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16. ABSTRACT

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Three beam heights, two post spacings, and two beam metals are tested. Short lengths of guardrail are also tested.

The over-all results of this test program are correlated to field performance and the results of past tests to arrive at a new standard guardrail design for California highways.

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DYNAMIC TESTS
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CORRUGATED METAL BEAM GUARDRAIL

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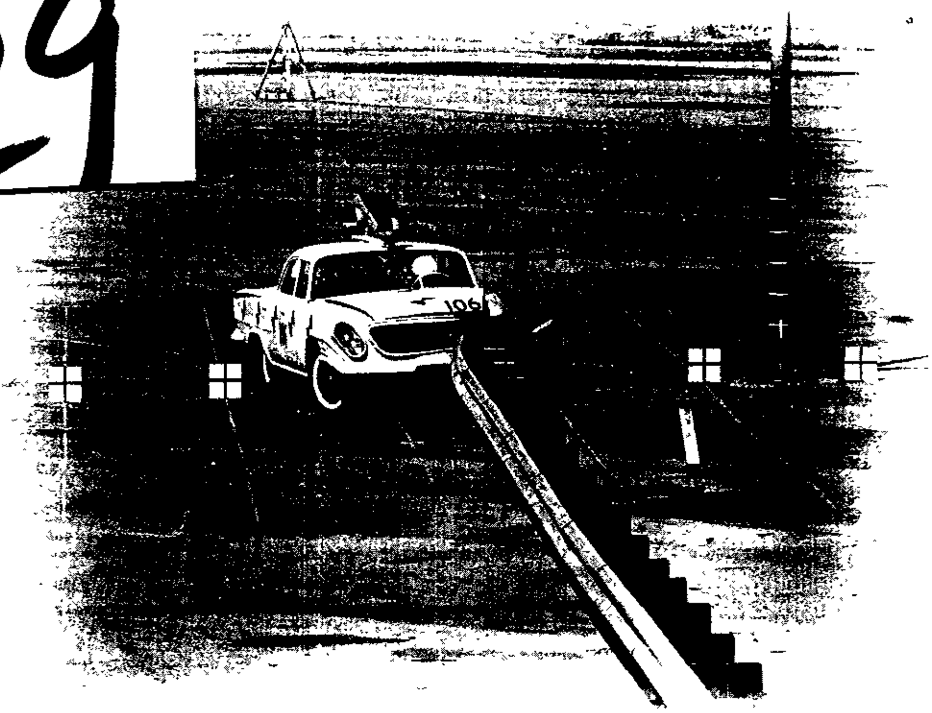

Presented at the 46th Annual Meeting of the Highway Research Board
January, 1967

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636392

Prepared in Cooperation with The U.S. Department of Commerce, Bureau of Public Roads

State of California
Department of Public Works
Division of Highways

DYNAMIC TESTS OF CORRUGATED METAL BEAM GUARDRAIL

By

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Presented at the 46th Annual Meeting
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SYNOPSIS

This report covers the results of seven full scale test collisions with several different designs of blocked-out corrugated metal beam guardrail.

Three beam heights, two post spacings, and two beam metals are tested. Short lengths of guardrail are also tested.

The over-all results of this test program are correlated to field performance and the results of past tests to arrive at a new standard guardrail design for California highways.

INTRODUCTION

A recent study(1) by the Traffic Department of the California Division of Highways of "ran-off-road" type accidents indicated that the primary reason for installing guardrail on embankments and adjacent to fixed objects is to reduce the combined effect of the severity and frequency of such accidents. They further concluded that guardrail will reduce accident severity only for those conditions where the over-all severity of striking the guardrail is less than the over-all severity of going down the embankment or striking the fixed object. This, combined with operational indications that our 1960 guardrail designs were somewhat inadequate for present day high speed traffic, led us to re-examine our current standard designs. We felt that when the employment of guardrail is necessary in the future, it must provide a positive means of redirecting the impacting vehicle. In addition, we wanted to verify the results of dynamic tests conducted at Lehigh University(2) which had indicated the possibility of utilizing aluminum as an alternate for steel in corrugated beam guardrail. The Lehigh tests had been conducted under collision conditions somewhat less severe than the general guidelines established by the Highway Research Board Committee on Guardrails and Guideposts(3).

Therefore, a series of full scale impact tests of blocked-out corrugated metal beam guardrail were conducted in 1964 by the California Division of Highways. In general, this report covers tests of two post spacings, three beam heights, two beam metals and, in addition, correlates the findings from other tests and field performance to this series.

Following the Missouri Highway guardrail test in 1934[4], the California Division of Highways adopted as their standard guardrail the curved steel plate beam mounted on heat treated spring steel brackets and wood posts. This guardrail served well until the late 1950's when the speed and weight of traffic started to overpower it.

In 1960, following full scale dynamic tests at the General Motors Proving Ground[5] and limited tests of our own[6], a guardrail utilizing 12 gage (0.105-in.) corrugated steel beam mounted 24-in. high over-all, blocked-out with 8- by 8- by 14-in. treated Douglas fir blocks, on 8- by 8- by 60-in. treated Douglas fir posts spaced 12-ft 6-in. on centers, was adopted as the California Division of Highways standard. This design was used until the results of the tests covered in this report were analyzed. As a result of these tests, the standard guardrail design now used by the California Division of Highways utilizes a 12 gage (0.105-in.) corrugated steel beam mounted 27-in. high over-all, blocked-out with 8- by 8- by 14-in. treated Douglas fir blocks, on 8- by 8- by 64-in. treated Douglas fir posts spaced 6-ft 3-in. on centers.

In 1965, following adoption of the aforesaid guardrail design as a standard, it was decided that the effectiveness of short sections of guardrail or other energy attenuation devices to protect traffic from collision with solid roadside objects should also be investigated. The first two tests of this current test series are included in this report as the results are considered fundamental to good guardrail design. Two short lengths (37.5- and 62.5-ft) of guardrail were tested to measure the effectiveness of such installations.

All tests followed the criteria outlined by the HRB Committee on Guardrails and Guideposts for full scale testing of guardrails(3). The test procedure, in general, followed that outlined in previous California reports(8)(9). The test vehicles, 1962 and 1964 4000 ± -lb automobiles utilizing their own power, were guided into the guardrail test installation collisions by radio control. An anthropometric dummy (Sierra Sam) occupied the driver's seat during each collision. He served two functions, namely: (1) as a human simulator to provide a record of the kinematics of a body during such collisions and (2) to test various restraint systems which were furnished and installed by the California Highway Patrol. The data from the first function are included in Table 3 of this report. The data from the second function were not considered germane to this report.

This report was prepared under HPR-1(4) D-4-37 in cooperation with the U. S. Department of Commerce, Bureau of Public Roads. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

CONCLUSIONS

1. A 12 gage (0.105-in.) corrugated steel guardrail beam mounted 27-in. high, blocked-out at least 8-in., on standard timber posts spaced 6-ft 3-in. on centers, will perform satisfactorily. A 27-in. beam height is optimum for blocked-out corrugated steel beam guardrail without a rubbing rail.
2. A guardrail (or median barrier) installation with the corrugated steel beam mounted more than 27-in. high, even though blocked-out, requires a rubbing rail to prevent wheel entrapment.
3. A blocked-out corrugated steel guardrail beam mounted 24-in. high, on standard timber posts spaced 6-ft 3-in. on centers, will generally perform satisfactorily. However, since this beam height is only slightly higher than the center of gravity of the average passenger car, there are possibilities of vehicle roll over and penetration under extreme conditions of impact.
4. A corrugated steel beam guardrail with a span length of 12-ft 6-in. provides insufficient lateral and torsional stability to resist heavy high-speed vehicle impact. The torsional stability of the beam is particularly critical at this span when a beam height of 24-in. is used.
5. The results of Test 109 indicate that 0.156-in. Alclad 2024-T3 aluminum alloy is not equivalent to 12 gage (0.105-in.) galvanized steel for use as a corrugated guardrail beam in the current California standard geometric design.
6. Short sections (37.5- and 62.5-ft) of corrugated steel beam guardrail are not satisfactory barriers when impacted at high

angles by heavy, high-speed vehicles. The relatively small number of posts in these short sections do not provide sufficient longitudinal resistance to the applied impact load. This permits the beam to form a pocket as it is pulled from each end toward the point of impact. The vehicle, under these circumstances, proceeds through the guardrail with very little redirection.

DISCUSSION

A. BEAM HEIGHT

Operational experience and previous test experience have indicated the height of the beam above ground to be one of the more significant variables contributing to the effectiveness of a barrier system. Experience[10] has indicated a beam height of 30-in. functions well in double blocked-out median barriers. In addition, the test on a single blocked-out metal beam median barrier (Test 106) gave excellent results. However, this test and others [6] indicate that a rubbing rail is needed with a 30-in. beam height.

Operational experience has also indicated that a beam height of 27-in., even though blocked-out, is about optimum for guardrail without a rubbing rail, if wheel entrapment is to be avoided. This was confirmed by the results of Test 107 in which the beam height was 27-in.

Test 105 showed that our 1960 standard guardrail design composed of a blocked-out steel beam mounted 24-in. high, on posts spaced 12-ft 6-in. on centers, was ineffective and unreliable in redirecting a modern vehicle traveling at high speed and impacting at an angle of 25°. The 24-in. beam height used in Test 105 was a factor in permitting the vehicle to mount, and thus vault, the guardrail. In this test the deflecting guardrail reached a point where, due to the location of impact forces (front bumper), the beam rotated about its own axis to a ramp position; then, as the front wheel of the vehicle retracted upward into the wheel well, it mounted the beam easily and smoothly (see Figure 1).

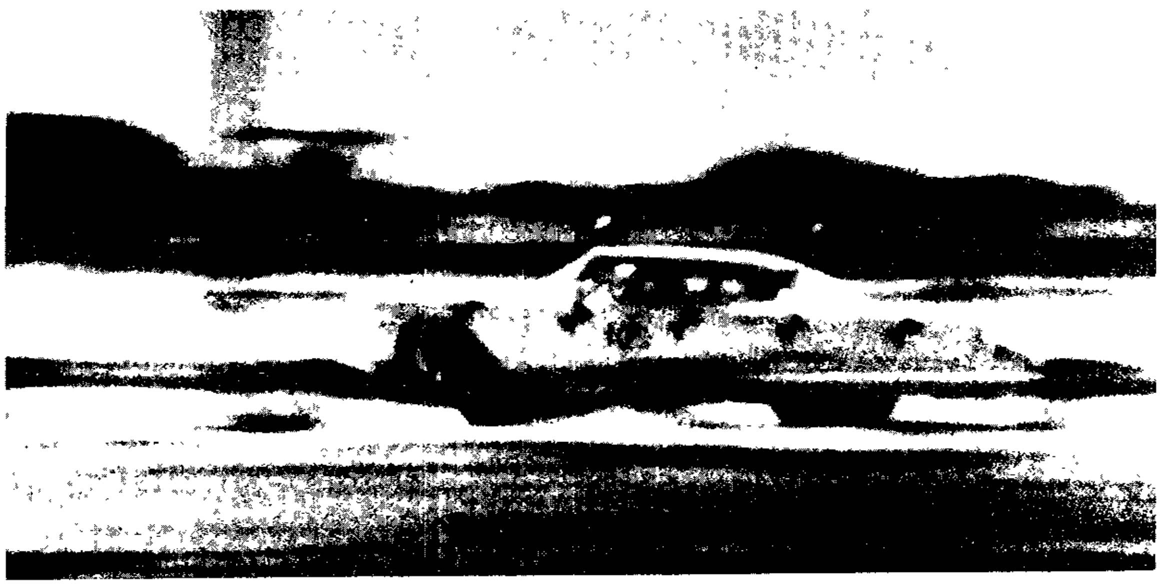


Figure 1

This 24-in. beam height was retained for Test 108; however, the post spacing was reduced to 6-ft 3-in. on centers. In contrast to Test 105, the vehicle in Test 108 was successfully redirected because the shorter span increased the lateral and torsional stability of the beam. However, the vehicle rolled slightly into the guardrail during impact (Table 1).

In Test 107, raising the beam height to 27-in. and retaining the 6-ft 3-in. post spacing produced results similar to those of Test 108. However, there was less pocketing and no tendency for the vehicle to roll (Table 1).

The 30-in.-high beam in Test 106 and the 27-in.-high beam in Test 107 deflected laterally and upward (Table 1). This upward deflection is caused by the "riding under" tendency of the vehicle. In this manner vehicular roll was held to a

TEST	BARRIER TYPE	BEAM MATERIAL	PERM. SET IN BEAM	BEAM HEIGHT		VEHICLE ROLL		VEHICLE SPEED	*EXIT ANGLE	LENGTH OF CONTACT
				BEFORE	AFTER	LEFT	RIGHT			
105	Single Blocked-out Guardrail	12 ga. Galv. Steel	5"	24"	16"	– Jump –		58 mph	30°	—
106	Single Blocked-out Median Barrier	12 ga. Galv. Steel	21"	30"	34"	– Flat –		60 mph	13°	19'
107	Single Blocked-out Guardrail	12 ga. Galv. Steel	18"	27"	29"	– Flat –		60 mph	17°	13'
108	Single Blocked-out Guardrail	12 ga. Galv. Steel	18"	24"	28"	5°	—	59 mph	19°	13'
109	Single Blocked-out Guardrail	0.156" Aluminum	—	24"	Failed	8° Before Failure	—	60 mph	—	—

* Exit angle measured as vehicle leaves barrier.

VEHICLE REACTION VS. BEAM HEIGHT

TABLE 1

minimum value as the guardrail provided a restraining force to the upward movement of the adjacent vehicle side. The 30-in.-high beam provides added insurance against vehicle roll-over or penetration, particularly where uneven or sloping terrain could cause a vehicle to vault immediately in advance of impact.

Guardrail beams mounted at a height of 24-in. showed a slight rotation outwardly (counter-clockwise in direction of vehicle travel) around the longitudinal axis due to a combination of the deflection behavior of the guardrail system and the roll of the vehicle. This rotation was not evident in beams mounted at a height of 27- or 30-in. where the upward deflection prevented vehicular roll.

B. RUBBING RAIL

A moderate amount of post damage caused by wheel entrapment was evident in the guardrail tested in Test 107, which indicated that 27-in. is the maximum beam height that should be used without a rubbing rail. The rubbing rail was found to be effective in installations with beam heights exceeding 27-in. In Test 106 the rubbing rail sustained considerable damage and materially aided the barrier in redirecting the vehicle. Although this function is secondary to that of preventing wheel entrapment, the rubbing rail on the 30-in.-high guardrail gives added strength to this system.

A rubbing rail of lessor section modulus than the structural channel employed in Test 106 was used in another test (not reported here). The results, as shown in Figure 2, emphasized the need of a strong rubbing rail to prevent pocketing when the 30-in. beam height is used.

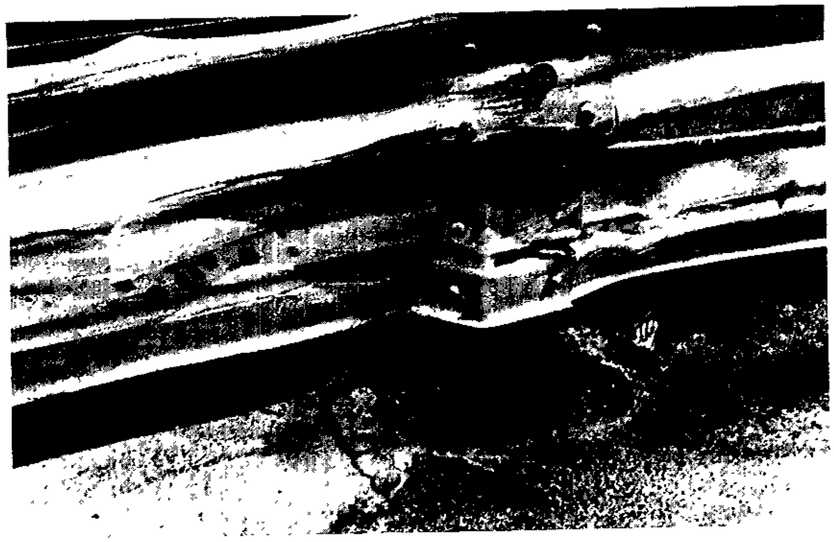


Figure 2

C. BUMPER HEIGHT VS. BEAM HEIGHT

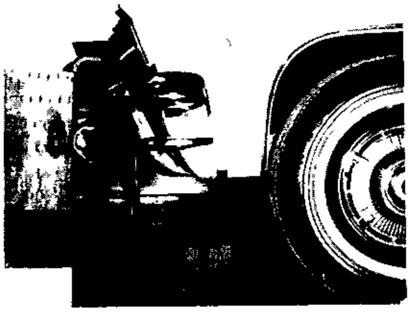
Analysis of the data from Test 105 indicated that the vaulting problem on the 24-in-high blocked-out corrugated steel beam guardrail was compounded by the front bumper geometrics of the 1962 Chrysler test vehicle (see Figure 3).

Figure 3

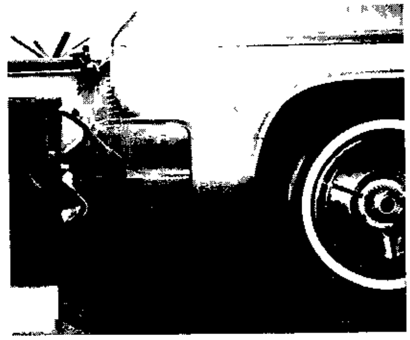
Investigation of bumper geometrics revealed that a majority of the U. S. manufactured vehicles for the years 1962-65 were equipped with bumpers having characteristics similar to those of the 1962 Chrysler test vehicle (Plate 1). It is possible that this feature of the newer vehicles has contributed to the high incidence of guardrail vaultings reported by our operational departments. It may be noted in Plate 1 that the bumpers of the newer automobiles from the four leading manufacturers would strike a 24-in.-high guardrail above the center of the beam. This point of impact, in conjunction with the curved, sloped-back bumper design, increases the possibility of vaulting due to the eccentric loading about the beam's longitudinal axis of rotation.

D. <u>POST SPACING</u>

The importance of the relationship between post spacing and torsional stability of the beam at critical beam heights can be demonstrated by comparing Tests 105 and 108. Although three of the posts spaced 6-ft 3-in. on centers were shattered or badly damaged in Test 108, there was sufficient resistance to rotation, provided for a sufficient length of time, to develop the beaming action necessary to effectively redirect the vehicle. In Test 105 with the beam at the same 24-in. height but with posts spaced 12-ft 6-in. on centers, the vehicle readily vaulted the guardrail. Therefore, post spacing, as well as beam height, should be considered a major factor affecting guardrail (or barrier) performance.

