Dynamic Tests of Corrugated Metal Beam Guardrail

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This report gives 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 were tested. Short lengths of guardrail were also tested. The overall results of this test program were correlated to field performance and the results of past tests to arrive at a new standard guardrail design for California highways.

•A RECENT study (1) 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 effects of the severity and frequency of such accidents. The study concluded that guardrail will reduce accident severity only when the overall severity of striking the guardrail is less than the overall severity of going down the embankment or striking the fixed object. This, combined with operational indications that 1960 guardrail designs were somewhat inadequate for present day high-speed traffic, led us to reexamine current California standard designs. We felt that, in the future, when guardrail is necessary 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 possiblity 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 HRB Committee on Guardrails and Guideposts (3).

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

Following the Missouri Highway guardrail test in 1934 (4), California adopted as the 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 new guardrail design was adopted as the California Division of Highways standard. It utilized a 12-gage (0.105-in.) corrugated steel beam mounted 24 in. high overall, 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. This design was used until the results of the tests in this report were analyzed. As a result of these tests, the standard guardrail design now used utilizes a 12-gage (0.105-in.) corrugated steel beam mounted 27 in. high overall, 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.

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In 1965, following adoption of this guardrail design, 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 series are included in this report and 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 report on 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 model 4000±-lb automobiles utilizing their own power, were guided into the test guardrail collisions by radio control. An anthropometric dummy (Sierra Sam) occupied the driver's seat during each collision. It served two functions: (a) as a human simulator to provide a record of the kinematics of a body during such collisions, and (b) 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. The data from the second function were not considered germane to this report.

DISCUSSION

Beam Height

Operational experience and previous tests indicate that beam height above ground is one of the more significant variables contributing to the effectiveness of a barrier system. Experience (10) also indicates 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, Appendix) gave excellent results. However, this test and others (6) indicate that a rubbing rail is needed with a 30-in. beam height.

Operational experience reveals 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 Test 107, in which the beam height was 27 in.

Test 105 showed that the 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 deg. The 24-in. beam height used in Test 105 was a factor in

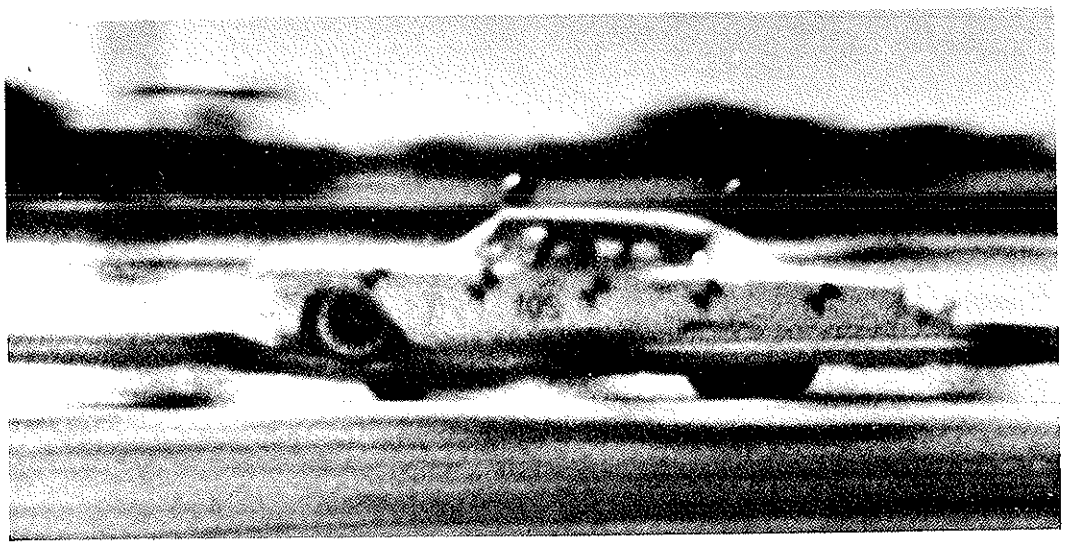


Figure 1.

TABLE 1

VEHICLE REACTION VS BEAM HEIGHT

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.

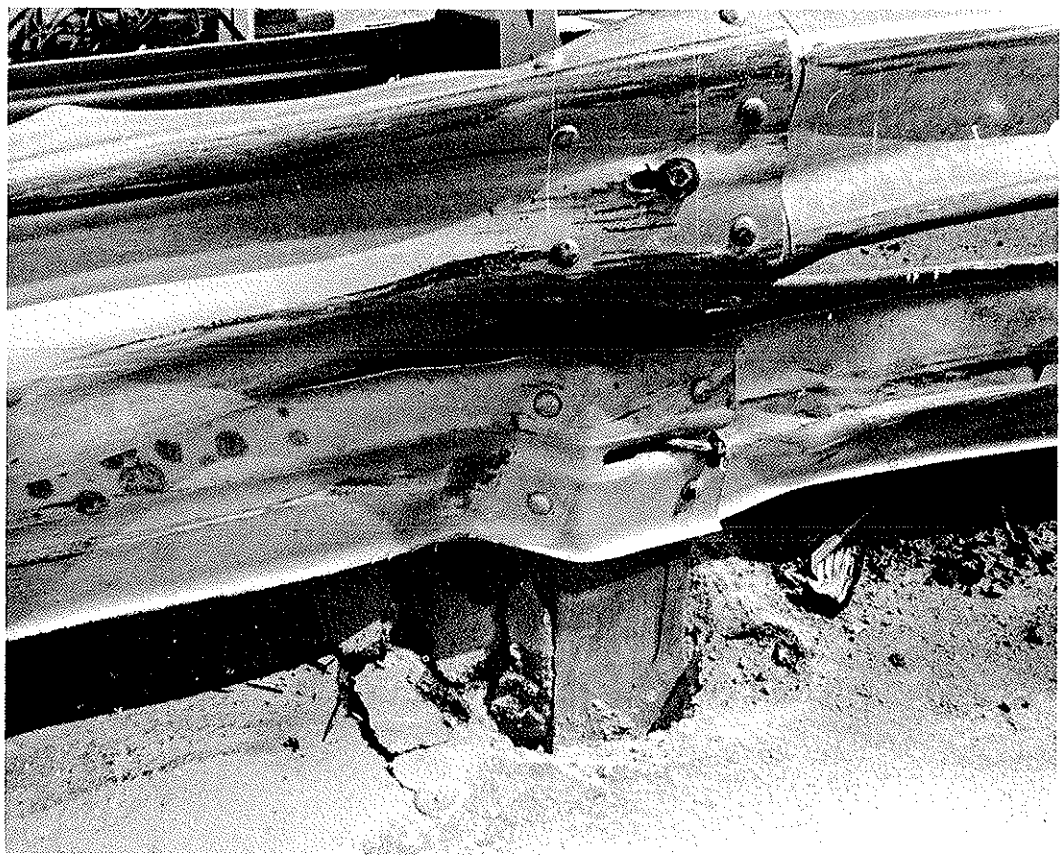


Figure 2.

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 (Fig. 1).

The 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 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 rollover 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 (counterclockwise in direction of vehicle travel) around the longitudinal axis due to a combination of the deflection behavior of the guardrail system and vehicle roll. This rotation was not evident in beams mounted at a height of 27 or 30 in. where the upward deflection prevented vehicular roll.

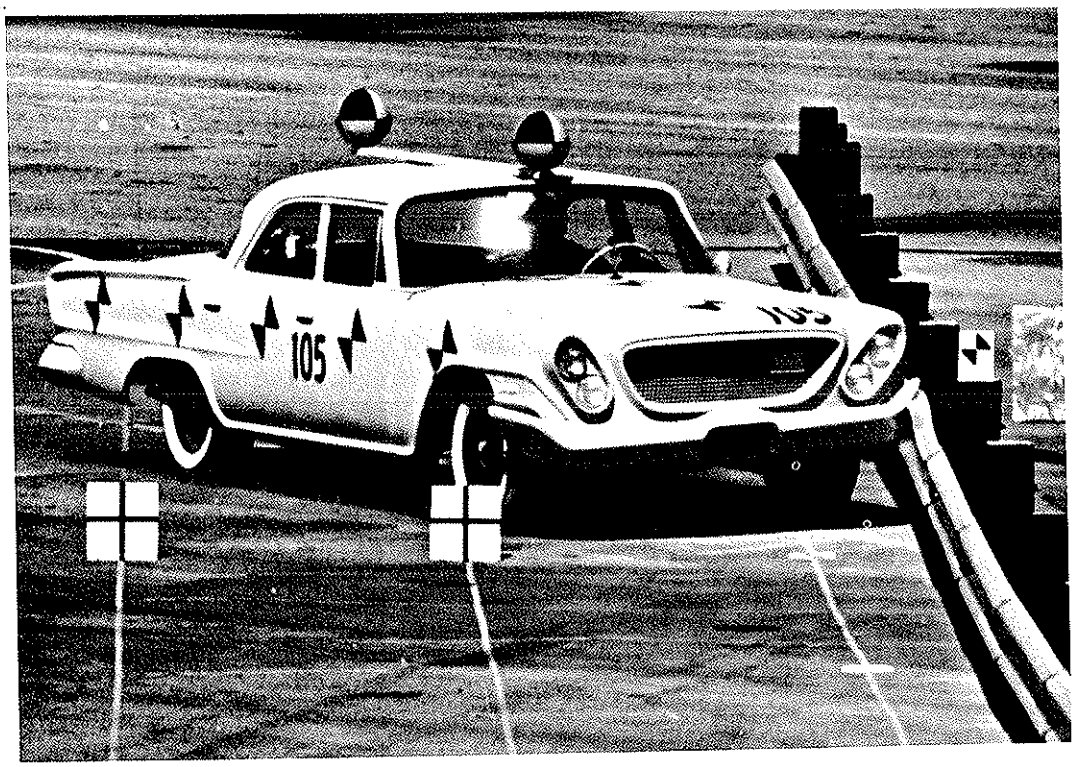


Figure 3.

Rubbing Rail

A moderate amount of post damage caused by wheel entrapment was evident in the guardrail studied 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 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 lesser section modulus than the structural channel employed in Test 106 was used in another test (not reported here). The results emphasized the need of a strong rubbing rail to prevent pocketing when the 30-in. beam height is used (Fig. 2).

Bumper Height vs Beam Height

Data analysis 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 (Fig. 3).

