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CRASH TEST OF TYPE III BARRICADES

University-Based Research, Education and Technology Transfer Program

AGREEMENT NO. 359704, WORK ORDER 32

FINAL REPORT

FEBRUARY 2000

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

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13. Abstract (Maximum 200 words)

This report presents the results of level 3 crash tests of Type III barricades used by the Pennsylvania Transportation Department as work-zone traffic-control devices. Two crash tests were conducted. In the first test, herein referred to as the head-on test, the face of the Type III barricade was impacted by the test vehicle. The second test was performed with the test article rotated 90 degrees relative to the head-on configuration so that the test vehicle first impacted the edge of the Type III barricade. The tests conducted conformed to NCHRP 350 level 3, test designation 3-71. The test vehicles used were 1994 Geo Metros with an impact speed of 100 km/h. The test article's performance was acceptable. The vehicle trajectory was not affected by the impact and no components of the test article penetrated the passenger compartment of the test vehicle. The test vehicles sustained minor damage to the roof and windshield from the impacts, but the windshield was not breached in either test.

The performance of the test article appears satisfactory for all criteria specified under NCHRP 350. Based on a review of the test results and performance criteria, the testing agency believes that the Type III barricade has passed the level 3 NCHRP 350 testing designation 3-71. The testing agency recommends that PennDOT submit the crash test results to the Federal Highway Administration (FHWA) for approval under NCHRP 350 test level 3, so that the Type III barricades may continue to be manufactured and sold after October 1, 2000 for use on Pennsylvania highways.

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Agreement No. 359704, Work Order 32

FINAL REPORT

Prepared for

Commonwealth of Pennsylvania
Department of Transportation
Office of Planning & Research

By

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The Pennsylvania Transportation Institute
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TABLE OF CONTENTS

Page(s)

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report presents the results of level 3 crash tests of Type III barricades used by the Pennsylvania Department of Transportation as work-zone traffic-control devices. The crash tests were conducted on November 3, 1999, and November 23, 1999 at the Pennsylvania Transportation Institute's Crash Safety Research Center.

Two crash tests were conducted. In the first test, herein referred to as the head-on test, the face of the Type III barricade was impacted by the test vehicle. The second test was performed with the test article rotated 90 degrees relative to the head-on configuration so that the test vehicle first impacted the edge of the Type III barricade. The tests conducted conformed to NCHRP 350 level 3, test designation 3-71. The test vehicles used were 1994 Geo Metros with an impact speed of 100 km/h. The test article's performance was acceptable. The vehicle trajectory was not affected by the impact and no components of the test article penetrated the passenger compartment of the test vehicle. The test vehicles sustained minor damage to the roof and windshield from the impacts, but the windshield was not breached in either test.

The performance of the test article appears satisfactory for all criteria specified under NCHRP 350. Based on review of the test results and performance criteria, the testing agency believes that the Type III barricade has passed the level 3 NCHRP 350 testing designation 3-71. The testing agency recommends that PennDOT submit the crash test results to the Federal Highway Administration (FHWA) for approval under NCHRP 350 test level 3, so that the Type III barricades may continue to be manufactured and sold after October 1, 2000 for use on Pennsylvania highways.

INTRODUCTION

Statement of Problem

In order to meet Federal Highway Administration (FHWA) requirements, the Pennsylvania Department of Transportation (PennDOT) needed to evaluate crashworthiness of Type III barricades by means of crash testing according to National Cooperative Highway Research Program (NCHRP) 350 requirements (Ross et al. 1993).

Objective and Scope

The objective of the test program described in this report was to evaluate the performance of Type III barricades when subjected to NCHRP level-3 testing criteria based on test designation 3-71.

The scope of the test program consisted of two tests. The first test was performed as a head-on collision with the face of the barricade, and the second test was performed with the barricade turned 90 degrees so that the edge of the barrier was impacted. The test vehicle for each test was a 1994 Geo Metro passenger car. The Pennsylvania Department of Transportation provided the test articles.

TECHNICAL DISCUSSION

Test Parameters

Test Facility

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

Test Article Design and Construction

The Type III barricade is a work zone traffic-control device consisting of a large sign, a small sign, three plastic rails, and a yellow flasher. The barricade used for the head-on collision is shown in ***Figure 1*** and the barricade for the edge-impact test is shown in ***Figure 2***. The battery pack for the flasher was placed on the ground and secured to one of the barricade's vertical posts for each test. The height of the barricade to the underside of the sign is 1.5 m (5 ft). The two signs are of plywood construction. The large sign is supported on two vertical posts made of steel tubing spaced 76 cm (30 in) on center. Three plastic rails are also supported on the vertical posts. The smaller plywood sign is bolted to two of the three plastic horizontal rails. The base consists of two 1.8-m (6-ft) long pieces of steel tubing supporting the vertical posts. The test article weighed 58.97 kg (130 lb). In the head-on test, two bags of ball bearing shot, each bag weighing 22.7 kg (50 lb), were placed on each of the forward legs of the barricade to prevent the test article from blowing over. In the edge-impact test, one bag of shot was placed on each of the legs (front and rear) of the barricade. A detailed drawing of the test article is provided in ***Appendix C***.

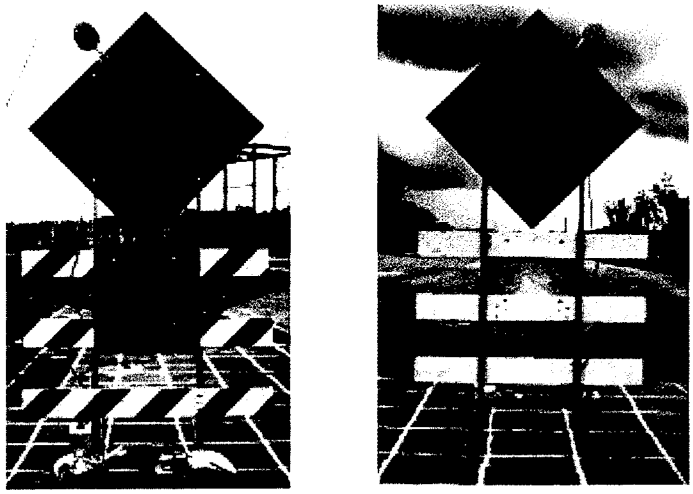


Figure 1. Type III barricade used in head-on test.

