Texas Transportation Institute

NCHRP REPORT 350 TEST 3-11 OF GEORGIA TEMPORARY CONCRETE BARRIERS

by

Wanda L. Menges
Associate Research Specialist

C. Eugene Buth, P.E.
Senior Research Engineer

Richard A. Zimmer
Senior Research Specialist

and

William F. Williams
Assistant Research Engineer

Contract No. T98170
Project No. 404821

Sponsored by
Georgia Department of Transportation

February 2000

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A & M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS 77843-3135

DISCLAIMER

KEY WORDS

Longitudinal barriers, temporary concrete barriers, PCB, CMB, portable concrete barriers, median barriers, crash testing, instrumentation, roadside safety

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle NCHRP REPORT 350 TEST 3-11 OF GEORGIA TEMPORARY CONCRETE BARRIERS		5. Report Date February 2000 6. Performing Organization Code
7. Author(s) Wanda L. Menges, C. Eugene Buth, Richard A. Zimmer, and William F. Williams		8. Performing Organization Report No. 404821-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. T98170
12. Sponsoring Agency Name and Address Georgia Department of Transportation Office of Materials and Research 15 Kennedy Drive Forest Park, GA 30297-2599		13. Type of Report and Period Covered Final Report April 1999-March 2000 14. Sponsoring Agency Code

15. Supplementary Notes
Research Study Title: Crash Testing of Georgia's Temporary Concrete Barriers
Name of Contacting Representative at Georgia DOT: Rick Deaver

16. Abstract

The main objective of this study was to evaluate the performance of Georgia's Temporary Concrete Barrier according to *NCHRP Report 350*, and a secondary objective was to obtain data that would be helpful in determining the length of barrier involved in a collision. To accomplish this, strains in the connecting loops at eight connections (four at the upstream end and four at the downstream end of the installation) were measured during the collision. A full-bridge set of strain gages were installed on the top loop and another on the bottom loop of each of the eight pin and loop connections, resulting in 16 channels of data. The barrier was placed, freestanding, on a concrete paved area with all slack removed at the connections.

NCHRP Report 350 test designation 3-11 with the 2000 kg pickup truck was performed on the Georgia Temporary Concrete Barrier. The pickup truck impacted the installation 1.2 m upstream of the joint between segments 7 and 8 while traveling at a speed of 99.9 km/h and 25.6 degrees. Strain gages were installed on the top and bottom loops at the joints between segments 1 and 2, 2 and 3, 3 and 4, and 4 and 5 on the upstream end and at the joints between segments 11 and 12, 12 and 13, 13 and 14, and 14 and 15 on the downstream end. The installation consisted of a total of 18 barriers.

The Georgia DOT Temporary Concrete Barrier with pin and loop connection met the required criteria for *NCHRP Report 350* test designation 3-11.

17. Key Words	18. Distribution Statement
Longitudinal barriers, temporary concrete barriers, PCB, CMB, portable concrete barriers, median barriers, crash testing, instrumentation, roadside safety	No restrictions. This document is available to the public through NTIS: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	58	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
EF	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	EC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
EC	Celcius temperature	1.8C+32	Fahrenheit temperature	EF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

(Revised September 1993)

TABLE OF CONTENTS

Page

INTRODUCTION 1
- **PROBLEM** 1
- **BACKGROUND** 1
- **OBJECTIVES/SCOPE OF RESEARCH** 1

TECHNICAL DISCUSSION 3
- **TEST PARAMETERS** 3
  - **Test Facility** 3
  - **Test Article – Design and Construction** 3
  - **Electronic Instrumentation** 5
  - **Test Conditions** 9
  - **Evaluation Criteria** 10
- **CRASH TEST 404821-1 (*NCHRP REPORT 350* TEST 3-11)** 11
  - **Test Vehicle** 11
  - **Soil and Weather Conditions** 11
  - **Impact Description** 11
  - **Damage to Test Article** 14
  - **Vehicle Damage** 14
  - **Occupant Risk Factors** 21
  - **Assessment of Test Results** 21

SUMMARY AND CONCLUSIONS 25
- **SUMMARY OF FINDINGS** 25
- **CONCLUSIONS** 25

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS 27
- **ELECTRONIC INSTRUMENTATION AND DATA PROCESSING** 27
- **ANTHROPOMORPHIC DUMMY INSTRUMENTATION** 28
- **PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING** 28
- **TEST VEHICLE PROPULSION AND GUIDANCE** 28

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION 31

APPENDIX C. SEQUENTIAL PHOTOGRAPHS 35

APPENDIX D. FORCE EXPERIENCED BY CONNECTION LOOPS 39

APPENDIX E. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS 47

REFERENCES 51

LIST OF FIGURES

Figure No. Page

1 Details of the Georgia Temporary Barrier with pin and loop connection 4
2 Layout of test installation 6
3 Georgia Temporary Concrete Barrier prior to testing 7
4 Typical strain gage installation used in test 404821-1 8
5 Vehicle/installation geometrics for test 404821-1 12
6 Vehicle before test 404821-1 13
7 Vehicle trajectory path after test 404821-1 15
8 Installation after test 404821-1 16
9 Damage at connection of segments 6 and 7 17
10 Damage at connection of segments 7 and 8 18
11 Vehicle after test 404821-1 20
12 Interior of vehicle for test 404821-1 22
13 Summary of results for test 404821-1, *NCHRP Report 350* test 3-11 23
14 Vehicle properties for test 404821-1 31
15 Sequential photographs for test 404821-1
(overhead and frontal views) 35
16 Sequential photographs for test 404821-1
(rear views) 37
17 Force experienced at connection of segments 1 and 2 39
18 Force experienced at connection of segments 2 and 3 40
19 Force experienced at connection of segments 3 and 4 41
20 Force experienced at connection of segments 4 and 5 42
21 Force experienced at connection of segments 11 and 12 43
22 Force experienced at connection of segments 12 and 13 44
23 Force experienced at connection of segments 13 and 14 45
24 Force experienced at connection of segments 14 and 15 46
25 Vehicular angular displacements for test 404821-1 47
26 Vehicle longitudinal accelerometer trace for test 404821-1
(accelerometer located at center of gravity) 48
27 Vehicle lateral accelerometer trace for test 404821-1
(accelerometer located at center of gravity) 49
28 Vehicle vertical accelerometer trace for test 404821-1
(accelerometer located at center of gravity) 50

LIST OF TABLES

Table No. Page

1 Movement of barriers during test 404821-1 19
2 Performance evaluation summary for test 404821-1, *NCHRP Report 350* test 3-11 26
3 Exterior crush measurements for test 404821-1 32
4 Occupant compartment measurements for test 404821-1 33

INTRODUCTION

PROBLEM

The Federal Highway Administration (FHWA) has formally adopted the performance evaluation guidelines for highway safety features set forth in National Cooperative Highway Research Program (*NCHRP*) *Report 350* as a "Guide or Reference" document in Federal Register, Volume 58, Number 135, dated July 16, 1993, which added paragraph (a) (13) to 23 CFR, Part 625.5.[1] FHWA has also mandated that, starting in October 1998, only Category III Work Zone Devices, such as temporary concrete barriers, that have successfully met the performance evaluation guidelines set forth in *NCHRP Report 350* may be used on the National Highway System (NHS) for new installations.

BACKGROUND

The Georgia Department of Transportation (GaDOT) Temporary Concrete Barrier with pin and loop connection is widely used in the State of Georgia in work zone applications. This temporary barrier was successfully evaluated to the previous guidelines of *NCHRP Report 230*.[2] In order for GaDOT to continue use of the Georgia Temporary Concrete Barrier in new work zone sites, the barrier needed to be evaluated to the new guidelines of *NCHRP Report 350*.

OBJECTIVES/SCOPE OF RESEARCH

Two crash tests are required to evaluate temporary barriers, such as Georgia's Temporary Concrete Barrier with pin and loop connection, to *NCHRP Report 350* test level three (TL-3). *NCHRP Report 350* test designation 3-10 involves an 820 kg passenger vehicle impacting the critical impact point (CIP) of the length of need (LON) section at a nominal speed and angle of 100 km/h and 20 degrees. *NCHRP Report 350* test designation 3-11 involves a 2000 kg pickup truck impacting the CIP of the LON section at a nominal speed and angle of 100 km/h and 25 degrees.

The main objective of this study was to evaluate the performance of Georgia's Temporary Concrete Barrier according to *NCHRP Report 350*, and a secondary objective of this study was to obtain data that would be helpful in determining the length of barrier involved in a collision. To accomplish this, strains in the connecting loops at eight connections (four at the upstream end and four at the downstream end of the installation) were measured during the collision. A full-bridge set of strain gages were installed on the top loop and another on the bottom loop of each of the eight pin and loop connections, resulting in 16 channels of data. The barrier was placed, freestanding, on a concrete paved area with all slack removed at the connections.

NCHRP Report 350 test designation 3-11 with the 2000 kg pickup truck was performed on the Georgia Temporary Concrete Barrier. The pickup truck impacted the installation 1.2 m upstream of the joint between segments 7 and 8 while traveling at a speed of 99.9 km/h and 25.0 degrees. Strain gages were installed on the top and bottom loops at the joints between segments 1 and 2, 2 and 3, 3 and 4, and 4 and 5 on the upstream end and at the joints between segments 11 and 12, 12 and 13, 13 and 14, and 14 and 15 on the downstream end. The installation consisted of a total of 18 barrier segments.

Reported herein are the results of *NCHRP Report 350* test designation 3-11 on the Georgia DOT Temporary Concrete Barrier with pin and loop connection. Included in this report are the construction details of the barrier, results of the crash test including the strain measured at the connections mentioned previously, *NCHRP Report 350* evaluation of the barrier, and summary and conclusions.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809-hectare complex of research and training facilities situated 16 km northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for placing of the Georgia Temporary Concrete Barrier is along a wide expanse of concrete aprons which were originally used as parking aprons for military aircraft. These aprons consist of unreinforced jointed concrete pavement in 3.8 m by 4.6 m blocks (as shown in the adjacent photo) nominally 203-305 mm deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level. Eighteen segments of the barrier were placed, freestanding, on the concrete apron with all slack removed at the connections.

Test Article – Design and Construction

The Georgia Temporary Concrete Barrier is an 810-mm height Jersey Shape portable concrete barrier (PCB). TTI received a draft construction drawing from Georgia Department of Transportation entitled, "Standard Details of Precast Temporary Barriers (Metric), Number 4961." This drawing provided details for construction of the PCB and information on connecting the barriers and is shown as figure 1 of this report.

Based on information from the construction drawing, each barrier is 3.0 meters in length and 810 mm in height. The bottom of the barrier is 760 mm wide with a 75 mm by 254 mm wide recess. The recess is located along the centerline of the barrier and runs along the entire length of the barrier. From the bottom of the barrier, upward, the width tapers to 400 mm wide at 330 mm above the base of the barrier. The barrier tapers to 300 mm wide at the top.

Reinforcement in each barrier consists of six longitudinal number 13 Bars with three bars located on each face of the barrier. Eleven V-shaped number 13 Bars are present in each barrier

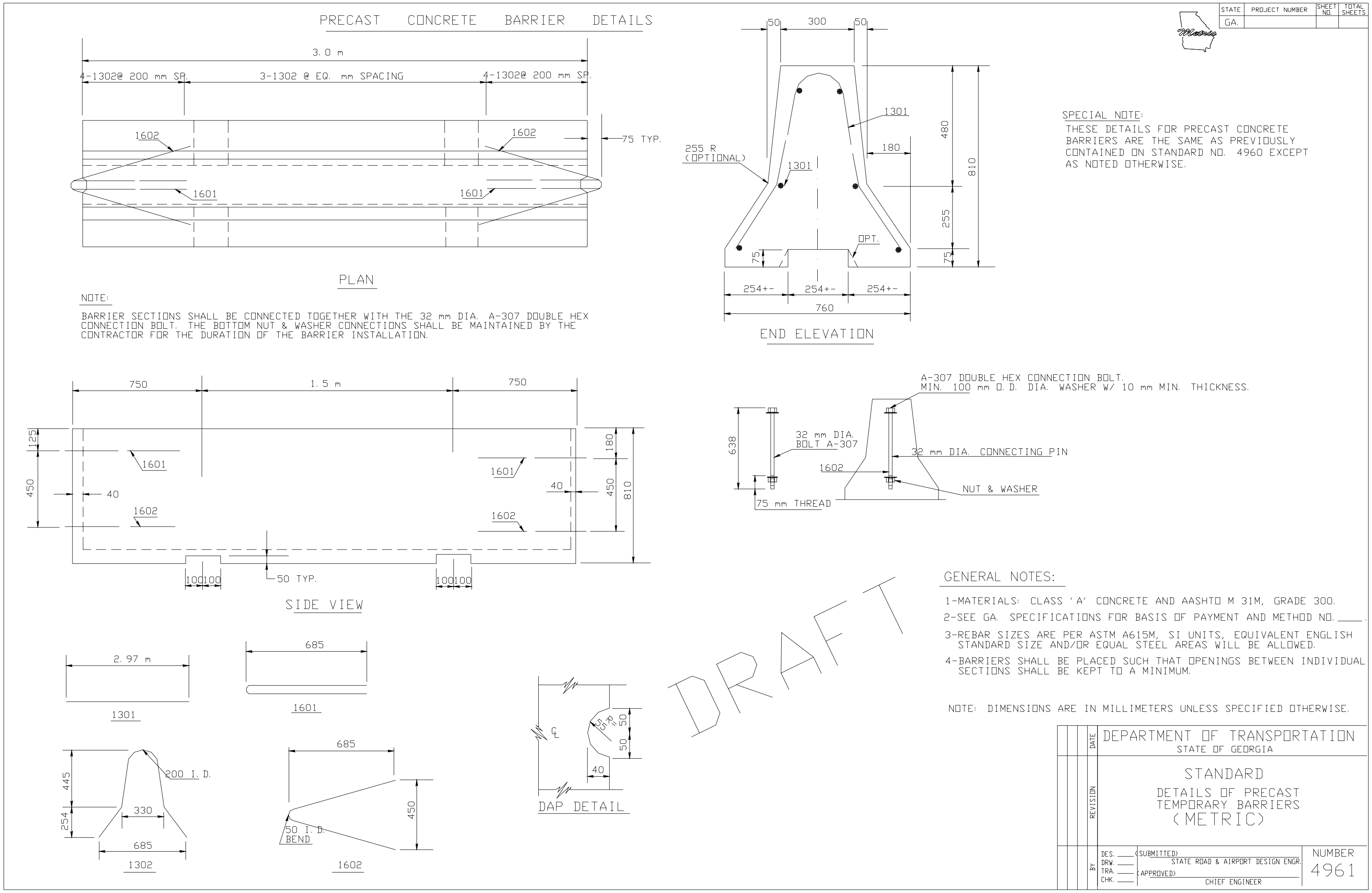


Figure 1. Details of the Georgia Temporary Barrier with pin and loop connection.

with four bars on each end of the barrier spaced at 200 mm on centers with an end cover of 40 mm. Three bars are evenly spaced in the interior of each barrier. A V-shaped and a U-shaped number 16 connection bar extend 75 mm beyond the ends on each barrier and serve as the connection between the barriers. The barriers are connected by aligning the connection bars and inserting a 638 mm long, 32 mm diameter A-307 double hex connection bolt through the bars. A heavy hex nut and washers were used for each connection bolt.

The test installation consisted of 18 barriers connected together for a total test installation length of approximately 55.3 m. This total length includes a joint width of approximately 75-mm at each connection. The barriers were placed on the existing concrete runway located at the TTI test facility. The layout of the barriers is shown in figure 2 and photographs of the completed installation are shown in figure 3.

Strain gages were located on the connecting “loop” bars for barriers 2, 4, 12, and 14. A total of 8 joints was instrumented. These strain gages were used to measure the tensile strains in the connecting bars during impact.

