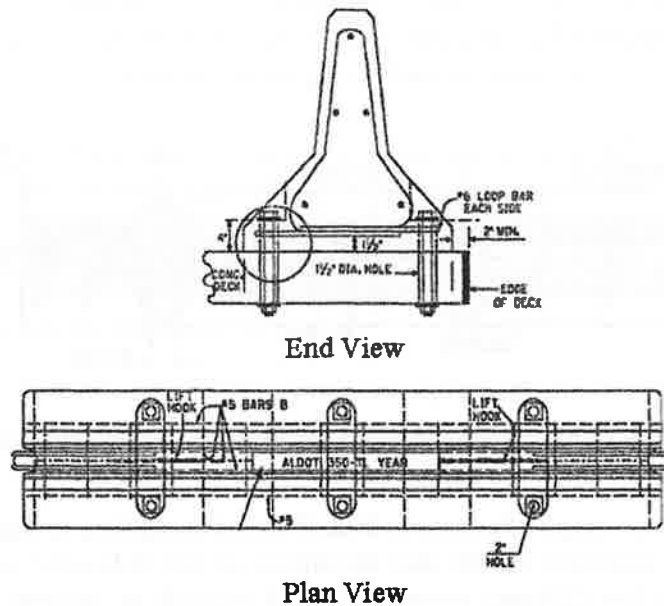


Figure 41 Anchor reinforcement – Alabama DOT  
Source: Alabama DOT PNJB-629 sheet 3

Idaho uses a similar method to reinforce its anchors although it accomplishes the reinforcement with a single 5.25 ft (1.6m) long No.4 (138mm) bar as shown in Figure 42. This design provides a minimum of 1 in (25mm) concrete coverage of the rebars.

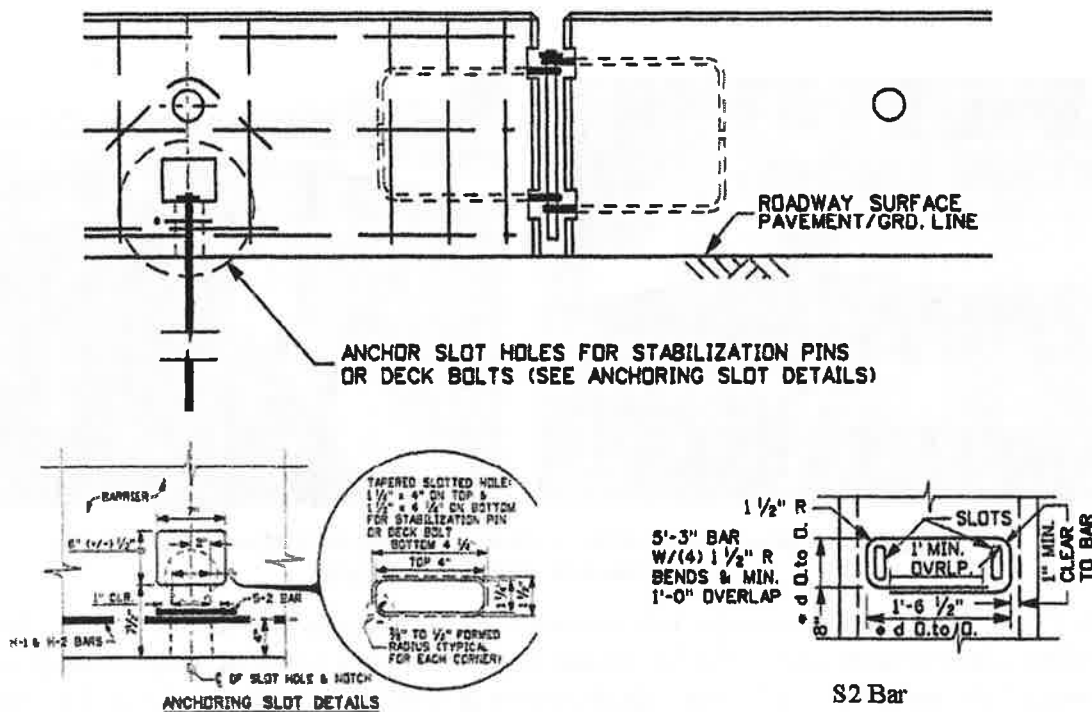


Figure 42 Anchor reinforcement for the Idaho system  
Source: Idaho DOT G-2-A-1 sheets 1 & 2

Figure 43 shows the reinforcement design for anchors in the widely used Kansas system. This design requires a minimum of 1 in (25mm) concrete coverage of the rebars. As in the Alabama PCB two No. 6 (19) rebars are used around each pair of anchors.

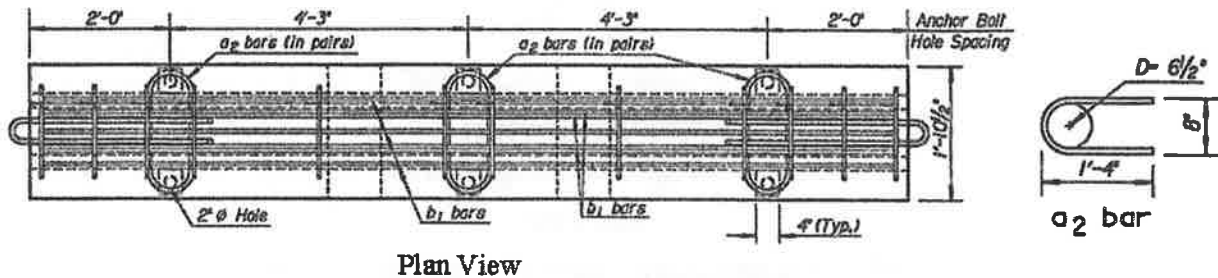


Figure 43 Anchor reinforcement for the Kansas system  
Source: Kansas DOT RD 622

The typical minimum coverage of rebars is 2 in (51mm) according to most states' specifications. However a common situation where this minimum is not followed is around anchor points. Figure 44 shows that 1 in (25mm) coverage is not enough to prevent failure of the concrete around anchor points in a typical NCHRP Report 350 3-11 crash test. On the left side of the figure the reinforcement bar can be seen just below the top of the anchor pin since all of the concrete outside of the reinforcement broke away during the crash test of this Kansas PCB. The picture on the right in the figure shows that the concrete broke away from all of the anchor points in the vicinity of the impact point. The concrete in the rest of the barrier appears to be in good shape. The crash test was successful despite the failure of the concrete around the anchor points. (40)

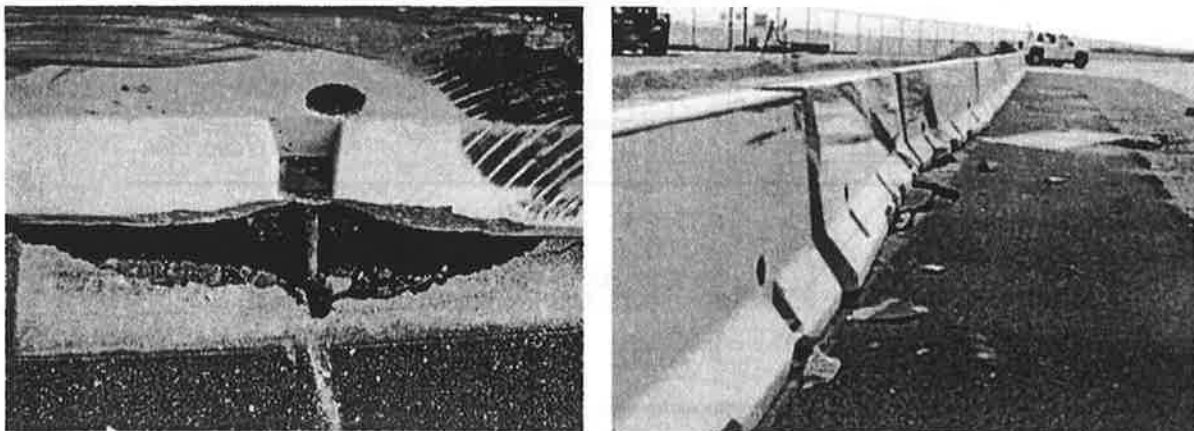


Figure 44 Failure of concrete around anchor points after crash test  
Source: MwRSF TRP 03-180-06 (40)

North Carolina has approached the reinforcement of its anchors in a different way. Instead of providing reinforcement only in the horizontal plane, the North Carolina design is angled upward and toward the center of the barrier. Each anchor is reinforced with one 52 in (1321mm) long No. 5 (16) bar designated as S1 in Figure 45. A minimum of 1 in (25mm) concrete coverage is specified.

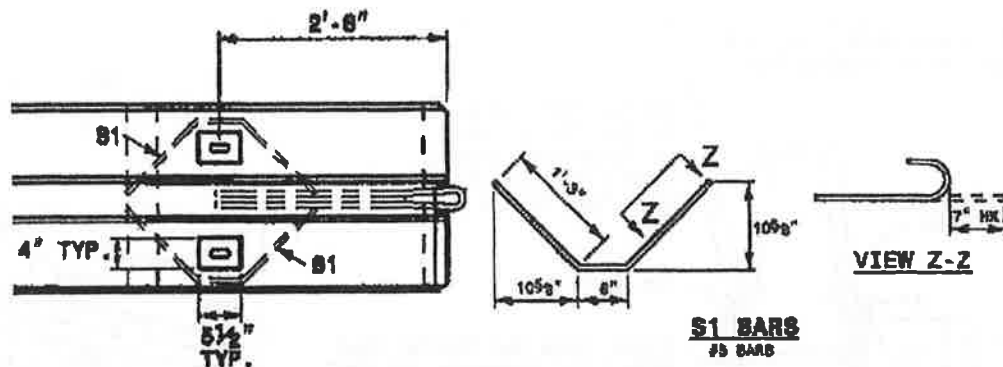


Figure 45 Anchor reinforcement for the North Carolina system  
Source: North Carolina DOT 1170D01 sheets 2 & 3

South Carolina uses the North Carolina FHWA acceptance letter for its system. South Carolina allows the use of the proprietary JJ-Hooks connection and for barriers where JJ-Hooks are used the anchor reinforcement design differs somewhat from the North Carolina design shown above. This barrier is 12 ft (3.7m) long in comparison to the 10 ft (3.0m) long North Carolina barrier.

Five pairs of anchoring slots are provided as shown in Figure 46. While the shape of the anchor reinforcement is similar to that used in the North Carolina system, the length, shape, and orientation of the No. 5 (16) bars are somewhat different. Also, South Carolina specifies a minimum of 1.5 in (38mm) concrete coverage over the rebars.

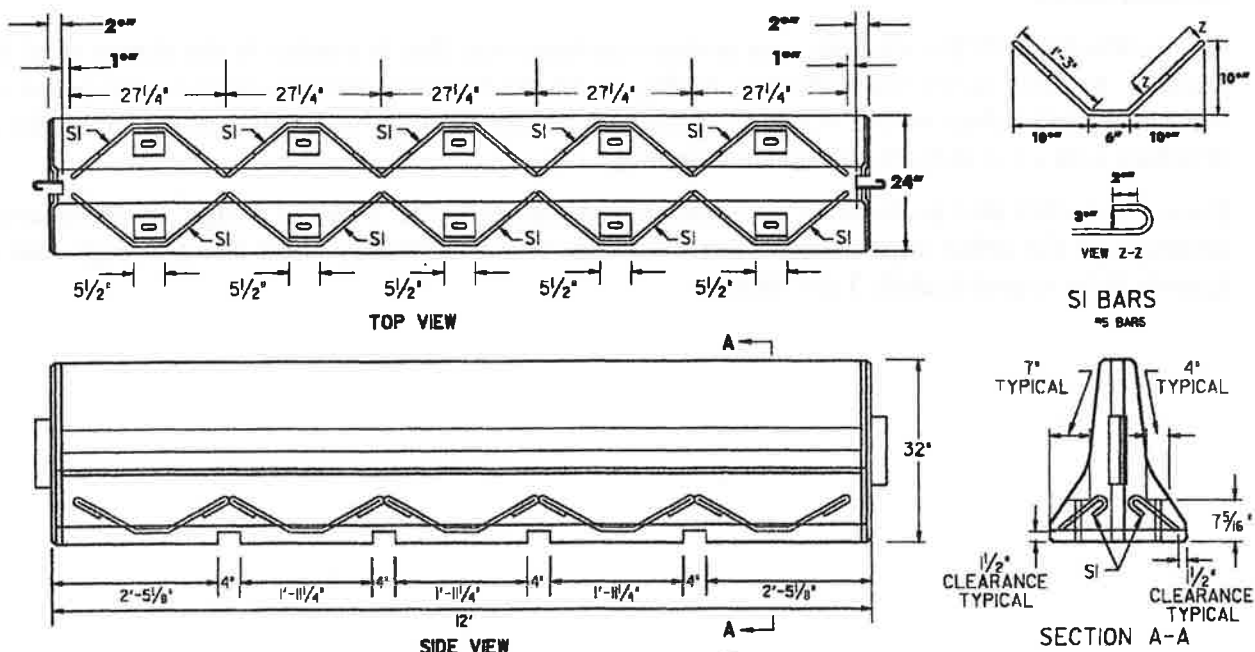


Figure 46 Anchor reinforcement for JJ-Hooks connection – South Carolina  
Source: South Carolina DOT 605-205-02

Oregon has another way to reinforce its anchors. In this design a single No. 4 (13) rebar is bent in an "S" shape as shown in Figure 47. While it appears that the concrete coverage of the rebars is greater than 1 in (25mm) the drawings do not indicate any minimum coverage.