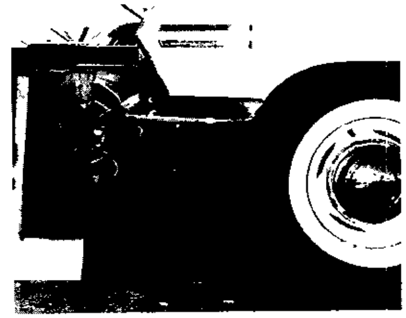


1965

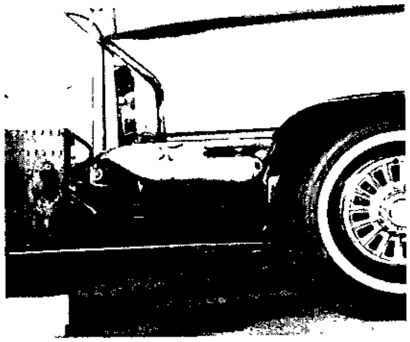


1964

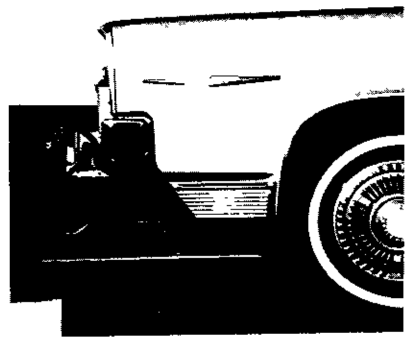
CHEVROLET



1963

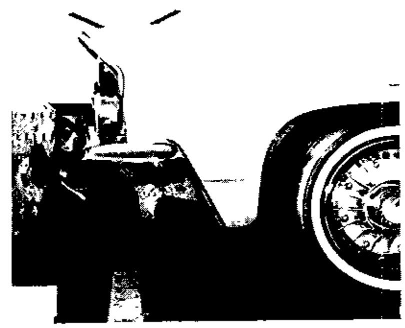


1965

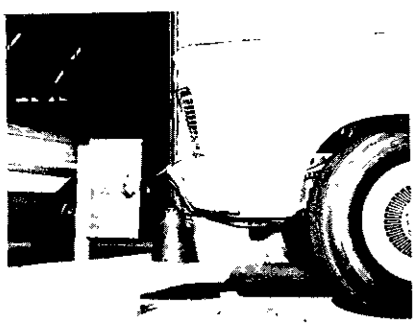


1964

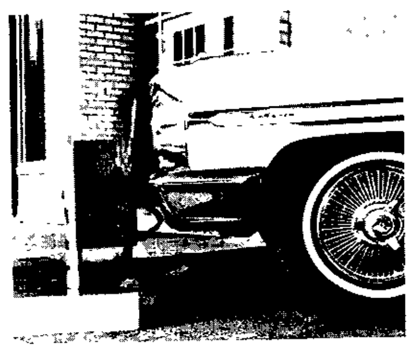
PONTIAC



1963

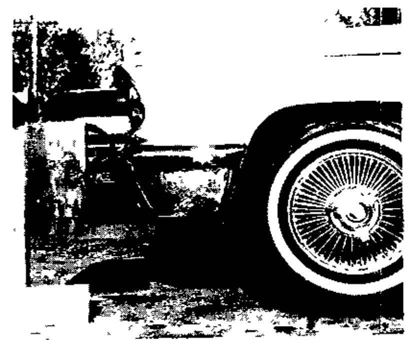


1965

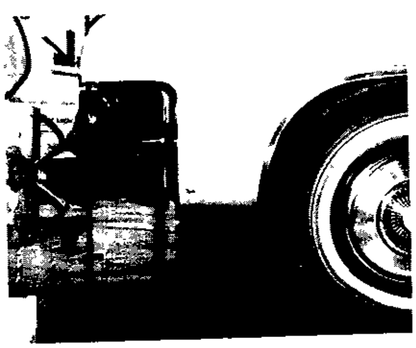


1964

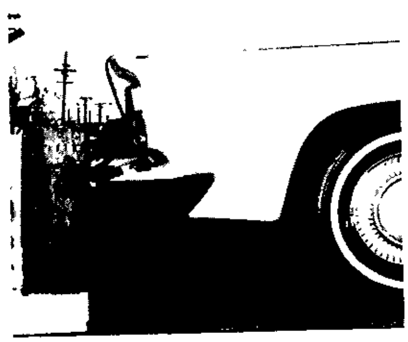
FORD



1963



1965



1963 & 1964

CHRYSLER

Comparison of vehicle bumper heights to 24-in.-high guardrail.

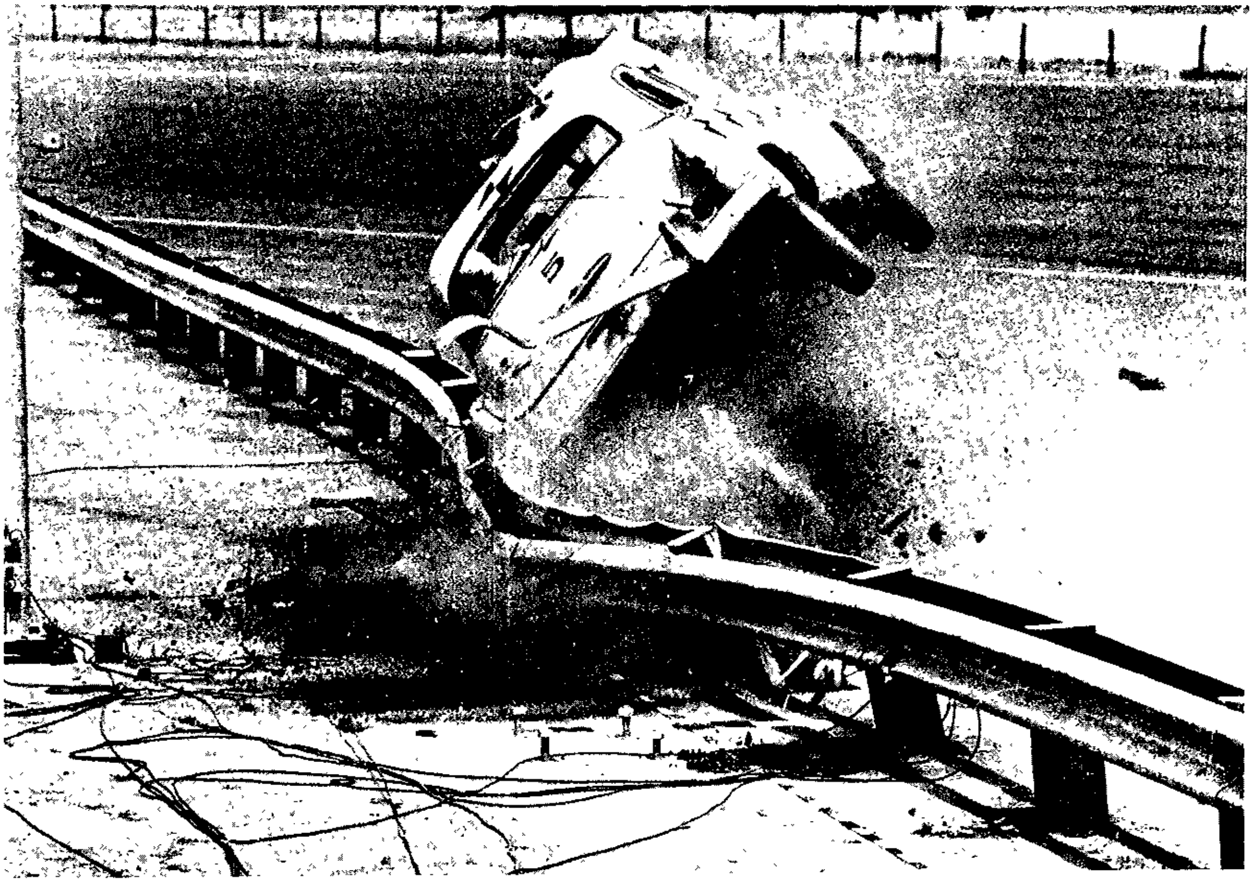
PLATE 1

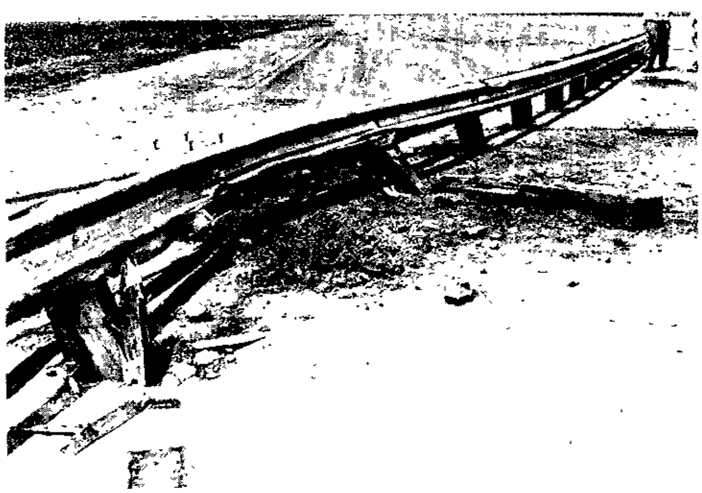
E. EFFECT OF BLOCKED-OUT BEAM

The relative effectiveness of the blocked-out barrier design in preventing excessive vehicular roll may be seen by comparing Test 505 conducted in 1958 (see Plate 2) with Test 108 (Plate C). Even with the additional rigidity provided by the double beam, the design used in Test 505 was ineffective in preventing vehicle roll-over. During contact with any semi-rigid beam-type barrier, an impacting vehicle tends to roll toward the barrier. Resistance to this roll is provided by the weight of the vehicle acting downward and is either helped or hindered by the moment couple between the horizontal center of gravity of the car and the center of gravity of the beam. Since the most critical time of any barrier collision occurs during the first few hundredths of a second after impact as the beam is being deflected but before axial tension has become effective, it is important that the beam height be maintained or increased slightly as the post rotates, as shown in Figure 4. The effect of blocking-out the beam is to minimize vehicular roll by providing restraining forces above the center of gravity of the vehicle during the early and most critical time of collision. In contrast, the height of the nonblocked-out beam immediately decreases during post rotation thereby decreasing the effectiveness of the barrier's restraining forces. This can result in the beam acting as a ramp before it has an opportunity to start resisting axially.

F. BEAM MATERIAL

Satisfactory guardrail performance may be expected only when a beam of sufficient strength is used in conjunction with a proven geometric design. This was amplified by all of the tests





TEST 505   1958

Double Metal Beam Median Barrier with galvanized steel corrugated beam mounted on 8- by 8-in. D. F. posts spaced 6-ft 3-in. on centers.

Impact Speed	58-mph
Impact angle	31°
Beam Height	25-in.

PLATE 2

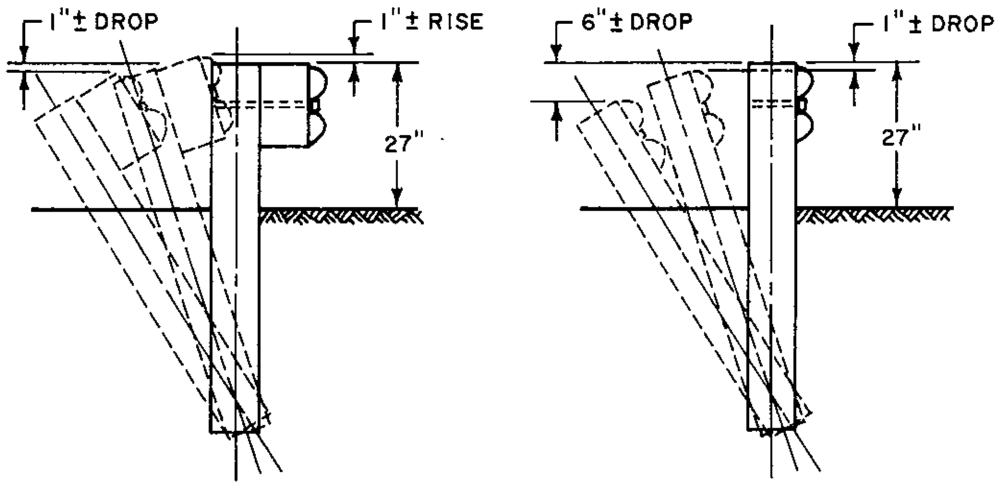


Figure 4

in general, and Tests 108 and 109 in particular. The aluminum beam of Test 109 exhibited numerous individual failures through the impact zone. In this test, failure resulted from a combination of tensile and bending stresses in excess of those capable of being resisted by the material (see Plate 3). The aluminum alloy used in this series of tests had been selected by the Aluminum Association Committee on Highway Applications following the results of tests conducted by Lehigh University[2]. It is important to note that the Lehigh tests were conducted at impact angles no greater than 15^{o} and utilized vehicles weighing less than 3500 lb.

Previous tests[9] on median barriers using aluminum beam material have shown that aluminum beam failures generally occur at posts, either through reduced sections at splice holes or at other points of high stress concentration induced by severe bending deformation. Some failures occurred near midspan and are believed to have been initiated by the same lack of resistance to high dynamic stress concentrations. These bending stresses, present with large beam deflections, cause local buckling at the top and bottom of the beam. The buckled areas, appearing as ripples, are more apparent in steel sections although they do not cause tears as in the aluminum. The difference in performance of steel and aluminum appears to stem from the difference in stress-strain relationships and ductility of the two materials (see Figure 5 and Table 2).

This difference can be observed by comparing the examples (a., b., and c.) of deformed steel beams that were successful in redirecting the vehicle with the examples of aluminum failures (d., e., and f.) shown on Plate 3.

Due to the unpredictable manner of load application by the various vehicle components, a barrier beam must have the capability of accepting large plastic deformations without failure or it must operate within its elastic limit and resist local deformations such as is done by most bridge rails[8]. Steel exhibited this plastic capability and performed satisfactorily with no failures that affected the effectiveness of the guardrail (see Plate 3).

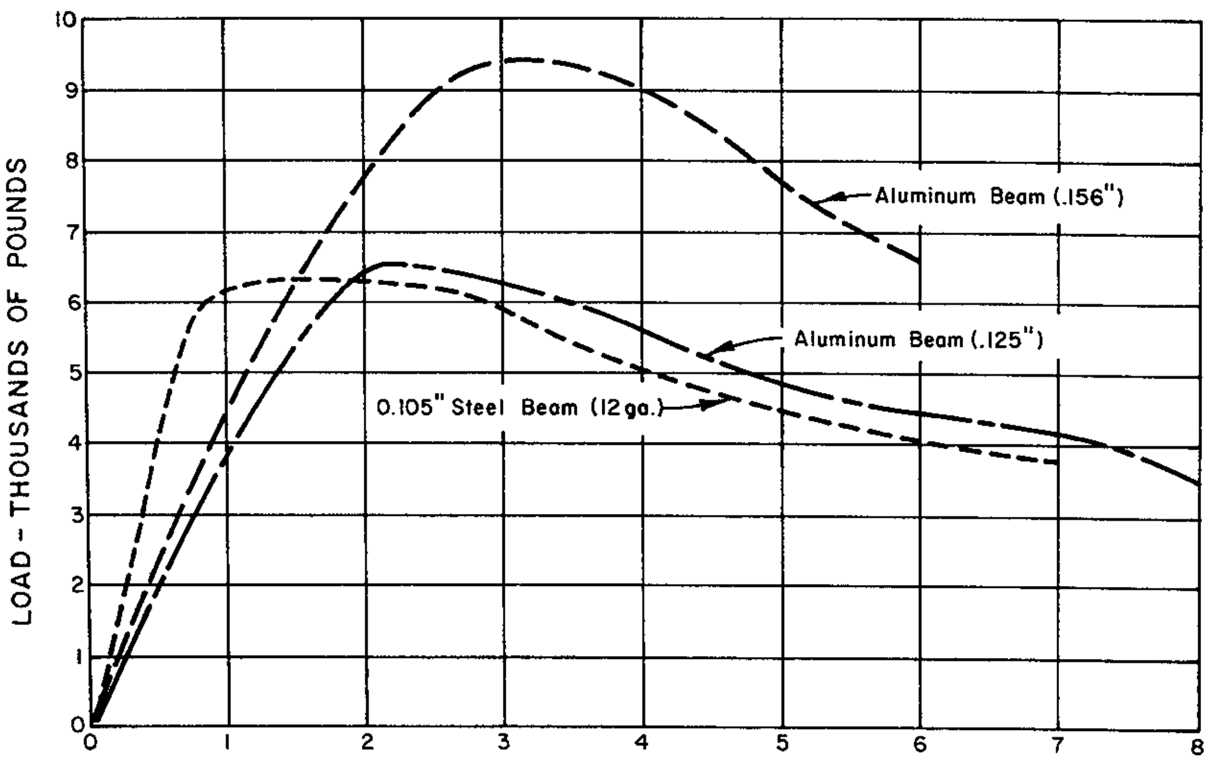
G. <u>ENERGY DISSIPATION</u>

The behavior pattern of any semi-rigid barrier subjected to vehicle impact must include deflections if the collision is to result in lower deceleration values, acting on both the vehicle and its occupants, than occur during a similar collision with a rigid barrier. At the instant of impact, the vehicle has a certain amount of kinetic energy (Table 3) which may be resolved into components parallel, perpendicular, and vertical to the barrier. If the vehicle is to be redirected effectively, the perpendicular and vertical energy components must be reduced or dissipated. In the semi-rigid corrugated metal beam guardrail the energy dissipation is accomplished through bending distortion and crushing of various parts of the vehicle and the barrier, including the foundation soil. In a rigid barrier most of the energy is absorbed by vehicular failure[11] although the New Jersey solid concrete barrier at low angles of impact appears to dissipate energy and minimize vehicle damage by uplift. A positive redirected trajectory is attained by the vehicle only when its lateral kinetic energy component is dissipated to the extent that it is less than the resistance of the barrier to further lateral deflection.

H. BARRIER BEHAVIOR

1. Beam Reaction:

Although the barrier considered in this report is referred to as a "beam" guardrail, the beam must withstand high axial tensile stresses, as well as bending stresses, if it is to function properly. This feature has received comments by other researchers, some of whom state that full tensile strength of the beam should be developed[4][12] while others claim by definition that axial tensile stresses may be considered to be negligible[13]. It is believed that more light should be brought to bear upon this aspect since a previous test [9] and Test 109 illustrate effects that may be expected when the imposed tensile stresses cannot be resisted by the beam.



STATIC LOADING OF 6-FT. 3-IN. BEAM SECTIONS
CONCENTRATED LOAD AT CENTER

BEAM DEFLECTIONS

FIGURE 5

SPECIMEN	NUMBER	YIELD POINT PSI	ULTIMATE PSI	ELONG. %	R.A. %	IMPACT ft.-lb.	
						TRANS.	LONG.
Steel Beam	105	54,122	71,491	21.1	56.4	9.0	16.7
	106	56,396	75,078	20.2			
	107	57,203	77,160	19.8			
	108	53,003	71,147	20.8			
Aluminum Beam(.156")	109	59,415	67,080	16.0	38.2	5.3	5.3
Steel Channel	106	47,370	65,297	24.3	50.1	16.7	38.7

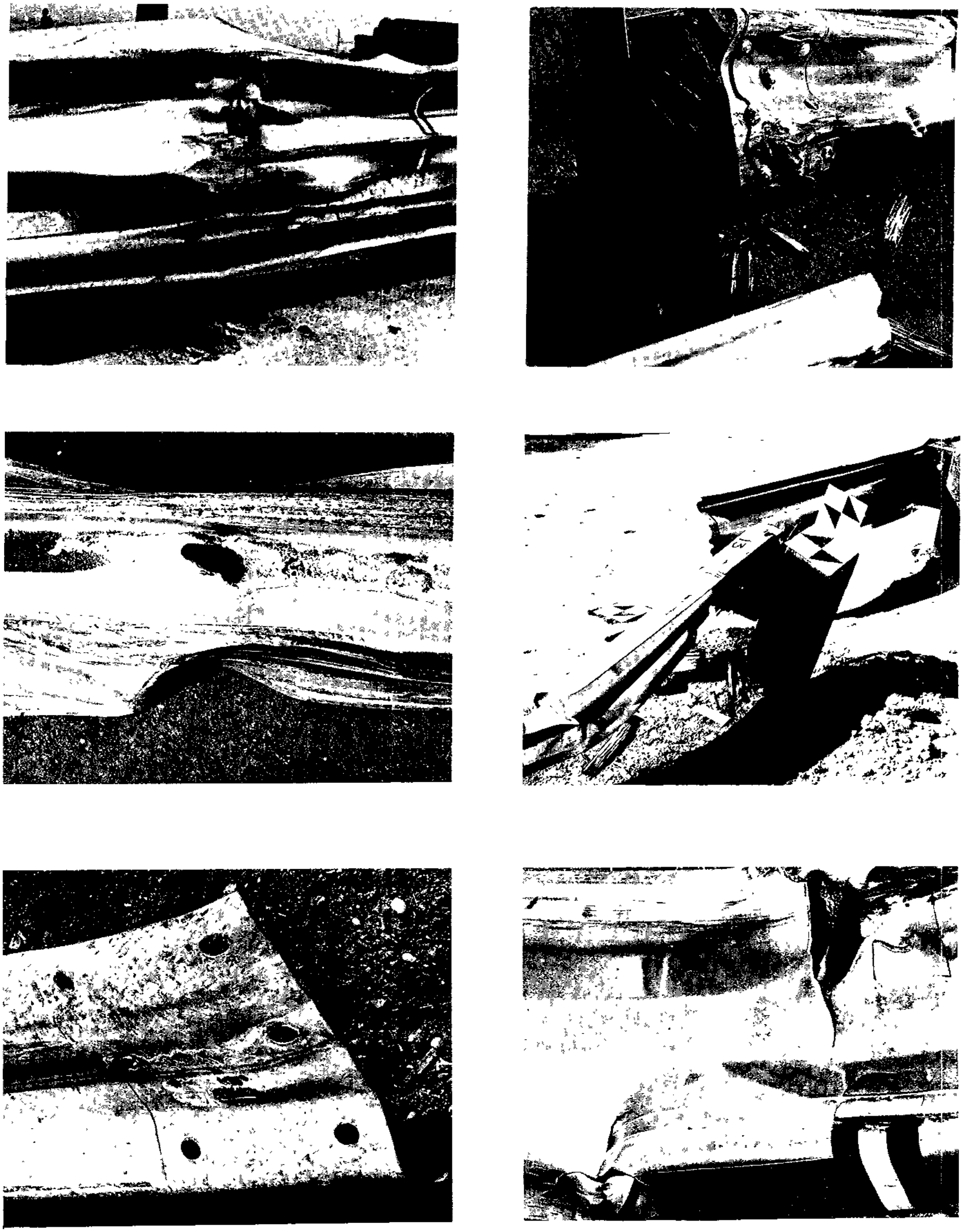
NOTE:

All samples taken from beam in immediate impact area.

