Dynamic Tests of Steel Box Beam and Concrete Median Barriers

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A study to determine the effectiveness of (a) a steel box beam median barrier design developed by the New York Department of Public Works and (b) a concrete median barrier design developed by the New Jersey Highway Department, by means of full-scale dynamic impact tests is reported. Three tests were conducted on the basic New York 6 by 8 by ¼-in. box beam design at speeds of 71, 64, and 49 mph and approach angles of 25, 25, and 7 deg, respectively, with slight modifications to the beam-to-post connections for each test. Three tests were conducted on the 32-in. high New Jersey concrete barrier design at speeds of 38, 65, and 63 mph and approach angles of 7, 7, and 25 deg, respectively.

Findings indicate that both the box beam and the concrete median barrier designs perform effectively and are suitable for use on flat, paved medians free of curbs, dikes, ditches, and sawtooth slopes. The median width for placement of the box beam barrier should be at least 10 ft to provide for large deflections. The concrete barrier appears to be relatively maintenance free and is particularly suitable for placement on narrow medians.

•FULL-SCALE impact tests on the New York steel box beam median barrier and the New Jersey concrete median barrier were conducted in 1966 and 1967 by the California Division of Highways. It was felt that these two barrier designs showed promise of being as effective on narrow medians as the current California W-beam median barrier and in addition appeared to offer improvement from an aesthetic viewpoint.

This report first presents the results of the tests to determine the effectiveness of a steel box beam median barrier design developed by the New York Department of Public Works. Three full scale dynamic impact tests were conducted on the basic New York 6 by 8 by ¼-in. box beam barrier design at speeds of 71, 64, and 49 mph and approach angles of 25, 25, and 7 deg, respectively, with slight modifications to the beam-to-post connections for each test.

Then, the results of the tests to determine the effectiveness of a concrete median barrier design developed by the New Jersey Highway Department are presented. Three full-scale dynamic impact tests were conducted on the 32-in. high New Jersey concrete barrier design at speeds of 38, 65, and 63 mph and approach angles of 7, 7, and 25 deg, respectively.

Although both of the basic barrier designs investigated had been subjected to previous testing by other researchers, neither had been fully tested to the California standards of 65 mph/25 deg for dynamic impact proof testing of barriers.

All tests were conducted under the general guidelines established by the Highway Research Board Committee on Guardrails and Guide Posts (1).

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DYNAMIC TESTS OF BOX BEAM MEDIAN BARRIER

The box beam median barrier's "strong beam/weak post" concept was developed during a test series conducted by the New York State Department of Public Works, in cooperation with the Bureau of Public Roads, and was reported in January 1964 (2). The report indicated that the box beam type median barrier was particularly effective in regard to vehicle redirection at a low exit angle and with a low deceleration rate.

In view of this favorable report and the generally pleasing appearance, the California Division of Highways felt that the box beam median barrier would be particularly applicable for use in narrow (6-ft and less) medians.

Objectives

The primary objectives of this series of tests were (a) to determine the effectiveness of box beam median barriers for use on narrow (6-ft or less) medians and (b) to determine its maintenance characteristics.

Conclusions

Based upon analysis of the results of this test series and the New York tests, it is concluded that the box beam median barrier is suitable for use subject to the following limitations and considerations that generally also apply to the California cable type median barrier:

1. Because of the dynamic and permanent laterial beam deflections recorded in the impact tests at critical speeds and angles, the minimum median width should be at least 10 ft to contain a box beam barrier located in the center. This minimum median width should be increased if adequate area is to be provided for maintenance vehicles on one or both sides of the barrier.
2. Until further operational or test experience is gained, the use of the box beam should be limited to flat surface medians. The median should be free of curbs, dikes, ditches, and sawtooth slopes in the vicinity of the barrier.
3. Even on flat medians, the box beam barrier may not prove to be as effective as the current California beam-type median barrier in containing trucks and other high center of gravity vehicles because the impact tests indicated that the box beam tends to deflect downward during impact, whereas the blocked-out beam tends to rise.
4. With the same vehicle at the same speed and angle, the impact into the box beam barrier resulted in lower lateral decelerations than observed during impacts with the current California W-beam type median barrier. However, lateral decelerations are higher on the box beam barrier than experienced during tests on the California cable-type barrier.
5. Due to the considerable wheel-to-post involvement observed even in the relatively moderate 49-mph/10-deg impact tests, maintenance repair costs will be greater than experienced on the beam barrier and almost as much as experienced on cable-type barrier installations.
6. Provisions to mount a glare screen on the box beam may present a problem during maintenance repairs, inasmuch as the screen would have to be mounted on the box beam itself (rather than on posts), independent of the beam, as in the case of the current blocked-out beam median barrier.
7. It is estimated that the initial construction cost in California for the box beam median barrier will range from approximately $8.50 to $11.50 per lin/ft as compared to an average of $2.50 per ft for the current cable type and $8.50 for the current blocked-out beam type median barrier.
8. Recommended design details for the box beam median barrier are shown in Exhibit 2 (Appendix).

DISCUSSION OF TESTS 141, 142, AND 143

Design and Performance. Common to each of the three box beam barrier test installations were the beams, beam splices, posts, and post footings (Exhibit 4, Appendix).

The beams were 8 by 6 by ¼-in. steel tubing ASTM A501 17 ft 11½ in. long. The beam splices utilized a one-piece sleeve-type connection. This exterior connection was selected instead of New York's two-piece clamp-type splice in an attempt to increase the beaming strength of the system, thus minimizing the lateral deflection. Due to the increased speed anticipated (65 mph vs New York's 56 mph) and the heavier test vehicles (4, 500 lb vs New York's 3, 800 lb), it was felt that the two-piece clamp might deform under the heavier impact loading conditions.

The posts were 3I5.7 by 36-in. structural steel ASTM A36 embedded 16 in. ± in a 4-in. diameter sheet metal can filled with paving grade asphalt. The post sockets were filled with 200-300 penetration asphalt for Test 141 and topped off with 85-100 penetration for Tests 142 and 143. (No 200-300 penetration asphalt was available on short notice for the later tests.)

The socketed post footings were 16 in. diam. by 24 in. deep, Class A concrete. The posts for all three barriers used the same post footings as no damage was incurred to the concrete in any of the tests.

Each of the test installations had a different type of beam to post connection. The end anchorage used for Tests 142 and 143 is detailed in Exhibit 3 (Appendix). No end anchorage was used for the Test 141 barrier.

Test 141. The installation for Test 141 was a 198-ft unanchored section of box beam barrier. The decision to test this barrier without anchoring the beam was based on (a) successful tests of 200-ft unanchored installations of box beam median barrier in the test series conducted by New York (3) and (b) successful tests of 162½-ft unanchored sections of W-beam guardrail used in the California Series X project (4).

As it was felt that the 1½ by 7-in. paddle slots in the New York design would permit localized bending to occur in the beam under severe impact loading, the post/beam connection was revised in an attempt to effect an economic and operational improvement. Figure 1 is a detail of the angle clip connection used in Test 141. It was anticipated that the ⅜-in. bolts would shear only in the immediate impact length of railing.

However, in Test 141 the barrier failed to retain the vehicle under the relatively severe 71-mph/25-deg impact conditions. The box beam was torn free of all posts and thrown more than 50 ft from the original centerline when the ⅜-in. diameter beam-to-post clip bolts throughout the entire length of the test installation failed in "zipper" action by shear and tension. Three 18-ft sections of beam were damaged beyond economical repair. However, based on the results of the succeeding Test 142, it is felt that an anchored installation with larger or high-strength beam-to-post bolts would have successfully retained the vehicle.

Due to time limitations, further testing to improve this unslotted design was discontinued in favor of testing of New York's then current paddle/slot design.

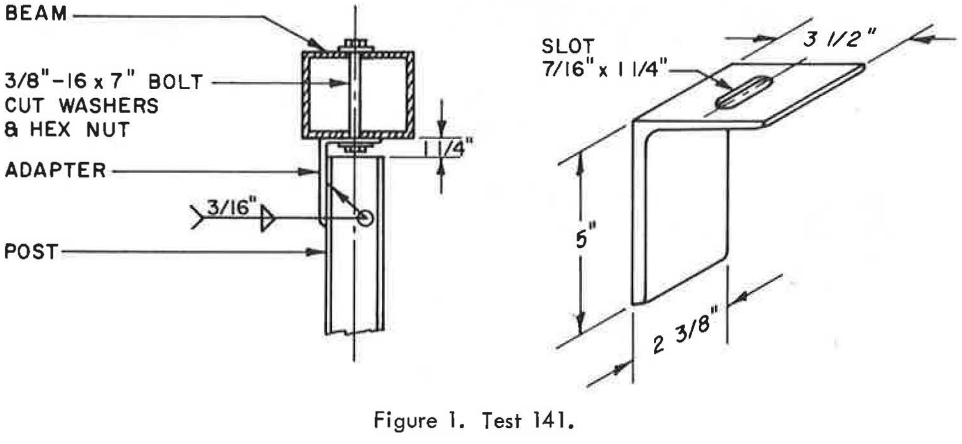

Figure 1. Test 141.

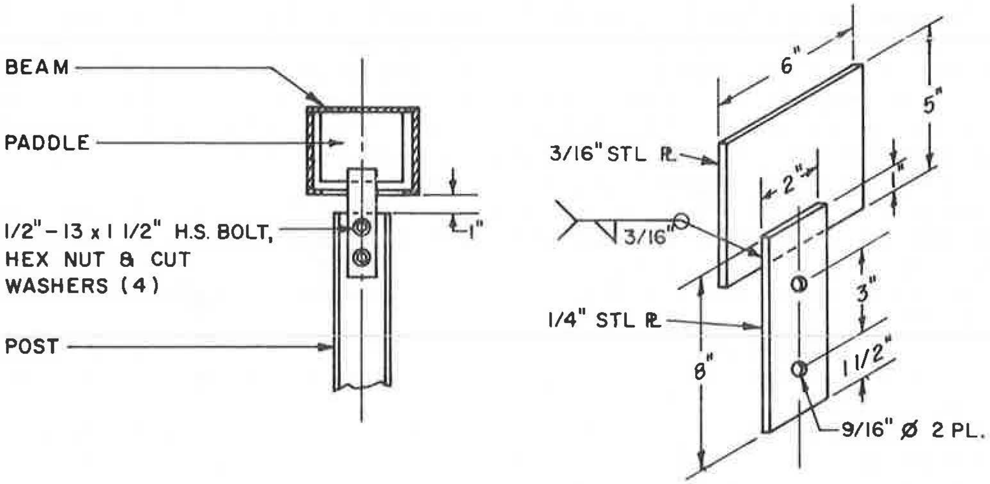

Figure 2. Test 142.

Test 142. For Test 142 a 201-ft installation of anchored box beam barrier utilizing the paddle/slot design (Fig. 2) was impacted at 64 mph/25 deg. The vehicle was effectively redirected to an exit angle of 6 deg during a contact distance of approximately 37 ft.

However, the 4-ft dynamic lateral deflection coupled with a considerable loss of beam height (10. 5 in.) permitted the vehicle to roll more than 18 deg into the barrier (Fig. 3).

This roll was considerably more than has been experienced with a blocked-out W-beam system impacted under similar conditions. Past impact test experience indicates it is possible that this vehicle reaction could result in a roll-over under more severe impact conditions. The 4-ft lateral deflection would govern the median width on which this barrier should be installed. Three sections of the beam, 11 posts, and 22 paddles

Figure 3.

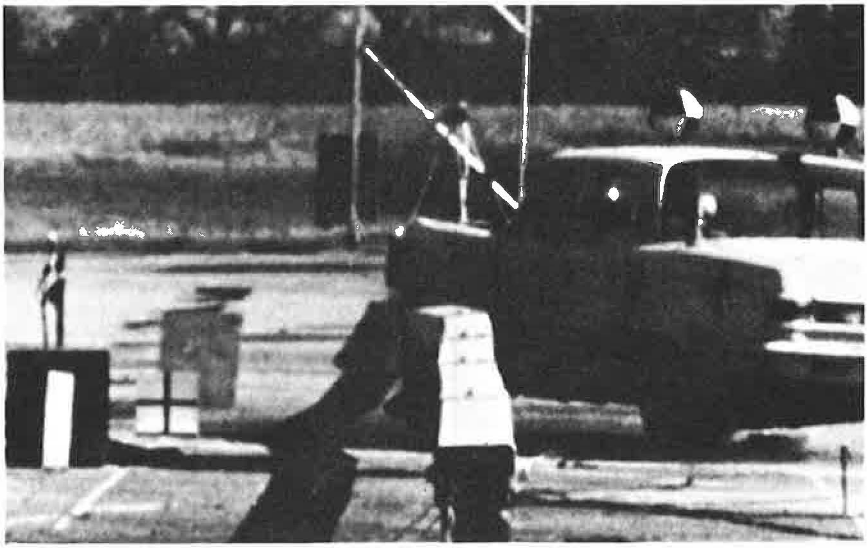

Figure 4. Impact + 0.075 sec.

were damaged during the impact and one post was pulled out of the socket. The paddles on posts that were contacted had damage that indicated they had snagged as they pulled out of the beam slot. The immediate entrapment of the left-front wheel with the first post contacted is shown in Figures 4 and 5.

