W-Beam Guiderail Transition from Light to Heavy Posts

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Two full-scale crash tests evaluated a transition between light- and heavy-post W-beam guiderail. The transition consisted of lowering the rail height from 30 to 27 inches and reducing the spacing of the light posts as the heavy-post section is approached. The crash-test impacts were just upstream of the heavy-post section using 1,800- and 4,500-pound sedans. Test results were generally acceptable in terms of National Cooperative Highway Research Program (NCHRP) criteria. Although the exit trajectory of the 4,500-pound sedan exceeded the recommended threshold limits, the vehicle was not judged to present a significant threat to other vehicles.

The state of New York makes extensive use of corrugated-steel (W-beam) guiderail on its highway system. Two W-beam systems are used—light post and blocked-out heavy post. Cable and box-beam light-post barriers are also used. Until recently, the light-post cable, W-beam, and box-beam systems were generally not used on the same highways as the heavy-post W-beams. The heavy-post system was limited primarily to high-volume urban roadways where high accident rates make it difficult to maintain light-post barriers in functional condition. Light-post barriers were generally used elsewhere.

When using light-post barriers, system selection depends on available deflection space behind the barrier. Because cable and W-beam are more flexible and provide a more forgiving impact, as well as a lower first cost, they are used where available deflection space permits. As deflection space decreases, dynamic impact deflection can be reduced somewhat by reducing post spacing. For more severe limitations, it becomes necessary to transition from cable to W-beam or from W-beam to box-beam. However, the transition from light-post W-beam to box-beam is very expensive and, thus, not a desirable option. In addition, though performance of these guiderail systems had been documented through full-scale crash tests and in-service performance evaluations (*1*, *2*), less is known about performance of the transition between them.

Increased use of heavy-post W-beam barrier in New York has provided an additional option for limiting dynamic impact deflections, and it was quickly recognized that a transition from light-post to heavy-post W-beam guiderail may offer advantages compared to the W-beam to box-beam transition previously used. Thus, the department's engineering staff developed the transition shown in Figure 1 and described in the Traffic and Safety Division publication *Guiderail II* (*3*).

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This transition was designed to provide a gradual stiffening of the W-beam to avoid snagging vehicles that impact near it. Spacing of the light posts is decreased as they near the heavy-post section, and the rails are gradually lowered from 30 inches to match the 27-inch height on the heavy posts. While this design apparently would perform acceptably, evaluation through full-scale crash tests was desirable to ensure acceptable impact performance.

METHODOLOGY AND BARRIER DESCRIPTION

This study consisted of two full-scale crash tests conducted to evaluate the transition section. The testing and data analysis procedures outlined in NCHRP Report 230 (*4*) were used. The test matrix consisted of the two tests—NCHRP Test Designations 30 and 12. Test 30 used a 4,500-pound vehicle to determine structural adequacy and is the only one specified in NCHRP 230 for transition sections. Test 12 was included to evaluate occupant risk in a small, 1,800-pound vehicle and to give a more complete picture of transition performance.

The barrier, constructed of standard 12-gauge W-beam guiderail, transitions from light post (S3 x 5.7) to heavy post (W6 x 9) with blockouts. The barrier consisted of eighteen W-beam sections totaling 225 feet in length and was terminated at both ends with standard turndowns and precast concrete anchors. A plan view of the barrier as tested is shown in Figure 2, with additional details in Figure 3.

The barrier was erected 30 inches high for the initial light-post sections. Post spacing was 6 feet 3 inches for the first two rail sections and 3 feet 1½ inches for Sections 3 and 4. In Section 4, rail height was transitioned from 30 to 27 inches. The beam was attached to every other post in Sections 3 and 4 using 5/16-inch hex-head bolts, with the quarter-point posts provided only to provide lateral support. Within the heavy-post section, the W-beam was attached to all posts using 5/8-inch hex-head bolts with rectangular washers.

