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DEPARTMENT OF TRANSPORTATION

PENNDOT RESEARCH

CRASH TEST OF PENNDOT'S PORTABLE F-SHAPED CONCRETE BARRIER

University-Based Research, Education and Technology Transfer Program

AGREEMENT NO. 359704, WORK ORDER 32

FINAL REPORT

MARCH 2000

By M. El-Gindy, A. Scanlon, and R. Tallon

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The objective of the test program described in this report was to evaluate the performance of PennDOT's portable F-shaped concrete barrier when subjected to NCHRP level-3 testing criteria based on test designation 3-11. The scope of the test program consisted of a single test in which a 1993 Ford F-250 pick-up truck impacted the barrier at 100 km/h (62 mph) at an impact angle of 25 degrees.

Following impact with the barrier, the vehicle mounted the barrier and rotated counter-clockwise with the rear of the vehicle crossing over the barrier. The front wheels came in contact with the ground and the vehicle began a passenger-side leading roll, coming to rest in a grassy area after rolling three times. Significant movement of the barrier occurred during impact, resulting in an undesirable trajectory of the vehicle. Spalling occurred at barrier joints 7 and 8, resulting in the separation of adjacent barrier sections in the vicinity of the impact.

The rollover following the initial impact and the damage to the vehicle compartment would be expected to place occupants at significant risk. Based on a review of the test results, it is concluded that the portable F-shaped concrete barrier tested does not meet the NCHRP 350 level 3 performance criteria. It is recommended that the joint design for the portable F-shaped barrier be reevaluated and modified before conducting further crash tests.

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Prepared for

Commonwealth of Pennsylvania
Department of Transportation
Office of Planning & Research

By

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The Pennsylvania Transportation Institute
The Pennsylvania State University
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March 2000

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PTI 2K13

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High speed filming was performed by John Yannaccone of ARCCA, Incorporated.

Dr. Richard McGinnis of Bucknell University provided advice on test preparations and interpretation of NCHRP test requirements. The contributions of James Tenaglia, P. E., and Paul Kokos, P.E., of the Pennsylvania Department of Transportation are also acknowledged with thanks.

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ABSTRACT

This report presents the results of a level 3 crash test of the portable F-shaped concrete barrier used by the Pennsylvania Department of Transportation in work zone areas. The crash test was conducted on November 22, 1999 at the Pennsylvania Transportation Institute's Crash Safety Research Center.

One test was conducted in accordance with NCHRP 350 level 3, test designation 3-11. The test vehicle used was a 1993 Ford F-250 pick-up truck with an impact speed of 100.9 km/h (62.7 mph). The test article's performance was not satisfactory. Following impact with the barrier, the vehicle mounted the barrier and rolled over three times. One of the barrier sections was completely separated from the adjacent sections, and was displaced significantly rearward and knocked over. The impact caused significant damage to the joint between adjacent barrier sections. The testing agency recommends that the connection detail be reevaluated before retesting the barrier.

INTRODUCTION

Statement of Problem

In order to meet Federal Highway Administration (FHWA) requirements, the Pennsylvania Department of Transportation (PennDOT) needed to evaluate the crashworthiness of its portable F-shaped concrete barriers by means of crash testing according to NCHRP 350 requirements (Ross et al. 1993). Barriers with joints that fail to transfer tension and moment from one segment to another will not be acceptable to FHWA after October 1, 2000, unless they are demonstrated to be crashworthy. A crash test is necessary to evaluate PennDOT's current portable concrete barrier with slotted connection as shown in *Roadway Construction Standards* (RC 57M).

Objective and Scope

The objective of the test program described in this report was to evaluate the performance of PennDOT's portable F-shaped concrete barrier when subjected to NCHRP level-3 testing criteria based on test designation 3-11.

The scope of the test program consisted of a single test in which a 1993 Ford F-250 pick-up truck impacted the barrier at 100 km/h (62 mph) at an impact angle of 25 degrees. The portable concrete barrier was manufactured in accordance with PennDOT standards.

TECHNICAL DISCUSSION

Test Parameters

Test Facility

Crash tests were performed at the Pennsylvania Transportation Institute Crash Test Facility. A detailed description of the test facility is provided in ***Appendix A***.

Test Article Design and Construction

The test article consisted of 20 sections of portable F-shaped concrete barrier, each 12 ft in length. The barriers were manufactured and installed by Eagle Concrete Products Co. of Somerset, Pennsylvania. The barrier sections were manufactured according to PennDOT Standards RC-57M. Compressive strengths of concrete test cylinders ranged from 4800 psi to 5677 psi. The barrier sections were placed directly on asphalt concrete pavement. Photographs of the barrier installation are shown in ***Figure 1***. The ends of the test section were anchored using reinforcing bar dowels driven into the ground adjacent to the sides of the end section. Four dowels were used on each side of each end section and four dowels were used at the end of the end section.

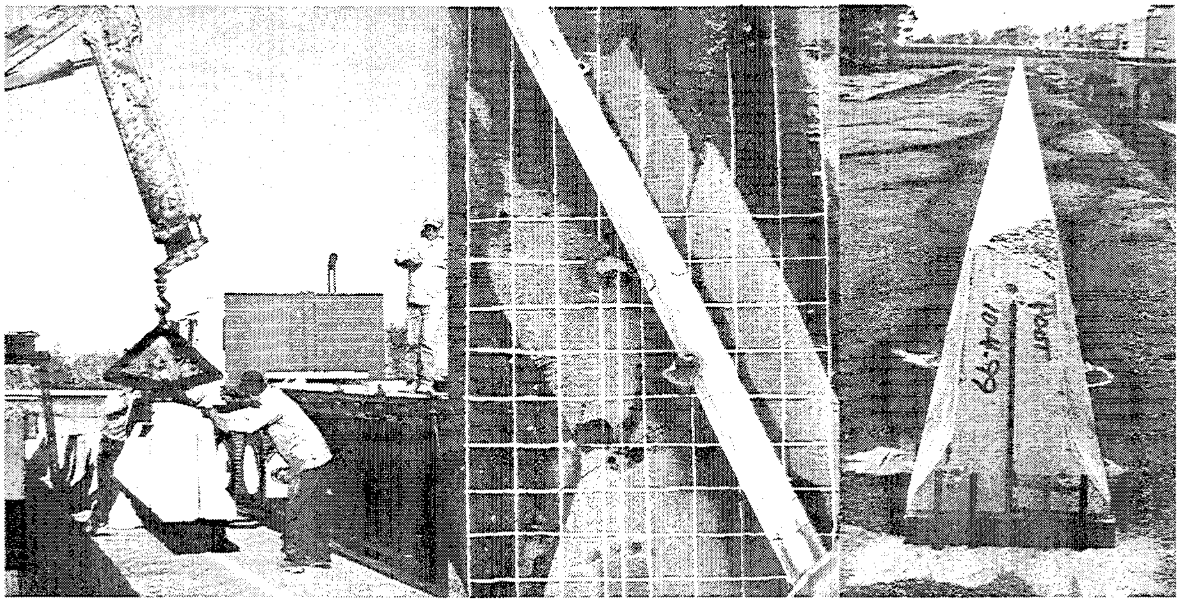
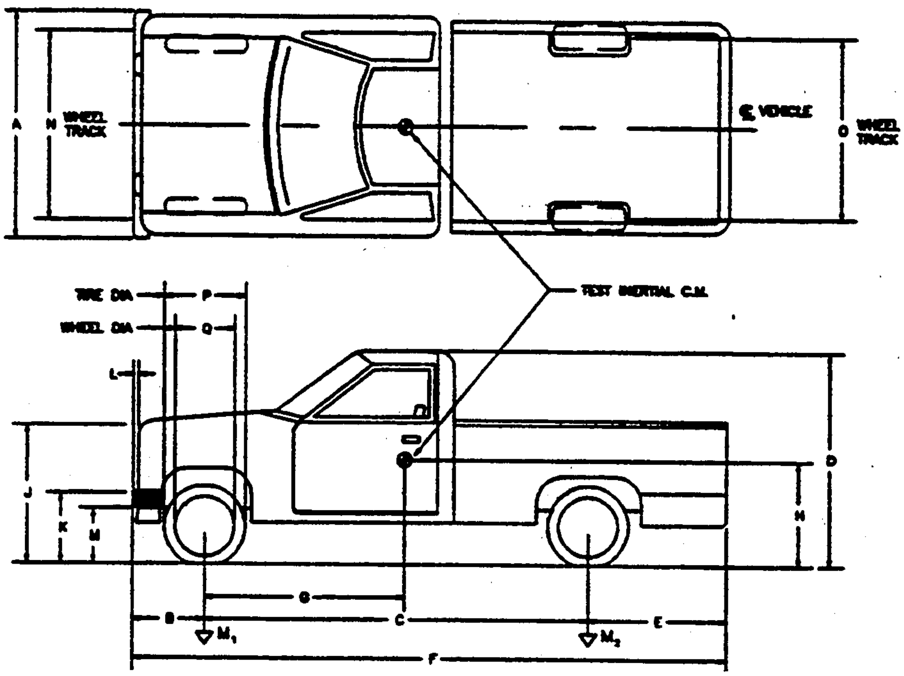


Figure 1. F-shaped barrier installation and end treatment (dowel) detail.

Test Vehicle

The test vehicle was a 1993 Ford F-250 pick-up truck. Vehicle specifications are provided in ***Figure 2***. Photographs of the vehicle are shown in ***Figure 3***.

Vehicle Dimensions							
Item		*Geometry (in/cm)*		*Item*		*Geometry (in/cm)*	
Overall Width	A	76.5	194.3	Hood Height	J	45.5	115.6
Front Overhang	B	32.8	83.2	Bumper Height (top)	K	28.0	71.1
Wheel Base	C	133.0	337.9	Bumper Overhang	L	4.0	10.1
Height	D	74.0	188.0	Bumper Height	M	17.5	44.5
Rear Overhang	E	51.0	129.5	Front Wheel Track	N	68.0	172.7
Total Length	F	216.5	550.6	Rear Wheel Track	O	65.5	166.4
Front Axle to CG	G	57.5	146.1	Tire Diameter	P	31.0	78.7
CG Height	H	29.3	74.3	Wheel Diameter	Q	17.4	44.1



Vehicle Data			
Gross Static Mass (kg)	2000	Engine Type	
Front	1135	Engine CID	
Rear	865	Transmission Type	
Test Inertial Mass (kg)		Optional Equipment:	
Mass Distribution (kg)			
Left Front	570		
Right Front	565		
Left Rear	430		
Right Rear	435	**Dummy Data**	
Dummy Mass (kg)		Type:	
Tire Inflation (psi)	50	Mass:	
Tire Size	LT235/85R16	Seat Position:	
Odometer	93,280		
Engine	4.9 liter, 6-cylinder		
Vehicle Identification No. (VIN)	1FTHF25Y9PNA76938		

Figure 2. Test vehicle specifications.