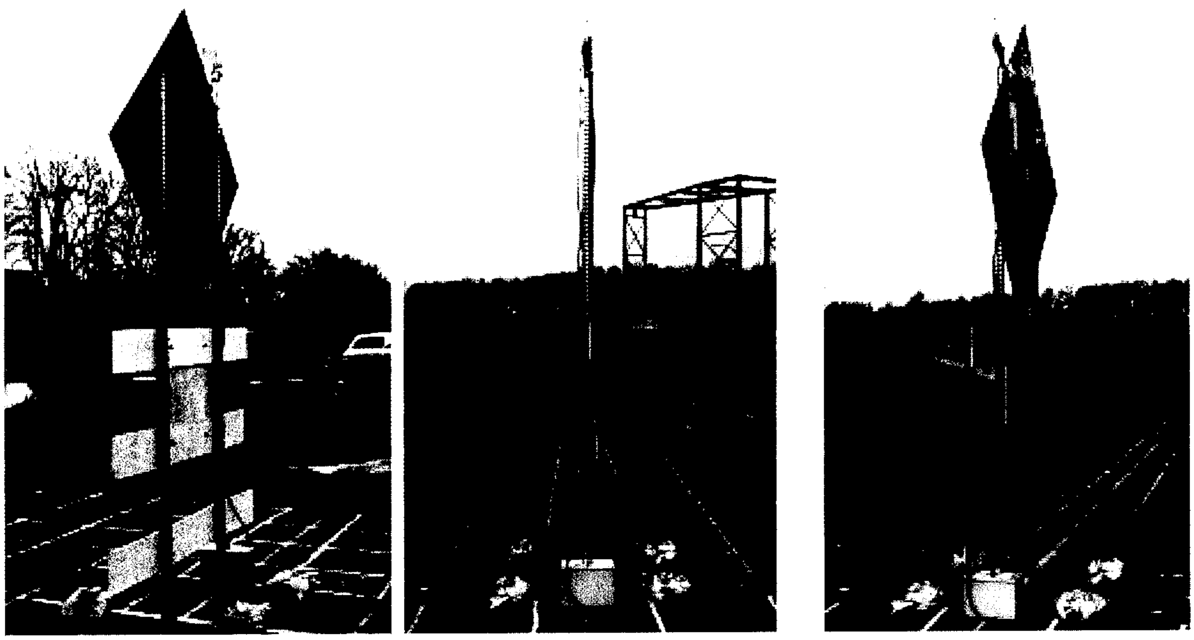
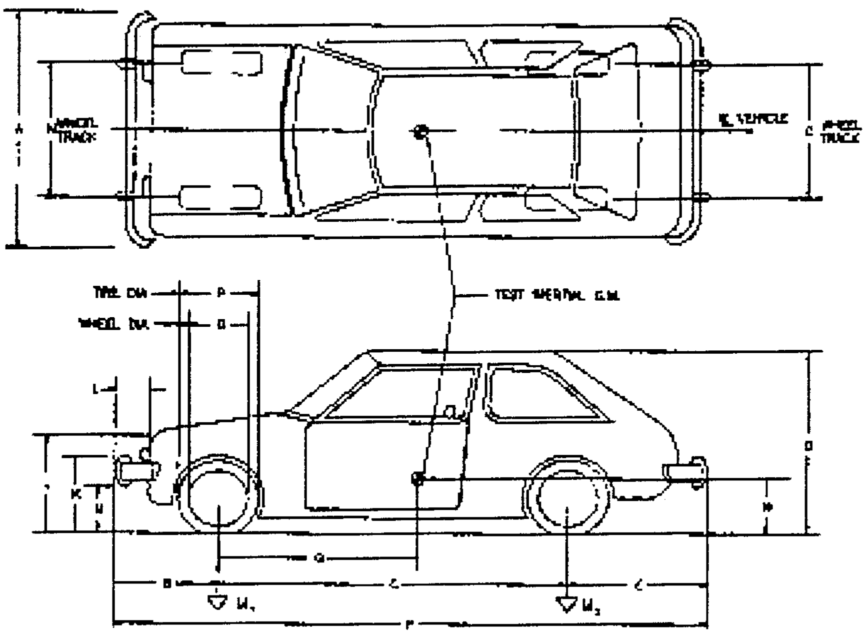


Figure 2. Type III barricade used in edge-impact test.

Test Vehicle
The test vehicle for each test was a 1994 Geo Metro. Vehicle specifications are provided in ***Figures 3 and 4***. Photographs of the test vehicles are shown in ***Figures 5 and 6***.

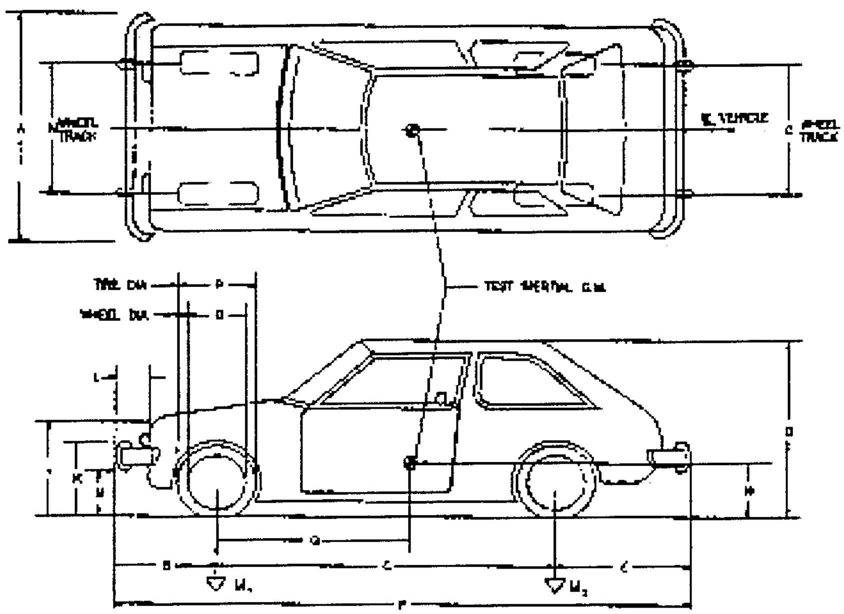
Vehicle Dimensions							
Item		***Geometry (in/cm)***		***Item***		***Geometry (in/cm)***	
Overall Width	A	62.6	159.0	Hood Height	J	27.6	70.0
Front Overhang	B	27.0	68.6	Bumper Height (top)	K	19.0	48.3
Wheel Base	C	89.2	226.5	Bumper Overhang	L	7.1	18.0
Height	D	52.4	133.0	Bumper Height	M	15.4	39.0
Rear Overhang	E	25.5	64.8	Front Wheel Track	N	53.7	136.4
Total Length	F	147.4	374.5	Rear Wheel Track	O	52.8	134.1
Front Axle to CG	G	36.5	92.8	Tire Diameter	P	13.0	33.0
CG Height	H	22.0	55.9	Wheel Diameter	Q	13.8	35.1



Vehicle Data	
Gross Static Mass (kg)	886
Front	523
Rear	363
Test Inertial Mass (kg)	815
Mass Distribution (kg)	
Left Front	274
Right Front	269
Left Rear	173
Right Rear	170
Dummy Mass (kg)	73
Tire Inflation (psi)	32
Tire Size	145/80R12
Odometer	49745
Engine VIN No.	2C1MR2467R6770862

Figure 3. Test vehicle specifications for 1994 Geo Metro used in head-on test.

Vehicle Dimensions							
Item		*Geometry (in/cm)*		*Item*		*Geometry (in/cm)*	
Overall Width	A	62.6	159.0	Hood Height	J	27.6	70.0
Front Overhang	B	27.0	68.6	Bumper Height (top)	K	19.0	48.3
Wheel Base	C	89.2	226.5	Bumper Overhang	L	7.1	18.0
Height	D	52.4	133.0	Bumper Height	M	15.4	39.0
Rear Overhang	E	25.5	64.8	Front Wheel Track	N	53.7	136.4
Total Length	F	147.4	374.5	Rear Wheel Track	O	52.8	134.1
Front Axle to CG	G	35.6	90.3	Tire Diameter	P	13.0	33.0
CG Height	H	22.0	55.9	Wheel Diameter	Q	13.8	35.1



Vehicle Data	
Gross Static Mass (kg)	915
Front	550
Rear	365
Test Inertial Mass (kg)	845
Mass Distribution (kg)	
Left Front	275
Right Front	275
Left Rear	180
Right Rear	185
Dummy Mass (kg)	73
Tire Inflation (psi)	32
Tire Size	145/80R12
Odometer	66129
Engine VIN No.	2C1MR2467R6704490

Figure 4. Test vehicle specifications for 1994 Geo Metro used in edge-impact test.

Figure 5. Test vehicle (1994 Geo Metro) used in head-on test.