RESULTS

Results of the two full-scale crash tests are summarized in Table 1. The vehicles and barrier after the tests are shown in Figure 4, and Figures 5 and 6 provide sequential impact photographs. Vehicle trajectories are diagrammed in Figure 7.

Test 108 evaluated the transition for snagging or rollover tendencies of small cars. Excessive vehicle decelerations that might cause occupant injuries were also noted. An 1,800-pound Honda Civic impacted the barrier at 61.2 mph and 13

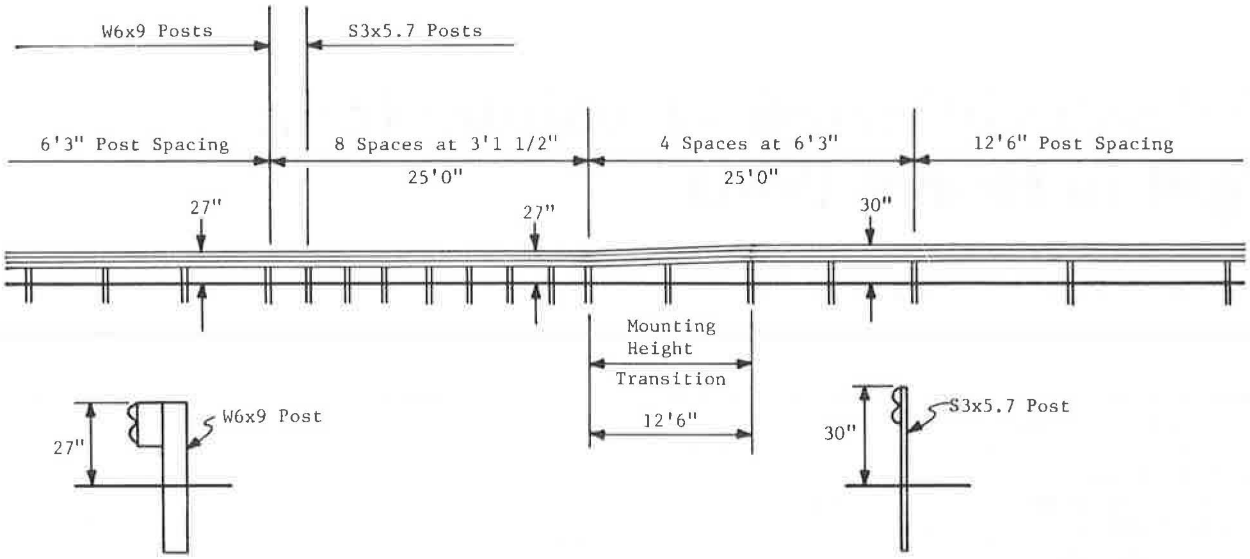

FIGURE 1 W-beam guiderail transition from light to heavy posts.

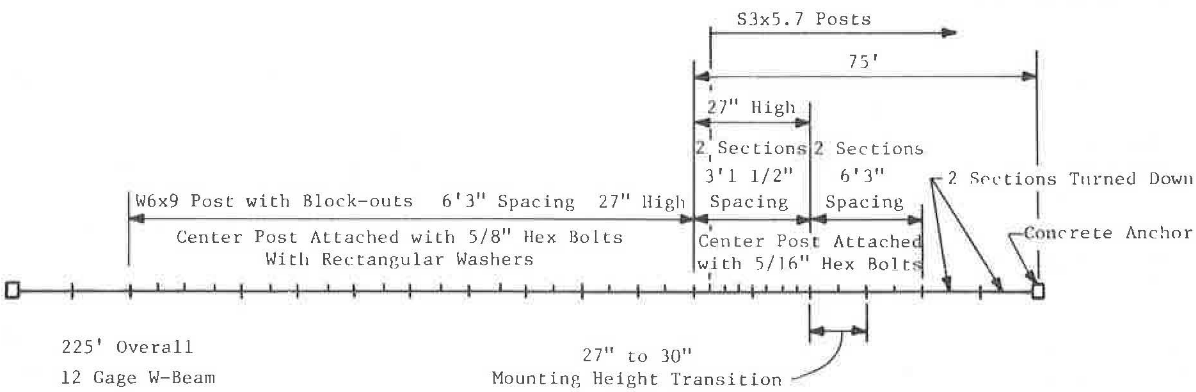

FIGURE 2 Plan view of barrier used for Tests 108 and 109.