Figure 3. Pre-test photos of the test vehicle (1993 Ford F-250 pickup).

Soil Conditions

Soil conditions were not applicable for this test because the barrier was placed on the surface of the pavement, a typical field installation in Pennsylvania. However, the skid resistance of the asphalt concrete pavement was measured. The data presented in ***Table 1*** summarize the results of the skid testing of the pavement on which the barrier was located. Six runs of the skid-testing equipment were used to calculate the average skid number. An average skid number of 82.3 was obtained with a standard deviation of 0.9. This corresponds approximately to a friction coefficient of 0.823.

Table 1. Pavement skid resistance measurements.

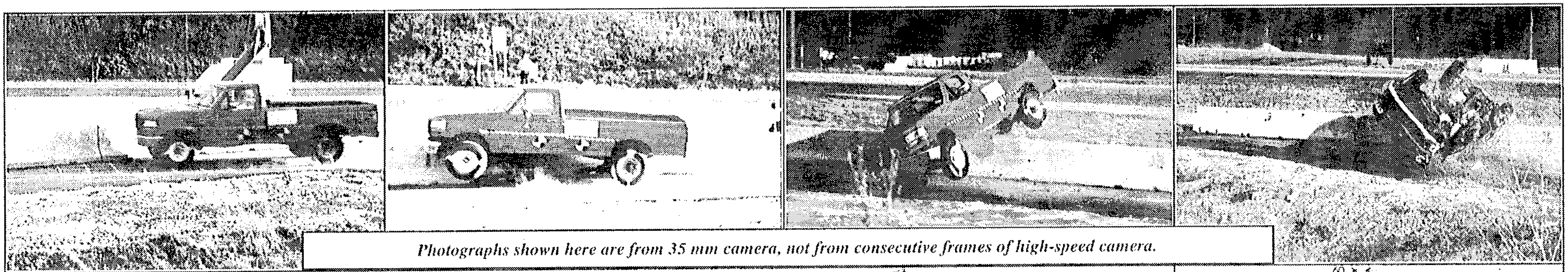
Date: November 8, 1999		Driver: Allen Homan	Tester: Two-Wheel
Weather: 53°F, partly cloudy		Operator: Robin Tallon	Tire: Ribbed
Time	***Test Number***	***SN***	***Speed***
11:49:01	3	81.4	40
11:50:31	5	83.8	40
11:52:02	6	81.4	40
11:53:32	7	82.1	40
11:55:03	8	82.8	40
11:56:32	9	82.3	40
Average SN		**82.3**	
Standard Deviation		**0.9**	

Impact Description/Vehicle Behavior

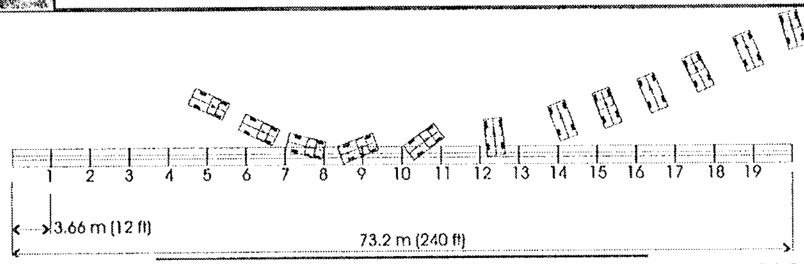
Based on video analysis of the test conducted on November 22, 1999, the approach speed at impact was 100.9 km/h (62.7 mi/h). Following impact with the barrier, the vehicle mounted the barrier and rotated counter-clockwise with the rear of the vehicle crossing over the barrier. The front wheels came in contact with the ground and the vehicle began a passenger-side leading roll, coming to rest in a grassy area after rolling three times. Examination of the barrier indicated that the initial contact occurred when the tire struck the barrier approximately 36 inches upstream from joint 7. Based on examination of the front bumper, which showed only minimal damage, the front bumper did not appear to have struck the barrier. Test results are summarized in ***Figure 4***.

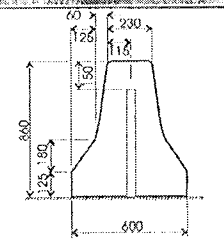
Test Article Damage/Debris Patterns

As a result of the impact, the barrier section between joints 6 and 7 moved approximately 27 inches rearward at joint 7. The barrier section between joints 7 and 8 was completely separated from the adjoining sections and was knocked over as shown in ***Figure 5***. Significant damage, including spalling of the concrete adjacent to the joint, occurred at joints 7 and 8 as shown in ***Figure 6***. Displacement of the barrier sections, along with the debris pattern resulting from the crash event, is illustrated in ***Figures 7 and 8***. A pre-test map of the barrier locations is provided in ***Figure 9*** for comparison purposes.



Photographs shown here are from 35 mm camera, not from consecutive frames of high-speed camera.





F-Shape Concrete Median Barrier

General Information	
Test Agency	Pennsylvania Transportation Institute
Test No.	3-11
Date	November 22, 1999
Test Article	
Type	Concrete F-shaped portable barrier (RC-57M)
	Pennsylvania Department of Transportation
Installation Length (m)	73.2 m (240 ft)
Size and/or dimension and material of key elements	3.66-m (12-ft) long by 600-mm (23.6-in) wide at the base and 230-mm (9-in) wide at the top
Soil Type and Condition	Pavement Skid # = 82.3
Test Vehicle	
Type	Production
Designation	2000P
Model	1993 Ford F-250 XL
Mass (Kg) Curb	Not measured
Test Inertial	1925
Dummy(s)	Not in the vehicle
Gross Static	2000
Impact Conditions	
Speed (km/h)	100.9 km/h
Angle (deg)	25 degrees
Exit Conditions	
Speed (km/h)	Not measured
Angle (deg)	Not measured

Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	Not calculated
y-direction	Not calculated
THIV (optional)	Optional
Ridedown Acceleration (g's)	
X-direction	Not calculated
Y-direction	Not calculated
PHD (optional)	Optional
ASI (optional)	Optional
Test Article Deflections (m)	
Dynamic	Not measured
Permanent	Not measured
Vehicle Damage	
Exterior	
VDS	1-R&T-5
CDC	01RYEK2, 00RDA09
Interior	
OCDI	
Post-Impact Vehicular Behavior	
Maximum Roll Angle (deg)	Not measured
Maximum Pitch Angle (deg)	Not measured
Maximum Yaw Angle (deg)	Not measured

Figure 4. Test summary sheet.

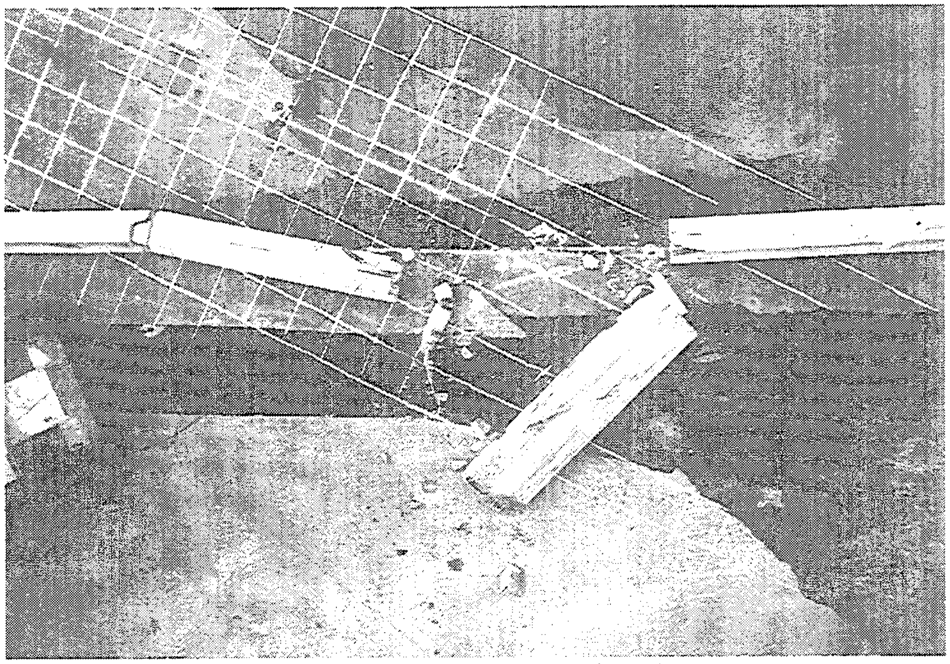


Figure 5. Post-test overhead view of the impact area.

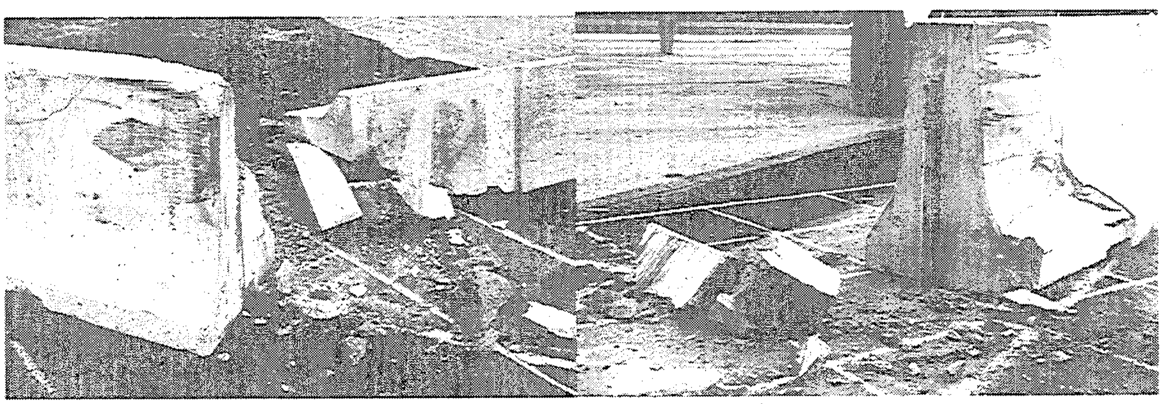


Figure 6. Damage to the test article.