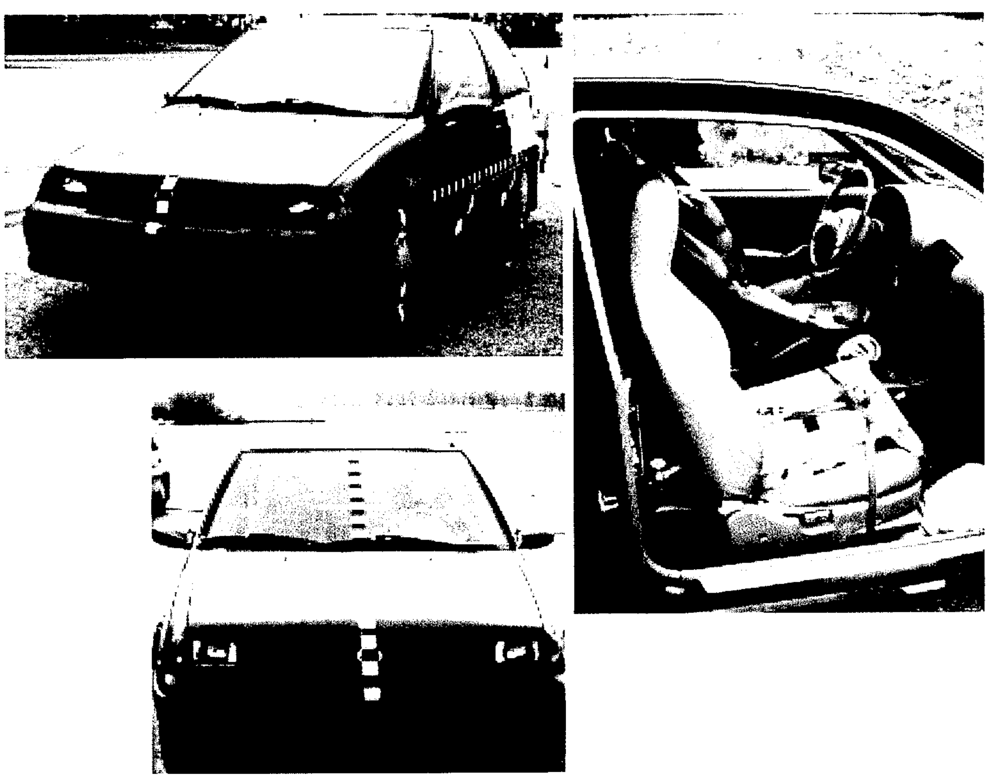


Figure 6. Test vehicle (1994 Geo Metro) used in edge-impact test.

Soil Conditions
Soil conditions were not applicable for this test because the barricade 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 barricade 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.

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	40.0
11:50:31	5	83.8	40.0
11:52:02	6	81.4	40.0
11:53:32	7	82.1	40.0
11:55:03	8	82.8	40.0
11:56:32	9	82.3	40.0
Average SN		**82.3**	
Standard Deviation		**0.9**	

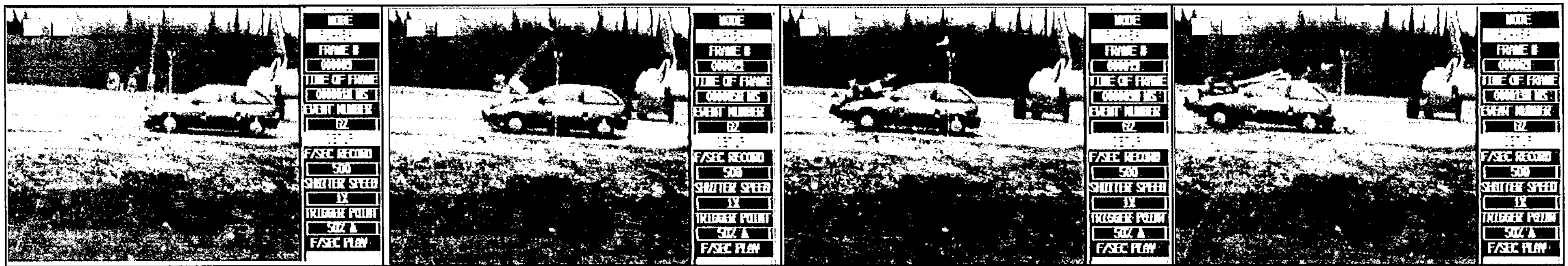
Test Conditions and Results

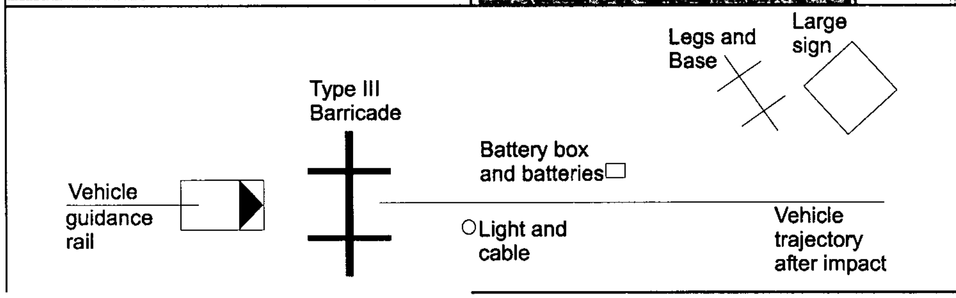
Impact Description /Vehicle Behavior
Based on video analysis of the test conducted on November 3, 1999, the approach speed at impact for the head-on collision (crash test #1) was 102.5 km/h (63.7 mi/h) and the exit speed was 98.3 km/h (61.1 mi/h). The video shows a slight rise of the vehicle near the point of contact with the barricade. This is attributed to the undercarriage contacting the shot bags used to hold the barricade in position and may have accounted for some of the loss of speed as the vehicle was exiting the test area. Upon impact the sign came to rest on the roof of the vehicle, eventually sliding off to the driver's side as the vehicle exited the test area.

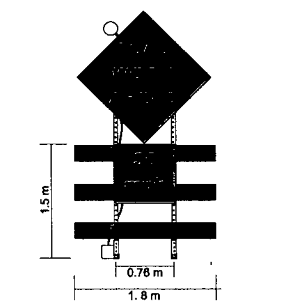
For the edge-impact test (crash test #2) conducted on November 23, 1999, video analysis indicated that the approach speed at impact was 103.4 km/h (64.3 mi/h) and the exit speed was 91.2 km/h (56.7 mi/h). On impact, the sign tipped over and struck the roof of the car causing a dent in the roof before detaching from the vertical posts and going into the air. The vehicle proceeded to its final resting place with the remainder of the barricade wrapped around the hood and front bumper area.

Test results for each test are summarized in ***Figures 7 and 8***.

Test Article Damage/Debris Patterns
In both the head-on test and the edge-impact test, the Type III barricade was essentially destroyed with debris coming to rest at the locations shown in ***Figures 9 and 10***. The final condition of each test article after the test can be seen in ***Figures 11 and 12***.



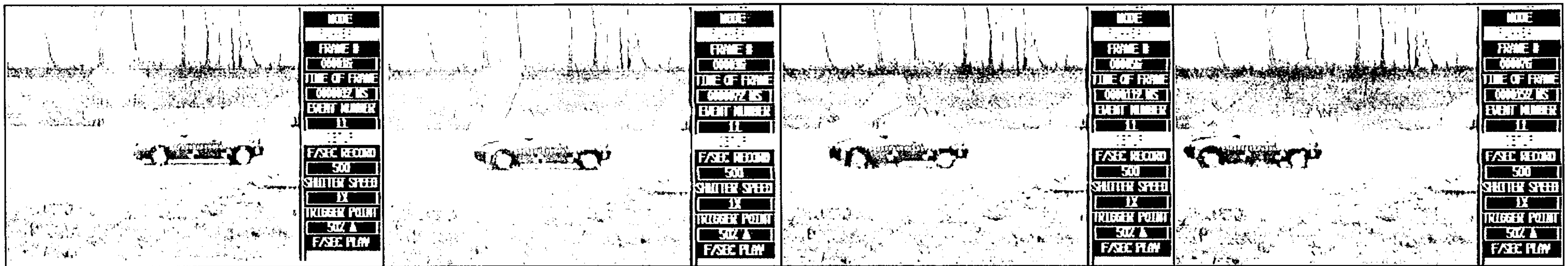


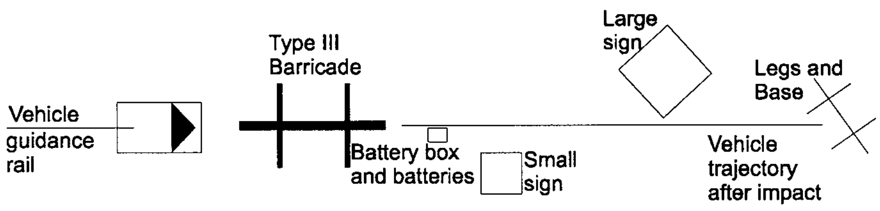


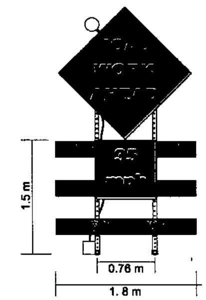
General Information	
Test Agency	Pennsylvania Transportation Institute
Test No.	3-71
Date	November 3, 1999
Test Article	
Type	Type III Barricade
	Pennsylvania Department of Transportation
Installation Length (m)	Not applicable
Size and/or dimension and material of	1.2 m plywood sign on square metal tube legs on 0.76 m
key elements	Centers. Width 1.8 m. Height to bottom of sign 1.5 m.
Soil Type and Condition	Pavement Skid # = 82.3
Test Vehicle	
Type	Production
Designation	820C
Model	1994 Geo Metro
Mass (Kg) Curb	Not measured
Test Inertial	815
Dummy(s)	73
Gross Static	886
Impact Conditions	
Speed (km/h)	102.5
Angle (deg)	89°
Exit Conditions	
Speed (km/h)	98.3
Angle (deg)	89°