degrees, with impact 4 feet upstream from the first heavy post. The vehicle was in contact with the barrier for only 4 feet, then exited smoothly at 8 degrees and 51.6 mph. There was no measurable barrier deflection, and the W-beam was only scuffed. Vehicle damage was light, consisting of sheet metal damage along the right side, and minor damage to the grill and bumper. Maximum vehicle roll was 3 degrees clockwise, with no measurable pitch or yaw. Peak 50-ms average decelerations were 1.2 g longitudinal and 12.2 g lateral. Thus, longitudinal critical distance was not reached, and occupant impact velocity and occupant ridedown deceleration were not computed. Lateral occupant impact velocity was 17.9 feet per second (fps), based on a measured flail distance of 0.5 feet with a ridedown deceleration of 13.5 g. Vehicle redirection was very smooth and the vehicle was operable after impact.

NCHRP Report 230 Test Designation 30 was used in Test 109 to evaluate the barrier for structural adequacy and redirectional capability. A 4,600-pound Chrysler sedan impacted the barrier 17 feet upstream from the first heavy post at 58.1 mph and 27 degrees. Dynamic barrier deflection was 4 feet during the 29-foot contact distance, and the vehicle exited at 21 degrees and 33.4 mph. Maximum vehicle roll was 2 degrees clockwise, pitch was 7 degrees nose down, and no yaw was observed. Barrier and vehicle damage (Figure 4) were moderate. Three rail sections, three heavy posts, and eight light posts were bent. The vehicle sustained sheet metal damage to the right front fender, right front door, and right rear fender; there was also grill and bumper damage. Both right tires were deflated, and the right front wheel was damaged. Although not required evaluation criteria for this test, the occupant impact velocities and ridedown decelerations are reported in Table 1. The lateral values are below recommended threshold values, and the longitudinal values nearly meet those for 15 degree impacts. Redirection of the vehicle was smooth, with no excessive roll, pitch, or yaw.

DISCUSSION AND FINDINGS

These tests were evaluated using the criteria in NCHRP 230 for structural adequacy, occupant risk, and vehicle trajectory. As mentioned previously, the only test specifically designated