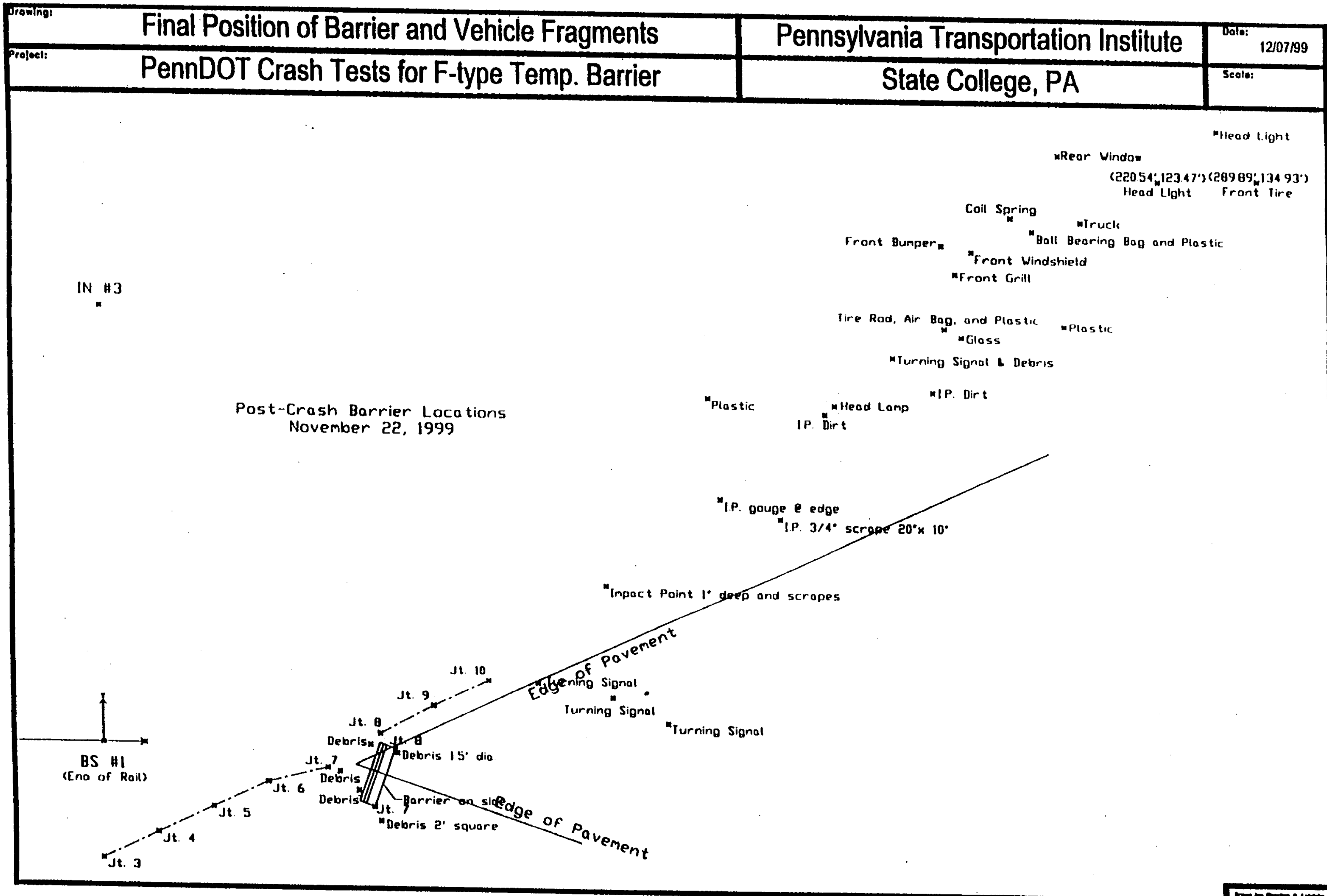


Figure 7. Debris field.

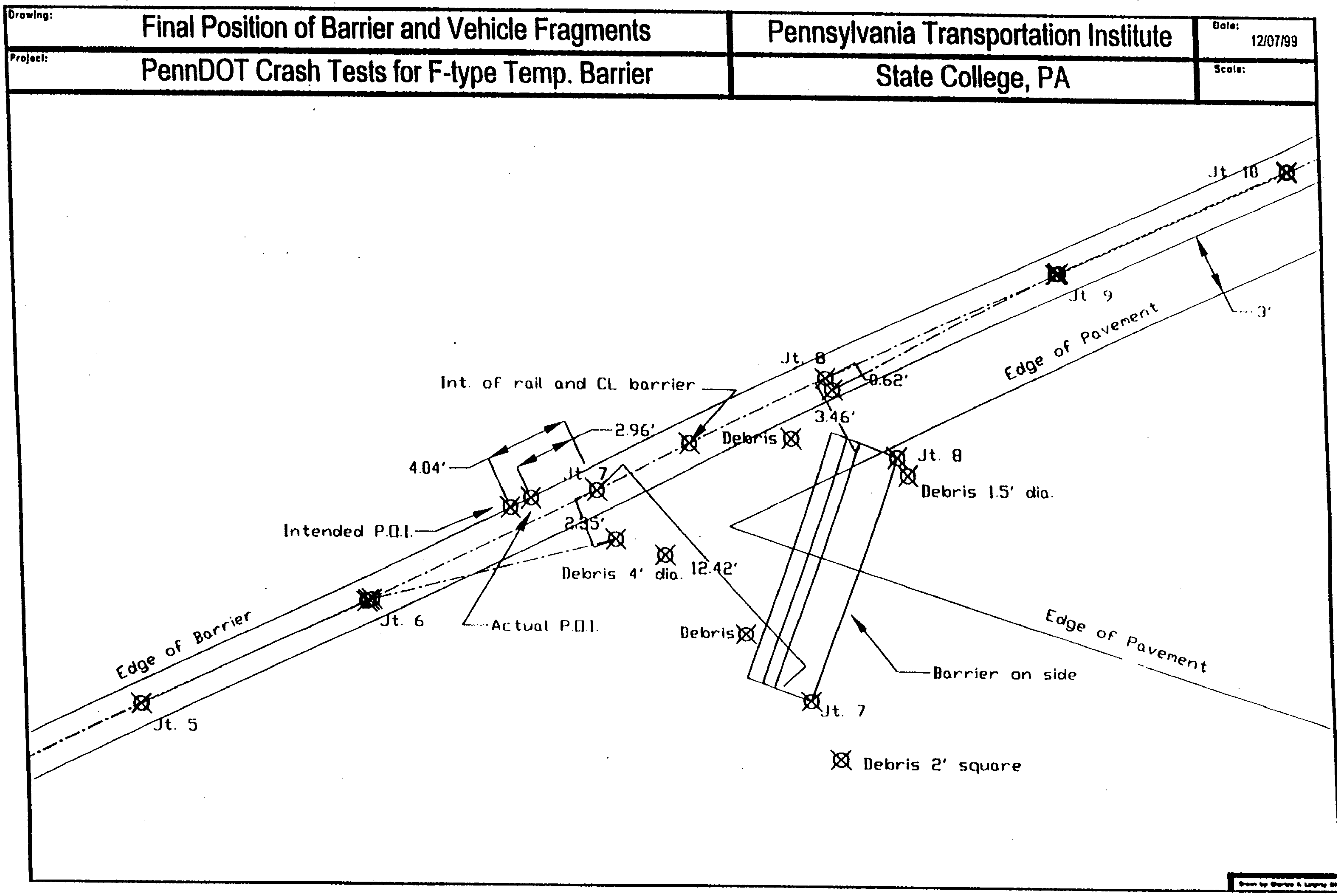


Figure 8. Closeup of debris field, joint 5 to joint 10.

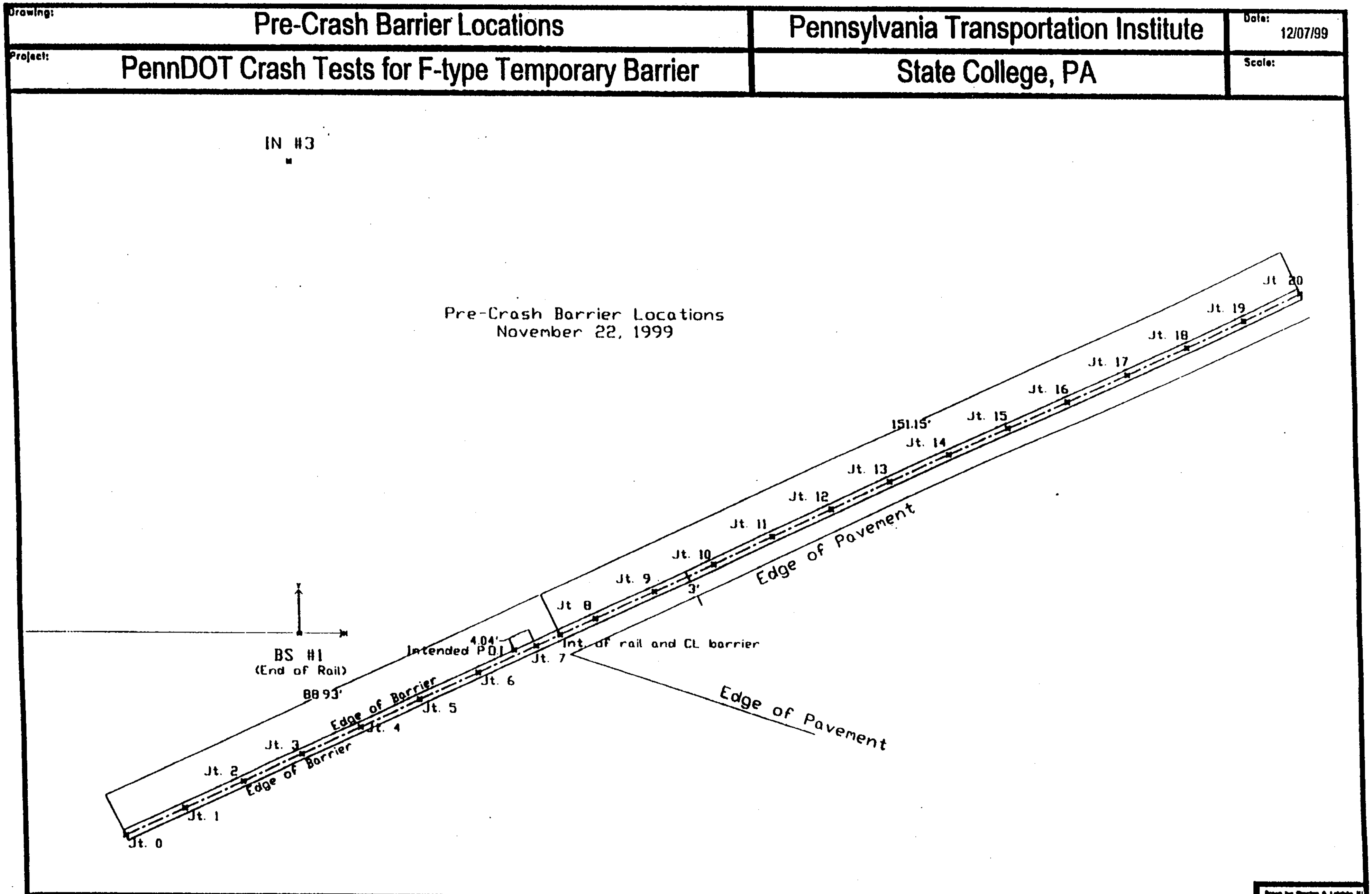


Figure 9. Pre-test map of barrier locations.