Past experience indicates that this wheel/post involvement is typical of most impacts on 27-in. high beam-type barriers that are not blocked-out, or barriers over 27 in. high that are not provided with a rubbing rail mounted below the beam. However, with this strong beam/weak post system, it was felt that the relatively light 3I5.7 posts did not affect the smooth progression of the vehicle through impact as would an 8 by 8-in. timber post or 6-in. steel H-post. Further review of the data films indicated that the

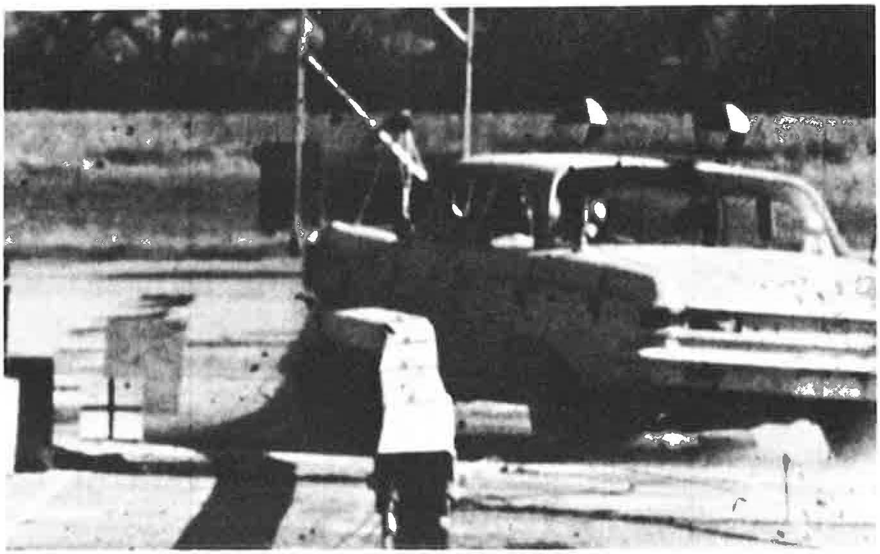

Figure 5. Impact + 0.100 sec.

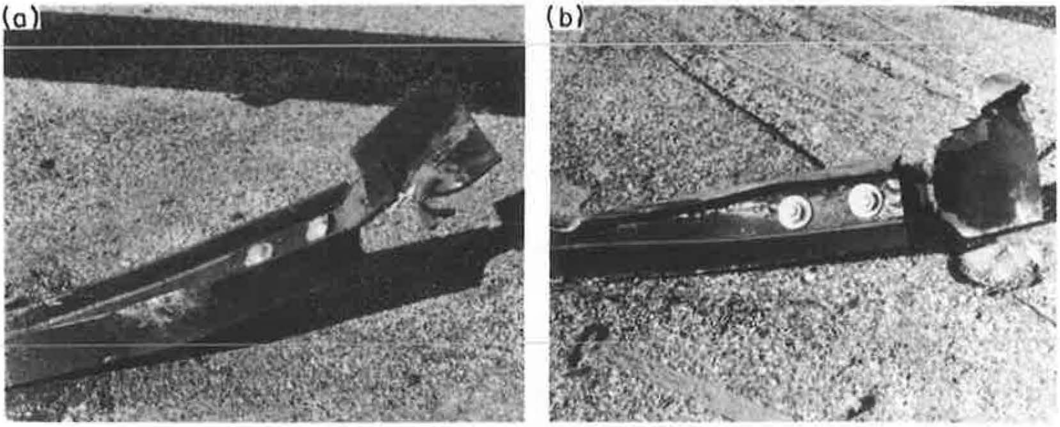

Figure 6. Two posts with sheared paddles.

severe damage to the front wheel and suspension was caused primarily by the paddles hanging up in the beam slots. It is apparent that the post twisted when impacted and the paddle hung up diagonally in the $1\frac{1}{2}$-in. beam slot, locking the post to the beam. Figure 6 shows two posts with sheared paddles. (For Test 143 the paddles were lengthened and beveled to minimize the snagging.)

The two upstream anchor rods in Test 142 were instrumented with SR-4 strain gages mounted and oriented as indicated in Exhibit 3 (Appendix). The barrier was pretensioned to approximately 1, 000 lb with the anchorage turnbuckles. During the 64-mph/25-deg impact, the strain gage instrumentation indicated that a peak load of approximately 32 kips was transmitted through one of the rods to the anchor.

All of the beam splice bolts (ASTM Designation: A307 steel) sustained some shear deformation and the top and bottom were sheared completely off one bolt. Figure 7 shows the head of the splice bolt and the washer just after shearing. This failure occurred

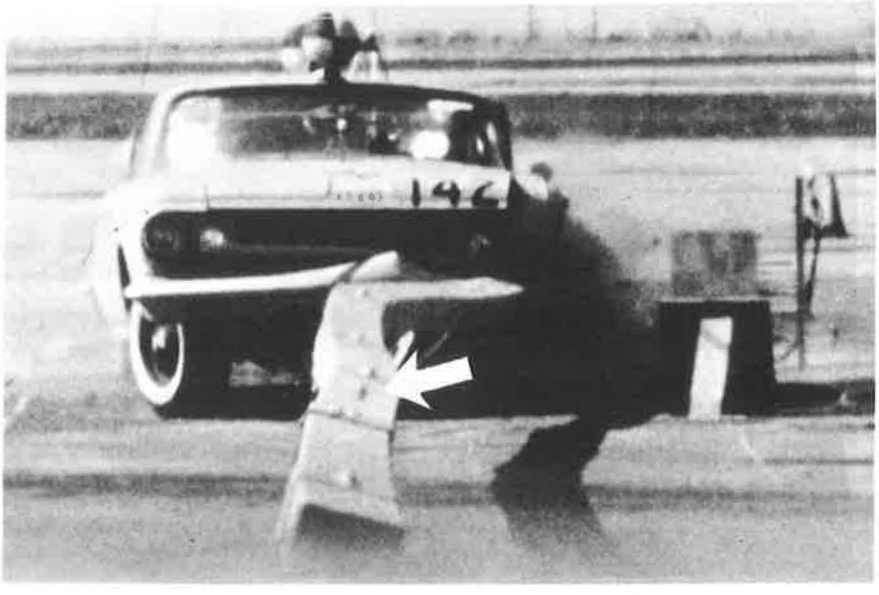

Figure 7. Impact + 0.225 sec.

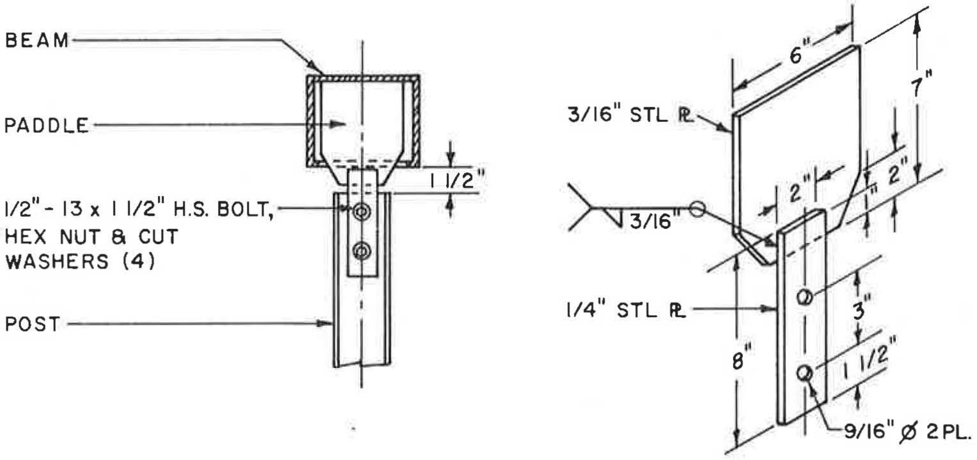

Figure 8. Test 143.

at the time of maximum dynamic deflection and is a good example of the magnitude of the tensile forces that can be transmitted a considerable distance downstream as well as upstream from impact on any tension barrier system such as the box beam barrier.

This splice bolt failure had no appreciable effect on the overall performance of the barrier as the vehicle had almost been redirected and maximum dynamic deflection had occurred. However, rather than chance a splice bolt failure affecting the results of succeeding tests, the A307 bolts were replaced with high-strength bolts.

The vehicle sustained moderate front-end sheet metal damage and severe front-end undercarriage damage.

Test. 143. After viewing the data film from Test 142 and observing the satisfactory performance of the system under the relatively severe impact conditions of 64 mph/25 deg, it was felt that no further high-speed, oblique-angle tests on the New York box beam median barrier were necessary. However, to acquire maintenance data on a moderate impact that would be representative of a majority of the freeway median barrier accidents, Test 143 was scheduled. The impact angle and speed were reduced to 49 mph/10 deg.

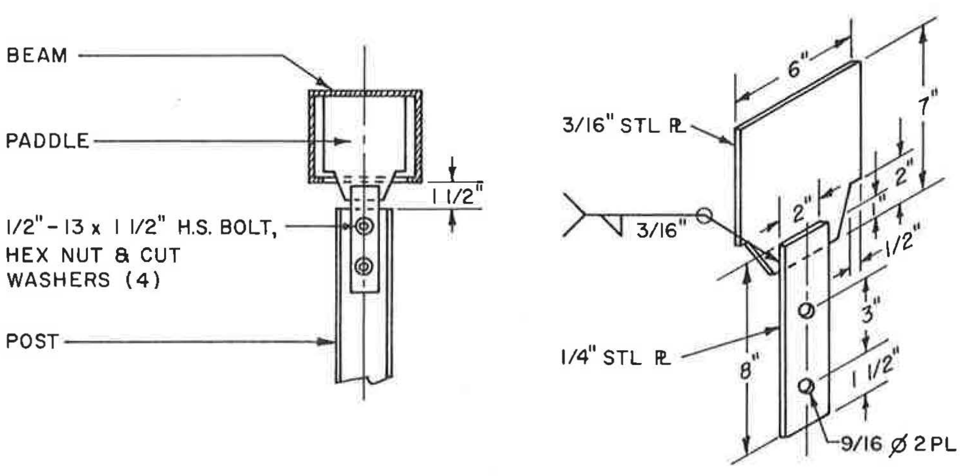

Figure 9. Offset in edge of paddle.

To correct the deficiencies noted in Test 142, the barrier used in Test 143 incorporated a beveled paddle design (Fig. 8) to minimize the snagging tendency and high-strength steel beam splice bolts (ASTM Designation: A325) to minimize the splice bolt shear deformation.

The box beam installation was 201 ft long. The end anchorage employed in Test 142 was used.

The test vehicle impacted the barrier 100 ft from the upstream end and was redirected to an exit angle of 3 deg during a contact distance of approximately 21 ft. The left-front tire was ruptured by a post causing the vehicle to curve into a secondary impact with the barrier 42 ft beyond the initial contact and to travel parallel in contact with the beam for an additional 30 ft before finally leaving the barrier at a 3-deg angle. Three posts were damaged beyond repair, and 9 paddles required replacement. However, the beam sustained the impact with no evidence of bending and, as expected, no damage to the $^3/_4$-in. high-strength splice bolts. There was no evidence of snagging with the beveled paddle design and no tendency for the vehicle to roll.

The vehicle sustained minor sheet metal damage and the left-front tire was ruptured..

In view of the successful test results obtained with the slotted beam and modified paddle design used in Test 143, no further testing of the box beam barrier was considered necessary.

New York's experience with the paddles in a test on an aluminum box beam design (3) indicates that an offset would be desirable in the edge of the paddle to restrain the vertical deflection of the beam upward under severe impact conditions. This offset (Fig. 9) would tend to restrain the beam until it was firmly embedded in the vehicle body and release before any serious snagging would occur.

Although there was little tendency for the vehicle to lift the beam free of the paddles in Test 143 and the beam was actually deflected down in Test 142, it is possible that a vehicle contacting the beam while the front suspension was depressed could dive under the beam and penetrate the barrier. We would consider this modification to the paddles a definite safety factor for unforeseen impact situations.

Test Procedure and Instrumentation. In general, the testing procedure and photographic instrumentation followed that outlined in previous California reports (4, 5). The test vehicles were 1964 Dodge sedans weighing 4,540 lb with dummy and instrumentation.

TABLE 1

DYNAMIC DATA

BARRIER	TEST NO.	DUMMY RESTRAINT	DUMMY IMPACT**						VEHICLE TRAJECTORY						BEAM			
			TRANS.		LONG.		VERT.		ANGLE		SPEED		ROLL		HEIGHT		MAX DYNAMIC DEFLECT	PERM SET
			L	R	FWD.	BK.	UP	DN.	ENT.	EXIT*	ENT.	EXIT*	L	R	BEFR.	AFTR.		
BOX BEAM	141	LAP BELT	2.0			0.25		0.5	25°		71	62		3°	27"	-0-	---	---
BOX BEAM	142	LAP BELT	2.0		1.0			1.0	25°	6°	64	46	18°		27"	24"	48"	28"
BOX BEAM	143	LAP BELT	1.7		0.25		0.2	0.2	10°	3	49	38	FLAT		27"	27.5"	9"	3"
W. BEAM BARRIER	101	LAP BELT & CHEST HARNESS	3.5		2.3			1.5	25°	15°	69	41		5°	30"	36"	17"	15"
W. BEAM GARDRAIL	107	LAP BELT	2.5		1.4		0.9		25°	17°	60	37	FLAT		27"	29"	21"	18"

* Exit angle and speed measured 25' to 50' from point of impact. and prior to cutting ignition and applying brakes.