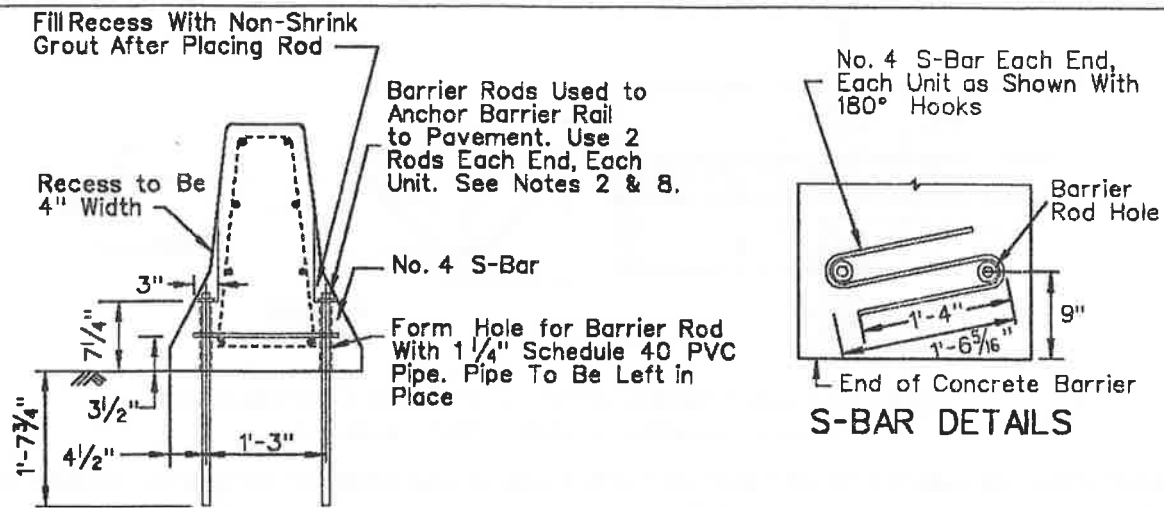


Figure 47 Anchor reinforcement – Nevada (Oregon system)

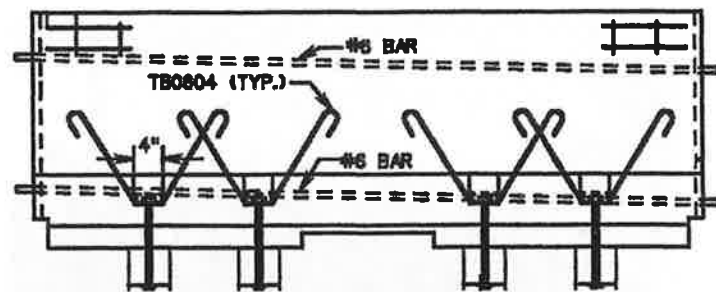
Source: Nevada DOT R.8.7.1 (502)

Virginia uses an anchor reinforcement design for its single-face PCB that is similar to the one used in South Carolina. However in the Virginia design the anchor sleeves are closer together than in the South Carolina design which causes the rebars to overlap as shown in Figure 48. The No. 6 (19) rebars are 56 in (1422mm) long and are bent in the approximate shape of the South Carolina rebars.

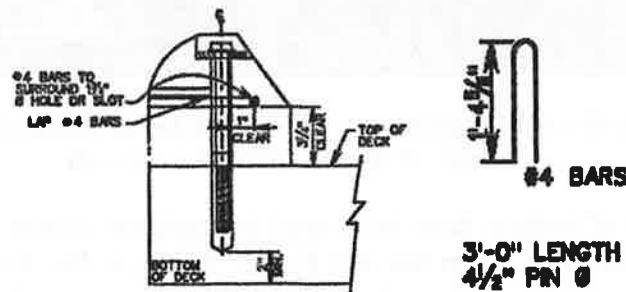
For double-faced PCBs Virginia uses anchor reinforcement that is similar to the design used by Kansas. As seen in the lower portion of Figure 48 the Virginia reinforcement is composed of two No. 4 (13) rebars with a 4.5 in (114mm) inside diameter. The Kansas system uses No. 6 (19) bars with a 6.5 in (165mm) inside diameter.

Since the anchor slot is closer to the center of the barrier in the Virginia design, more concrete coverage of the rebar is provided. The drawings do not explicitly show the coverage, but it appears to be approximately 3 in (76mm).





Single Face Anchor Reinforcement



Double Face Anchor Reinforcement

Figure 48 Anchor reinforcement – Virginia DOT

Source: Virginia DOT 501.51 and 501.54

Ohio does not show in its drawings any extra reinforcement for its anchors. However as shown in Figure 49 it does provide up to 4.4 in (111mm) of concrete between the bolt hole and the outside of the barrier.

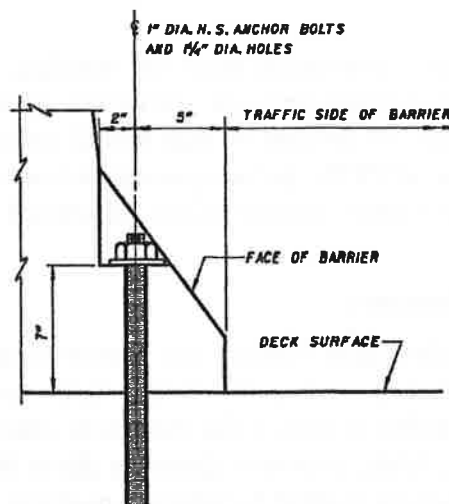


Figure 49 Ohio PCB without anchor reinforcement

Source: Ohio DOT PCB-91

Washington DOT also does not provide any additional reinforcement around the anchor points in its barrier. In a crash test of a barrier very similar to the Washington DOT design the concrete around the anchor pin hole failed catastrophically as shown in Figure 50. The failure of the concrete led to high barrier roll and ultimately to a failed test when the vehicle rolled over. (41)

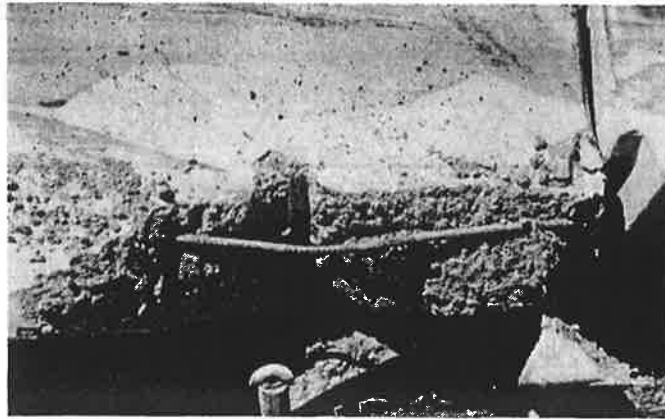


Figure 50 Lack of anchor reinforcement led to a concrete failure  
Source: TTI Report 405160-3-1 (41), p40.

In summary, a variety of designs have been used to reinforce anchor points in precast concrete barriers. The reinforcement is either No. 4 (13), No. 5 (16), or No. 6 (19) bars, and the bars are placed horizontally around the anchor sleeves or inclined at an angle toward the center of the barrier. Many states provide only 1 in (25mm) concrete coverage over the bars which is not sufficient under all crash conditions to prevent failure of the concrete. Given that all barriers should be designed for the same crash loads, it is interesting that the size of the reinforcement bars varies so much. Not providing extra reinforcement around the anchor points can lead to failure in the concrete surrounding the anchor point and in some cases to failure of the barrier system to contain and redirect impacting vehicles.

### **Anchorage**

Precast concrete barriers are most commonly used free standing without anchorage especially for temporary installations on construction projects. However, under some circumstances PCBs are anchored to reduce the amount of deflection that would occur if the barrier were impacted. Conditions requiring anchoring of PCBs include permanent installations, bridge decks, and areas where the clearance behind the barrier is insufficient because of close-by hazards or construction workers.

### **Minimum behind-barrier clearance**

Theoretically the minimum clearance behind the barrier should be related to the expected deflection that would occur during an impact. Some states use the deflection observed in the crash test of their barrier as a guide in setting the minimum clearance required to avoid having to anchor the barrier. One state, Ohio, provides charts to allow the designer to specify minimum clearance and/or number of anchors needed for specific roadway widths and speed limits.

Figure 51 shows the charts used in Ohio to determine if PCBs on bridge decks can remain unanchored. Using the chart on the left, the known roadway width, i.e., clear distance between traffic toe of barrier and the bridge railing or face of sidewalk curb, is used along with the posted speed limit to determine the expected crash impact severity. The expected crash impact severity is used in the right-hand chart to determine the clear distance required to avoid having to anchor the barrier.

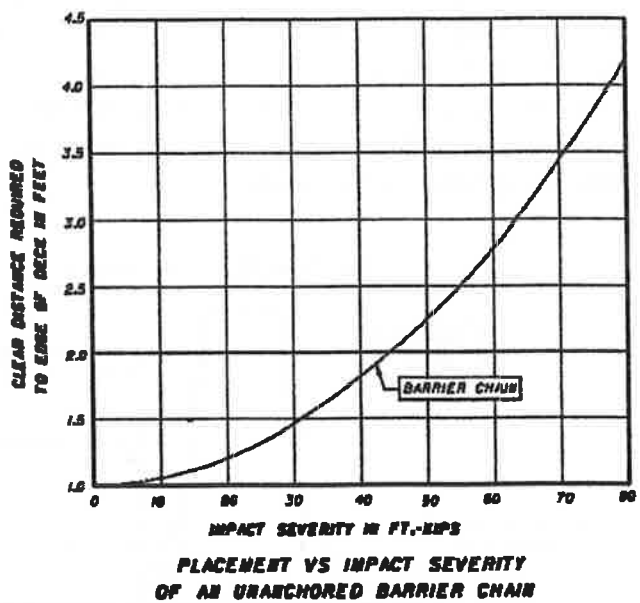
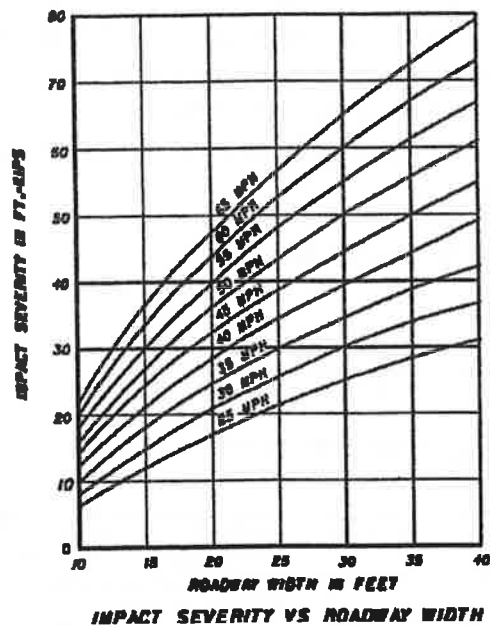


Figure 51 Required Clear Distance Charts – Ohio

Source: Ohio DOT PCB-DD

If it is determined that anchors are needed, Figure 52 is used to determine the required number of anchors. When anchoring is used, the desired minimum distance to the edge of the deck is 1 ft (0.3m). However, if conditions require that the barrier be located closer than 1 ft (0.3m) from the edge of deck, the number of anchors is doubled.