Occupant Risk Values	
Impact Velocity (m/s)	Not required
x-direction	Not required
y-direction	Not required
THIV (optional)	Optional
Ridedown Acceleration (g's)	Not required
X-direction	Not required
Y-direction	Not required
PHD (optional)	Optional
ASI (optional)	Optional
Test Article Deflections (m)	
Dynamic	Not measured
Permanent	Not measured
Vehicle Damage	
Exterior	
VDS	12-FC-1
CDC	12FDAK6 and 12TPGW1
Interior	
OCDI	FS00000 (no occupant compartment damage)
Post-Impact Vehicular Behavior	
Maximum Roll Angle (deg)	Not required
Maximum Pitch Angle (deg)	Not required
Maximum Yaw Angle (deg)	Not required

Figure 7. Test summary sheet for head-on test (crash test #1).







General Information	
Test Agency	Pennsylvania Transportation Institute
Test No.	3-71
Date	November 23, 1999
Test Article	
Type	Type III Barricade
	Pennsylvania Department of Transportation
Installation Length (m)	Not applicable
Size and/or dimension and material of key elements	1.2 m plywood sign on square metal tube legs on 0.76 m Centers. Width 1.8 m. Height to bottom of sign 1.5 m.
Soil Type and Condition	Pavement Skid # = 82.3
Test Vehicle	
Type	Production
Designation	820C
Model	1994 Geo Metro
Mass (Kg) Curb	Not measured
Test Inertial	845
Dummy(s)	73
Gross Static	915
Impact Conditions	
Speed (km/h)	103.4
Angle (deg)	0°
Exit Conditions	
Speed (km/h)	91.2
Angle (deg)	0°

Occupant Risk Values	
Impact Velocity (m/s)	Not required
x-direction	Not required
y-direction	Not required
THIV (optional)	Optional
Ridedown Acceleration (g's)	Not required
X-direction	Not required
Y-direction	Not required
PHD (optional)	Optional
ASI (optional)	Optional
Test Article Deflections (m)	
Dynamic	Not measured
Permanent	Not measured
Vehicle Damage	
Exterior	
VDS	12-FC-3
CDC	12FZAK6 and 12TPGN2
Interior	
OCDI	RS0200000
Post-Impact Vehicular Behavior	
Maximum Roll Angle (deg)	Not required
Maximum Pitch Angle (deg)	Not required
Maximum Yaw Angle (deg)	Not required

Figure 8. Test summary sheet for edge-impact test (crash test #2).

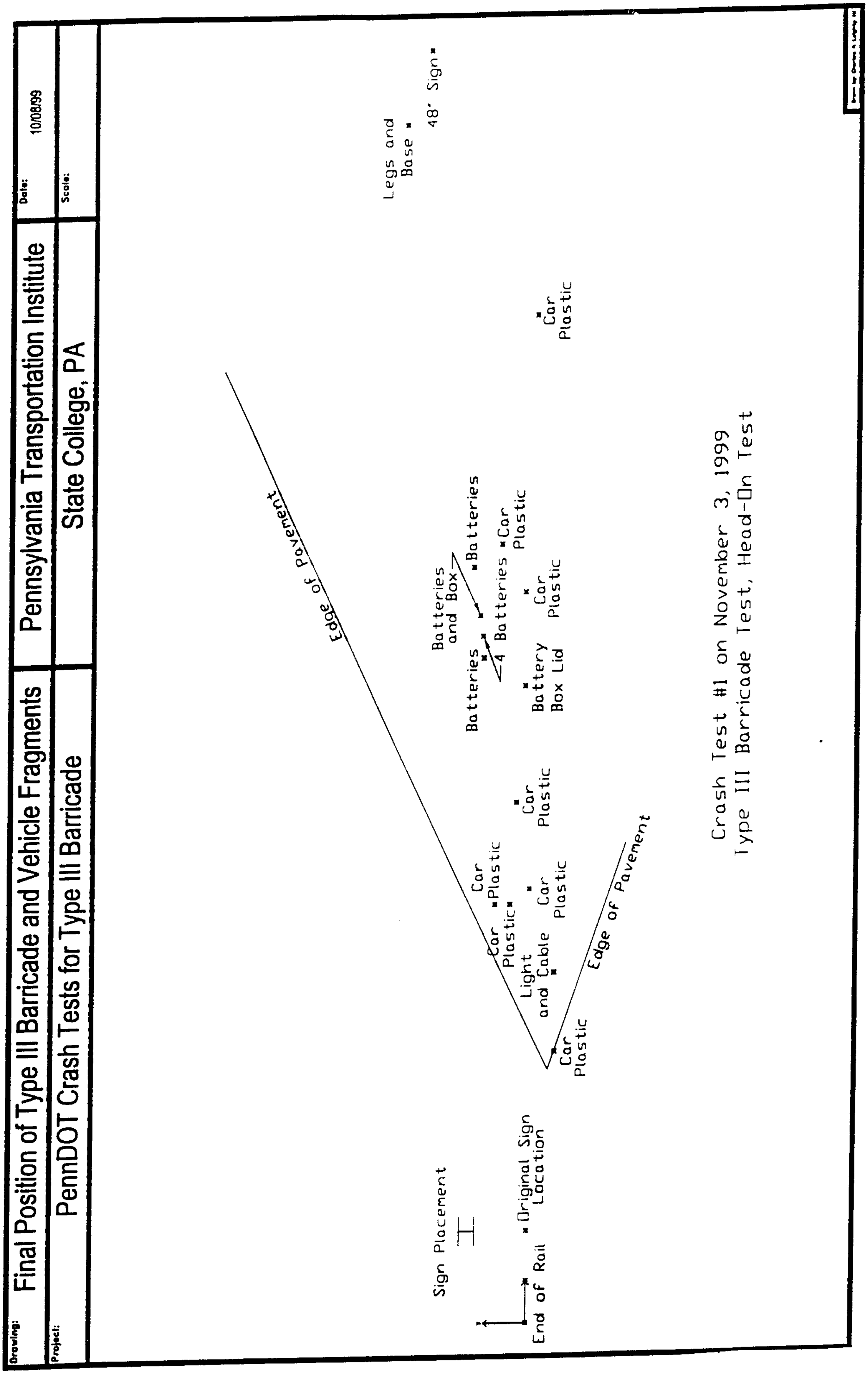


Figure 9. Crash Test #1: Type 3 barricade head-on test (November 3, 1999).