** Readings indicate relative impact intensities as recorded on mechanical stylus "Impactograph". The magnitudes are not to be construed as actual "G" forces.

Utilizing their own power, they were guided into the box beam test installations by radio control. "Sierra Sam," an anthropometric dummy, occupied the driver's seat during each collision. "His" kinematics were recorded by a data camera mounted above the rear seat. A typical photographic instrumentation plan is shown in Exhibit 1 (Appendix).

Two "impactograph" recorders, each utilizing mechanical stylus type accelerometers recording on a strip chart were used to record the transverse, longitudinal and vertical accelerations during impact. One recorder was mounted in the chest cavity of the dummy and one on the rear floor of the vehicle. Due to the effects of "ringing" caused by transient vibrations through the vehicle frame, the recordings from the vehicle impact recorder were not considered representative of the actual decelerations sustained by the vehicle and are not reported herein. Table 1 gives dynamic data including impact readings taken from the dummy for each of the three tests, including for comparisons dynamic data from a previous test series on W-beam barriers.

The low exit angles for the semiflexible box beam barrier impacts are accompanied by large lateral deflections as compared to the high exit angles and small lateral deflections of the semirigid W-beam barrier impacts. Also, as would be expected, the lateral decelerations are much lower with the box beam barrier than with the W-beam under similar impact conditions. This would favor the box beam barrier insofar as disorientation of the driver is concerned.

DYNAMIC TESTS OF CONCRETE MEDIAN BARRIER

This test series is a continuation of an investigation by the California Division of Highways into the development of a concrete median barrier for use on narrow medians, 6 ft or less (6). It was initially proposed that a rigid-type barrier be developed which would retain the effectiveness of the current standard metal W-beam median barrier as well as be more maintenance free for placement in very narrow medians. It was felt that a nonyielding concrete barrier could provide for these factors and also be designed to be more pleasing in appearance than the W-beam and treated-timber post design.

The first prototype of the New Jersey concrete median barrier design was installed on a test section of its highway system in 1955. The overall height of the prototype barrier was 18 in. However, after adverse operational experience, the height was increased to 24 in. and then in 1959 to the present 32 in. Accident statistics indicated that this 32-in. design is performing effectively (7).

In 1963, General Motors conducted a series of 21 full-scale tests on a concrete bridge parapet design (8) adapted from the New Jersey median barrier design—Figure 10 compares this design with that of New Jersey.

The GM sloped-front design proved to be entirely adequate in redirecting an impacting vehicle with no barrier damage and minimal vehicle damage. However, the tests were all conducted at speeds less than 50 mph and at impact angles of 12 deg or less. This test criterion did not impose as severe a test loading as would the California standards of 65 mph/25 deg for dynamic impact proof testing of barriers. The GM design included a metal railing mounted on top of the concrete wall to insure containment of high-speed wide-angle impacts.

To obtain additional factual accident analysis of their barrier design, New Jersey commissioned the Stevens Institute of Technology to conduct a research program to "correlate the geometric properties of rigid concrete median barriers and the trajectory parameters of impacting vehicles" (9). These correlations were to be obtained from the analysis of high-speed movies of automobile-barrier impact simulation by scale-model vehicles and barriers. Barrier design modifications were to be proposed as a result of this study. However, Stevens Institute reported that full realization of the intent of its study was not accomplished in that (a) full-scale crash data against rigid barriers that would be pertinent to this study could not be located and (b) a complete description of automobiles in terms of all the parameters needed for accurate scaling could not be assembled.

California had proposed in the initial work plan that the test program should include (a) a review and analysis of the results of the Stevens Institute's theoretical study and

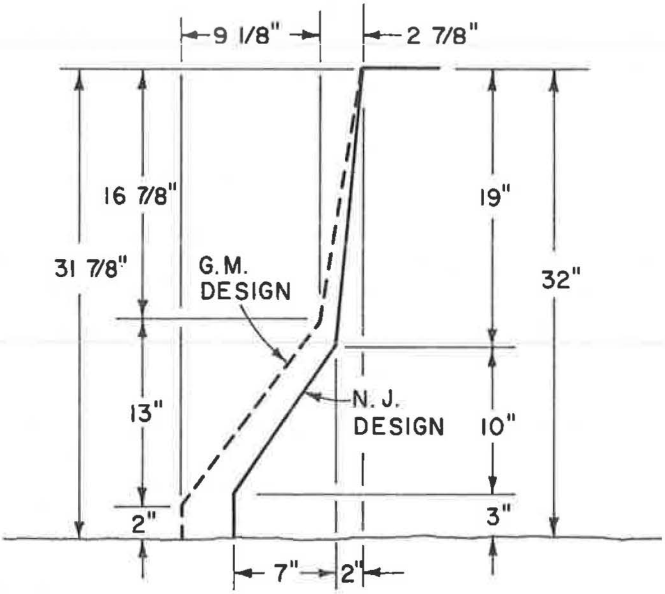

Figure 10. GM design compared with that of N. J.

(b) dynamic full-scale testing of Stevens' final design. However, due to the technical difficulties, the Stevens Institute was unable to make any barrier design recommendations. The California tests were therefore conducted on the standard 32-in. high design as developed by the New Jersey Highway Department.

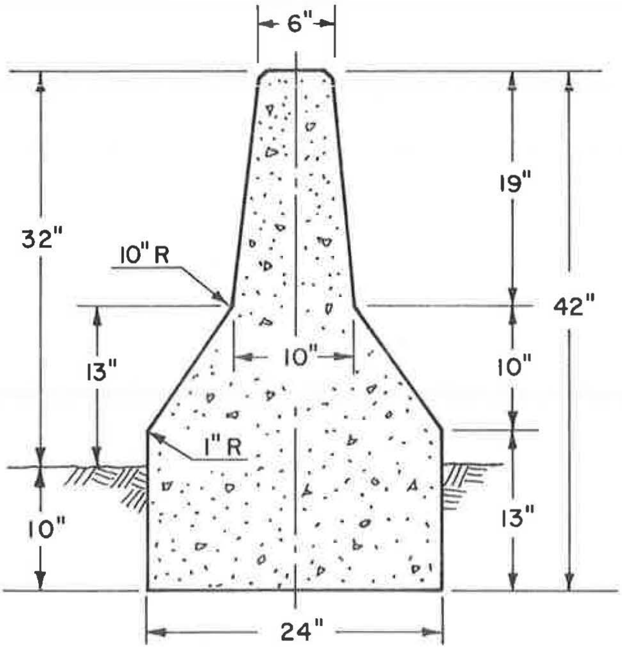

Figure 11. New Jersey median barrier design.

Objective

The primary objective of this series of tests was to dynamically proof test the New Jersey concrete median barrier design to determine its effectiveness for use in narrow medians (6 ft or less).

Conclusions

The following conclusions are based on an analysis of the results of the full-scale tests conducted during this test series:

1. The New Jersey concrete barrier design effectively redirects a medium weight sedan impacting at acute angles (less than 10 deg) with no or minimal vehicle damage and no barrier damage, indicating that this design would be particularly applicable to narrow medians.
2. This barrier design also redirects a medium weight sedan when impacting at a high speed (60 mph) and wide angle (25 deg) with little or no barrier damage. However, vehicle damage and passenger deceleration rates can be expected to be relatively severe.
3. Although this concrete barrier design would provide definite maintenance advantages over the California standard metal beam median barrier, placement of this design should be limited to flat, paved medians free of curbs, dikes, ditches, and sawtooth slopes.
4. Construction cost of this barrier on one project in Phoenix, Ariz., was $5.88 per lin/ft as compared to the average weighted price of $11.91 per lin/ft for 30,700 ft of barrier constructed in New Jersey during 1965. Accurate construction costs for California have not been determined.

Discussion of New Jersey Design

Design Tested. The median barrier was a contoured, solid concrete wall design developed by the New Jersey Highway Department (Fig. 11).

TABLE 2

DYNAMIC DATA

BARRIER	TEST NO.	DUMMY RESTRAINT	DUMMY IMPACT **						VEHICLE TRAJECTORY					
			TRANS.		LONG.		VERT.		ANGLE		SPEED		ROLL	
			L	R	FWD.	BK.	UP	DN.	ENT.	EXIT*	ENT.	EXIT*	L	R
NEW JERSEY MEDIAN	161-A	LAP BELT	1.0		0.2	0.1		0.2	7°		38	41		
NEW JERSEY MEDIAN	161-B	LAP BELT	1.2		0.7		0.7	0.2	7°		65	61		14°
NEW JERSEY MEDIAN	162	LAP BELT	4.3		0.8	0.7	1.0	1.7	25°	12°	63	55		25°
W. BEAM MEDIAN	101	LAP BELT & HARNESS	3.5		2.3			1.5	25°	15°	69	41		5°
W. BEAM GARDRAIL	107	LAP BELT	2.5		1.4		0.9		25°	17°	60	37	FLAT	
NEW YORK MEDIAN	142	LAP BELT	2.0		1.0			1.0	25°	6°	64	46	18°	
CONCRETE TP. 1 BR. RAIL	B-5	LAP BELT & HARNESS	4.0		2.0			1.3	25°	5°	78	62		2°

* Exit angle and speed measured 25' to 50' from point of impact and prior to cutting ignition and applying brakes.

** Readings indicate relative impact intensities as recorded on mechanical stylus "Impactograph". The magnitudes are not to be construed as actual "G" forces.

The installation consisted of eight 32-in. high, 20-ft long, nonreinforced, cast-in-place concrete wall sections. Each individual section consisting of a footing and parapet was a single monolithic pour of approximately 3 cu yd weighing 6 tons. Adjacent sections were not doweled or connected at the expansion joints. The strength of the Class A concrete, specified at 3,000 psi minimum at 28 days, was in excess of 6,200 psi at the time of the impact test.

Test Parameters. The test vehicle was a 1965 Dodge sedan weighing 4,540 lb with dummy and instrumentation. The test impact speeds and angles were as follows: (a) initial trial test—20 mph/2 deg; (b) Test 161-A—38 mph/7 deg; (c) Test 161-B—65 mph/7 deg; and (d) Test 162—63 mph/25 deg.

For the initial test the vehicle was driven into the barrier at a low speed and narrow angle by a test driver. For the succeeding three tests the vehicle was radio remote controlled from a following vehicle.

The procedures taken to prepare, control remotely, and target the test vehicle are generally similar to those used in past test series and are detailed in previous California reports (4, 5).

Instrumentation. Photographic and mechanical instrumentation procedures and equipment were generally similar to those used in the New York box beam barrier test series and in other past California test series.

Table 2 gives dynamic data including readings on the impactograph installed in the chest of the dummy driver during each of the three tests in this series. Included in the exhibit for comparisons are dynamic data from previous tests on semi-flexible box beam barrier, semirigid W-beam median barrier and guardrail, and rigid concrete parapet California Type 1 bridge rail.

Although the transverse decelerations are relatively large for Test 162, they are typical of those recorded on rigid concrete bridge rails. Vertical decelerations are generally in the same range as with the other types of barrier systems. Of particular interest is the comparison of the longitudinal deceleration when impacting three different barrier systems at a 25-deg angle. The low longitudinal decelerations recorded in the concrete barrier tests indicate that, even at this severe impact angle, forward progression through impact was relatively smooth.

Barrier-Vehicle Performance. Energy Dissipation. In theory, a structurally adequate rigid-type barrier will contain and redirect an impacting vehicle. However, to be effective, vehicle trajectory parameters and the dissipation of force must be within limits tolerable to the passengers.

The actual forces involved in impacting a barrier consist of relatively large quantities of kinetic energy. The effective redirection of an impacting vehicle by the barrier involves the dissipation or reduction of the kinetic energy with as little as possible absorbed by the vehicle. The amount of energy that must be absorbed to obtain effective redirection depends on vehicle weight, speed, and impact angle and can be determined by resolving it into velocity components parallel with and perpendicular to the barrier. The total theoretical kinetic energy developed during each of the three tests conducted are given in Table 3.

Assuming the brakes are not applied, dissipation of the energy component parallel with the barrier during satisfactory redirection is accomplished through friction force that is developed through vehicle-barrier contact, and wheel-pavement contact. With most barrier designs, the body of an impacting vehicle is in contact with the barrier throughout redirection. However, with the design tested, at low angles the only vehicle contact may be that of the impacting front wheel. Thus the vehicle-barrier friction force may be provided for only by the scrubbing action of this wheel as it climbs and is redirected by the lower sloping parapet face. The wheel-pavement interactions in any vehicular redirection depend on factors such as (a) tire condition, (b) weather, (c) weight distribution, and (d) roadway surface material and condition. In these tests the wheel-pavement friction force was generally provided

TABLE 3

THEORETICAL KINETIC ENERGY (ft-lb)

Test	Parallel Component	Perpendicular Component	Total Energy
161-A	219,000	3,000	222,000
161-B	626,000	9,000	635,000
162	500,000	108,000	608,000

through overcoming (a) "crabbing" of the wheels during redirection, (b) turning force of the tires against the pavement, and (c) normal tire-pavement rolling friction. The test surface was an open-grade plant-mix bituminous pavement with a coefficient of friction of approximately 0. 30. The tires were nearly new, 6-ply 7:60-15, inflated to 30 psi.