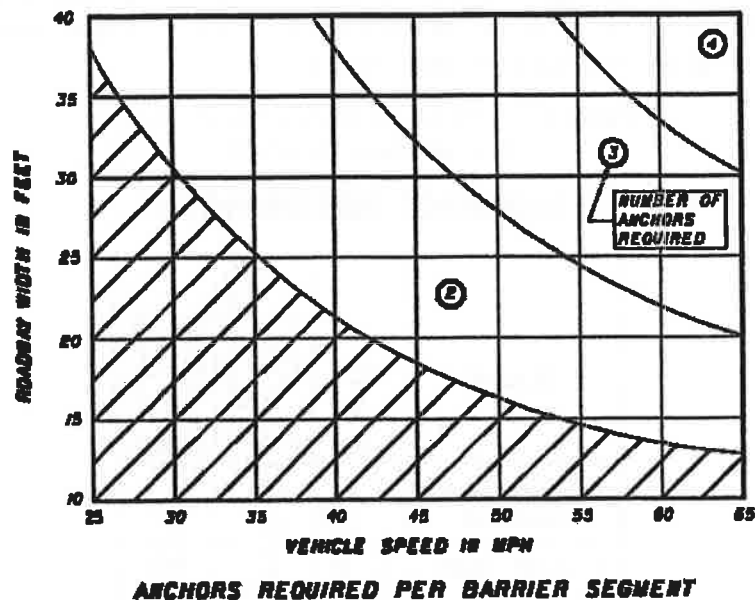


Figure 52 Required number of anchors on bridge decks in Ohio

Source: Ohio DOT PCB-DD

Minimum clearances do vary among states that use the same system. For example, the most widely used PCB, the Kansas system, had a deflection of 3.8 ft (1.2m) in its TL-3 crash test. Of

the nine states using the system, Kansas and Oklahoma specify a minimum 2 ft (0.7m) clearance while Florida requires 2 ft (0.7m) for speeds 45 mph (72km/h) and under and 4 ft (1.4m) for speeds 50 mph (80km/h) or greater (see Figure 53). Wisconsin is similar to Florida except it uses 45 mph (72km/h) as the break-point speed. Missouri also has minima of 2 ft (0.7m) and 4 ft (1.4m) except it uses the lower minimum for roadways and the higher one for bridge decks. Illinois specifies 3.5 ft (1.1m)

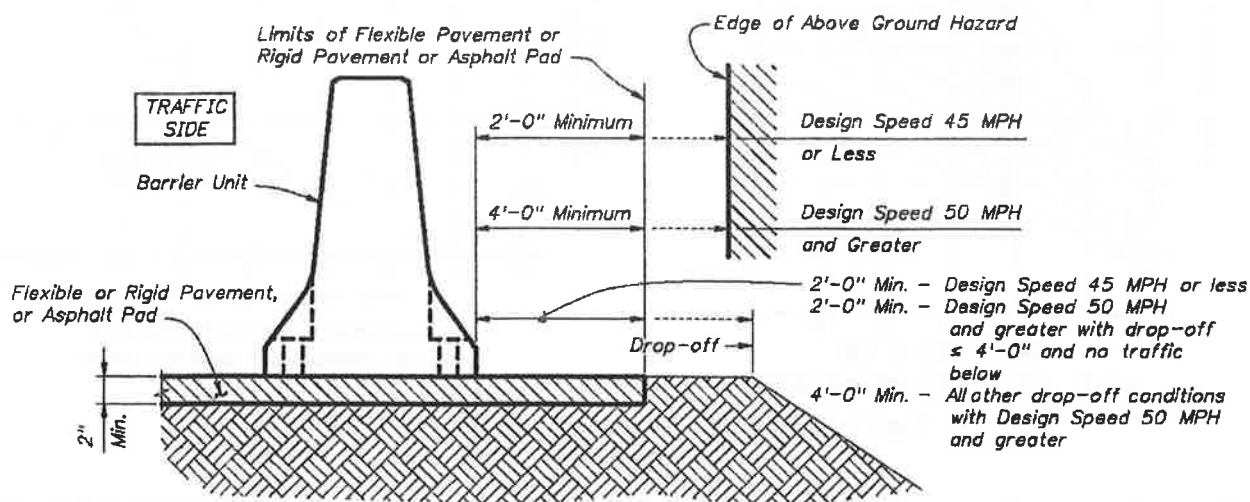


Figure 53 Behind the barrier clearance specified by Florida DOT

Source: FL DOT 414 Sheet 5

Iowa's requirements for anchorage are shown in Table 12. This table also indicates that the minimum clearance is 6 in (152mm) when anchors are used. No data could be obtained from Minnesota or South Dakota on clearance requirements.

Table 12 – Iowa's clearance requirements

Source: Iowa DOT RE-71

### ANCHORAGE REQUIREMENTS

Hazard	Dropoff	Min. offset where TBR is Unanchored	Min. offset where TBR is Anchored
Dropoff from pavement	≤ 24"	24"	6"
	> 24"	45"	6"
Dropoff from bridge	≤ 3"	1"	N/A
	> 3"	45"	6"
Fixed vertical object	N/A	24"	6"

The Oregon system is used by six states. Only one state, Arizona specifies a minimum clearance of 2 ft (0.6m), which is less than the 2.5 ft (0.8m) deflection observed in the crash test. Alaska and Oregon require 3 ft (0.9m); Colorado, 4 ft (1.2m); and Nevada requires 3 ft (0.9m) on shoulders but 4 ft (1.2m) on bridges. Louisiana did not provide information on minimum clearances.

The other popular barrier used by six states, the Idaho system, had crash test deflections of 3.3 ft (1.0m) and 3.6 ft (1.1m). Idaho, Kentucky, and Utah all specify a minimum clearance distance of 3 ft (0.9m), while Hawaii specifies, 3 ft – 3 in (1.0m). California requires only 2 ft (0.6m) clearance. No information was found for Arkansas.

For the less widely used systems a comparison of crash test deflections with specified minimum behind-the-barrier clearance for unanchored barriers is presented in Table 13. For the most part the specified minimum clearances follow closely the observed crash test deflections. The biggest exception is Pennsylvania, which does not specify a minimum clearance even though its barrier had the largest crash test deflection, 8.4 ft (2.6m), among all barriers tested. Washington's minimum clearance of 3 ft (0.9m) is lower than the 4.1 ft (1.3m) and 4.5 ft (1.4m) observed crash test deflections. The Ohio barrier had a crash test deflection of 5.5 ft (1.7m) which is close to the 5 ft (1.5m) minimum clearance specified by Alabama which uses the Ohio barrier. However, as shown in Figure 51, Ohio specifies a minimum clearance of only 4.2 ft (1.3m) for the most severe expected crash. For less severe cases, the minimum clearance required is even lower.

**Table 13 Comparison of crash test deflections and minimum behind-barrier clearances**  
Sources: FHWA acceptance letters and standard drawings and specifications from the state DOTs

Barrier System	NCHRP Report 350 Test 3-11 Crash Test Deflection		Minimum Behind-Barrier Clearance for Unanchored Barriers	
	ft	m	ft	m
PA	8.4	2.6	0	0.0
GA	6.3	1.9	6	1.8
VA	6.0	1.8	6	1.8
OH	5.5	1.7	5 (AL)	1.5
IN	5.3	1.6	5	1.5
NC	5.0	1.5	5 (NM)	1.5
MT	4.2	1.3	4.5	1.4
WA	4.1, 4.5	1.3, 1.4	3	0.9
TX	1.6	0.5	2	0.6

As noted above a few states require less clearance behind their unanchored barriers than the barrier deflection expected from a crash similar in impact severity to the NCHRP Report 350 TL-3 pickup truck crash. If these barriers are located on bridge decks or in construction zones problems could occur if the barriers are impacted.

### **Tie-down methods for precast concrete safety-shaped barriers**

In the late 1980s Noel, Sabra, and Dudek studied tie-down methods for PCBs and published a report, *Work Zone Traffic Management Synthesis* (42). They identified eight different PCB anchorage methods being used at that time:

1. Through-bolts, nuts and washers
2. Slip resistant plates attached to decks
3. Berm behind barrier
4. Connecting anchor plate
5. Anchor plate with through-bolts, washers and nut
6. Bolts and resin embedment
7. Dowel pins
8. Pavement pins

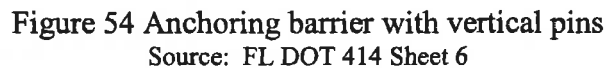
At that time the most popular PCB connectors were pin and loop, tongue and groove, and plate insert. However these designs had not been subjected to crash tests to allow determination of the minimum tension and shear capacity for their respective anchoring systems. Nine of the ten states studied did anchor PCBs in work sites where needed, but no state had developed any performance standards for PCB anchors. The researchers concluded:

1. PCBs are anchored when there is inadequate space behind them to accommodate energy-absorbing displacement without endangering drivers or workers, e. g., drop offs, bridge construction, and sharp curves where barrier segments cannot be interconnected. Anchors are designed to control tilting, overturning, and sliding of barriers.
2. The minimum desired space behind PCBs is a factor in anchorage determination, but it had not been determined for the majority of barrier and connector designs in use.
3. Given the large variety of barrier designs in use, uniformity may not be practical; thus there is a need to develop performance specifications for anchoring systems.
4. Based on findings of the study, anchorage on the traffic side using a system of through-bolts, vertical dowels through barriers, nuts, plates, and washers appears to be the preferred practice for long-term work on bridges.

Four recommendations came out of this research effort:

1. The *AASHTO Design Guide* (RDG) should discuss the need to anchor PCBs and offer situations where anchorage should be considered. The *RDG* should also advise on anchor treatments (with design details) to control sliding, tilting, and overturning.
2. There is a need for research on the behavior of anchored PCBs during highway accidents.
3. There is a need for research to develop performance standards for anchoring systems and to identify the current anchoring systems which satisfy the standards.
4. Until the results of anchor research are available, practitioners should use anchoring systems which utilize dowel holes in barriers, through-bolts, nuts, washers, and plates instead of pins for anchoring PCBs on bridges. (42)

Steel pins are the most common way to anchor precast concrete barriers on bituminous pavements and shoulders. The pins are usually driven through holes in the barrier either vertically or at an angle. Figure 54 shows details for Florida's (Kansas system) PCB anchoring using a vertical pin.



**TAPERED SLOTTED HOLE:**

- $\frac{1}{4}" \times 4"$  ON TOP &
- $\frac{1}{2}" \times 4 \frac{1}{4}"$  ON BOTTOM FOR STABILIZATION PIN OR THREADED BOLT
- BOTTOM  $4 \frac{1}{4}"$
- TOP  $4"$
- $\frac{3}{8}"$  TO  $\frac{1}{2}"$  FORMED RADIUS (TYPICAL FOR EACH CORNER)

**6" DIA. PLATE WASHER WELDED TO TOP OF PIN HEAD**

**7"**

**6"  $\frac{1}{2}"$**

**7  $\frac{1}{2}"$**

**7" DIA. STABILIZATION PIN**

67

**Table 14 Embedment depths for vertical pins**  
Sources: Standard drawings and specifications from the state DOTs

State	Embedment Depth in (mm)			Pin Characteristics		Number of Pins per Segment
	Shoulder/ Soil	PCC Pavement	Asphaltic Pavement	Diameter in (mm)	Length in (mm)	
Arkansas	12 (305)	4 (102)	8 (203)	1.0 (25)	Emb+7.5 (191)	2
California		5 (127)	18 (457)	1.0 (25)	Emb+5/6 (127/152)	4
Colorado	33 (838)		27 (686)	1.0 (25)	Emb+9 (229)	4
Florida		7.5 (191)		1.25 (32)	11.5 (292)	3
Florida			36 (914)	1.50 (38)	40 (1016)	3
Hawaii			32 (813)	1.0 (25)	40 (1016)	2
Idaho		32 (813)	32 (813)	1.0 (25)	40 (1016)	4
Illinois			17 (432)	1.0 (25)	24 (610)	3
Indiana	23 (584)		23 (584)	1.0 (25)	24 (610)	2
Iowa				1.50 (38)	38.5 (978)	3
Kansas				1.50 (38)	40 (1016)	3
Kansas		5.5 (140)		1.13 (29)	10 (254)	3
Nevada			19.8 (502)	1.0 (25)	27 (686)	4
New Jersey	32 (813)	5 (125)	18 (460)	1.0 (25)		varies
New Mexico	25 (635)		19 (483)	.875 (22)	Emb+5 (127)	4
New York	30 (760)	5 (125)	18 (460)	1.0 (25)		9
North Carolina	25 (635)		19 (483)	.875 (22)	Emb+5 (127)	4
Oklahoma				1.50 (38)	38.5 (978)	3
Virginia	16 (406)	16 (406)	16 (406)	1.0 (25)	24 (610)	4
Wisconsin		34 (864)	34 (864)	.75 (19)	40 (1016)	3

As part of the process of designing the pining system for the Kansas PCB, MwRSF conducted component testing of asphalt pins. The pins tested were 36 in (914mm) long and made of A36 steel and had a 3 in (76mm) x 3 in (76mm) x ½ in (13mm) cap welded to the top to provide vertical restraint. Pins of two different diameters, 1 1/8 in (29mm) and 1 ½ in (38mm), were tested with 3 different thicknesses of asphalt, 2 in (51mm), 4 in (102mm), and 6 in (152mm). The pins were loaded laterally through the soil and asphalt by pulling on a steel sleeve that simulated the vertical hole in the barrier. The force was applied by a cable attached to a 4,762 lb (2160kg) bogie sled moving away from the pin at 15 mph (6.7 m/s) as shown in Figure 56. (40)