MECHANICAL TEST AVERAGES

OF GUARDRAIL MEMBERS

TABLE 2



Typical Failures of
Steel and Aluminum Beams

PLATE 3

Some insight as to the magnitudes of the tensile stresses was gained from observations of the longitudinal movements of the beams during impact loading and the effects of such movements. As the vehicle strikes the barrier, the lateral deflection of the beam pulls the beam longitudinally toward the point of impact from both directions along the installation. This movement is resisted by the posts through the bolts used for mounting the beams and blocks to the posts. As the beam begins to move and before all the slack in the bolt slots is taken up, the resisting force consists primarily of friction between the beams and blocks. When the ends of the slots reach the bolts, an additional resisting force is provided but, in most instances, some movement will still occur and this tends to bend the bolts, causing extremely high bearing pressures on one-half of the block-post interface. Observations during this test series revealed that the block frequently splits through the bolt hole in a plane perpendicular to the barrier. There were instances where the tearing action of the bolts extended the slot length in the steel beam by approximately 5 inches (see Figure 6). However, these severe reactions were limited to the impact zone, where larger strains in the beams were evident.

Two types of post splitting were observed. In the impact zone, posts sometimes split through the bolt holes. At locations outside the impact zone, cracks were observed near the edges of the posts, caused by the high bearing pressures of the blocks. When no slack was available in the bolt hole slots for longitudinal beam movement, greater torsional loads

TEST NO.	DOOR DEFORM-ATION	DUMMY RE-STRAINT	DOOR OPENED CLOSED	DUMMY IMPACT *						VEHICLE IMPACT *						VEHICLE TRAJECTORY				
				TRANSV.		LONG.		VERT.		TRANSV.		LONG.		VERT.		ANGLE **		SPEED **		IMPACT LOCATION
				L	R	FWD.	BCK.	UP	DN.	L	R	FWD.	BCK.	UP	DN.	ENT.	EXIT	ENT.	EXIT	
105	0	TYPE 4	CLOSED	.5		.2		.5	.4	NO RECORDINGS						25°	JUMP	58	55	AT POST # 8 + 2'
106	1/2"	TYPE 4	CLOSED	2.9		1.6			.2	1.4		1.5		1.6		25°	13°	60	43	AT POST # 12 + 2'
107	3-1/2"	LAP BELT	OPENED	2.5		1.4		.9		1.1		1.9		1.5		25°	17°	60	37	AT POST # 12 + 4'
108	2"	LAP BELT	OPENED	3.3		2.4		1.8		1.0		1.8		1.5		25°	17°	59	35	AT POST # 13
109	2-1/2"	TYPE 4	OPENED	3.6		6	5	3.3	4.4	1.2		2.2		1.2		25°	—	60	0	AT POST # 12

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

** Exit angle and speed measured 25 ft. from point of impact.

DYNAMIC DATA ON VEHICLES

TABLE 3

were transmitted to the posts and into the soil as was evidenced by wedge-shaped gaps between the posts and the soil along the sides of the posts. Operational experience indecates that post splitting near points of impact on guardrail installations is fairly common for Douglas fir posts.

Figure 6

2. Post-Soil Reactions:

Reviews of test data film and inspection of the installations after impact indicate that posts are subjected to severe damaging forces from direct vehicle contact and beam restraint. Final deflected positions of the posts were somewhere between the original vertical positions and the maximum dynamic deflected positions. Maximum horizontal dynamic deflections through the impact zone exeeded permanent deflections by as much as 150 percent. In transmitting the forces to the soil at the test site, a clayey loam, the posts deflected as cantilevers and rotated about points along their vertical axes. As the lateral deflections of the post tops increased, the centers of rotation moved down along the post axes. For very large deflections the rotation center appeared to be very near the bottom of the post, which is in agreement with previous findings(14) for rigid posts (see Figure 7).

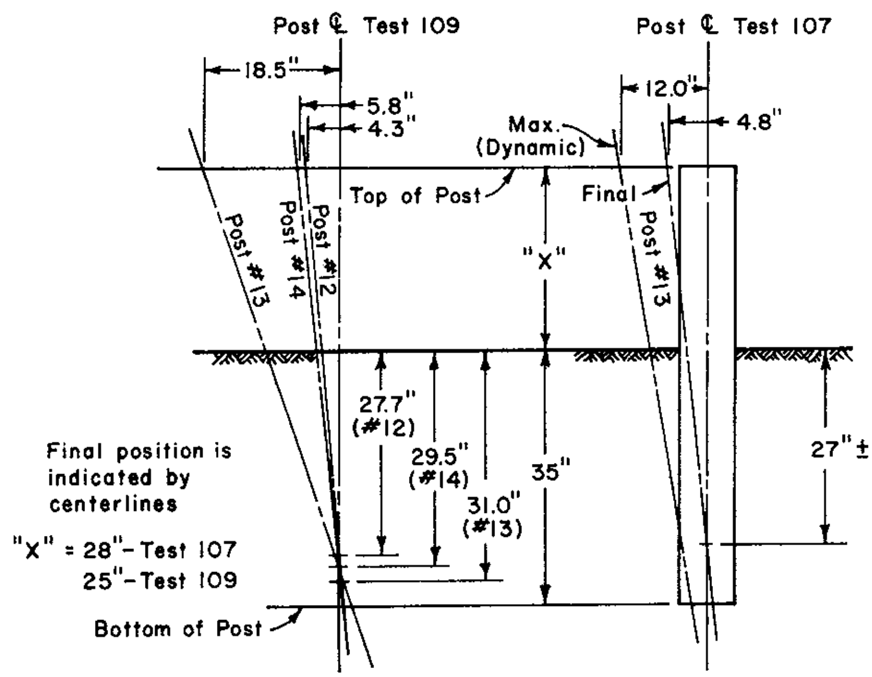


Figure 7

Since the installation was constructed on an airport runway with no imported base material, the 2-inch asphalt wearing surface provided a cover which afforded an excellent opportunity to observe the zones of maximum stress within the soil. The asphalt behind the posts sheared cleanly in almost perfect circles approximately 2 feet in diameter with the back faces of the posts cutting chords from them. These circles were apparent only for posts in the impact zone and indicated, at the ground surface, the limits of shear failure within the soil.

Figure 8 shows soil heave after one of the latter tests and illustrates the need for adequate set-back from the hinge-point, or deeper post embedment, for guardrail installations on fill slopes.

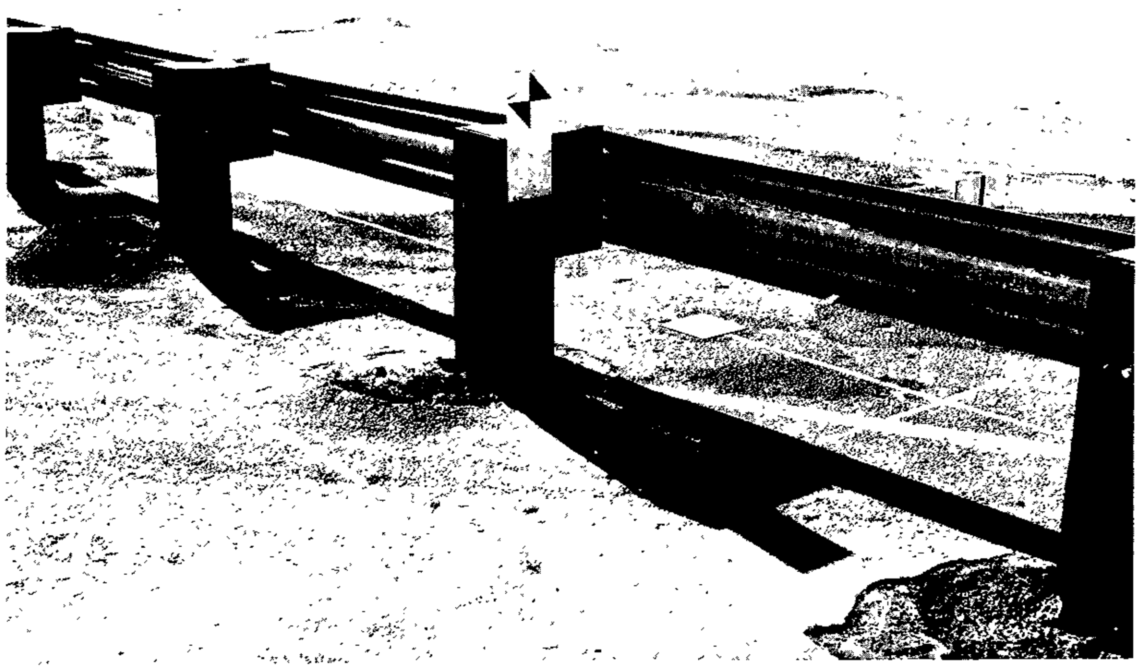


Figure 8

I. OPERATIONAL EXPERIENCE

The blocked-out beam barrier concept has been supported consistently by satisfactory performances of single and double blocked-out corrugated steel beam barrier field installations. Investigations of in-service barriers at accident locations revealed barrier behavior patterns almost identical to those exhibited by successful test barriers. Double blocked-out median barriers have performed exceptionally well as illustrated by Figures 9 and 10.

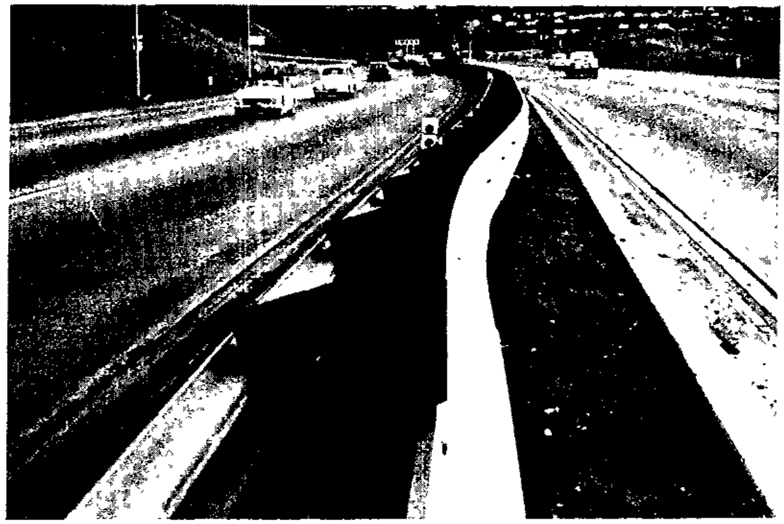


Figure 9

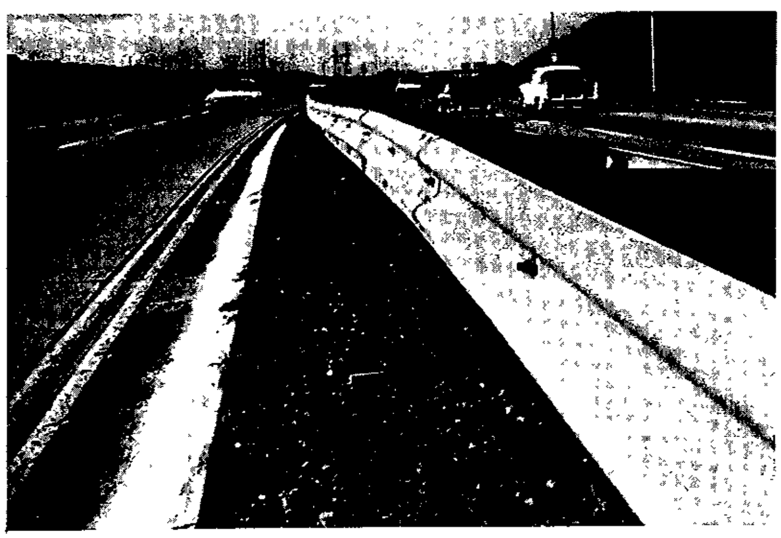


Figure 10

The operational success of 24-in.-high blocked-out guardrail with 12-ft 6-in. post spacing did not equal that of the double blocked-out median barrier. However, Test 108 showed that the basic single blocked-out design was effective in redirecting the vehicles, providing appropriate design dimensions such as 6-ft 3-in. post spacing and 24-in. (preferably 26- to 27-in.) beam height, were used.

Field surveys of damaged short sections of blocked-out guardrail with 12-ft 6-in. post spacing, used as obstruction deflectors for sign posts and bridge columns, revealed marginal performances, as illustrated in Figures 11 and 12 and verified by Tests 131 and 132.

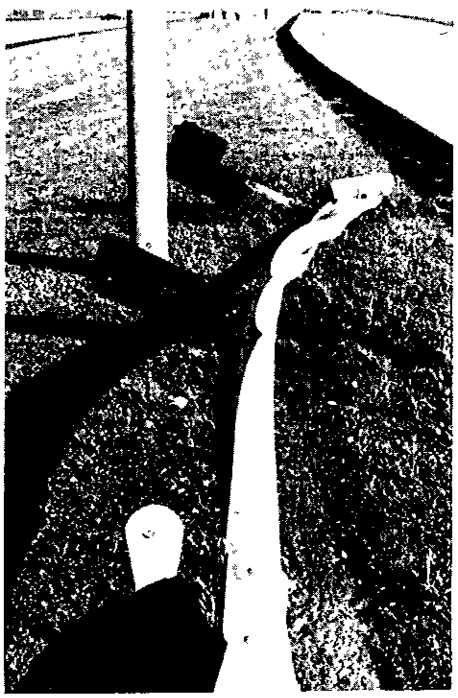


Figure 11

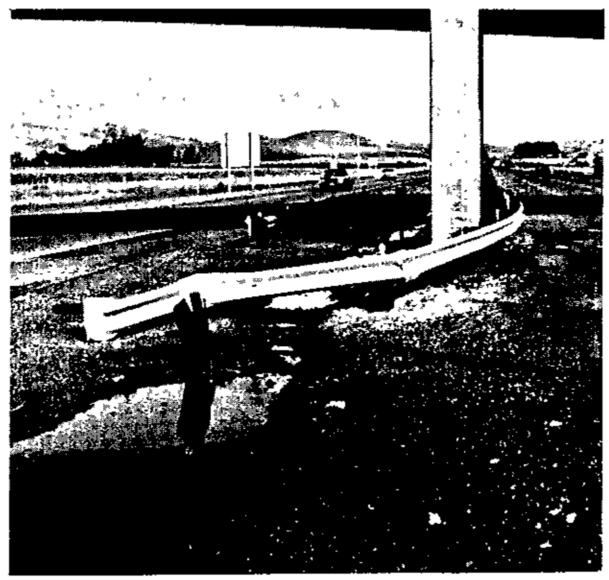


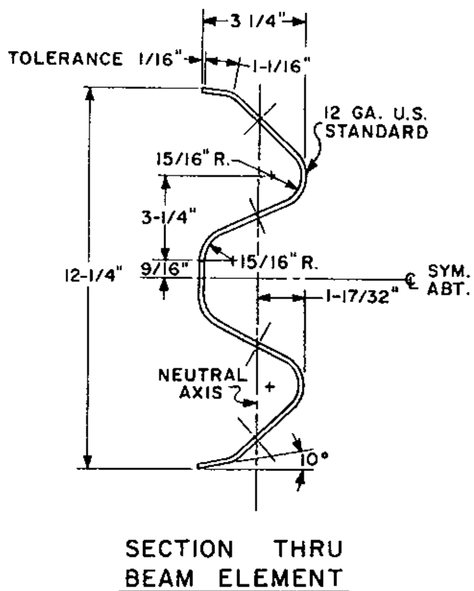
Figure 12

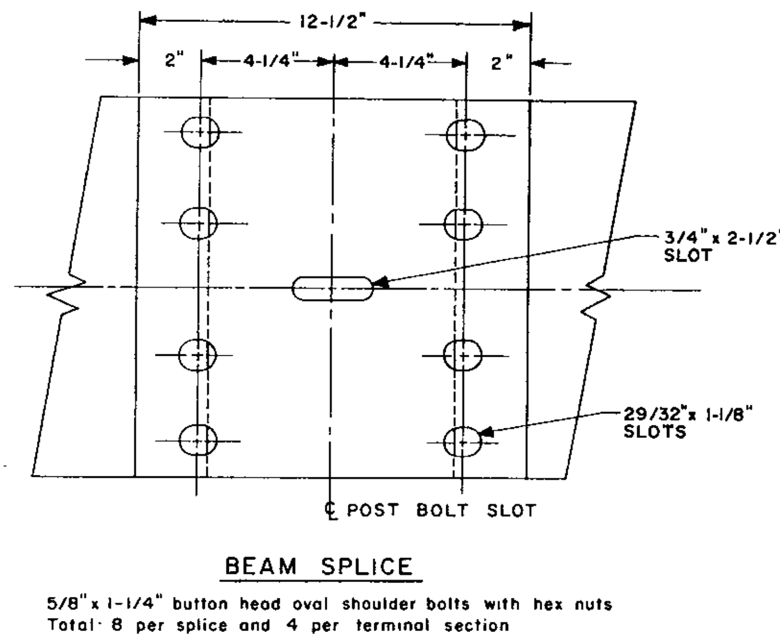
J. EFFECT OF LENGTH

Certain design factors appear to be more significant in short deflector type guardrail installations than in the longer median barrier or guardrail installations. For instance, in short installations the individual connections (Figure 13) to posts must withstand greater loads than those of longer installations. The long lengths of guardrail permit load transfer to posts at appreciable distances in both directions from the point of impact. The tendency of the short barrier to deflect laterally as a unit (Tests 131 and 132) indicates that the combined resistance of the connections to the posts is less than the strength of the beam.

In other words, there must be a sufficient number of posts in any beam and post system to completely develop the axial strength of the beam. If not, then the strength must be developed in some other manner, such as anchors. It may be possible to design connections to each post that would develop the full strength of the post-soil system. This would also require closer, than present, tolerances in compaction and moisture content control of the soil around posts. It appears that an anchoring system would be the most practical.

Test 133, next in the current test series on short lengths of guardrail, will be conducted on a short length of guardrail utilizing special 26-ft. corrugated steel beam end sections to form approximately 18-ft 9-in. of beam extension at each end. In a manner employed by the Texas Highway Department, the extended beam ends will each be twisted down and fastened to a concrete anchor.





The beam is fastened at each post with a 5/8-in. carriage bolt (large head) utilizing a cut steel washer under the nut.

Fig. 13 Corrugated Beam Splice Details

IV. REFERENCES

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3. Highway Research Board Committee on Guardrails and Guide Posts, "Proposed Full-Scale Testing Procedures for Guardrails", Circular 482, September 1962.

4. Reagel, F. V., Willis, T. F., and DeReus, M. E., "Tests of Various Highway Guardrails", Missouri State Highway Bulletin, 1934.

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6. Beaton, J. L. and Field, R. N., "Dynamic Full Scale Tests of Median Barriers", HRB Bulletin 266, 1960.

7. "Highway Guardrail", Highway Research Board Special Report No. 81, 1964.

8. Nordlin, E. F., Field, R. N., and Hackett, R. P., "Dynamic Full Scale Impact Tests of Bridge Barrier Rails, Test Series VIII", presented at the 43rd Annual Meeting of the Highways Research Board, January 1964.

9. Field, R. N. and Prysock, R. N., "Dynamic Full Scale Impact Tests of Double Blocked-Out Metal Beam Barriers and Metal Beam Guard Rail, Series X", California Division of Highways, February 1965.

10. Beaton, J. L., Field, R. N., and Moskowitz, K., "Median Barriers--One Year's Experience and Further Controlled Full Scale Tests", Highway Research Board Proceedings, Volume 41, 1962.

11. "Development of an Analytical Approach to Highway Barrier Design and Evaluation", Physical Research Project No. 15, New York State Department of Public Works, May 1963.

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13. Shoemaker, N. E., "Test Report for Full-Scale Dynamic Tests of Highway Barriers", Cornell Aeronautical Laboratory, Inc., December 1963.