Electronic Instrumentation

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented in appendix A.

In addition to the usual *NCHRP Report 350* instrumentation, strains in the steel connecting loops of the barriers were measured at eight connections (four at the upstream end and four at the downstream end of the installation) to obtain data that would be helpful in determining the length of barrier involved during the collision. A strain gage rosette was installed on the top loop and another on the bottom loop of each the eight pin and loop connections designated in figure 2. This resulted in 16 channels of data that were digitized and recorded on computer disk during the impact.

Precision metal-foil strain gages, from Micro-Measurements, designed for stress analysis applications, were used on the #16 rebar connection loops. In order to provide proper adhesive bonding of the gages to the steel, the rebar was ground smooth on the top and bottom of each instrumented loop, within 25-50 mm from the concrete. This reduced the average diameter of the bars from 16 mm to about 14 mm. This reduction in area was not a concern for these joints due to the location being a significant distance away from the impact area. A photograph of an installed gage is shown in figure 4. After gage bonding, the gages on each loop were wired and the lead wires were added, and terminated at the top of the barrier into a screw terminal strip. The gages and lead wires were then sealed with epoxy and mastic tape for weatherproofing.

Each of the 16 instrumented loops were physically calibrated to produce a force versus microstrain curve. This was done with a precision load cell attached between the rebar loop and

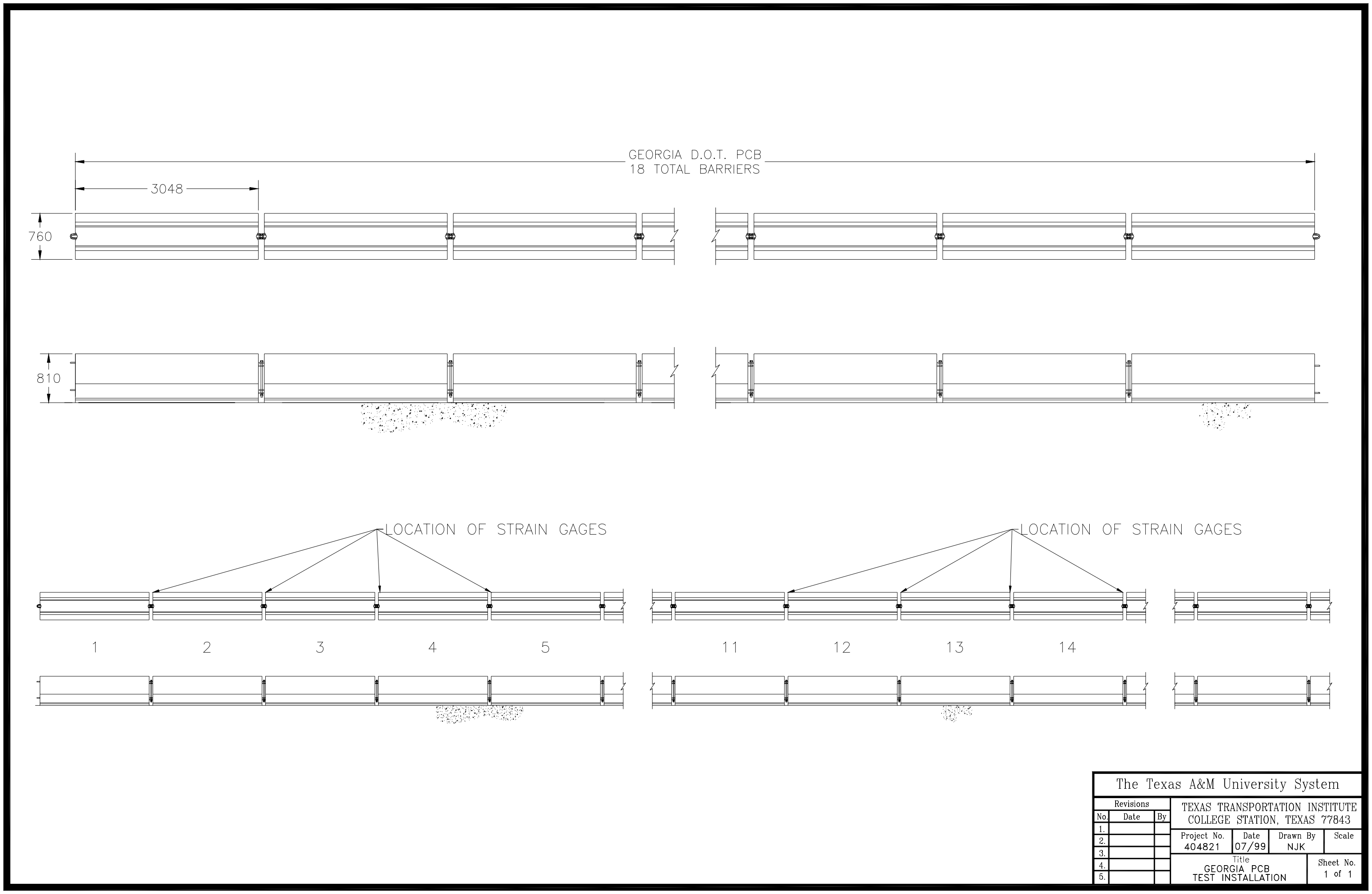


Figure 2. Layout of test installation.

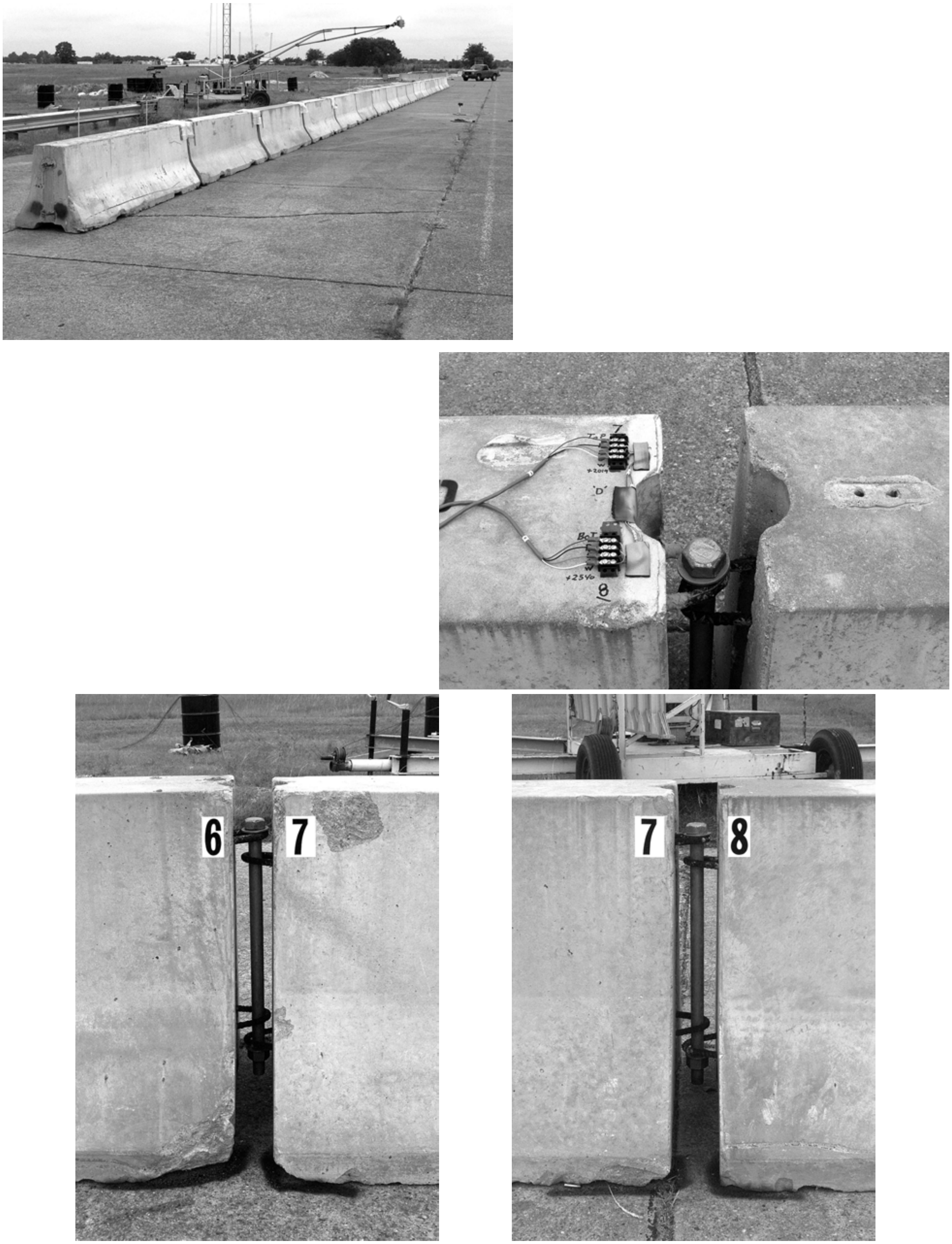


Figure 3. Georgia Temporary Concrete Barrier prior to testing.

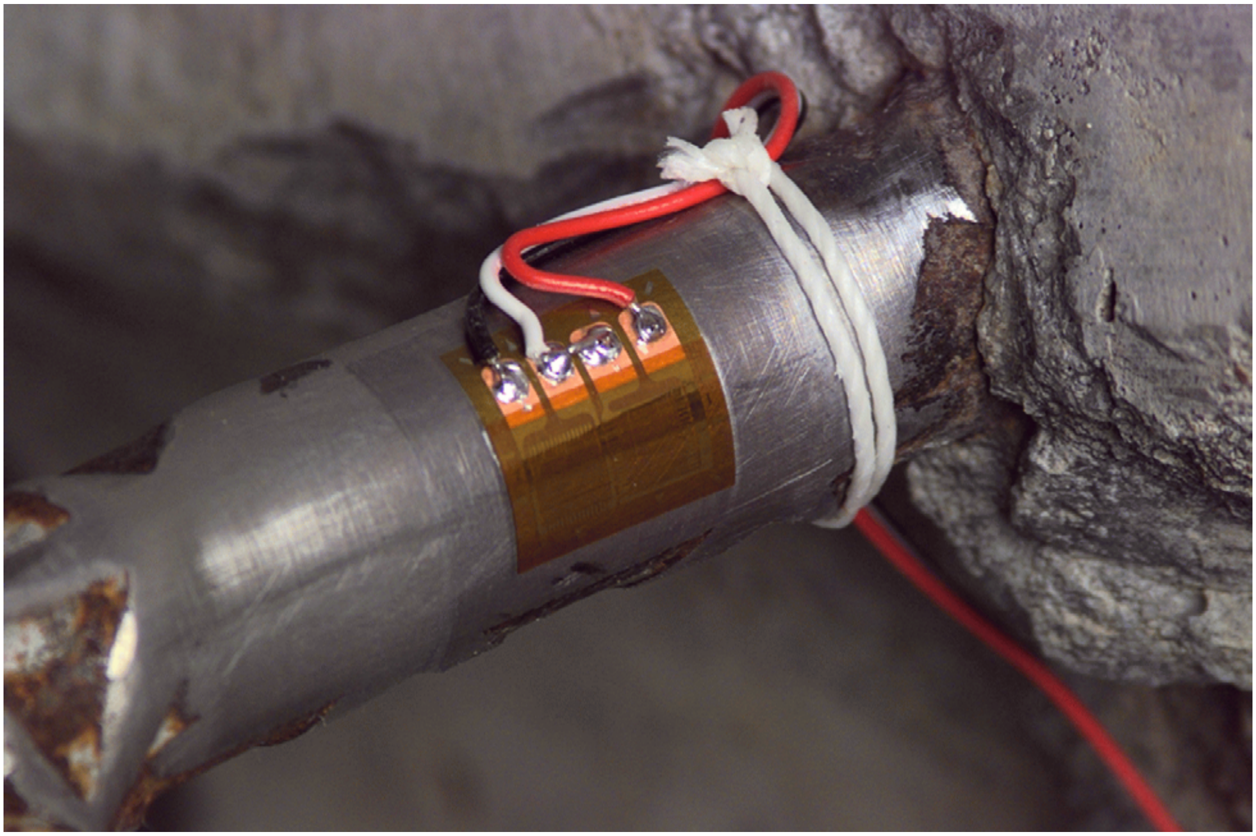


Figure 4. Typical strain gage installation used in test 404821-1.

a winch. Several readings of force and microstrain were made as the pull was increased to near 4448 Newtons (1000 lb). These results were then applied to the field calibration the day of the test to scale the readings to pounds force on each loop.

Sixty meters of instrumentation cable connected each of the 16 gaged loops to the Vishay strain gage amplifiers in a nearby van. The output of the amplifier fed a 16 channel low pass filter set to 350 Hz each. These data were then sent to a 16 channel analog to digital (A/D) converter inside a Pentium computer. This device reads and records the value of each channel, 2000 times a second. Recording was started by the vehicle running over a pressure switch, 4.5 m prior to impact. Once started, the digitizer continued to record values at this rate for one and a half seconds producing 48,000 values total or 3,000 per channel. Once on disk, the data were subsequently imported to an Excel spreadsheet for analysis.

Identification of each of the instrumented joints was by means of a letter plus (top or bottom). The following describes the location of these joints.

Upstream:	Downstream:
A – between barriers 1 and 2	E – between barriers 11 and 12
B – between barriers 2 and 3	F – between barriers 12 and 13
C – between barriers 3 and 4	G – between barriers 13 and 14
D – between barriers 4 and 5	H – between barriers 14 and 15

Test Conditions

According to *NCHRP Report 350*, two tests are required to evaluate longitudinal barriers to test level three (TL-3) and are as described below.

***NCHRP Report 350* test designation 3-10**: This test involves an 820 kg passenger vehicle (820C) impacting critical impact point (CIP) of the length-of-need (LON) of the barrier at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this test is to evaluate the overall performance of the LON section, in general, and occupant risk, in particular.

***NCHRP Report 350* test designation 3-11**: The test involves a 2000 kg pickup truck (2000P) impacting the CIP of the LON of the barrier at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 2000P vehicle.

The test performed on the Georgia Temporary Barrier and reported herein corresponds to *NCHRP Report 350* test designation 3-11. The CIP was determined using procedures recommended in *NCHRP Report 350*, and was determined to be 1.2 m upstream of the joint near the one-third point of the installation, which in this case was the joint between segments 7 and 8.

Evaluation Criteria

The crash test performed was evaluated in accordance with the criteria presented in *NCHRP Report 350*. As stated in *NCHRP Report 350*, "Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, the following safety evaluation criteria from table 5.1 of *NCHRP Report 350* were used to evaluate the crash test reported herein:

- **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.*

- **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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*

  F. *The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.*

- **Vehicle Trajectory**

  K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

  L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.*

  M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

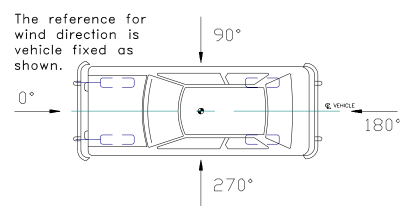
CRASH TEST 404821-1 (*NCHRP REPORT 350* TEST 3-11)

Test Vehicle

A 1996 Chevrolet 2500 pickup truck, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The height to the lower edge of the vehicle front bumper was 430 mm and to the upper edge of the front bumper was 650 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 14. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The crash test was performed the morning of June 22, 1999. Five days prior to the test 8 mm of rainfall was recorded. No other rainfall of significance was recorded for the remaining ten days prior to the test. Weather conditions at the time of testing were as follows: wind speed: 11 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 29 EC; relative humidity: 69 percent.