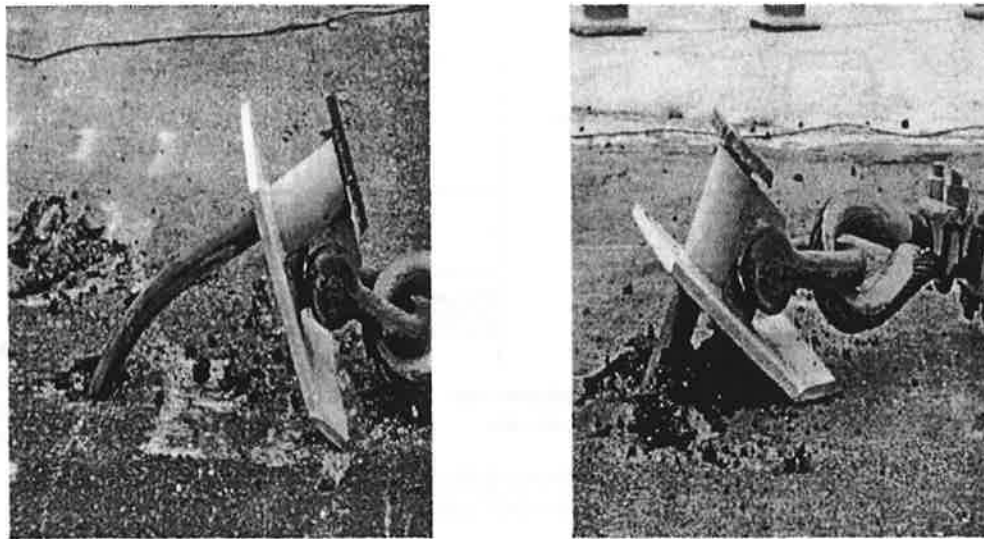


Figure 56 Component testing of pins in asphalt  
Source: MwRSF Report TRP-03-180-06 (40)

The test results indicated that the depth of the asphalt pavement had no significant effect on the strength of the pin. However, the 1 ½ in (48mm) diameter pin developed a peak load of 20.5 kips (91.4 kN), which was 8 % greater than the 19.0 kip (84.6kN) load developed by the smaller 1 1/8 in (29mm) diameter pin. (40)

The number of anchors and the location of anchors vary among the states. Nevada, for example uses two pins (one on each side of the barrier) for a total of four pins per barrier segment. Nevada's anchoring configuration for the Oregon system is shown in Figure 57.

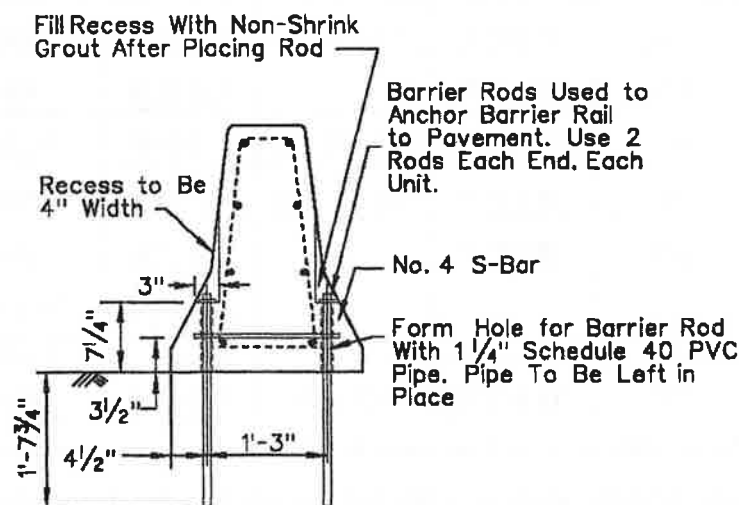


Figure 57 Vertical pin anchoring for the Nevada barrier  
Source: NV DOT R-8.7.1 (502)

Indiana also uses vertical pins, but instead of pinning through the barrier it uses a bracket across the joint between the segments to provide additional stiffening of the joint. Figure 58 shows the details of this anchoring configuration.

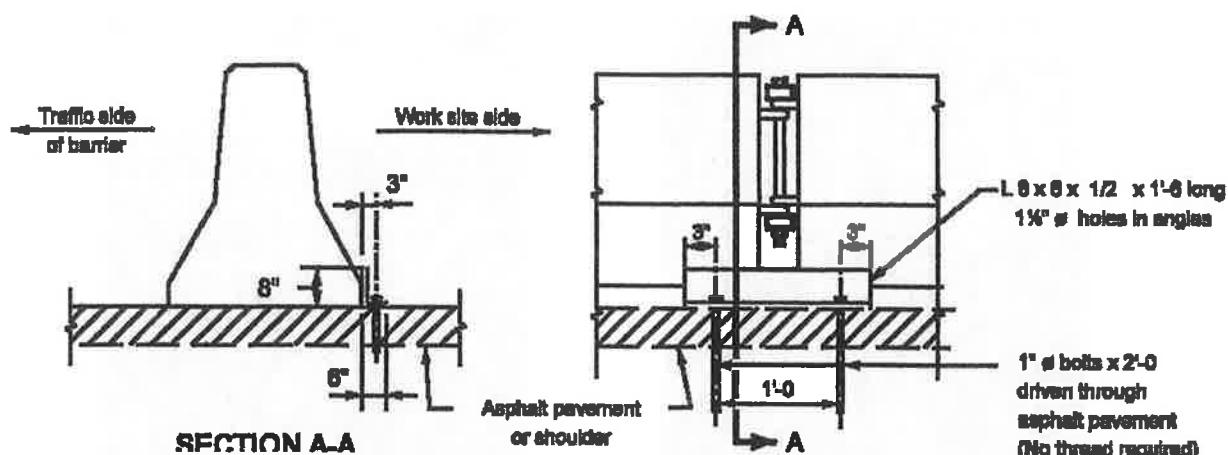


Figure 58 Indiana's cross-joint vertical pinning design

Source: IN DOT E801-TCCB-04

A number of states anchor their PCBs using pins driven at an angle. Table 15 shows embedment depths for angled pins for states indicating such usage. On bridge decks the use of angled pins can make it more likely to encounter bridge reinforcement when drilling the holes.

Table 15 Embedment depths for angled pins

Source: Standard drawings and specifications from the state DOTs

State	Embedment Angle, Depth in (mm)			Pin Characteristics		Number of Pins per Segment
	Angle (deg)	Angled distance	Vertical projection	Diameter in (mm)	Length in (mm)	
Alaska	NS	18 (457)		1.0 (25)	30 (762)	2
Arizona	60	18 (457)	15.6 (396)	1.0 (25)	30 (762)	2
Colorado	NS	18 (457)		1.0 (25)	30 (762)	2
Louisiana	40	7.4 (188)	6.25 (159)	1.5 (38)	21.25 (540)	2
Montana	45	18 (457)	12.7 (323)	1.0 (25)	30 (762)	2
Oregon	NS	18 (457)		1.0 (25)	30 (762)	4
Texas	40.1			1.25 (32)	30 (762) AP 21 (533) PCC	4 or 8
Washington	50	18 (457)	13.8 (351)	1.0 (25)	30 (762)	2 or 4

NS – not specified, AP – asphaltic pavement/base material, PCC – Portland cement concrete pavement/bridge deck

Figure 59 shows how Arizona anchors its Oregon system barrier. It uses two pins per barrier on the traffic side embedded 18 in (457mm) at a 60° angle.

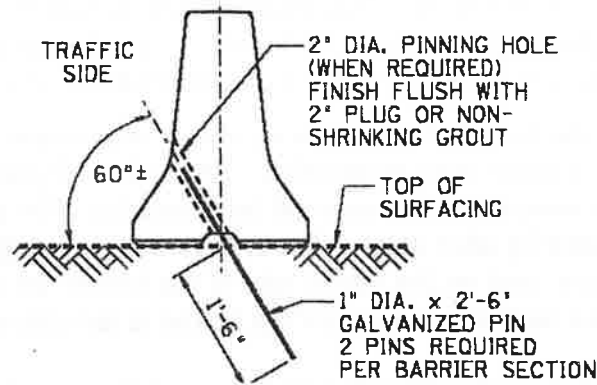


Figure 59 Arizona's angled pinning design  
Source: AZ DOT C-3 sheet 2

Washington also pins its PCBs but at a 50° angle. Figure 60 shows two pinning configurations for the Washington system, one for construction zones where pinning is done only on the traffic side (two pins per segment) and the other for a median application with pinning on both sides of the barrier (four pins per segment). Anchor pins are 1 in (25mm) in diameter and are embedded 1.5 ft (m) into the pavement.

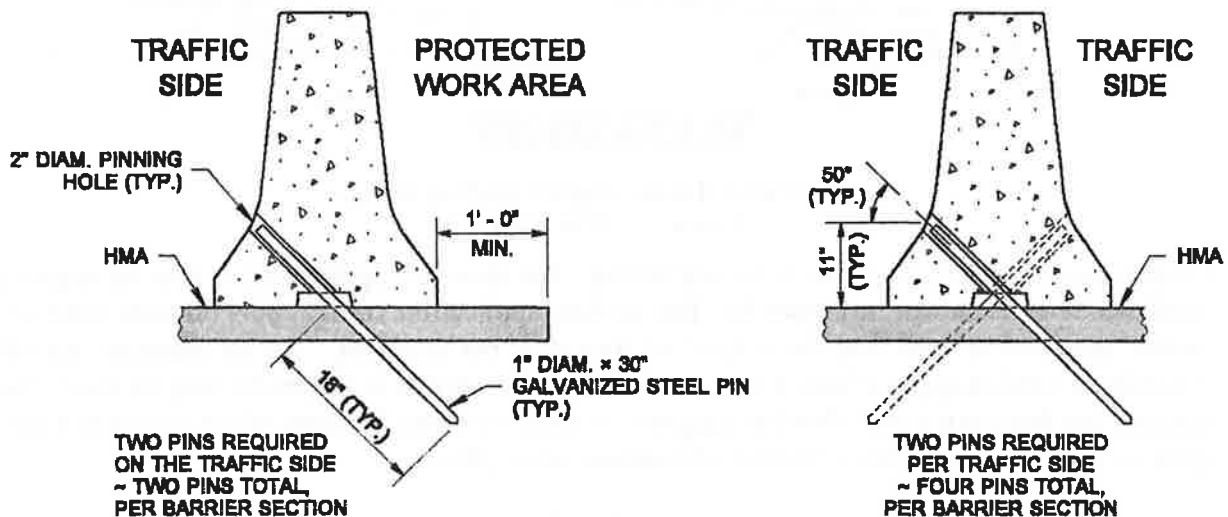


Figure 60 Washington's angled pinning design  
Source: WA DOT K-80.35-00 sheet 1

A system very similar to this design was crashed tested at TTI in 2006. After studying the Washington DOT NJ-shape system using finite element simulations, the diameter of the pin was increased from 1 in (25mm) to 1.5 in (38mm), and the pin angle was increased from 50° to 55° to avoid interference with reinforcing bars in PCBs of the other states participating in this pooled-fund project. In the crash test the barrier rotated, dropped off the deck, and the vehicle rolled over. TTI observed that concrete around one of the pins failed catastrophically (see Figure 50) which allowed high barrier roll and vehicle climb. As the barrier rotated and dropped off the deck edge, lift in downstream segments occurred, which allowed even greater barrier rotation.

During this rotation the pins pulled out of the concrete without significant resistance which led to the conclusion that the pin angle should be reduced. In a subsequent crash test of an F-shape barrier with a pin angle of 40° the anchored PCB performed satisfactorily. (40)

Texas is one of the few states that does not use a pin and loop connection for its PCB. It uses a X-bolt design to obtain a more rigid connection. Detail 2 in Figure 61 shows Texas' use of angled pins for asphaltic concrete pavements and base material. The pinning angle is 40.1° which is flatter than the angle used by other states. The elevation view in Figure 61 shows the locations for the pins. Four pins are used on the traffic side of the barrier for temporary installation, and four additional pins on the back side are used if the barrier is installed permanently.

