[Note: This memo has been canceled. See the NCHRP Report 537 – Recommended Guidelines for Curb and Curb-Barrier Installations.]

Memorandum

U.S. Department of Transportation
Federal Highway Administration

Subject: INFORMATION: Performance of Guardrail/Curb Combinations

Date: FEB 28 1992

From: Chief, Federal-Aid and Design Division

Reply to Attn of: HNG-14

To: Regional Federal Highway Administrators
Federal Lands Highway Program Administrator

For many years, most design engineers assumed that a curb in front of a w-beam guardrail was acceptable if the curb was no closer to traffic than the face of the w-beam. However, it has been shown that such curbs can still degrade barrier performance. This happens because the semi-rigid guardrail will deflect under relatively severe impact conditions thereby allowing wheel contact with the curb and possible vaulting over or onto the barrier.

A series of tests were conducted recently to quantify barrier performance when the guardrail was behind a curb. (Note: Summary sheets for each of the following tests are attached for your information. Each sheet includes a sketch of the curb with dimensions and its location in relation to the guardrail.)

In Test Number 1862-1-88, a 2,450 kg (5,400-pound) pickup truck vaulted over a G4(1S) w-beam on strong post guardrail after an impact at 100 km/h (60 mi/h), and 20 degrees. The guardrail had a 20 cm (8-inch) high concrete curb (AASHTO Type A) installed behind the face of the w-beam rail. In Test Number 1862-5-89, a 2040 kg (4,500-pound) sedan impacted at 100 km/h (60 mi/h), and 25 degrees, and vaulted over a G4(1S) guardrail with a 15 cm (6-inch) high asphalt dike. In both tests, the guardrail deflected enough for the wheels to impact the curb. The resulting compression of the suspension systems produced upward forces on the vehicles that caused them to vault over the guardrail.

In Test Number 1862-4-89, the same guardrail/asphalt dike combination smoothly redirected an 820 kg (1,800-pound) car that impacted at 100 km/h (60 mi/h), and 20 degrees. In this test, the guardrail did not deflect enough for the wheels to contact the curb.

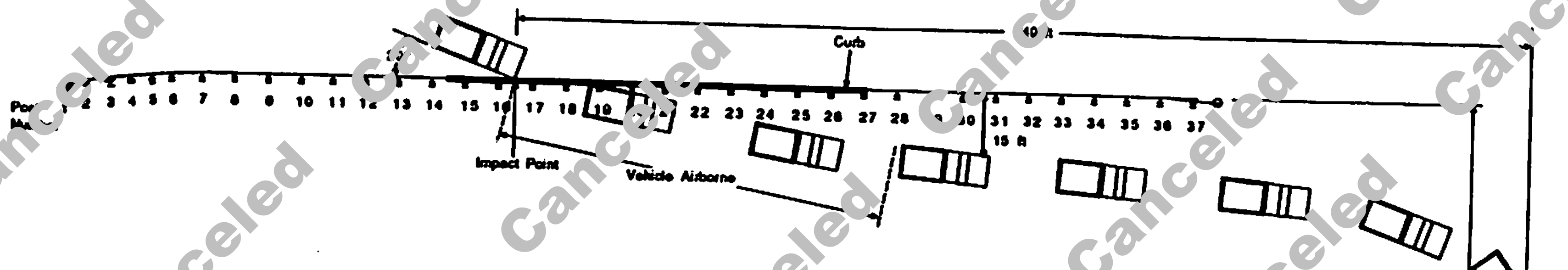
In Test Number 1862-12-90, the G4(1S) guardrail had a 10 cm (4-inch) high concrete curb (AASHTO Type H). When a 2040 kg (4,500-pound) sedan impacted this combination at 100 km/h (60 mi/h), and 25 degrees, the car became airborne but did not vault the rail. This test showed that reducing the curb height to 10 cm (4-inches) or less is one solution to the vaulting problem. However, stiffening the guardrail to reduce its deflection, as noted below, may be a better approach because the vehicles in these tests were redirected in a more stable manner.