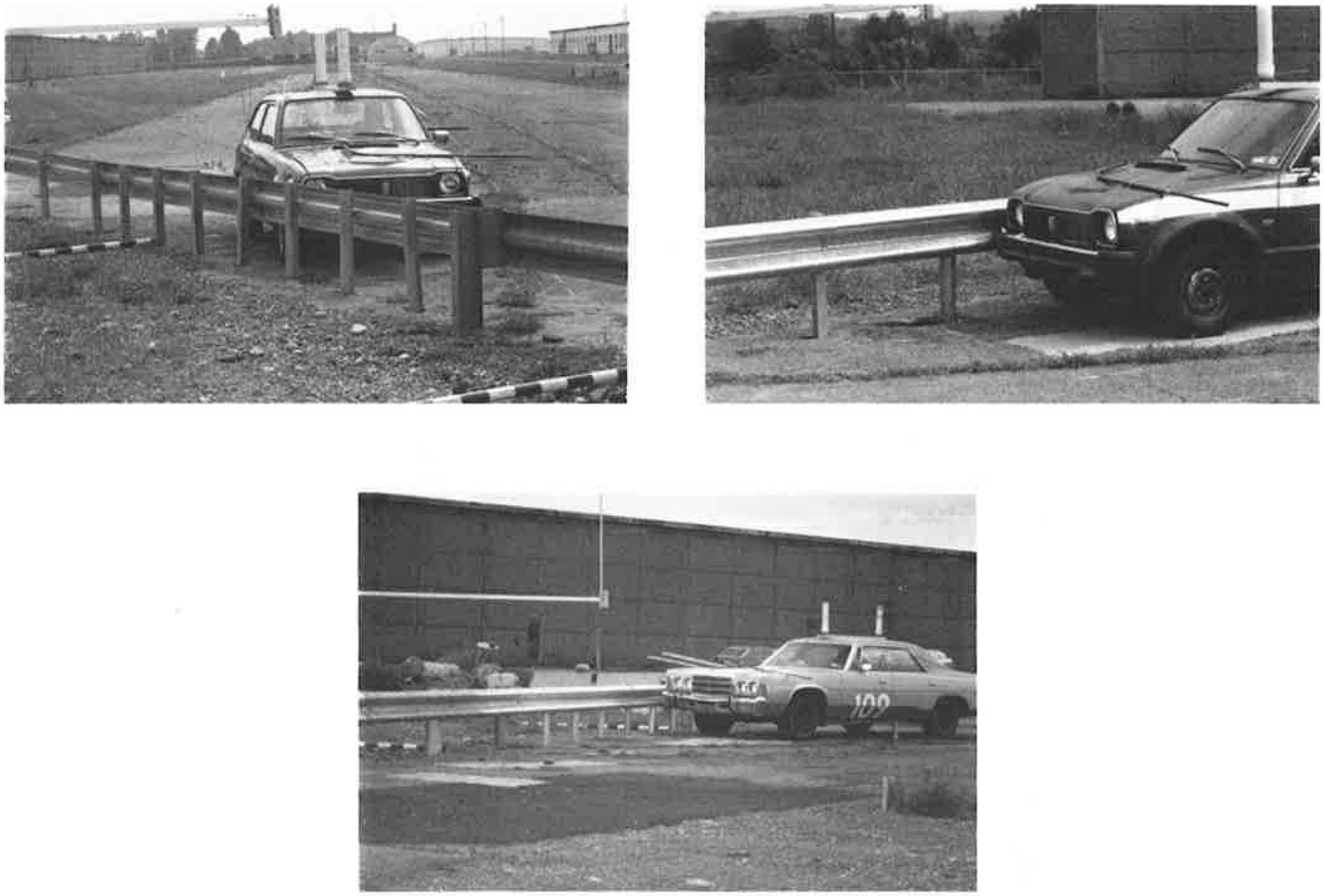

FIGURE 3 Vehicles and barriers before impacts in Test 108 (top) and Test 109 (bottom).

for transitions is with a 4,500-pound vehicle impacted at 60 mph at a 25 degree angle. To provide a more complete picture of the transition's performance, a subcompact vehicle was included in this evaluation. The small-vehicle test would help point out deficiencies in redirection or occupant risk that might not affect a heavier vehicle. Measured test values and NCHRP criteria are compared in Table 2.

Structural adequacy criteria require that the barrier smoothly redirect the vehicle, without threatening the integrity of the passenger compartment by detached elements or fragmenting. The barrier showed no tendency to break apart or have loose elements fly off. As expected of a semi-rigid barrier system, the small vehicle in Test 108 caused minimal deflection, and was quickly redirected after contacting the rail for a short distance. In Test 109, the heavier vehicle caused considerable deflection, but redirection was smooth with no snagging as it traveled from the light-post to the heavy-post section. Both tests, thus, were judged to be in compliance with the structural adequacy evaluation factors.