Impact Description

The 2000 kg pickup truck, while traveling at a speed of 99.9 km/h, impacted the Georgia Temporary Concrete Barriers 1.2 m upstream of the connection of segments 7 and 8 at an impact angle of 25.6 degrees. Shortly after impact the left front tire rode up the face of the concrete barrier and at 0.020 s segment 6 moved rearward at the connection to segment 7. At 0.021 s the tire deflated and at 0.034 s the vehicle began to redirect and segment 7 moved rearward at the connection to segment 6. Segment 8 moved toward traffic lanes at the connection with segment 7 at 0.064 s, and the right front tire lost contact with the ground at 0.120 s. At 0.125 s segment 5 moved toward traffic lanes at the connection with segment 6, at 0.138 s segment 8 moved rearward at the connection to segment 7, at 0.167 s segment 9 moved toward traffic lanes at the connection with segment 8, and at 01.77 s segment 5 moved rearward at the connection with segment 6. At 0.207 s the vehicle was traveling parallel with the barriers at a speed of 73.1 km/h. The rear of the vehicle contacted the concrete barriers at 0.275 s and the left rear tire lost contact with the ground at 0.282 s. At 0.303 s the right rear tire lost contact with the ground and by 0.317 s the vehicle was over the connection at segments 8 and 9. The lower connection loop on segment 6 ruptured at 0.465 s. At 0.527 s the vehicle lost contact with the barriers and was traveling at a speed of 80.2 km/h and an exit angle of 19.4 degrees. The right front tire returned to the ground at 0.642 s and the left rear tire contacted the top of the concrete barrier at 0.889 s.

Figure 5. Vehicle/installation geometrics for test 404821-1.

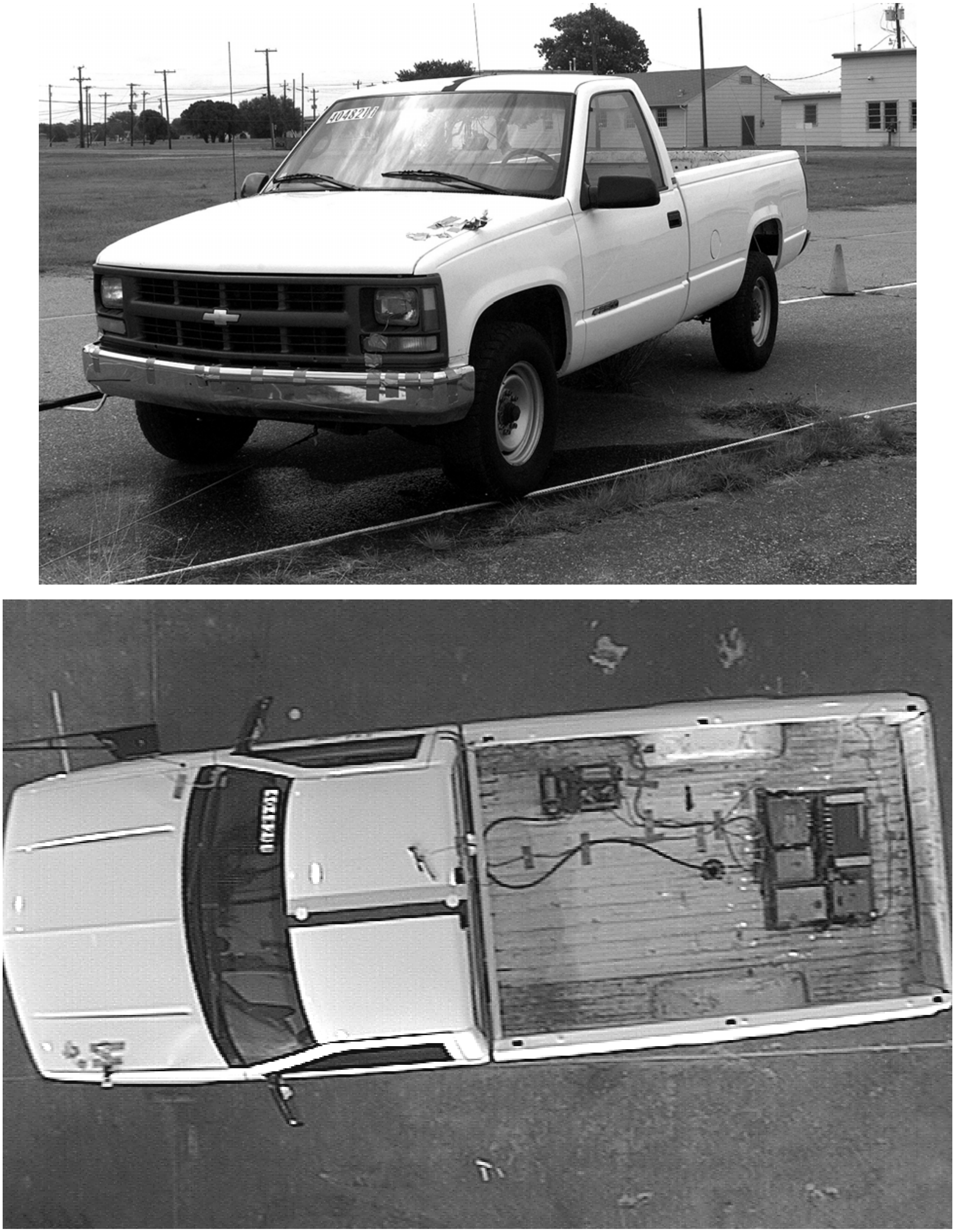


Figure 6. Vehicle before test 404821-1.

At 0.990 s the outer rim of the left rear wheel separated from the inner rim section. By 1.793 s all four wheels returned to the ground. Brakes on the vehicle were applied at 2.46 s. The vehicle yawed clockwise and subsequently came to rest 73.2 m down from impact and 9.1 m toward traffic lanes. Sequential photographs of the test period are shown in appendix C, figures 15 and 16.

Damage to Test Article

As can be seen in figures 7 through 10, the Georgia Temporary Concrete Barrier installation pulled apart at the connection of segments 6 and 7. The pin was deformed and the lower loop on segment 6 ruptured. At the connection of 7 and 8, the pin was deformed and pulled out of the upper loop on segment 7. The pins at the connections of 8 and 9, 9 and 10, and 10 and 11 were slightly deformed and the pin pulled out of the top loop of segment 11. Tire marks marred the face of segments 6 through 8 and the concrete was spalled at the lower edges near the pavement and along the edges at the joints. Segment 1 moved slightly on the end connected to segment 2 and segments 2 through 11 moved as shown in table 1. Maximum lateral movement of the barriers was 1.88 m at the connection of segments 8 and 9. The total length of contact of the vehicle with the barriers was 4.32 m.

As stated previously, a set of strain gages was installed on the top loop and another on the bottom loop of each the eight pin and loop connections as designated in figure 2. Each of the 16 instrumented loops were physically calibrated to produce a force versus microstrain curve. This was done with a precision load cell attached between the rebar loop and a winch. Several readings of force and microstrain were made as the pull was increased to near 4448 N. These results were then applied to the field calibration the day of the test to scale the readings to Newtons on each loop.

Graphs of forces computed from the readings made during the test are shown in appendix D, figures 17 through 24. As seen in these graphs, the top loops experienced most of the strain during the collision period. Maximum force experienced on the top loops on the upstream end was 42296 N at 0.120 s at the connection of segments 4 and 5 while only a maximum of 12868 N at 0.193 s occurred in the top loops at the connection of segments 1 and 2. On the top loops on the end downstream of impact a maximum force of 53754 N at 0.312 s occurred at the connection of segments 11 and 12 and a maximum of 18179 N at 0.364 s occurred at the connection of segments 14 and 15.

Vehicle Damage

Damage sustained by the vehicle is shown in figure 11. Structural damage to the left frame rail, left upper and lower A-arm, and left outer tie rod occurred. The outer sections of the wheel rims on the left side front and rear wheels separated at the welds. The front bumper, grill,

Figure 7. Vehicle trajectory path after test 404821-1.

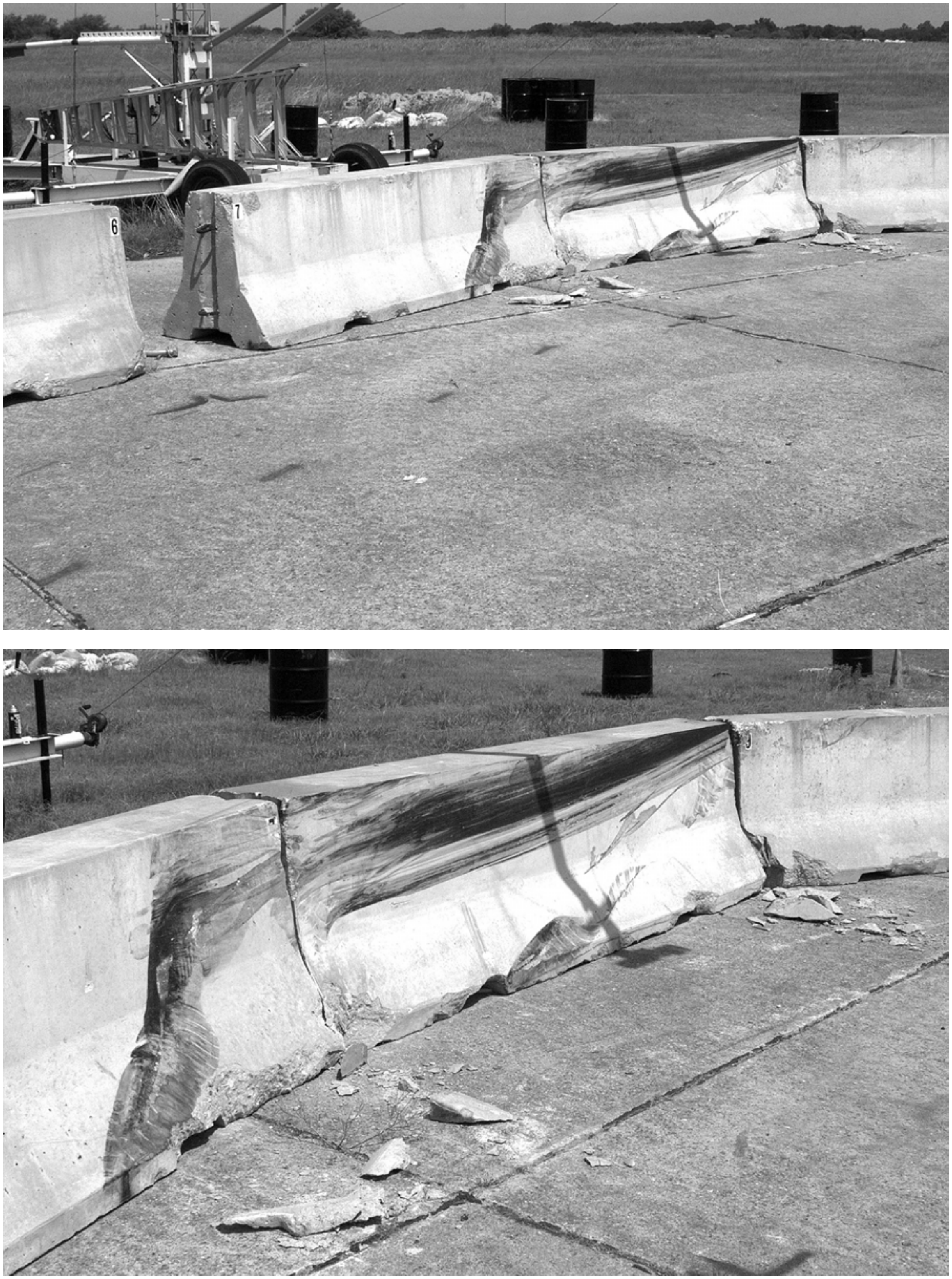


Figure 8. Installation after test 404821-1.

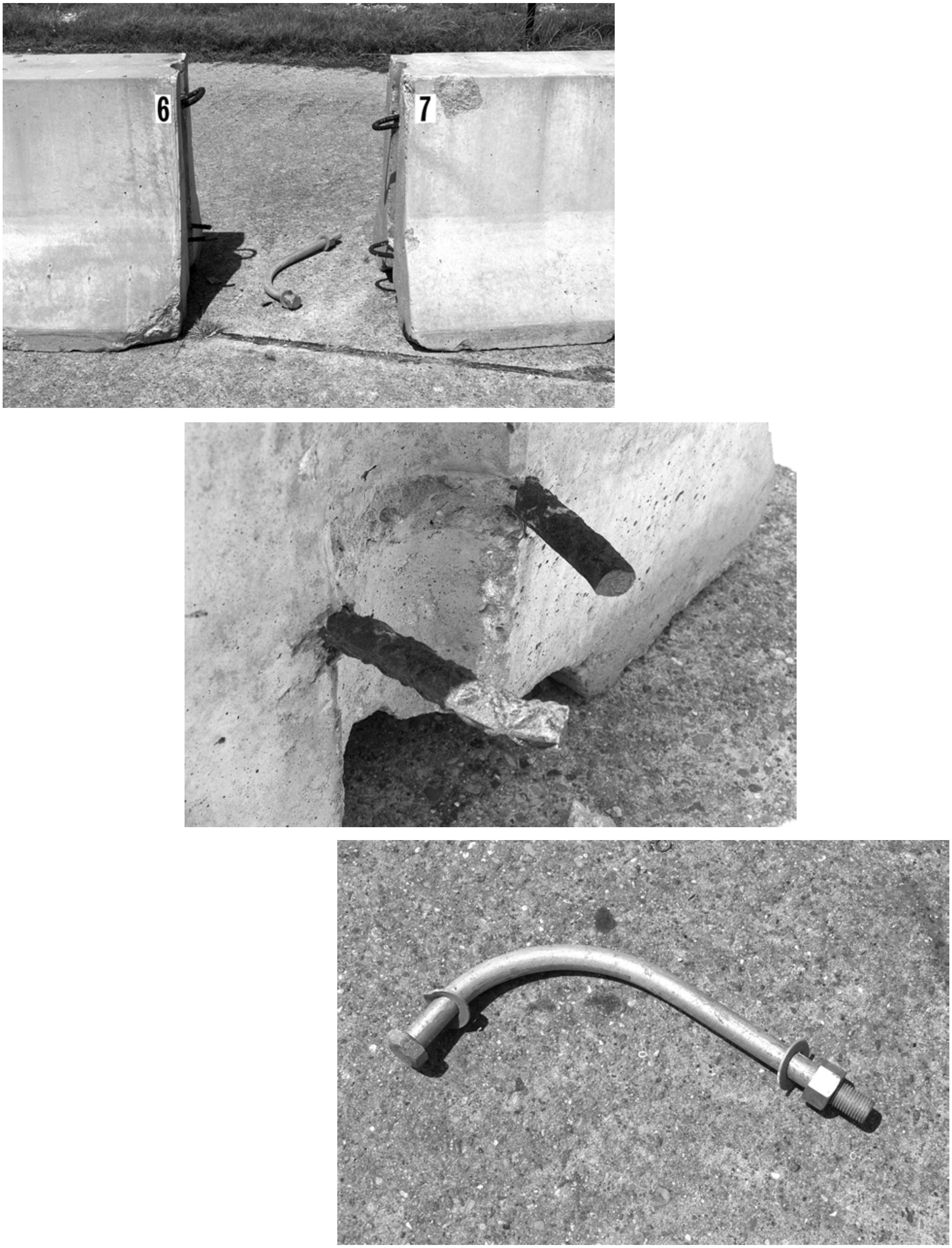


Figure 9. Damage at connection of segments 6 and 7.

Figure 10. Damage at connection of segments 7 and 8.

Table 1. Movement of barriers during test 404821-1.