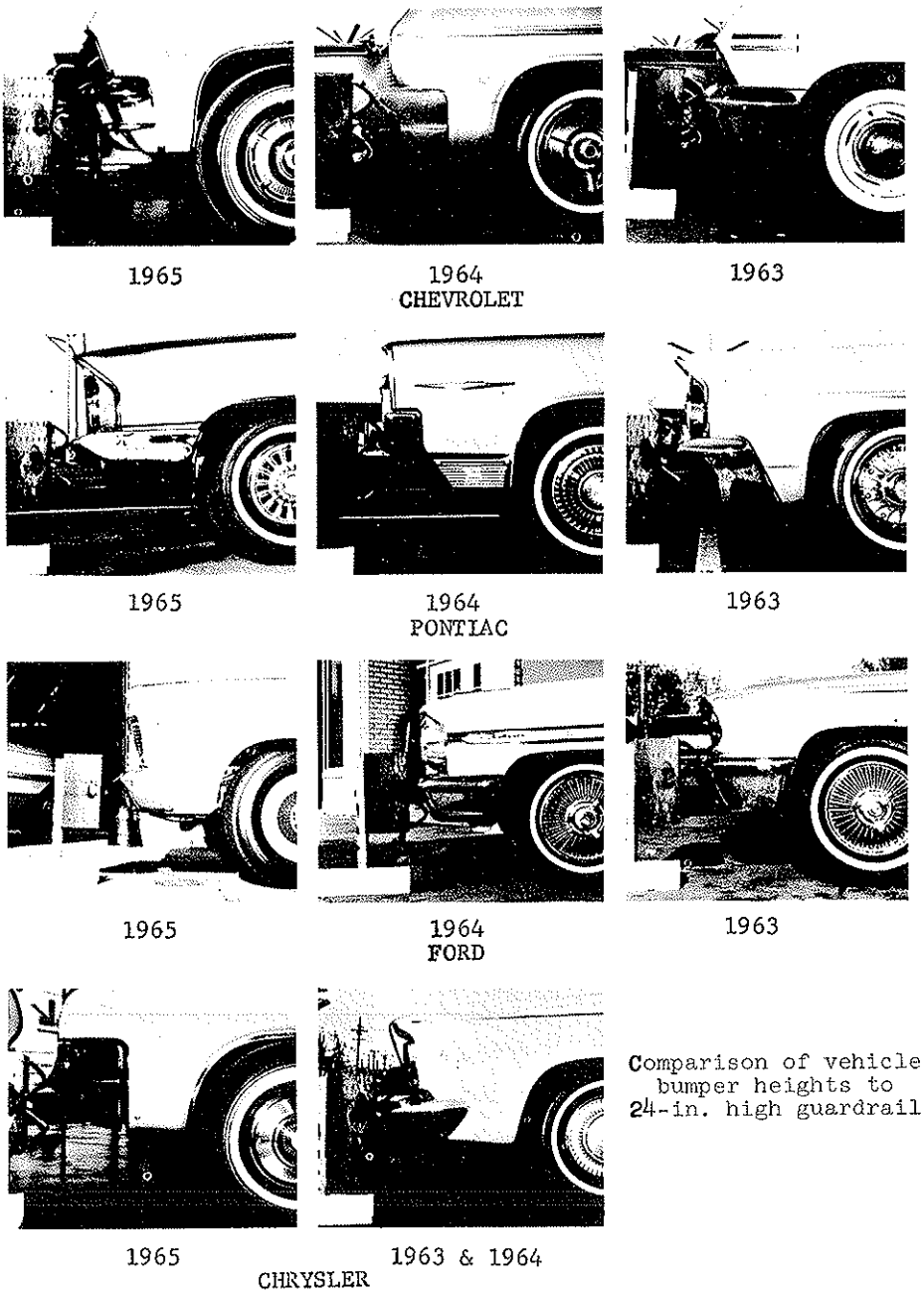
Investigation of bumper geometrics revealed that a majority of U.S.-manufactured vehicles for the years 1962 through 1965 were equipped with bumpers having characteristics similar to those of the 1962 Chrysler test vehicle (Fig. 4). It is possible that this feature of the newer vehicles has contributed to the high incidence of guardrail vaultings reported by our operational departments. Note in Figure 4 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.

Post Spacing

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 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.

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 (Fig. 5), with Test 108, Plate C (Appendix). 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 semirigid 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 it 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 (Fig. 6). 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 non-blocked-out beam immediately decreases during post rotation, thereby decreasing the



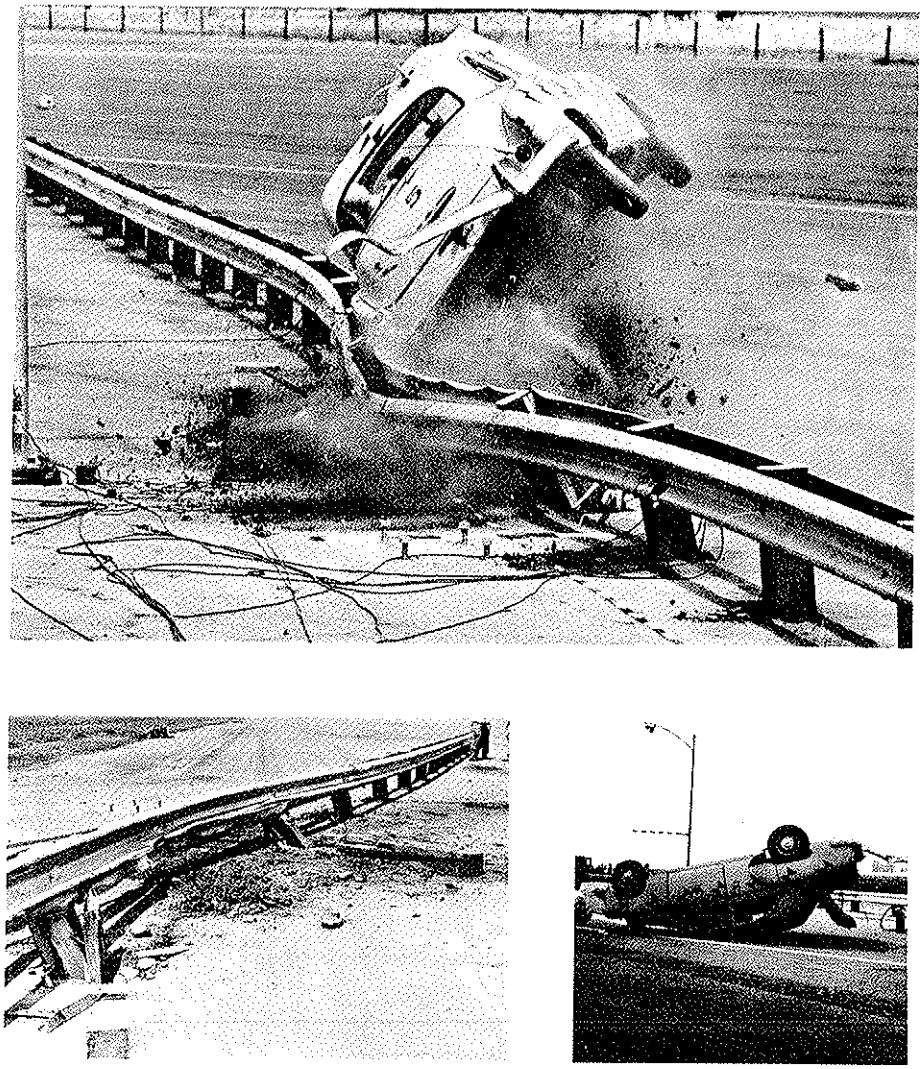
Comparison of vehicle bumper heights to 24-in. high guardrail.

Figure 4.

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.

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



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.

Figure 5.

by all of the tests 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 (Fig. 7). 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 deg and utilized vehicles weighing less than 3500 lb.

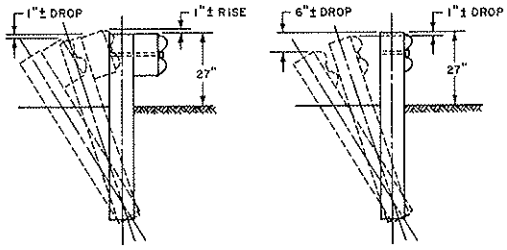


Figure 6.

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 (Fig. 8 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 in Figure 7.

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 (Fig. 7).

Energy Dissipation

The behavior pattern of any semirigid 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 semirigid 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.

Barrier Behavior

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 negligible (13). It is believed that more information is needed concerning this aspect, since a previous study (9) and Test 109 illustrate effects that may be expected when the imposed tensile stresses cannot be resisted by the beam.

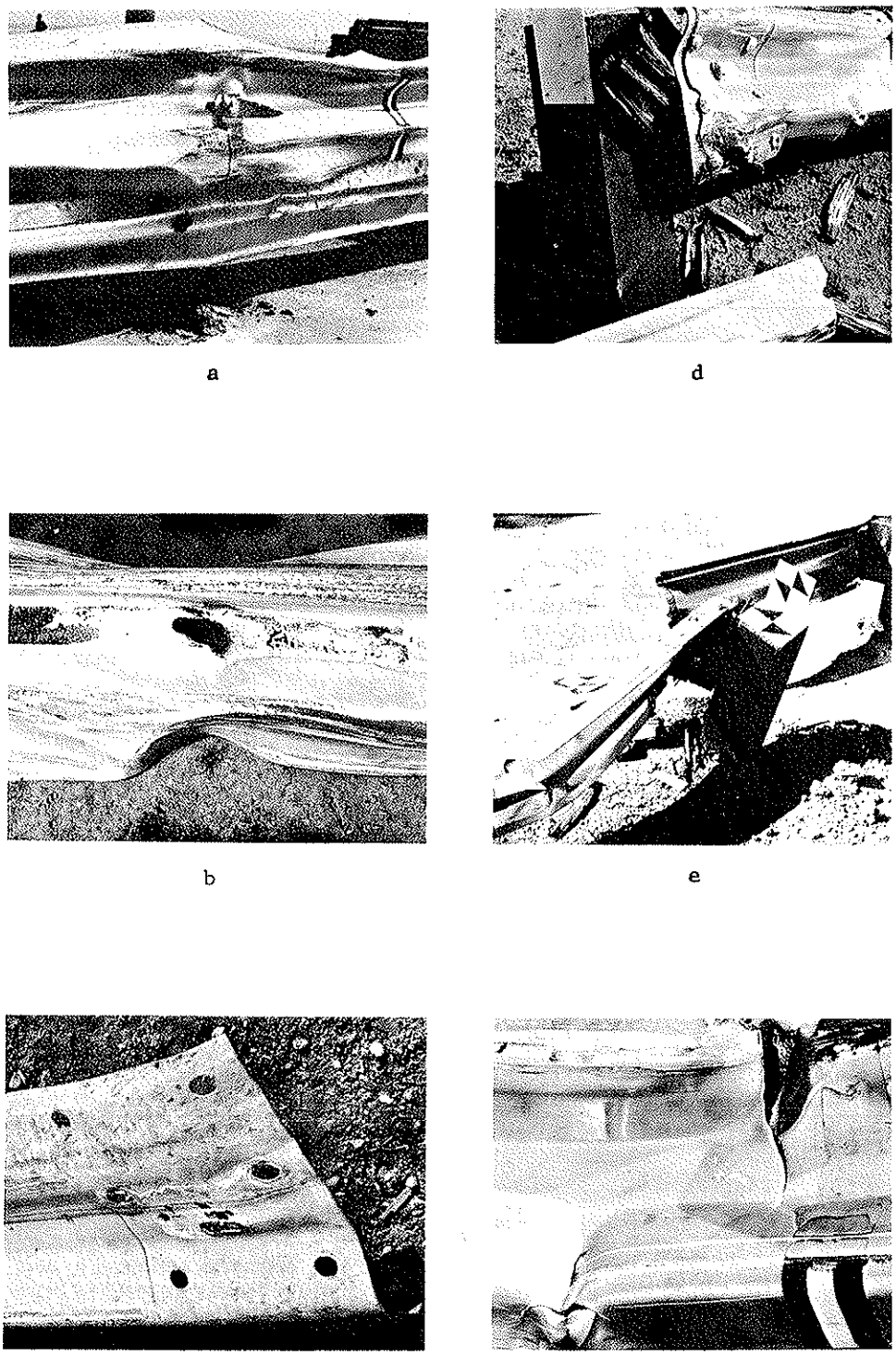


Figure 7. Typical failures of steel and aluminum beams.