The entire energy component perpendicular to the barrier must be absorbed for effective vehicle retention. This is accomplished through elastic and plastic deformation of the barrier, vehicle, or both. The barrier can transmit a portion of this energy to the structure as in the case of the concrete bridge rail or to the soil such as with the W-beam barrier on wood posts. However, with a rigid system, such as this design, if the barrier does not fail, minimal energy is absorbed by the barrier and very little by the soil. Therefore, the vehicle must absorb or dissipate almost all of the energy.

The unique feature of this barrier design is the sloping lower face of the parapet which provides for the absorption of a large portion of the energy by lifting the vehicle wheels on the sloping face and by compression of the vehicle suspension system before any contact with the barrier by the body or chassis. With low-angle impacts, this application of initial resistance force at the wheel rather than at the body provides satisfactory vehicular redirection with little or no damage to the vehicle. When the vehicle weight, speed, and impact angle are such that the perpendicular component is beyond the energy absorption capacity of the vehicle wheel and suspension system, the remainder of the energy must be absorbed by deformation of the vehicle body and chassis.

Because a substantial uplift force is imparted to the impacting side of the vehicle as the wheel ascends the sloping face of the barrier, the rolling moment toward the barrier is overcome, and the vehicle rolls away from the barrier. The degree and duration of this roll depends on the amount of climb and the absorption capacity of the vehicle's suspension system.

General Motors found similar vehicle reactions (8). With a standard size sedan impacting at 50 mph/12 deg, the vehicle climb was 18 in. and the resulting roll approximately 30 deg away from the barrier, whereas a truck impacting at 37 mph/13 deg did not climb the barrier, and consequently, the roll was toward the barrier.

The Stevens Institute using scale-model vehicles was unable to duplicate these vehicle trajectories (9). In Stevens' tests of the GM barrier design, the model vehicle climbed much higher; although the roll was away from the barrier, it was extreme as the model vehicle landed on its right-rear wheel and appeared to have overturned. Stevens' test of the New Jersey barrier design exhibited no correlation as the model vehicle rolled toward the barrier and landed on its left wheels in all tests. Stevens indicated that valid proportioning of the model vehicle, particularly its dynamic response, was the major factor contributing to their lack of correlation with full-scale impacts.

Preliminary Tests. As a preliminary to the proposed dynamic tests and to obtain a "feel" for the redirective properties of this barrier design, a familiarization test was conducted with the test vehicle driven into the barrier by a test engineer at 20 mph/2 deg.

Immediately before impact, the test driver released the steering wheel to simulate the worst condition of an out-of-control vehicle where the driver was either drunk, unconscious or completely inattentive.

Because the 7:10 slope (55 deg upward) on the lower face of this barrier closely approximates the face slope of the California Standard Type C mountable curb and the Type B semimountable curb, it was anticipated that the impacting wheel would climb this face. However, the rapidity with which it climbed up the lower face to a height of 17 in. so startled the test driver that he took over control of the vehicle and steered it down and off the barrier. Although this left some doubt as to how much higher the vehicle might have climbed, it did indicate that a driver, following a "casual" impact with this barrier, could readily regain control of his vehicle.

No damage was sustained by either the vehicle or the barrier.

Test No. 161-A. Test 161-A, the first remote radio-controlled test on the New Jersey concrete barrier design was conducted at an approach angle of 7 deg and at a speed of 38 mph.

The test vehicle was effectively redirected with no rebound into the travel lanes and with a maximum roll of 2 deg away from the barrier. Within 3 ft of initial contact, the impacting wheel had climbed 8 in. up the sloping lower face and remained approximately at this height throughout the remaining 92 ft of contact with the barrier.

Contrary to the general hypothesis, the front wheels were not deflected or turned away from the barrier by the sloping lower face, but "crabbed" or turned into the barrier. The wheels retained this attitude through impact and, as the vehicle came off the end of the barrier, turned it in a sweeping curve to the left toward the projected line of the barrier. The effect was to keep the vehicle steering into the barrier, whereas if the wheels had been turned away, the vehicle would have swung out away from the barrier and into the travel lanes.

The vehicle body contacted the upper barrier parapet 3 ft beyond initial impact and for a distance of 6.5 ft. The only vehicle damage was slight sheet metal damage and scratched paint on the left-front fender area. Inspection of the steering mechanism and running gear revealed no damage or misalignment that would alter the vehicle's steering characteristics. This vehicle was used without repairs for the succeeding test.

Data film and impactograph recordings of the dummy driver indicate that a live driver would not have been injured. The barrier was not damaged.

Test No. 161-B. For Test 161-B, the same 7-deg approach angle was used, but the impact speed was increased to 65 mph. The vehicle was effectively redirected with a maximum rebound of only 1.4 ft and a maximum roll of 14 deg away from the barrier.

Within 7.5 ft of initial contact, the impacting wheel had climbed 14 in. up the sloping lower face. It remained approximately at this height for an additional 17.5 ft before rebounding away from the barrier. The vehicle did not make contact with the barrier again. However, it was yawing toward the barrier through impact and would have reestablished contact had the barrier installation been longer. Application of the brakes caused the vehicle to veer to the right in a sweeping curve away from the barrier.

The vehicle body contacted the upper portion of the parapet at initial impact and for a distance of 12.5 ft. Vehicle damage consisted of minor sheet metal damage to the front fender, a dented bumper, and scratched paint at the left-rear door and quarter panel. The left-front wheel was bent and required replacement. No damage to the steering mechanism or running gear was found, and this vehicle was used with no further repairs for the succeeding test.

Data film and impactography recordings of the dummy driver indicate that a live driver would have received slight shoulder bruises. The barrier was not damaged.

Test No. 162. The final test on the New Jersey barrier, Test 162, was conducted at 63 mph/25 deg and within close tolerance to the California Division of Highways standard criteria for proof testing a barrier.

The vehicle was redirected to an exit angle of 12 deg at a maximum roll of 25 deg away from the barrier. The impacting wheel climbed 21 in. up the lower sloping face immediately after initial contact and remained approximately at this height for a distance of 12.5 ft. As the vehicle left the barrier, it was entirely airborne for a distance of 20 ft before coming down on the right-front wheel 32 ft beyond impact and 4 ft out from the face of the barrier.

The vehicle body contacted the barrier immediately at initial impact and for a distance of 12 ft. As the vehicle was redirected parallel to and away from the barrier, moderate damage was sustained by the left-front quarter panel and rear bumper, with minor scratches of the paint along the left side. The left-front-end sheet metal and undercarriage were damaged severely.

Although the vehicle damage was considered severe, it was comparable to that sustained in similar high-speed, wide-angle tests on the standard blocked-out beam-type barrier and a test on a concrete parapet bridge rail.

Restrained by a conventional lap belt, the dummy driver was propelled by the relatively severe lateral deceleration forces into the left-front door and door frame with sufficient force to "spring" the door open and tear the door post from the roof.

The barrier sustained no damage other than very slight spalling of concrete at the expansion joint immediately adjacent to the point of impact.

Maintenance and Operation. The results of the flat-angle tests indicate that "casual" impacts into the New Jersey concrete barrier, representing a majority of freeway median barrier accidents, would result in little or no damage to either the barrier or the vehicle. The high-speed, wide-angle test indicates that maintenance repairs to this barrier design would be minimal even after a relatively severe impact. This would reflect a maintenance advantage over the W-beam-type barrier under moderate to severe impact conditions where damaged beams or posts require replacement. However, operational studies have indicated that a majority of the "casual" to moderate impacts with the W-beam-type barrier are unreported and require no maintenance. On the other hand, any impact, however minor, with the California cable barrier results in barrier damage which usually requires immediate repair.

Damage to the New Jersey concrete barrier resulting from a more severe collision, such as a very high-speed, wide-angle vehicle impact or a truck impact, could be readily and inexpensively made using the improved epoxy-grout method. Extensive damage could by handled by replacement of the entire damaged section with a precast replacement unit. Initial construction of the barrier using precast units has been proposed and deserves consideration.

Arizona constructed the New Jersey concrete barrier on an existing 6-in. curbed raised median. Operational reports indicate that this raised median presents vaulting problems causing impacting vehicles to contact the barrier initially above the lower sloped face. On two occasions, the vehicles vaulted after impacting the curbing and were partially airborne when they struck the upper portion of the barrier parapet knocking out pieces of concrete. A recent accident picture shows a vehicle with the left wheels projecting over the top of the parapet. Tire marks on the face of the barrier indicate that initial contact was made on the upper portion of the parapet approximately 16 in. from the top and continued for approximately 20 ft at the same elevation before straddling the barrier. Vehicle damage appeared to be relatively moderate, and there was no apparent barrier damage. These illustrations from operational experience emphasize the importance of placing this barrier on flat medians free of curbs, dikes, ditches, and sawtooth cross sections.

Accident statistics from states currently using the New Jersey barrier design have not indicated any severe concrete spalling from impacts. However, due to the high ADT and proportionally high truck traffic recorded on this state's urban freeways, the likelihood of this occurring should not be overlooked. Therefore, some consideration should be given to reinforcing the relatively thin upper 18-in. portion of the parapet with a heavy-gage steel mesh. The purpose of this mesh would not be for adding structural strength to the system but to prevent broken pieces of concrete from being dislodged into the travel lanes after an impact by a heavy vehicle.

ACKNOWLEDGMENT

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads, as Item D-04-37 of Work Program HPR-1(4), Part III, Research.

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2. McAlpin, G. W., et al. Development of an Analytical Procedure for Prediction of Highway Barrier Performance. Highway Research Record 83, p. 188-200, 1965.
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4. Field, R. N., and Prysock, R. H. Dynamic Full Scale Impact Tests of Double Blocked-Out Metal Beam Barriers and Metal Beam Guard Railing, Series X. California Division of Highways, Feb. 1965.
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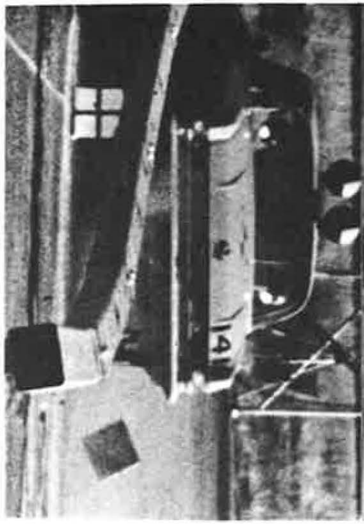
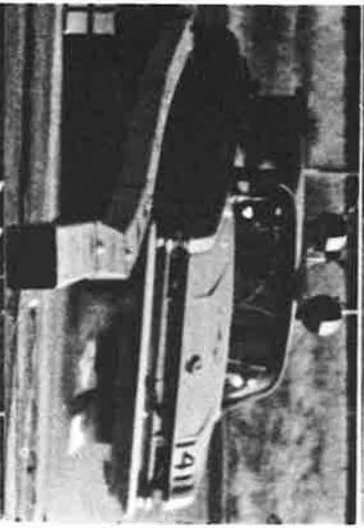
Appendix

The following groups of plates contain pertinent data and photographs of the impact tests discussed in this report. Included are the following: data sheets showing panned camera views of vehicle through impact and tabulations of test parameters, detailed photographs of barrier and vehicle damage, and Exhibits 1 through 4.

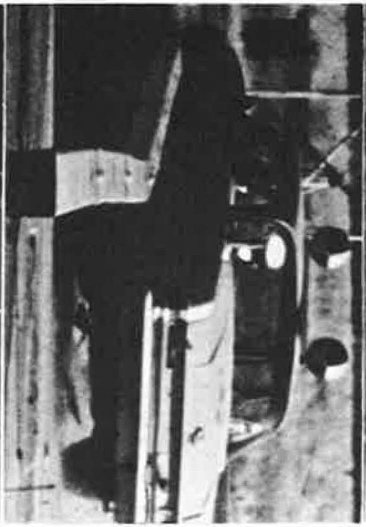
TEST 141. PLATE A.



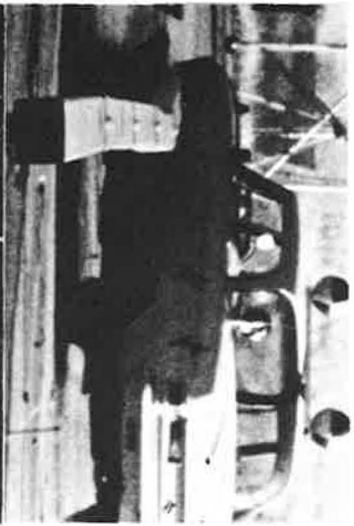
I + .295 sec.



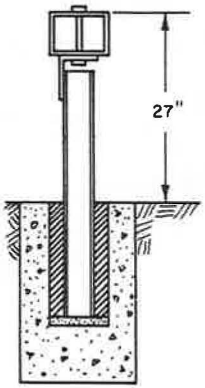
I + .175 sec.