@ Connection	Separation before	Separation after	Movement
1-2	95 mm	100 mm	2 mm rwd*
2-3	91 mm	95 mm	3 mm rwd
3-4	91 mm	100 mm	15 mm rwd
4-5	98 mm	131 mm	10 mm fwd**
5-6	89 mm	690 mm	75 mm fwd
6-7	88 mm	110 mm	760 mm rwd
7-8	98 mm	180 mm	1625 mm rwd
8-9	93 mm	66 mm	1880 mm rwd
9-10	86 mm	142 mm	810 mm rwd
10-11	94 mm	85 mm	90 mm fwd
11-12	87 mm	90 mm	0
12-13	86 mm	97 mm	0
13-14	95 mm	95 mm	0
14-15	95 mm	95 mm	0
15-16	90 mm	90 mm	0
16-17	96 mm	96 mm	0
17-18	77 mm	77 mm	0

* rwd = rearward movement of the segment
** fwd = forward movement of the segment

Figure 11. Vehicle after test 404821-1.

left front headlight, left front quarter panel, left door and left rear bed also were damaged. Maximum exterior crush to the vehicle was 350 mm to the front left side at bumper height. The floor pan was deformed with maximum occupant compartment deformation of 42 mm (3 percent reduction of space) on the left side of the floor pan/firewall area. The interior of the vehicle is shown in figure 12. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 3 and 4.

Occupant Risk Factors

Data from the tri-axial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. The occupant impact velocity and ridedown accelerations in the longitudinal axis only are required from these data for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 6.5 m/s at 0.172 s, maximum 0.010-s ridedown acceleration was -5.9 g's from 0.328 to 0.338 s, and the maximum 0.050-s average was -6.8 g's between 0.047 and 0.097 s. In the lateral direction, the occupant impact velocity was 5.9 m/s at 0.110 s, the highest 0.010-s occupant ridedown acceleration was 7.4 g's from 0.113 to 0.123 s, and the maximum 0.050-s average was 9.1 g's between 0.036 and 0.086 s. These data and other information pertinent to the test are presented in figure 13. Vehicle angular displacements and accelerations versus time traces are shown in appendix E, figures 25 through 28.

Assessment of Test Results

As stated previously, the following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **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 Georgia Temporary Concrete Barrier contained and redirected the 2000 kg pickup truck. The connection at segments 6 and 7 ruptured; however, impact occurred at 1.2 m upstream of the connection at segments 7 and 8, therefore the vehicle did not penetrate the installation. The vehicle did not underride or override the installation. Maximum movement of the barrier was 1.88 m.

Before test

After test

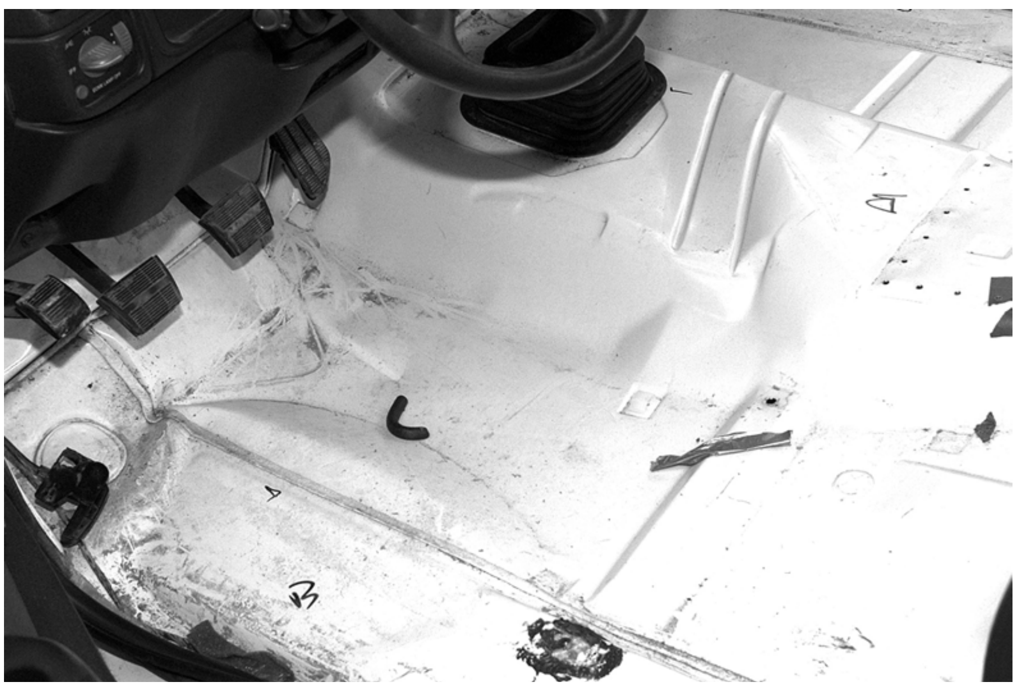
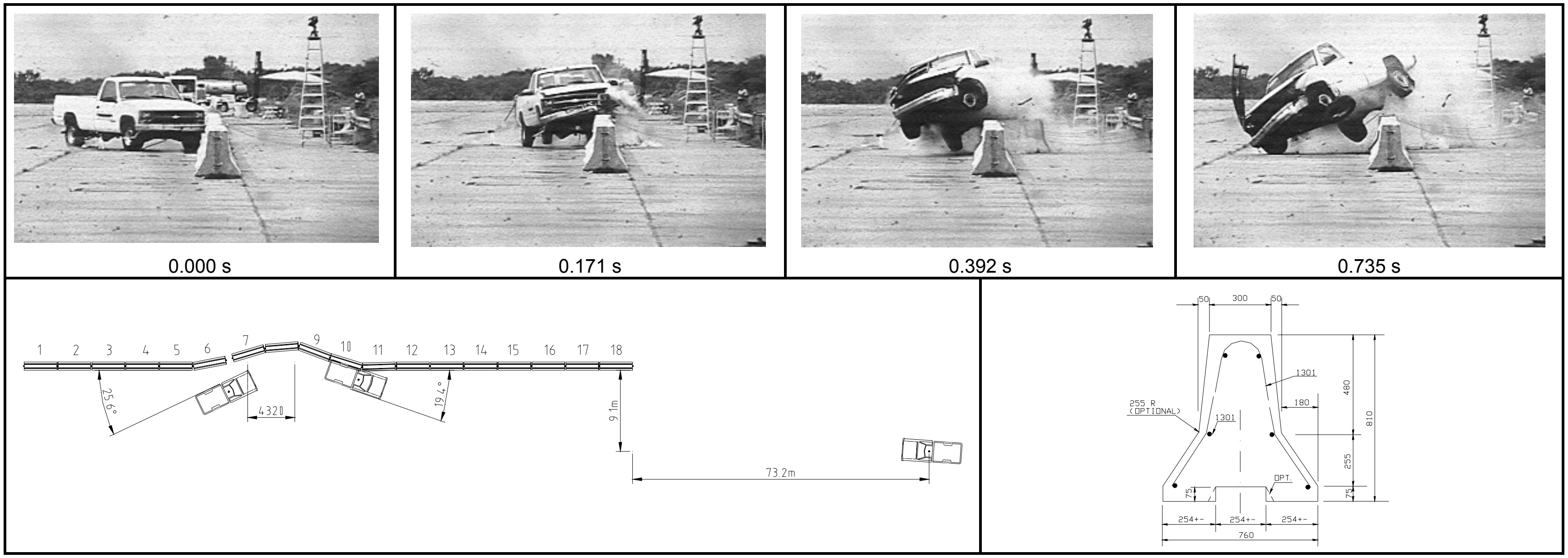


Figure 12. Interior of vehicle for test 404821-1.



General Information

Test Agency	Texas Transportation Institute
Test No.	404821-1
Date	06/22/99
Test Article	
Type	Portable Concrete Barrier
Name	Georgia Temporary Concrete Barrier
Installation Length (m)	54.9
Material or Key Elements	3 m long, 810 mm tall segments Jersey Shaped Concrete Barrier
Soil Type and Condition	Concrete Pavement, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1996 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	2120
Test Inertial	2000
Dummy	No Dummy
Gross Static	2000

Impact Conditions

Speed (km/h)	99.9
Angle (deg)	25.6
Exit Conditions	
Speed (km/h)	80.2
Angle (deg)	19.4
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.5
y-direction	5.9
THIV (km/h)	26.0
Ridedown Accelerations (g's)	
x-direction	-5.9
y-direction	7.4
PHD (g's)	9.6
ASI	1.15
Max. 0.050-s Average (g's)	
x-direction	-6.8
y-direction	9.1
z-direction	-4.0

Test Article Deflections (m)

Dynamic	1.93
Permanent	1.88
Vehicle Damage	
Exterior	
VDS	11LFQ5
CDC	11FLEK3 & 11LYEW3
Maximum Exterior Vehicle Crush (mm)	350
Interior	
OCDI	LF0111000
Max. Occ. Compart. Deformation (mm)	42
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	71
Max. Pitch Angle (deg)	9
Max. Roll Angle (deg)	38

Figure 13. Summary of results for test 404821-1, *NCHRP Report 350* test 3-11.

- **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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*

The detached pin and segments did not penetrate nor show potential for penetrating the occupant compartment, not to present undue hazard to others in the area. Maximum occupant compartment deformation was 42 mm (3 percent reduction of space) in the firewall/floor pan area and was judged to not cause serious injury.

F. *The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.*

The vehicle remained upright during and after the collision.

- **Vehicle Trajectory**

K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

The vehicle may intrude into adjacent traffic lanes as it came to rest 9.1 m toward traffic lanes.

L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.*

Longitudinal occupant impact velocity was 6.5 m/s and longitudinal ridedown acceleration was -5.9 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

Exit angle at loss of contact was 19.4 degrees, which was 76 percent of the impact angle.

SUMMARY AND CONCLUSIONS

SUMMARY OF FINDINGS

The Georgia Temporary Concrete Barrier contained and redirected the 2000 kg pickup truck. The connection at segments 6 and 7 ruptured; however, impact occurred at 1.2 m upstream of the connection at segments 7 and 8, therefore the vehicle did not penetrate the installation. The vehicle did not underride or override the installation. Maximum movement of the barrier was 1.88 m. The detached pin and segments did not penetrate nor show potential for penetrating the occupant compartment, not to present undue hazard to others in the area. Maximum occupant compartment deformation was 42 mm (3 percent reduction of space) in the firewall/floor pan area and was judged to not cause serious injury. The vehicle remained upright during and after the collision. The vehicle may intrude into adjacent traffic lanes as it came to rest 9.1 m toward traffic lanes. Longitudinal occupant impact velocity was 6.5 m/s and longitudinal ridedown acceleration was -5.9 g's. Exit angle at loss of contact was 19.4 degrees, which was 76 percent of the impact angle.

As stated previously, a set of strain gages was installed on the top loop and another on the bottom loop of each the eight pin and loop connections as designated in figure 2. The graphs of the readings from these strain gages are shown in appendix D. As seen in these graphs, the top loops experienced most of the strain during the collision period. Maximum force experienced on the top loops on the upstream end was 42296 N at 0.120 s at the connection of segments 4 and 5 while only a maximum of 12868 N at 0.193 s occurred at the connection of segments 1 and 2. On the top loops on the end downstream of impact a maximum force of 53754 N at 0.312 s occurred at the connection of segments 11 and 12 and a maximum of 18179 N at 0.364 s occurred at the connection of segments 14 and 15.

CONCLUSIONS

As shown in table 2, the Georgia Temporary Concrete Barriers with pin and loop connection met the required criteria for *NCHRP Report 350* test designation 3-11.

Table 2. Performance evaluation summary for test 404821-1, *NCHRP Report 350* test 3-11.

Test Agency: Texas Transportation Institute	Test No.: 404821-1	Test Date: 06/22/99
***NCHRP Report 350* 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 Georgia Temporary Concrete Barrier contained and redirected the 2000 kg pickup truck. The vehicle did not penetrate, underride, or override the installation. Maximum movement of the barrier was 1.88 m.	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 of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	The detached pin and segments did not penetrate nor show potential for penetrating the occupant compartment, not to present undue hazard to others in the area. Maximum occupant compartment deformation was 42 mm (3 percent reduction of space) in the firewall/floor pan area and was judged to not cause serious injury.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision.	Pass
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle may intrude into adjacent traffic lanes as it came to rest 9.1 m toward traffic lanes.	Fail*
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal occupant impact velocity = 6.5 m/s Longitudinal ridedown acceleration = -5.9 g's.	Pass
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.	Exit angle at loss of contact was 19.4 degrees, which was 76 percent of the impact angle.	Fail*

*Criterion K and M are preferable, not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer near the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Rate of turn transducers are solid state, gas flow units designed for high g service. Signal conditioners and amplifiers in the test vehicle increase the low level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15 channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals, from the test vehicle, are recorded minutes before the test and also immediately afterwards. A crystal controlled time reference signal is simultaneously recorded with the data. Pressure-sensitive switches on the bumper of the impacting vehicle are actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an "event" mark on the data record to establish the exact instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received at the data acquisition station, and demultiplexed onto separate tracks of a 28 track, (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine, filtered with Society of Automotive Engineers (SAE J211) filters, and digitized using a microcomputer, at 2000 samples per second per channel, for analysis and evaluation of impact performance.

All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of an ENDEVCO 2901, precision primary vibration standard. This device along with its support instruments is returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations will be made at any time a data channel is suspected of any anomalies.

The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (Excel).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0005-s intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

Use of a dummy in the 2000P vehicle is optional according to *NCHRP Report 350* and there was no dummy used in the test with the 2000P vehicle.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement and angular data. A BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2 to 1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

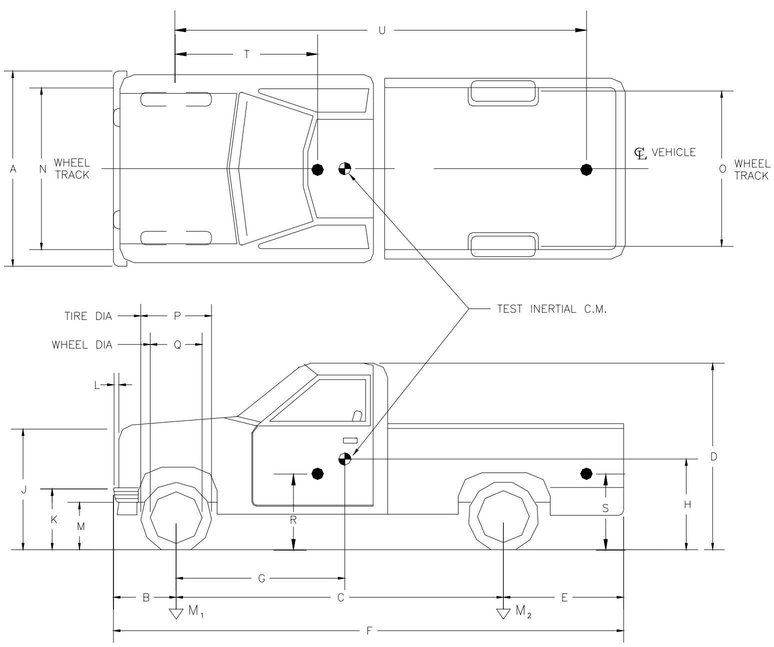
DATE: 06/22/99 TEST NO.: 404821-1 VIN NO.: 1GCGC24R6TF171854

YEAR: 1996 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 135341 TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 553 RF 539 LR 455 RR 454

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: R-100mmTOLT

ENGINE TYPE: ______

ENGINE CID: ______

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

8 LUGS

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1860	E	1310	J	1070	N	1610	R	710
B	780	F	5440	K	650	O	1620	S	910
C	3350	G	1520.9	L	60	P	760	T	1480
D	1860	H		M	430	Q	445	U	3970

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1214	1092	
M_2	916	908	
M_T	2120	2000	

Figure 14. Vehicle properties for test 404821-1.