In Test Number 1862-13-91, a G4(1S) guardrail with a 15 cm (6-inch) asphalt dike was stiffened by bolting an extra w-beam to the back of the steel posts. This retrofitted guardrail successfully redirected a 2040 kg (4,500-pound) sedan impacting at 100 km/h (60 mi/h), and 25 degrees. In Test Number 1862-14-91, a G4(1S) guardrail with a 15 cm (6-inch) asphalt dike was modified by adding a C6x8.2 hot-rolled channel rub rail. This design also worked well, smoothly redirecting a 2040 kg (4,500-pound) sedan impacting at 100 km/h (60 mi/h), and 25 degrees.

Except for specific guardrail-to-bridgerail transition designs that include a curb and have been successfully crash-tested, the continued use of <u>any</u> guardrail/curb combinations should be discouraged at locations where high-speed, high-angle impacts are likely. Where there are no feasible alternatives to guardrail/curb combinations, the use of a low curb no higher than 10 cm (4-inches) and/or one of the modifications to the w-beam guardrail described above will usually prove satisfactory. On lower speed facilities, a vaulting potential still exists, but since the risk of such an occurrence is lessened, a design change may not be cost-effective. Such locations are best analyzed on a case-by-case basis, taking actual or anticipated operating speeds into account and considering the consequences of vehicular penetration.

L. A. Staron

Attachments



Contract Number:	DTFH61-87-C-00126
Date:	6 December 1988
Weather:	Clear 6_° F
Test Vehicle:	1982 Chevrolet C20 Pickup
Device Configuration:	G4(2B) W-Beam with AASHTO Type 7 curb in front of barrier, 2__ total length, 37.5-ft BCT

1. Vehicle Weight:
   - Planned, Inertial: 5400
   - Actual, Inertial: 5417
   - Actual, Gross: 5742
2. Number of Occupants: Two
3. Occupant Model: Part 5__ 50 percentile male
4. Occupant Locations: Driver Seat, Restrained; Passenger Seat, Unrestrained
5. Impact:

	Speed	Angle	Location
Planned:	60.0 mi/h	20°	Midspan posts 16 and 17
Actual:	61.3 mi/h	20°	Midspan posts 16 and 17

Tolerances: Speed: -1.0, +2.5 mi/h; Angle: -1.0, +2.5 degrees

6. Redirection Angle: n/a
7. Redirection Speed: n/a
8. Total Speed Change: n/a
9. Total Momentum Change: n/a
10. Vehicle Damage Index: (SAE J224a) 01__E2
11. NCHRP 230 Test Number: Special; AASHTO Test Type: PL2

13. Vehicle Analysis:

	Observed	Design/ Limit Value
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-16.__ ft/s	30/40 ft/s
Ridedown Acceleration:	-2.__ g's	15/20 g's
Lateral:		
Delta-V at 1 ft:	10.2 ft/s	20/30 ft/s
Ridedown Acceleration:	5.5 g's	15/20 g's
TRB 191:		
Peak 50 ms acceleration:		
Longitudinal:	-5.2 g's	
Lateral:	3.8 g's	

14. Vehicle-Railing Interaction Coefficient of Friction:

$mu = (\cos theta - V_p/V) / \sin theta$	mu	Assessment
	n/a	n/a

15. Test Results Conclusion: (evaluated using June 1, 1988 revision of "AASHTO Standard Specifications for Highway Bridges")

a. The vehicle was NOT contained by the test article. b. There were no detached elements. c. Integrity of the passenger compartment was maintained. d. The vehicle remained upright. e. The vehicle was not redirected. f. Not evaluated. g. Not required, see above for data. h. No exit angle, vehicle exited on the field side of rail. THE TEST ARTICLE FAILED DUE TO VEHICLE PENETRATION AND VEHICLE VAULTING RAIL.