14. Davisson, M. T., and Prakash, S., "A Review of Soil-Pole Behavior", Highway Research Board Record 39, 1964.

V. APPENDIX

The following seven groups of plates contain pertinent data and photographs of the seven impact tests discussed in this report. Each group covers the following:

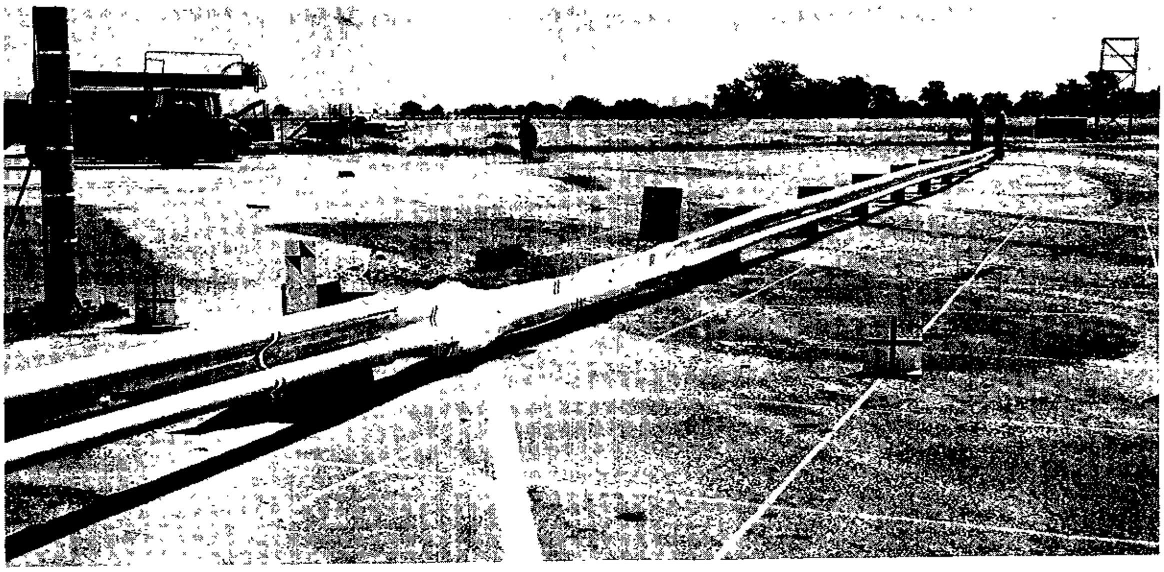
A. A detailed description of the barrier installation, purpose, performance, barrier damage, and vehicle damage.

B. A data sheet showing overhead or panned camera view of vehicle through impact and a tabulation of test parameters.

C. A series of sequence pictures from the front data camera or scaffold mounted camera.

D. & E. Detailed photographs of barrier and vehicle damage.

TEST 105 PLATE A



BARRIER: Blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 24-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5-ft 6-in. treated DF posts spaced 12-ft 6-in. on centers.

PURPOSE: To proof test the 1960 California standard blocked-out metal beam guardrail design to obtain base data for comparison with test data from other guardrail designs.

PERFORMANCE: The vehicle impacted the guardrail between posts at a speed of 58-mph. The bumper rotated the beam axially into a ramp position, enabling the car to vault the barrier. The vehicle rose to a maximum height of 30-in. and was airborne for 25-ft.

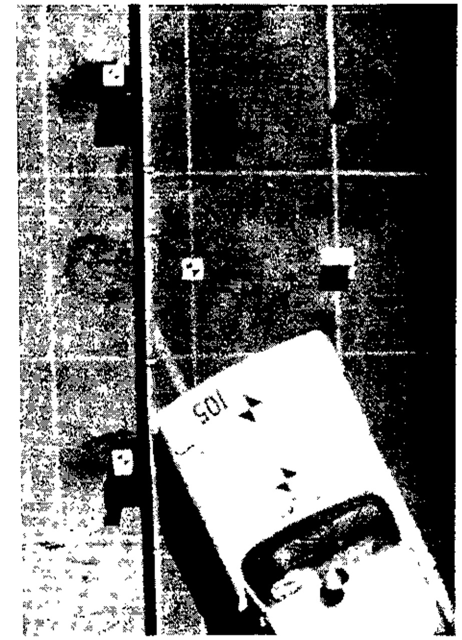
BARRIER DAMAGE: Two sections of beam were damaged. Three posts were knocked out of alignment, one of which was shattered. One block-out block was splintered and one was split.

VEHICLE DAMAGE: The vehicle sustained moderate front end damage. This vehicle was repaired for $250 and used as the impact vehicle in Test 109.

IMPACT + 130 M Sec

IMPACT + 57 M Sec

IMPACT + 36 M Sec



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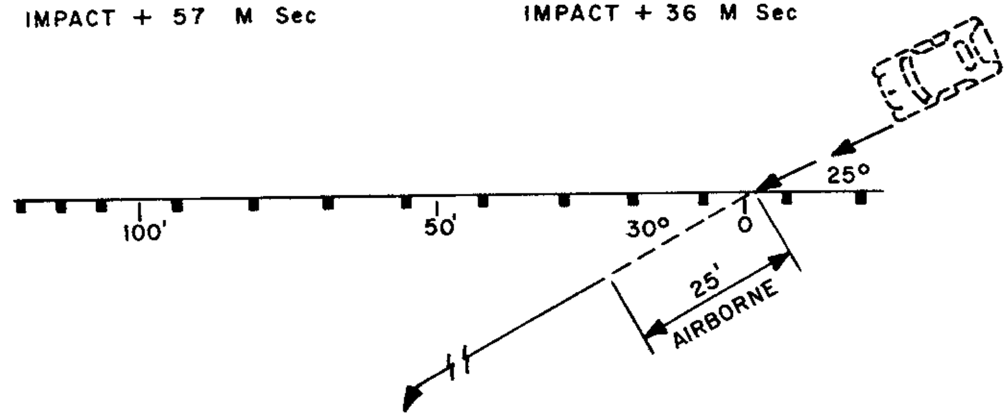
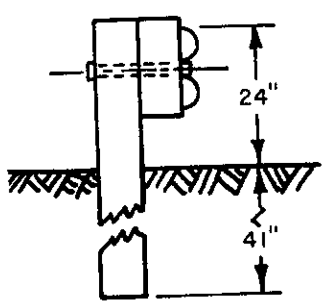
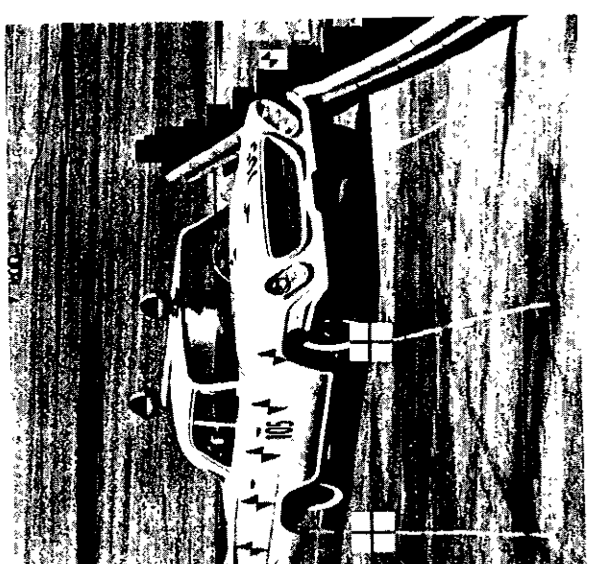




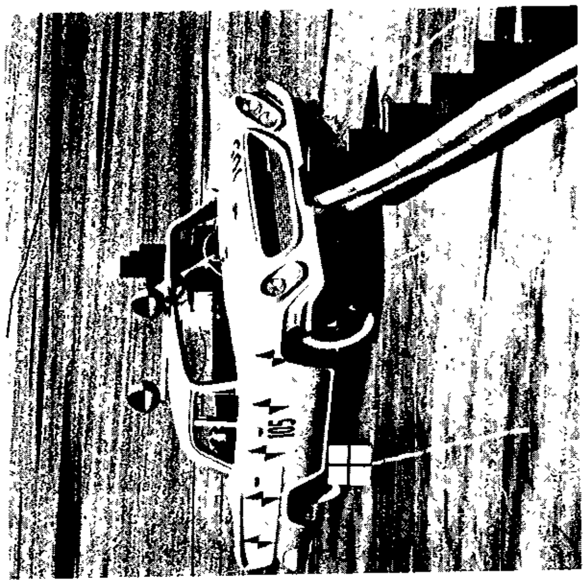
METAL BEAM GUARDRAIL

BEAM RAIL	12 ga. Galv. Steel x 13'-6.5"
RUBBING RAIL	None
POST	8"x 8" Rough D. F. x 5'-6"
POST EMBEDMENT	41"
POST SPACING	12'-6"
LENGTH OF INSTALLATION	175'
GROUND CONDITION	DRY
BEAM RAIL DEFLECTION-PERMANENT	5"

TEST NO.	105
DATE	9-9-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570#
IMPACT SPEED	58 mph
IMPACT ANGLE	25°
EXIT ANGLE	30°
DUMMY RESTRAINT	Type 4



Impact



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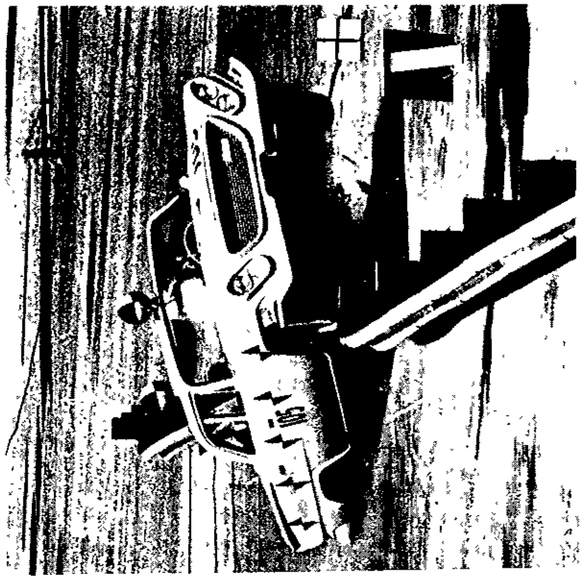

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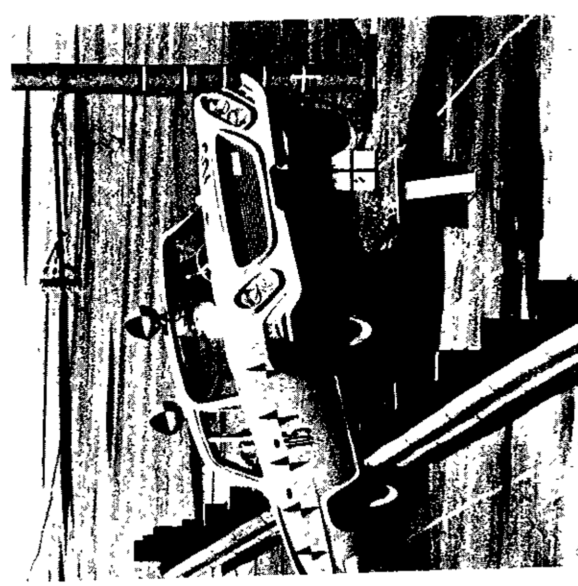

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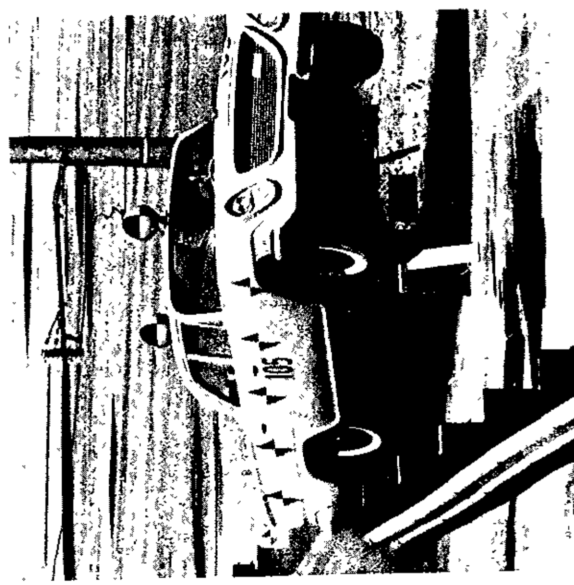

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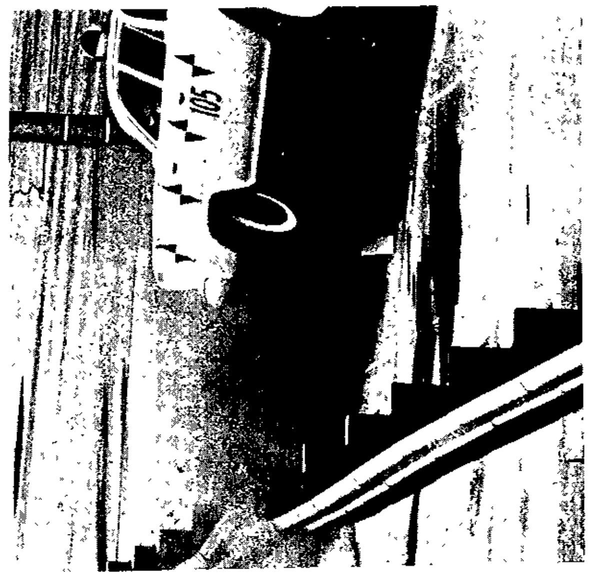

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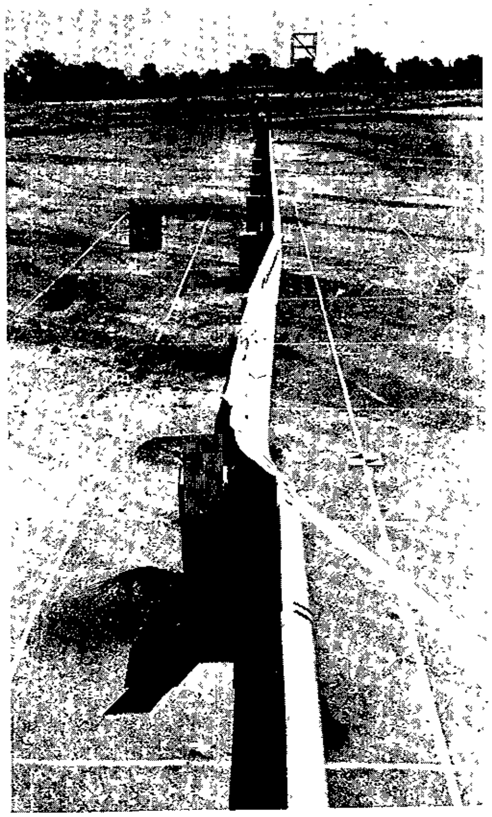
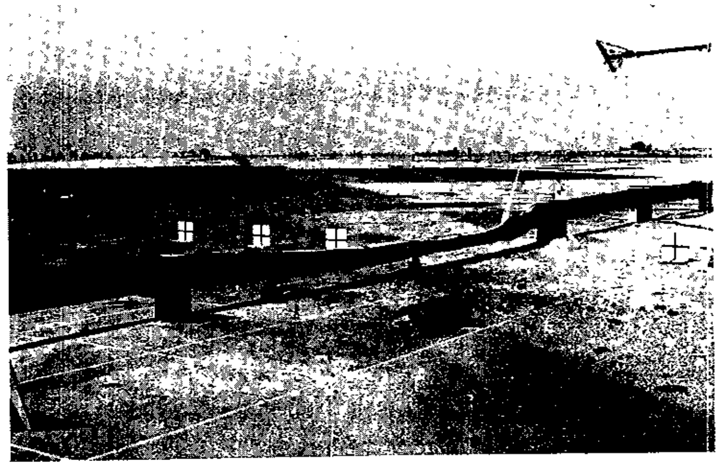
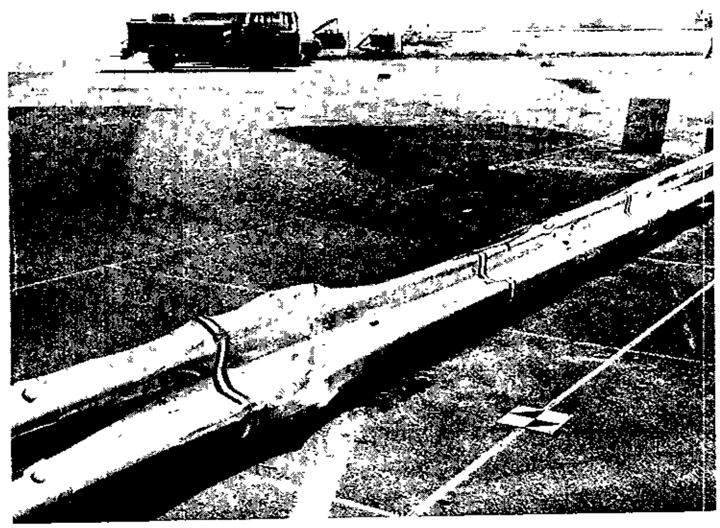
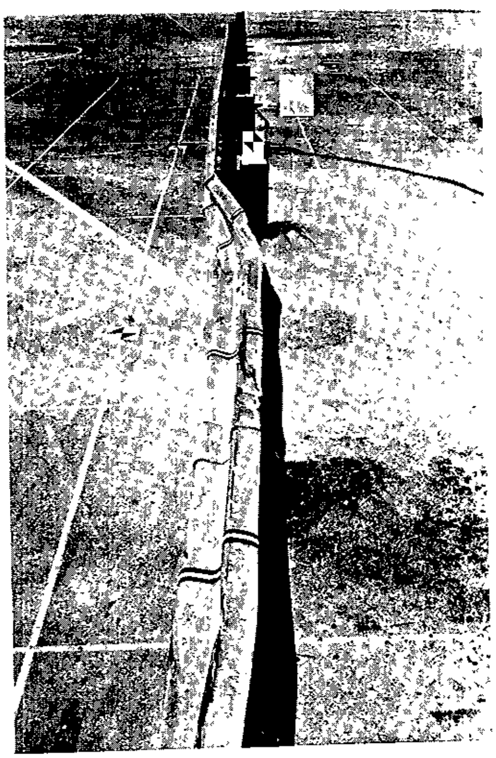


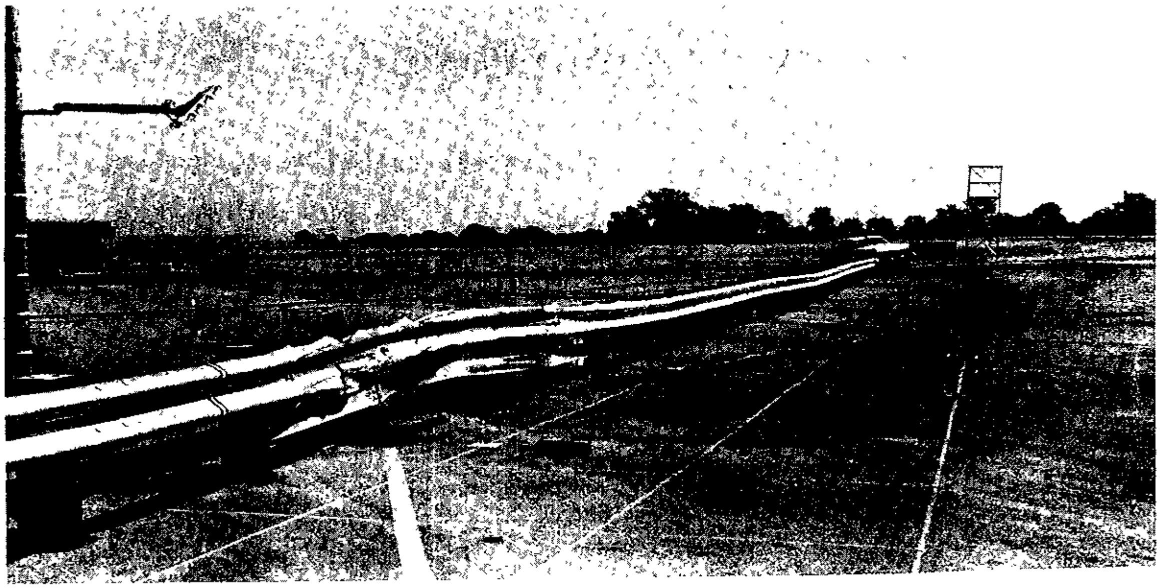







105

TEST 106 PLATE A



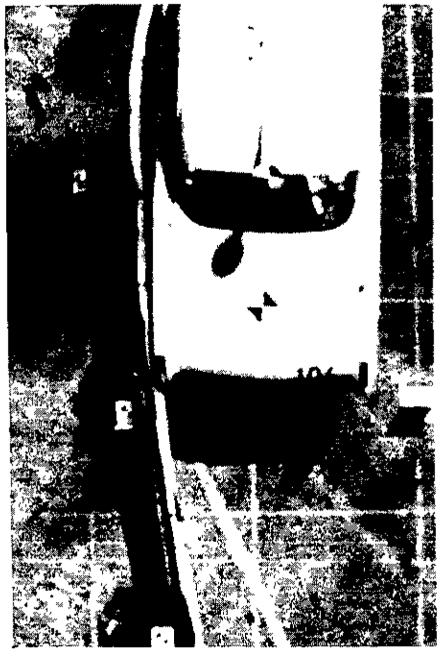
BARRIER: Single blocked-out metal beam median barrier with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 30-in. high (top edge of beam to ground) and blocked-out with 8- by 8- by 14-in. treated DF blocks, and 6-in. 8.2-lb galvanized steel channel rubbing rail mounted 12-in. high (center of rail to ground) on 8- by 8-in. by 6.0-ft treated DF posts spaced 6-ft 3-in. on centers.