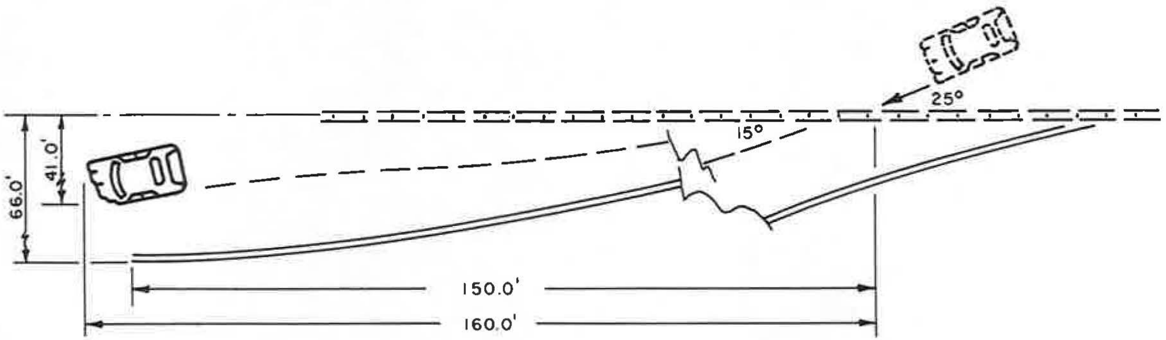


I + .115 sec.



Impact + 0.55 sec.

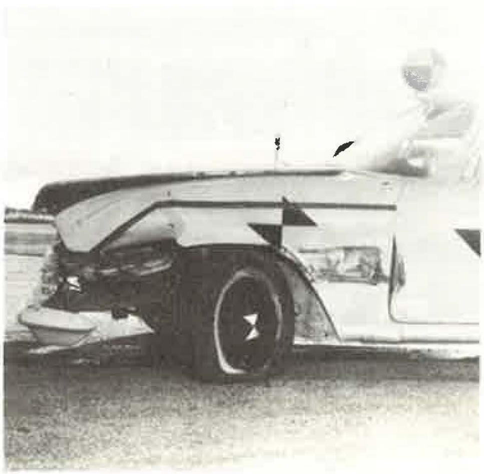




BEAM	6" x 8" x 1/4" x 17'-11 1/2" Steel Tube
SPLICE	6 5/8" x 8 5/8" x 1/4" x 24" Steel
POST	3" I 5.7 # x 36"
POST SPACING	6'-0"
POST EMBEDMENT	16 1/4"
FOOTING	16" dia. x 17" Cl. "A" Conc.
LENGTH OF INSTALLATION	198'
BEAM DEFLECTION - MAXIMUM	NA
BEAM DEFLECTION - PERMANENT	NA

TEST NO.	141
DATE	12-14-65
VEHICLE	1964 Dodge Sedan
VEHICLE WEIGHT (WITH DUMMY & INSTRUMENTATION)	4540#
IMPACT SPEED	71 mph
IMPACT ANGLE	25°
EXIT ANGLE	15°
DUMMY RESTRAINT	Lap Belt

TEST 141. PLATE B.

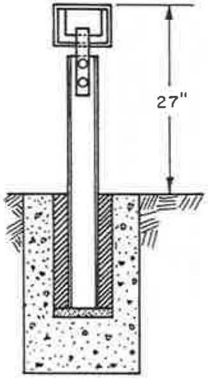


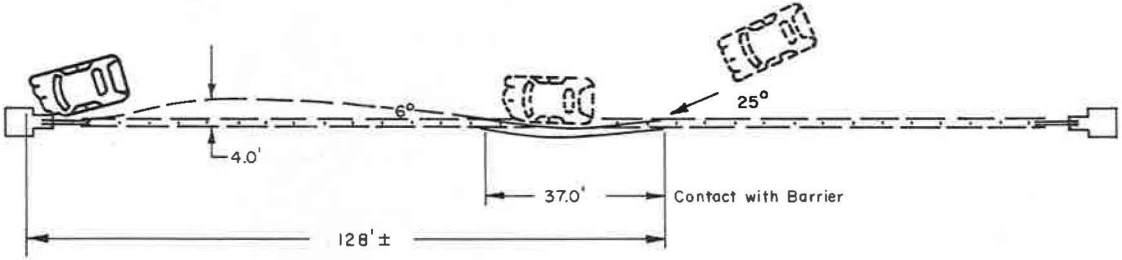
TEST 142. PLATE A.

I + .400 sec.

I + .255 sec.

I + .160 sec.

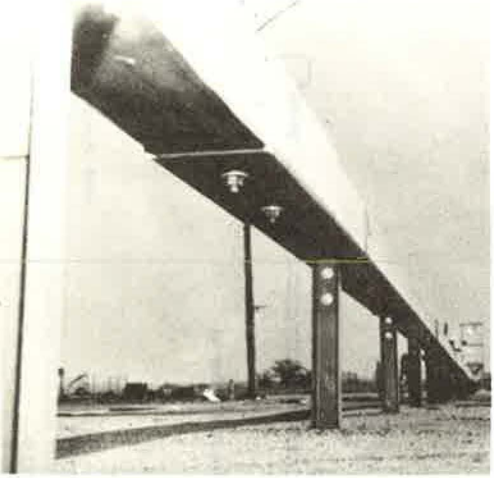


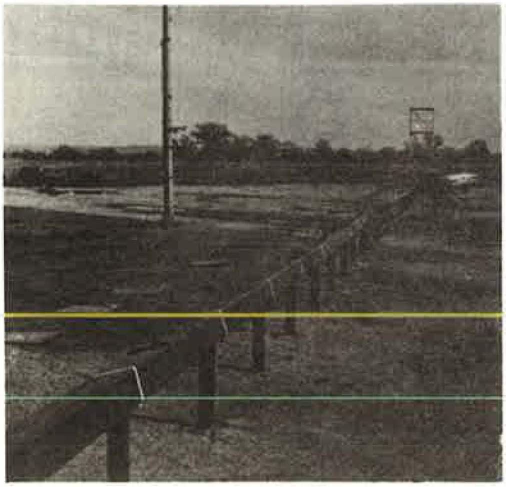


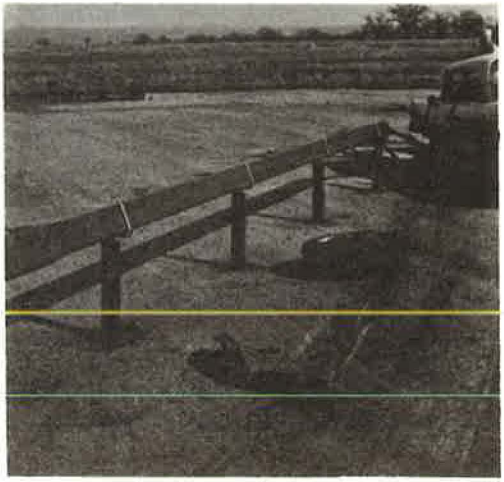
BEAM	6" x 8" x 1/4" x 17'- 11 1/2" Steel Tube
SPLICE	6 5/8" x 8 5/8" x 1/4" x 24" Steel
POST	3" I 5.7 # x 36"
POST SPACING	6'-0"
POST EMBEDMENT	16"
FOOTING	16" dia. x 17" Cl. "A" Conc.
LENGTH OF INSTALLATION	201'
BEAM DEFLECTION - MAXIMUM	4.05'
BEAM DEFLECTION - PERMANENT	2.35'

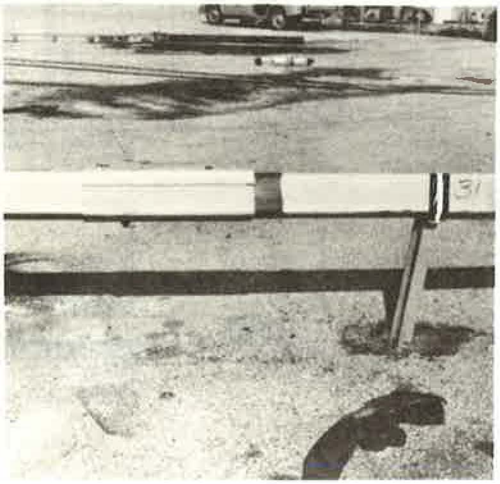
TEST NO.	142
DATE	3-3-66
VEHICLE	1964 Dodge Sedan
VEHICLE WEIGHT (WITH DUMMY & INSTRUMENTATION)	4540#
IMPACT SPEED	64 mph
IMPACT ANGLE	25°
EXIT ANGLE	6°
DUMMY RESTRAINT	Lap Belt

TEST 142. PLATE B.

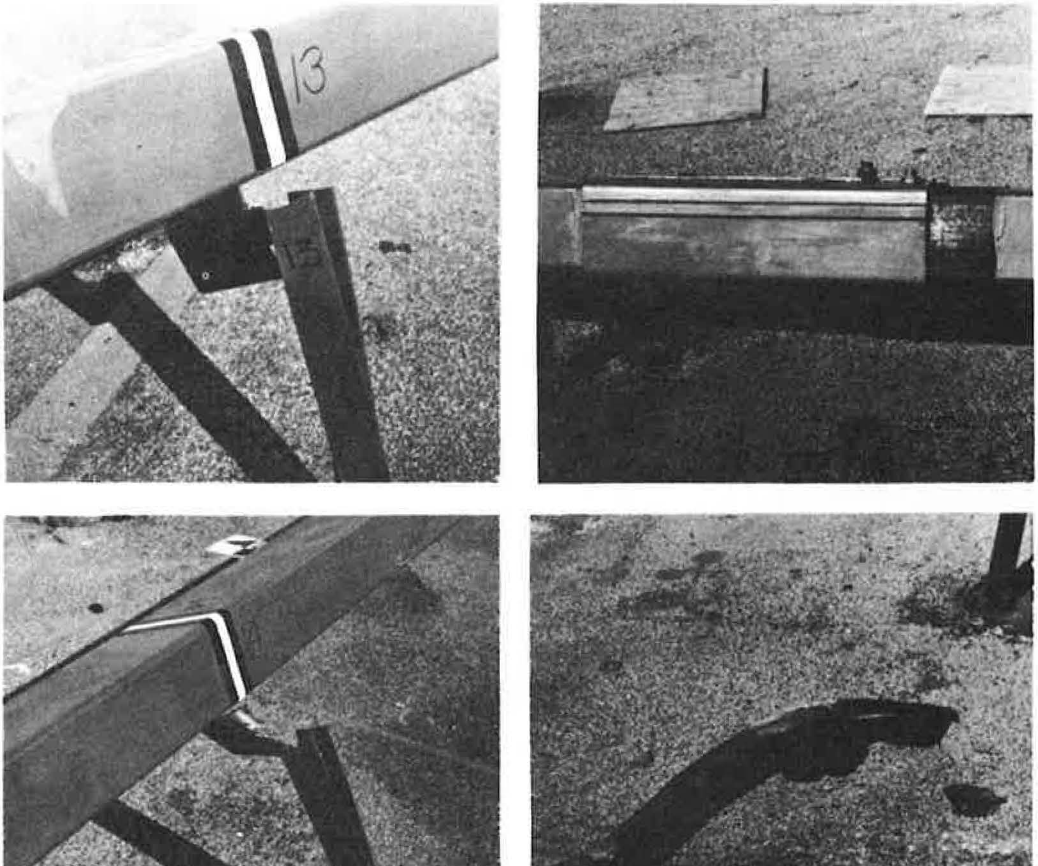






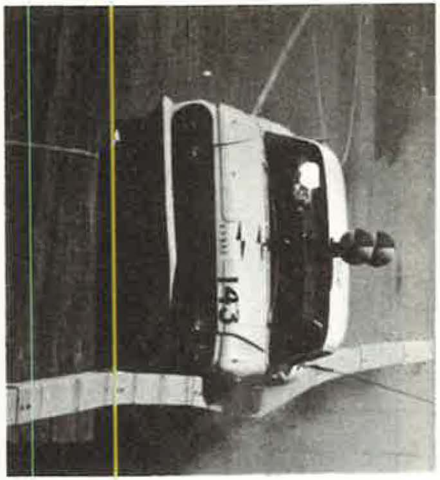


TEST 142. PLATE C.



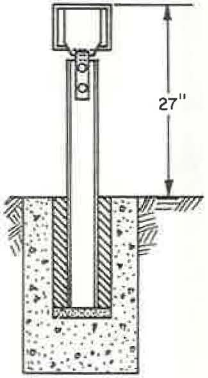
TEST 143. PLATE A.

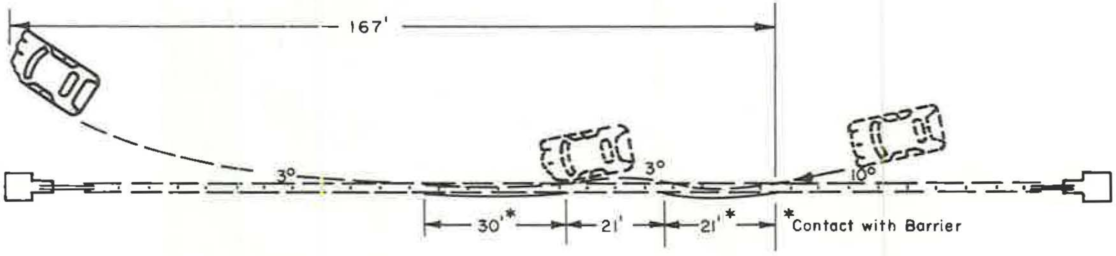
I + .430 sec.