Both tests easily met Evaluation Factor *E* that the vehicle remain upright, experiencing only mild roll, pitch, or yaw. Neither vehicle sustained passenger compartment damage. Factor *F* (occupant impact values) does not apply to the large-car test. However, those test values were provided for information, and it is seen that the longitudinal values for this 25 degree impact only slightly exceeded desirable values for 15 degree impacts, and the lateral values were below the recommended thresholds. The small-car test easily passed the longitudinal criterion, because the theoretical occupant did not travel the flail distance. Based on a measured flail distance of 0.5 feet, the lateral occupant impact velocity and ridedown acceleration were both within recommended thresholds. NCHRP Report 230 specifically provides for the use of actual measured flail distance when available, rather than the standard assumed value of 1.0 foot. Both tests thus were judged to meet the occupant risk factors.

The post-collision trajectory is required to result in no more than minimal intrusion into adjacent traffic lanes. In addition, these tests require the exit angle be less than 60 percent of the impact angle, with less than a 15-mph speed loss.

In Test 108, the speed change was less than 10 mph, and the departure angle was 62 percent of the impact angle. The vehicle departed the barrier on a straight path, and would eventually have crossed into the adjacent lane as it continued away from the barrier. However, damage to the vehicle was light, and it was fully operable after impact. Combined with the smooth redirection trajectory, risk of a secondary collision appeared low, and the test, thus, was considered satisfactory in terms of post-impact trajectory.

For Test 109, the post-impact trajectory was less favorable. Velocity change was nearly 25 mph, and the departure angle was 78 percent of the impact angle. In addition, the exit

TABLE 1 TEST RESULTS

Item	Test 108	Test 109
Point of Impact	4 ft upstream from first heavy post	17 ft upstream from first heavy post
Barrier Length, ft	225	225
Vehicle Weight, lb	1800	4600
Vehicle Speed, mph	61.2	58.1
Impact Angle, deg	13	27
Exit Angle, deg	8	21
Exit Speed, mph	51.6	33.4
Maximum Roll, deg	3 clockwise	2 clockwise
Maximum Pitch, deg	0	7 down
Maximum Yaw, deg	0	0
Contact Distance, ft	4	29
Contact Time, ms	190	750
Barrier Deflection, ft		
Dynamic	0*	4.0
Permanent	0*	2.6
Deceleration, g		
50-ms avg		
Longitudinal	1.2	8.7
Lateral	12.2	5.6
Occupant Impact Velocity, fps		
Longitudinal (2.0 ft)	**	32.1
Lateral (0.5)***	17.9	15.4
Occupant Ridedown, 10-ms avg		
Longitudinal	**	21.0
Lateral	13.5	18.7
Redirection	Smooth	Smooth
Vehicle Damage		
TAD	RFQ-3	RFQ-4
SAE	01RDMS1	01RFMP2

*Deflections were too slight to permit measurement.
**Critical distance not reached.
***Measured flail distance was 0.5 ft for 1800-lb sedan; assumed distance of 1.0 ft was used for 4500-lb sedan.

trajectory carried the vehicle away from the barrier where it would have entered the adjacent lanes. Although post-impact vehicle trajectory was smooth, these test results do not comply technically with the recommended criteria. However, considering the difficulty in transitioning from a relatively flexible to a relatively stiff barrier, this comparatively abrupt redirection is not unexpected. Recently reported test results (5) show that the recommended threshold values for post-impact vehicle trajectory are not met by a number of barrier systems widely recognized as providing an acceptable level of in-service performance. It may be possible to smooth this departure trajectory somewhat by adding additional light posts to effect a more gradual stiffening of the barrier. However, these additional posts would interact with smaller cars and might adversely affect the good performance seen in Test 108. In light of the good results achieved for all other evaluation factors, vehicle trajectory in Test 109 is considered an acceptable compromise, especially since secondary collisions with other vehicles have been shown to be a rare event (*6*).