Vehicle Damage
The impact and subsequent rollover caused significant damage to the vehicle. The roof of the vehicle buckled and the windshield and rear window separated from the vehicle. Damage to the vehicle is illustrated in ***Figure 10***.

Figure 10. Post-test views of the test vehicle.

Dummy Behavior
The NCHRP-350 specification for this test states that the use of the Hybrid III dummy is optional. Therefore, the dummy was not used in this test.

Assessment of Test Results

Occupant Risk
The rollover following the initial impact and the damage to the vehicle compartment would be expected to place occupants at significant risk.

Structural Adequacy
Significant movement of the barrier during impact occurred, resulting in an undesirable trajectory of the vehicle. Spalling occurred at barrier joints 7 and 8, resulting in the separation of adjacent barrier sections in the vicinity of the impact.

Vehicle Trajectory Hazard

The vehicle climbed the barrier and rolled over three times resulting in significant risk to occupants and, potentially, to oncoming traffic. ***Table 2*** provides a tabular assessment of structural adequacy, occupant risk, and vehicle trajectory.

Table 2. Risk assessment table.

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable.	The test vehicle was not contained by the F-shaped portable concrete barrier. The vehicle penetrated the installation and then overrode the installation before going into a series of side-over-side rolls.	Not acceptable
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	The penetration of the portable F-shaped concrete barrier resulted in a section of the barrier separating from the installation. The separated section of the barrier would have presented an undue hazard to traffic, pedestrians, or personnel in the work zone behind the installation.	Not acceptable
F. The vehicle should remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.	The test vehicle rolled a total of three times before coming to rest in an upright position.	Not acceptable
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	After impacting the F-shaped barrier, the vehicle's trajectory was such that the vehicle would have rolled into adjacent traffic lanes.	Not acceptable
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 Gs.	Occupant impact velocity and ridedown accelerations were not calculated. Although the initial impact was captured by the data acquisition equipment, the equipment was subsequently thrown from the vehicle during the rollover and data beyond 2 sec from the initial impact was lost.	Not calculated
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle contact with the barrier ended as the vehicle began its series of rolls, therefore making the measurement of an exit angle difficult, especially without the overhead high-speed video camera data.	Not measured

CONCLUSIONS AND RECOMMENDATIONS

Based on a review of the test results, it is concluded that PennDOT's portable F-shaped concrete barrier that was tested does not meet the NCHRP 350 level 3 performance criteria. It is recommended that the joint design for the portable F-shaped barrier be reevaluated and modified before conducting further crash tests.

REFERENCES

Ross, H. E. Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. NCHRP Report 350. National Cooperative Highway Research Program, National Academy Press (1993).

APPENDIX A:
TEST VEHICLE EQUIPMENT
AND
GUIDANCE METHODS

TEST VEHICLE EQUIPMENT AND GUIDANCE METHODS

The Pennsylvania Transportation Institute (PTI) facility uses a rigid rail to provide vehicle guidance, a reverse towing system to accelerate the vehicle to the required test speed, and a release mechanism that disconnects the tow cable prior to impact. The guidance systems currently being used by crash-testing facilities can be generally categorized into three types: remote control guidance, flexible cable guidance, and rigid rail guidance. Remote (radio) control systems have been used with limited success, largely due to problems caused by delays in reaction time and response of the control system and operator. Cable guidance systems are attractive because of their low set-up cost and versatility. However, the instability introduced by the lateral deflection of the guidance cable makes it difficult to reliably achieve the tolerances specified in NCHRP Report No. 350. The rigid rail guidance system effectively removes many of the lateral instability problems associated with cable-guided systems.

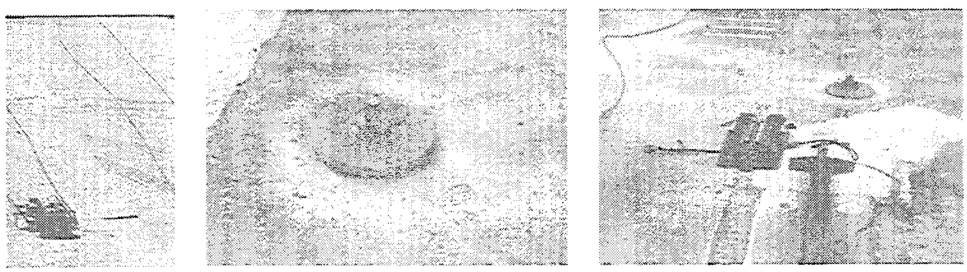


Figure A1. Speed multiplier pulley, alignment pulley, and pulley shown with bogey and guidance rail.

PTI's rail guidance system consists of a guide rail, release post, bogey assembly, and tow cable as depicted in ***Figure A1***. The guide rail is a 930-ft-long, 3.5-in-high I-beam. The east end of the rail terminates into the impact zone (see ***Figure A1***). The rail is securely anchored to the pavement along the edge of the vehicle dynamics test pad. This test designation requires a 2000P vehicle. Therefore, a pickup truck is used for the crash vehicle. The pickup is run along the rail with a bogie mounted onto the rail so that it fits underneath the truck. The bogie is attached to the truck's lower suspension arms.

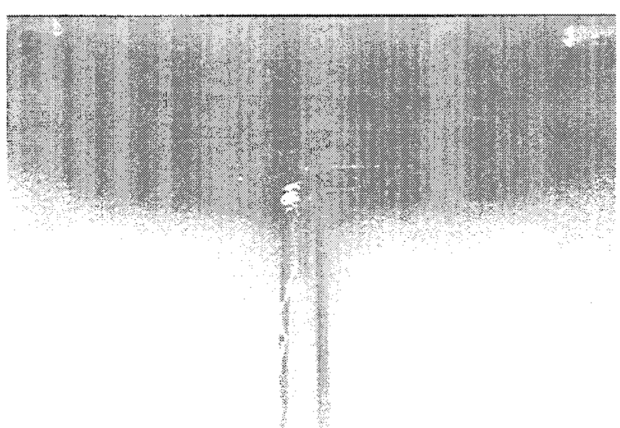


Figure A2. Bogey aligned on guidance rail and attached to test vehicle.

The towing system is used to bring the test vehicle up to the desired impact speed. This system consists of a tow vehicle, a tow cable, two anchored re-directional pulleys, a speed multiplier pulley attached to the towing vehicle, and a quick-release mechanism attached to the bogey as shown in ***Figure A2***. This configuration results in a speed-doubling effect, in that the speed of the test vehicle is twice the speed of the towing vehicle.

TEST LAYOUT AND PREPARATION

The test article is aligned at a 25-degree angle with the guide rail using a CAD package and total station, taking into account the position of the vehicle with respect to the guidance rail. The critical impact point (CIP) for the article and the vehicle is also determined. Typically, it reflects a worst-case scenario.

TEST VEHICLE

For this test, a 2000P pickup truck was used. The test vehicle, as presented in the main text of the report (***Figure 3, p. 4***), was a 1993 Ford F-250 pickup truck, structurally sound, and possessing characteristics that match closely with the national fleet. The test vehicle had no rust damage or damage to the frame or suspension, and no modifications to the bumper or ride-height were incorporated.

VEHICLE PREPARATIONS

—Vehicle wheels were balanced and aligned.
—Vehicle geometry was measured.
—The battery was removed and the radiator and fuel tank were drained.
—Guidance, data acquisition (DAQ), and emergency systems were installed
—Tow hooks were mounted to the front suspension A-arms.
—The air actuator was installed in the vehicle with brake control cables.
—The pressure tank and radio controlled air valves were secured.
—Large reference marks were placed on the vehicle.

APPENDIX B: PHOTO INSTRUMENTATION

High Speed Video Coverage and Analysis Report for Portable F-shaped Concrete Barrier

Tests Performed by:	The Crash Safety Research Center The Pennsylvania Transportation Research Institute The Pennsylvania State University University Park, Pennsylvania
Test Dates:	November 22, 1999
Device Tested:	Portable F-shaped concrete barrier
Impacting Vehicles:	1993 Ford F-250
Report Date:	6 December 1999 Revised 20 December 1999

Report By: ______________________________

John R. Yannaccone, P.E.
ARCCA, Incorporated
Penns Park, Pennsylvania

Introduction:

This report documents the setup and results of high-speed video coverage of impacting an F-shaped portable concrete barrier with a 1993 Ford F-250 pickup at approximately 100 kilometers per hour (km/h). The purpose of this test was to evaluate the performance of the device and its ability to meet the requirements of NCHRP-350, level 3.

The goal of the portable F-shaped concrete barrier test was to impact the barrier with the vehicle at 100 km/h. The barrier was placed at an angle of 25 degrees to the line of travel of the vehicle. The point-of-impact on the barrier was to be approximately 1 meter from the joint between barrier sections.

High-speed video was used to allow post-test analysis, including vehicle speed prior to impact, angle at impact, point-of-impact to the vehicle, and the exit speed for the vehicle. This video will also be used to analyze the performance of the devices, although that is beyond the scope of this report.