I + 340 sec.

I + .150 sec.

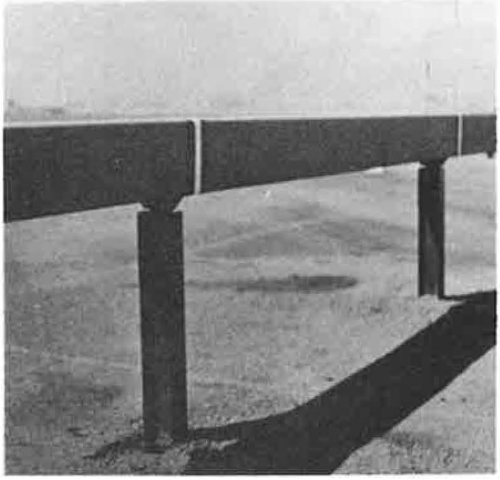


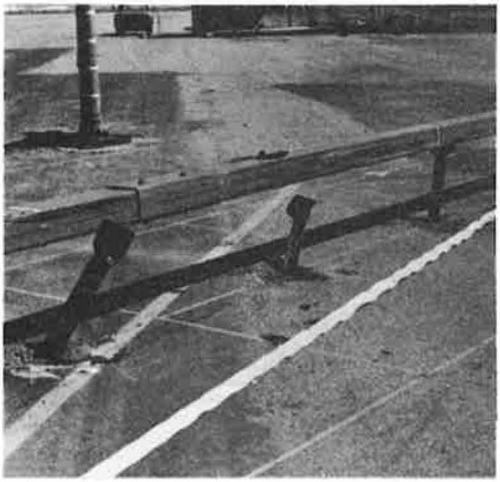


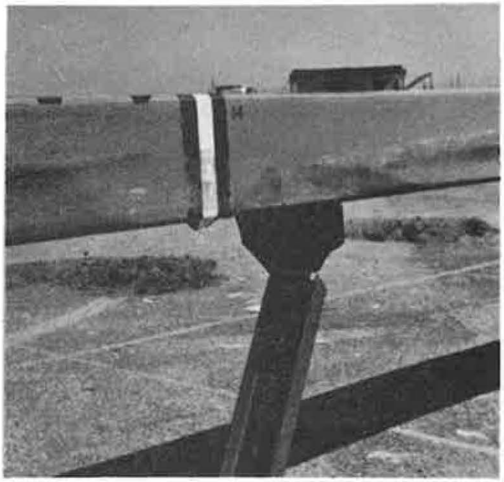
BEAM	6" x 8" x 1/4" x 17'- 11 1/2" Steel Tube
SPLICE	6 5/8" x 8 5/8" x 1/4" x 24" Steel
POST	3" I 5.7 # x 36"
POST SPACING	6'-0"
POST EMBEDMENT	16 1/2"
FOOTING	16" dia x 17" Cl. "A" Conc.
LENGTH OF INSTALLATION	201'
BEAM DEFLECTION - MAXIMUM	0.75'
BEAM DEFLECTION - PERMANENT	0.27'

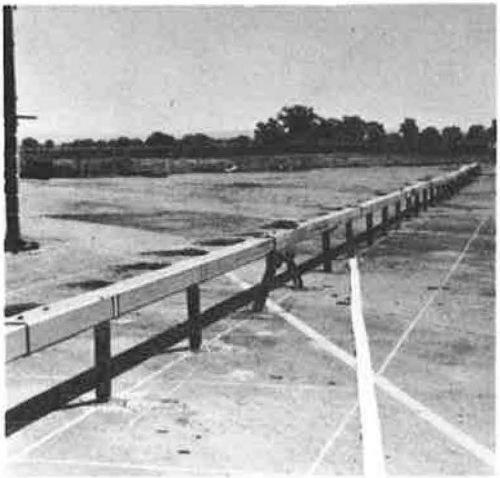
TEST NO.	143
DATE	9-22-66
VEHICLE	1964 Dodge Sedan
VEHICLE WEIGHT (WITH DUMMY & INSTRUMENTATION)	4540#
IMPACT SPEED	49 mph
IMPACT ANGLE	10°
EXIT ANGLE	3°
DUMMY RESTRAINT	Lap Belt

TEST 143. PLATE B.





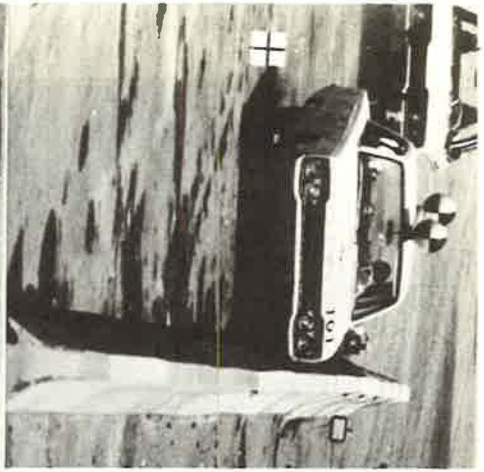




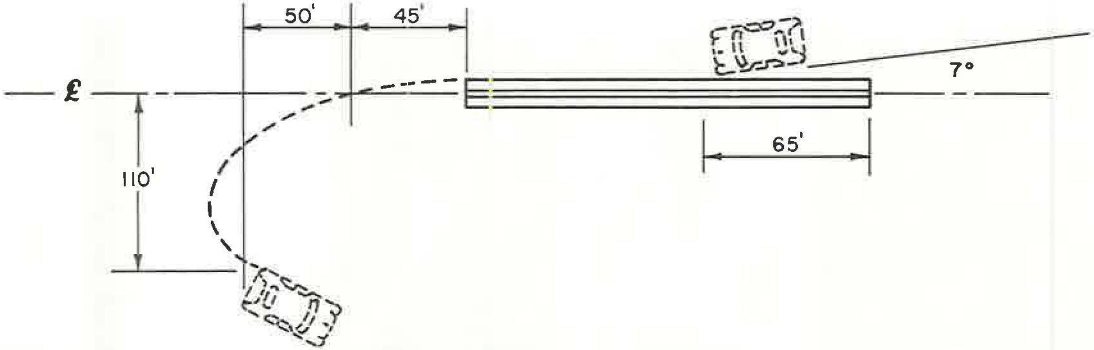
TEST 161-A. PLATE A.

I + 1.75 sec.

I + .65 sec.



Impact.



BARRIER	Unreinforced Concrete
LENGTH OF INSTALLATION	160 ft.
UNIT LENGTH	20 ft.
UNIT WEIGHT	13,200#
GROUND CONDITION	Dry
CONTACT W/BARRIER	95'
MAX. VEHICLE CLIMB	8"
MAX. VEHICLE REBOUND	0

TEST NO.	161-A
DATE	5-4-67
VEHICLE	1965 Dodge sedan
VEHICLE WEIGHT (W/DUMMY AND INSTRUMENTATION)	4540 #
IMPACT SPEED	38 mph
IMPACT ANGLE	7°
EXIT ANGLE	0°

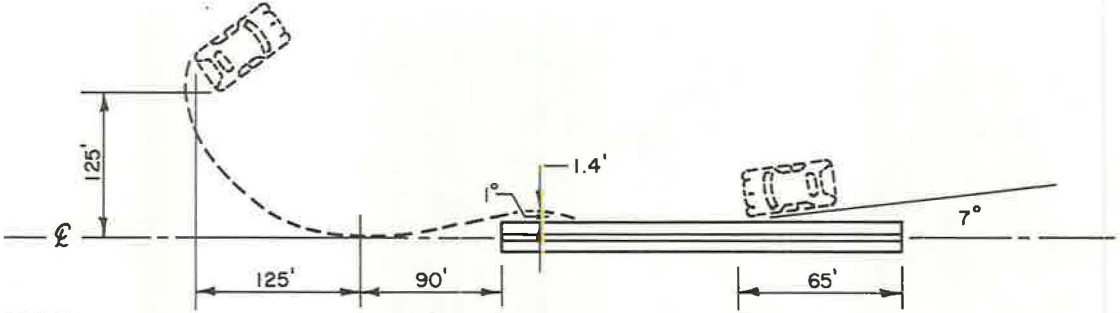
TEST 161-A. PLATE B.

TEST 161-B. PLATE A.

I + .50 sec.

I + .20 sec.

Impact.

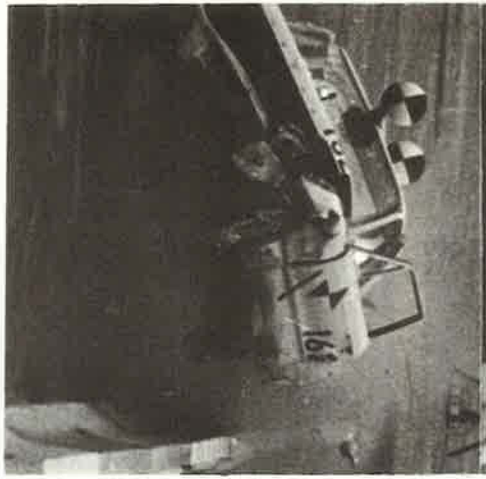


BARRIER	Unreinforced Concrete
LENGTH OF INSTALLATION	160 ft.
UNIT LENGTH	20 ft.
UNIT WEIGHT	13,200#
GROUND CONDITION	Dry
CONTACT W/BARRIER	35'
MAX. VEHICLE CLIMB	14"
MAX. VEHICLE REBOUND	1.4'

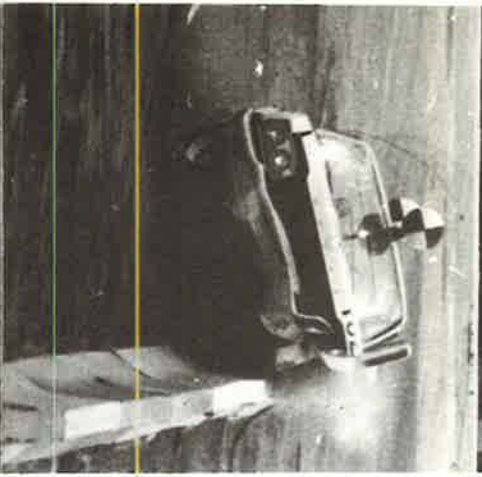
TEST NO.	161-B
DATE	5-4-67
VEHICLE	1965 Dodge sedan
VEHICLE WEIGHT (W/DUMMY AND INSTRUMENTATION)	4540#
IMPACT SPEED	65 mph
IMPACT ANGLE	7°
EXIT ANGLE	1°

TEST 161-B. PLATE B.

TEST 162. PLATE A.

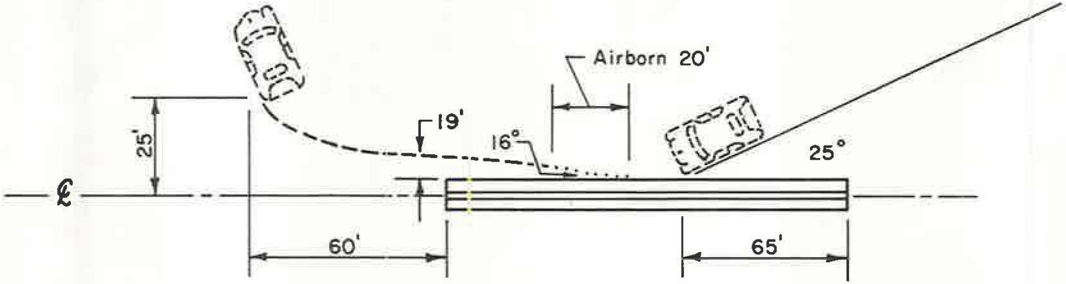


I + .60 sec.



I + .20 sec.

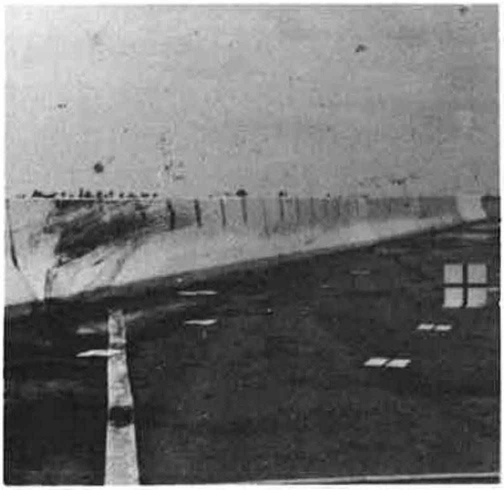
I + .10 sec.

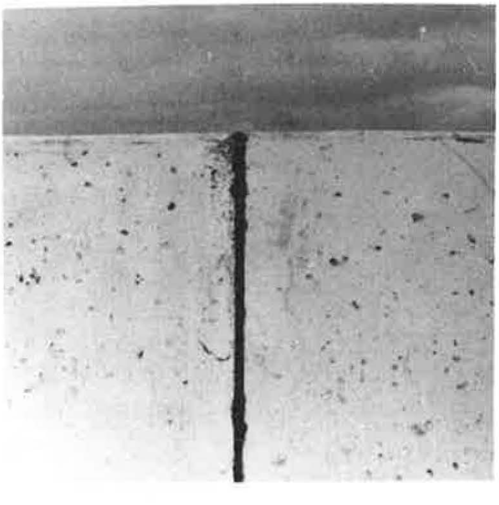


BARRIER	Unreinforced Concrete
LENGTH OF INSTALLATION	160 ft.
UNIT LENGTH	20 ft.
UNIT WEIGHT	13,200#
GROUND CONDITION	Dry
CONTACT W/BARRIER	12.5'
MAX. VEHICLE CLIMB	21"
MAX. VEHICLE REBOUND	9.0'

TEST NO.	162
DATE	5-9-67
VEHICLE	1965 Dodge sedan
VEHICLE WEIGHT (W/DUMMY AND INSTRUMENTATION)	4540#
IMPACT SPEED	63 mph
IMPACT ANGLE	25°
EXIT ANGLE	16°

TEST 162. PLATE B.





