STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICE CENTER,
DIVISION OF MATERIALS ENGINEERING AND TESTING SERVICES

COMPLIANCE CRASH TESTING OF K-RAIL USED IN SEMI-PERMANENT INSTALLATIONS

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This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled "COMPLIANCE CRASH TESTING OF K-RAIL USED IN SEMI-PERMANENT INSTALLATIONS".

16. ABSTRACT

A semi-permanent K-rail barrier was tested in accordance with NCHRP Report 350. The barrier consisted of eight concrete segments 6045 mm in length. The segments were placed on AC pavement and connected with 61.8 x 660 - mm pins. Each segment was then secured to the ground using four 25 x 610-mm steel stakes. The barriers were constructed and tested at the Caltrans Dynamic Test Facility in West Sacramento, California.

A total of two crash tests were conducted under Report 350 test level 3, one with an 820 kg sedan, and one with a 2000-kg pickup truck. The results of both tests were within the limits of the Report 350 criteria.

It is recommended that the semi-permanent K-rail be approved for use on California State highways where semi-permanent TL–3 barriers are required.

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To Convert From	To	Multiply By
	ACCELERATION	
m/s^2	ft/s^2	3.281
	AREA	
m^2	ft^2	10.76
	ENERGY	
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	FORCE	
Newton (N)	lb_f	0.2248
	LENGTH	
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m	in	39.37
cm	in	0.3937
mm	in	0.03937
	MASS	
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	PRESSURE OR STRESS	
kPa	psi	0.1450
	VELOCITY	
km/h	mph	0.6214
m/s	ft/s	3.281
km/h	ft/s	0.9113

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1. INTRODUCTION

1.1. Problem

The Federal Highway Administration has established a number of deadlines by which roadside safety hardware will have to comply with the crash testing criteria embodied in the National Cooperative Highway Research Program (NCHRP) Report 350[1]. Two deadlines must be met regarding the use of temporary barrier (K-rail). The deadline for K-rail used in semi-permanent installations is October 1, 1998, while the deadline for temporary K-rail as used in work zones is October 1, 2002. Caltrans does not have an approved construction barrier that will meet NCHRP Report 350 Test Level 3 criteria for either the temporary or the semi-permanent applications. In the near term, this could result in the loss of federal funding on projects that use K-rail for semi-permanent installations.

1.2. Objective

This research project addresses compliance testing of semi-permanent installations of K-rail and is the first in a series of projects that will ultimately result in having temporary barrier which is approved for both work zone and semi-permanent applications. The objective of this project is two-fold. First is to determine whether or not the California K-rail, as configured for semi-permanent installation, will contain and redirect 820 to 2000-kg vehicles effectively in 100 km/h impacts at angles of 20° to 25° (see Table 1-1 below). Second is to modify the existing K-rail system, if necessary, so that it will meet the Report 350 criteria in work zone applications. Full-scale crash testing will be done in accordance with NCHRP Report 350 Test Level 3 for longitudinal barriers.

1.3. Background

California's current standard for concrete temporary barrier is the K-rail.[2] This barrier, when properly installed, may also be used in semi-permanent applications. K-rail evolved from the Type 50 ("New Jersey") median barrier, which has been used in California and other states since about 1970. By 1971, there was substantial interest in the U.S. in developing a movable barrier that could be used in work zones. In 1972, the California Department of Transportation ran a series of crash tests on what is now called K-rail. The results of the testing led to the approval of K-rail for use as a temporary barrier in California. The K-rail that has become the standard within California consists of 6.1-m long sections with pin-and-loop connections, each weighing approximately 3630 kg. Eventually, details were developed which also allowed K-rail to be used as a semi–permanent barrier.

Currently, there is a considerable amount of research being done on the various types of temporary barrier used in the United States.[3] The two principal barrier profiles used in this country are the New Jersey (used in the K-rail) and the F–shape. The lengths of the individual segments vary from 2.44 m to 9.14 m for both types of barriers.

Other states, including Iowa, Nebraska, Virginia, Washington, Indiana, Texas and New York are all doing research on temporary barrier. Only Iowa, Nebraska and New York are currently doing any research on New Jersey profile barriers, and no research at all is being conducted on 6.10-m long barrier sections with this profile (i.e., California K-rail).