Setup:

Four high-speed video cameras were set up to provide test coverage (see ***Table B1*** and ***Figure B1***). In addition, two real-time video cameras were used to supplement the high-speed video coverage. Pre- and post-test conditions were documented with a Minolta 35-mm camera. The placement of the cameras was as follows:

Table B1. Camera Placement

Camera	Type	Speed Frames/sec	Lens (mm)	Location/View
1	Motionscope 8000S	500	6	90° from left side of vehicle
2	Motionscope 8000S	500	6	Overhead
3	Kodak Ektapro EM	500		Head of barrier looking down centerline of barrier
4	Kodak Ektapro TR	500	85	Approx. 65° from line of travel of vehicle looking at rear of the barrier
5	Sony CCD-TRV65 8 mm palmcorder		Zoom	90° from right side of vehicle
6	Sony CCD-TR910 8 mm palmcorder		Zoom	Approx. 45° from right side of vehicle

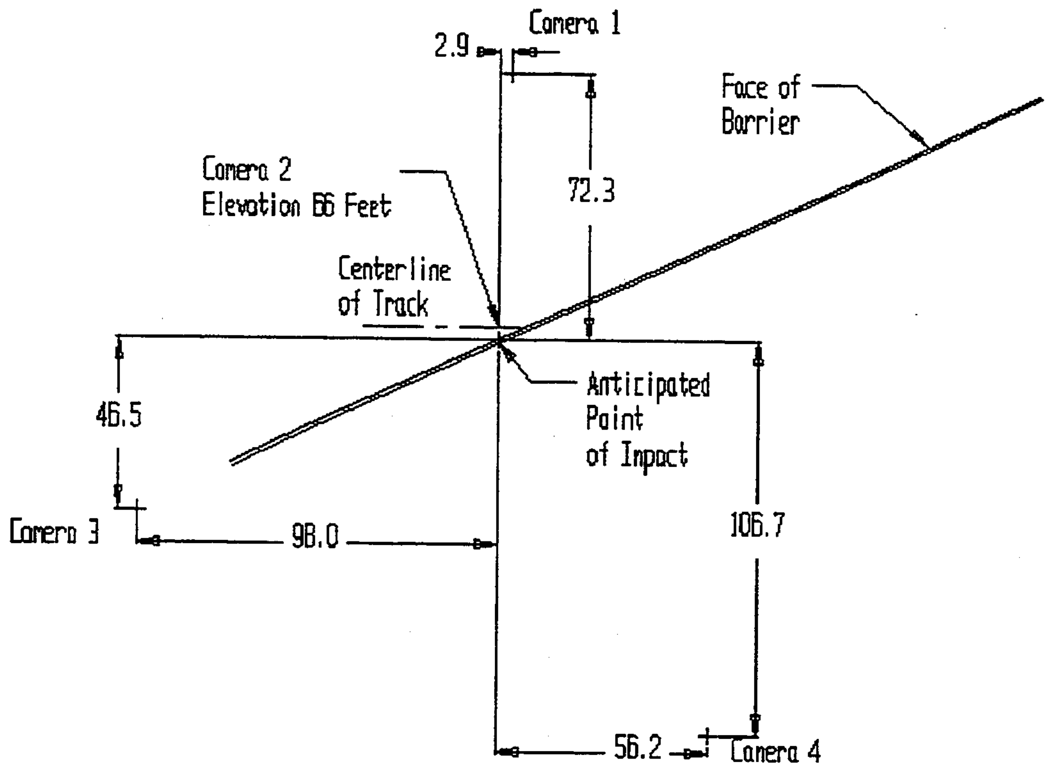


Figure B1. Diagram of camera placement.

The exact location of the real-time cameras, cameras 5 and 6, was not included on the survey information received from PTI. However, these cameras were located to the right and left of camera 4. During the test, the power cord for cameras 2 and 3 became entangled in the tow cable, resulting in a loss of power to these cameras. Thus, no images were recorded for this test by either of these cameras.

General information on the vehicle used for the test is summarized in ***Table B2***.

Table B2. Vehicle Information.

Test	Vehicle	VIN	Mfd. Date
3	1993 Ford F-250	1FTHF25Y9PNA76938	3/93

Prior to the tests, the vehicle had a visual target placed at the center of gravity (CG) on both right and left sides and the top of the vehicle. In addition, a target was placed 36 inches aft of the CG on both sides of the vehicle. These targets were used to determine the speed of the vehicle as it approached and exited the barrier. There was also a 24- by 24-inch grid painted on the ground in the test area that was used for both speed and direction calculation from the overhead camera. In addition, two lines were painted on each of the tires, which could be used to determine vehicle speed.

The portable F-shaped concrete barrier was composed of 12-foot sections of steel-reinforced concrete approximately 34 inches high. The thickness of the barrier was approximately 23 inches at the base and 9 inches at the top. Twenty sections of this barrier were joined together and the entire barrier was pinned with reinforcing bars at both ends.

Results:

In this test, conducted on November 22, 1999, a 1993 Ford F-250 was used to impact the face of a portable F-shaped concrete barrier. The barrier was placed at a 25-degree angle to the direction of travel of the vehicle.

The vehicle's approach speed is summarized in ***Table B3*** below. Only the overhead and left side views were placed such that the images could be used to calculate the speed of the vehicle. Due to the aforementioned loss of power, no images were collected by the overhead camera. Thus, speed was determined from the left side camera only.

Table B3. Vehicle approach speed.

Camera	Approach Speed km/h (mph)
Left side - Linear motion	100.9 km/h (62.7 mph)
Left front - Tire rotation	101.2 km/h (62.9 mph)

Following impact with the barrier, the vehicle mounted the barrier and rotated counter-clockwise with the rear of the vehicle over the barrier. After the front wheels of the vehicle contacted the ground, the vehicle began a passenger-side leading roll, coming to rest in a grassy area after completing three rolls. Examination of the vehicle following the test showed minimal damage to the right front portion of the bumper. Marks on the wall failed to show any significant damage attributable to the bumper of the vehicle. The first mark seen on the barrier was at a point between 35.5 and 36 inches before joint 7. This mark was at the lowest portion of the barrier and is consistent with right front tire contact. The barrier section between joints 6 and 7 was shifted approximately 27 inches rearward at joint 7. The barrier section between joints 7 and 8 was displaced significantly rearward and knocked over. This section was completely separated from the adjoining sections. The barrier section between joints 8 and 9 was shifted approximately 8 inches rearward at joint 8.

Due to the loss of video coverage from the overhead camera, the angle of impact between the vehicle and the barrier could not be determined.

Comments and Suggestions for Future Testing:

For the F-shaped barrier test, the initial point of contact with the wall of an exemplar Ford F-250 pickup should be verified. This would be helpful in evaluating the test, as it appears the right front tire contacted the wall prior to the bumper. This information would be useful prior to placement of a barrier for a test. Knowing the first point-of-contact would allow the barrier section to be placed so that the initial contact point is at a proper distance from the joint between sections.

In order to prevent loss of power to cameras, such as occurred in this test, a change should be made. Cameras located in the position of camera 3 should have their power lines routed on the ground, under the tow cable. A piece of sheet metal should then be nailed down over top of the lines to prevent the tow cable from contacting the power cords. This should allow the tow cable to safely pass over the power cords. Although the power cords were placed on top of the barrier and a 55-gallon drum, this failed to prevent the whipping cable from damaging them.

When placing targets on the side of the vehicle where they could be obscured by the concrete barrier, the targets should be placed at a level greater than the barrier. For these tests, the targets should have been at least 36 inches high on the vehicle.

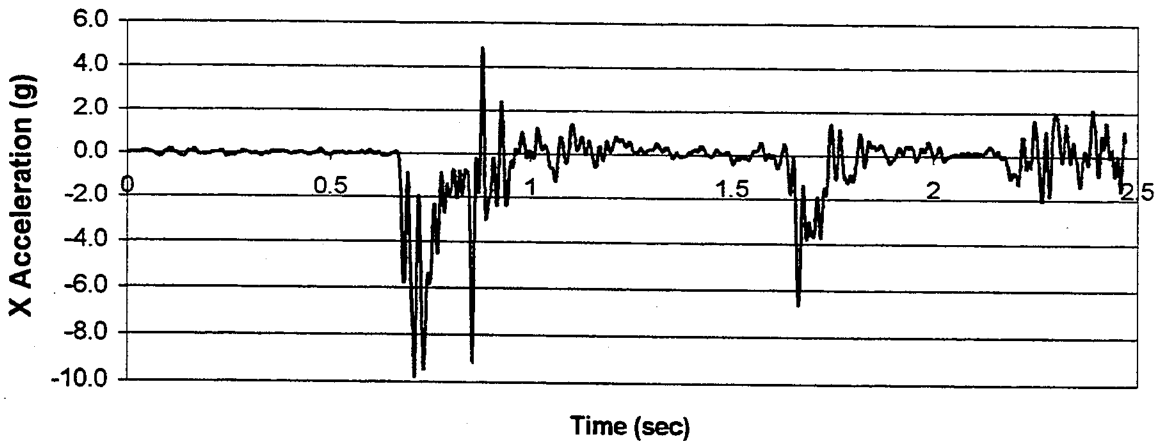
APPENDIX C: ELECTRONIC INSTRUMENTATION

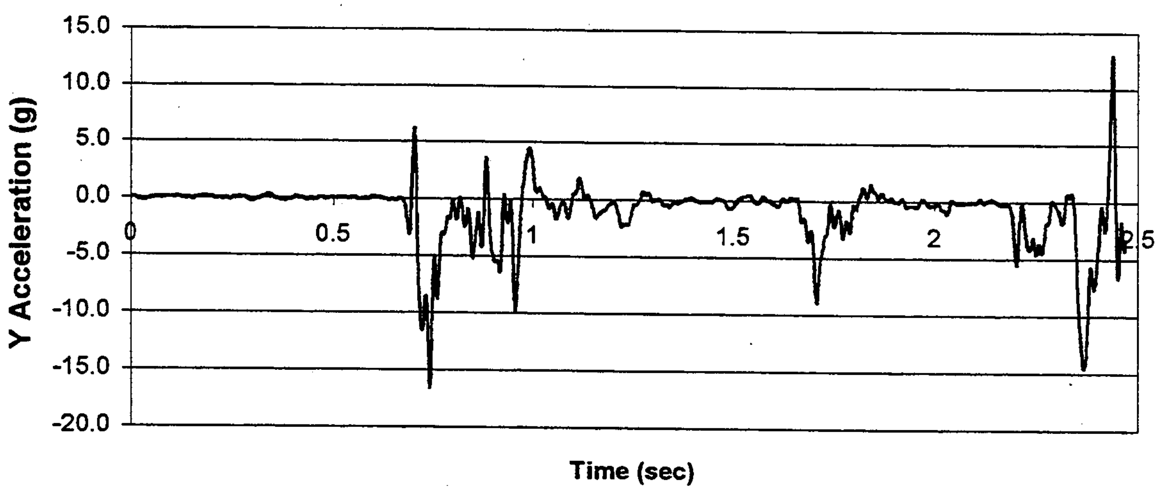
ELECTRONIC INSTRUMENTATION

The portable F-shaped concrete barrier was tested according to NCHRP 350, test 3-11, at a speed of 100 km/h (62 mi/h). The test vehicle was instrumented with two tri-axial measurement systems (NeuwGhent Technology, TAA-3121M4-1%-1000 and Crossbow Technology Inc., DMU-VGX) designed to measure linear acceleration along three orthogonal axes and rotation rates around three orthogonal axes. The first system uses three +/- 20 G accelerometers to measure longitudinal, lateral and vertical acceleration levels. The second system uses three 100 degree/sec angular-rate sensors to measure roll, pitch, and yaw rates. The two systems were secured to the vehicle in a location near the vehicle center-of-gravity. The vehicle was also instrumented with a Keyence PZ-61 photoelectric sensor for speed and an impact sensor built in house.