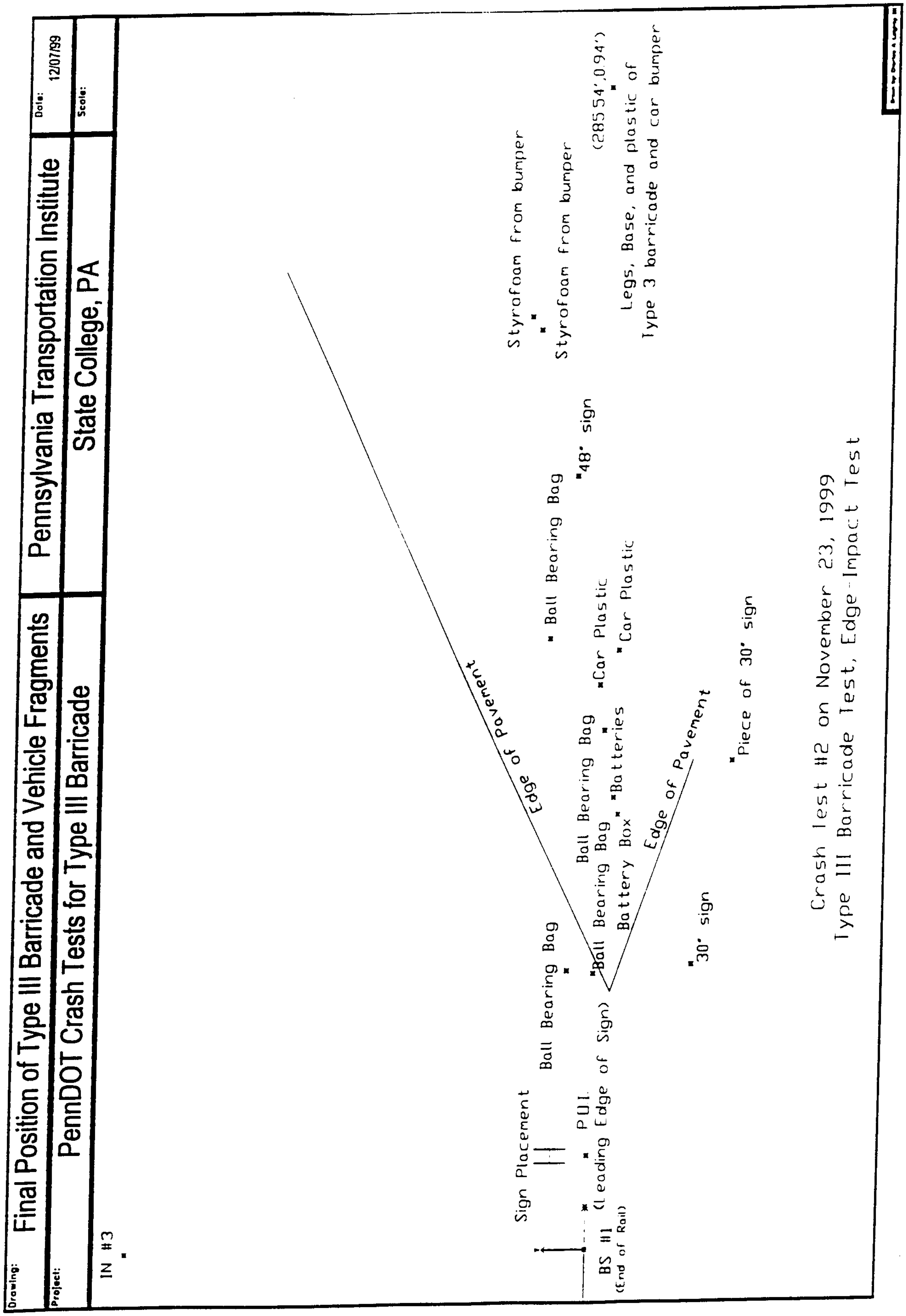


Figure 10. Crash Test #2: Type 3 barricade edge-impact test (November 23, 1999).

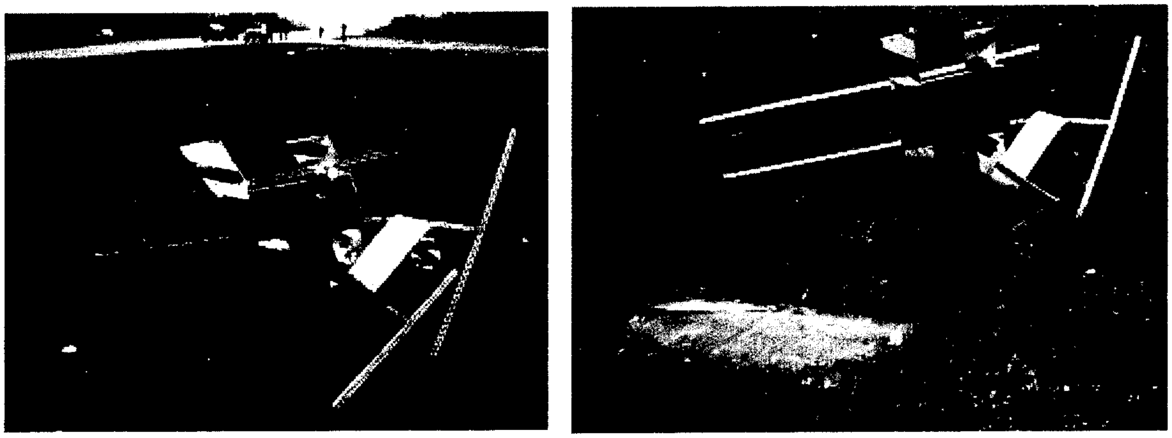


Figure 11. Test article after head-on test.

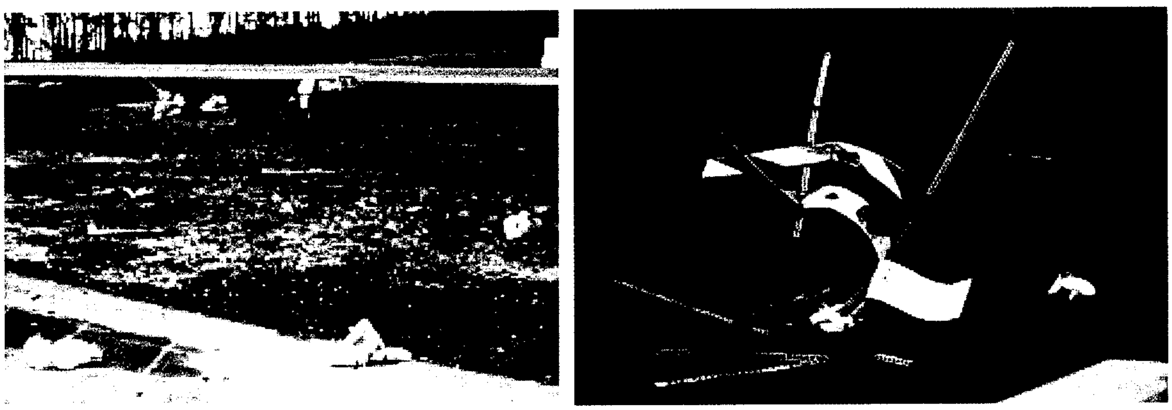


Figure 12. Test article after edge-impact collision.

Vehicle Damage

During the head-on collision (crash test #1), the barricade rotated toward the vehicle upon impact, with the upper sign impacting the roof of the vehicle causing a small dent that is consistent with contact by the bolt used to mount the warning light on the top of the barricade. As shown in ***Figure 13***, some damage occurred to the windshield of the car but there was no penetration of the passenger compartment and good visibility was maintained through the windshield. The impact of the vertical post caused a dent in the front of the hood of the vehicle.

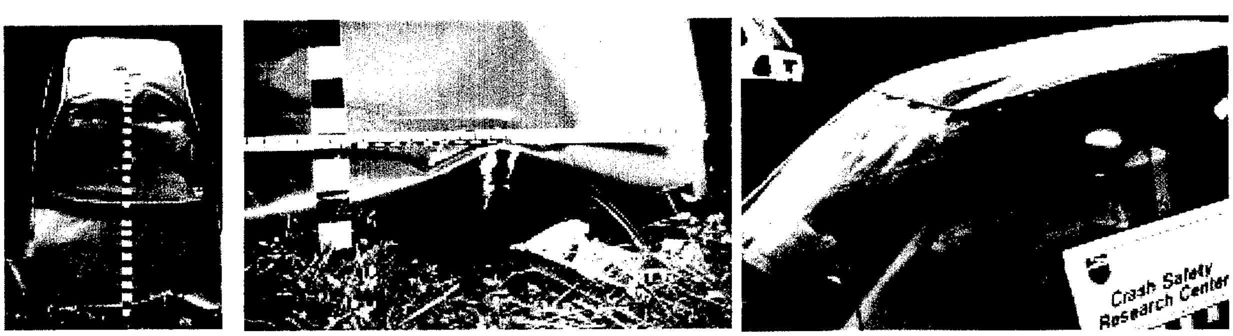


Figure 13. Damage to the test vehicle as a result of the head-on test.

During the edge-impact collision (crash test #2), a corner of the large top sign struck the roof of the car, causing a dent approximately 2 in. deep as shown in ***Figure 14***. The impact also caused damage to the windshield as shown in ***Figure 14***. Impact of the vertical post caused a dent at the front of the hood of the vehicle. Small pieces of glass from the inside laminate were found in the passenger compartment as illustrated in ***Figure 15***; however, there was no penetration of the test article into the passenger compartment.