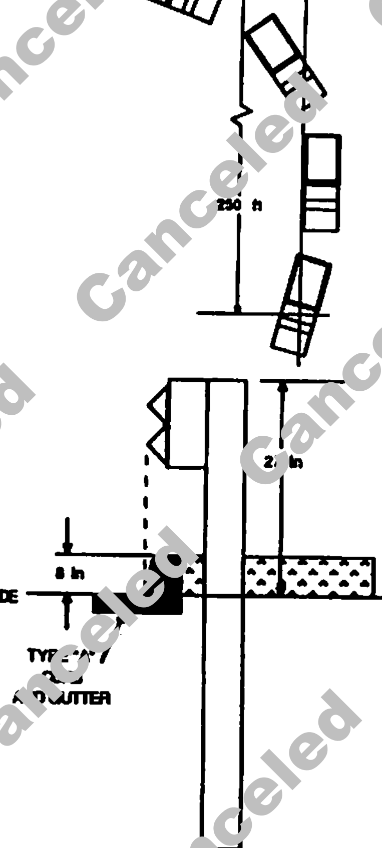
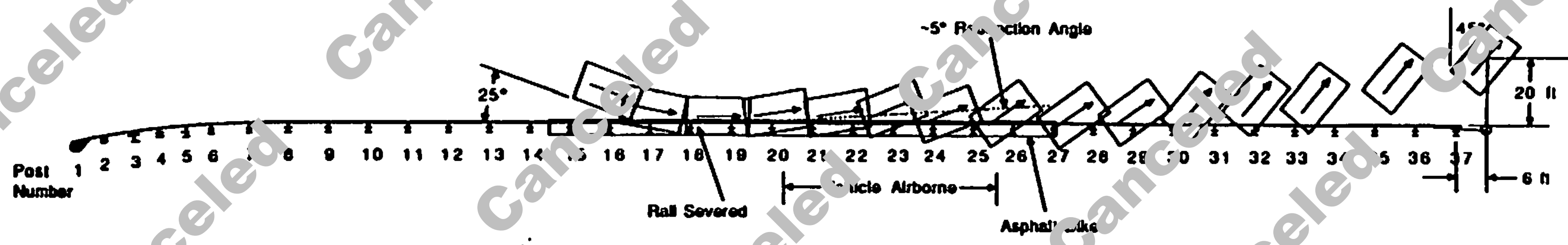


Figure 4. Test summary, test 1862-1-88.



Date:	28 March 19[illegible]
Weather:	Clear 80 [illegible]
Test Vehicle:	1980 [illegible]outh Gran Fury
Device Configuration:	[illegible] W-Beam with AASHTO 6-in, [illegible] G asphalt dike in front of barrier, 219 ft total length [illegible]7.5-ft BCT

1. Vehicle Weight:
   - Planned, Inertial: 4500 ± 200
   - Actual, Inertial: 4310
   - Planned, Gross: 4500 ± 300
   - Actual, Gross: 4625
2. Number of Occupants: Two
3. Occupant Model: [illegible]t 572, 50[illegible] percentile male, uninstrumented
4. Occupant Location: Driver Seat, Restrained; Passenger Seat, Unrestrained
5. Impact:

	Speed	Angle (a)	Location
Planned:	60.0 [illegible]	25°	Midspan posts [illegible] and 17
Actual:	60.[illegible] mi/h	25°	6 in downstream of design point

6. Redirection Angle: ~5°*
7. Redirection Speed: ~39.8 mi/h (~58.4 ft/s)*
8. Total Speed Change: ~20.5 mi/h (~30 ft/s)*
9. Total Momentum Change: ~4[illegible] lb-s*
10. Vehicle Damage Index: (SAE J224a) [illegible]RDEW2
11. NCHRP 230 Test Number: S13; AASHTO Test Type: n/a
12. NCHRP 230 Impact Severity:

    $\frac{m(V \sin a)^2}{2}$ 93.4 kip-ft (Spec: [illegible]9 to 114 kip-ft)

13. Vehicle Analysis:

	Observed	Design/ Limit Value
Longitudinal:		
Delta-V at 2 ft:	-21.7 ft/s	30/40 ft/s
Ridedown Acceleration:	-4.7 g's	15/20 g's
Lateral:		
Delta-V at 1 ft:	17.2 ft/s	[illegible]/30 ft/s
Ridedown Acceleration:	9.8 g's	[illegible]/20 g's
TRC 191:		
Peak 50 ms acceleration:		
Longitudinal:	[illegible] g's	
Lateral:	5.[illegible] g's	

14. Test Results Conclusion:

    NCHRP 230: MEETS ALL CRITERIA. Although the test barrier successfully redirected the vehicle, it [illegible] the barrier is at its performance limit.

* Due to the yawing and pitching of the vehicle, exact measures of the redirection angle and speed are not possible.