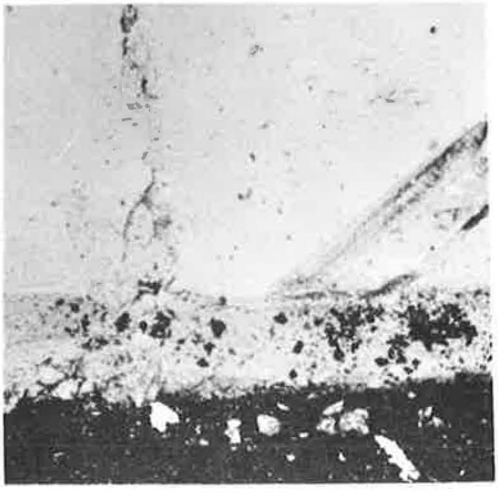
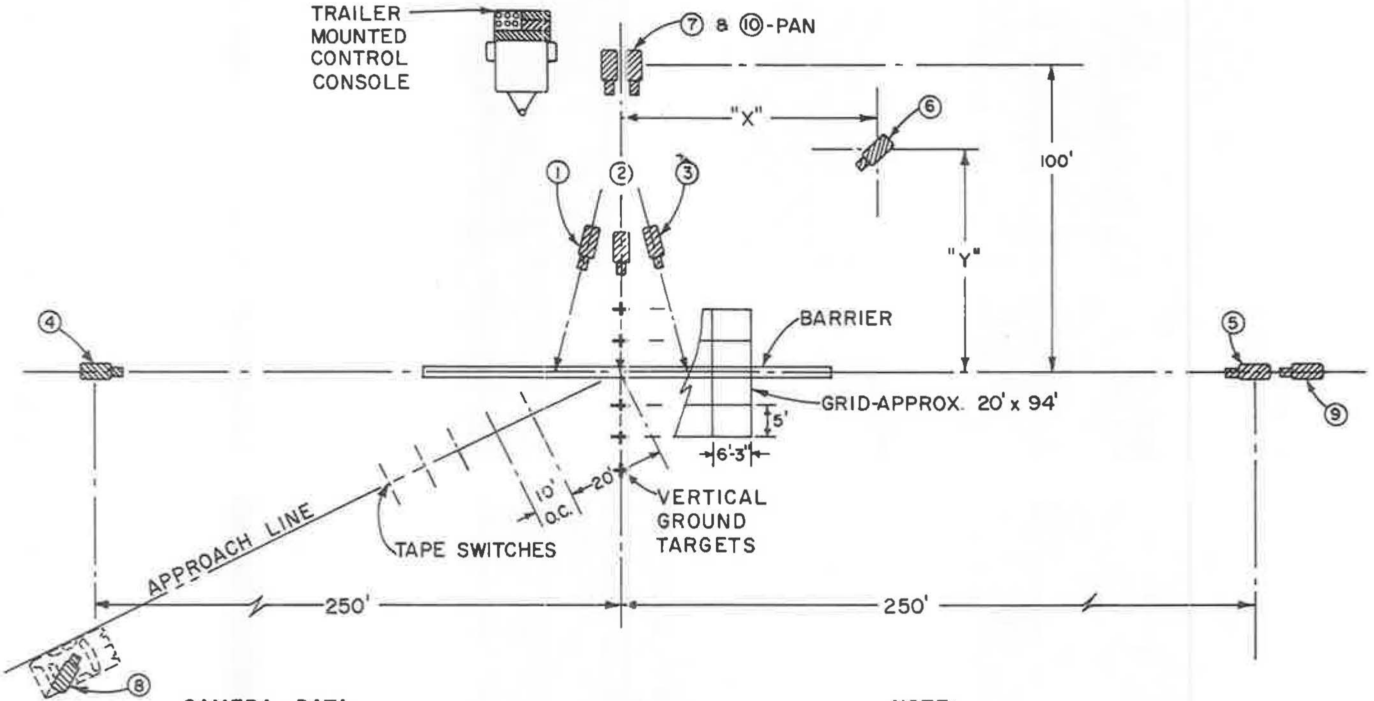


EXHIBIT 1



CAMERA DATA

①②③ PHOTO – SONICS, 13.0 MM LENS, 380 FPS,* MOUNTED ON 35' TOWER AND ORIENTED TO COVER THE AREAS INDICATED ABOVE.
④⑤ PHOTO – SONICS, 4" LENS, 380 FPS.
⑥ PHOTO – SONIC, 2" LENS, 380 FPS.
⑦ PHOTO – SONIC, 2" LENS, 380 FPS.
⑧ PHOTO – SONIC, 5.3 MM WIDE ANGLE LENS, 200 FPS, INSIDE TEST CAR.
⑨ HULCHER, 70MM SEQUENCE CAMERA, 12" LENS, MOUNTED ABOUT 12' HIGH ON SCAFFOLD.
⑩ BOLEX, 1" LENS, 24 FPS.
* FRAMES PER SECOND.

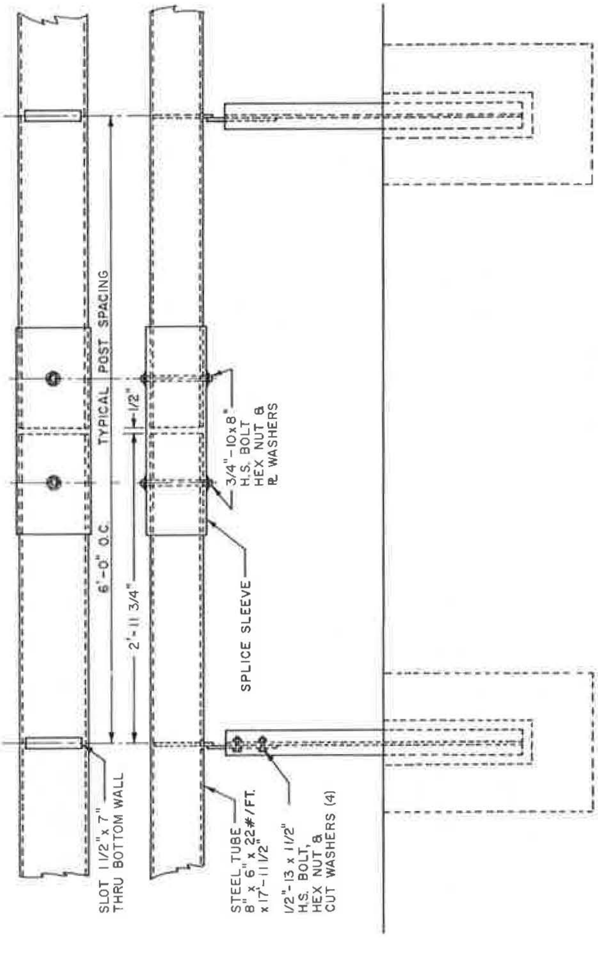
NOTE:

CAMERAS 4 AND 5 HAVE THEIR HORIZONTAL AXES ALIGNED ON A PLANE 5' ABOVE GRADE AS MEASURED AT THE DESIRED POINT OF IMPACT.

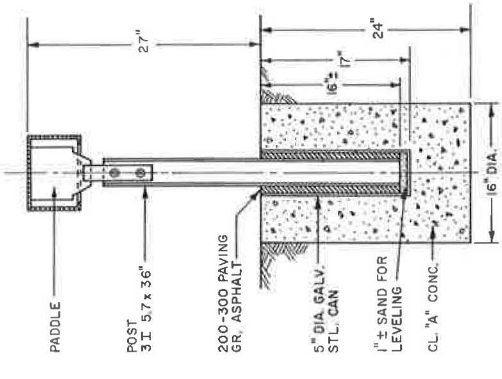
DIMENSIONS "X" & "Y" DEPEND UPON BARRIER LENGTH, AND IMPACT ANGLE.