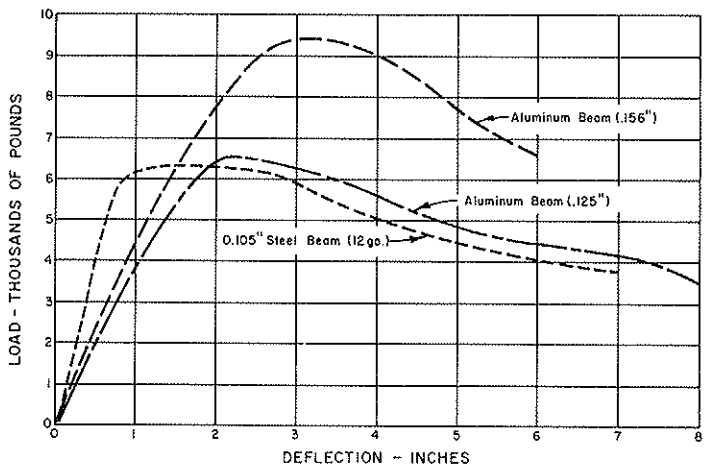


Figure 8. Beam deflections: Static loading of 6-ft 3-in. beam sections, concentrated load at center.

Some insight as to the magnitude 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. 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 in. (Fig. 9). However, these severe reactions were limited to the impact zone, where larger strains in the beams were evident.

TABLE 2

MECHANICAL TEST AVERAGES OF GUARDRAIL MEMBERS

SPECIMEN	NUMBER	YIELD POINT PSI	ULTIMATE PSI	ELONG. %	R.A. %	IMPACT ft.-lb. TRANS.	IMPACT ft.-lb. 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.

TABLE 3

DYNAMIC DATA ON VEHICLES

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.

Figure 9.

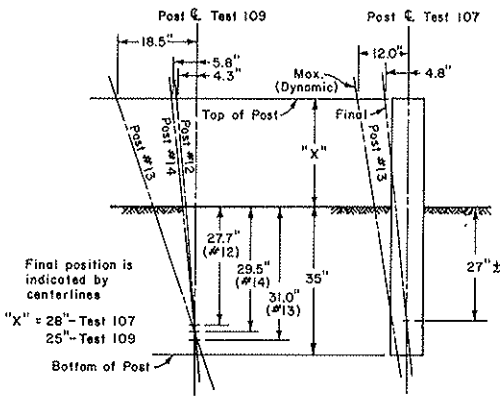


Figure 10.

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 slots for longitudinal beam movement, greater torsional loads 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 indicates that post splitting near points of impact on guardrail installations is fairly common for Douglas fir posts.

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 postions of the posts were somewhere between the original vertical positions and the maximum dynamic deflected positions. Maximum horizontal dynamic deflections through the impact zone exceeded 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 very near the

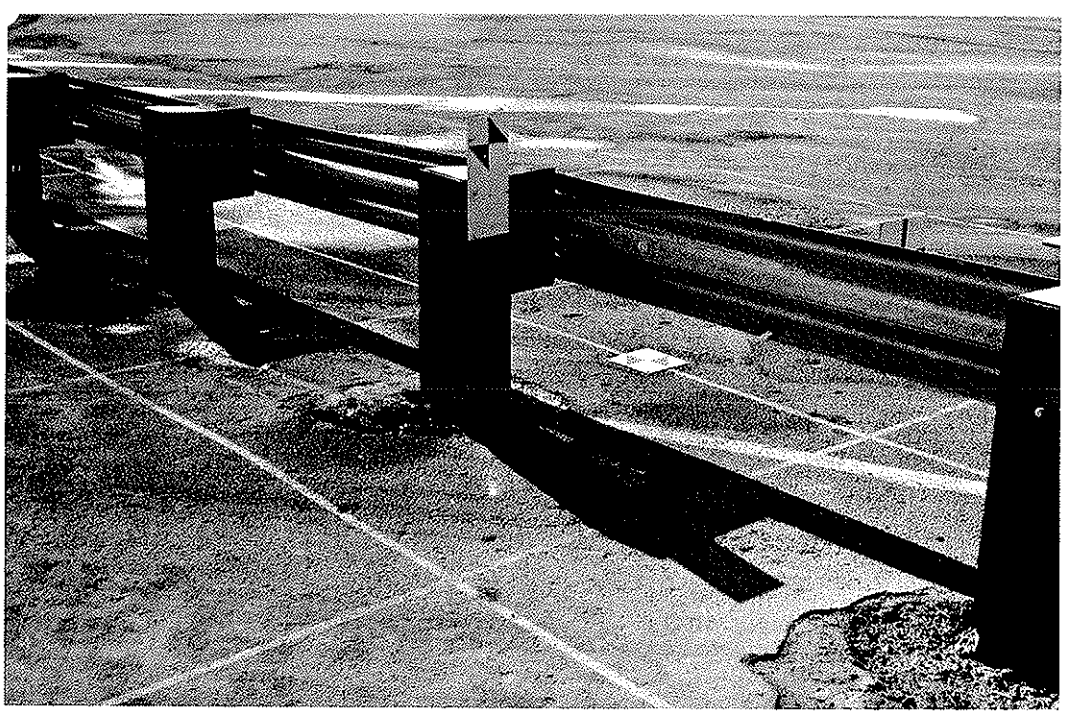


Figure 11.

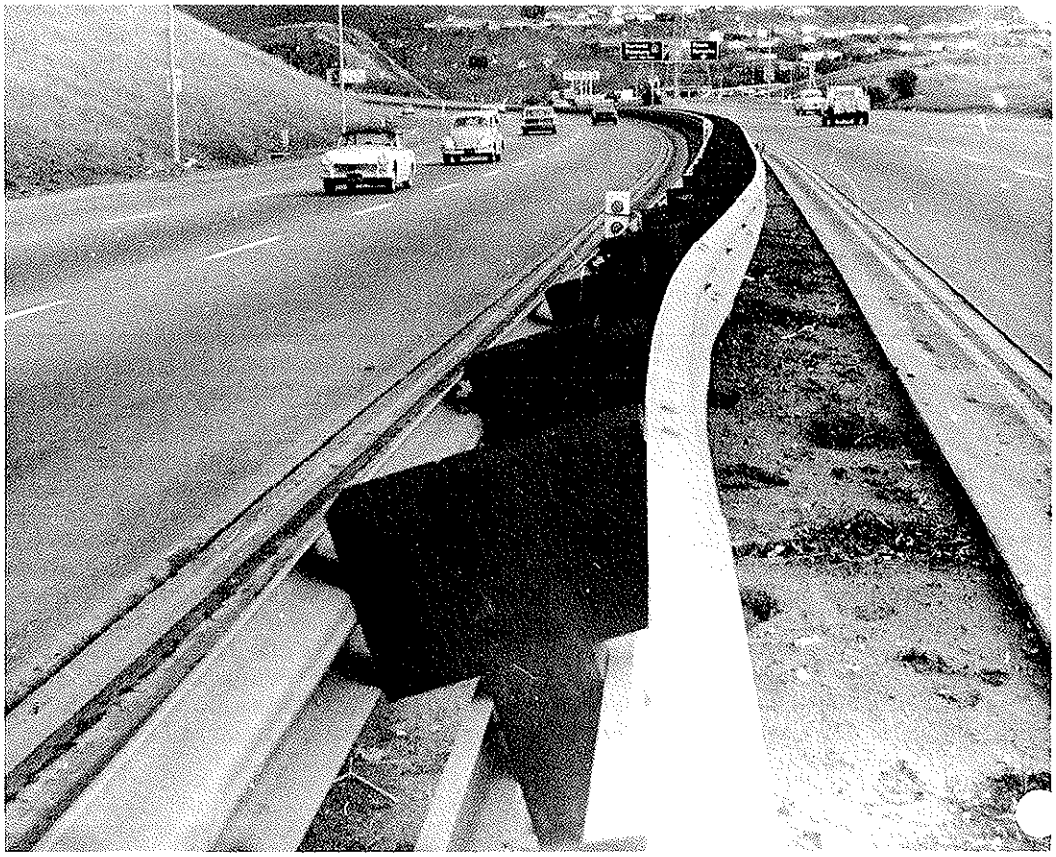


Figure 12.

bottom of the post, which is in agreement with previous findings (14) for rigid posts (Fig. 10).

Since the installation was constructed on an airport runway with no imported base material, the 2-in. 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 ft 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 11 shows soil heave after one of the latter tests and illustrates the need for adequate setback from the hinge point, or deeper post embedment, for guardrail installations on fill slopes.

Operational Experience

The blocked-out beam barrier concept has been supported consistently by satisfactory performances of single and double block-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.

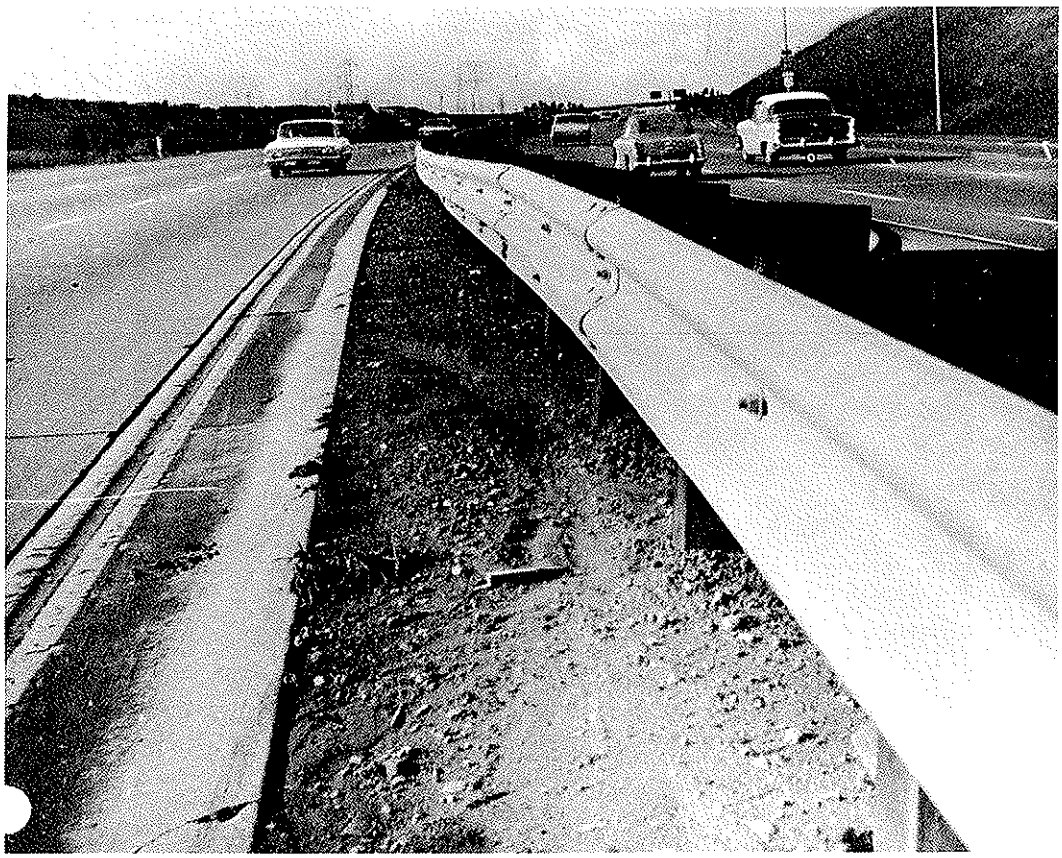


Figure 13.