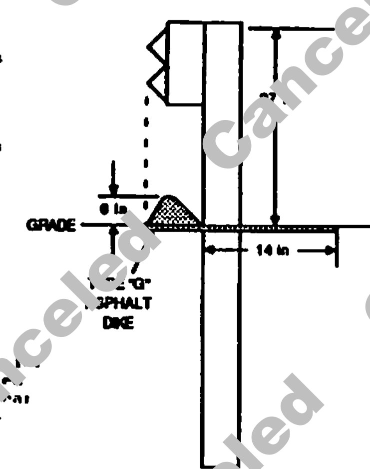
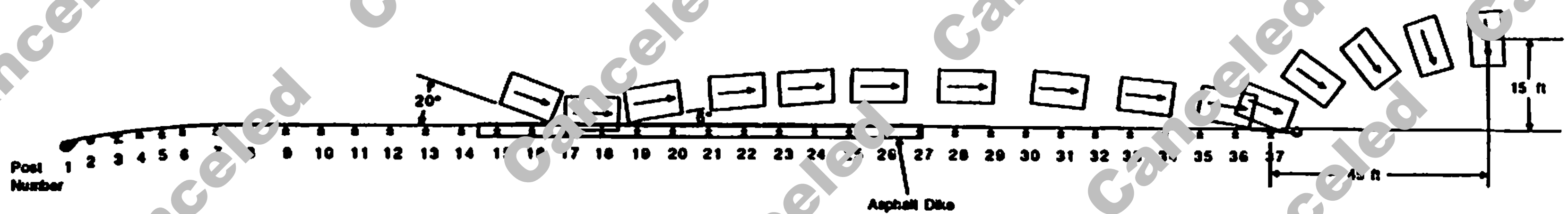


Figure 4. Test summary, test 1862-5-89.



Date:	17 March 198[illegible]
Weather:	Clear 60° F
Test Vehicle:	1982 Honda Civic
Device Configuration:	G4(1S) W-Beam with AASHTO 6-in, Type [illegible] asphalt dike in front of barrier, 219 ft total length, 37.5-ft BCT

1. Vehicle Weight:

Planned, Inertial:	1800
Actual Inertial:	1799
Planned Gross:	1950
Actual Gross:	1946

2. Number of Occupants: One
3. Occupant Model: Part 572 50th percentile male, fully instrumented
4. Occupant Location: Driver Seat, Restrained
5. Impact:

	Speed	Angle (a)	Location
Planned:	60.0 mi/h	20°	Midspan posts 16 and 17
Actual:	62.2 mi/h	20°	Midspan posts 16 and 17

Tolerances: Speed: -1.0, +2.5 mi/h; Angle: -1.0, +2.5 degrees

6. Redirection Angle: 6°
7. Redirection Speed: 45.5 mi/h ([illegible] ft/s)
8. Total Speed Change: 16.7 mi/h (24.4 ft/s)
9. Total Momentum Change: 1475 lb-s
10. Vehicle Damage Index (SAE J224a): 01[illegible]EW2
11. NCHRP 230 Test Number: S11
AASHTO Test Type: PL2
12. NCHRP 230 Impact Severity:

$\frac{m(V \sin a)^2}{2}$ 27.2 kip-ft (Spec. 2[illegible] to 29 kip-ft)

13. Vehicle Analysis:

	Observed	Design/ Limit Value
Longitudinal:		
Delta-V at 2 ft:	-22.8 ft/s	30/40 ft/s
Ridedown Acceleration:	-2.4 g's	15/20 g's
Lateral:		
Delta-V at 1 ft:	23.7 ft/s	20/[illegible] ft/s
Ridedown Acceleration:	12.5 g's	[illegible] g's
TRC 191:		
Peak 50 ms Acceleration:		
Longitudinal:	-5.8 g's	
Lateral:	10.0 g's	

14. Vehicle-Railing Interaction Coefficient of Friction:

$\mu = \frac{\cos\theta - V_p/V}{\sin\theta}$ mu 0.43, assessment Marginal

V_p = 49.4 mi/h (72.4 ft/s)

15. Test Results Conclusions:

AASHTO Bridge Rail Specification:	MEETS ALL REQUIRED CRITERIA.
NCHRP 230:	MEETS ALL CRITERIA.