Based on these two full-scale crash tests, the following findings can be stated:

1. The transition from light- to heavy-post W-beam guiderail successfully contained 1,800- and 4,500-pound sedans.
2. This transition met the occupant risk criteria of NCHRP 230 for 1,800- and 4,500-pound vehicles.
3. Both vehicles were smoothly redirected by the transition, with no danger of vehicle rollover or other adverse vehicle reactions. Although the exit trajectory of the 4,500-pound sedan exceeded the limits recommended in NCHRP 230, neither vehicle was judged a significant threat to other vehicles.
4. The design tested appears suitable for field use to transition between light- and heavy-post W-beam barrier systems.

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FIGURE 4 Vehicles and barriers after Test 108 (top) and Test 109 (bottom).

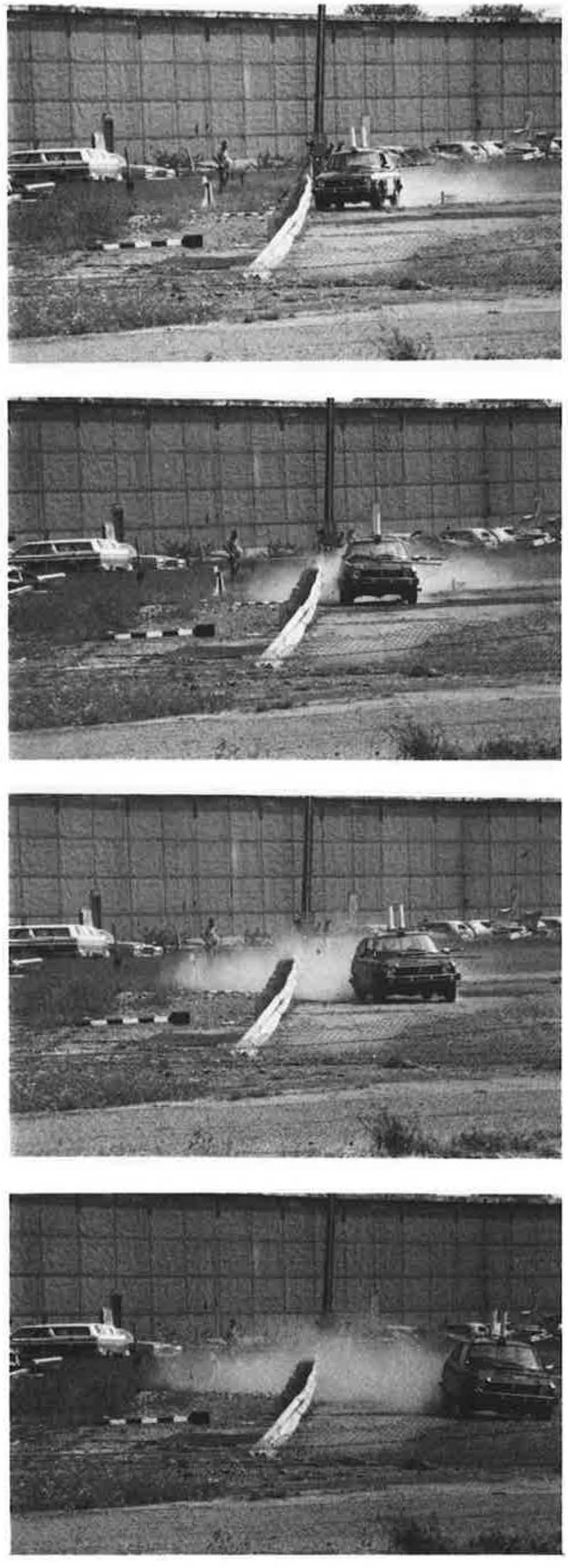

FIGURE 5 Sequential photographs of Test 108.