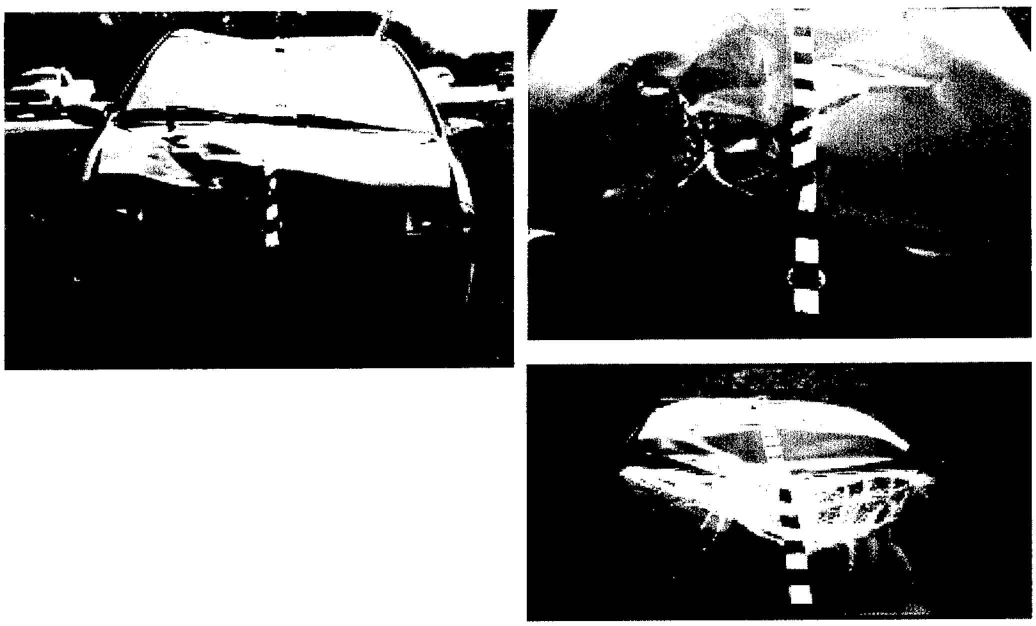


Figure 14. Damage to the test vehicle as a result of the edge-impact test.

←Glass

Figure 15. Pieces of glass inside the passenger compartment after the edge-impact test.

Dummy Behavior

In both tests, the dummy performed as anticipated. No significant movements were noted in either the forward or lateral directions. There was no evidence of dramatic changes in occupant velocity and accelerations

Assessment of Test Results

Occupant Risk

The impact with the test article did not result in damage that would cause risk to the passengers in the vehicle in either of the tests. There was no penetration of test article debris into the passenger compartment. The windshield was damaged; however, it was not breached and provided adequate visibility after impact. In the head-on collision (test #1), the plastic rails rested on the windshield for a short period of time before sliding off to the side. Small pieces of glass were found inside the passenger compartment after the edge-impact test (test #2); however, this was not considered a significant risk to occupants.

Structural Adequacy

In both tests, the barricades sustained extensive damage but did not influence the trajectory of the vehicle after impact.

Vehicle Trajectory Hazard

The vehicle's trajectory was not influenced by impact with the barricade in either test. ***Table 2*** provides a tabular assessment of structural adequacy, occupant risk, and vehicle trajectory.

CONCLUSIONS AND RECOMMENDATIONS

Based on a review of the test results and performance criteria, it is concluded that the Type III barricades described in this report meet the NCHRP 350 level 3 testing criteria covered by test designation 3-71. It is recommended that Pennsylvania submit the Type III barricade to the Federal Highway Administration (FHWA) for NCHRP 350 approval under test level 3 so that the Type III barricades may continue to be manufactured and sold after October 1, 2000 for use on Pennsylvania highways.

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).

Table 2. Assessment of risk.

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The Type III barricade yielded to the head-on and edge-impact with the vehicle in a predictable manner.	Pass
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 or intrusions into the occupant compartment that could cause serious injuries should not be permitted.	In both tests, the windshield was damaged; however, there was no penetration of the Type III barricade into the passenger compartment. During the head-on test (test #1), the sign impacted the roof and then slid off the side of the car. In the edge-impact test (test #2), the sign impacted the roof of the car before breaking away from the vertical posts and landing behind the car.	Pass
E. Detached elements, fragments, or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	In the head-on test (test #1), the horizontal rails of the Type III barricade rested on the hood and windshield of the vehicle for a brief time before sliding off the side of the car. Although visibility was considered reduced, it was not completely blocked. In both tests, the windshield was damaged, but a sufficient level of visibility was maintained.	Pass
F. The vehicle should remain upright during and after collision, although moderate roll, pitching, and yawing are acceptable.	The vehicle remained upright during both tests.	Pass
H. Occupant impact velocities should satisfy Table 5.1 of NCHRP 350.		NA
I. Occupant ridedown accelerations should satisfy Table 5.1 of NCHRP 350.		NA
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle was not redirected into traffic.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle continued through the test article with no redirection.	Pass

APPENDIX A:
TEST VEHICLE EQUIPMENT
AND
GUIDANCE METHODS

TEST VEHICLE EQUIPMENT AND GUIDANCE METHODS

The Pennsylvania Transportation Institute 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.

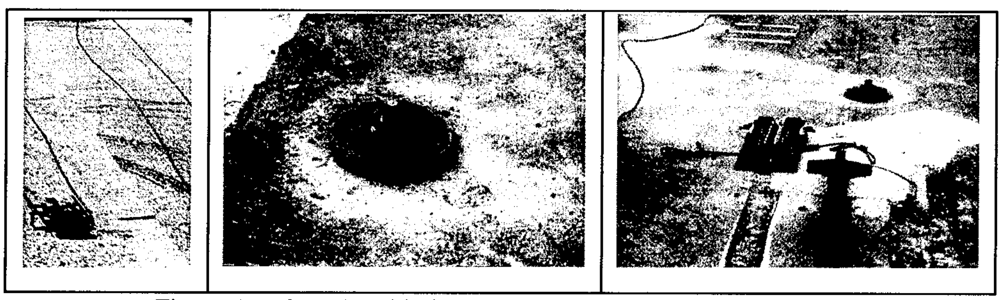


Figure A1. Speed multiplier pulley; alignment pulley; pulley shown with bogey and guidance rail.

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 is a sign stand requiring an 820C vehicle. Therefore, a small passenger car is used for the crash vehicle. The car is run alongside the rail with a bogie mounted onto the rail so that it fits underneath the car. The bogie is attached to the car's suspension lower arms.

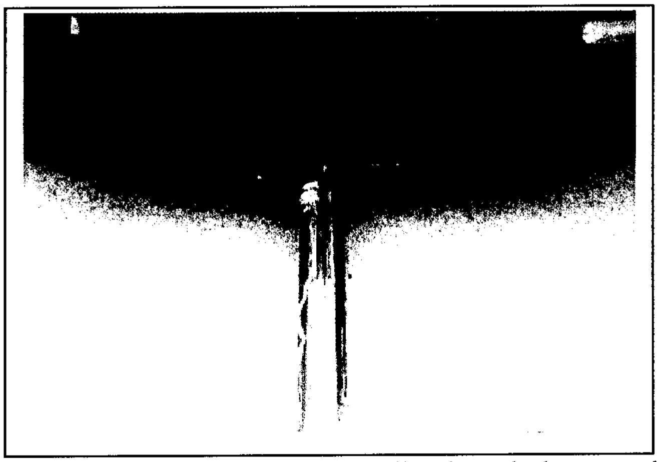


Figure A2. Bogey aligned on guidance rail and attached to test vehicle.

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 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, an 820C passenger car is used. The test vehicles, as presented in the main text of the report (***Figures 3 and 4, pp. 3-4***), are 2-door 1994 Geo Metros, structurally sound, and possessing characteristics that match closely with the national fleet. The test vehicles have no rust damage or damage to the frame or suspension, and no modifications to the bumper or ride-height have been 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 Type III Barricade Testing

Tests Performed by:	**The Crash Safety Research Center**
	The Pennsylvania Transportation Research Institute The Pennsylvania State University University Park, Pennsylvania
Test Dates:	November 3 and 23, 1999
Device Tested:	Type III Barricade
Impacting Vehicles:	1994 Geo Metro
Report Date:	11 November 1999
Revised:	6 December 1999

Report By: ______________________________

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INTRODUCTION

This report documents the setup and results of high-speed video coverage of two tests performed at the Crash Safety Research Center (CSRS) of the Pennsylvania Transportation Institute (PTI) on November 3 and 23, 1999. Both crash tests consisted of impacting a Type III barricade with a Geo Metro at approximately 100 kilometers per hour (kph). The purpose of these tests was to evaluate the performance of the barricades and their ability to meet the requirements of NCHRP-350.