PURPOSE: To proof test the 1960 California standard single blocked-out metal beam median barrier design.

PERFORMANCE: The vehicle impacted the barrier at a post at a speed of 60-mph and remained in contact for approximately 19-ft before being redirected to an exit angle of 13°. The vehicle showed no tendency to jump or roll.

BARRIER DAMAGE: Three sections of beam and two sections of rubbing rail were damaged. Six posts were knocked out of alignment, one of which was broken and one was split. Three block-out blocks were splintered, and two were split.

VEHICLE DAMAGE: The vehicle sustained major front end damage and was considered a total loss.



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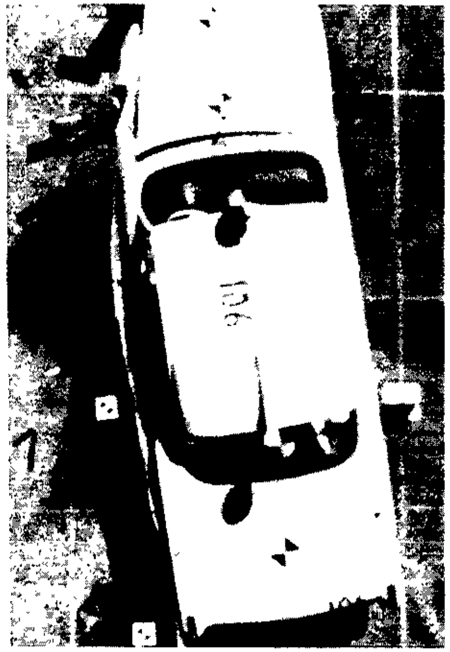
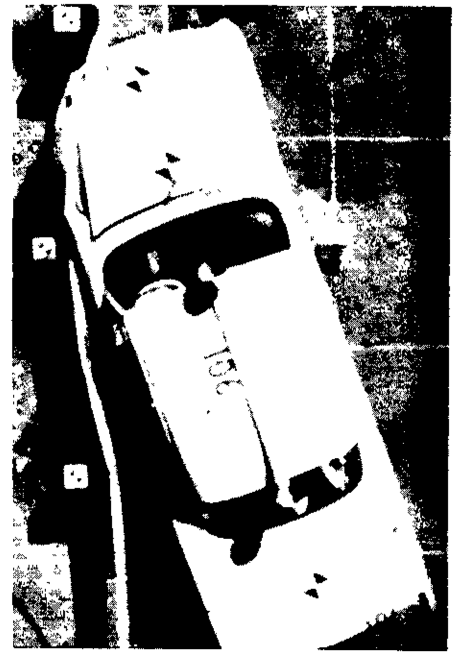
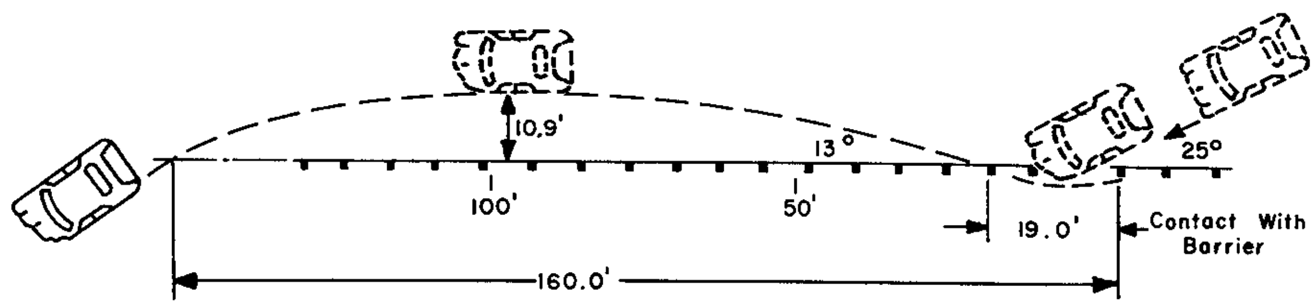


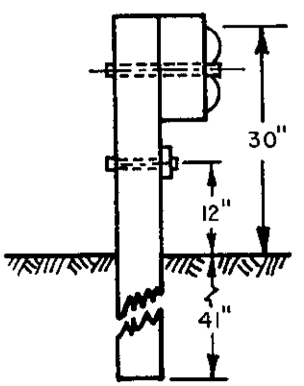
IMPACT + 179 M Sec



IMPACT + 93 M Sec

IMPACT + 2 M Sec



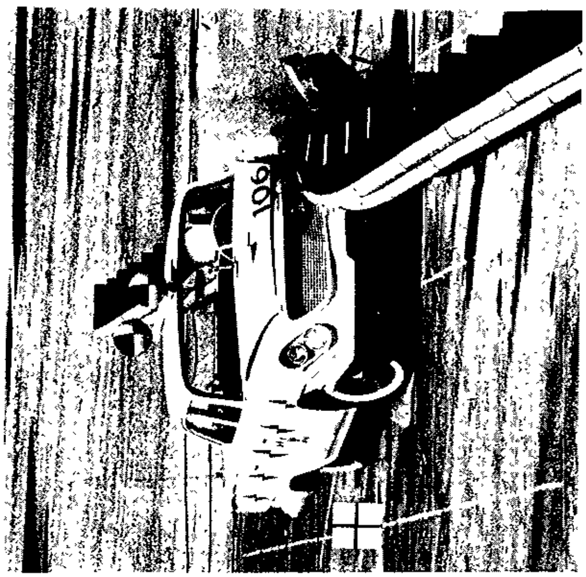


SINGLE BLOCKED – OUT
METAL BEAM BARRIER

BEAM RAIL	12 ga. Galv. Steel x 13'-6.5"
RUBBING RAIL	6 [8.2 Galv. Steel x 12'-6"
POST	8" x 8" Rough D. F. x 6'-0"
POST EMBEDMENT	41"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	162.5
GROUND CONDITION	Dry
BEAM RAIL DEFLECTION – PERMANENT	21"
RUBBING RAIL DEFLECTION – PERMANENT	17"

TEST NO.	106
DATE	9-25-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/ DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	60 mph
IMPACT ANGLE	25°
EXIT ANGLE	13°
DUMMY RESTRAINT	Type 4

Impact + .082 Sec.



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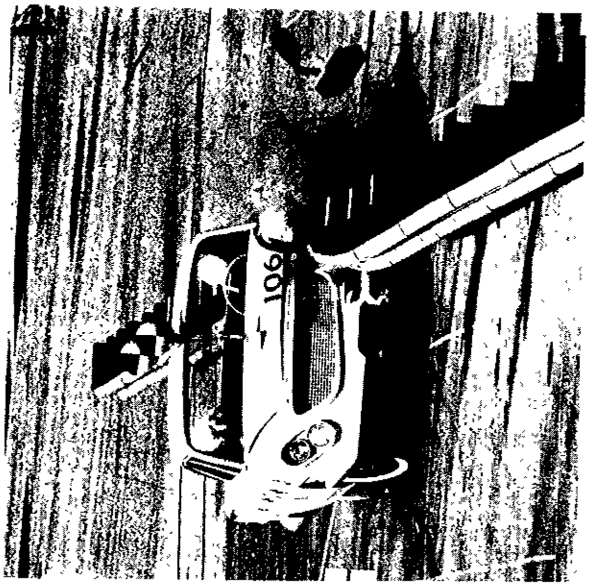

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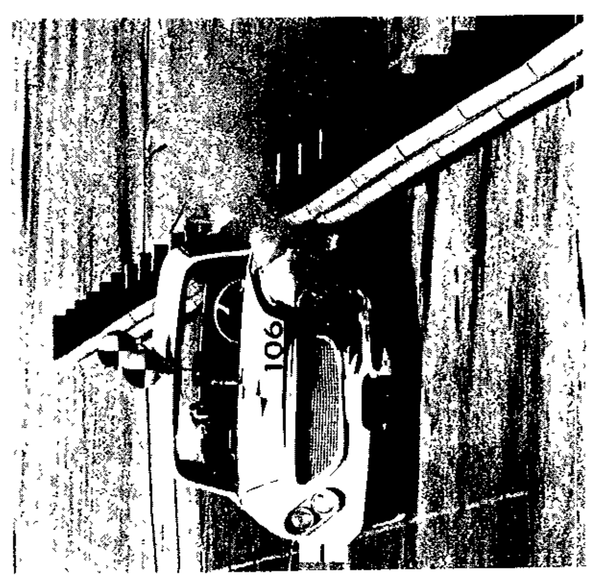

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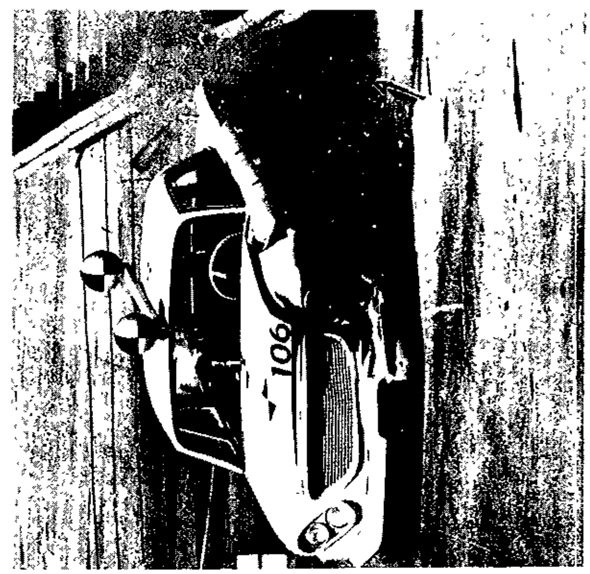

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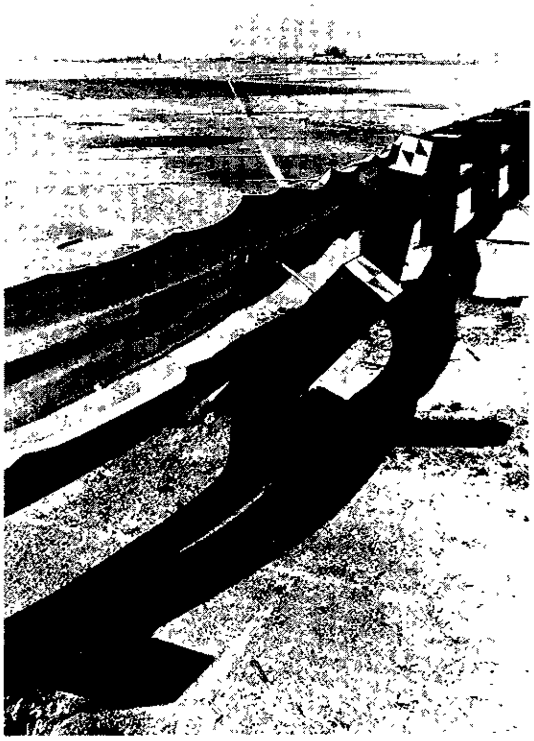
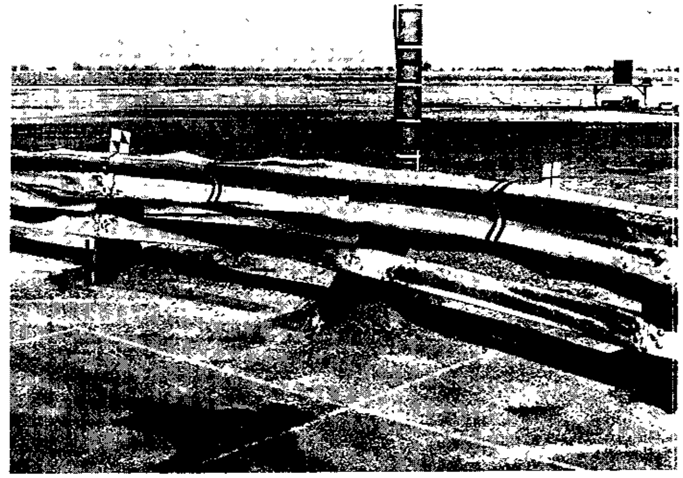
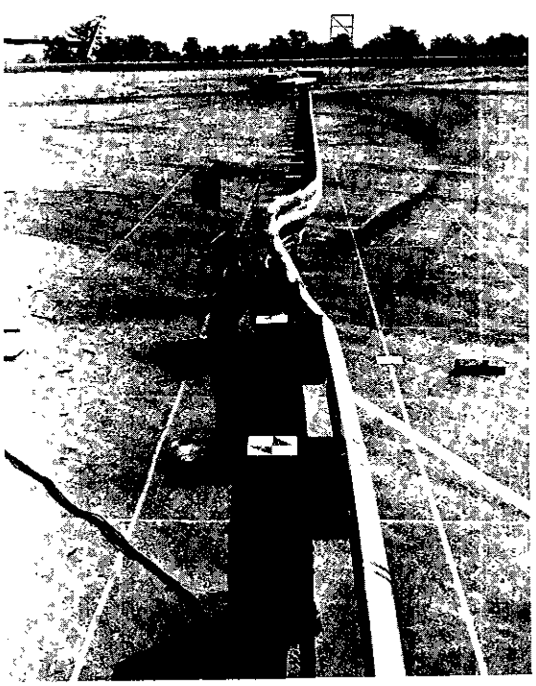
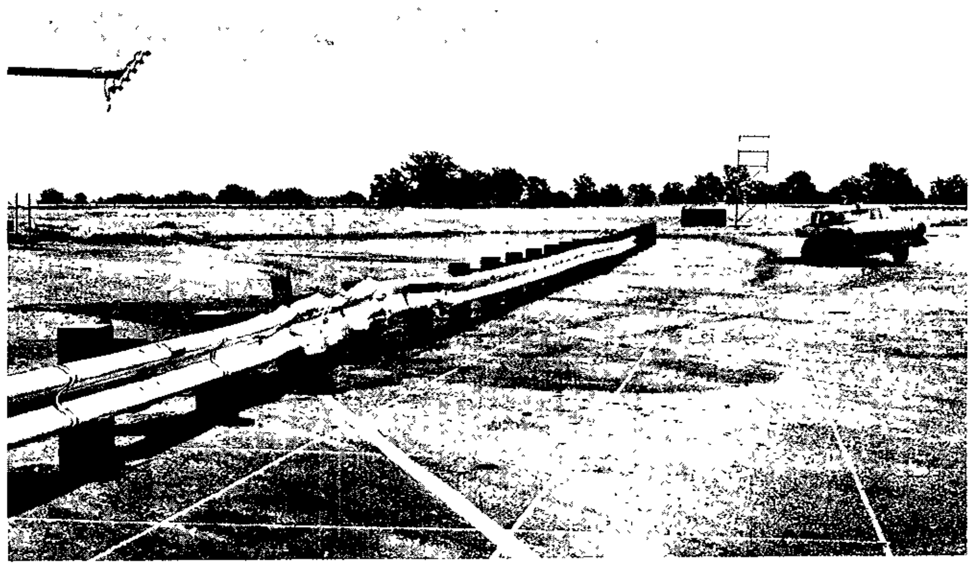
I + .889 Sec.







TEST 107 PLATE A



BARRIER: Blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 27-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5-ft 3-in. treated DF posts spaced 6-ft 3-in. on centers.

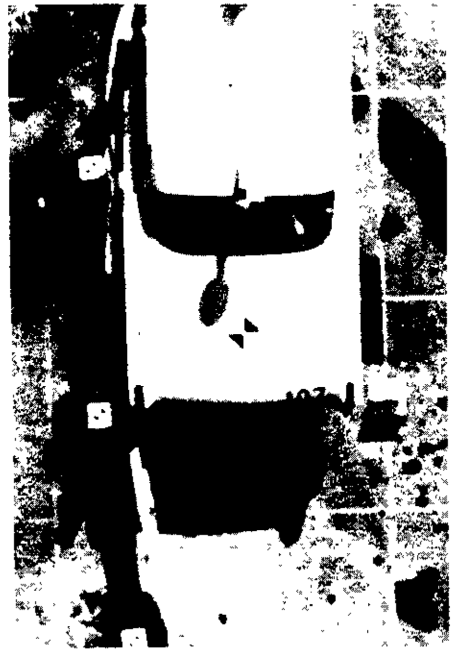
PURPOSE: To test the effectiveness of the 1960 California standard blocked-out metal beam guardrail design with the beam height increased from 24- to 27-in. and the post spacing decreased from 12-ft 6-in. to 6-ft 3-in. on centers.

PERFORMANCE: The vehicle impacted the guardrail at a post at a speed of 60-mph and remained in contact for approximately 13-ft before being redirected to an exit angle of 17°. The vehicle showed no tendency to jump or roll.

BARRIER DAMAGE: Three sections of beam were damaged. Four posts were knocked out of alignment and two were split. Two block-out blocks were splintered and three were split.

VEHICLE DAMAGE: The vehicle sustained major front end damage and was considered a total loss.

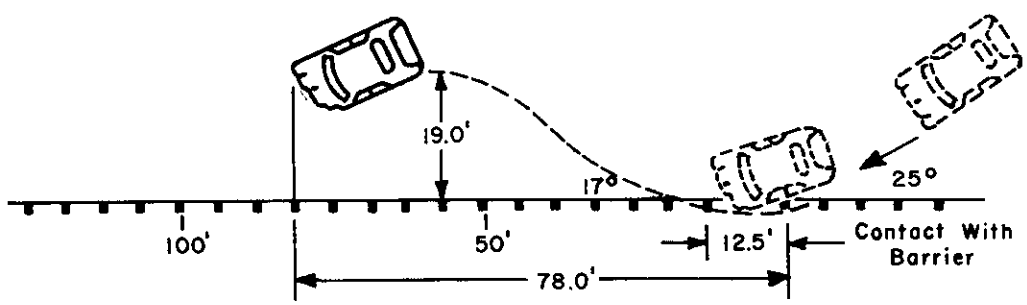
IMPACT + 384 M Sec

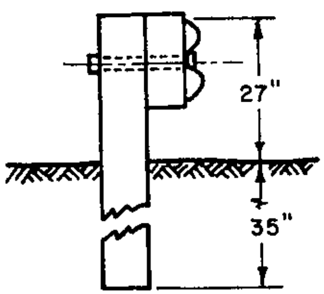


IMPACT + 280 M Sec

IMPACT + 112 M Sec

IMPACT

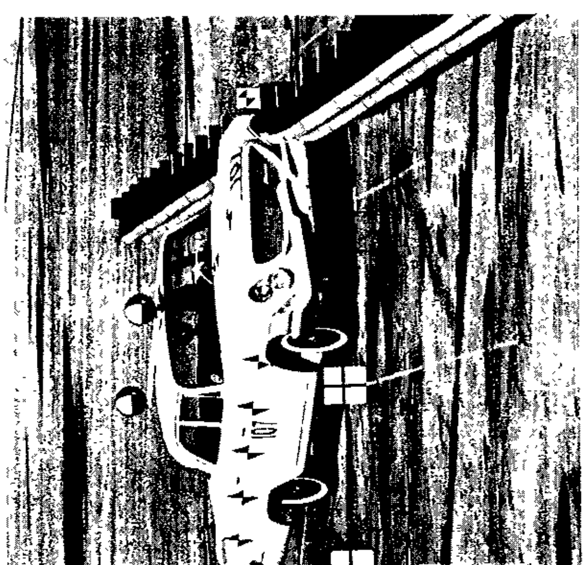




METAL BEAM GUARDRAIL

BEAM RAIL	12 ga. Galv. Steel x 13'-6.5"
RUBBING RAIL	None
POST	8" x 8" Rough D.F. x 5'-3"
POST EMBEDMENT	35"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	162.5'
GROUND CONDITION	DRY
BEAM RAIL DEFLECTION - PERMANENT	18"

TEST NO.	107
DATE	10-1-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	60 mph
IMPACT ANGLE	25°
EXIT ANGLE	17°
DUMMY RESTRAINT	Lap Belt



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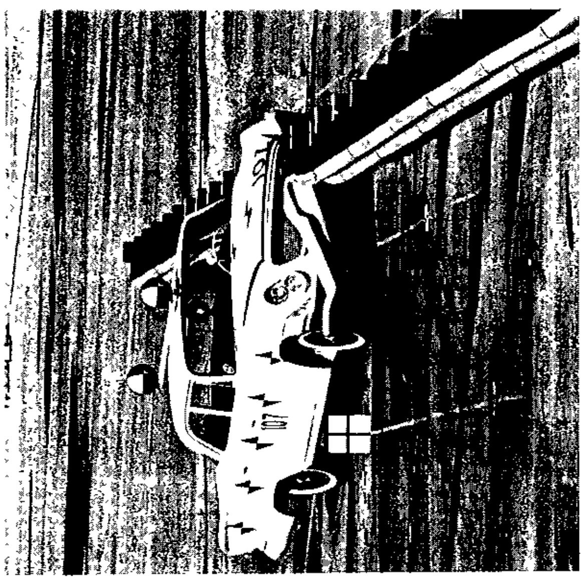

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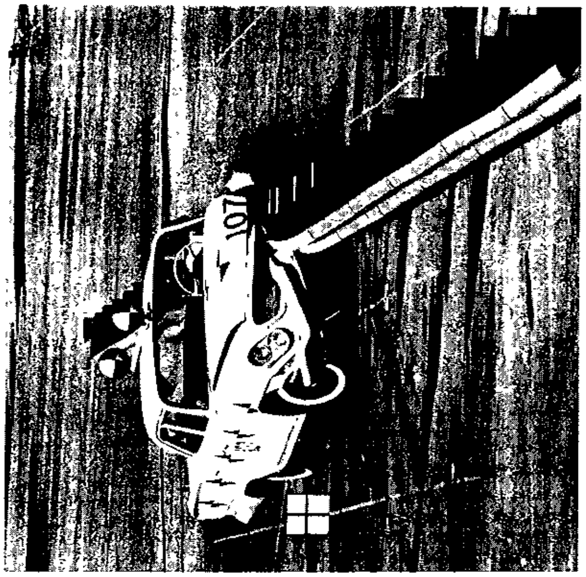

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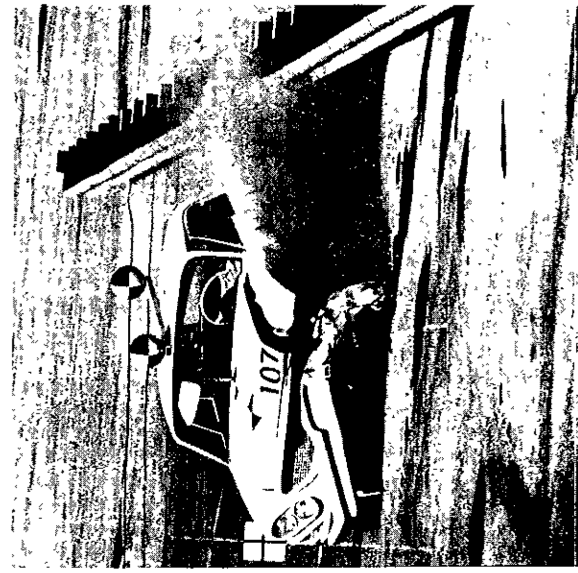
I + .360 Sec.