1.4. Literature Search

A search for information about construction barrier was conducted using three separate sources. The first source was Charles McDevitt, with the Federal Highway Administration's (FHWA) Design Concepts Research Division in McLean, Virginia. The second source was the database of reports held by the Roadside Safety Technology Branch within the Caltrans Division of Materials Engineering and Testing Services. The third and final location was the Caltrans Library within Caltrans Headquarters.

Each of the sources produced information on design history. Conversations with the FHWA staff revealed current research direction within the United States.

1.5. Scope

A total of two tests were performed and evaluated in accordance with NCHRP Report 350. The testing matrix established for this project is shown in Table 1-1.

Table 1-1 - Target Impact Conditions

Test Number	Barrier Type	Mass of Test Vehicle (kg)	Speed (km/h)	Angle (deg)
551	K-rail staked to asphalt concrete	2000	100	25
552	K-rail staked to asphalt concrete	820	100	20

2. TECHNICAL DISCUSSION

2.1. Test Conditions - Crash Tests

2.1.1. Test Facilities

Each of the crash tests was conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface. There were no obstructions nearby except for a 2 m-high earth berm 40 m downstream from the barrier in test 551.

2.1.2. Test Barrier

2.1.2.1. Design

The primary design parameters for the development of a semi-permanent barrier were:

1) Compliance with NCHRP Report 350 TL-3.

2) Minimum lateral movement during impact.

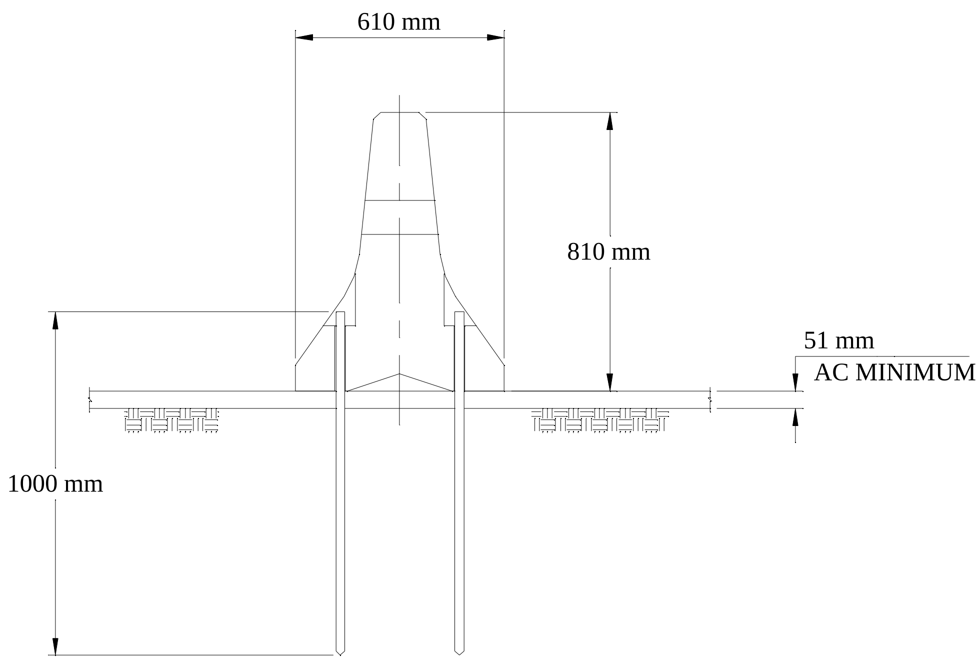
3) Ease of installation and removal.

Secondary design parameter for this project were two-fold:

1) If possible, use currently existing K-rail in the final design.

1) Use a currently established method of element restraint (see James B. Borden memo in appendix).

These design parameters lead to the following test profile.



Refer to Standard Plans July 1997 for
Dimensions, page 132 SECTIONS A-A, B-B.

Figure 2-1 - Cross Section of Planned Test Barrier

The final test design consisted of placing eight segments of California K-rail (New Jersey profile) on asphalt concrete (AC) pavement 50-80 mm thick. Each 6.096-m long rail element connected to adjoining elements with 31.8 x 660-mm long pins. Each element was also secured to the AC pavement with four 25 x 1000-mm steel stakes. The head of each stake was driven below the face of the barrier to prevent snagging of the impacting vehicles.