Table 3. Exterior crush measurements for test 404821-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ________	Bowing: B1 ____ X1 ____
Corner shift: A1 ________	B2 ____ X2 ____
A2 ________	
End shift at frame (CDC) (check one) < 4 inches ________ $ 4 inches ________	Bowing constant X1 % X2 , 2 _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	Front bumper	740	350	580	350	290	200	120	80	30	-290
2	720 mm above ground	740	340		340	310	N/A	N/A	40	0	+1670
							Fender Well				

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

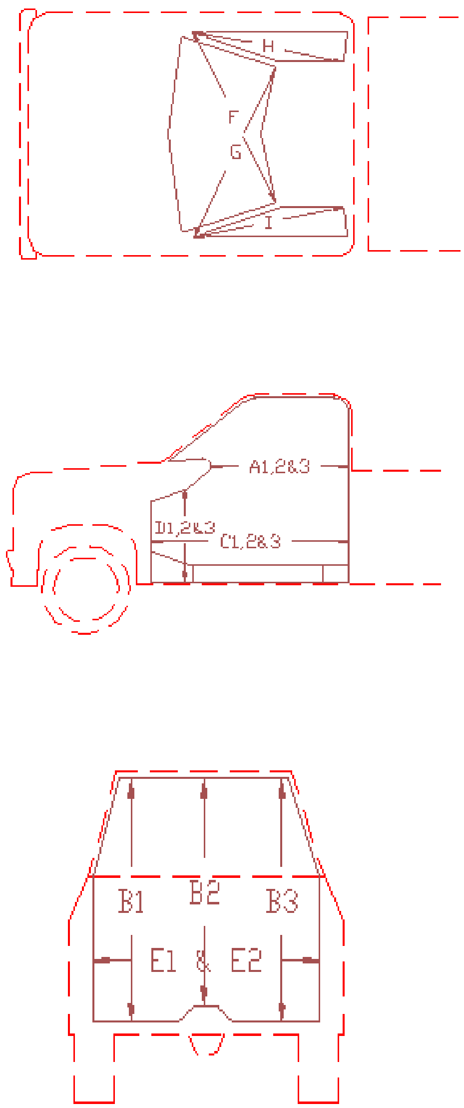
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.
Note: Use as many lines/columns as necessary to describe each damage profile.

Table 4. Occupant compartment measurements for test 404821-1.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	908	905
A2	930	935
A3	940	940
B1	1091	1056
B2	1075	1154
B3	1077	1077
C1	1372	1330
C2	1256	1250
C3	1370	1370
D1	315	311
D2	161	152
D3	314	314
E1	1591	1600
E2	1600	1608
F	1470	1470
G	1470	1470
H	1000	1000
I	1000	1000
J	1527	1500

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

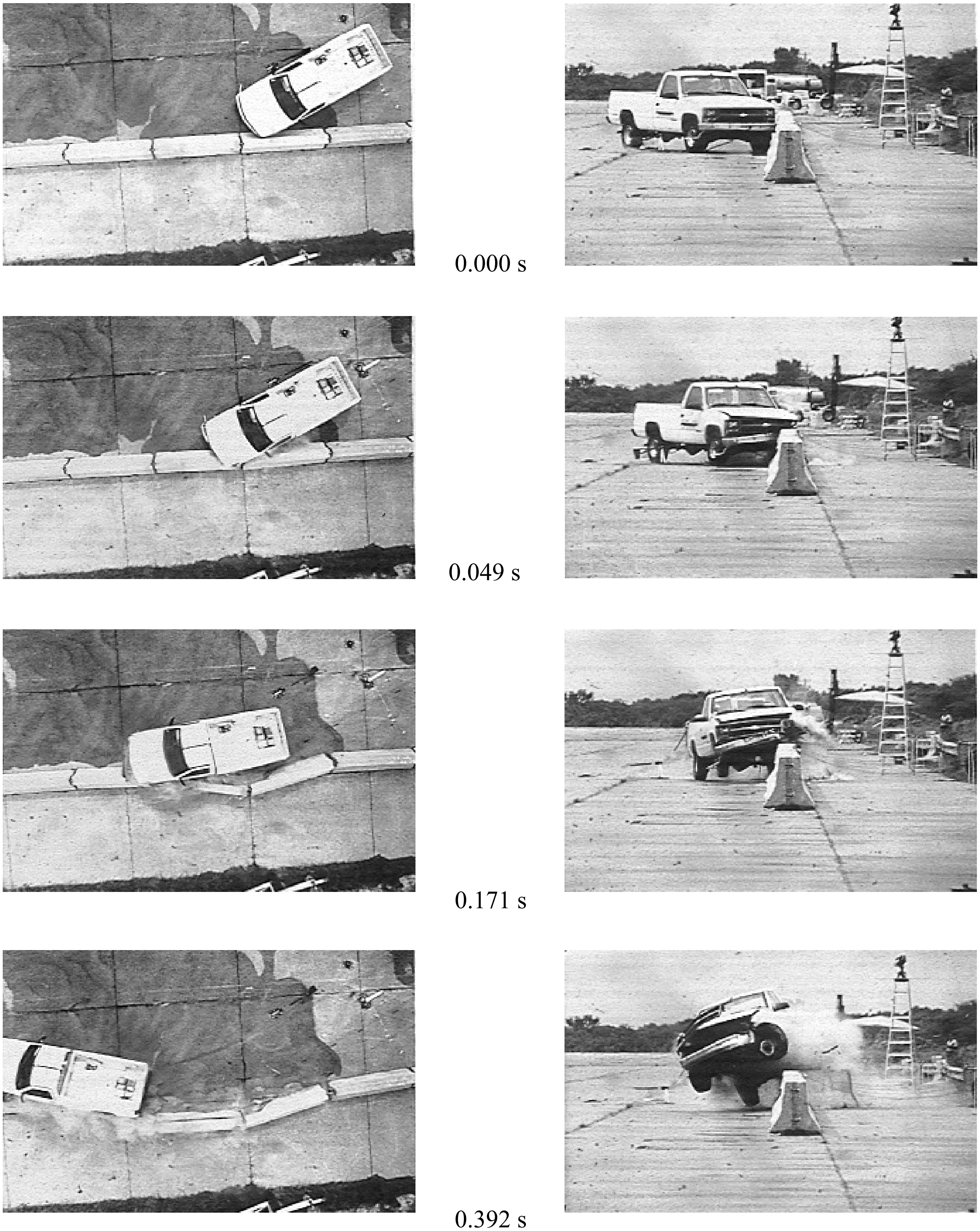
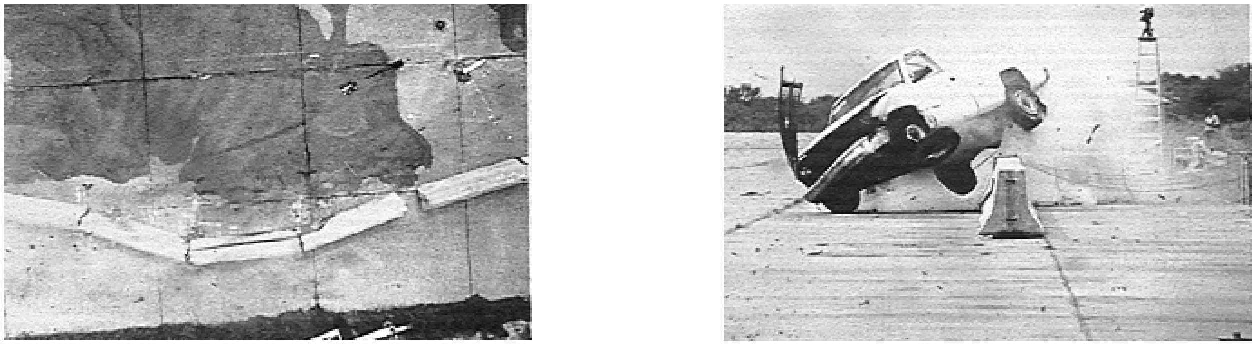
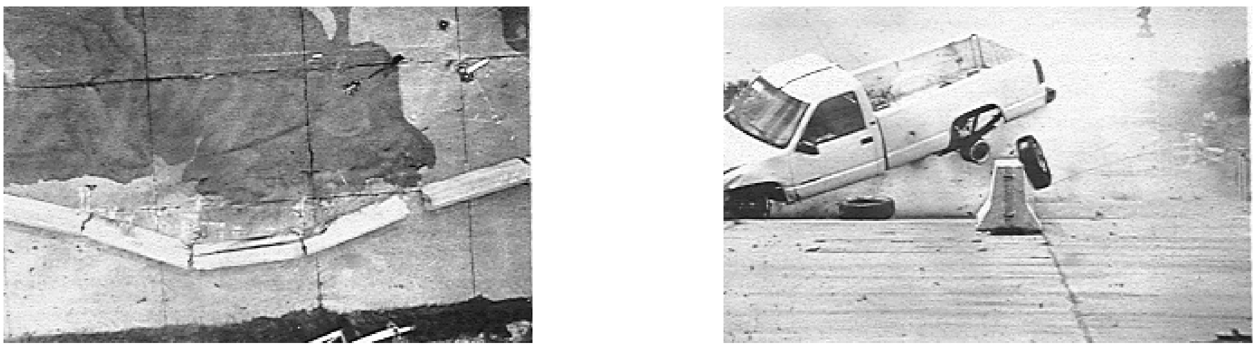


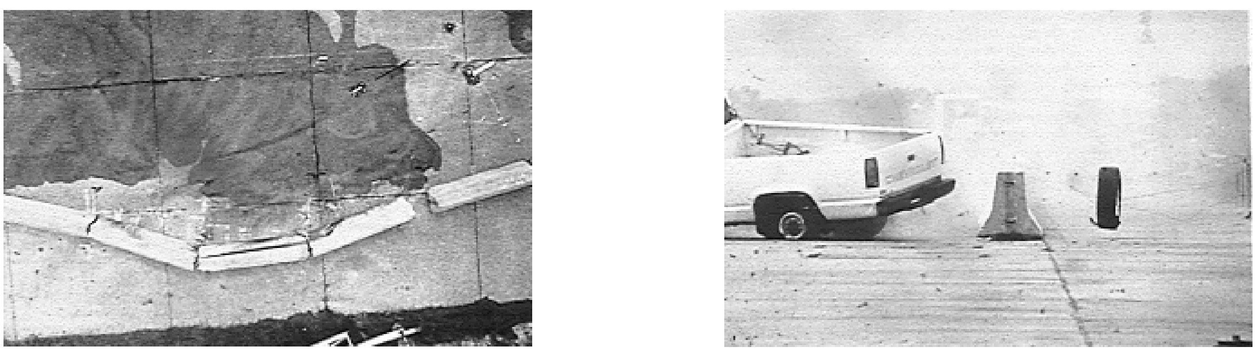
Figure 15. Sequential photographs for test 404821-1
(overhead and frontal views).



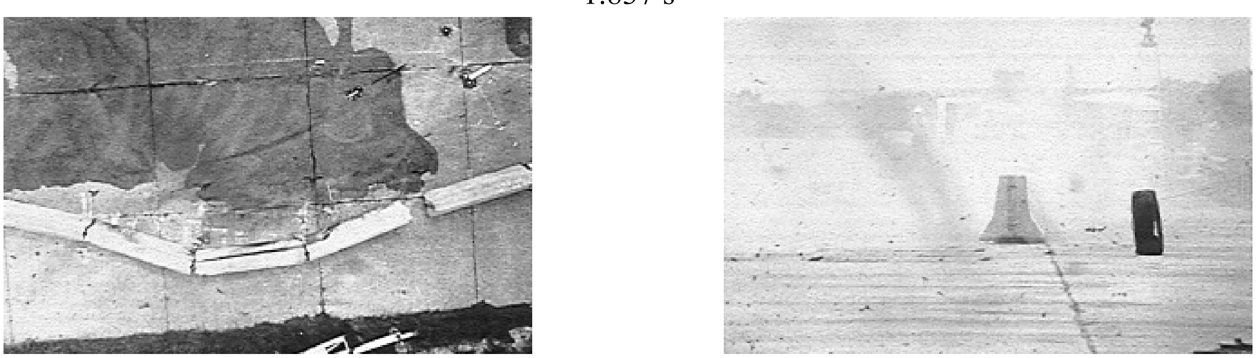
0.735 s



1.225 s

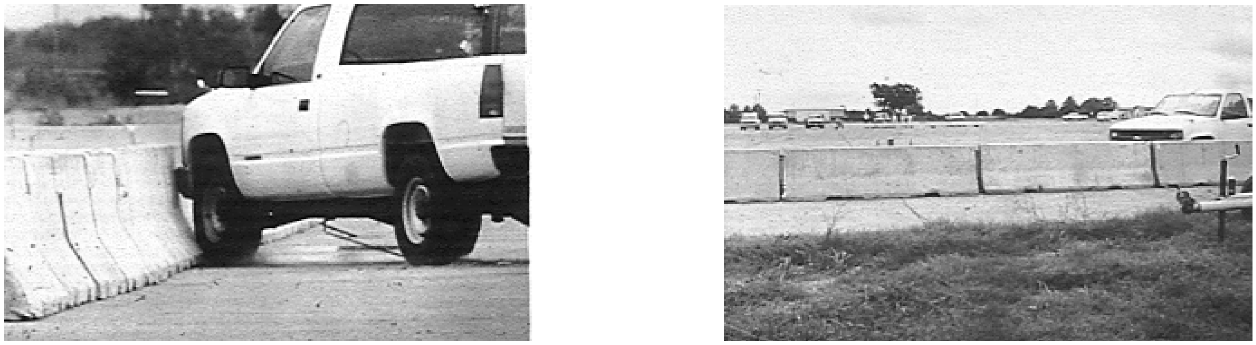


1.837 s

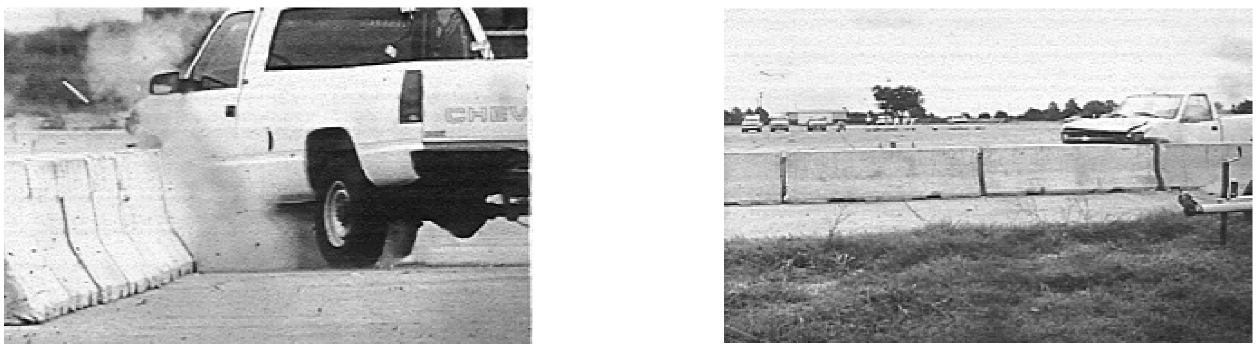


2.450 s

Figure 15. Sequential photographs for test 404821-1
(overhead and frontal views) (continued).

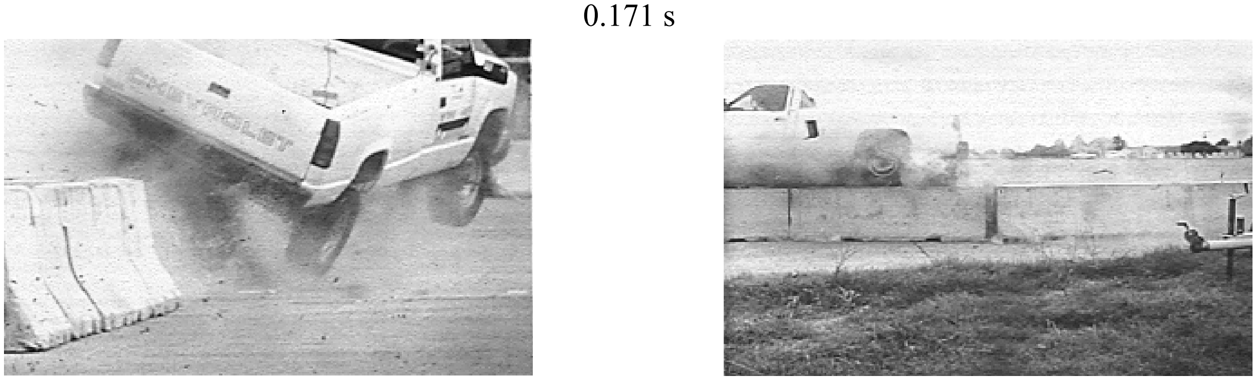


0.000 s



0.049 s

0.171 s



0.392 s

Figure 16. Sequential photographs for test 404821-1
(rear views).