The electronic signals from the accelerometers, rate, speed and impact sensors were recorded by an 8-channel Data BRICK data acquisition system. Data collection was triggered with the release of the bogey. A small wire was attached between the bogey and the vehicle. The separation of the two broke the wire, which triggered the acquisition of data a few seconds before impact. Two seconds of pre-triggered data and 20 seconds of post-triggered data were collected. Calibration and offset signals were recorded before the test. The signals were sampled at 1,000 Hz and then filtered with a lowpass 300 Hz. The data was downloaded to a notebook computer after the test for analysis.

The plots of the data acquired from the test are provided in ***Figures C1 and C2. Table C1*** provides a summary of the minimum and maximum accelerations and angular rates encountered during the test.





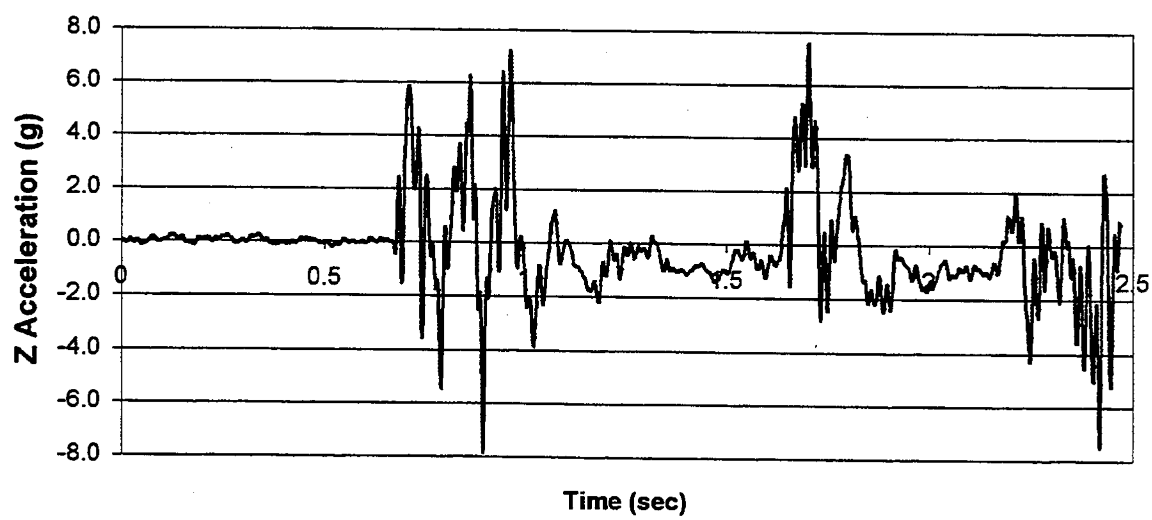


Figure C1. Acceleration data for the portable F-shaped concrete barrier test.

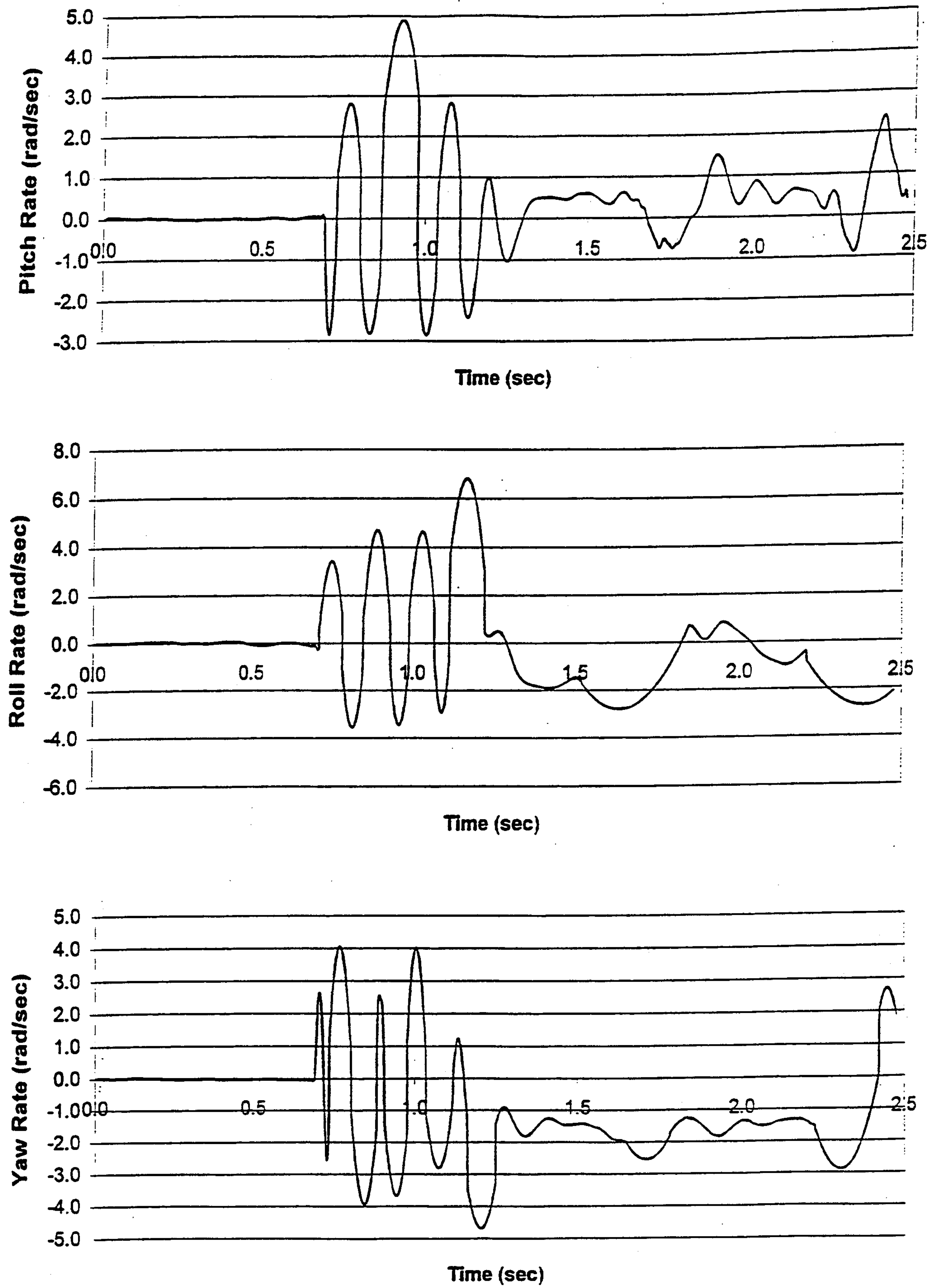


Figure C2. Gyroscopic data for the F-shaped portable concrete barrier test.

Table C1. Maximum and minimum accelerations and angular rates.

	November 22, 1999	
	Maximum	Minimum
X-acceleration (g)	4.82	-9.81
Y-acceleration (g)	12.94	-16.60
Z-acceleration (g)	7.56	-7.88
X-gyro (rad/sec)	6.82	-3.57
Y-gyro (rad/sec)	4.90	-2.86
Z-gyro (rad/sec)	4.06	-4.68