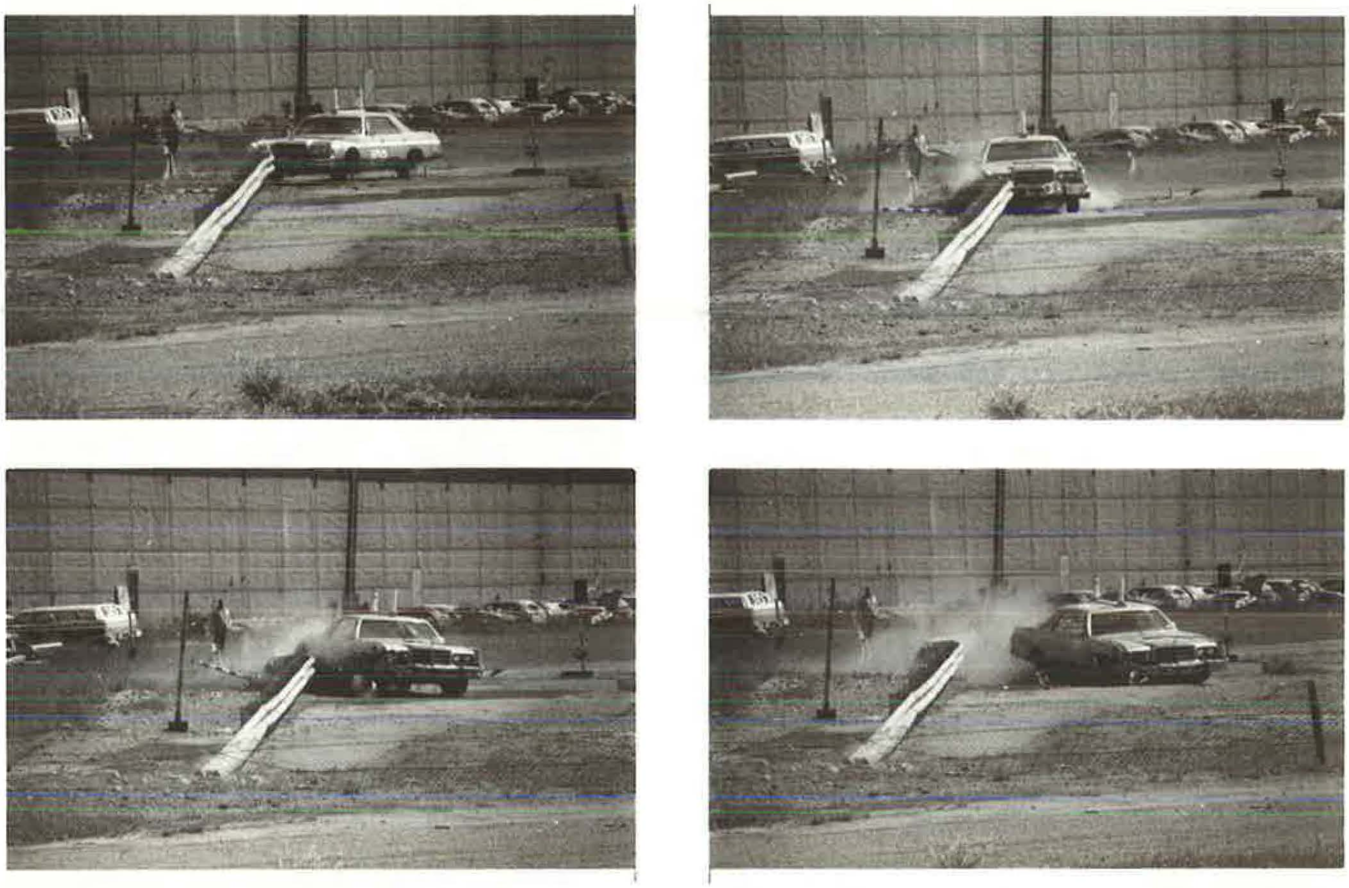

FIGURE 6 Sequential photographs of Test 109.