0.735 s

1.225 s

1.837 s

2.450 s

Figure 16. Sequential photographs for test 404821-1
(rear views) (continued).

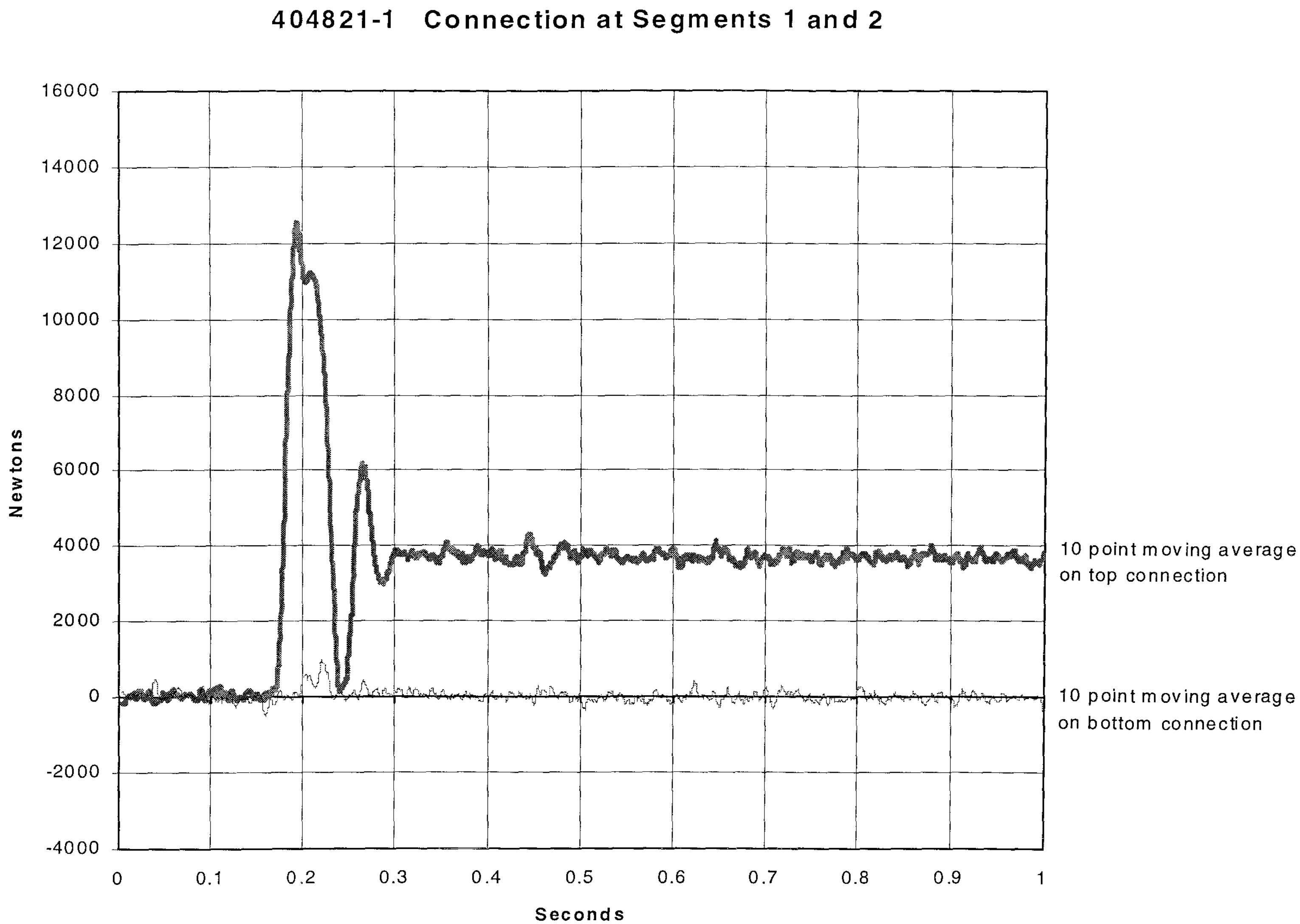


Figure 17. Force experienced at connection of segments 1 and 2.

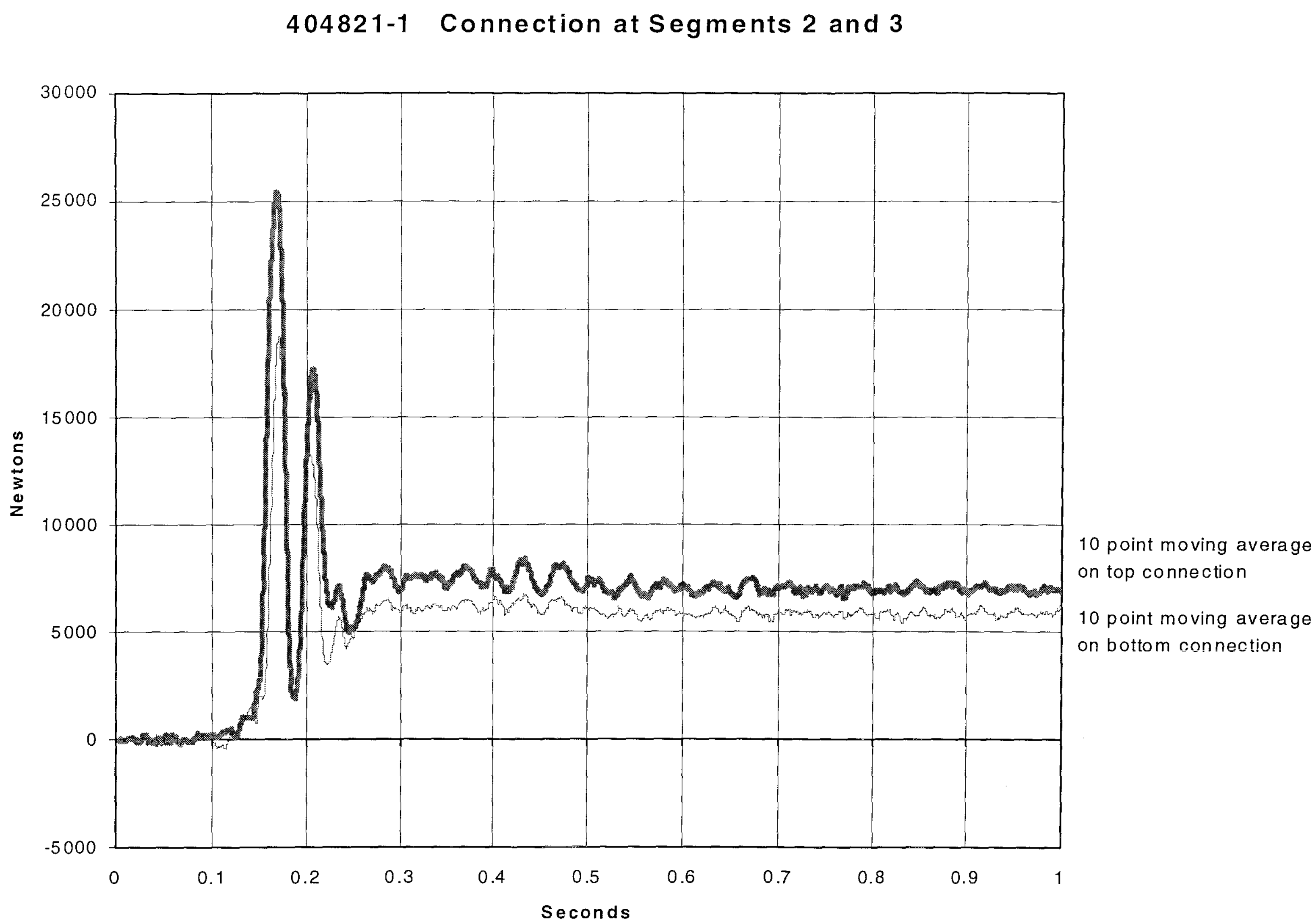


Figure 18. Force experienced at connection of segments 2 and 3.

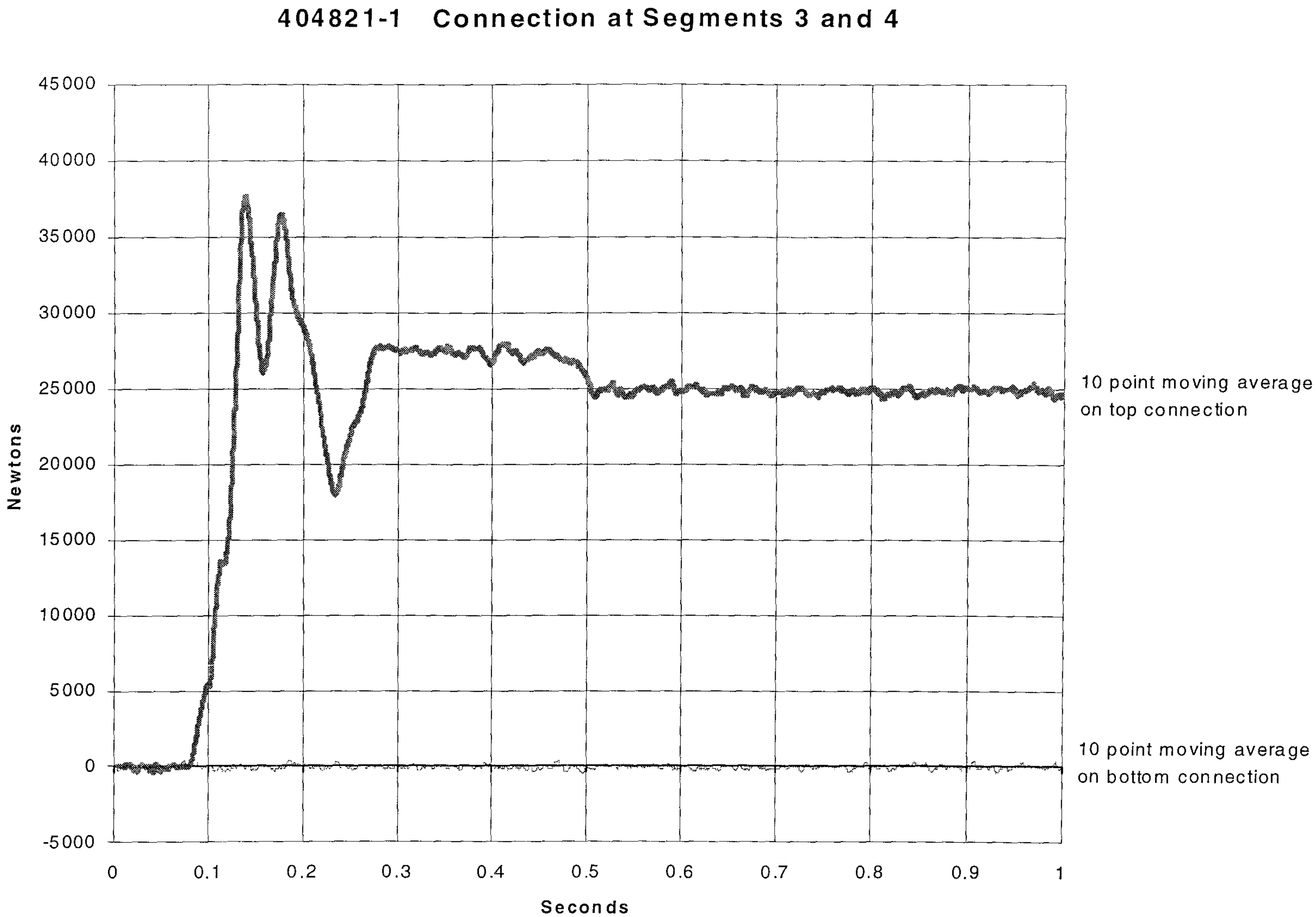


Figure 19. Force experienced at connection of segments 3 and 4.

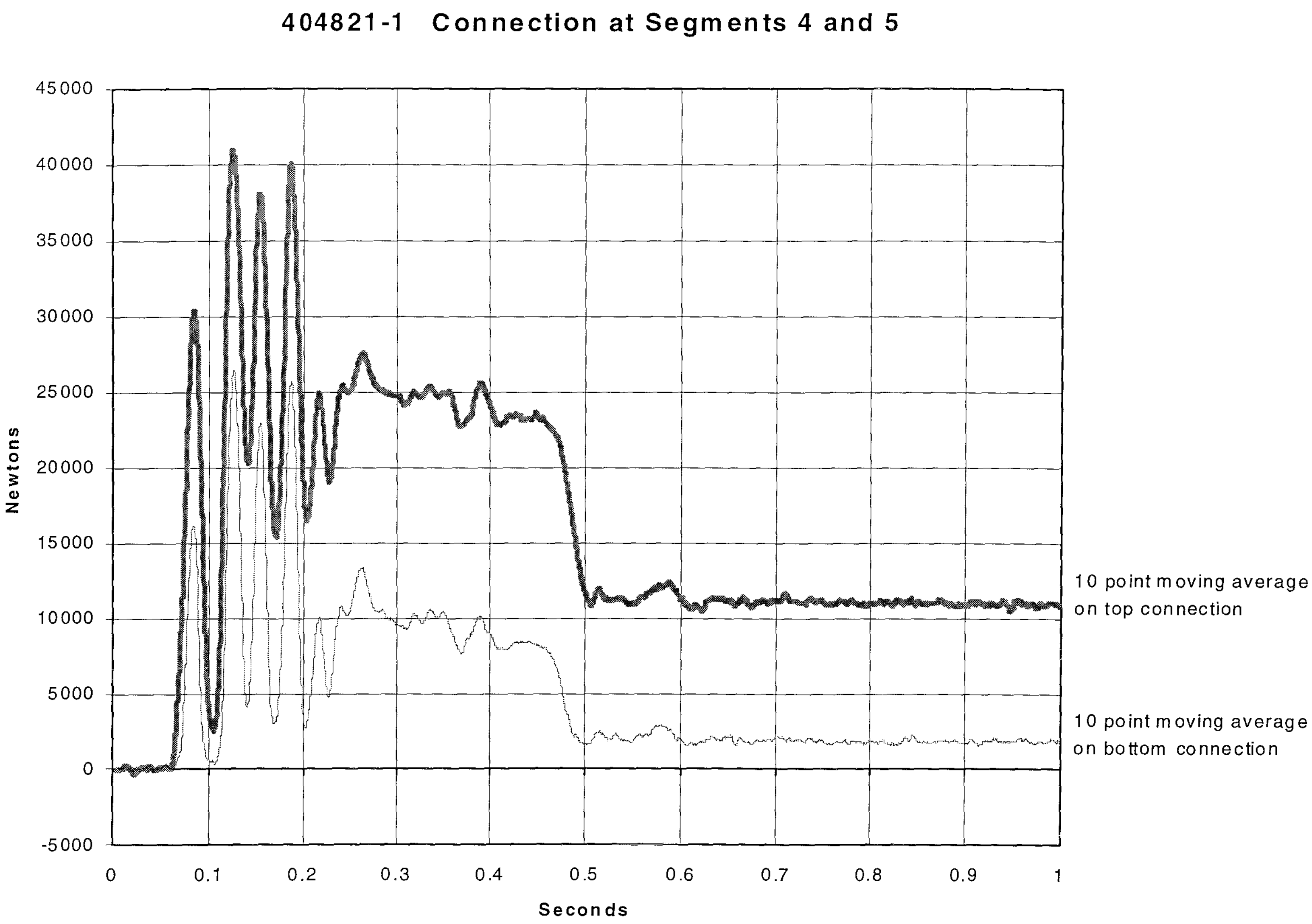


Figure 20. Force experienced at connection of segments 4 and 5.