APPENDIX D: DETAILED DRAWINGS OF TEST ARTICLE

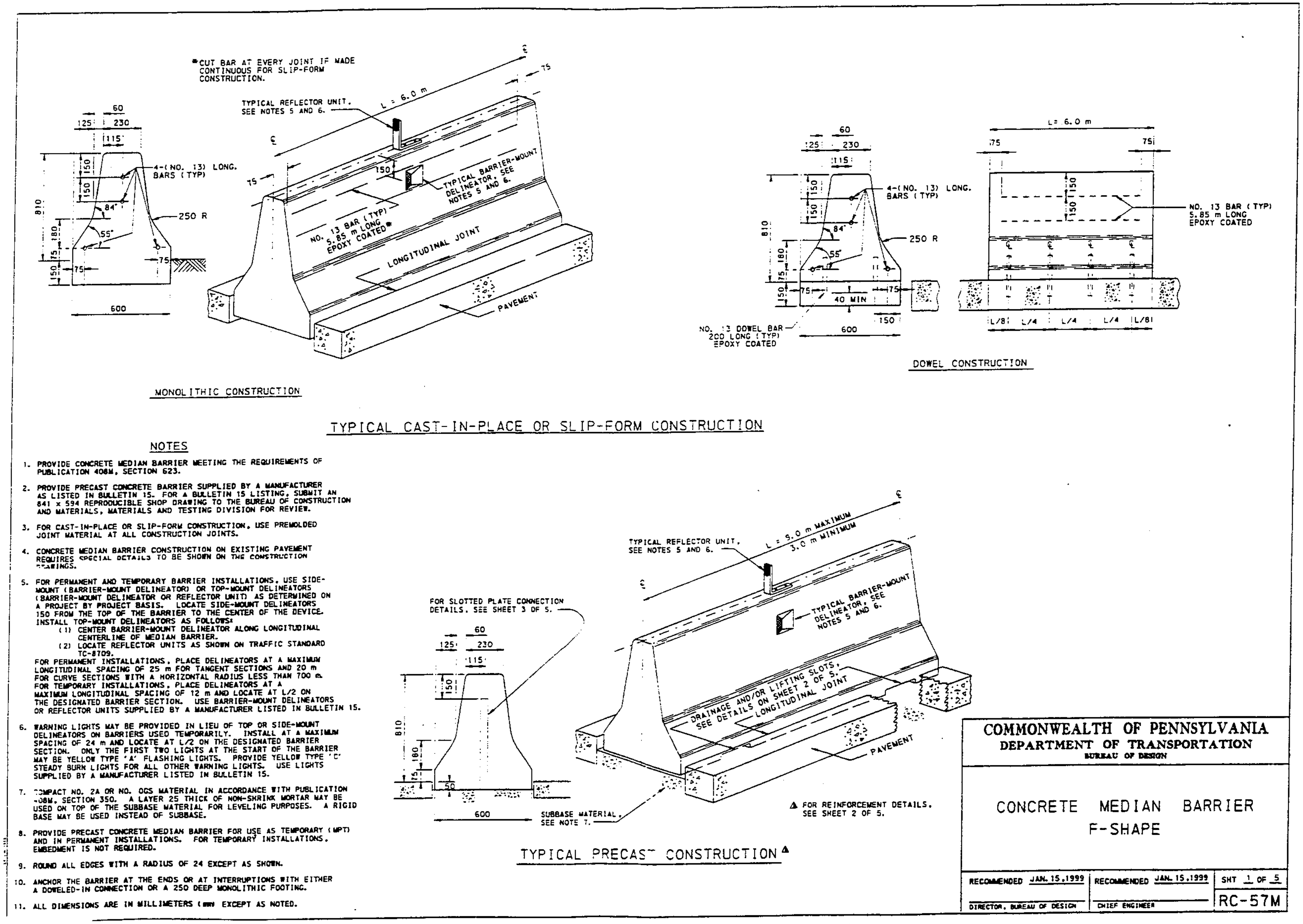
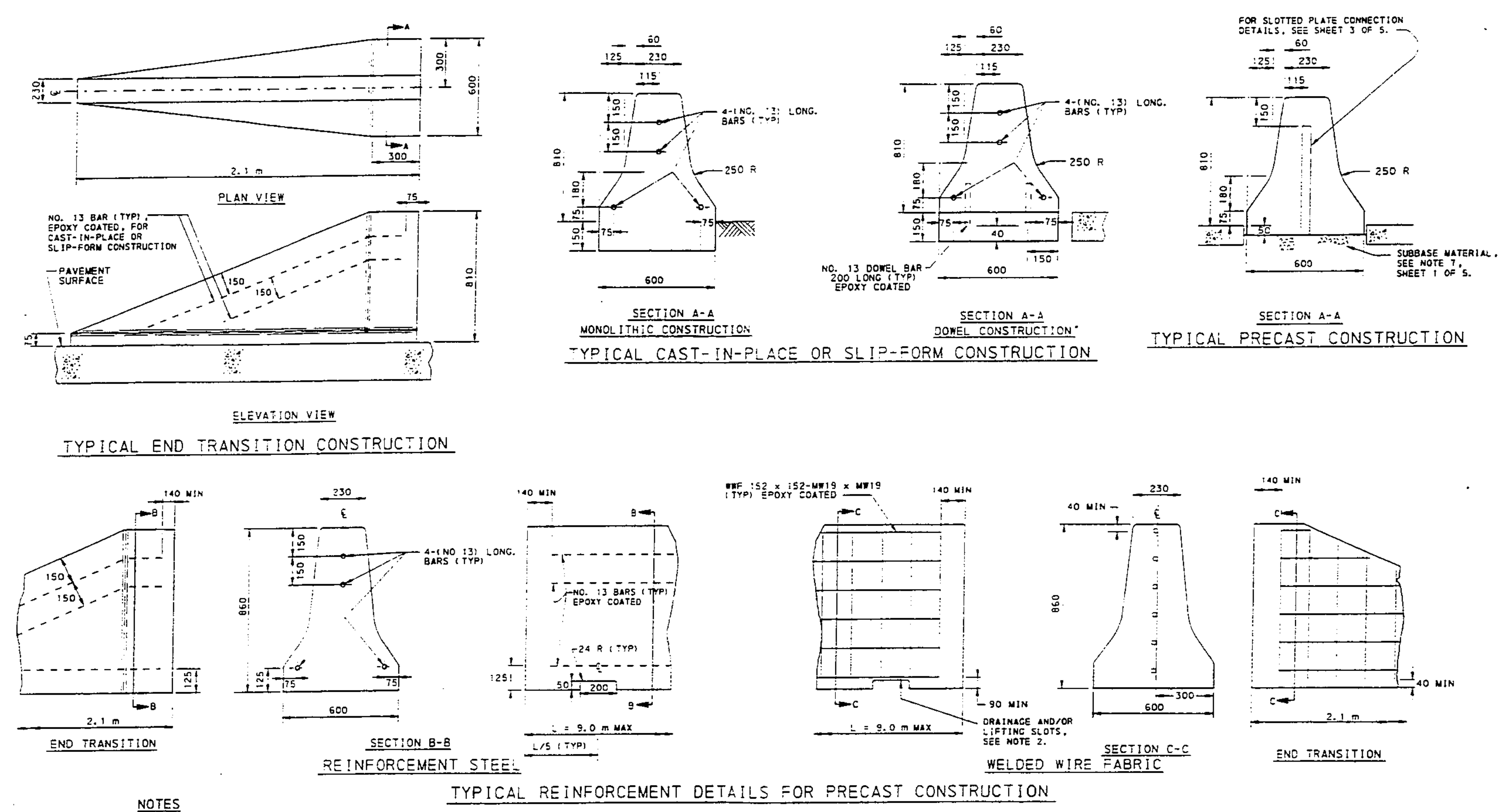


Figure D1. Detailed drawing of concrete median barrier F-shape (1 of 5).



NOTES

1. A TYPICAL END TRANSITION MAY BE USED FOR PERMANENT BARRIER INSTALLATIONS ONLY WHEN THE LAST BARRIER SECTION IS LOCATED OUTSIDE THE REQUIRED CLEAR ZONE, AS DETERMINED IN PUBLICATION 13M, DESIGN MANUAL, PART 2, CHAPTER 12. A 20:1 SLOPED END TRANSITION IS ACCEPTABLE FOR PERMANENT INSTALLATIONS WHERE THE LEGAL SPEED LIMIT IS 60 km/h OR LESS; OTHERWISE, USE AN IMPACT ATTENUATING DEVICE DESIGNED TO ABSORB THE ENERGY OF AN IMPACTING VEHICLE IN THE WEIGHT RANGE OF 520 kg TO 2000 kg AT THE SPECIFIED DESIGN SPEED, WITH A MAXIMUM AVERAGE DECELERATION FORCE OF 8.5 G's AND A MAXIMUM PEAK DECELERATION FORCE OF 15 G's. WHEN CONCRETE BARRIER IS TERMINATED AT THE END OF PARALLEL RAMPS OR T INTERSECTIONS, A 2.1 m END TRANSITION MAY BE USED WHERE THE LEGAL SPEED IS 60 km/h OR LESS. FOR BARRIER INSTALLATIONS, AN IMPACT ATTENUATING DEVICE IS NOT REQUIRED IF ANY OF THE FOLLOWING CONDITIONS ARE SATISFIED:
   - (A) THE BARRIER IS EXTENDED AT THE PROPER FLARE RATE UNTIL THE END OF THE BARRIER SYSTEM IS LOCATED OUTSIDE THE REQUIRED CLEAR ZONE AS DETERMINED IN PUBLICATION 13M, DESIGN MANUAL, PART 2, CHAPTER 12.
   - (B) THE BARRIER IS EXTENDED AT THE PROPER FLARE RATE UNTIL THE END OF THE BARRIER SYSTEM CAN BE BURIED IN A CUT SECTION.
   - (C) THE BARRIER IS EXTENDED AT THE PROPER FLARE RATE UNTIL THE END OF THE BARRIER SYSTEM IS PROPERLY CONNECTED OR OVERLAPPED WITH EXISTING GUIDE RAIL.

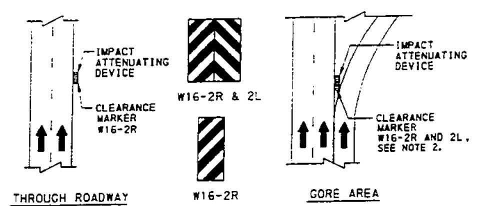
   REFER TO TABLE 1, SHEET 3, FOR FLARE RATE REQUIREMENTS.
2. PROVIDE SUITABLE LIFTING DEVICES FOR HANDLING, INSTALLING AND REMOVING PRECAST CONCRETE BARRIER. GALVANIZE METAL DEVICES AS SPECIFIED IN PUBLICATION 408M, SECTION 1105.02(s).
3. PROVIDE REINFORCEMENT STEEL MEETING THE REQUIREMENTS OF PUBLICATION 408M, SECTION 709 WITH A MINIMUM CONCRETE COVER OF 40.
4. EPOXY COATED REINFORCEMENT IS NOT REQUIRED WHEN PRECAST CONCRETE MEDIAN BARRIER IS TO BE USED IN TEMPORARY INSTALLATION ONLY, IN ACCORDANCE WITH SECTION 627, AND IDENTIFIED AS SUCH, AS SPECIFIED IN SECTION 714.6(c)
5. ROUND ALL EDGES WITH A RADIUS OF 24 EXCEPT AS SHOWN.
6. ALL DIMENSIONS ARE IN MILLIMETERS (mm) EXCEPT AS NOTED.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF DESIGN

CONCRETE MEDIAN BARRIER
F-SHAPE .

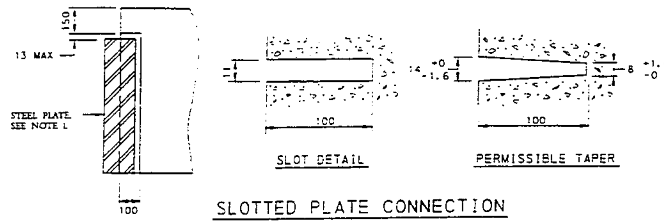
RECOMMENDED JAN. 15, 1999	RECOMMENDED JAN. 15, 1999	SHT 2 OF 5
DIRECTOR, BUREAU OF DESIGN	CHIEF ENGINEER	RC-57M

Figure D2. Detailed drawing of concrete median barrier F-shape (2 of 5).



DETAIL A

DELINEATION OF IMPACT ATTENUATING DEVICES



SLOTTED PLATE CONNECTION

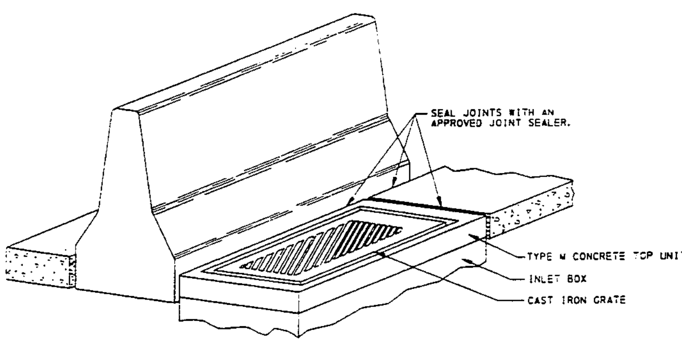
NOTES

1. PROVIDE PLATES, 8 x 180 x 685, MEETING THE REQUIREMENTS OF PUBLICATION 408M, SECTION 1105.02(a). GALVANIZE PLATES AS SPECIFIED IN PUBLICATION 408M, SECTION 1105.02(a). ALTERNATE CONNECTIONS MAY BE USED AS APPROVED BY THE BUREAU OF DESIGN. SUBMIT AN 841 x 594 REPRODUCIBLE SHOP DRAWING FOR REVIEW. SEE NOTE 2, SHEET 1 OF 5.