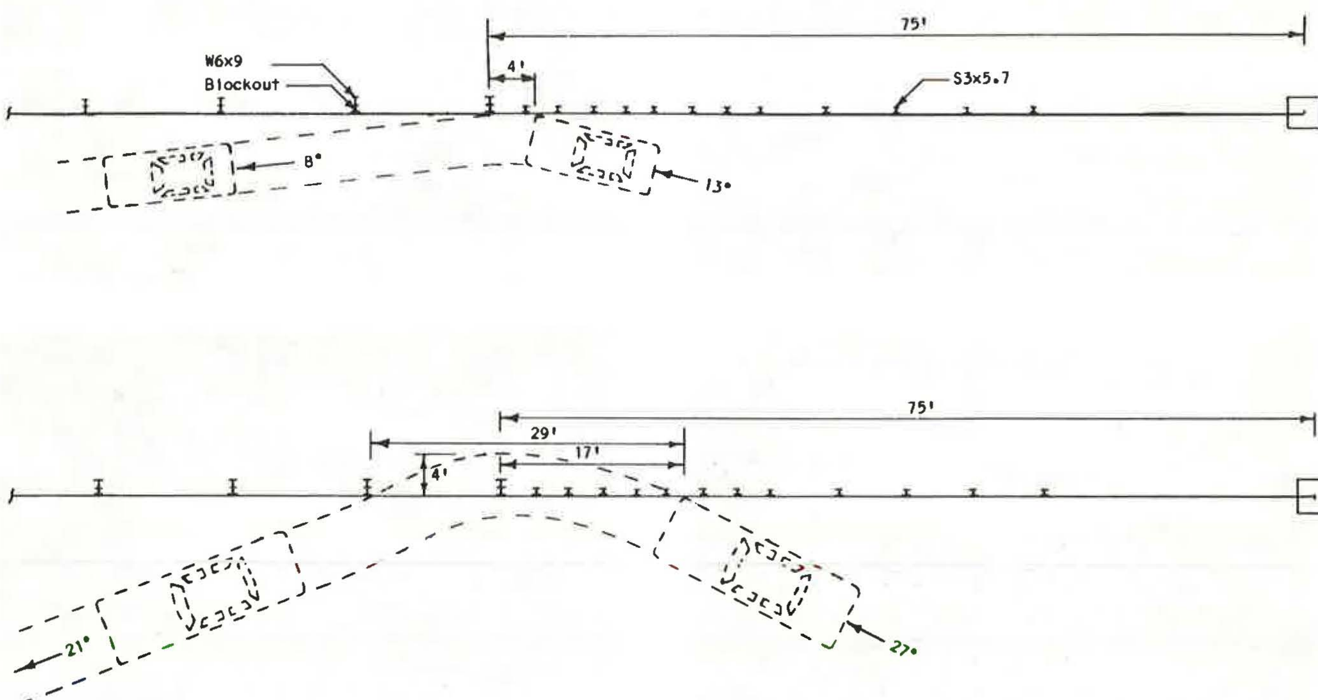

FIGURE 7 Vehicle impact trajectories in Test 108 (top) and Test 109 (bottom).

TABLE 2 TEST RESULTS COMPARED WITH NCHRP REPORT 230 EVALUATION FACTORS

NCHRP 230 Evaluation Factors	NCHRP 230 Recommended Value	Test 108 (NCHRP 12)	Test 109 (NCHRP 30)
Structural Adequacy			
A	Smooth redirection	OK	OK
D	No fragments, passenger compartment intact	OK	OK
Occupant Risk			
E	Vehicle upright, passenger compartment intact	OK	OK
F	Occupant Impact Velocity		
	30 longitudinal	*	***
	20 lateral	17.9**	***
	Ridedown Deceleration		
	15 longitudinal	*	***
	15 lateral	13.5	***
Vehicle Trajectory			
H	Minimum intrusion into adjacent lane	OK	Marginal
I	Speed change <15 mph	9.6	24.7
	Exit angle $\leq$0.6 impact angle	62%	78%

*Occupant did not travel the flail distance
**Based on 0.5-ft flail distance.
***Evaluation Factor F not required for 25° impacts.

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