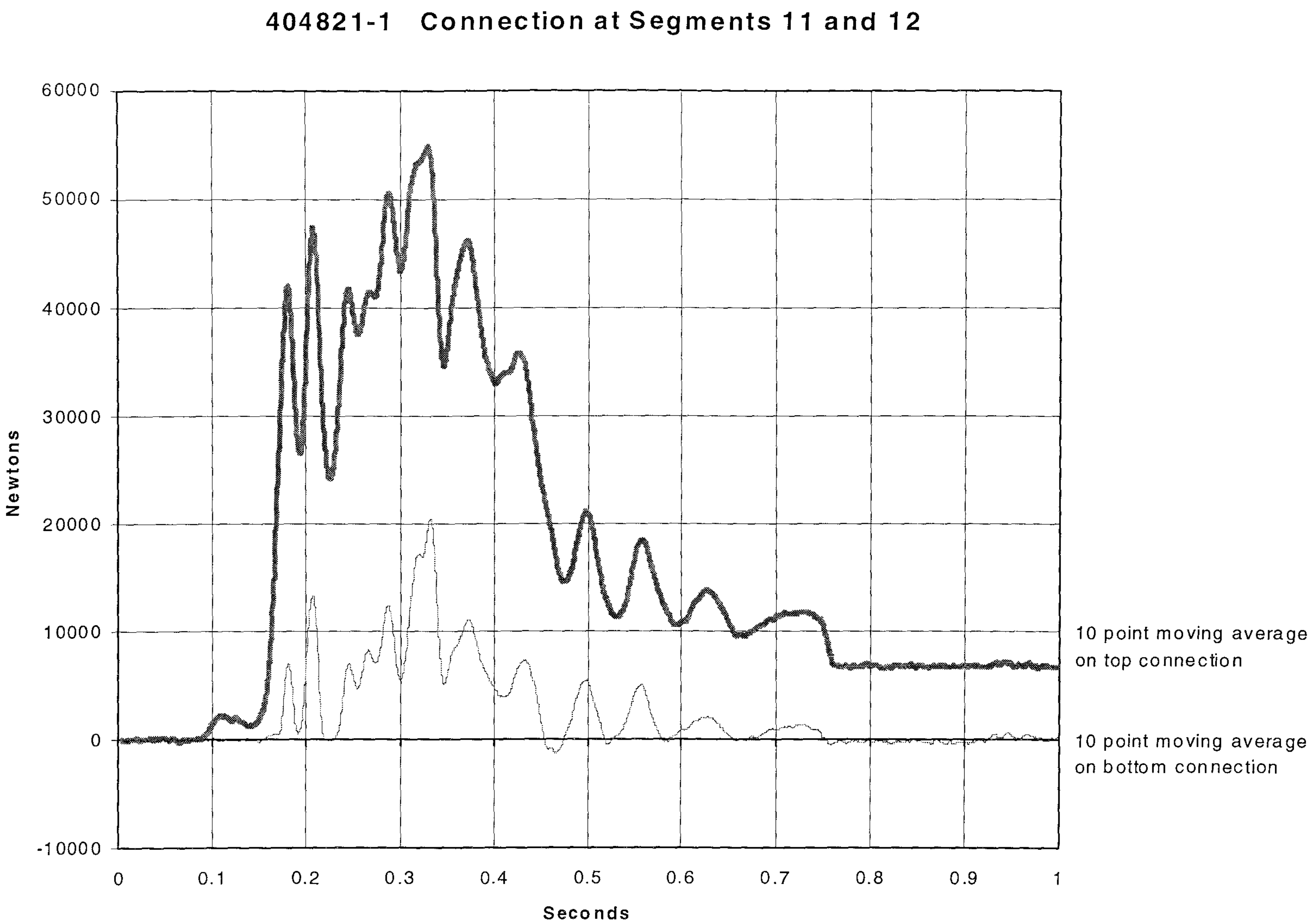


Figure 21. Force experienced at connection of segments 11 and 12.

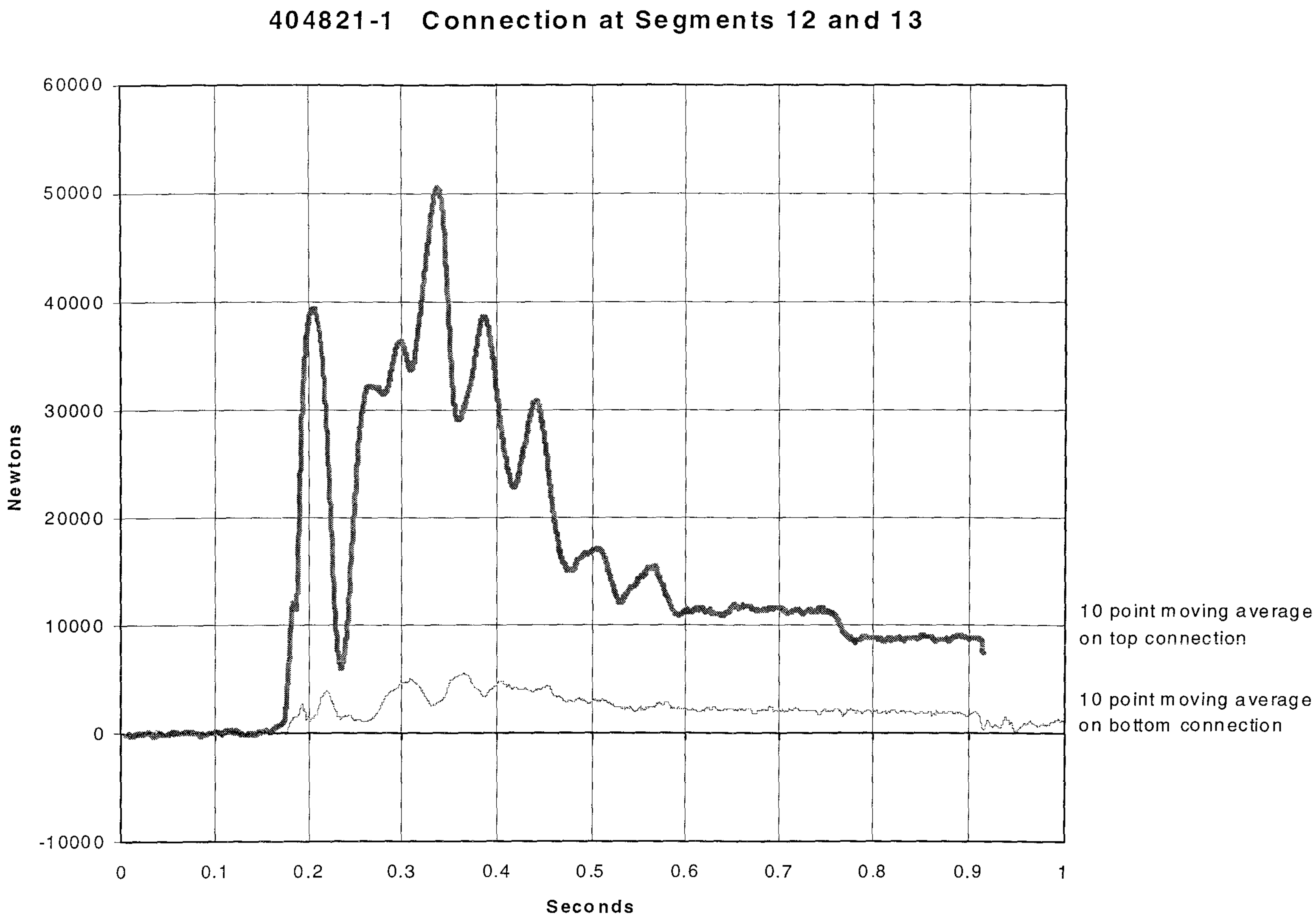


Figure 22. Force experienced at connection of segments 12 and 13.

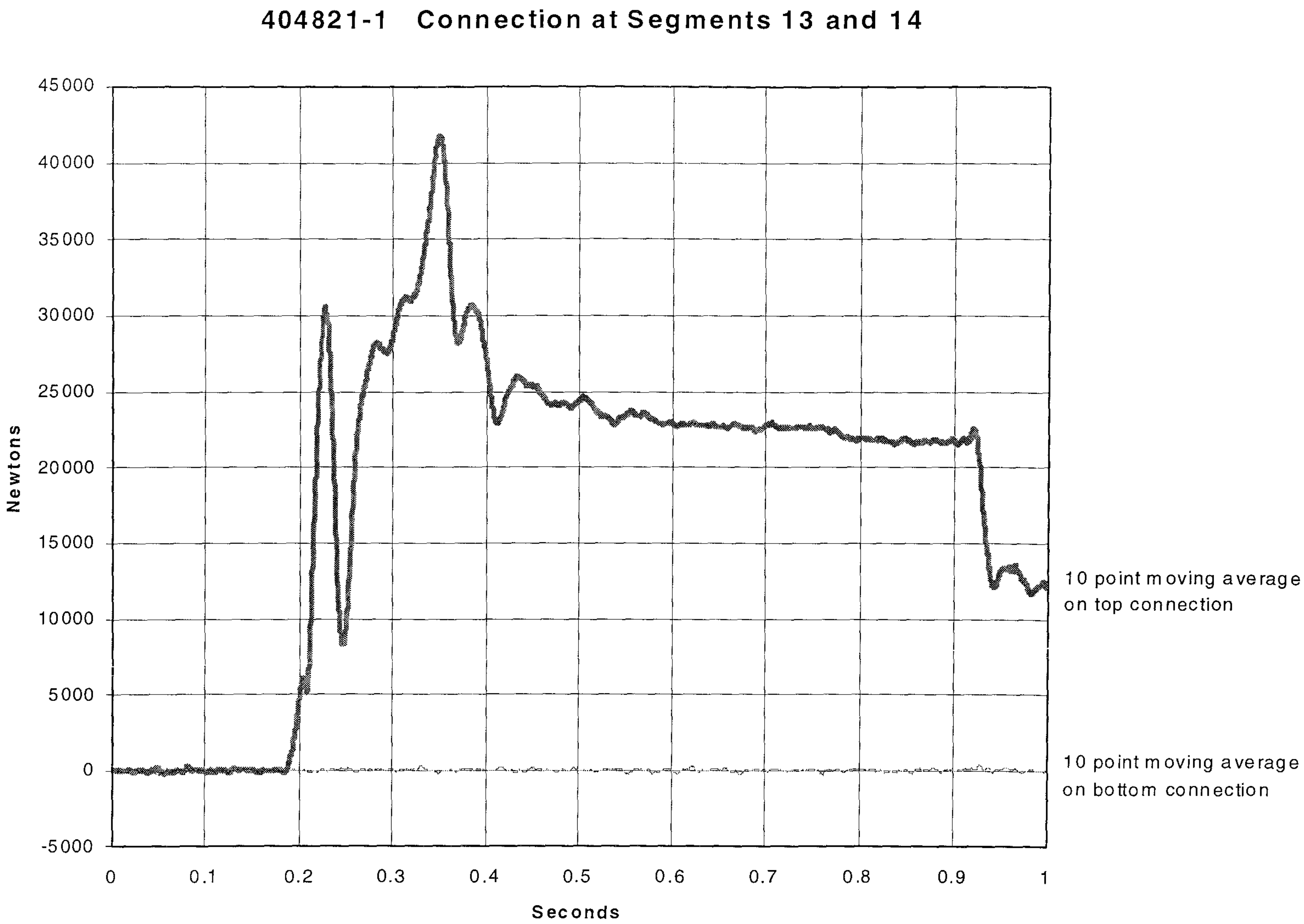


Figure 23. Force experienced at connection of segments 13 and 14.

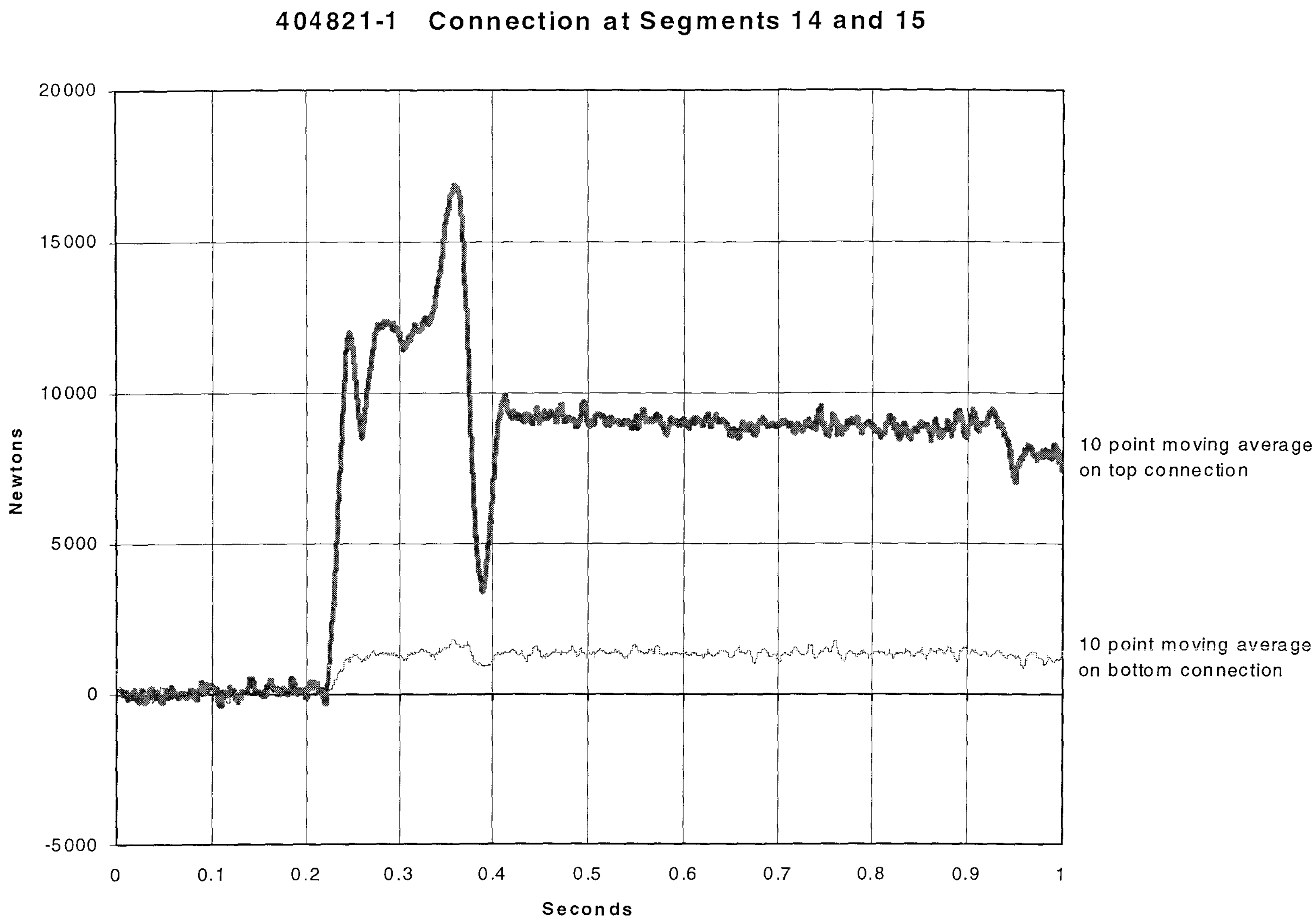


Figure 24. Force experienced at connection of segments 14 and 15.