The goal of the tests was to impact the barricade with the vehicle at 100 kph at angles of 90 and 180 degrees between the velocity vector of the vehicle and the face of the barricade. Additionally, it was a goal of these tests that the vehicle and barricade centerlines be aligned, thereby centering the sign on the vehicle at the point-of-impact.

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 barricade. However, the barricade's performance is beyond the scope of this report.

TYPE III BARRICADE (TEST 1)

Setup

Four high-speed video cameras were set up to provide coverage of this testing (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 (test #1).

Camera	Type	Speed Frames/sec	Lens (mm)	Location/View
1	Kodak Ektapro EM	500	35	90° from right side of vehicle
2	Motionscope 8000S	500	6	90° from left side of vehicle
3	Motionscope 8000S	500	6	Overhead
4	Kodak Ektapro TR	500	60	Approx. 30° from vehicle line of travel, looking at front of vehicle
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

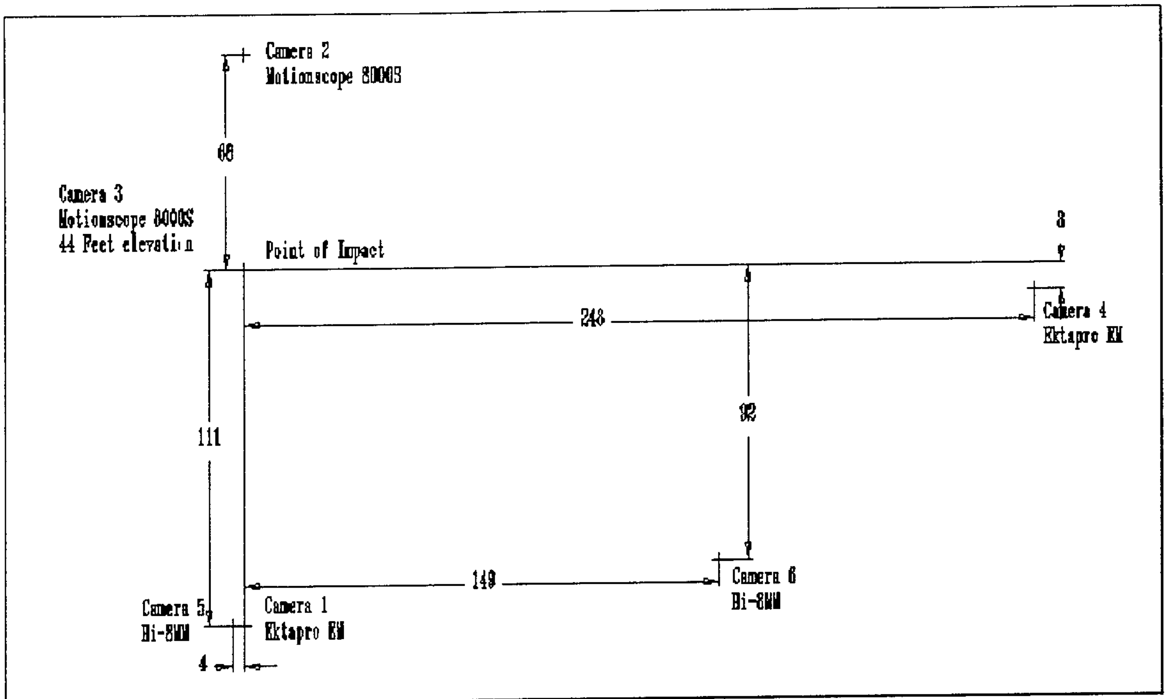


Figure B1. Diagram of camera placement (test #1).

Due to an equipment malfunction just prior to the first test, camera 4, the Ektapro TR, was not functional for the first test. PTI investigators decided to continue the first test without this camera. This problem was subsequently resolved and the camera functioned for the second test.

General information on the vehicle used for the test is summarized in the table below.

Table B2. Vehicle information (test #1).

Test	Vehicle	VIN	Mfd. Date
1	1994 Geo Metro	2C1MR2467R6770862	4/94

Prior to the test, the vehicle had a visual target placed at the center of gravity (CG) on both the 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 barricade. 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.

The Type III barricade consisted of three horizontal bars, a small square sign, and a large square sign all mounted on two steel legs spaced 30 inches apart, center-to-center. A warning light and battery box were also installed on the barricade.

Results

For Test 1, conducted on November 3, 1999, a 1994 Geo Metro was used to impact the front face of a Type III barricade. The barricade was placed at the end of the rail facing the approaching vehicle; two bags of shot were placed on each of the forward legs of the barricade to prevent it from blowing over. It was noted during the video analysis that the legs of the barricade were slightly out of parallel.

The approach and exit speeds for the vehicle are summarized in ***Table B3***.

Table B3. Approach and exit speeds (test #1).

Camera	Approach Speed kph (mph)	Exit Speed kph (mph)
Right side	Not collected	Not collected
Left side	102.9 kph (63.9 mph)	96.8 kph (60.2 mph)
Overhead	102.1 kph (63.5 mph)	99.8 kph (62.0 mph)
Average	**102.5 kph (63.7 mph)**	**98.3 kph (61.1 mph)**

Examination of the vehicle following the test showed that one leg of the barricade impacted the front of the vehicle approximately 11 inches left of centerline. Damage on the right side of the vehicle failed to demonstrate a clear point-of-impact. Using the 11-inch measurement from centerline of the vehicle and the 30-inch spacing of the barricade legs, it appears that the separation between the centerline of the vehicle and the centerline of the barricade was approximately 4 inches. The angle of the vehicle at impact with the barricade was 89°. Information acquired after completing the first version of this report showed that the centerline of the guide rail is not centered on the grid. The overhead video shows that the sign was placed approximately on the center of the grid. This resulted in the sign being approximately 4 inches off center of the guide rail. This would account for the 4-inch misalignment of the point-of-impact.

Upon impact, the barricade rotated toward the vehicle with the upper sign impacting the roof of the vehicle. There is a small dent on the roof of the vehicle to the left of center that is consistent with contact by the bolt, which was used to mount the warning light on the top of the barricade.

Review of the video shows a slight rise of the vehicle near the point-of-contact with the barricade. This is thought to be caused by the undercarriage contacting the shot bags used to hold the sign in position. This contact is likely the reason for some of the loss of speed as the vehicle was exiting the test area.

TYPE III BARRICADE (TEST 2)

Setup

Four high-speed video cameras were set up to provide test coverage (see ***Table B4*** and ***Figure B2***). 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 B4. Camera placement (test #2)

Camera	Type	Speed Frames/sec	Lens (mm)	Location/View
1	Motionscope 8000S	500	6	90° from left side of car
2	Kodak Ektapro EM	500	30	90° from right side of car
3	Motionscope 8000S	500	6	Overhead
4	Kodak Ektapro TR	500	60	Approx. 30° from line of travel of vehicle looking at front of vehicle
5	Sony CCD-TRV65 8 mm palmcorder		Zoom	Approx. 45° from right side of car
6	Sony CCD-TR910 8 mm palmcorder		Zoom	90° from right side of car