Double blocked-out median barriers have performed exceptionally well, as shown in Figures 12 and 13.

The operational success of 24-in.-high blocked-out guardrail with 12-ft 6-in. post spacing did not equal that of the doubled blocked-out median barrier. However, Test 108 showed that the basic single blocked-out design was effective in redirecting the vehicles if 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 shown in Figures 14 and 15 and verified by Tests 131 and 132 (Appendix).

Effect of Length

Certain design factors appear to be more significant in short deflector-type guardrail installations than in the longer median barrier of guardrail installations. For instance, in short installations the individual connections (Fig. 16) 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

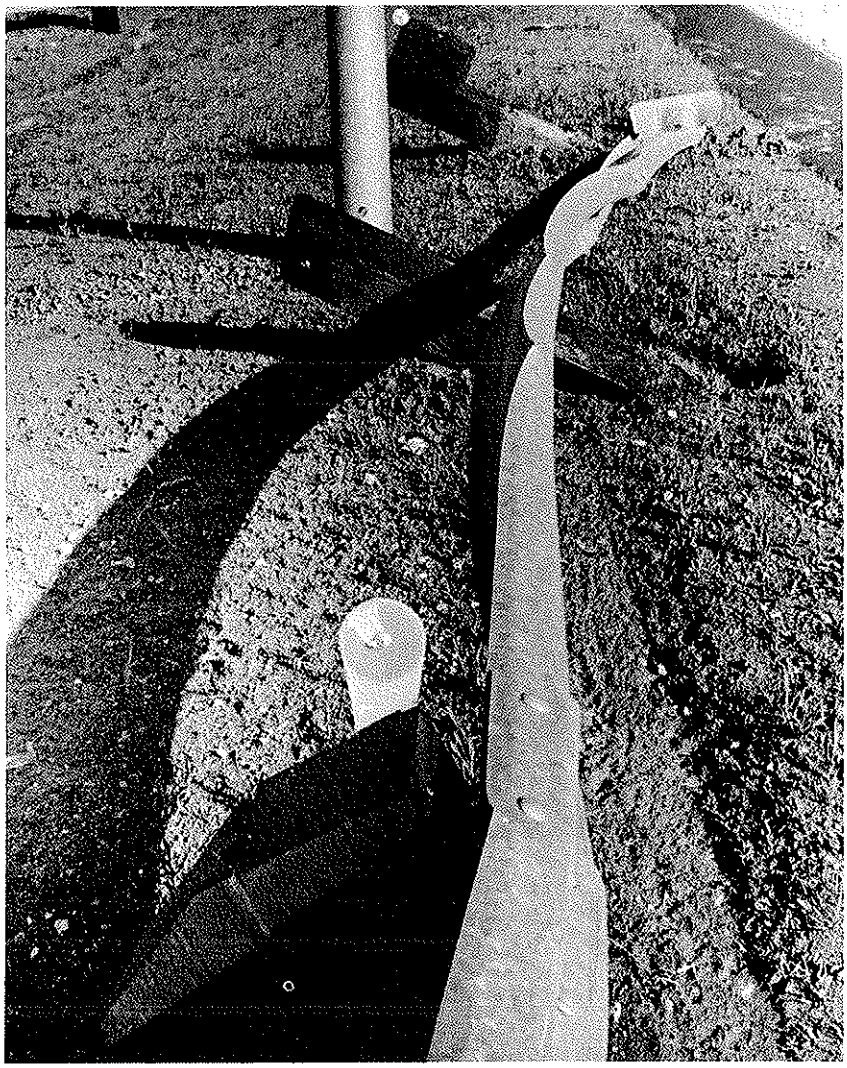


Figure 14.

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.

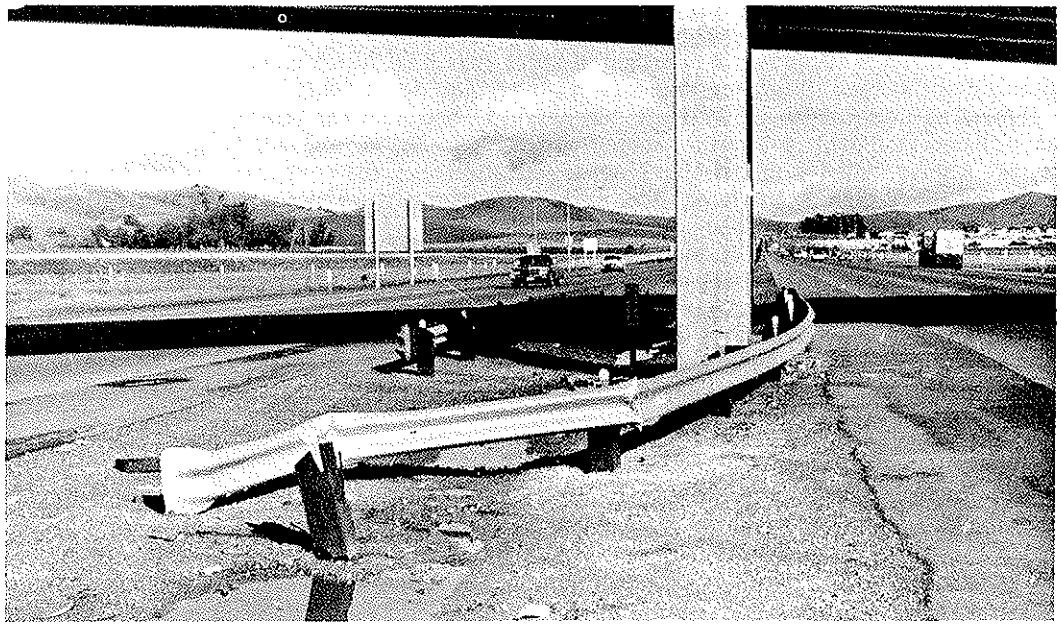


Figure 15.

Test 133, next in the current test series on short lengths of guardrail, will be onducted 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.

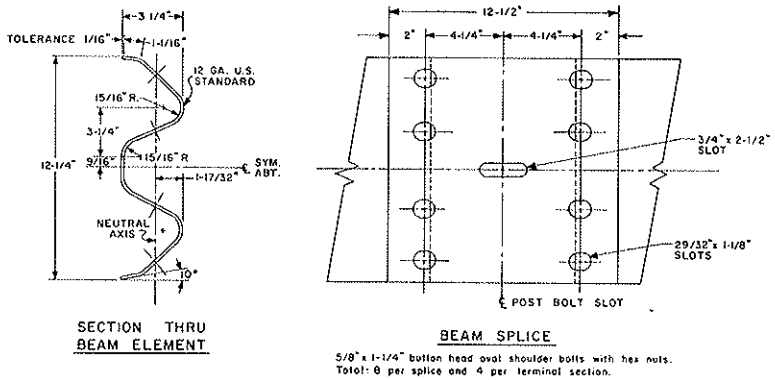


Figure 16. Corrugated beam splice details. The beam is fastened at each post with a $^5/_8$-in. carriage bolt (large head) utilizing a cut steel washer under the nut.

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.

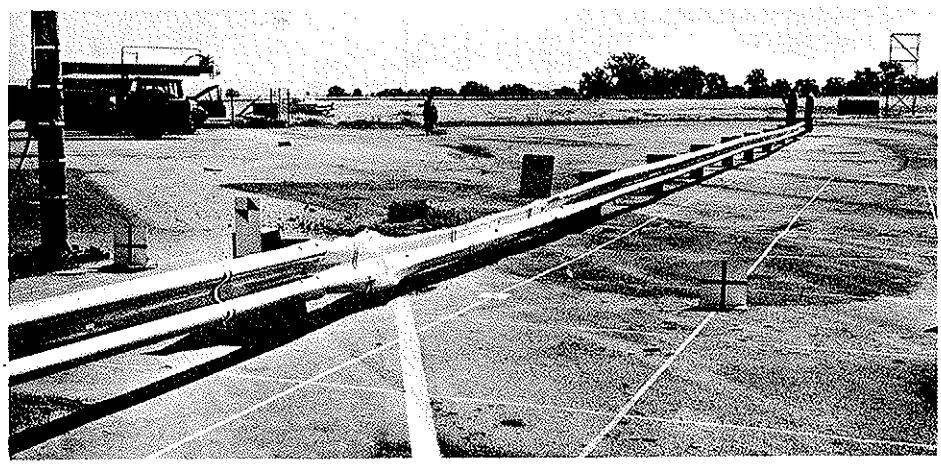
REFERENCES

1. Tamburri, T. N., and Glennon, J. C. Objective Criteria for Guardrail Installation. Calif. Div. of Highways, July 1966.
2. Dynamic Tests of Aluminum Guard Rail. Inst. of Research of Lehigh Univ.
3. HRB Committee on Guardrails and Guide Posts. Proposed Full-Scale Testing Procedures for Guardrails. Circular 482, Sept. 1962.
4. Reagel, F. V., Willis, T. F., and DeReus, M. E. Tests of Various Highway Guardrails. Missouri State Highway Bull., 1934.
5. Lundstrom, L. C., and Skeels, P. C. Full-Scale Appraisals of Guardrail Installations by Car Impact Tests. HRB Proc., Vol. 38, 1959, pp. 353-355.
6. Beaton, J. L., and Field, R. N. Dynamic Full-Scale Tests of Median Barriers. HRB Bull. 266, 1960, pp. 78-125.
7. Highway Guardrail. HRB Spec. Rept. 81, 1964.
8. Nordlin, E. F., Field, R. N., and Hackett, R. P. Dynamic Full-Scale Impact Tests of Bridge Barrier Rails. Highway Research Record 83, 1965, pp. 132-168.
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. Calif. Div. of Highways, Feb. 1965.
10. Beaton, J. L., Field, R. N., and Moskowitz, K. Median Barriers: One Year's Experience and Further Controlled Full-Scale Tests. HRB Proc., Vol. 41, 1962, pp. 433-468.
11. Development of an Analytical Approach to Highway Barrier Design and Evaluation. Physical Research Proj. 15, New York State Dept. of Public Works, May 1963.
12. Finkbiner, N. M. Highway Guard Fence. Oregon State Highway Dept. Tech. Bull. 21, April 1950.
13. Shoemaker, N. E. Test Report for Full-Scale Dynamic Tests of Highway Barriers. Cornell Aeronautical Lab. Inc., Dec. 1963.
14. Davisson, M. T., and Prakash, S. A Review of Soil-Pole Behavior. Highway Research Record 39, 1964, pp. 25-48.