I + .405 Sec.



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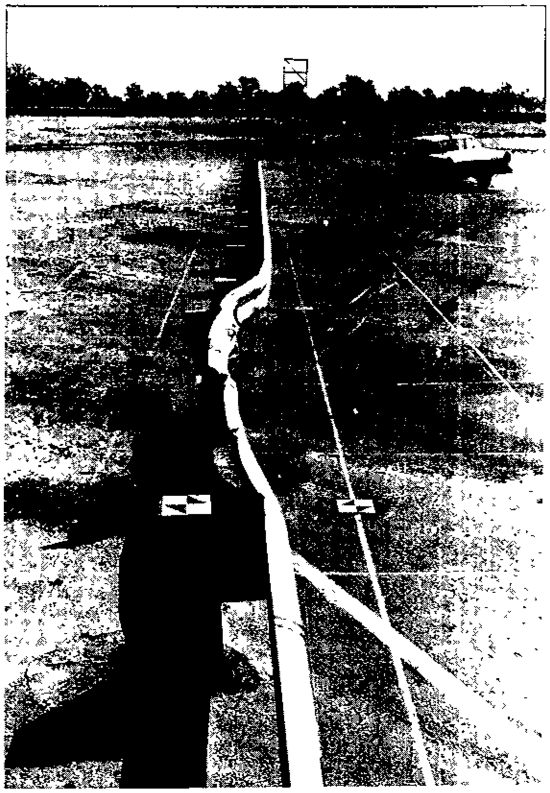

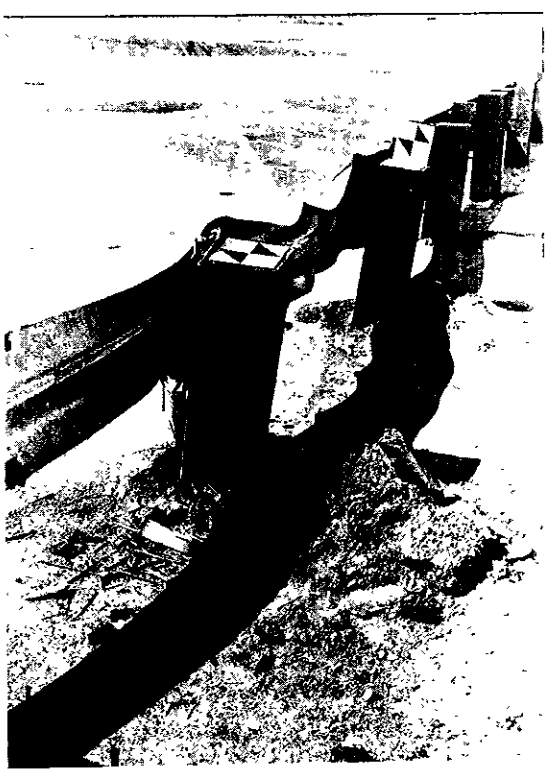

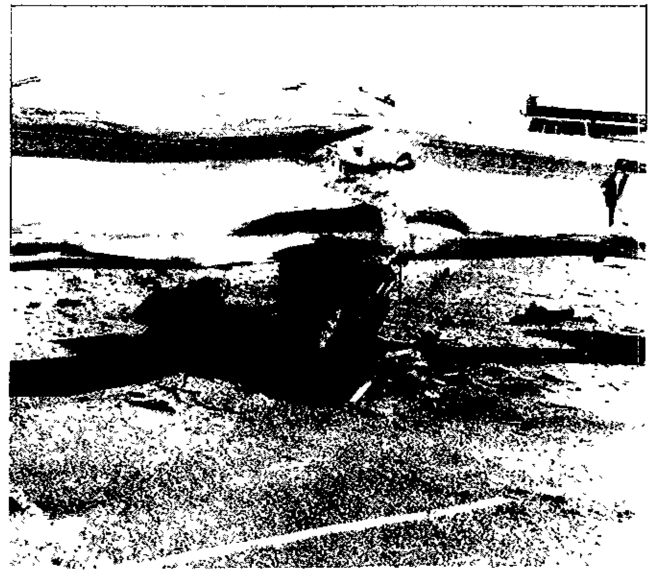

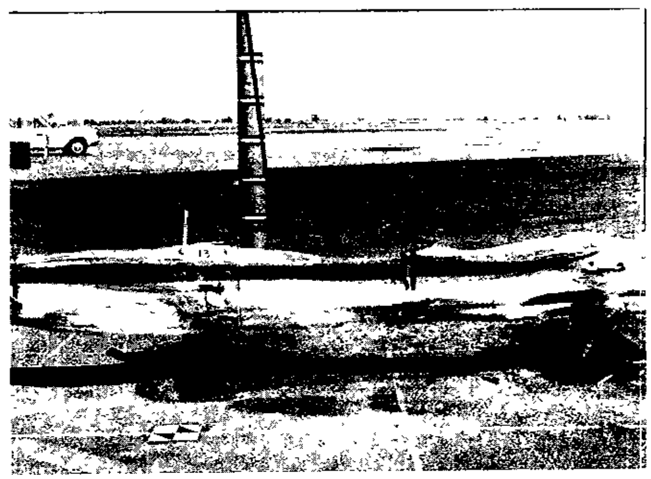


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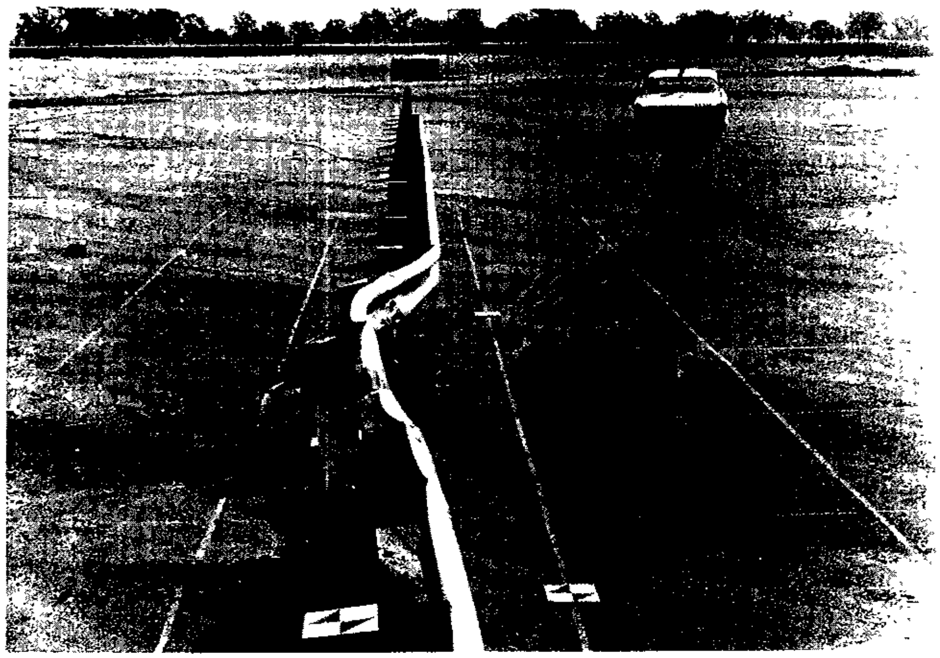
TEST 108 PLATE A



BARRIER: Blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 24-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5.0-ft treated DF posts spaced 6-ft 3-in. on centers.

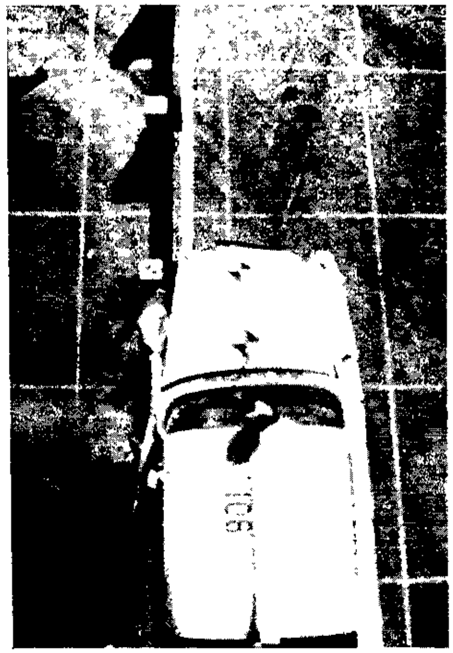
PURPOSE: To test the effectiveness of the 1960 California standard blocked-out metal beam guardrail design with the post spacing decreased from 12-ft 6-in. to 6-ft 3-in. on centers.

PERFORMANCE: The vehicle impacted the guardrail between posts at a speed of 59-mph and remained in contact for approximately 13-ft before being redirected to an exit angle of 19°. The vehicle showed no tendency to jump. The barrier deflection permitted the vehicle to roll to a maximum of 5° left.

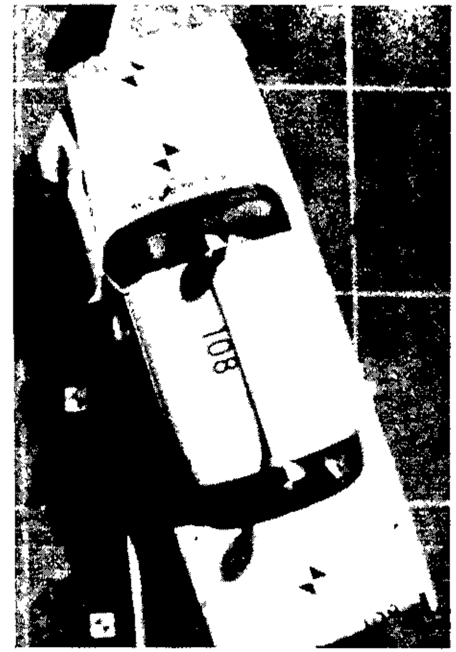
BARRIER DAMAGE: Three sections of beam were damaged. Five posts were knocked out of alignment and five were split. Two block-out blocks were splintered and four were split.

VEHICLE DAMAGE: The vehicle sustained major front end damage and was considered a total loss.

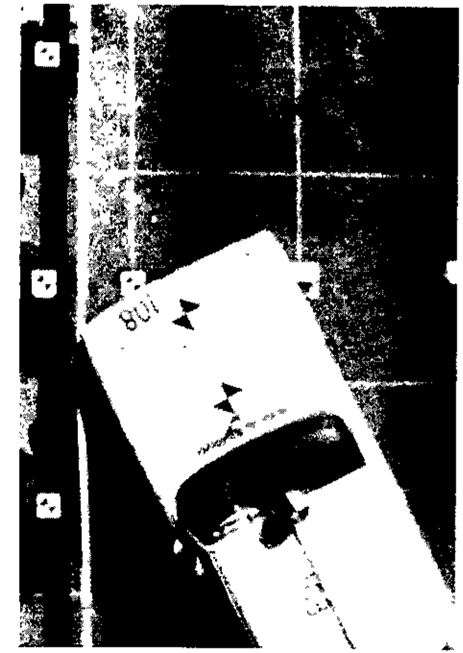
IMPACT + 317 M Sec



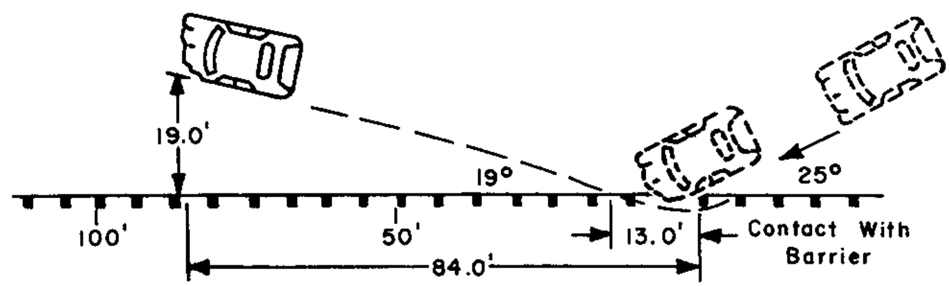
IMPACT + 177 M Sec

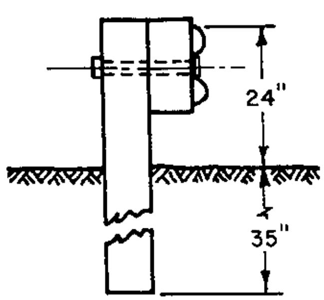


IMPACT + 125 M Sec



IMPACT





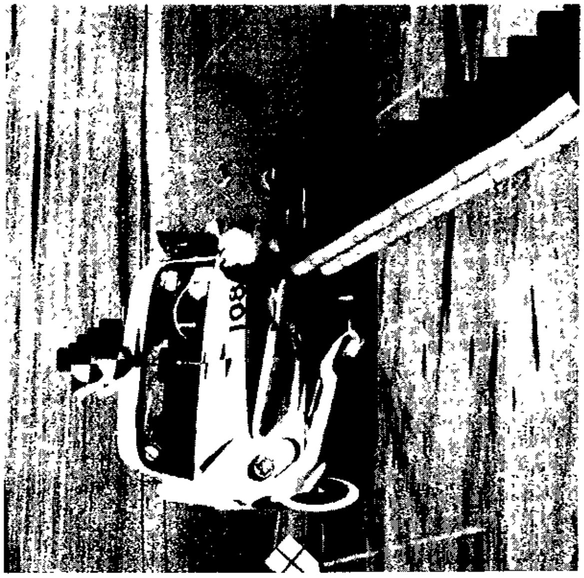
METAL BEAM GUARDRAIL

BEAM RAIL	12 ga. Galv. Steel x 13'-6.5"
RUBBING RAIL	None
POST	8" x 8" Rough D.F. x 5'-0"
POST EMBEDMENT	35"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	162.5'
GROUND CONDITION	DRY
BEAM RAIL DEFLECTION - PERMANENT	18"

TEST NO.	108
DATE	10-7-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	59 mph
IMPACT ANGLE	25°
EXIT ANGLE	19°
DUMMY RESTRAINT	Lap Belt

Impact + .118 Sec.

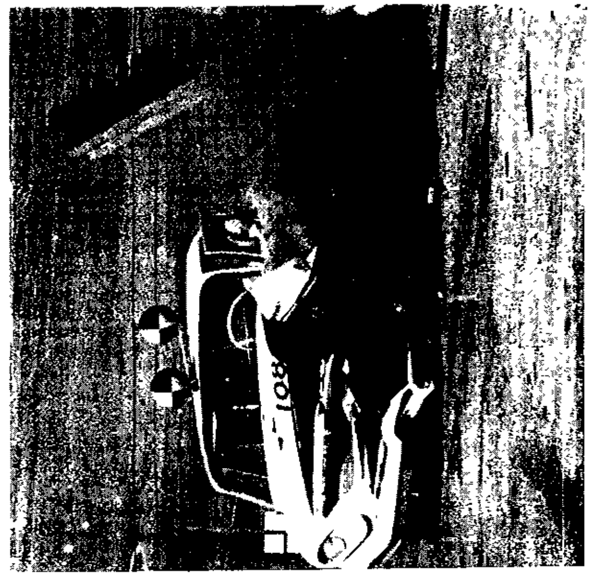
I + .171 Sec.



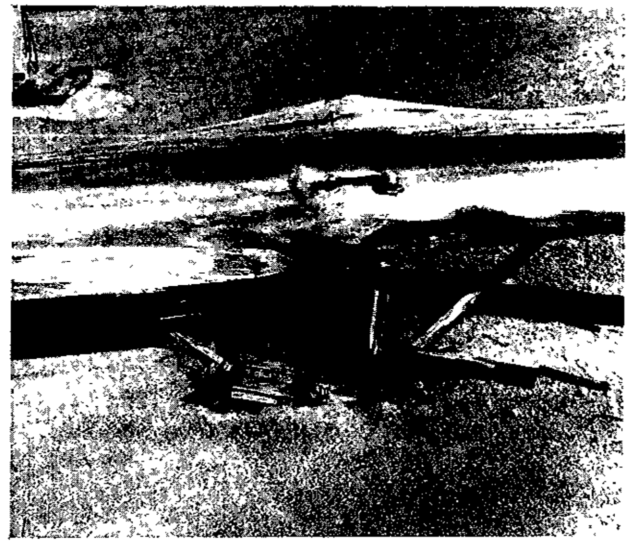
I + .304 Sec.

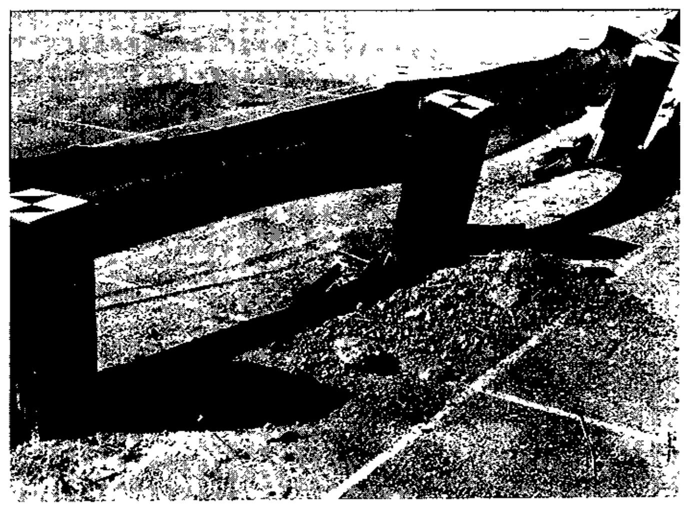
I + .379 Sec.

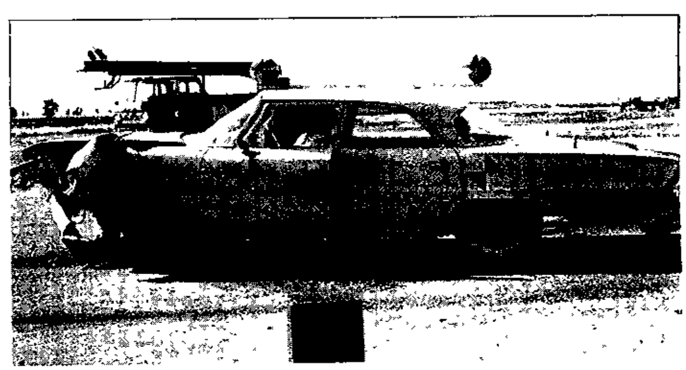
I + .536 Sec.