2.1.3. Construction

Construction of the barrier consisted of obtaining the K-rail, clearing the holes for the stakes, placing and connecting the rail elements, and staking the individual elements to the AC pavement (see Figure 2-2). The final test barrier length was 48.77 m.

Because K-rail elements are vary common in California, it was decided to order eight used rail elements. The elements were in good condition, except for the stake holes. The quality control of the K-rail elements is clearly a problem. All but two holes had to be cleared of concrete using various methods. Some holes were pounded out with a hammer and chisel. Others were drilled out with a roto-hammer using a 32-mm bit. During some of the stake-hole clearing, the concrete spalled away from the rail element, revealing mislocated reinforcing steel or even the absence of such steel (see Figure 2-3). One hole split completely, eliminating the possibility of getting positive anchoring from the stake.

The barrier was assembled one segment at a time. The elements were placed using a 3600-kg capacity forklift. Pins were placed in the pin-and-loop connections by hand. Those segments that had spalled during the stake-hole clearing were placed at the ends of the test barrier. The barrier was not pulled tight to take up slack in the pin-and-loop connections (see Figure 2-4).

Where possible, four stakes were placed in each rail element. The stakes were pounded in with a tie-rod driver and either a 60 or 90-lb. jackhammer. The stakes went in smoothly, but occasionally bound up the tie-rod driver against the face of the rail. Where the stake-holes had spalled completely away a stake was still put in place to offer some lateral restraint. A stake was not placed at one of the stake-holes located at the upstream end of the barrier because it was located directly on top of a concrete footing that had been used for a previous test. Only two stakes were not placed in the stake-holes properly.

Note: Due to a misinterpretation of the original design, the stakes were cut to 610 mm instead of 1000 mm. The error in length was not discovered until the barrier was being constructed. It was decided that the shorter stakes would only make the test more conservative, so they were not replaced with the longer ones.

Figure 2-2 - View of Anchor Stake in Barrier

Figure 2-3 - Exposed Rebar

Figure 2-4 - Assembled Barrier

2.1.4. Test Vehicles

The test vehicles complied with NCHRP Report 350. For both tests, the vehicles were in good condition, free of major body damage and were not missing structural parts. All of the vehicles had standard equipment and front-mounted engines (see Figure 2-5 through Figure 2-9 and Figure 2-17 through Figure 2-20). The vehicle inertial masses were within recommended limits (see Table 2-1).

Table 2-1 - Test Vehicle Information

Test No.	Vehicle	Ballast (kg)	Test Inertial (kg)
551	1989 Chevrolet 2500	0	2016
552	1994 Geo Metro	0	844

The pickup was self-powered; a speed control device limited acceleration once the impact speed had been reached. The Geo was connected by a steel cable to another vehicle and towed to impact speed. Remote braking was possible at any time during the test for all vehicles through a tetherline. A short distance before the point of impact, each vehicle was released from the guidance rail and the ignition was turned off (for the Geo, the tow cable was released from the undercarriage). A detailed description of the test vehicle equipment and guidance systems is contained in Sections 6.1 and 6.2 of the Appendix.

2.1.5. Data Acquisition System

The impact phase of each crash test was recorded with seven high-speed, 16-mm movie cameras, one normal-speed 16-mm movie camera, one Beta format video camera, one 35-mm still camera with an autowinder and one 35-mm sequence camera. The test vehicles and the barrier were photographed before and after impact with a normal-speed 16-mm movie camera, a Beta format video camera and a color 35-mm camera. A film report of this project was assembled using edited portions of the film coverage.

Two sets of orthogonal accelerometers were mounted at the centers of gravity for each of the test vehicles. An additional set of orthogonal accelerometers was mounted 600 mm behind the center of gravity in the small car test. Rate gyro transducers were also placed at the centers of gravity of the test vehicles to measure the roll, pitch and yaw. The data were used in calculating the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation.

An anthropomorphic dummy was used in Test 552 to obtain motion data, but was not instrumented. The dummy, a Hybrid III built to conform to Federal Motor Vehicle Safety Standards by the Humanoid Systems Division, Humanetics, Inc., simulated a 50th percentile American male weighing 75 kg. The dummy was placed in the passenger’s seat and was restrained with a lap and shoulder belt.