APPENDIX E. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

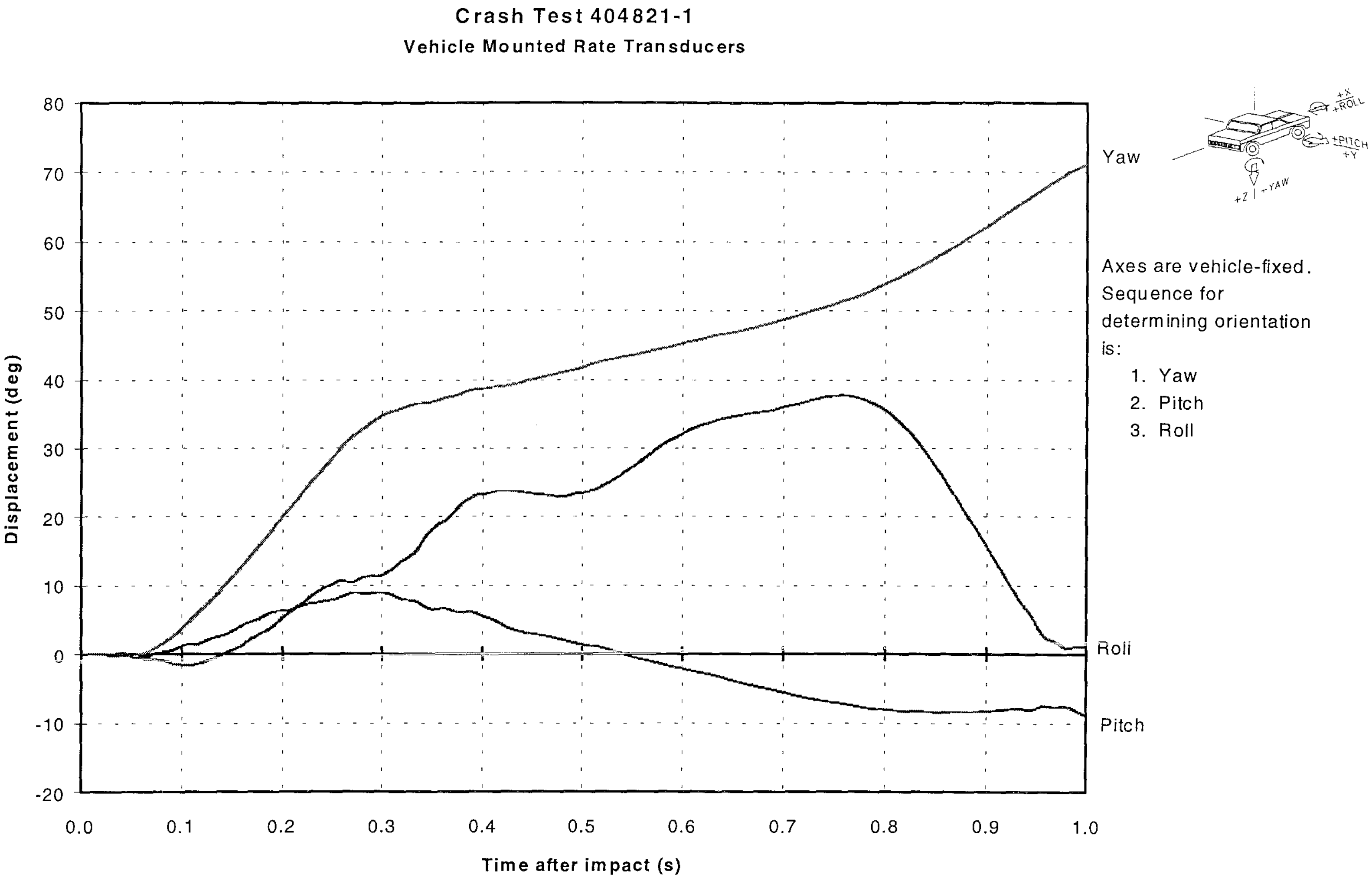


Figure 25. Vehicular angular displacements for test 404821-1.

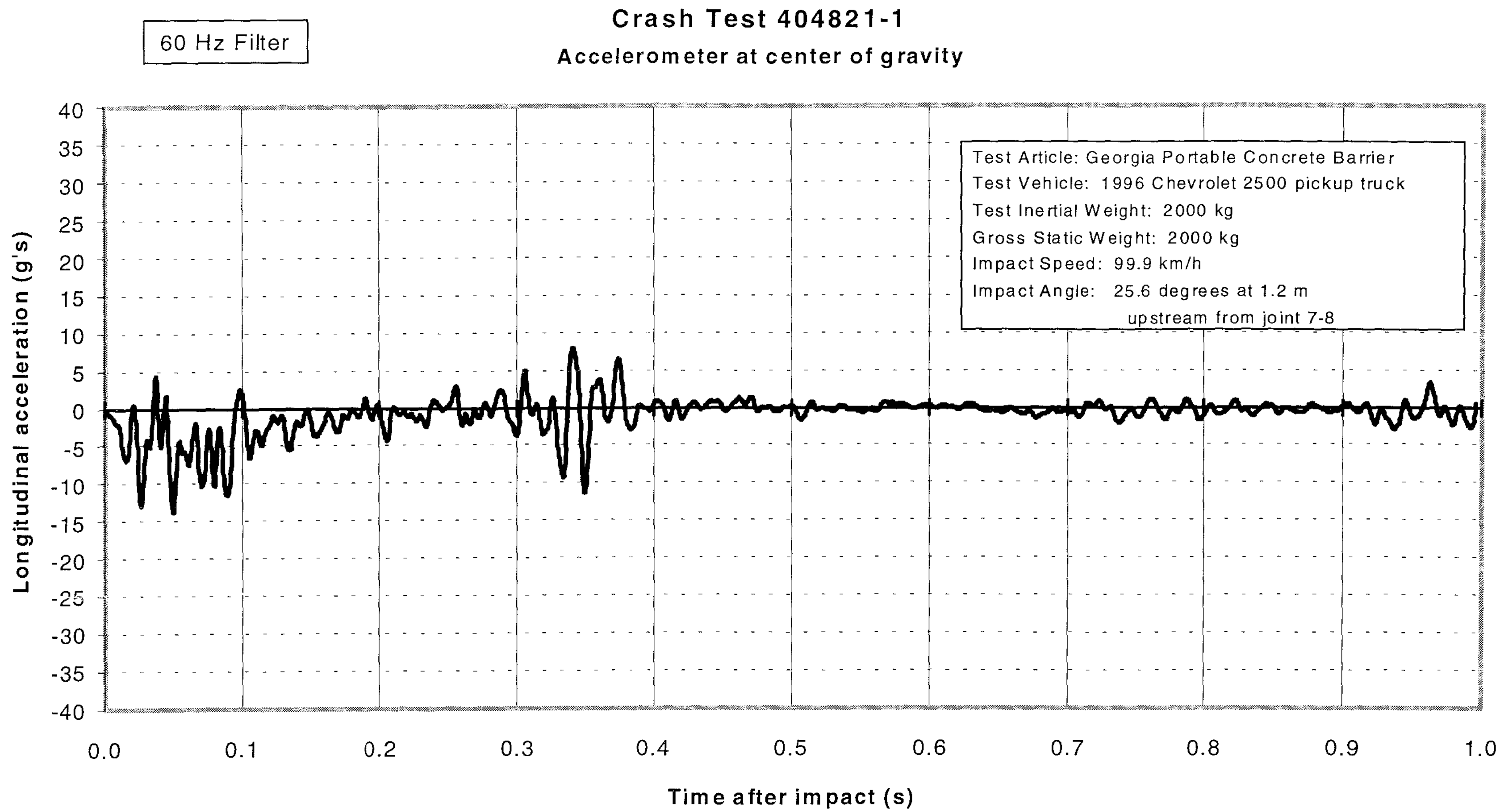


Figure 26. Vehicle longitudinal accelerometer trace for test 404821-1 (accelerometer located at center of gravity).

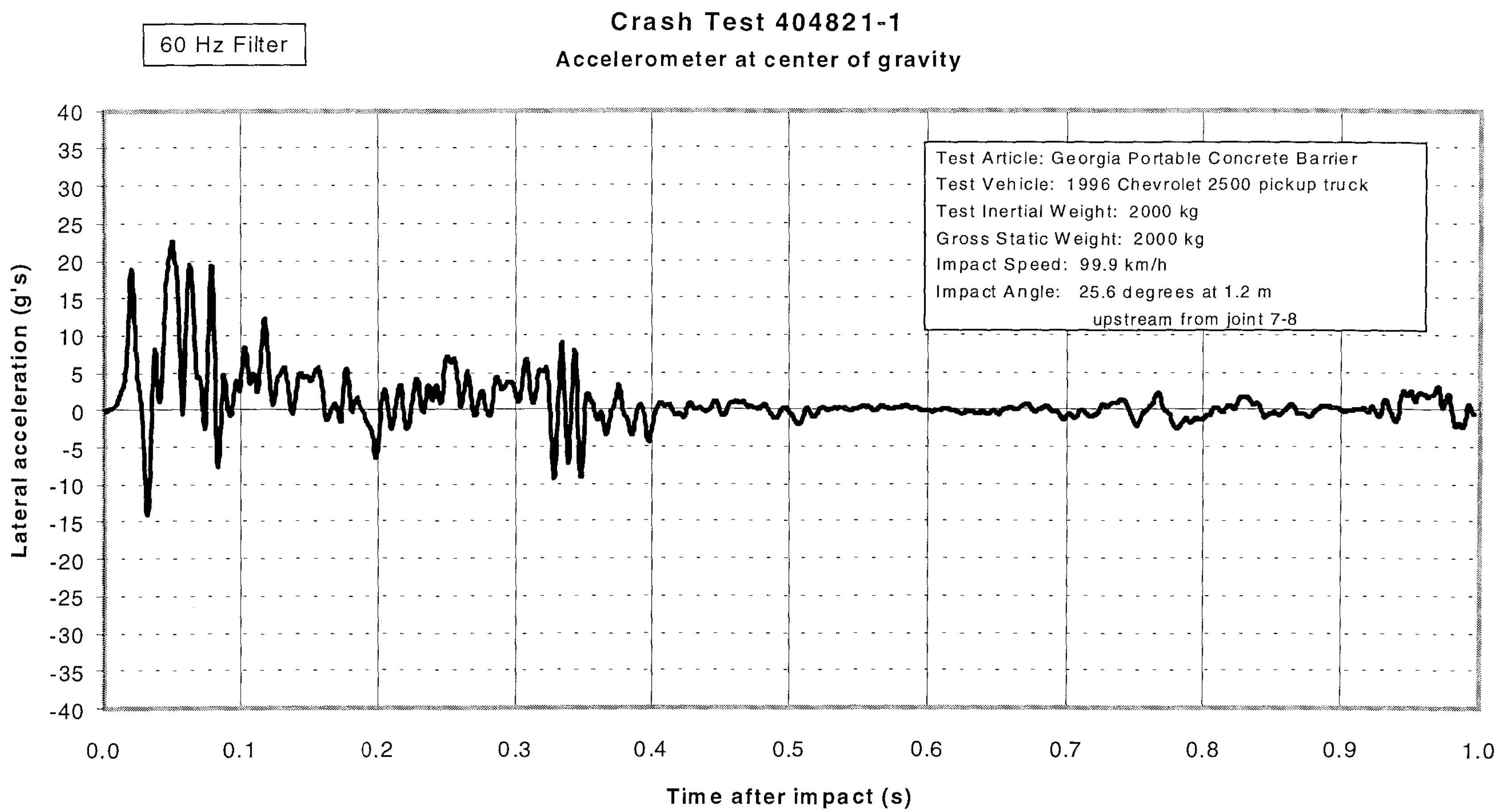


Figure 27. Vehicle lateral accelerometer trace for test 404821-1 (accelerometer located at center of gravity).

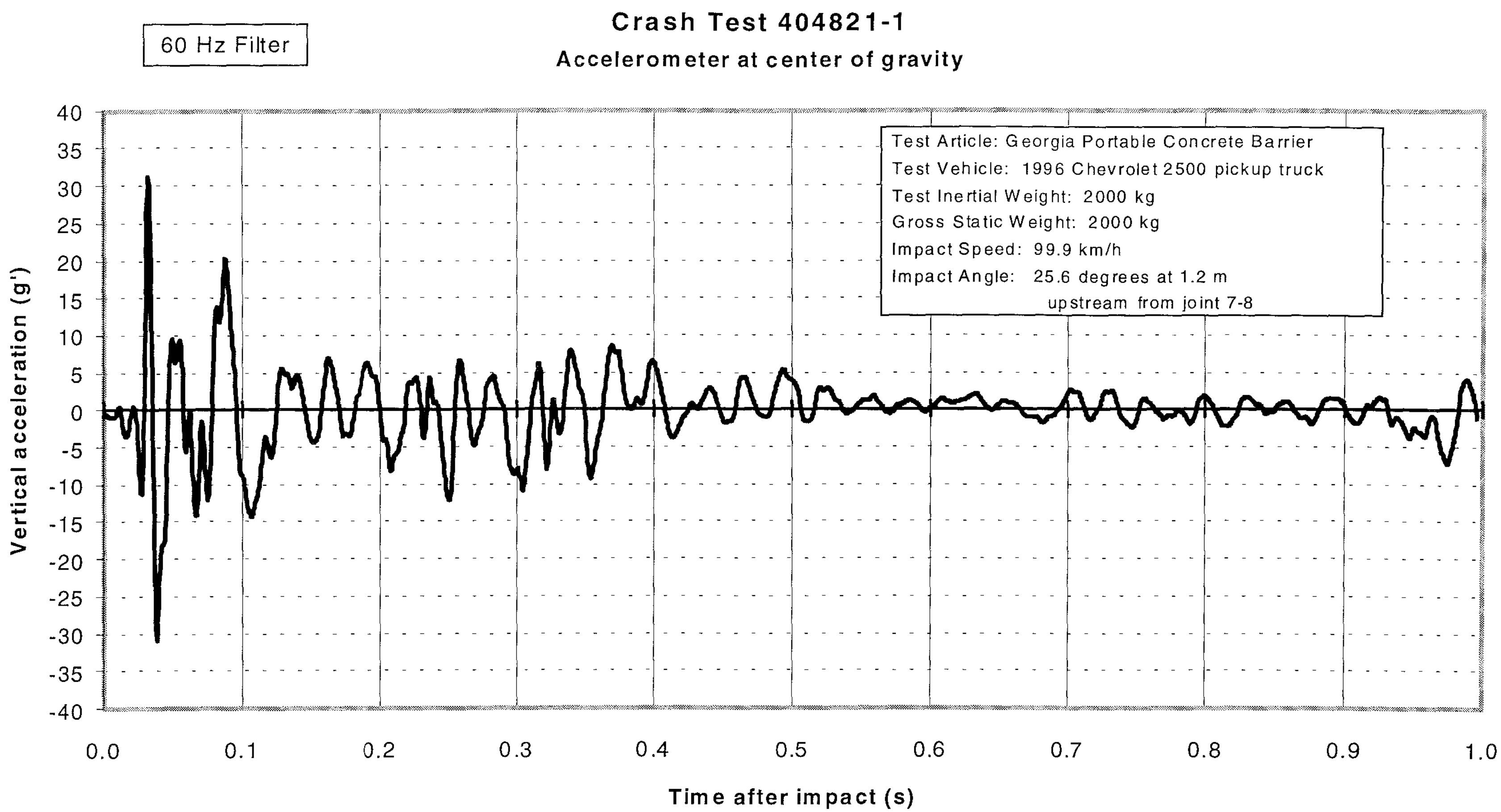


Figure 28. Vehicle vertical accelerometer trace for test 404821-1
(accelerometer located at center of gravity).

REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer and J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

2. Jarvis D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program Report 230, Transportation Research Board, National Research Council, Washington, D.C., March 1981.