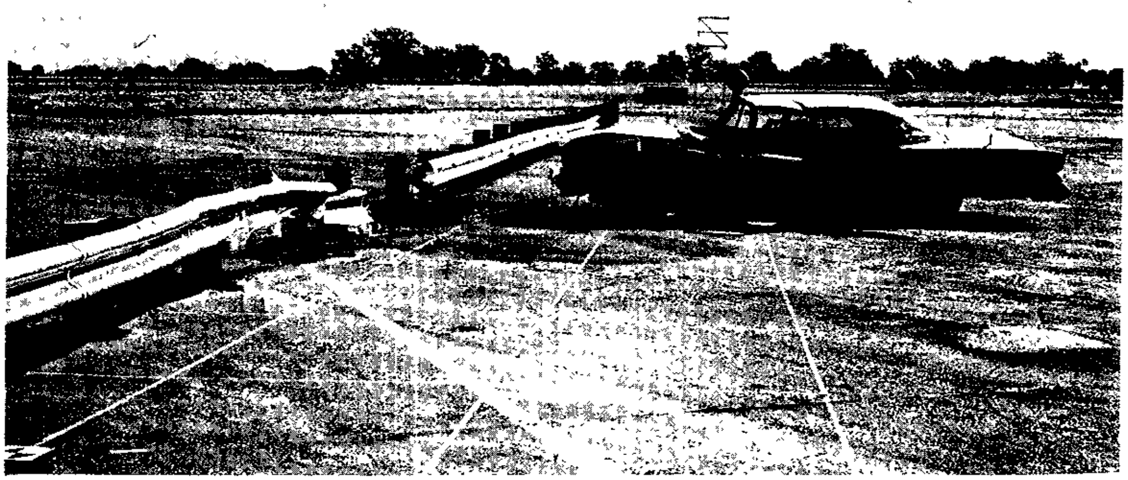
I + .714 Sec.







TEST 109 PLATE A



BARRIER: Blocked-out metal beam guardrail with 0.156-in. Alclad 2024-T3 aluminum alloy corrugated beam mounted 24-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5.0-ft treated DF posts spaced 6-ft 3-in. on centers.

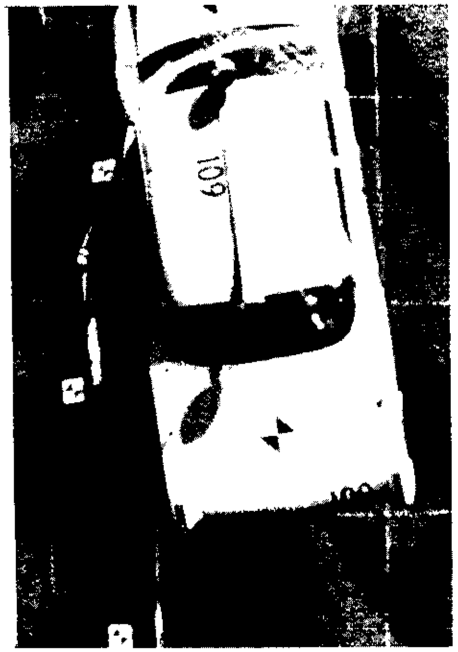
PURPOSE: To test the effectiveness of the 1960 California standard blocked-out metal beam guardrail design with 0.156-in. aluminum alloy corrugated beam substituted for the standard 0.105-in. galvanized steel corrugated beam and the post spacing decreased from 12-ft 6-in. to 6-ft 3-in. on centers.

PERFORMANCE: The vehicle impacted the guardrail between posts at a speed of 60-mph and remained in contact for approximately 12-ft before the beam separated. The vehicle snagged the separated beam, resulting in a violent 100° spin-out. The vehicle's momentum, as it snagged, caused the failed beam to penetrate the wheel well and floor boards and impale the dummy. As the vehicle spun-out, 8-ft of the beam broke off near the wheel well and remained in the vehicle.

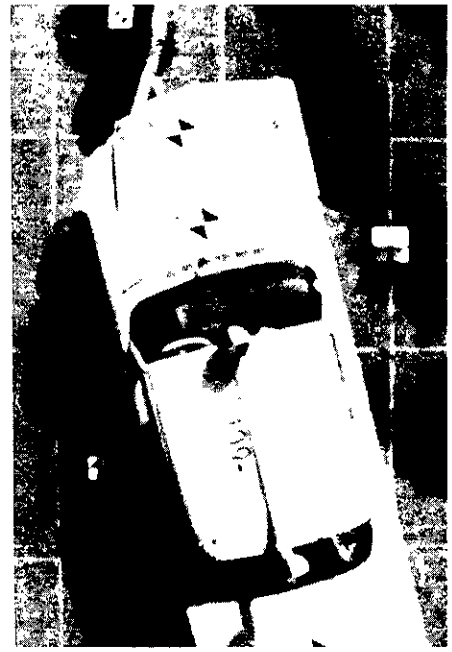
BARRIER DAMAGE: Two sections of beam were destroyed. The beam failed completely in three places. Five posts were knocked out of alignment, three of which were split. Three block-out blocks were splintered and six were split.

VEHICLE DAMAGE: The vehicle sustained major front end, dashboard, and passenger compartment damage and was considered a total loss.

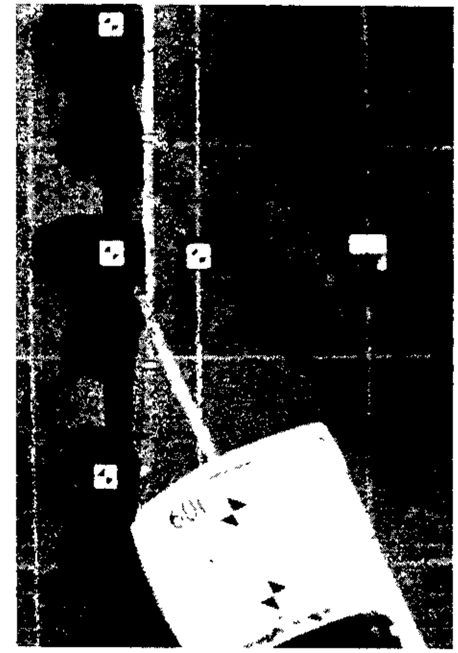
IMPACT + 524 M Sec



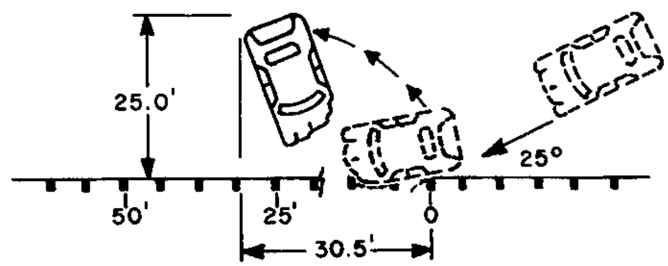
IMPACT + 330 M Sec

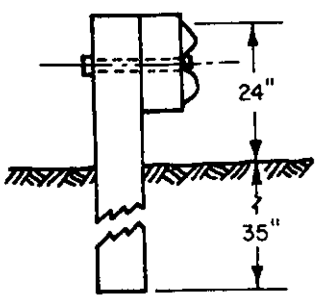


IMPACT + 122 M Sec



IMPACT + 3 M Sec

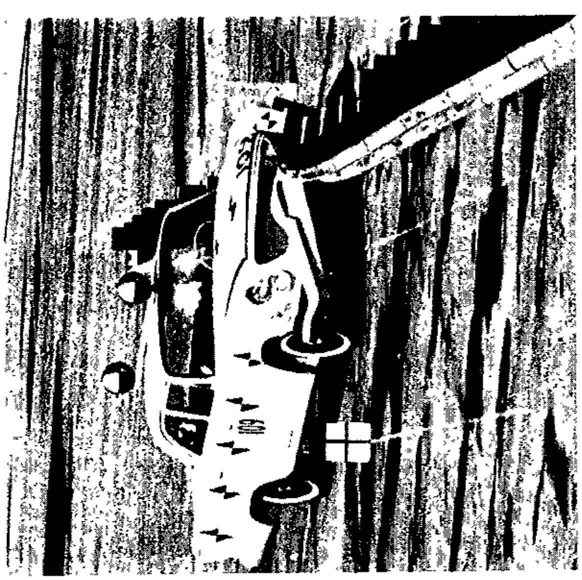




METAL BEAM GUARDRAIL

BEAM RAIL	0.156" Aluminum x 13'-6.5"
RUBBING RAIL	None
POST	8"x 8" Rough D.F. x 5'-0"
POST EMBEDMENT	35"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	162.5'
GROUND CONDITION	Dry
BEAM RAIL DEFLECTION-(BEFORE FAILURE)	24"

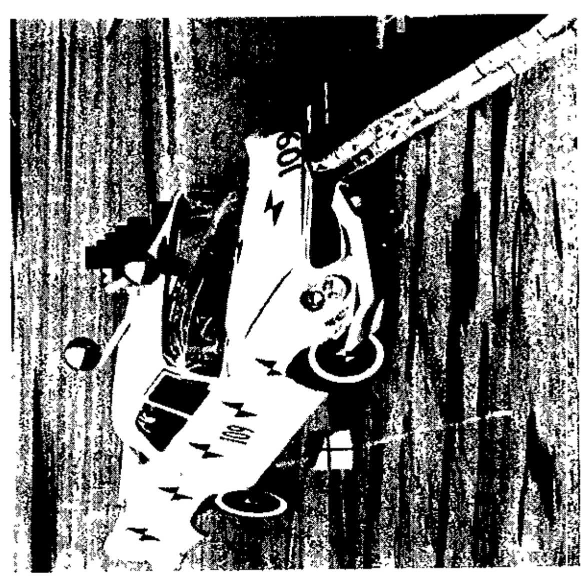
TEST NO.	109
DATE	10-14-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	60 mph
IMPACT ANGLE	25°
EXIT ANGLE	0° at time of failure
DUMMY RESTRAINT	Type 4



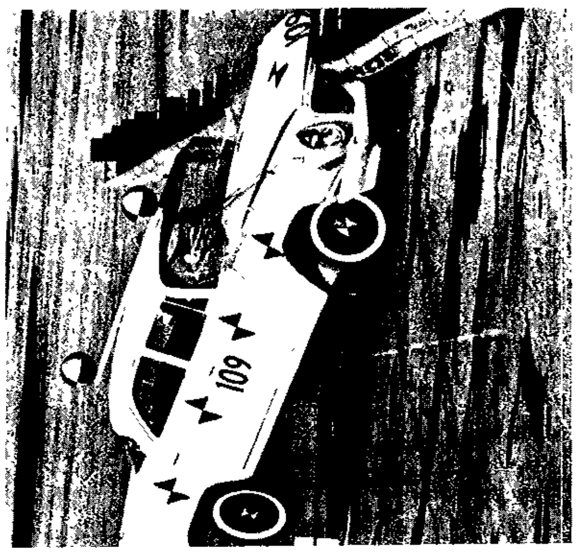
Impact + .112 Sec.

I + .241 Sec.

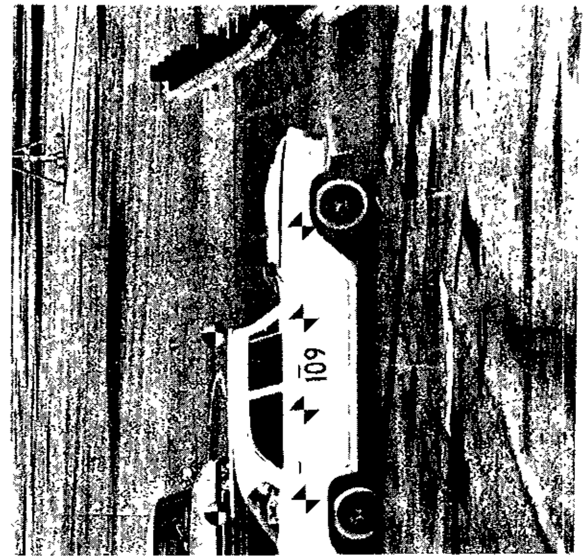
I + .272 Sec.



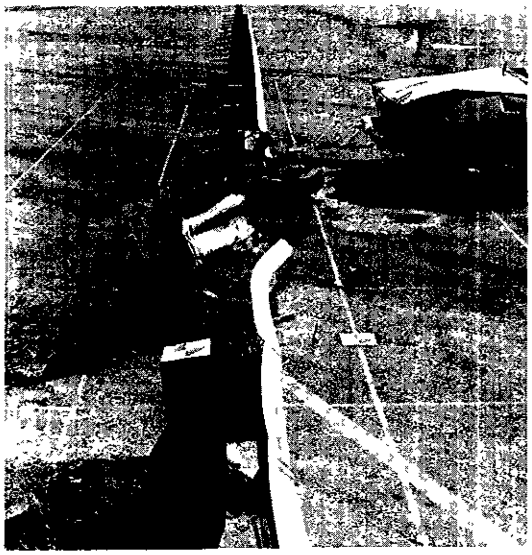
I + .474 Sec.

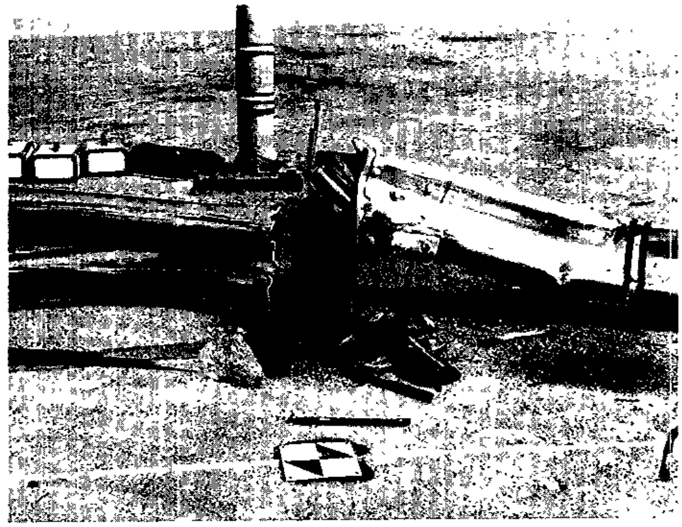


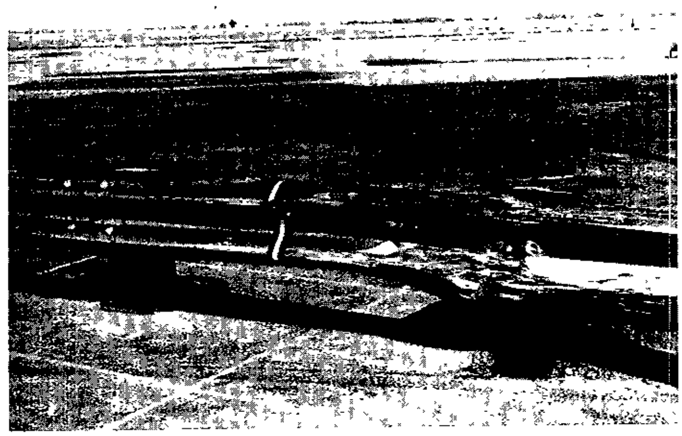
I + .624 Sec.

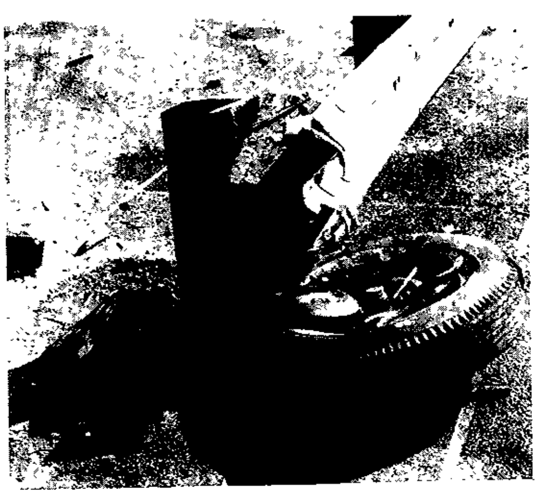


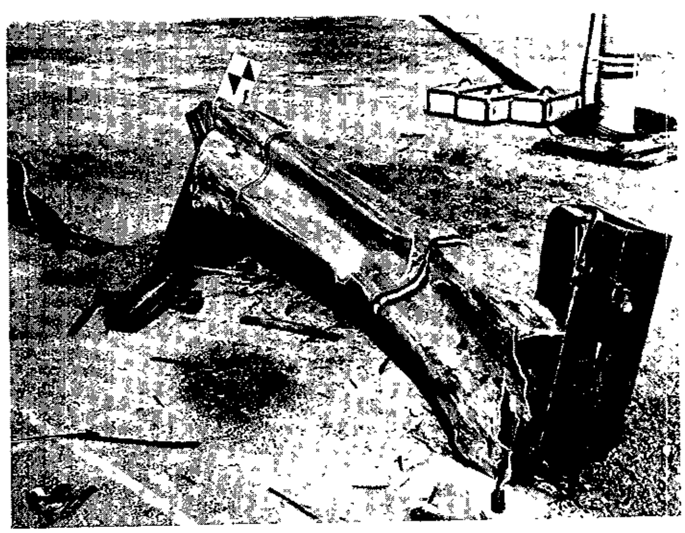
I + 1.618 Sec.

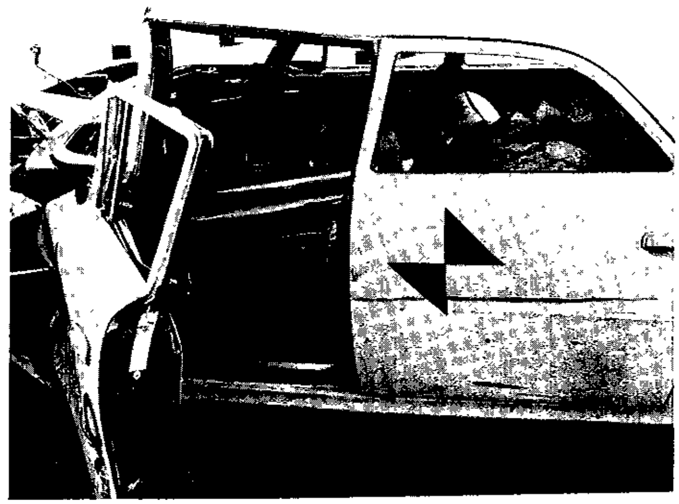












TEST 131 PLATE A

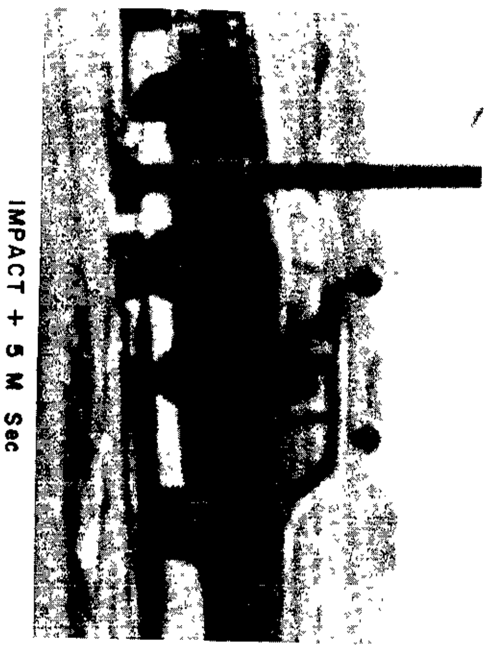
BARRIER: A 37-ft 6-in. unanchored installation of blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 27-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5-ft 4-in. treated DF posts spaced 6-ft 3-in. on centers.

PURPOSE: To test the effectiveness of a 37-ft 6-in. unanchored length of 1965 California standard blocked-out metal beam guardrail.

PERFORMANCE: The vehicle impacted the guardrail at the center post at a speed of 63-mph, pocketed the beam and pulled it, intact, free of all posts excepting No. five; and, dragging the beam and post No. five, traveled through the installation with 3° redirection.

BARRIER DAMAGE: All three beam sections and all seven posts and blocks were damaged. Posts one, two, three, four, and seven were split as the bolts were pulled through the post by the beam. Post six split but partially retained the bolt, causing the beam to pull free of the bolt. Post five pulled out of the ground and remained attached to the beam. One post bolt failed at the beam bearing point. There was no indication of failure at the beam splices.

VEHICLE DAMAGE: The vehicle sustained major front end damage and was considered a total loss.