A digital transient data recorder (TDR), Pacific Instruments model 5600, was used to record electronic data during the tests. The digital data were analyzed using a desktop computer.

2.2. Test Results - Crash Tests

A film report with edited footage from tests 551 and 552 has been compiled and is available for viewing.

2.2.1. Impact Description - Test 551

The vehicle impact speed and angle were 100.6 km/h and 25 degrees, respectively. Impact occurred at the joint between the forth and fifth segments (see Figure 2-6). As the vehicle hit the barrier, it yawed left until the entire right side of the vehicle was in contact with the face. At 0.2 seconds the vehicle started to ride upward. All four wheels lost contact with the ground as the front bumper reached the next segment (about 6 m downstream). The vehicle touched down 12 m further downstream. As the front left tire hit the ground, the roll and pitch were measured to be 12.8° and 25°, respectfully. The vehicle immediately started to right itself and was stable about 4 meters past the end of the barrier (about 16 m downstream of the point of impact). The exit speed and angle were 82 km/h and 6 degrees respectively. The 6-degree exit angle is well within the 60% limit of Report 350.

Figure 2-5 - Rear View of Vehicle with Barrier

Figure 2-6 - Vehicle 551 At Barrier

Figure 2-7 - Vehicle 551 At Point Of Impact

Figure 2-8 - Front View of Test Vehicle 551

Figure 2-9 - Side View of Vehicle 551

2.2.2. Vehicle Damage - Test 551

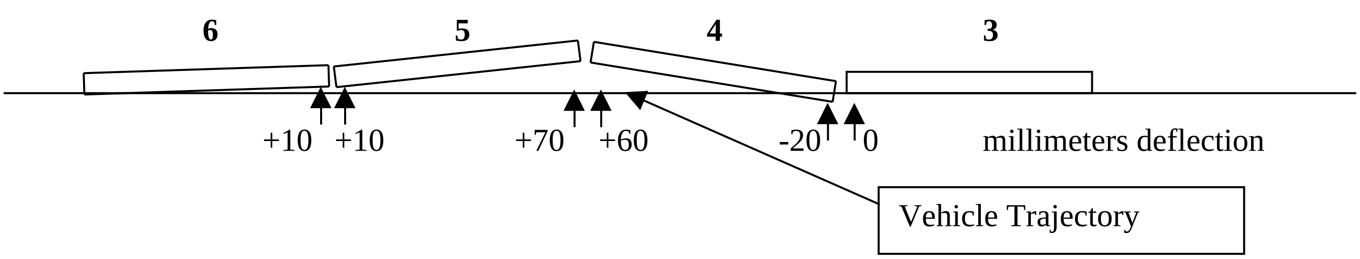
Most of the damage to the vehicle was confined to right front corner. The right front tire was separated from the wheel. The right front fender and bumper were crushed (Figure 2-10). The tie-rod was broken, but the left front wheel could still be controlled by the steering wheel. There were scuff marks and scratches along the entire right side of the vehicle. The left rear wheel sustained minor damage, but the tire was still inflated.

The occupant compartment sustained some minor crumpling on the right side floorboard. The maximum deformation was 40 mm. The right door was jammed closed. The windshield was not cracked. Figure 2-16 presents a summary of the test results.

Figure 2-10 - Front Impact Side of Vehicle

2.2.3. Barrier Damage - Test 551

The barrier underwent some permanent deflection:



Damage to the barrier was minimal (Figure 2-11 through Figure 2-15). The connecting pin-and-loop at joint 4-5 bent enough that it caused minor spalling and the pin had to be cut before the barrier could be moved. The maximum lateral displacement measured at the top of the barrier was 260 mm during impact. There was also some minor spalling of anchor stakes in segments 4 and 6.