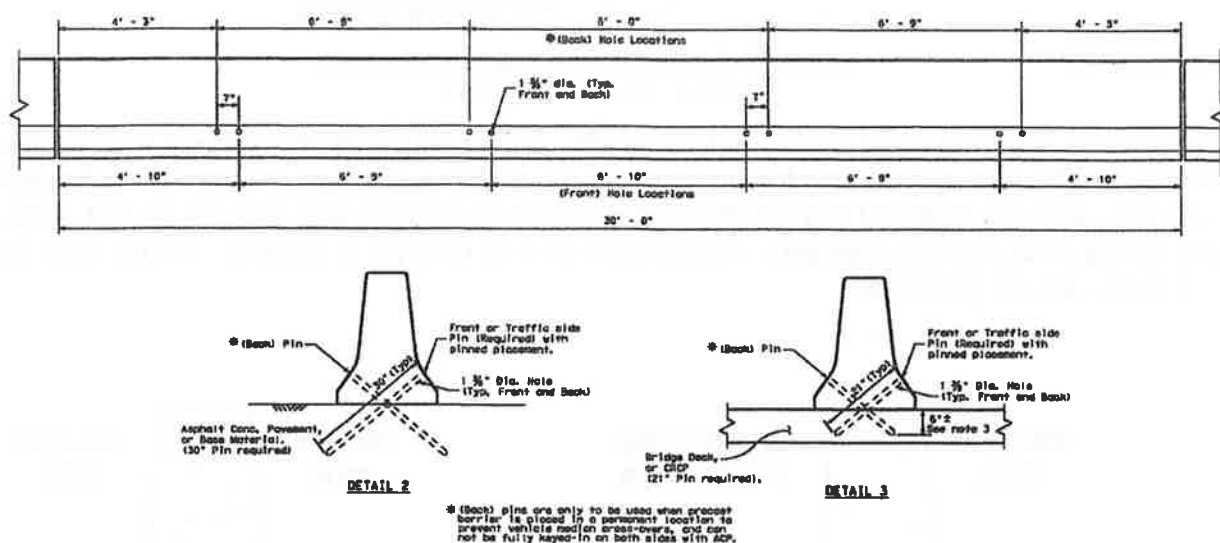


Figure 61 Texas' angled pinning design

Source: TX DOT CSB(7)-04

Oregon uses a variety of methods for anchoring. For shoulder application it uses an angled pin similar to what is shown in Figure 59. For median application vertical pins on both sides of the barrier are used at each end for a total of four pins per segment. As an alternate for either shoulder or median applications, a grout under-laying as shown in Figure 62 may be used. Some concern has been expressed about using grout to secure barriers because of the propensity for the grout to deteriorate with time because of moisture absorption.

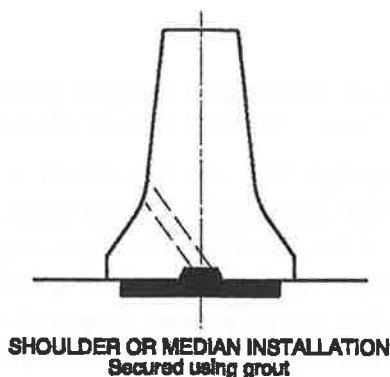


Figure 62 Oregon's alternate anchoring system using grout

Source: OR DOT RD 516

Pennsylvania, anchors its PCBs by “keying” them in with a 2 in (51mm) layer of asphaltic concrete pavement. Figure 63 shows the details of this design.

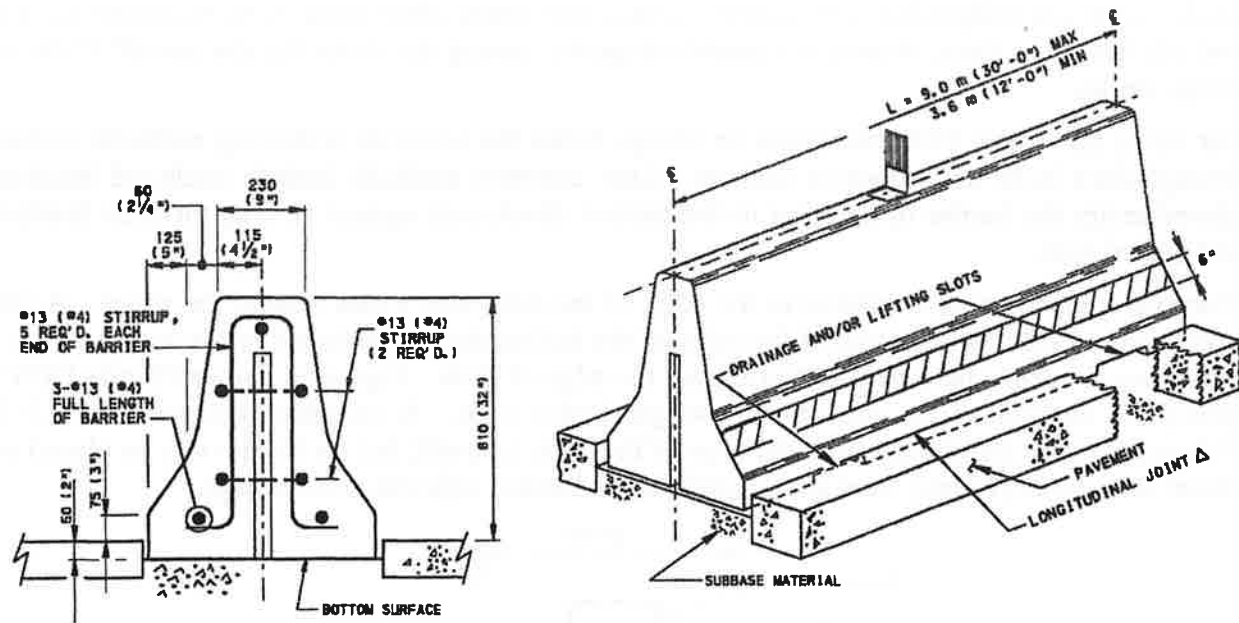


Figure 63 Pennsylvania's “keyed” anchoring system using pavement

Source: PA DOT RC-57M sheet 1

A few states have developed methods to reduce barrier deflection that do not require attaching the barrier to the pavement. The common way is to stiffen the barrier connection by attaching a box beam to the back of the barrier segments. Figure 64 shows New York's box beam stiffening design. This design has been crash tested successfully at MASH TL-3. (10) With the box beam stiffening, the dynamic deflection in the MASH 3-11 test was 2.3 ft (0.7m). In another MASH 3-11 test, the NY system was anchored in every other segment with four 1 in (25mm) diameter vertical pins embedded 5 in (127mm) into concrete pavement. This test was recorded as a pass, but there was separation at the joint and the deflection was 5.4 ft (1.6m). (11)

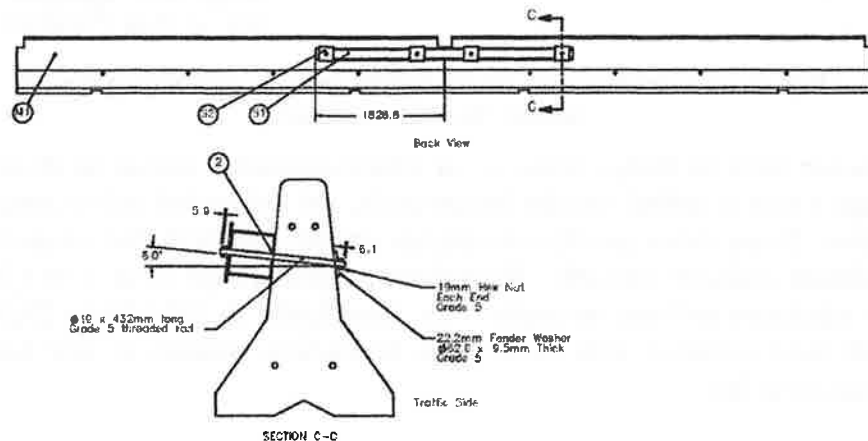


Figure 64 New York's PCB stiffening system using box beams

Source: MwRSF Research Report No. TRP-03-216-09 (11)

## Use and anchorage of PCBs on bridge decks

Precast concrete barrier usage on bridge decks varies among the states. Some states do not allow PCBs on bridges, some allow them to be used only if freestanding, others allowing them to be anchored on old bridges but not on new bridges, and others allow them to be anchored on new and old bridges. Thus, there is no consistent policy among the states for the use of PCBs on bridge decks,

For states that allow PCB anchorage on bridge decks the common anchoring methods include through-deck bolts and adhesive anchors. Less common methods include anchored brackets placed under the barrier or adjacent to the barrier, block outs against an edge-of-deck bracket, and angled pins.

Placement of the barriers relative to the edge of the deck also varies among the states. A few states allow PCBs to be placed at the edge of the bridge deck if anchored while most require a minimum clearance between the barrier and the edge of deck. Figure 65 shows Florida DOT's policy for locating PCBs close to the bridge deck's edge. A minimum clearance of 1.5 in (38mm) must be maintained from the edge of the deck drop-off, but the barrier can be placed no closer than 3.5 in (91mm) from any ground hazard located adjacent to the bridge.

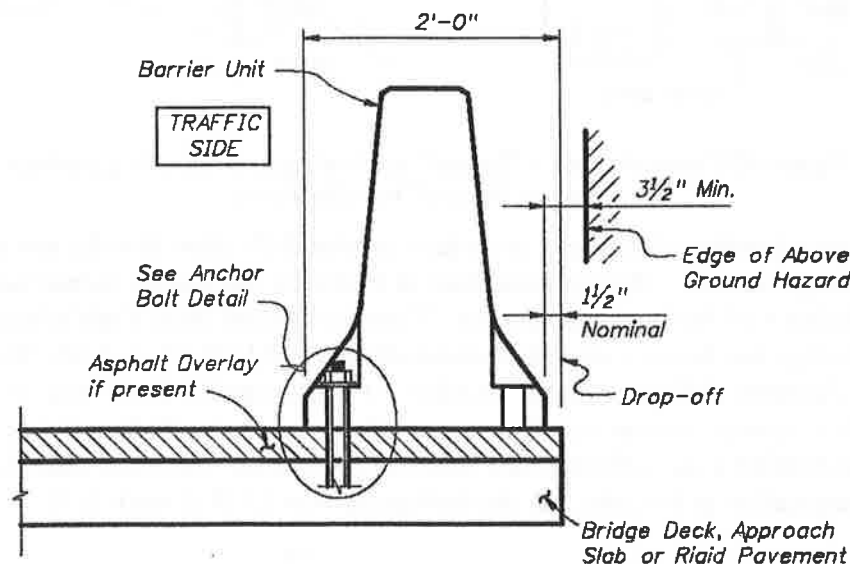


Figure 65 Florida's minimum clearance to bridge deck drop-off

Source: FL DOT 414 Sheet 5

A common anchor used on bridge decks is an adhesive-bonded anchor as shown in Figure 66. With this design a hole is drilled into the bridge deck, and a threaded bolt is inserted and secured with an adhesive. Some states specify a minimum embedment depth for the anchor while others require a minimum pull-out strength. Embedment depths range from 3 in (76mm) to 7.5 in (191mm) and minimum pull-out strengths vary from 6,000 lb (27 kN) to 29,800 lb (132kN). Some problems have occurred with these types of anchors because of low adhesive strengths causing the anchors to fail.

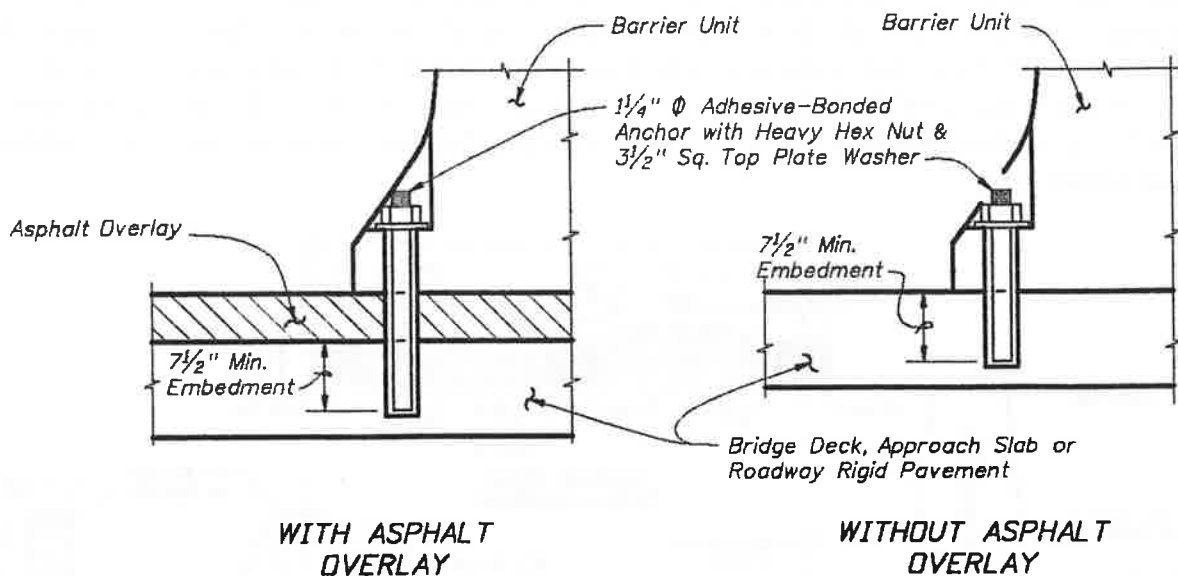


Figure 66 Florida's adhesive bond anchor on bridge decks

Source: FL DOT 44 Sheet 5

A more reliable method for anchoring PCBs to bridge decks is a through-deck anchor. With this method a hole is drilled through the entire deck, a bolt is inserted through the barrier and deck and it is secured with a nut on the underside of the bridge. A drawback of this method is getting access to the underside of the bridge to secure the nut. The undersides of high-level bridges are not easily accessed, and for temporary uses of PCBs the costs can be prohibitive.