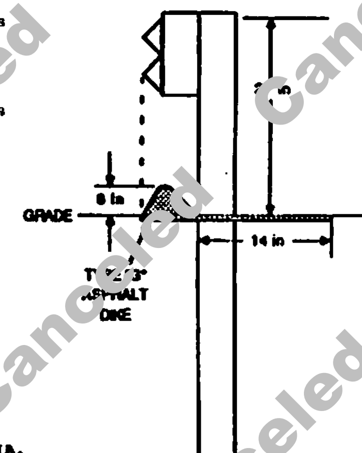
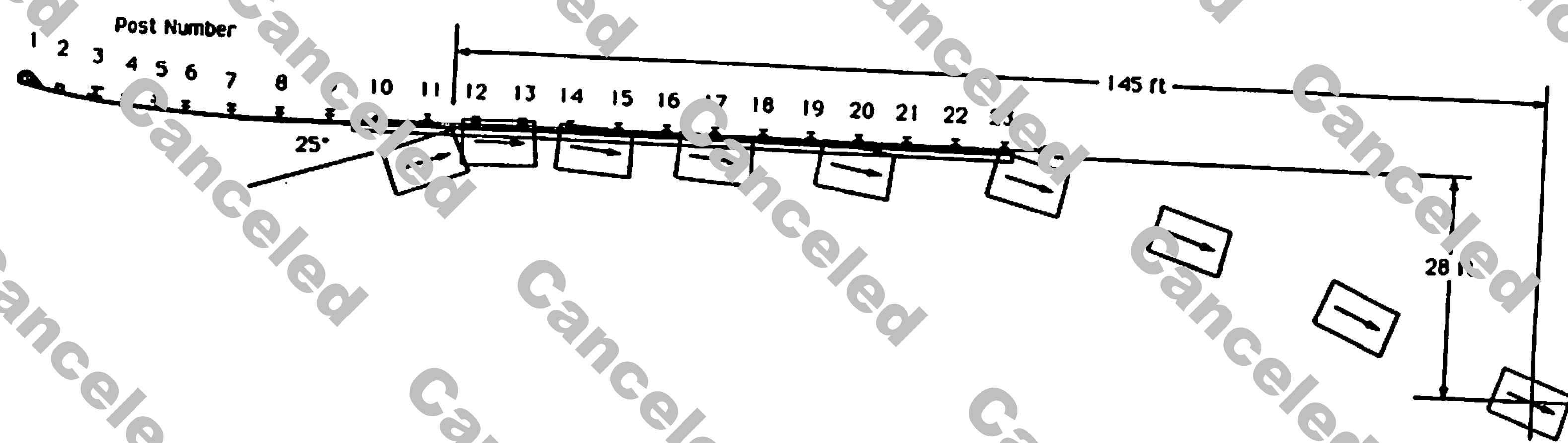


Figure 4. Test summary, test 1862-4-89.



Contract Number: DTFH61-87-C-00126
Date: 10 October 1990
Weather: Clear, 80° F

Test Vehicle: 1980 Chrysler Newport

Device Configuration: (SIS) W-Beam with AASHTO 4-in, Type H concrete curb in front of barrier, 131.25 ft total length, 37.5-ft BCT Terminal, 93.75-ft LON.

1. Vehicle Weight:
   - Planned, Inertial: 4500 ± 200
   - Actual, Inertial: 4310
   - Planned, Gross: 4500 ± 200
   - Actual, Gross: 4645
2. Number of Occupants: Two
3. Occupant Model: Part 572, 50 percentile male
4. Occupant Locations: Driver Seat, Restrained; Passenger Seat, Unrestrained
5. Impact:

	Speed	Angle	Location
Planned:	60.0 mi/h	25°	Midspan, posts 11 and 12
Actual:	61.6 mi/h	25°	Midspan, posts 11 and 12

6. Redirection Angle: -3 degrees
7. Redirection Speed: 38.3 mi/h (56.2 ft/s)
8. Total Speed Change: 23.3 mi/h (34.2 ft/s)
9. Total Momentum Change: 4934 lb-sec
10. Vehicle Damage Index: (SAE J224a) 11LDEW2
11. NCHRP 230 Test Number: 10
12. NCHRP 230 Impact Severity:

$\frac{M(V \sin\theta)^2}{2}$ 97.8 kip-ft (Spec: 89 to 114 kip-ft)

13. Vehicle Analysis:

	Observed	Design/Limit Value
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-21.1 ft/s	30/40 ft/s
Ridedown Acceleration:	-5.4 g's	15/20 g's
Driver:		
Delta-V at 2.25 ft (actual):	-22.3 ft/s	30/40 ft/s
Ridedown Acceleration:	-5.4 g's	15/20 g's
Passenger actual was also 2.25 ft		
Lateral:		
Delta-V at 1 ft:	-14.8 ft/s	20/30 ft/s
Ridedown Acceleration:	-10.0 g's	15/20 g's
Driver and passenger actuals were also 1.00 ft		
SAE 191:		
Peak 50 ms acceleration:		
Longitudinal:	-[illegible] g's	
Lateral:	-5.[illegible] g's	

14. Test Result/Conclusion:

NCHRP 230: MEETS ALL CRITERIA.

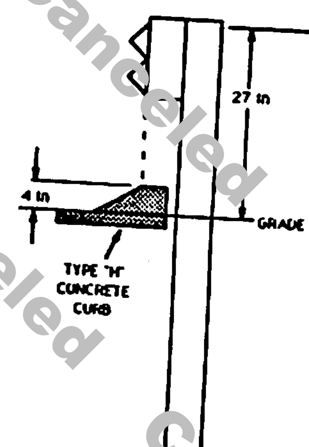
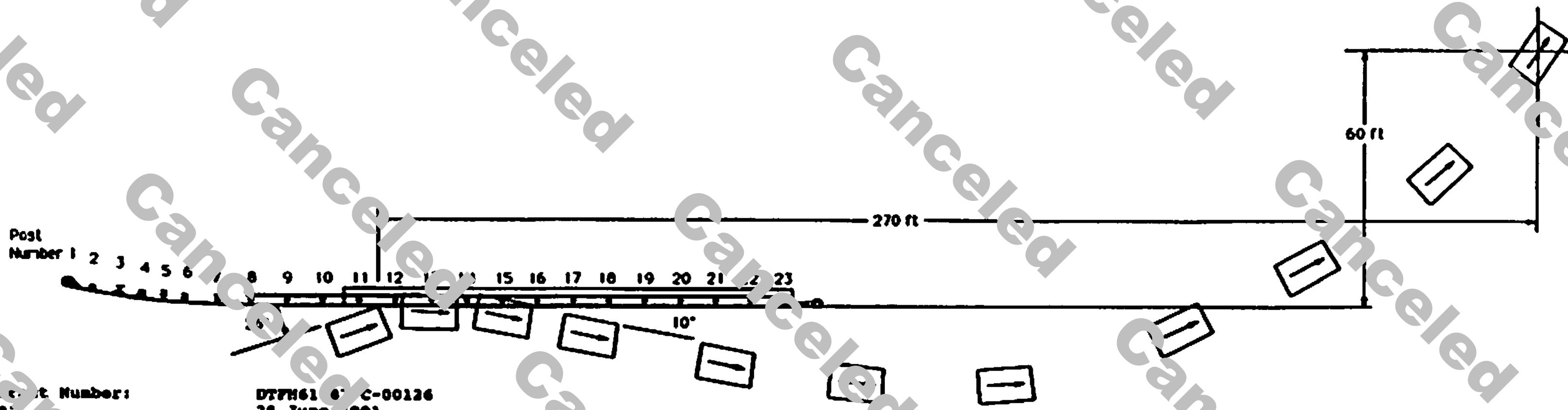


Figure 4. Test summary, test 1862-12-90.



Contract Number:	DTFH61-8[illegible]-C-00126
Date:	25 June 1991
Weather:	Clear, 70° F
Test Vehicle:	1979 Chrysler Newport
Device Configuration:	Modified G4(1S) W-beam with AASHTO 6-in, Type G asphalt [illegible] in front of barrier, 131.25 ft [illegible] length, 37.5-ft BCT Terminal, [illegible].75-ft LON. Second span of W-beam [illegible] to back of posts with no blockout [illegible] at 27 in height.