2. PROVIDE VERTICAL RECTANGLE, STANDARD ALUMINUM, PRESSURE SENSITIVE CLEARANCE MARKERS, W16-2R AND/OR W16-2L, FABRICATED FROM CLASS II SHEETING MATERIAL, FOR DELINEATION OF IMPACT ATTENUATING DEVICES AS PRESENTED IN DETAIL A. ATTACH MARKERS DIRECTLY TO THE LEADING END OF IMPACT ATTENUATING DEVICES. ON INERTIAL BARRIERS (SAND BARRELS), PROVIDE SENSITIVE SHEETING, WITHOUT RIGID BACKING, DIRECTLY TO BARRIER FRONT OR NOSE SECTION. DO NOT POST-MOUNT MARKERS IN FRONT OF IMPACT ATTENUATING DEVICES. MARKERS ARE PROVIDED IN TWO SIZES: 305 x 914 AND 457 x 914. WHEN ONE MARKER IS REQUIRED, USE 457 x 914. WHEN TWO MARKERS ARE REQUIRED SIDE BY SIDE, USE 305 x 914. PROVIDE COLOR FOR CLEARANCE MARKERS AS FOLLOWS:

   (A) MESSAGE : BLACK STRIPES (NON-REFLECTORIZED)
   (B) FIELD : YELLOW (REFLECTORIZED)
   ORANGE (REFLECTORIZED), CONSTRUCTION ZONES

3. ALL DIMENSIONS ARE IN MILLIMETERS (mm) EXCEPT AS NOTED.



TYPICAL INLET PLACEMENT AT CONCRETE MEDIAN BARRIER

TABLE 1
FLARE RATES FOR BARRIER DESIGN

DESIGN SPEED (km/h)	MAXIMUM FLARE RATES	
	CONCRETE BARRIER	GUIDE RAIL
120	20 : 1	15 : 1
110	20 : 1	15 : 1
100	18 : 1	14 : 1
90	16 : 1	12 : 1
80	14 : 1	11 : 1
70	12 : 1	10 : 1
60	10 : 1	8 : 1
50	8 : 1	7 : 1

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF DESIGN

CONCRETE MEDIAN BARRIER
F-SHAPE

RECOMMENDED JAN. 15, 1999	RECOMMENDED JAN. 15, 1999	SHT 3 OF 5
DIRECTOR, BUREAU OF DESIGN	CHIEF ENGINEER	RC-57M

Figure D3. Detailed drawing of concrete median barrier F-shape (3 of 5).

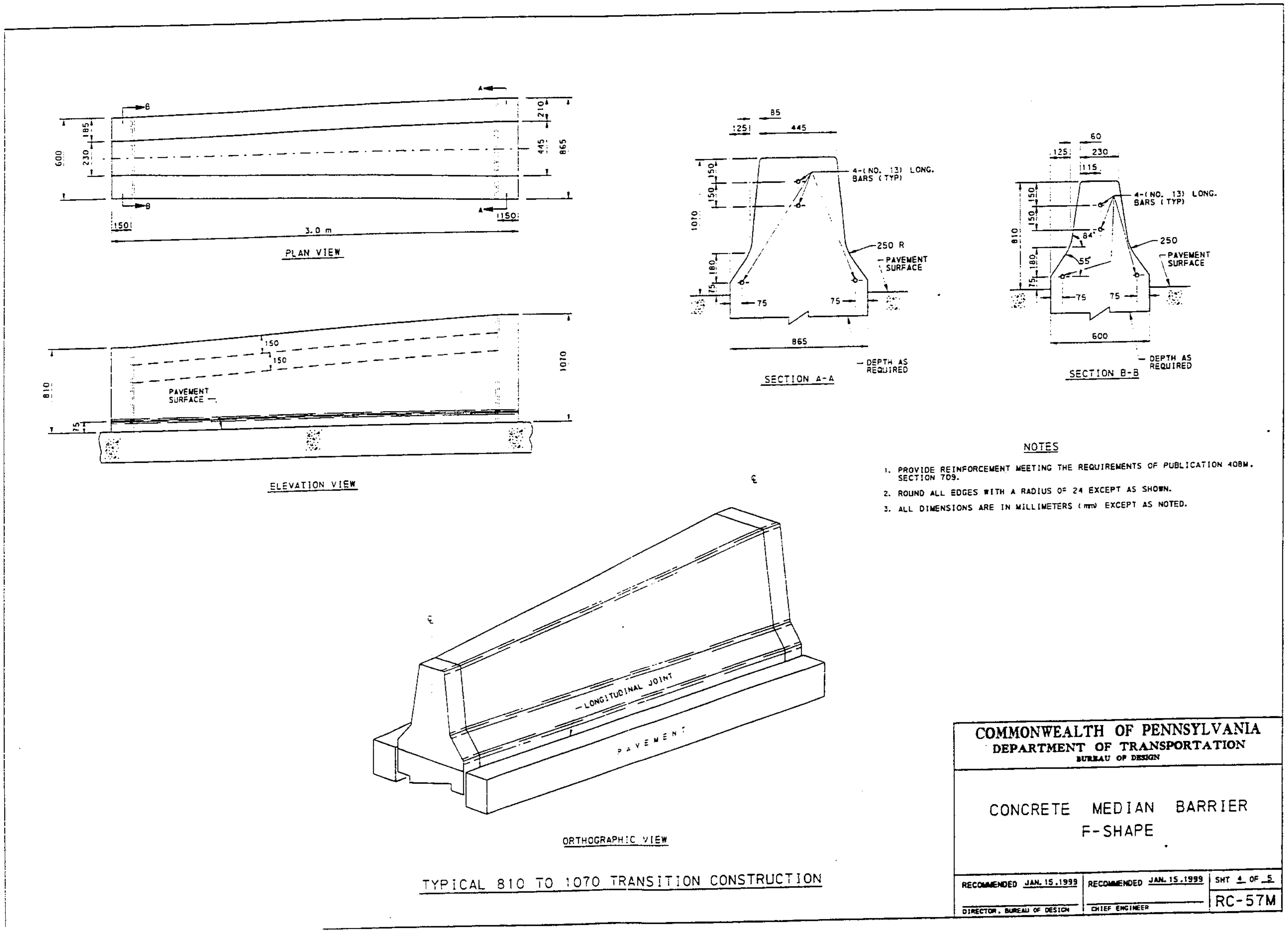


Figure D4. Detailed drawing of concrete median barrier F-shape (4 of 5).

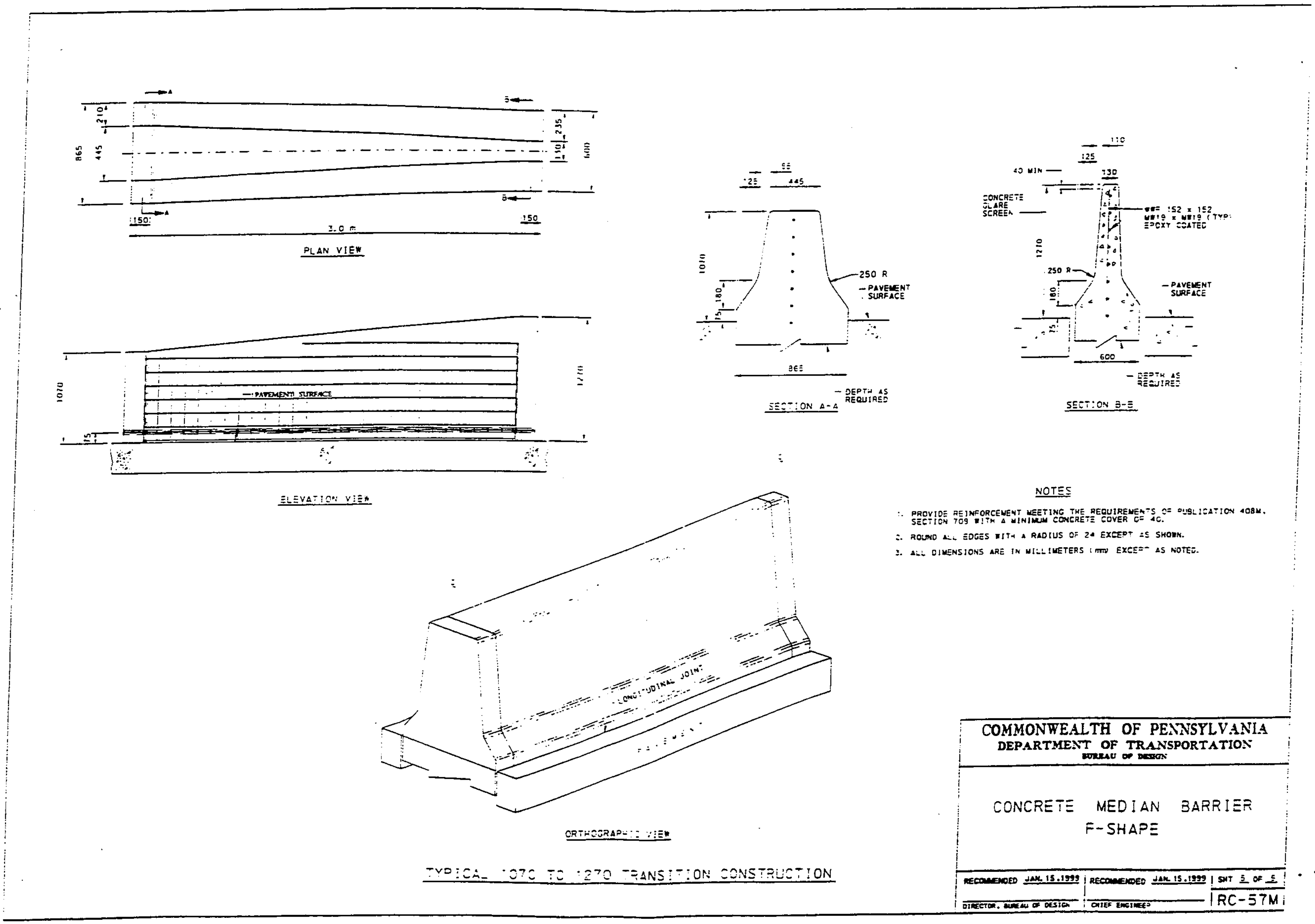


Figure D5. Detailed drawing of concrete median barrier F-shape (5 of 5).