Appendix

The following plates contain pertinent data and photographs of the seven impact tests discussed in this report. Each group covers (a) a description of the barrier installation, purpose, performance, barrier damage and vehicle damage; (b) a data sheet showing overhead or panned camera views of vehicles through impact, and a tabulation of test parameters; (c) a sequence of pictures from the front data camera or scaffold-mounted camera; and (d) photographs of barrier and vehicle damage.

TEST 105 PLATE A



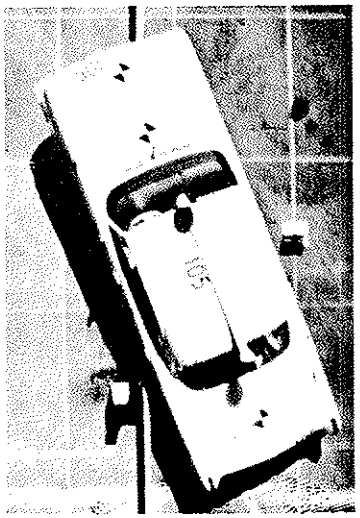
BARRIER: Blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 24-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5-ft 6-in. treated DF posts spaced 12-ft 6-in. on centers.

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.

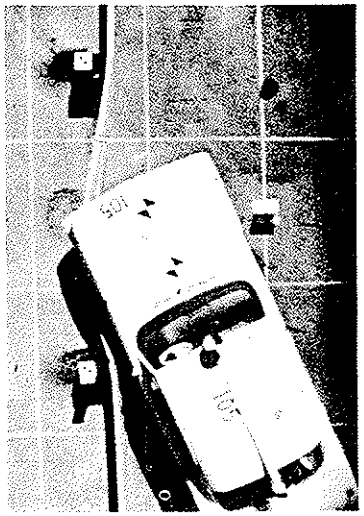
PERFORMANCE: The vehicle impacted the guardrail between posts at a speed of 58-mph. The bumper rotated the beam axially into a ramp position, enabling the car to vault the barrier. The vehicle rose to a maximum height of 30-in. and was airborne for 25-ft.

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.

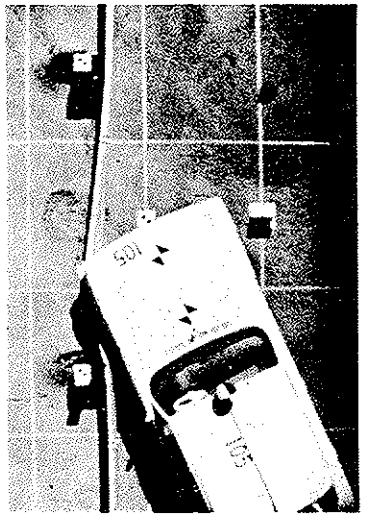
VEHICLE DAMAGE: The vehicle sustained moderate front end damage. This vehicle was repaired for $250 and used as the impact vehicle in Test 109.



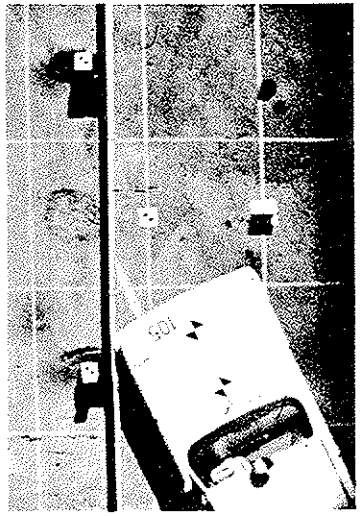
IMPACT + 130 M Sec



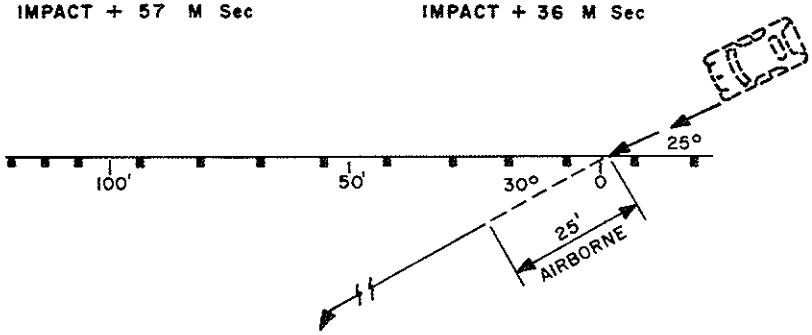
IMPACT + 57 M Sec

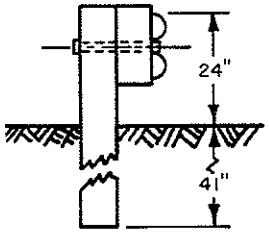


IMPACT + 36 M Sec



IMPACT



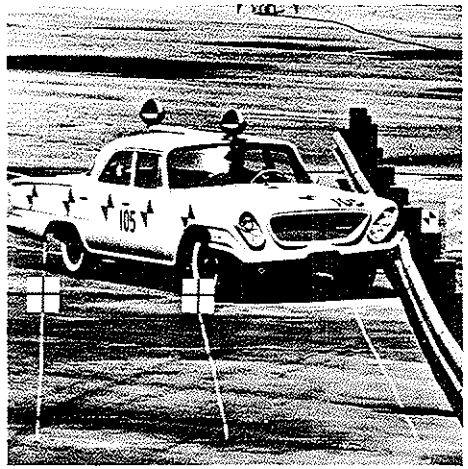


METAL BEAM GUARDRAIL

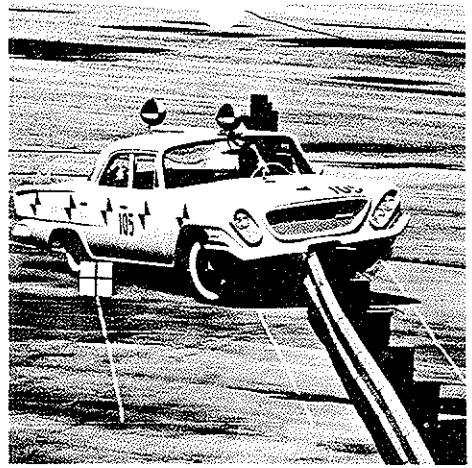
BEAM-RAIL	12 ga. Galv. Steel x 13'-6.5"
RUBBING RAIL	None
POST	8"x 8" Rough D. F. x 5'-6"
POST EMBEDMENT	41"
POST SPACING	12'-6"
LENGTH OF INSTALLATION	175'
GROUND CONDITION	DRY
BEAM RAIL DEFLECTION-PERMANENT	5"

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

TEST 105 PLATE B

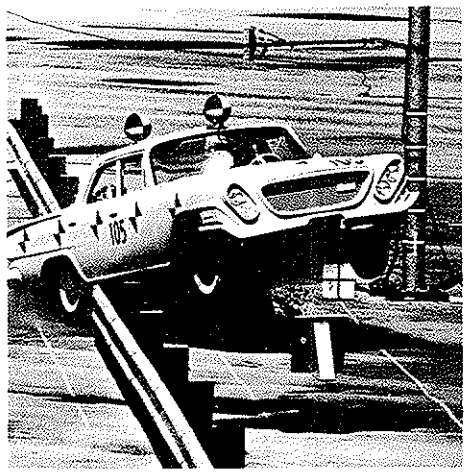


Impact

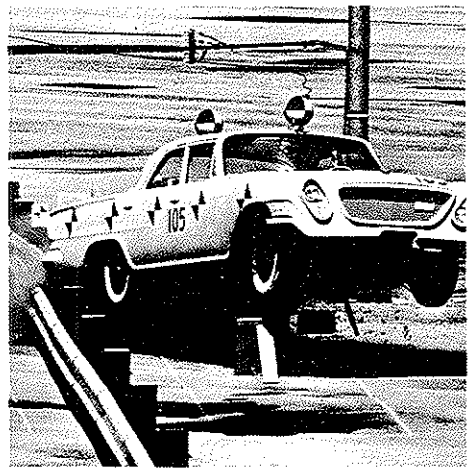


I + .102 Sec.

I + .252 Sec.



I + .331 Sec.

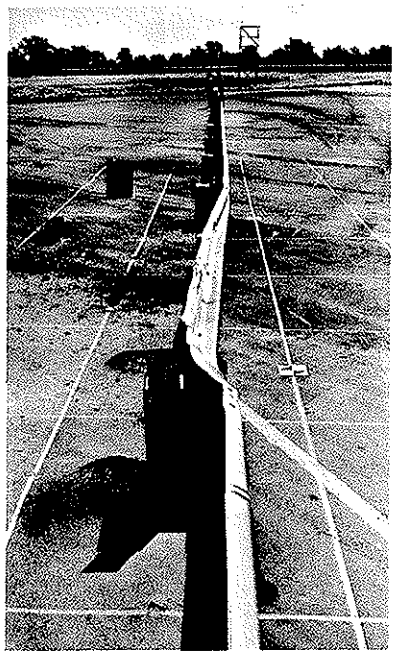


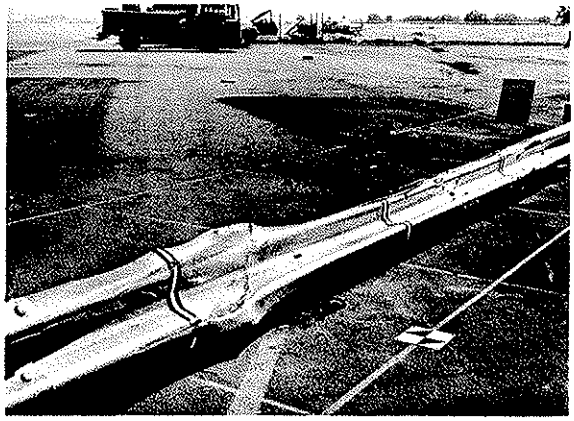
I + .451 Sec.

I + .646 Sec.