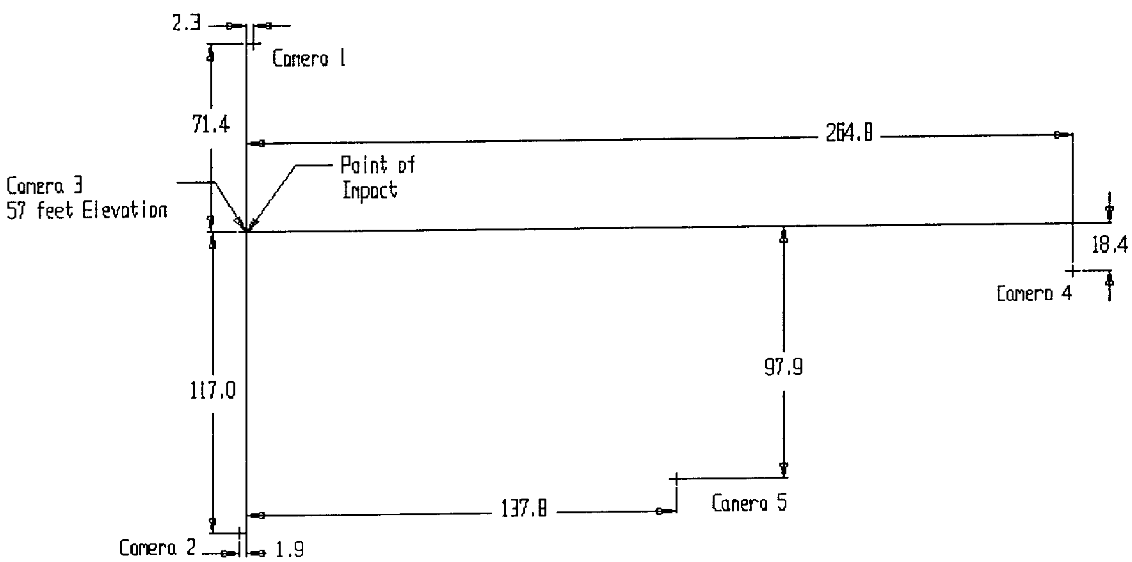


Figure B2. Diagram of camera placement (test #2).

The exact location of the second real-time camera, number 6, was not included on the survey information received from PTI. The location of this camera was approximately 15 feet to the left of camera 2. General information on the vehicle used for the test is summarized in ***Table B5*** below.

Table B5. Vehicle Information (test #2).

Test	Vehicle	VIN	Mfd. Date
2	1994 Geo Metro	2C1MR2467R6704490	8/93

Prior to the test, 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 barricade. There was also a 24 by 24 inch grid painted on the ground in the test area, which was used for both speed and direction calculation from the overhead camera. In addition, two lines were painted on each of the tires that could be used to determine vehicle speed.

The Type III barricade consisted of three horizontal rails, a small square sign, and a large square sign all mounted on two steel legs spaced 30 inches apart, center-to-center. A warning light and battery box were also installed on the barricade. The battery box was located on the side of the barricade first contacted by the vehicle.

Results

For Test 2, conducted on November 23, 1999, a 1994 Geo Metro was used to impact the side of a Type III barricade. The barricade was placed at the end of the rail with the side facing the approaching vehicle; one bag of shot was placed on each of the legs of the barricade.

The approach and exit speeds of the vehicle are summarized below in ***Table B6***.

Table B6. Approach and exit speeds (test #2)

Camera	Approach Speed kph (mph)	Exit Speed kph (mph)
Right side	102.9 kph (63.9 mph)	90.8 kph (56.4 mph)
Left side	102.9 kph (63.9 mph)	91.4 kph (56.8 mph)
Overhead	104.5 kph (64.9 mph)	91.4 kph (56.8 mph)
Average	**103.4 kph (64.3 mph)**	**91.2 kph (56.7 mph)**

Based on tire rotation, the approach speeds were calculated and are summarized below in ***Table B7***.

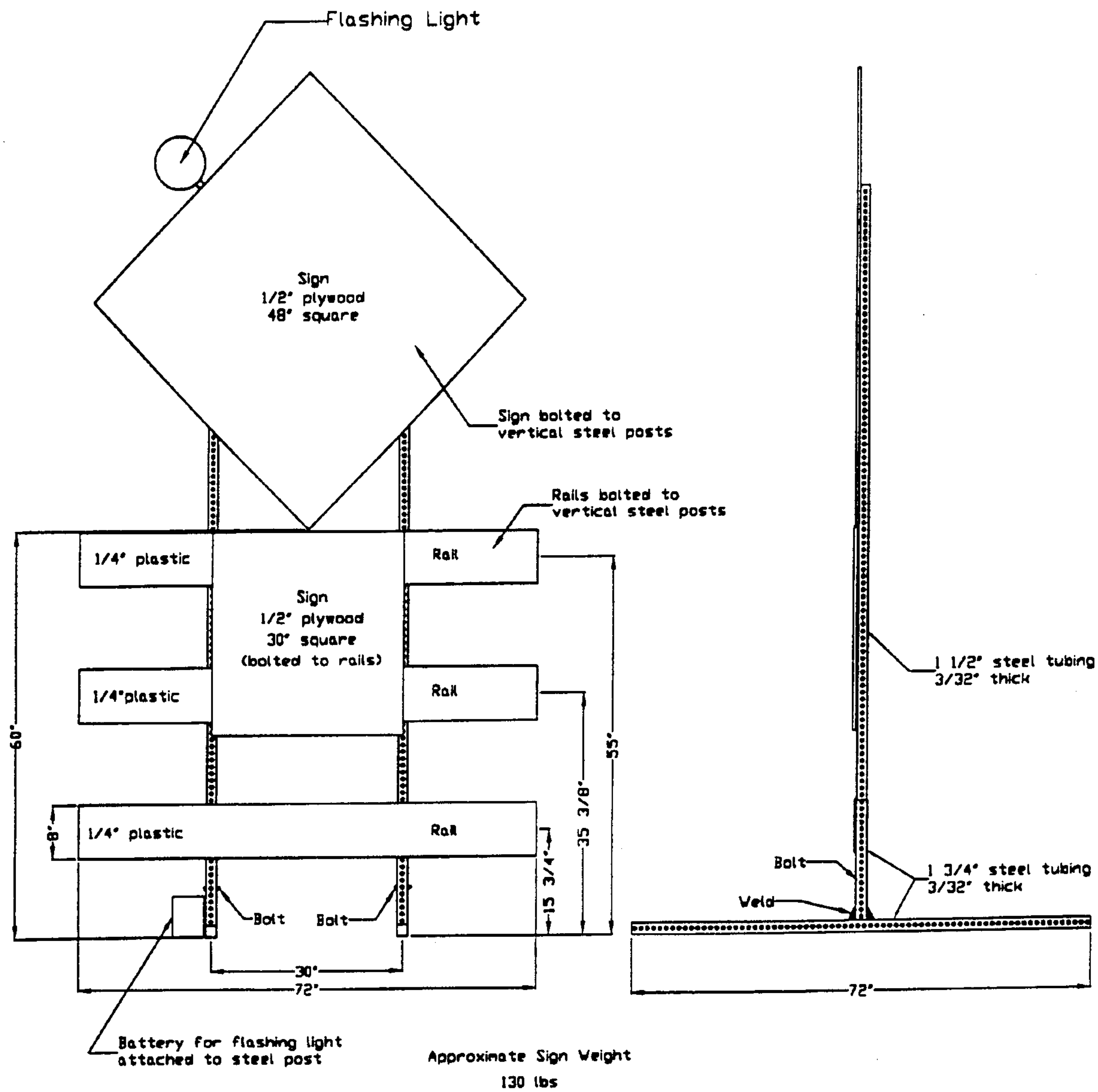
Table B7. Approach speeds based on tire rotation (test #2)

Camera	Approach Speed kph (mph)	Exit Speed kph (mph)
Right side	98.2 kph (61.0 mph)	Not calculated
Left side	103.3 kph (64.2 mph)	89.2 kph (55.4 mph)
Average	**100.8 kph (62.6 mph)**	**89.2 kph (55.4 mph)**

It appears that while use of the paint marks on the tires may assist in determining if a problem occurred during testing, the speeds derived from this method do not yield consistent results. This may be due to the difficulty in determining when the paint mark on the tire had made one complete revolution.

Examination of the vehicle following the test showed that the leg of the barricade impacted within one inch of the centerline of the vehicle. The overhead video revealed that the sign was very well aligned with the track centerline and the vehicle centerline tracked right down the track centerline.

APPENDIX C:
Detailed Drawing of Test Article



Drawing:	Type III Barricade Dimensions	**Date:** 11/29/99
Project:	PTI Crash Tests	**Scale:** 1/2" = 1'-0"

Figure C1. Detailed drawing of test article.