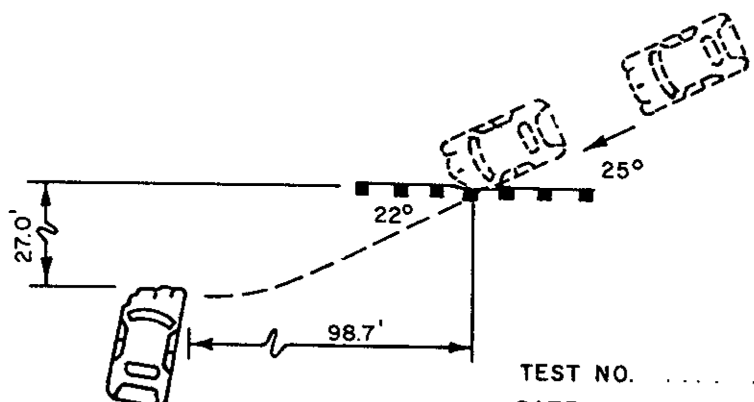


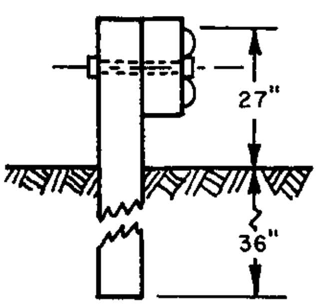
IMPACT + 5 M Sec

IMPACT + 137 M Sec

IMPACT + 375 M Sec

IMPACT + 654 M Sec





METAL BEAM
GUARDRAIL

BEAM RAIL . . . . 12 ga. Galv. Steel x 13' - 6.5"
RUBBING RAIL. . . . . None
POST . . . . 8" x 8" Rough D. F. x 5' - 4"
POST EMBEDMENT . . . . 36"
POST SPACING . . . . 6' - 3"
LENGTH OF INSTALLATION . . . . 37.5'
GROUND CONDITION . . . . Damp

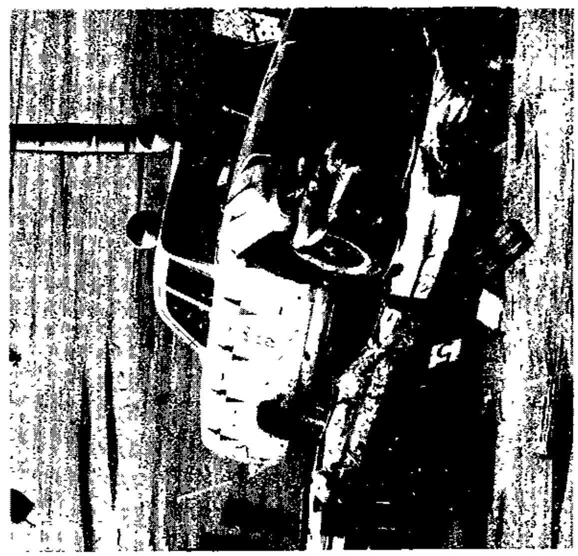
TEST NO. 131
DATE 11-30-65
VEHICLE . . . . 1964 Dodge Sedan
VEHICLE WEIGHT . . . . 4540 #
(W/DUMMY & INSTRUMENTATION)
IMPACT SPEED . . . . 63 mph
IMPACT ANGLE . . . . 25°
EXIT ANGLE . . . . 22°
DUMMY RESTRAINT . . . . Lap Belt

Impact + .032 Sec.

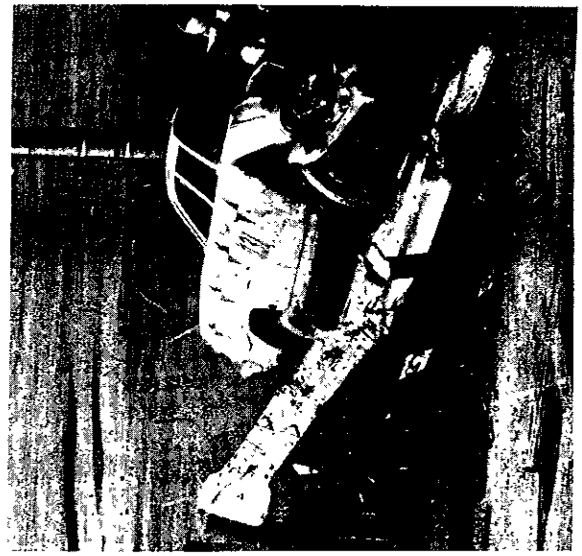
I + .150 Sec

I + .250 Sec

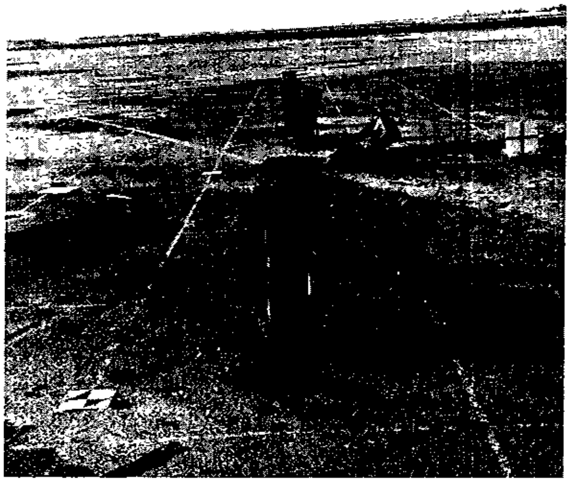
I + .350 Sec.

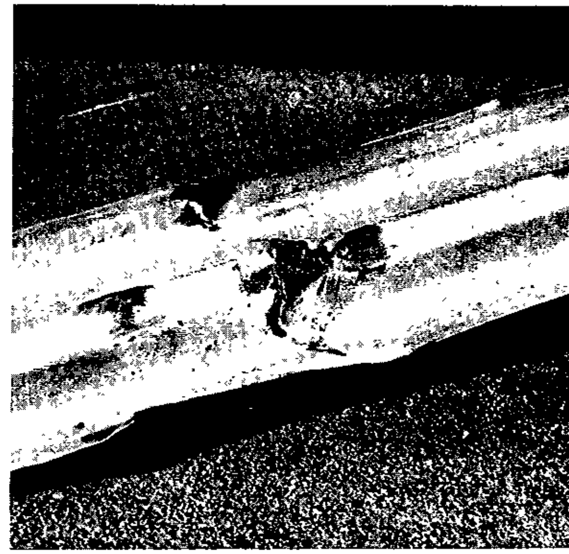


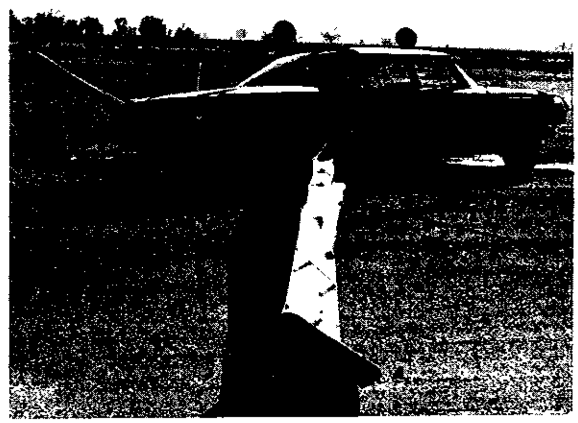
I + .550 Sec.

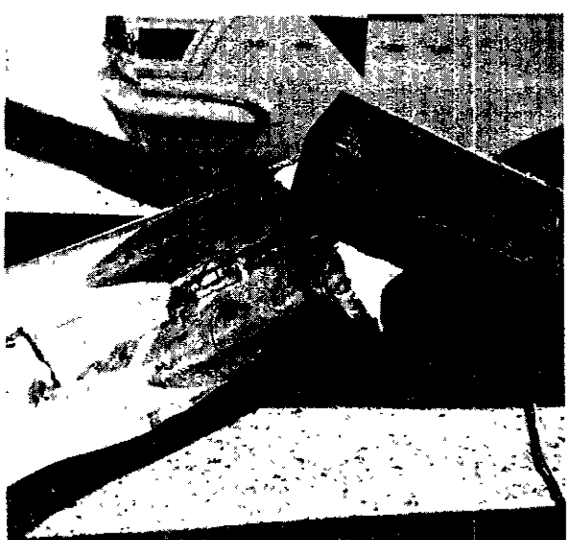


I + .650 Sec.







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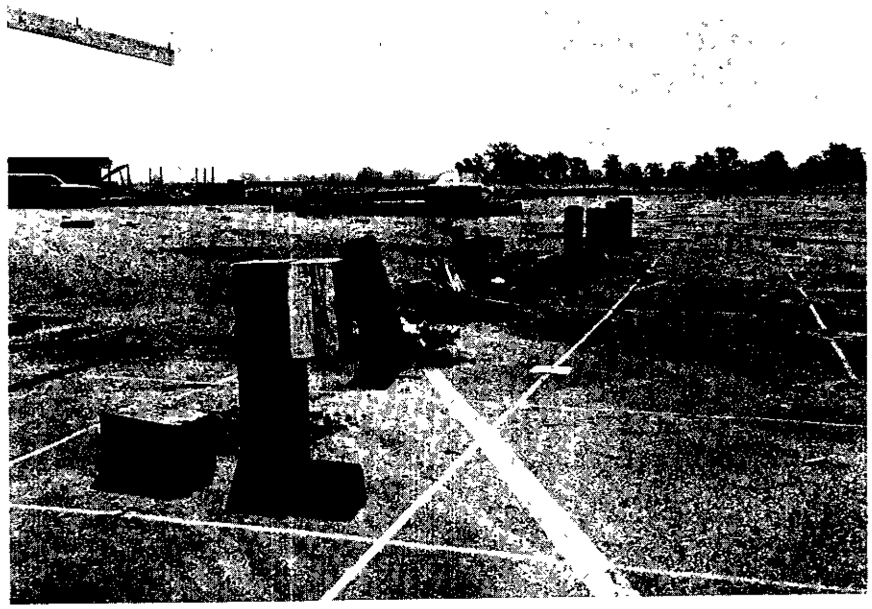
TEST 132 PLATE A



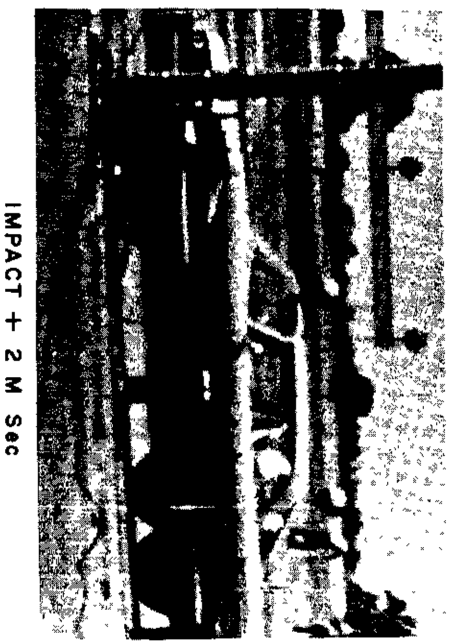
BARRIER: A 62-ft 6-in. unanchored installation of blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 27-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks (except as noted below), on 8- by 8-in. by 5-ft 4-in. treated DF posts spaced 6-ft 3-in. on centers. The end posts used no block-out blocks, the second post from each end used block-out blocks 4-in. thick. The bolts through these four posts utilized a head washer in addition to the standard nut washer.

PURPOSE: To test the effectiveness of a 62-ft 6-in. unanchored length of 1965 California standard blocked-out metal beam guardrail with modified end-blocking forming a slight flare.

PERFORMANCE: The vehicle impacted the guardrail at post four plus 2-ft at a speed of 61-mph, pocketed the beam and pulled it, intact, free of all posts; and, with the beam wrapped around its front end, traveled through the installation with 6° redirection.

BARRIER DAMAGE: All five beam sections, ten of eleven posts and eight of nine blocks were damaged. Posts one, three, five, nine, ten, and eleven were split as the bolts were pulled through the posts by the beam. Posts six and seven were shattered to ground level. Posts two, four, and eight retained the bolt causing it to pull through the beam. Extreme bending caused three cracks to occur in the beam. There was no indication of failure at the beam splices.

VEHICLE DAMAGE: The vehicle sustained major front end damage and was considered a total loss.

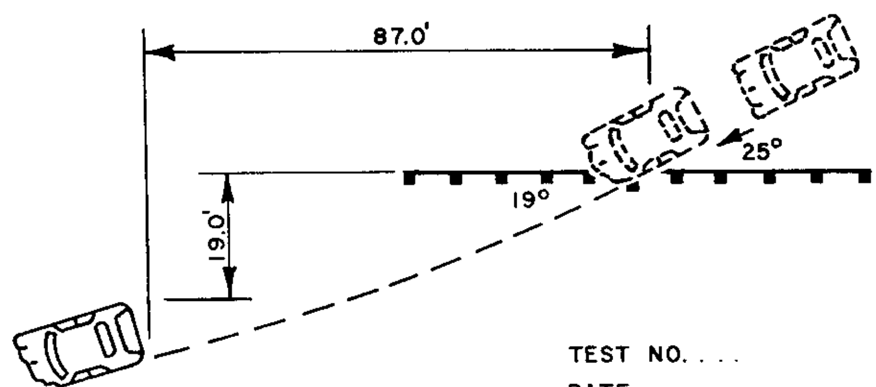


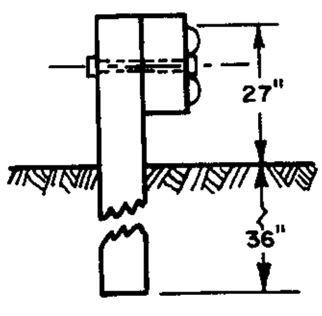
IMPACT + 2 M Sec

IMPACT + 167 M Sec

IMPACT + 446 M Sec

IMPACT + 908 M Sec





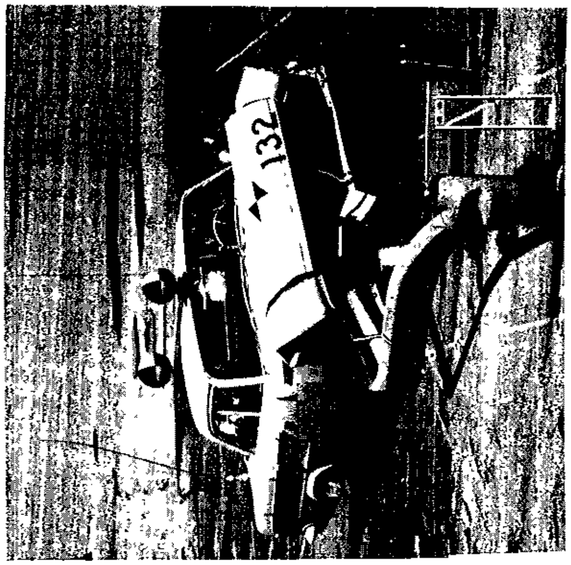
METAL BEAM
GUARDRAIL

BEAM RAIL	12 ga. Galv. Steel x 13'-6.5"
RUBBING RAIL	None
POST	8" x 8" Rough D.F. x 5'-4"
POST EMBEDMENT	36"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	62.5'
GROUND CONDITION	DRY

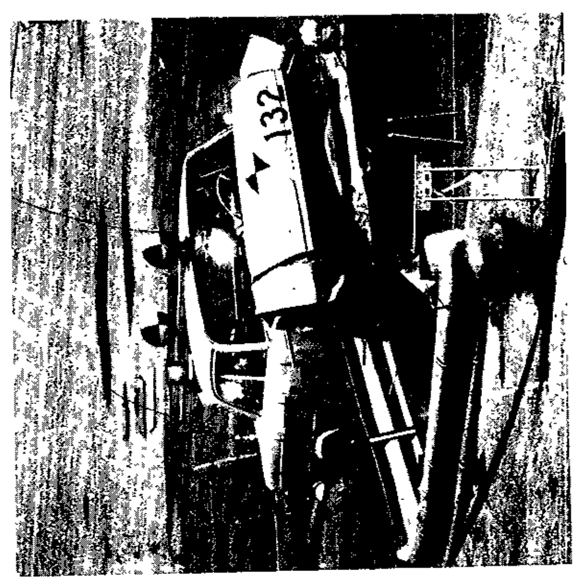
TEST NO.	132
DATE	6-15-66
VEHICLE	1964 Dodge Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4540 #
IMPACT SPEED	61 mph
IMPACT ANGLE	25°
EXIT ANGLE	19°
DUMMY RESTRAINT	Lap Belt

Impact + .042 Sec.

I + .100 Sec.

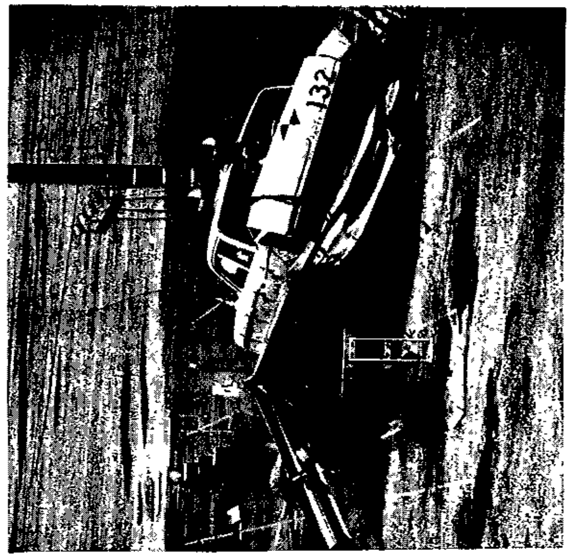


I + .200 Sec.



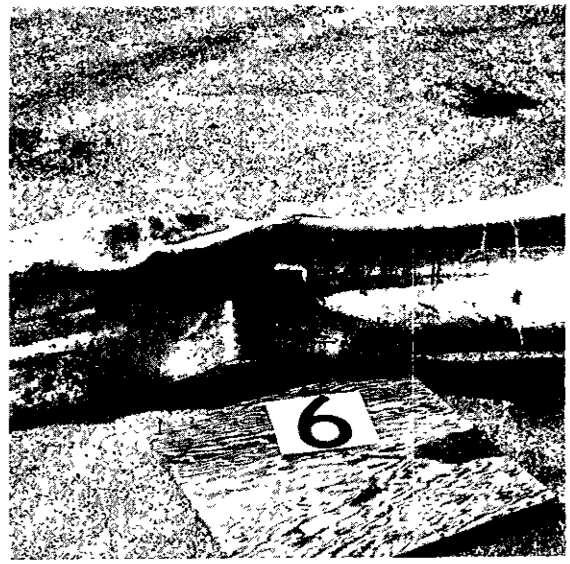
I + .300 Sec.

I + .400 Sec.



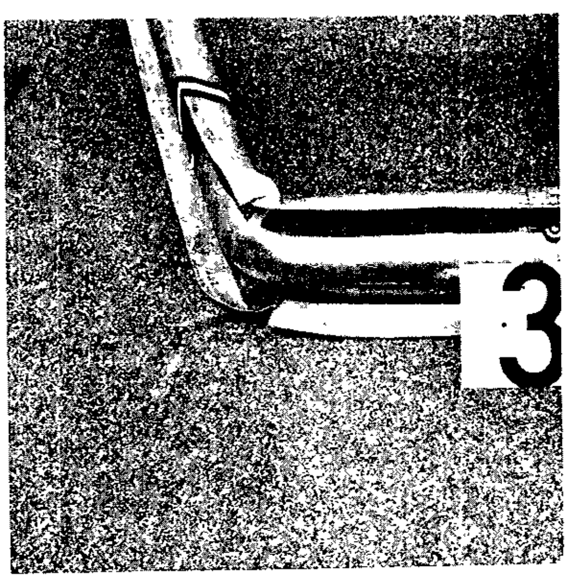
I + .600 Sec.


7


6


8


7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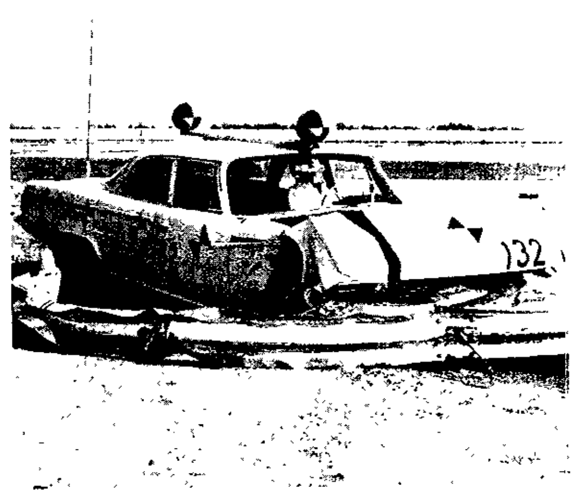
132