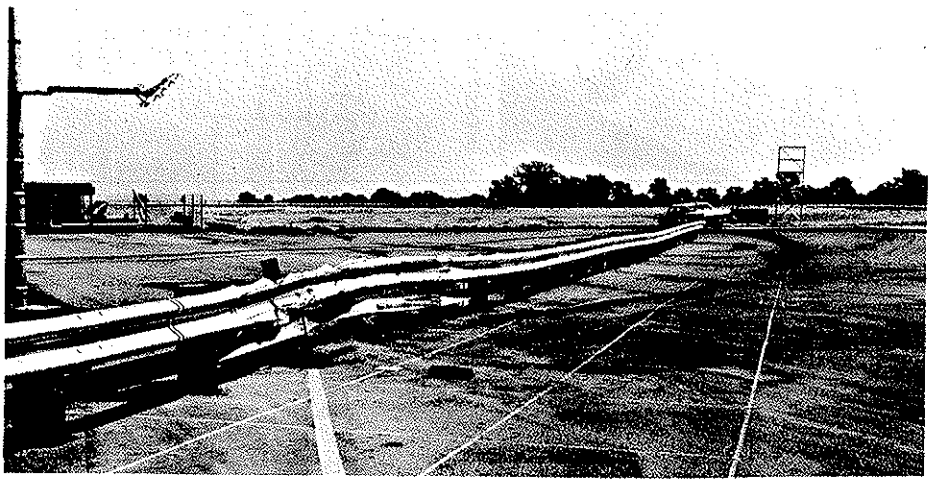
TEST 105 PLATE C

TEST 105 PLATE D





TEST 106 PLATE A



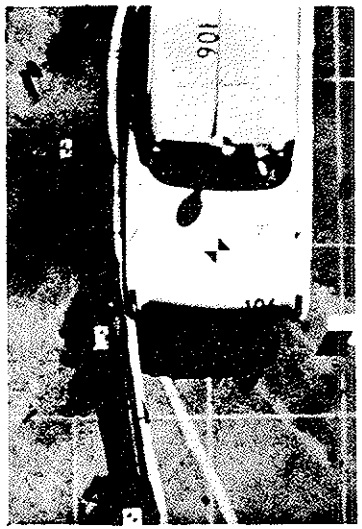
BARRIER: Single blocked-out metal beam median barrier with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 30-in. high (top edge of beam to ground) and blocked-out with 8- by 8- by 14-in. treated DF blocks, and 6-in. 8.2-lb galvanized steel channel rubbing rail mounted 12-in. high (center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

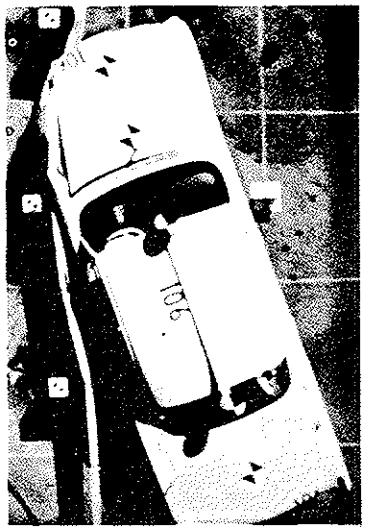
BARRIER DAMAGE: Three sections of beam and two sections of rubbing rail were damaged. Six posts were knocked out of alignment, one of which was broken and one was split. Three block-out blocks were splintered, and two were split.

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

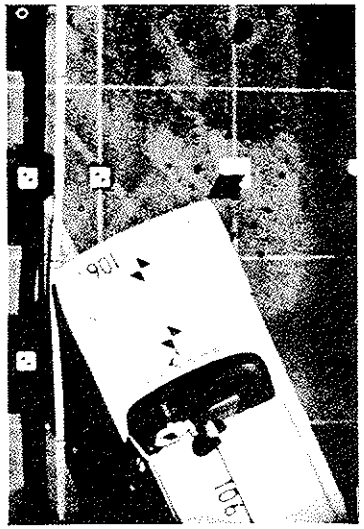


IMPACT + 312 M Sec

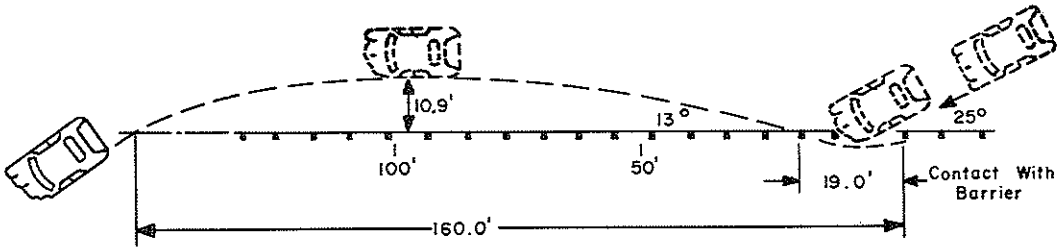
IMPACT + 179 M Sec

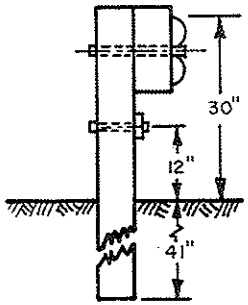


IMPACT + 93 M Sec



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

TEST 106 PLATE B

Impact + .082 Sec.

I + .181 Sec.

I + .243 Sec.

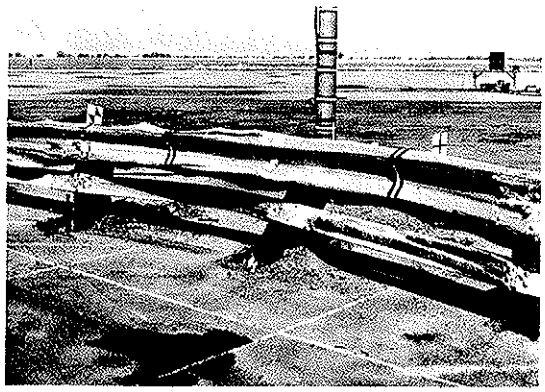
I + .373 Sec.

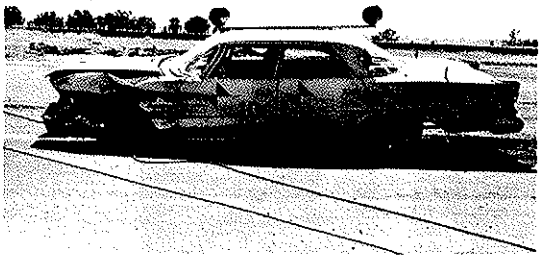
I + .624 Sec.

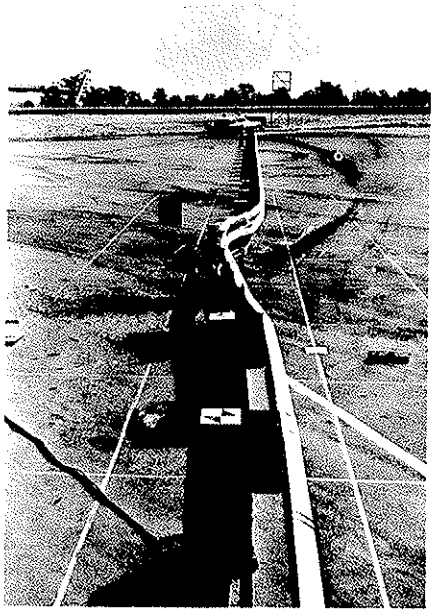
I + .889 Sec.

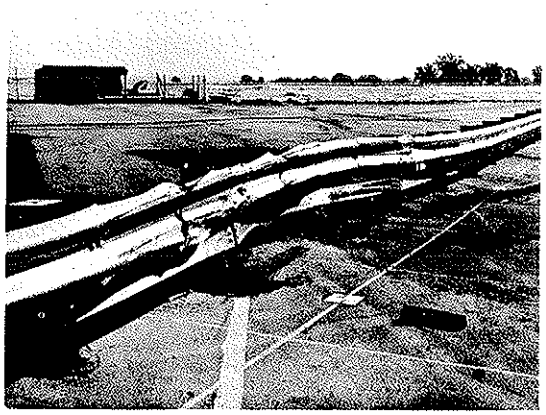
TEST 106 PLATE C

TEST 106 PLATE D

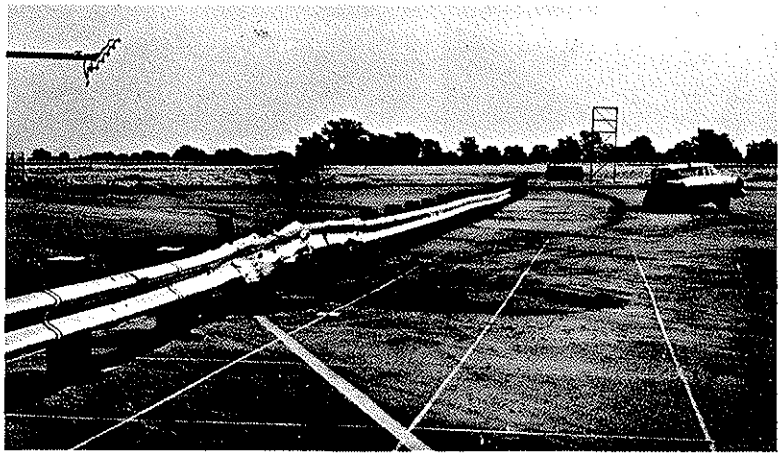








TEST 107 PLATE A



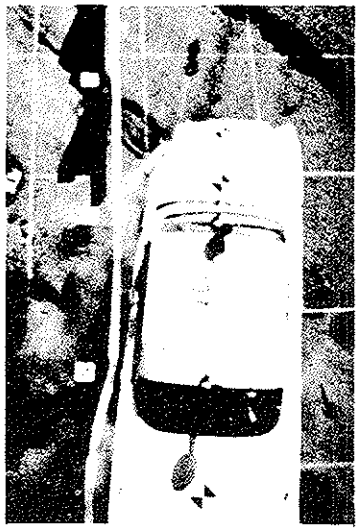
BARRIER: Blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 27-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5-ft 3-in. treated DF posts spaced 6-ft 3-in. on centers.

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.

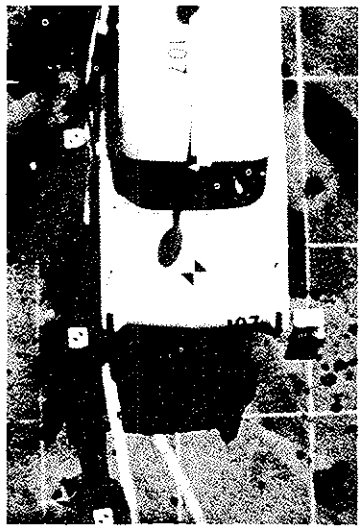
PERFORMANCE: The vehicle impacted the guardrail at a post at a speed of 60-mph and remained in contact for approximately 13-ft before being redirected to an exit angle of 17°. The vehicle showed no tendency to jump or roll.

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.

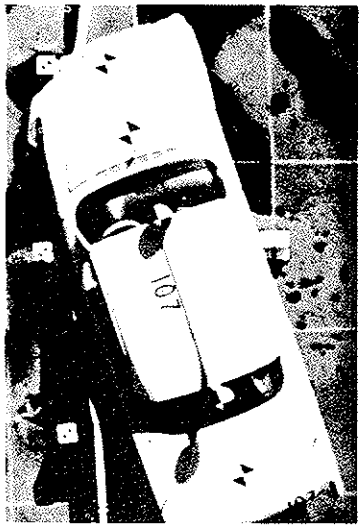
VEHICLE DAMAGE: The vehicle sustained major front end damage and was considered a total loss.