1. Vehicle Weight:

Planned, Inertial:	4500 ± 200
Actual, Inertial:	4341
Planned, Gross:	[illegible]500 ± 300
Actual, Gross	4679

2. Number of Occupants: Two
3. Occupant Model: Part [illegible], 50 percentile male
4. Occupant Locations: Driver Seat, Unrestrained; Passenger Seat, Restrained
5. Impact:

	Speed	Angle	Location
Planned:	60 mi/h	25°	Midspan, posts 11 and 12
Actual:	61.[illegible] mi/h	26°	Midspan, posts [illegible] and 12

6. Redirection Angle: -10 degrees
7. Redirection Speed: 33.1 mi/h (48.5 ft/s)
8. Total Speed Change: 28.3 mi/h (41.6 ft/s)
9. Total Momentum Change: 6045 lb-sec
10. Vehicle Damage Index: (SAE J224a) 11LDE[illegible]
11. NCHRP 230 Test Number: 10
12. NCHRP 230 Impact Severity:

$\frac{m(V \sin a)^2}{2}$ 105.2 kip-ft (Spec: 89 to 114 [illegible])

13. Vehicle Analysis:

	Observed	Design/ Limit Value
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-26.4 ft/s	30/40 ft/s
Ridedown Acceleration:	-9.2 g's	15/20 g's
Driver:		
Delta-V at 2.17 ft (actual):	-2[illegible] ft/s	30/40 ft/s
Ridedown Acceleration:	-9.2 [illegible]	15/20 g's
Passenger:		
Delta-V at 1.83 ft (actual):	-24.5 ft/s	30/40 ft/s
Ridedown Acceleration:	-9.2 g's	[illegible] g's
Lateral:		
Delta-V at 1 ft:	-18.3 ft/s	20/30 [illegible]
Ridedown Acceleration:	-8.8 g's	15/20 g's
Driver:		
Delta-V at 1.[illegible] ft (actual):	[illegible].2 ft/s	20/30 ft/s
Ridedown Acceleration:	-6.8 g's	15/20 g's
Passenger:		
Delta-V at 1.17 ft (actual):	-19.6 ft/s	20/30 ft/s
Ridedown Acceleration:	-8.8 g's	15/20 g's
TRC 191:		
[illegible] 50 ms acceleration:		
Longitudinal:	-7.1 g's	
Lateral:	-6.2 g's	

14. Test Results Conclusion:

NCHRP 230 — MEETS ALL CRITERIA.

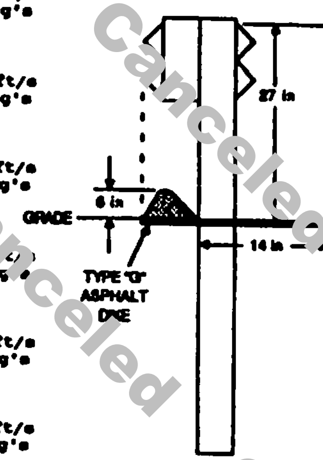
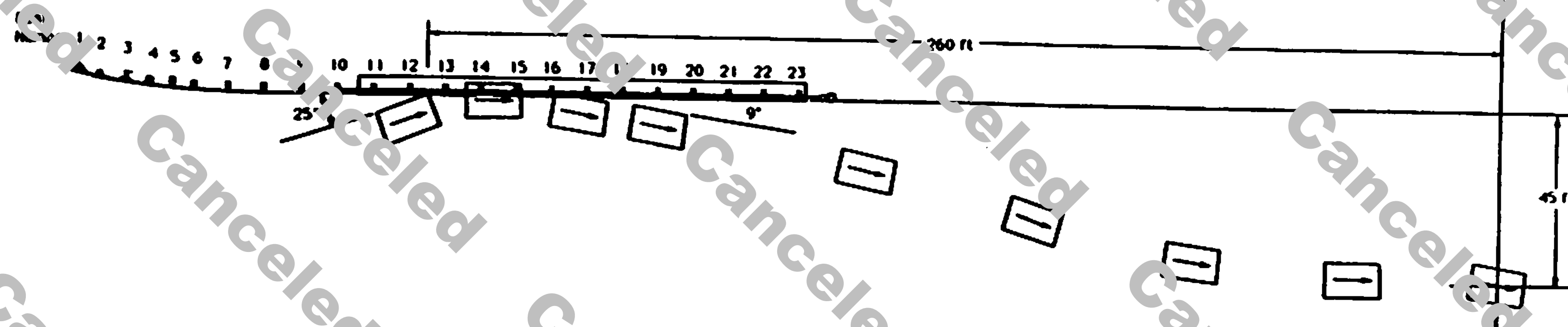


Figure [illegible]. Test summary, test 1862-13-91.