Figure 2-11 - Post Impact View of Barrier

Figure 2-12 - Concrete Spalling At Anchor Stake

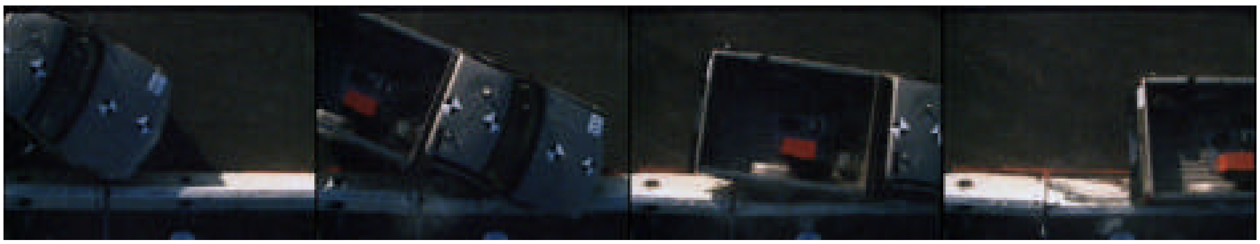
Figure 2-13 - Post Impact Scuff Marks Test 551

Figure 2-14 - Downstream View of Barrier Post Impact

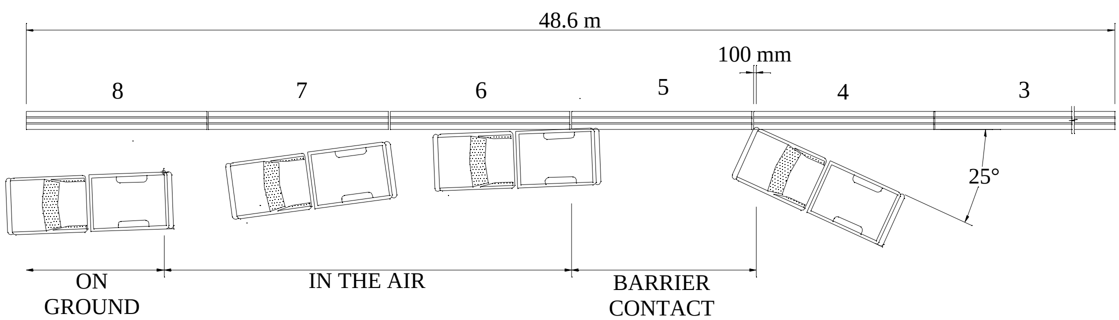
Figure 2-15 - Backside of Barrier Post Impact

Figure 2-16 - Test 551 Data Summary Sheet

t = 0.000 t = 0.200 t = 0.400 t = 0.600



t = 0.000 t = 0.080 t = 0.160 t = 0.240



General Information:
- Test Agency: California DOT
- Test Number: 551
- Test Date: January 27, 1999

Test Article:
- Name: Pinned K-rail
- Installation Length: 48.77 m
- Description: 8 segments of K-rail, staked with 24-mm stakes & connected with 31.8-mm pins

Test Vehicle:
- Model: 1989 Chevy 2500
- Inertial Mass: 2016 kg

Impact Conditions:
- Velocity: 100.6 km/h
- Angle: 25°

Exit Conditions:
- Velocity: 82 km/h
- Angle: 6 degrees

Test Dummy:
- Type: NA
- Weight / Restraint: NA
- Position: NA

Vehicle Exterior:
- VDS[4]: FR-4, RD-4
- CDC[5]: 02RFEW4

Vehicle Interior:
- O.C.D.I.: RF0000000

Barrier Damage: Spalling at the pin-and-loop connection at point of impact, also at some of the anchor stakes. Superficial scuffing

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	5.17 m/s	6.62 m/s
Ridedown Acceleration	-5.48 g	-14.88 g
Max. 50 ms avg. Acceleration	-5.99 g	-11.33 g

2.2.4. Impact Description - Test 552

The vehicle impact speed and angle were 101.7 km/h and 20 degrees, respectively. Impact occurred at the joint between the forth and fifth segments (see Figure 2-17). Within the first 3 m of barrier contact, the vehicle rotated 20 degrees to the left, the rear hatch opened up and all four wheels left the ground. Contact with the barrier continued for about 8 m while the vehicle rose. The vehicle stayed level while rising to an ultimate height of 630 mm. The vehicle came back down 15 m downstream of the impact point (see Figure 2-21 through Figure 2-23).

The exit speed and angle were 97 km/h and 4 degrees respectively. This exit angle is well within the limit of 60% of the impact angle, as specified by Report 350. The vehicle stayed upright and tracked smoothly until coming to rest approximately 67 m downstream.