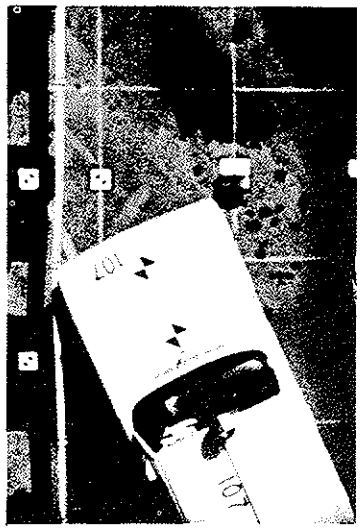
IMPACT + 384 M Sec



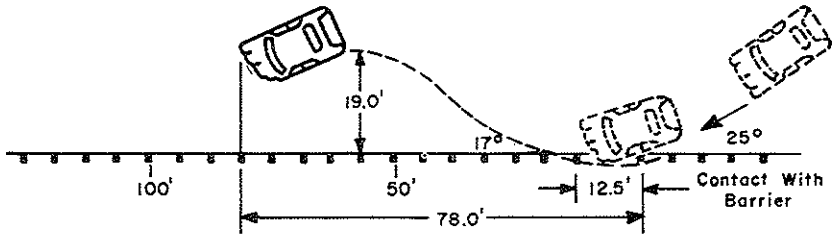
IMPACT + 280 M Sec

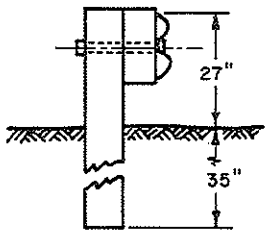


IMPACT + 112 M Sec



IMPACT



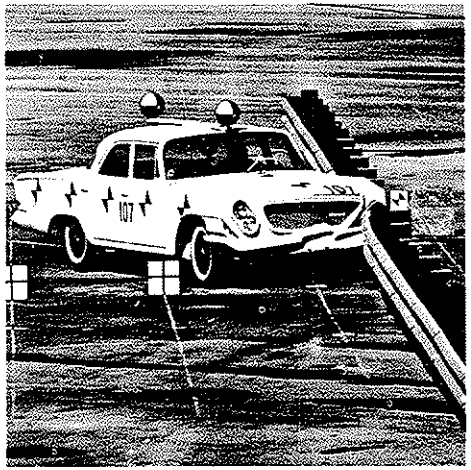


METAL BEAM GUARDRAIL

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"

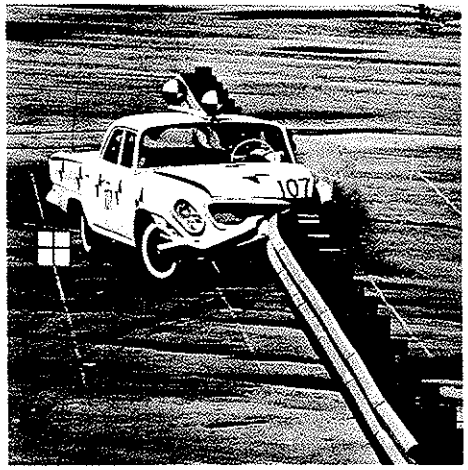
TEST NO.	107
DATE	10-1-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W / DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	60 mph
IMPACT ANGLE	25°
EXIT ANGLE	17°
DUMMY RESTRAINT	Lap Belt

TEST 107 PLATE B

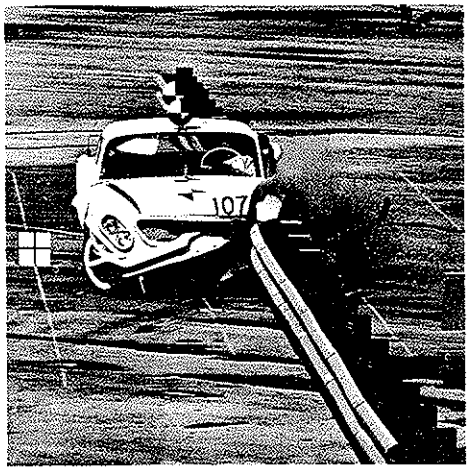


Impact + .045 Sec.

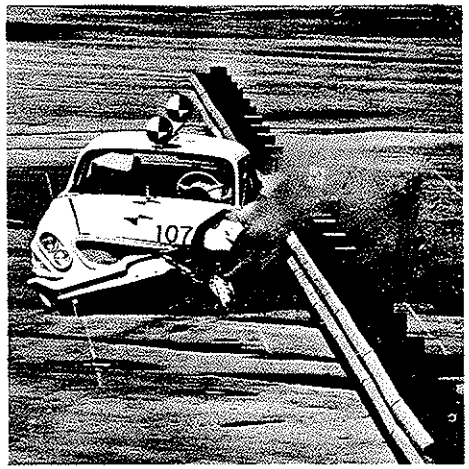
I + .090 Sec.



I + .180 Sec.



I + .360 Sec.

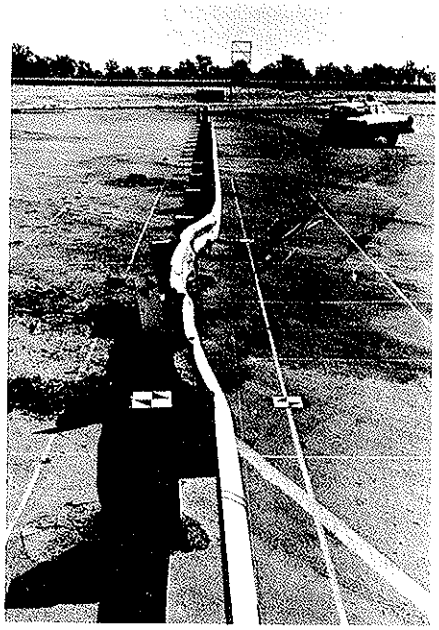


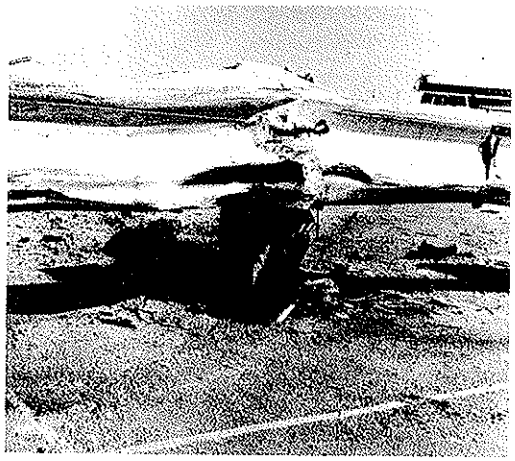
I + .405 Sec.

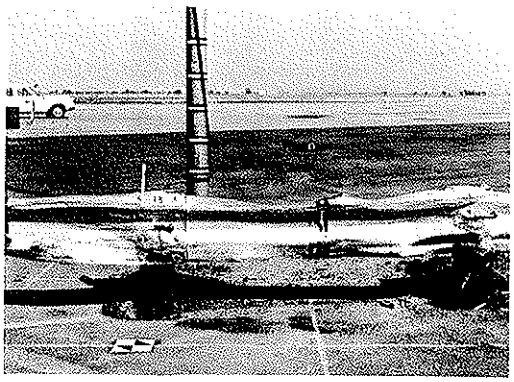
I + .601 Sec.

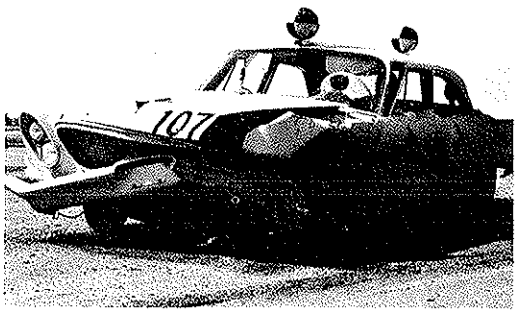
TEST 107 PLATE C

TEST 107 PLATE D

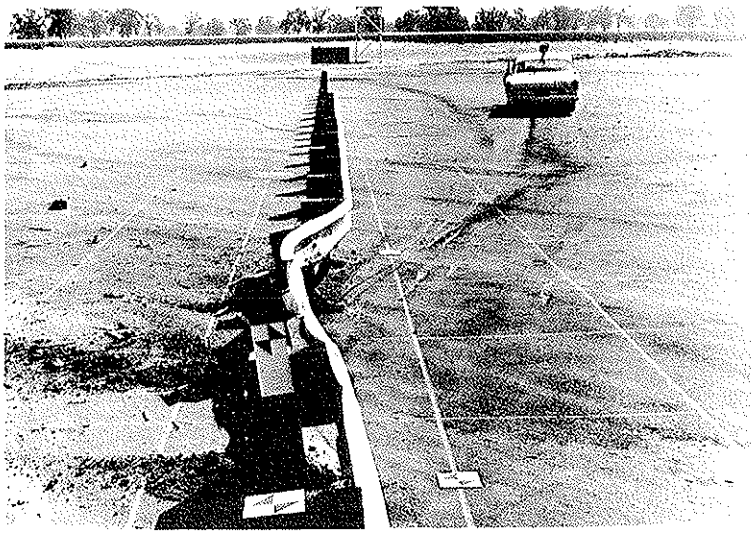








TEST 108 PLATE A



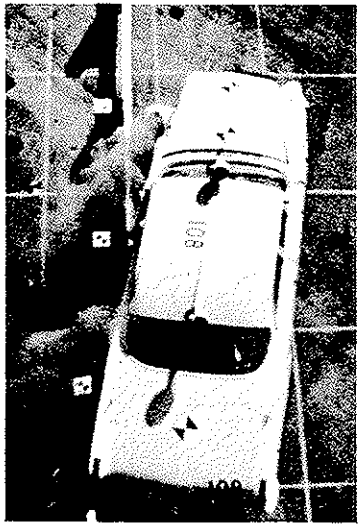
BARRIER: Blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 24-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5.0-ft treated DF posts spaced 6-ft 3-in. on centers.

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.

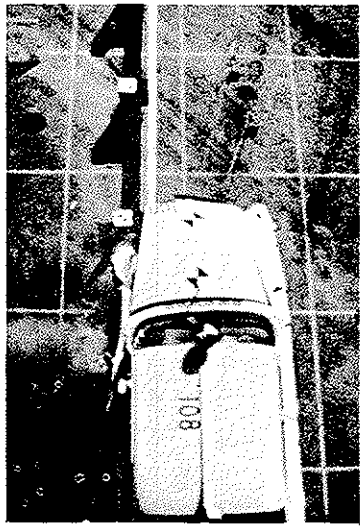
PERFORMANCE: The vehicle impacted the guardrail between posts at a speed of 59-mph and remained in contact for approximately 13-ft before being redirected to an exit angle of 19°. The vehicle showed no tendency to jump. The barrier deflection permitted the vehicle to roll to a maximum of 5° left.

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.