Contract Number:	DTFH61-87-C-00126
Date:	18 July 1991
Weather:	Clear, 90° F
Test Vehicle:	1981 Plymouth Gran Fury
Device Configuration:	Modified G4(1S) W-beam with AASHTO 6-in. Type G asphalt dike in front of barrier, 131.25 ft total length, 37.5-ft BCT Terminal, 93.75-ft LON. C6x8.2 channel rubrail mounted 0.5 in below bottom of blockout.

1. Vehicle Weight:

Planned, Inertial:	4500 ± 200
Actual, Inertial:	4380
Planned, Gross:	[illegible]00 ± 300
Actual, Gross	4708

2. Number of Occupants: Two

3. Occupant Model: Part 572, 50 percentile male

4. Occupant Locations: Driver Seat, Unrestrained; Passenger Seat, Restrained

5. Impact:

	Speed	Angle	Location
Planned:	60.0 mi/h	25°	Midspan, posts 12 and 13
Actual:	62.1 mi/h	25°	3 ft downstream of desired

6. Redirection Angle: -9 degrees

7. Redirection Speed: [illegible].7 mi/h (67.1 ft/s)

8. Total Speed Change: 16.4 mi/h (24.0 ft/s)

9. Total Momentum Change: 3509 lb-sec

10. Vehicle Damage Index: (SAE J224a) 11LDEW

11. NCHRP 230 Test Number: 10

12. NCHRP 230 Impact Severity: $\frac{m(V \sin a)^2}{2}$ 100.8 kip-ft (Spec: 89 to 116 kip-ft)

13. Vehicle Analysis:

	Observed	Design/ Limit Value
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-18.8 ft/s	30/40 ft/s
Ridedown Acceleration:	-4.0 g's	15/20 g's
Driver:		
Delta-V at 2.42 ft (actual):	-20.6 ft/s	30/40 ft/s
Ridedown Acceleration:	-3.5 g's	15/20 g's
Passenger:		
Delta-V at [illegible].08 ft (actual):	-18.[illegible] ft/s	30/40 ft/s
Ridedown Acceleration:	-4.0 g's	15/20 g's
Lateral:		
Delta-V at 1 ft:	-16.9 ft/s	20/30 ft/s
Ridedown Acceleration:	-9.4 g's	15/20 g's
Driver:		
Delta-V at 1.04 ft (actual):	-17.2 ft/s	20/30 ft/s
Ridedown Acceleration:	-9.4 g's	15/20 g's
Passenger:		
Delta-V at 0.1[illegible] ft (actual):	-16.[illegible] ft/s	20/30 ft/s
Ridedown Acceleration:	-[illegible] g's	15/20 g's
TRC 191:		
Peak 50 ms acceleration:		
Longitudinal:	-4.0 g's	
Lateral:	-7.0 g's	

14. Test Results Conclusion:

NCHRP 230: DOES NOT MEET ALL CRITERIA. The vehicle speed change at redirection is greater than the 15 mi/h maximum. The test meets all other evaluation criteria.

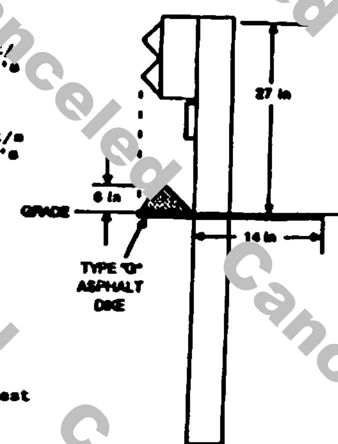


Figure 4. Test summary, test 1862-14-91.