Figure 67 shows a typical through-deck design for anchoring PCBs to bridges. Heavy washers with nuts are used at both ends of the steel bolt. Bolt diameters vary from 0.875 in (22mm) to 1.25 in (31mm). Fifteen states showed through-deck anchor bolts on their standard drawings. Of these states four use 0.875 in (22mm) diameter bolts, five states use 1 in (25mm) bolts, five use 1.125 in (28mm) bolts, and one uses 1.25 in (31mm) bolts.

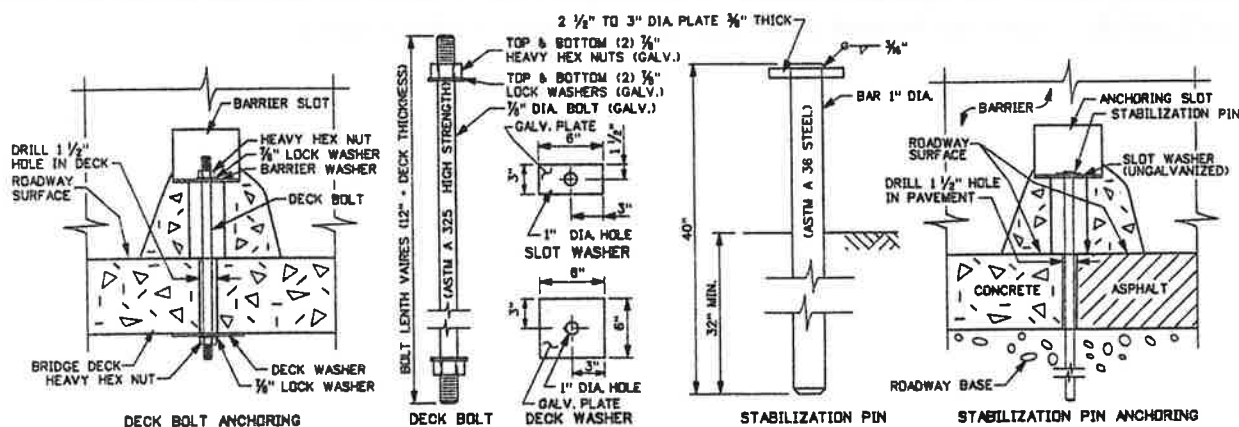


Figure 67 Idaho's design for through-deck bolting of PCBs

Source: ID DOT G-2-A-1 sheet 2

Several alternative anchoring methods employ brackets that are attached first to the bridge deck and then to the barrier. Figure 68 shows Iowa's (Kansas system) under-the-barrier tie-down

bracket. The bracket is attached to the bridge deck with adhesive anchors and then connected to the barrier at each joint with the pin that extends through the loops. This design provides strengthening of the segment joints which lessens barrier deflection during impacts. This design was crash tested under NCHRP Report 350 test 3-11 conditions and had a dynamic deflection of 3.1 ft (0.9m), which is slightly less than the 3.8 ft (1.2m) deflection observed in the unanchored Kansas barrier. (43)

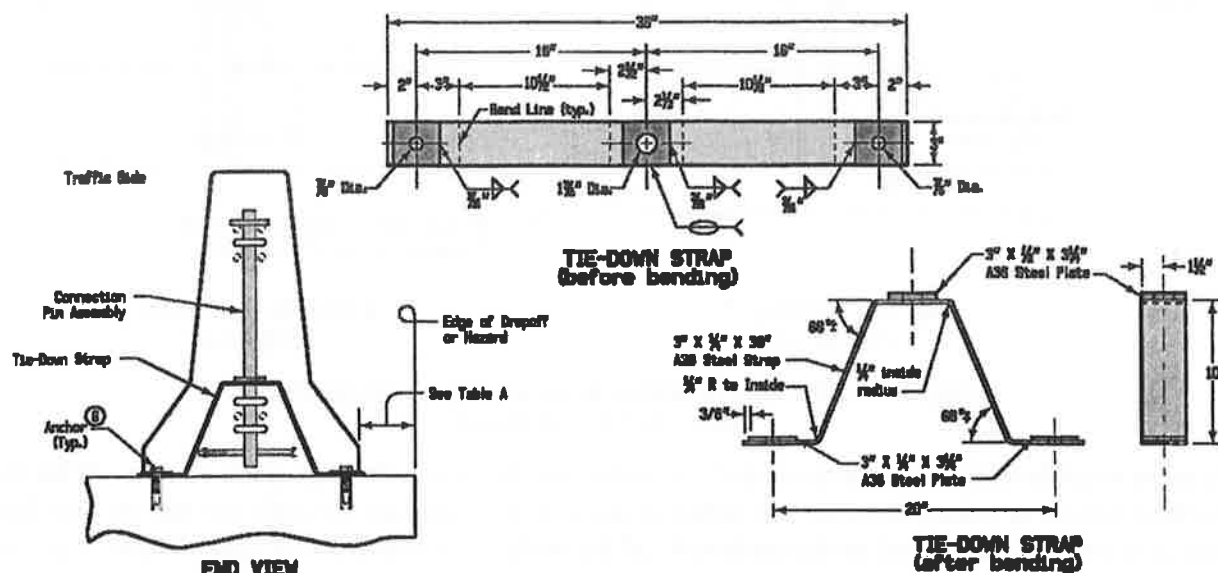


Figure 68 Iowa's Under-barrier tie-down bracket

Source: IA DOT RE-71 sheet 3

Illinois and Iowa both use the "Kansas" barrier, but Illinois has a different anchoring method which uses a bracket attached to the outer edge of the bridge deck as shown in Figure 69. This bracket is required when the available clearance behind the barrier is less than 3.5 ft (1.1m). The wood block can be eliminated if travel lane width requires the barrier to be located at the edge of the bridge deck. An expansion anchor or cast in place insert with a certified minimum proof load of 5,000 lb (22kN) can be used in place of the bolt shown in the diagram.



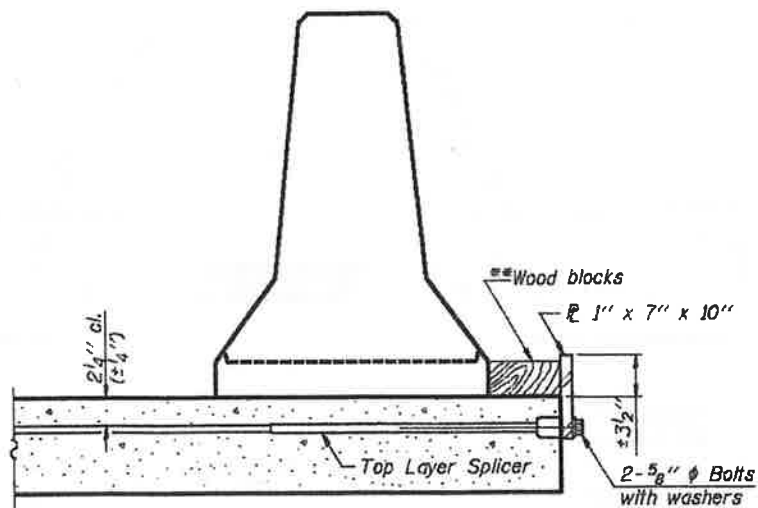


Figure 69 Illinois' block-out with edge-of-deck bracket  
Source: IL DOT R27

Arkansas, a user of the Idaho barrier, anchors its PCBs with L-shape brackets on the backside of the barrier as shown in Figure 70. The threaded anchor bolts are cast-in place in new decks and drilled and grouted in existing decks. A minimum ultimate load capacity of 8,000 lb (36kN) tension is required.

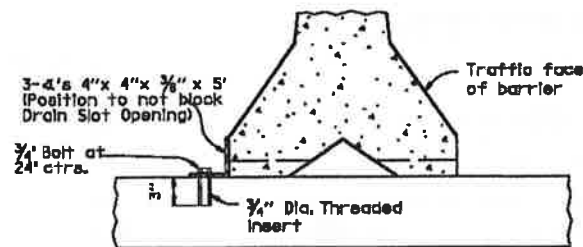


Figure 70 PCB bridge anchorage using an anchored bracket attached to the side of the barrier  
Source: AR DOT TC-4

Washington State DOT uses a larger bracket to anchor its barrier. Figure 71 shows this larger bracket in Attachment "A" Detail and its L-shape bracket in Attachment "B" Detail. The larger bracket is used on the traffic side of the barrier, and if the barrier is used on the edge of a bridge deck or to protect a work area, an L-shape bracket is used on the outside edge. The locations of the six anchors per barrier section are shown in Figure 72.

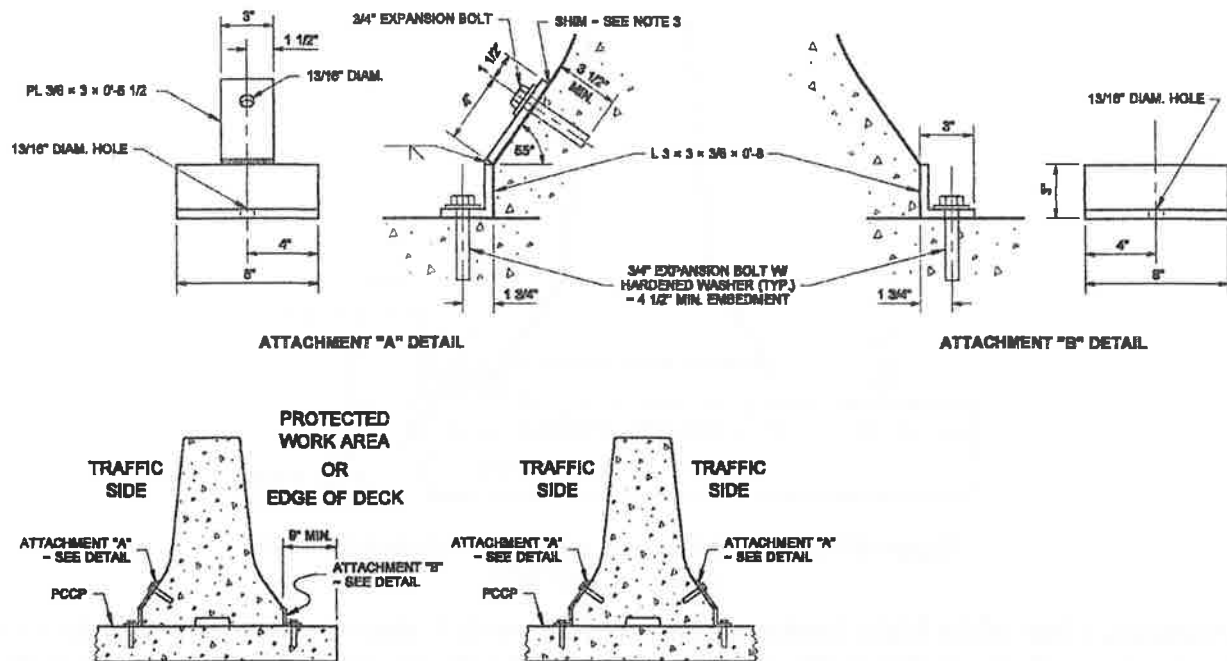


Figure 71 Washington State DOT's brackets used to anchor PCBs on bridge deck  
Source: WA DOT K-60.35-00

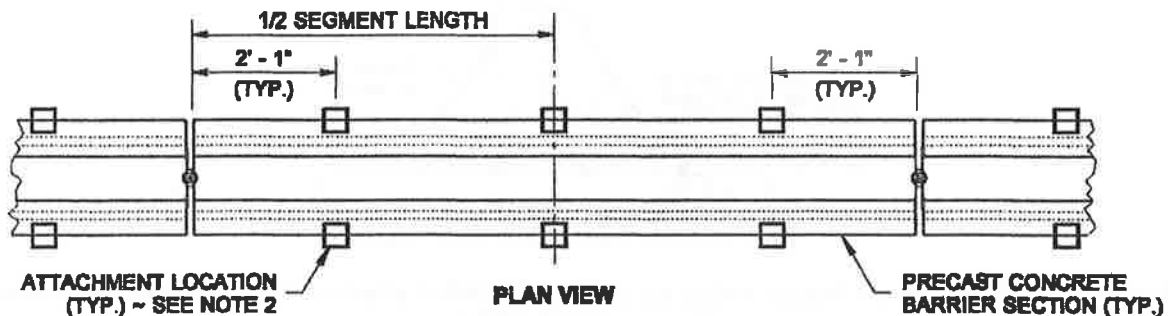


Figure 72 Washington State DOT's PCB anchor pattern on bridge decks  
Source: WA DOT K-60.35-00

Indiana's standard method for anchoring PCBs on concrete bridge decks is similar to its anchor method used for pavements as shown previously in Figure 58. The 1 in (25mm) anchor pins shown in Figure 58 are replaced with 0.75 in (19mm) expansion anchors on bridge decks. An alternative anchoring method on bridge decks is to use a longer connection pin which extends through the deck as shown in Figure 73. A washer and nut are used on the underside of the deck to secure the anchorage.