Figure 2-17 - Vehicle 552 At Impact Point

Figure 2-18 - Vehicle 552 With Barrier

Figure 2-19 - Side View of Test Vehicle 552

Figure 2-20 - Pre-Crash View of Impact Side of Vehicle

Figure 2-21 - Vehicle 552 Impacting Barrier

Figure 2-22 - Vehicle 552 Exiting Barrier

Figure 2-23 - Vehicle 552 Landing Upright and Stable

2.2.5. Vehicle Damage - Test 552

As in Test 551, most of the damage to the vehicle was confined to the right front corner. The right 300 mm of the bumper was slightly pushed into the fender panel and the fender had considerable sheet metal damage. The parking light was broken. The right wheel assembly was pushed back and to the left, with the bottom of the wheel canted outward (see Figure 2-24 and Figure 2-25).

Other damage to the vehicle was minor. The hood had some minor crumpling. The right front door was scraped and jammed closed, but could be worked open by hand. The rest of the right side received scraping and minor crumpling. The windshield was unbroken.

Figure 2-24 -Front View of Vehicle Impact Damage

Figure 2-25 - Side Impact Damage

2.2.6. Barrier Damage - Test 552

Damage occurred only on the front of the barrier. Vehicle contact was limited to segments 4 and 5, where the barrier received superficial scuffing (see Figure 2-27). The K-rail cracked around several of the stake holes, but they all retained their integrity. The barrier rotated back approximately 30 mm during impact, but righted itself as the vehicle lost contact with the barrier.

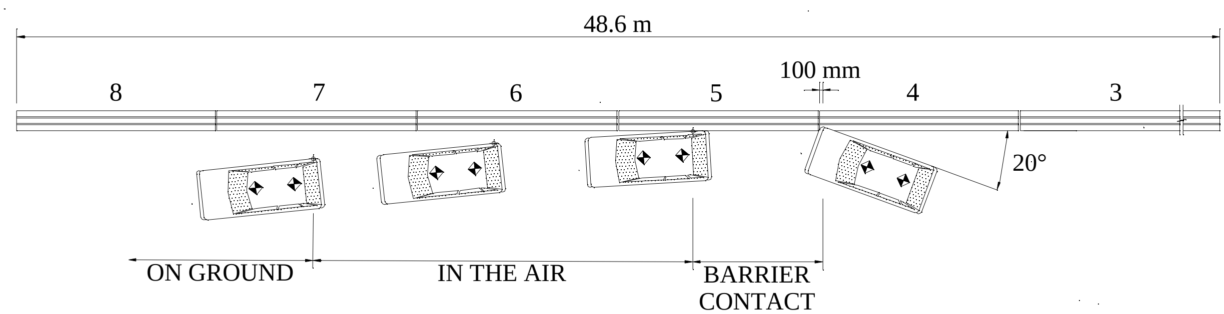
Segment 4 had a permanent deformation of 25 mm, with the front edge of the barrier raised about 10 mm. The loop connections did not incur any damage.

Figure 2-26 - Test 552 Barrier Scuffing

Figure 2-27 - Test 552 Data Summary Sheet

t = 0.000 t = 0.200 t = 0.400 t = 0.600

t = 0.800 t = 1.000 t = 1.200 t = 1.400



General Information:
- Test Agency .... California DOT
- Test Number 552
- Test Date .... February 24, 1999

Test Article:
- Name .... Pinned K-rail
- Installation Length .... 48.77 m
- Description .... 8 segments of K-rail, staked with 24-mm stakes & connected with 31.8-mm pins

Test Vehicle:
- Model .... 1994 Geo Metro
- Inertial Mass .... 844 kg

Impact Conditions:
- Velocity .... 101.7 km/h
- Angle .... 20°

Exit Conditions:
- Velocity .... 97 km/h
- Angle .... 4 degrees

Test Dummy:
- Type .... Hybrid III
- Weight / Restraint .... 74.8 kg / belted
- Position .... Front Right

Vehicle Exterior:
- VDS[4] FR-4, RD-4
- CDC[5] 02RFEW3

Vehicle Interior:
- OCDI RF0000000

Barrier Damage: .... Superficial scuffing.

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	3.94 m/s	5.8 m/s
Ridedown Acceleration	-1.13 g	-17.62 g
Max. 50 ms avg. Acceleration	-7.29 g	-11.2 g