DYNAMIC FULL-SCALE BARRIER TESTS:
PHOTOGRAPHIC INSTRUMENTATION – TYPICAL PLAN

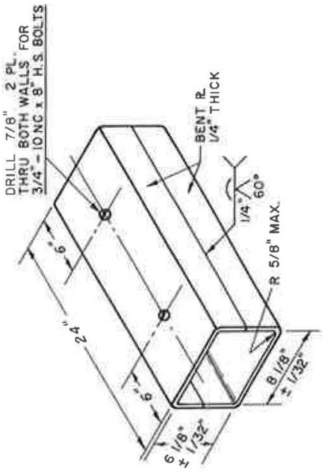
EXHIBIT 2



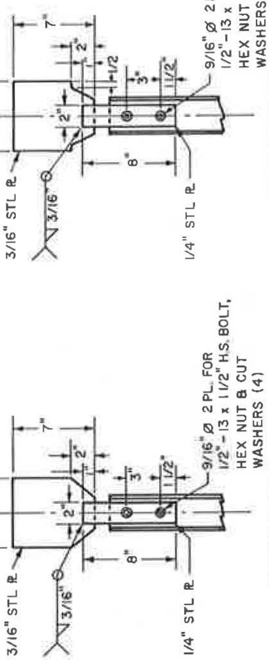
TYPICAL INSTALLATION



TYPICAL SECTION



SPLICE SLEEVE DETAIL

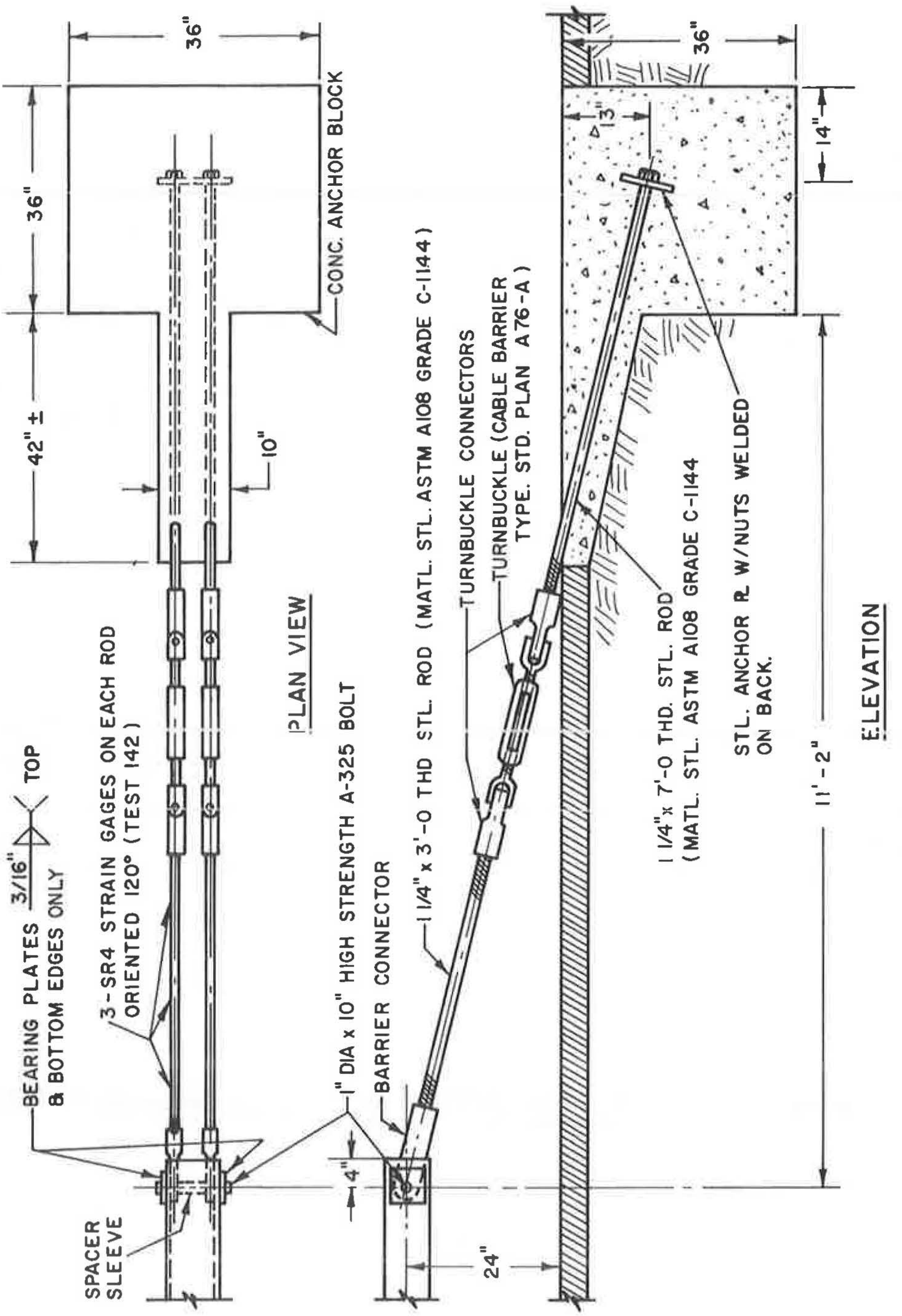


DESIGN TESTED TEST NO. 143

ALTERNATE DESIGN

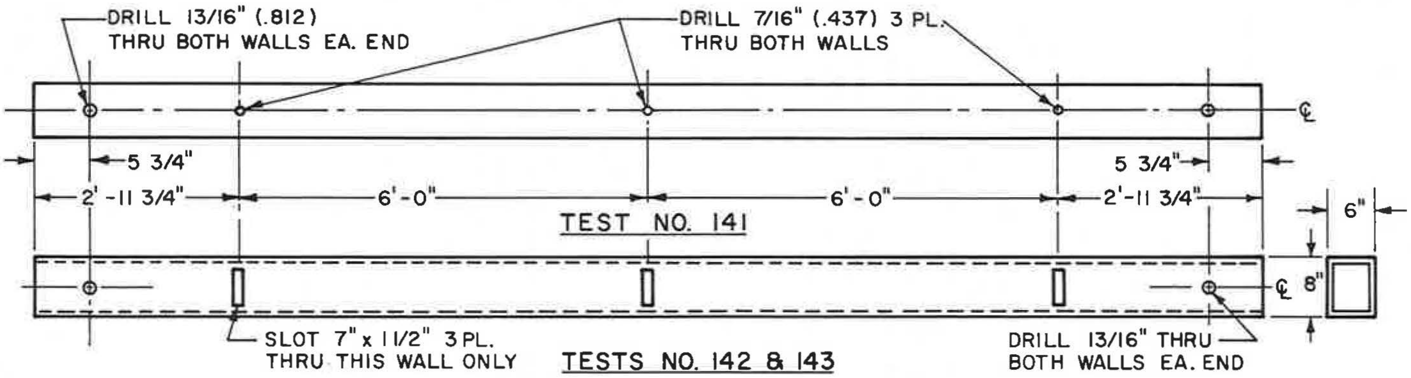
PADDLE DETAILS

EXHIBIT 3

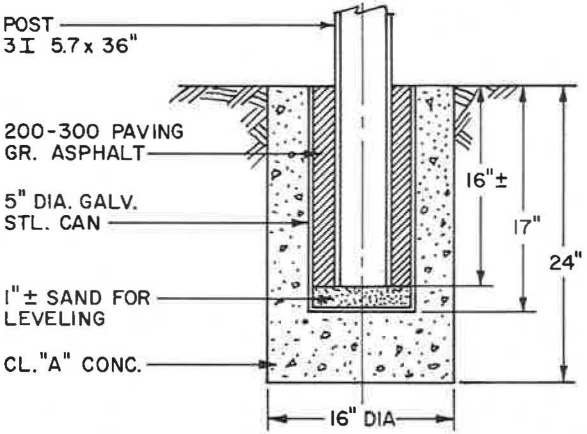


END ANCHOR ASSEMBLY
TESTS NO. 142 & 143

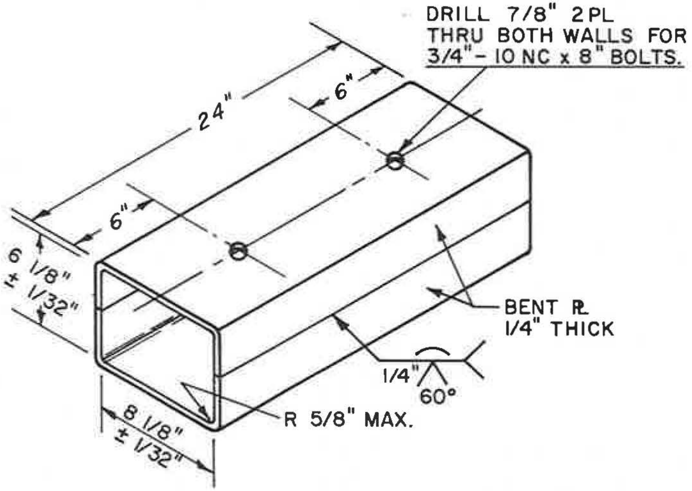
EXHIBIT 4



BEAM MOUNTING HOLE LOCATION DETAILS



POST FOOTING DETAIL



SPLICE SLEEVE DETAIL

Discussion

MALCOLM D. GRAHAM and JOHN VAN ZWEDEN, Bureau of Physical Research, New York State Department of Transportation—Our compliments are extended to the authors for their excellent paper and for the data they have gathered on the performance of these two median barrier systems. In New York, we are pleased that California successfully tested our box beam barrier, since their test conditions of 65 mph/25 deg with a 4, 500-lb vehicle were substantially more severe than our design conditions of 60 mph/25 deg with a 3, 500-lb vehicle. Having reviewed the report, we would like to make several comments about the work with the box beam median barrier and relate our field experience during the last three years.

California's first test (No. 141) on the box beam barrier represents a unique design, deviating considerably from any tested by New York, in that the rail was bolted directly to the posts. In our design, the posts are not bolted to the rail but are connected by paddles inserted in slots in the bottom of the rail. The purpose of these paddles is to transmit lateral rail load to the posts. These paddles also transmit minimal vertical forces to the posts so that when the barrier is deflected, posts in the immediate impact area detach from the rail and allow it to remain at a constant elevation. The paddles also bend easily when the posts are impacted by a vehicle sliding along the rail, thereby preventing the posts from snagging the vehicle. The ⅜-in. diameter bolt used in the California test was apparently too weak to develop the necessary resistance to lateral forces; consequently, the entire length of rail detached during impact. We feel that a larger or high-strength bolt used with this same design would given even worse performance, because either the vehicle would snag on the post since the stronger bolt could not shear, or the rail would remain rigidly attached to the post and lie down during impact, allowing the vehicle to pass over the barrier.

The results for Tests 142 and 143 are essentially what we would anticipate from extrapolating our data to a higher speed and greater vehicle weight. To compensate for the increased impact energy, California anchored the ends of the box beam, permitting it to act as a tension barrier. The New York design relies on rail bending to provide the lateral force necessary to retain an impacting vehicle. Deflection of the New York barrier is controlled by adjusting the bending strength of the rail, and/or by changing post spacing. Thus, we feel that the 4-ft deflection experienced by California could have been reduced had they redesigned the system to meet their impact conditions, using closer post spacing or a rail with a higher section modulus rather than electing to use the box beam in tension. The splices are also designed to transmit bending primarily with a capability of transmitting some tension. This design was not substantially changed with the result that one of the splice bolts was sheared during a test.

Regarding the barrier's tendency to deflect downward, we feel this may have been caused by the use of tension anchors. We fasten the ends of the rail, but this does not constitute a tension anchor; thus, during impact the box is not restrained. We have noticed a tendency for the rail to rise during impact, but never to lie down. Furthermore, we feel that had the barrier remained at a constant elevation or risen slightly, vehicle roll toward the barrier would have been eliminated.

We certainly must agree with the authors that curbs or depressions in the median may in some instances cause the vehicle to "jump" or "dive," and these movements make it difficult for any barrier system to perform effectively. Flat medians are desirable for any barrier design. However, on roadways having a curbed median we permit use of the box beam barrier. On these narrow medians (6 ft wide or less), curbs cause little problem because the vehicle is in contact with the barrier before jump can occur. If the median is wider, we recommend that the median be flattened before installing any barrier system.

The Bureau of Physical Research is currently studying the field performance and maintenance requirements of our barrier designs. Box beam median barrier performance is summarized in Table 4. Two of these three roadways require discussion.

TABLE 4

ACCIDENT AND MAINTENANCE EXPERIENCE BEFORE AND AFTER BOX BEAM BARRIER INSTALLATION

Data	Cross-Bronx Expressway	Bronx River Parkway	Taconic State Parkway
Project:			
Lanes	4	6	4
Median width	4-5 ft	5-6 ft	no median
Curb height	6 in.	6 in.	no curb
ADT	40,000	50,000[a]	18,000[a]
Speed limit	50 mph	50 mph	50 mph
Barrier installed	1964	1966	1966
Barrier length	$^1/_2$ mi	2 mi	3 mi
Accident:			
Period before barrier installation	18 months	24 months	59 months
Cross-median accidents	5	10	25[b]
Fatal accidents	2	2	4
Total killed	2	NA	6
Personal injury accidents	2	5	14
Total injury	3	NA	42
Property damage accidents	1	3	7
Period since barrier installation	24 months	18 months	18 months
Cross-median accidents	0	0	0[b]
Fatal accidents	0	0	0
Total killed	0	0	0
Personal injury accidents	0	9	3
Total injured	0	NA	5
Property damage accidents	8	12	8
Maintenance:			
Total accidents reported	8	21	11
Rail length replaced, ft	0	0	0
Posts replaced	0	6	13
Posts reset	5	12	0

[a] No commercial traffic.
[b] Cross-centerline accidents.

NA = Data no available.

In 1964, New York's first trial installation of box beam median barrier was placed in service on the Cross-Bronx Expressway in New York city which carries high volumes of mixed traffic. Since installation, only eight accidents have been reported. Repairs to the barrier have been limited to straightening and resetting several posts. There is evidence of numerous "brushing" accidents with this barrier. Significantly, no new material has been needed for maintenance during the entire 3-yr service period.

In 1966, a 3-mi box beam was installed on what was once termed the most dangerous section of the Taconic State Parkway—an undivided portion consisting of four 11-ft lanes. During a 5-yr period before erection of the barrier, 67 percent of all deaths and 42 percent of all injuries on this section resulted from head-on collisions. Barrier installations have completely eliminated accidents of this type. During the past 18 months, police have investigated 11 accidents involving the median barrier. The three most serious resulted in only minor personal injuries (lacerations and abrasions). Paint marks on the barrier indicate that at least 80 sideswipe accidents have occurred; presumably no injuries resulted, and the vehicles continued without reporting the accidents. Because of satisfactory performance of this installation, the East Hudson Parkway Authority has scheduled 22 additional miles of box beam barrier protection for the Taconic Parkway.

Based on the successful field experience achieved on the Cross-Bronx Expressway, the Bronx River Parkway and the Taconic State Parkway, we consider box beam median barrier performance excellent, both in terms of safety and maintenance. To date 40 accidents have been reported on these roadways: no fatal, 12 personal injury and 28 property damage. Maintenance is equally impressive. No rail has been replaced; 18

posts have been replaced, and 20 posts have been straightened and reused. Numerous brushing accidents required no maintenance, and we assume no injuries occurred because the accidents were not reported. The box beam has successfully eliminated all cross median accidents. In no case was the barrier deflected enough to represent a hazard to opposing traffic even though the median was less than 6 ft wide on all these roadways.

We feel the box beam barrier is one of the best semirigid barriers presently available for use in narrow medians, and our research is continuing to improve this design in any way possible.

ERIC F. NORDLIN and ROBERT N. FIELD, Closure—We appreciate the concern about our test results and feel that the comments that Mr. Graham and Mr. Van Zweden offered are of value. We would, however, like to offer the following clarification of some of the points mentioned:

1. The anchorage used for Tests 142 and 143 was provided to simulate the resistance to deformation that would be provided by the inertia of continuous lengths of box beam barrier. This inertia would, as did the anchors, permit a significant tensile force to develop in the beam. The anchors were not preloaded to apply tension to the beam, but were tightened just enough to obtain a reading on the strain gages (approximately 500 lb). Any influence this load may have had on the performance of the barrier would tend to decrease the deflection of the beam rather than increase it.
2. As stated in the discussion, the deflection of the barrier could be decreased by redesigning the barrier components. This would, however, tend to negate the desirability of this semirigid design and increase its cost as the design approached that of a rigid barrier.
3. The amount of vehicular rise imparted to a vehicle when it impacts a curb is a function of the distance traveled after the impact occurs. If given enough distance, the vehicle will rise even at impact angles as great as 30 deg. With a narrow 6-ft median, if a vehicle impacted the curb at a shallow angle, the vehicle could travel the distance required to rise 7 in. before transversing 2 ft 7 in. laterally. This might cause vaulting of the barrier.
4. We are impressed with the effectiveness of this barrier in the New York locations. It is apparently providing a positive barrier and presenting minimal maintenance problems. However, in at least one instance the lanes are reported as being only 11 ft wide and in all instances, the speed limit is only 50 mph. This, in combination with the relatively high ADT, indicates that a large majority of the collisions are probably low-angle low-speed impacts. This would be similar to the test conditions for Test 143, in which the barrier performance was very satisfactory. (A recent study made by our Traffic Department indicates that in 85 percent of the fatal accidents involving fixed objects over a recent period of California's freeways, the impacting vehicle was traveling in excess of 50 mph, with 60 percent traveling in excess of 60 mph.)

We feel that the strong beam-weak post concept of barrier design, pioneered and developed by the New York Bureau of Physical Research, is a significant contribution to the development of effective median barrier and guardrail design. As with all other barriers, however, the effectiveness of this design is dependent on the locations in which it is placed. The conclusions offered in our report were based on the most probable conditions in which this barrier would be placed if used in California. Our analysis was in no way intended to negate or contradict experience with this design in New York.