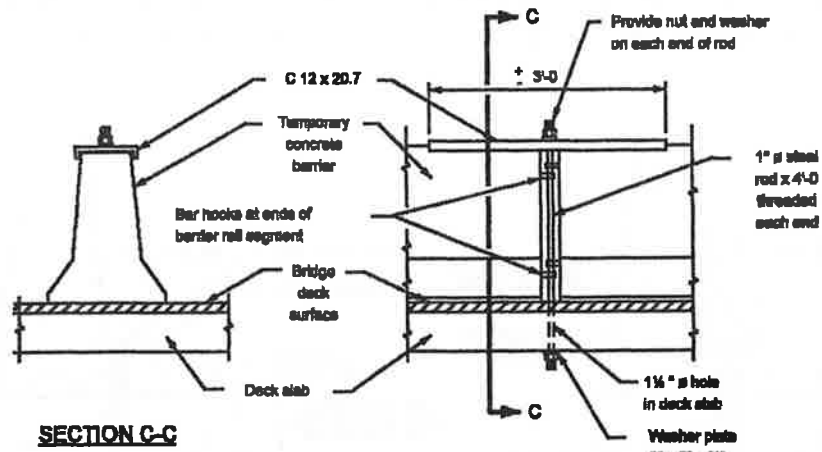


Figure 73 Indiana's anchoring method using extended joint pins through the bridge deck  
Source: INDOT E801-TCCB-04

Expansion joints are used on bridge decks to accommodate thermal expansions and contractions. To allow for such longitudinal movements of the bridge deck, Kansas eliminates one of the PCB anchors adjacent to the expansion joint. Figure 74 shows this anchoring pattern for PCBs spanning an expansion joint.

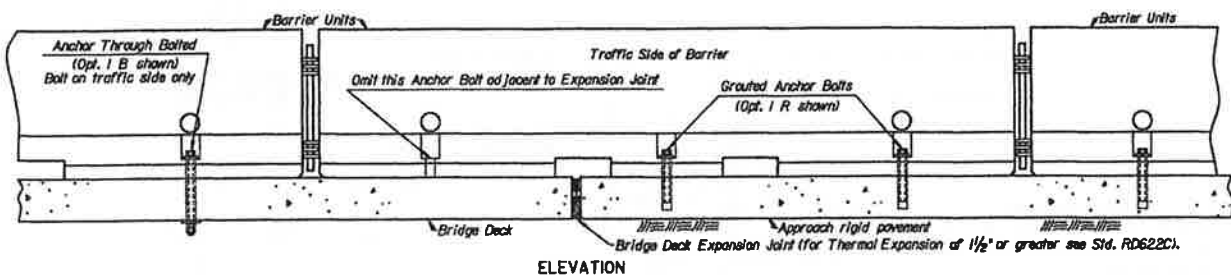


Figure 74 Kansas' design for anchorage of PCBs at expansion joints on bridge decks  
Source: KS DOT RD 622B

The anchors shown in Figure 74 are vertical anchors, either through-deck or adhesive anchors. Other states that use the "Kansas" barrier use various types of brackets to anchor their PCBs as discussed earlier in the report. Thus, anchoring methods are independent of barrier profile and segment length.

MwRSF developed the anchorage system used for the Kansas barrier. For placement on bridge decks they recommend that the bolts be installed only on the traffic-side of the barrier. Bolts placed on the backside of the barrier could potentially degrade barrier performance by allowing the barrier to rotate around the anchorage which could allow vehicles to climb the barrier. Also, placement of the anchors on the traffic side allows the barrier to be placed closer to the deck edge. (35)

Bolting a barrier to a bridge deck with an asphalt overlay is not recommended. High bending moments will be introduced in the anchor bolts at the interface between the concrete deck and the asphalt pavement which could cause the bolts to bend at lower loads. (35)

Figure 75 provides a summary of three of the common ways to anchor PCBs. It shows New Mexico's design for through-deck anchors, adhesive bonding anchors, and anchor bolts.

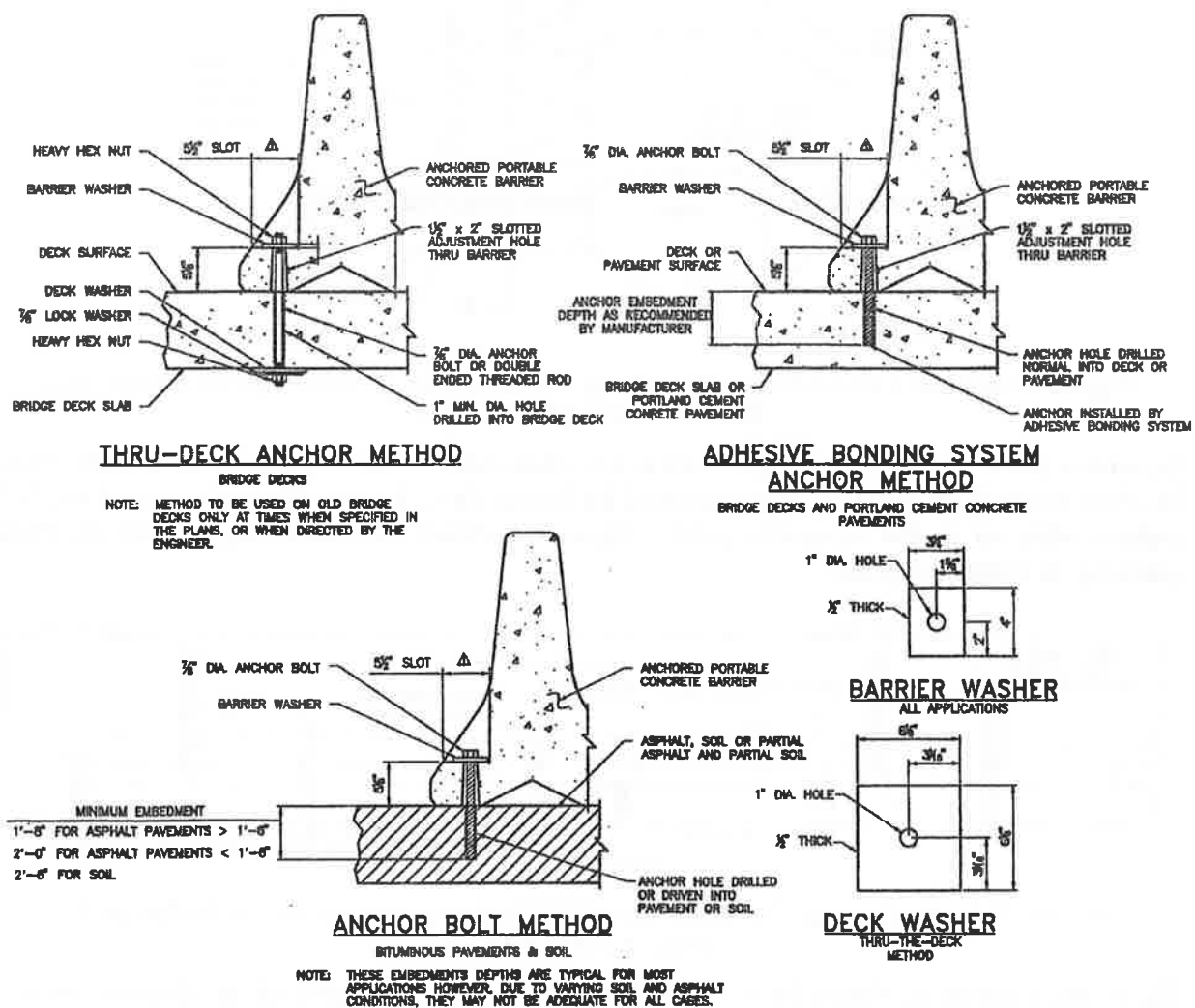


Figure 75 Three methods used to anchor PCBs in New Mexico

Source: NM DOT 606-20 sheet 3

MwRSF is in the process of developing a precast concrete bridge railing system for fiber reinforced polymer (FRP) composite panel bridge decks. Their first attempt of developing a half-section NJ-shape barrier attached with six 1 in (25mm) anchor bolts did not meet NCHRP Report 350 TL-3 crash test criteria. In the crash test the vehicle climbed the railing causing the barrier to deflect laterally which was caused by deck panel shift, girder deformation, and rotation of the deck cantilever. After reviewing the crash test in detail several recommendations for fixing the problem were made:

1. Decrease the gap width between barrier segments by incorporating a recessed area at the barrier ends similar to what is used with the Oregon barrier.
2. Minimize lateral joint slack by either increasing the pin diameter, inserting a pipe sleeve, or some other way to increase the transfer of moment across the joint.

3. Increase the length of the barrier segments or arrange barriers so that deck joints do not align with barrier joints so that each segment is attached to at least two deck panels.
4. Attach a structural beam to the bottom of the deck that runs parallel with the barrier and attaches to more than one deck panel. (44)

In March 2009 MwRSF ran a successful MASH Test 3-11 crash test on a modified barrier on a fiber reinforced polymer (FRP) composite panel bridge deck. The dynamic deflection was 4.4 in (112mm) and the maximum roll angle 22.5°. Additional details of the barrier modification and crash test were not available at the time this report was written. (45)

## Materials

Precast concrete barriers are composed of concrete and steel. The steel is used for reinforcing the concrete, providing the connection between adjacent segments, and for anchoring and stiffening of the barrier. Concrete and steel are available in different strengths and types and the specific materials selected can affect the performance of the barrier system.

## Concrete

A common way to characterize concrete is its 28-day compressive strength expressed in psi or mPa. Not all states include material specifications on their PCB engineering drawings, but for the 34 states that do provide information on the compressive strength of the concrete, seven different values are specified. Concrete strengths from 2,500 psi (17.2 mPa) to 5,000 psi (34.5 mPa) are used with 3,000 psi (20.7 mPa) and 4,000 psi (27.6 mPa) being the most common. Table 16 shows the concrete strengths specified for PCBs in 31 different states.

Table 16 Minimum 28-day compressive strengths specified for concrete in PCBs

28-Day Compressive Strength		No. of States	States
psi	mPa		
2,500	17.2	3	AR, MS, NJ
3,000	20.7	11	AK, GA, HI, MI, MT, NV, NM, NY, TN, VT, WV
3,500	24.1	1	PA
3,600	24.8	1	TX
4,000	27.6	11	AZ, ID, IL, MO, NE, NH, OH, OK, SD, VA, WA
4,500	31.0	2	CO, MD
5,000	34.5	5	FL, IA, KS, MA, MN

The Kansas system is arguably the system that has received the most development and crash testing of any of the PCB design. It has been under development through pooled funds projects at the Midwest Roadside Safety Facility since the early 1990s. Concrete specifications were located for 8 of the 9 states using the Kansas PCB. Four of these states specify 4,000 psi (27.6 mPa) concrete and the other 4 specify 5,000 psi (34.5 mPa) concrete. The important point is that the Kansas barrier contains stronger concrete than the majority of the other PCB systems.

## **Reinforcement bars**

Steel reinforcement in concrete adds the strength needed to endure vehicular impacts on precast concrete barriers. The material used for reinforcement bars in almost all PCBs is ASTM A-615 grade 60 (AASHTO M-31) deformed and plain carbon steel with a yield strength of 60,000 psi (414 mPa, nominally 420 mPa) and a tensile strength of 90,000 psi (620 mPa). Four states (HI, LA, MN, and MO) specify grade 60 steel without any ASTM or AASHTO designation. Two states, Georgia and Michigan, specify grade 40 steel for their reinforcement bars, which is only two-thirds as strong as the grade 60 steel. South Carolina specifies ASTM A-706, low-alloy deformed steel for its rebars.

## **Loop bars**

Most states now use smooth steel bars for the connection loops, but two states, Michigan and Washington, still use wire rope for loops. Fourteen states specify A-36 or A709 grade 36 steel for their loop connections. This steel has a yield strength of 36,000 psi (248 mPa) and a tensile strength between 58,000 psi (400 mPa) and 80,000 psi (552 mPa). Iowa, Kansas, Nebraska, Oklahoma, South Dakota, Wisconsin, and Vermont use a grade 60 steel with a yield strength of 60,000 psi (414 mPa) and a tensile strength of 80,000 psi (552 mPa). All of these states except for Vermont use the Kansas PCB design. Minnesota, another state that uses the Kansas system, specifies grade 50 for its loop bars.

Both states that use wire rope for loop bars now specify 5/8 in (16mm) diameter 6 x 19 wire rope. Michigan used to use 1/2 in (13mm) wire rope but now requires 5/8 in (16mm) diameter A-1023 wire rope with a minimum breaking strength of 31,860 lb (142 kN) and Washington specifies A-603 wire rope with a minimum breaking strength of 30,000 lb (133 kN).

## **Connection pins**

As with the loop bars, most states specify A-36 steel for the connection pins. Nine states specify A-36 steel; three states, A-709 grade 36; and four states, A-307, which is usually made from A-36 steel. The next most common steel is A-449 or A-325, which is used by seven states. This steel is stronger than A-36 steel, with a yield strength of 92,000 psi (634 mPa). Two states specify AASHTO M-314 steel for their connection pins. Alabama uses grade 35 while Mississippi requires grade 55. Vermont uses an M-31 (A-615) grade 60 rebar for its connection pin.

## **Anchor pins**

Anchor pins are usually fabricated from grade 36 steel. Fifteen states specify grade 36 steel using A-36, A-307, A-709, F-1554, M-183, M-270, or M-314 designations for their anchor pins. Nevada specifies A-449 grade 60; Ohio and New Mexico, A-325; and Pennsylvania, A-193, a high strength bolt with a yield strength of 105,000 psi (724mPa).

## **Anchor bolts**

A number of states do not anchor PCBs to bridges so information on anchor bolts was found for only 19 states. Nine of these states use A-307, A-36, or M-270 grade 36 steel for their anchor bolts. Seven states use A-307 steel, two use A-449 steel, and one uses F-1554 grade 724.

MwRSF conducted component testing of drop-in anchors and screw-in anchors for the purpose of identifying alternative anchoring bolts for the Kansas barrier steel-strap anchoring system. The current design uses a 3/4 in (19mm) drop-in anchor as shown in Figure 76, and the

researchers wanted to see if a screw-in anchor, also shown in Figure 76, could be used as an equally strong alternative. (46)

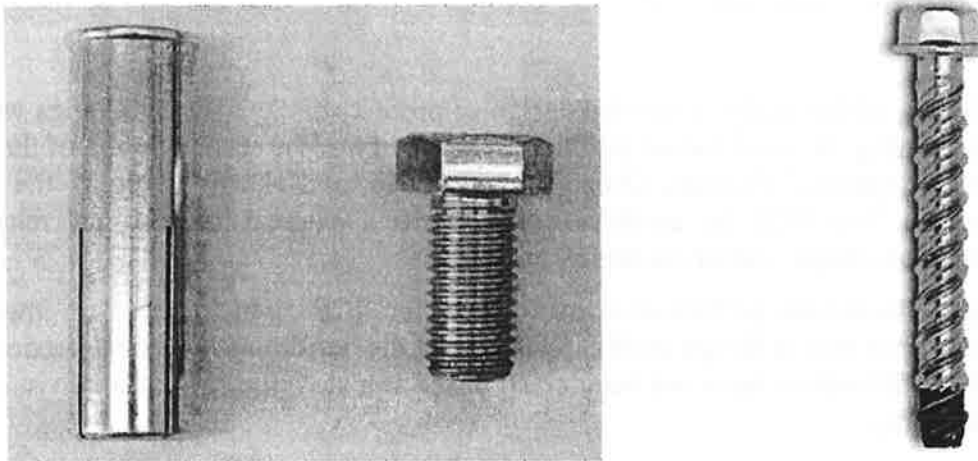


Figure 76 Drop-in anchor and screw-in anchors

Source: MwRSF Report TRP-03-182-07 (46)

The currently specified drop-in anchors were tested first to verify their shear and tensile strengths. Two tests each were conducted for shear and tension, and the results were averaged to establish the minimum capacities that equivalent screw-in anchors would have to meet. The average tensile strength of the drop-in anchors was 18.7 kips (83.1 kN), and the average shear strength was 25.6 kips (113.8 kN).

The screw-in anchors tested were limited to  $\frac{3}{4}$  in (19mm) diameter so that they could be used in existing barrier/strap anchor holes. All of the screw-in anchors tested performed well and peak tensile loads were generally higher than manufacturers' published values. However, the screw-in anchors did not perform as well in the shear tests. The peak shear loads were generally lower than the shear capacity of the drop-in anchor. Two distinct failure modes were observed. For all screw-in anchors with embedment depths of 3.5 in (89mm) or less concrete crush and subsequent pullout of the anchors occurred. For all anchor embedment depths of 4 in (102mm) or greater shear fracture of the anchor was observed. The 28-day compressive strength of the concrete used in the test was slightly greater than 4,000 psi (27.6 mPa). It should be noted that the steel used in the drop-in anchors had higher strength than the steel used in the screw-in anchors which partly explains the lower shear strengths observed in the testing. Two suitable screw-in anchor alternatives for the drop-in anchor were identified. (46)

## Chapter 9

### Findings and recommendations

#### Findings

The main finding of this study is that the design of precast concrete barriers varies widely with very few states using identical barrier designs. While thirty of the states use one of the five most popular barrier "systems" (Kansas, Oregon, Idaho, Ohio, and North Carolina), the individual states customize their PCB by modifying the barrier's external dimensions, reinforcement design, connection design, and/or anchoring method.

No meaningful in-service performance data exists for PCBs which makes it impossible to determine how each state's design modifications affect the performance of their barrier. Most of these design modifications have not been crash tested to determine if they improve or degrade barrier performance.

NCHRP Report 350 and MASH crash test evaluation criteria address only the safety of vehicle occupants involved in impacts with roadside barriers. The safety of the workers who potentially are positioned behind the barriers is not considered at all by these test criteria. Crash tests in which barrier segments broke apart completely and deflected over 12 ft (3.8m) have been judged to have met all test criteria successfully.

Based on information obtained in this study it appears that five states, Connecticut, Maine, Rhode Island, Vermont, and West Virginia are using PCBs that have not been crash tested nor accepted by FHWA as being NCHRP Report 350 crashworthy. Michigan uses a PCB that was crash tested but failed to meet NCHRP Report 350 criteria. Pennsylvania uses a PCB that has been accepted as meeting NCHRP Report 350 criteria in 2000 but does not meet AASHTO's requirement of having a connection that transfers tension across barrier joints. This barrier separated completely during its crash test and deflected over 8 ft (2.6m).

Barrier performance is heavily dependent on the design of the inter-segment connection. Important factors include the capacity of the connection to transfer tension and moment across the joint, the tightness of the joint (lack of slack in pin and loop connections), the size of the gap between barrier segments, and the physical condition of the concrete on the segment ends.

The Kansas barrier system has been under development for approximately 15 years through a pooled fund project at the Midwest Roadside Safety Facility in Lincoln, NE. It is currently used by nine states, and it is being updated and improved on a continuing basis. No other PCB system has been studied and developed as much as the Kansas system.

Anchoring design and performance is an aspect of PCBs that is not well developed or understood. PCBs are anchored in a variety of ways that provide mixed results on vehicle stability and barrier deflection. Most anchoring methods have not been crash tested with the barrier system on which they are used.

States assume that PCBs crash tested successfully unanchored can be anchored in many different ways and used on the national highway system without further crash testing.

Reinforcement of PCBs varies widely from state to state. The type (vertical or horizontal), quantity, quality, and configuration differ even for the states using the same PCB system.



State policies on minimum clearances required behind unanchored (and anchored) PCBs are inconsistent and nonexistent for some states. Often these policies do not appear to be related to the deflections observed in crash tests of the barrier.

PCBs that are in too poor condition to perform effectively are being used on heavily-traveled highways as shown in Figure 77.

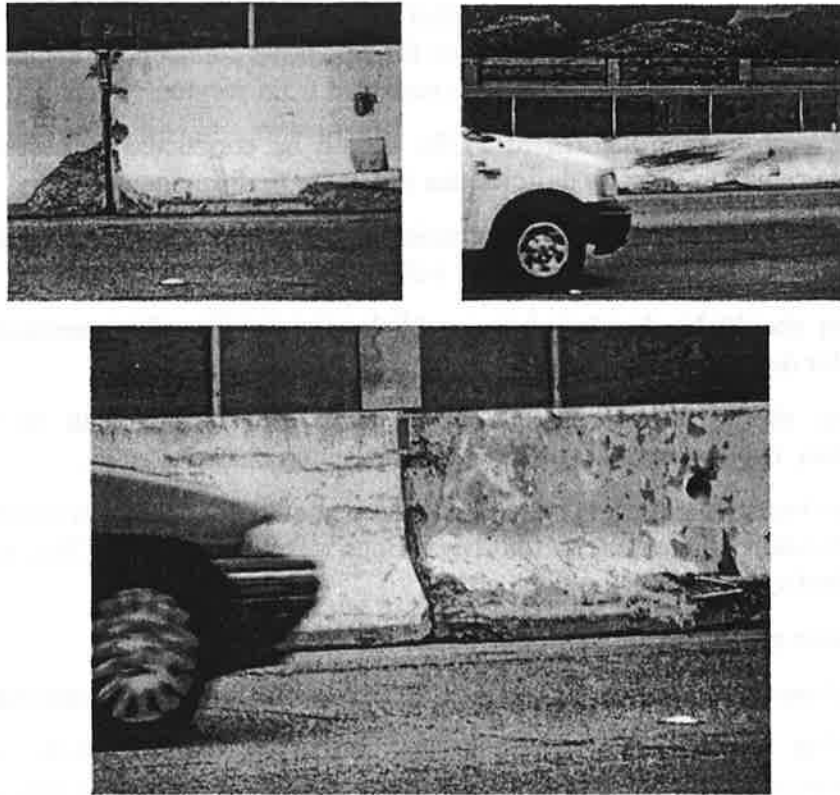


Figure 77 Heavily-damaged PCBs in use on Highway US 101 in Burlingame, CA

Source: Photographs taken by R.G. McGinnis on 22 November 2008

Initial results from TL-3 crash tests of PCBs with the larger 5,000 lb (2270kg) pickup truck have been encouraging. Vehicle stability seems to be improved, and barriers tested so far have been strong enough to contain the vehicle. However, barrier deflections are greater than observed in the NCHRP Report 350 crash tests because of the larger mass of the test vehicle.

No MASH TL-4 crash tests were found in this study. It is not likely that a 32 in (813mm) PCB will be able to meet the MASH TL-4 criteria because of the large increase in energy of the MASH TL-4 test compared to the NCHRP Report 350 TL-4 test.

Additional research is needed to answer a number of questions/concerns about PCBs and to optimize PCB design. Simulations have been used to analyze PCB performance and may have potential for use in understanding anchored performance. Crash tests will be needed to confirm the research results.

#### **Recommendations**

- Crash test criteria that consider the safety of workers behind PCBs need to be developed and applied to crash tests of PCBs that will be used in construction zones. PCBs that

separate completely during crash tests should not be allowed to be used in work zones where workers could be located behind the barrier.

- The number of different non-proprietary barrier systems should be reduced to no more than four systems, and future research and development should be focused on these systems.
- Temporary PCBs currently in service that do not meet NCHRP Report 350 requirements or do not meet AASHTO's requirement for a positive connection that can transfer tension and moment across the joint should be removed from service.
- In-service performance studies of PCBs should be conducted to assess overall barrier performance and to identify deficiencies in barrier performance/design.
- PCB anchoring methods that have not been crash tested successfully should be crash tested with the barrier system on which they will be used.
- Guidelines should be developed to establish minimum quality standards for PCBs and criteria for determining when it is time to retire a barrier from use.
- Guidelines should be developed for labeling barrier elements to enhance proper application, inspection, and awareness of deflection characteristics.
- Guidelines based on expected barrier deflection should be developed to establish minimum behind-the-barrier clearances for the various applications of PCBs, e.g., work zones, bridge decks, medians, shoulders, etc.
- Performance standards for anchoring systems should be developed.
- Additional research should be conducted to answer the following questions:
  - What can be done to the barrier profile to reduce vehicle ramping without compromising occupant safety and consider the need to accommodate pavement overlays?
  - What is the optimum gap width between adjoining barrier segments?
  - Is the pin and loop connection the optimum design for temporary PCBs? If so, how can its design be improved to reduce barrier rotation and deflection during impacts?
  - How can the friction between the bottom of the barrier and its support surface be increased to reduce dynamic deflection?
  - What are the best methods for reducing PCB dynamic deflections for the various surfaces (bridge decks, Portland cement concrete pavements, bituminous concrete pavements, shoulders, and soil) and applications (permanent installations, temporary traffic control uses, and temporary work zone uses)?
  - From a life cycle cost viewpoint that considers vehicular impacts as well as damage caused to barriers during installation, transport, and disassembly, what is the optimum reinforcement design for each of the commonly-used PCB systems?
  - Is welded wire fabric an adequate substitute for reinforcement bars?

- What is the optimum segment length for PCBs? Is it dependent on the connection design?
- What are the optimum strengths for the concrete and steel used in PCBs?
- What can be done to reduce the long-term performance deterioration of grout and adhesive anchoring methods for PCBs?

## Chapter 10

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