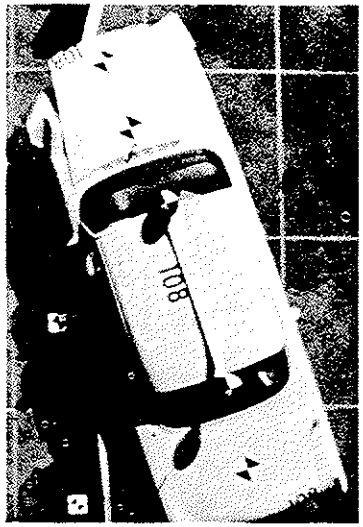
VEHICLE DAMAGE: The vehicle sustained major front end damage and was considered a total loss.



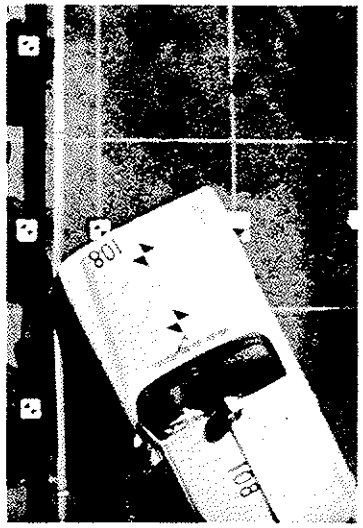
IMPACT + 317 M Sec



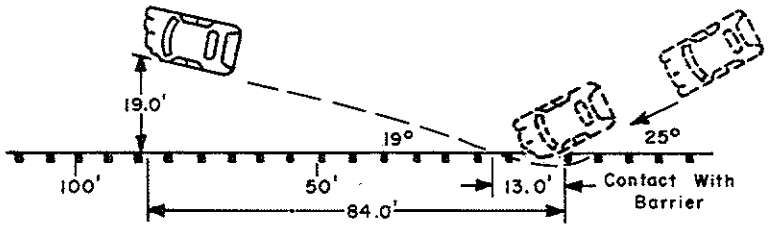
IMPACT + 177 M Sec

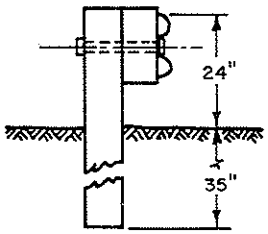


IMPACT + 125 M Sec



IMPACT



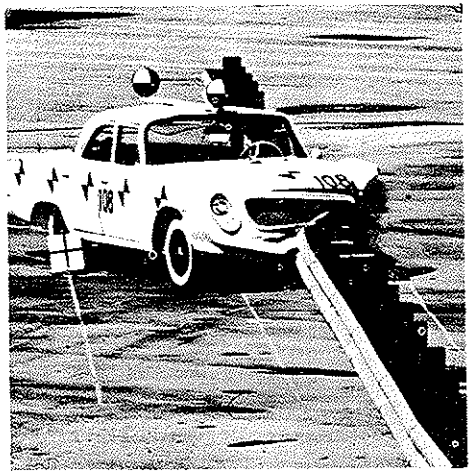


METAL BEAM GUARDRAIL

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"

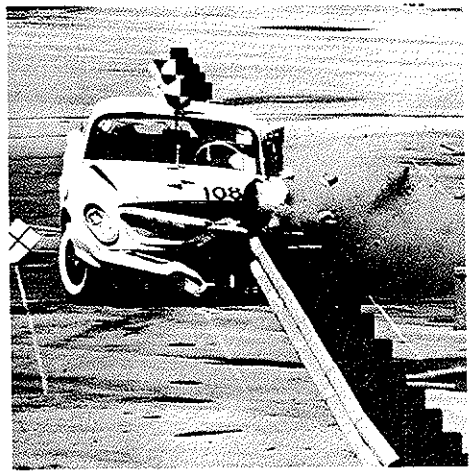
TEST NO.	108
DATE	10-7-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	59 mph
IMPACT ANGLE	25°
EXIT ANGLE	19°
DUMMY RESTRAINT	Lap Belt

TEST 108 PLATE B

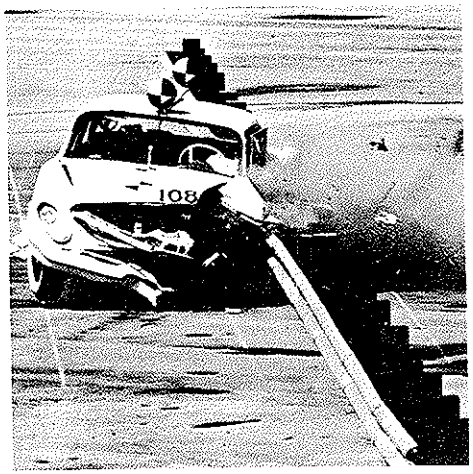


Impact + .118 Sec.

I + .171 Sec.



I + .304 Sec.



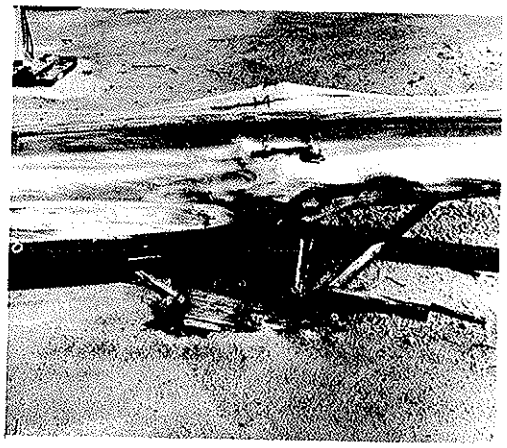
I + .379 Sec.

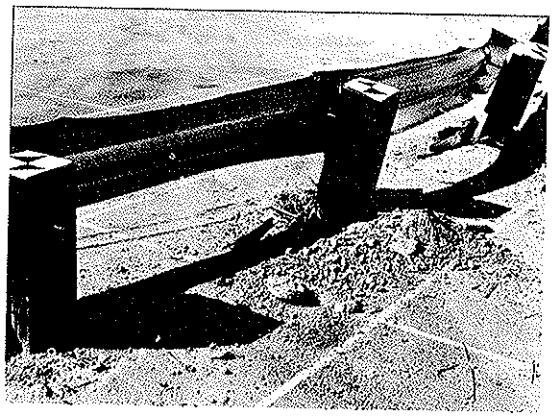
I + .536 Sec.

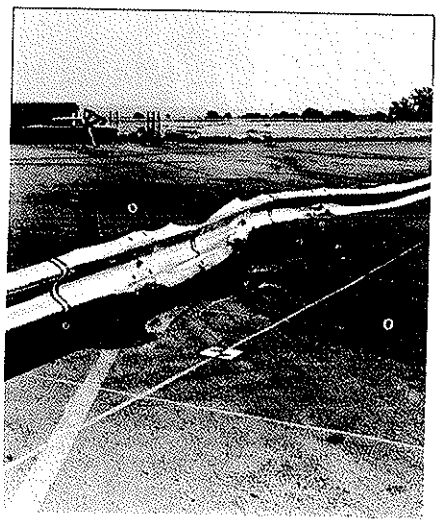
I + .714 Sec.

TEST 108 PLATE C

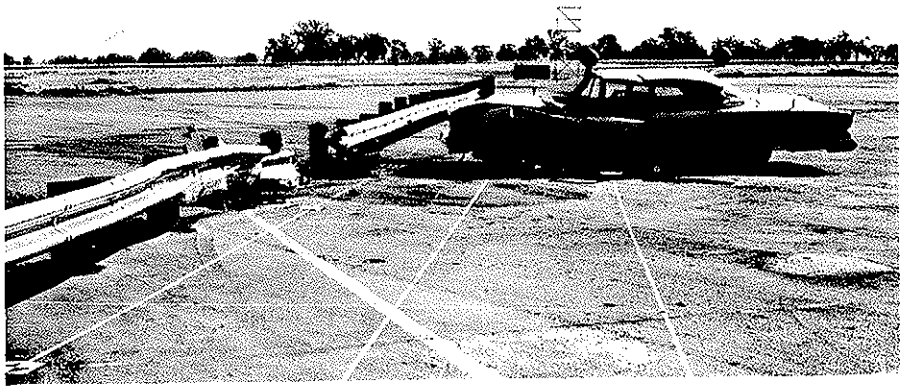
TEST 108 PLATE D







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.

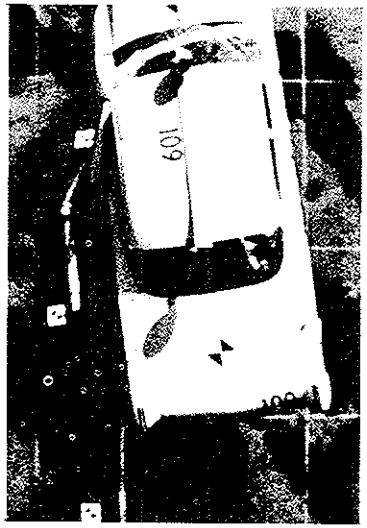
PURPOSE: To test the effectiveness of the 1960 California standard blocked-out metal beam guardrail design with 0.156-in. aluminum alloy corrugated beam substituted for the standard 0.105-in. galvanized steel corrugated beam and the post spacing decreased from 12-ft 6-in. to 6-ft 3-in. on centers.

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.

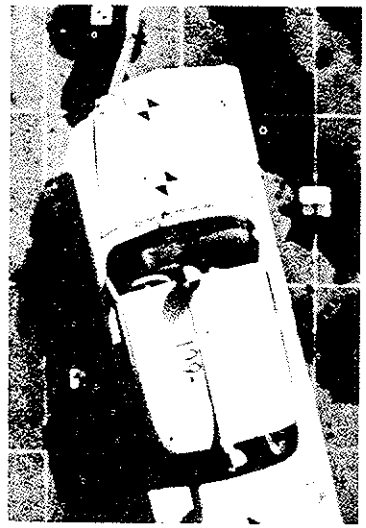
BARRIER DAMAGE: Two sections of beam were destroyed. The beam failed completely in three places. Five posts were knocked out of alignment, three of which were split. Three block-out blocks were splintered and six were split.

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

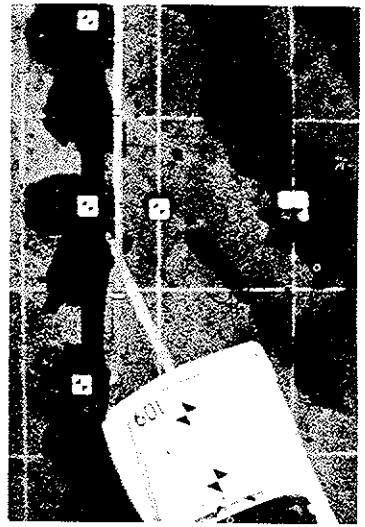
IMPACT + 524 M Sec



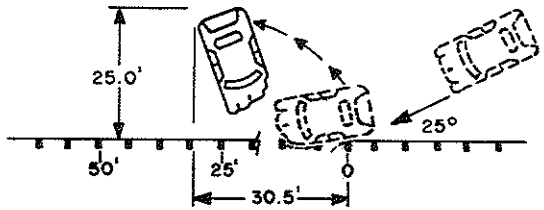
IMPACT + 330 M Sec

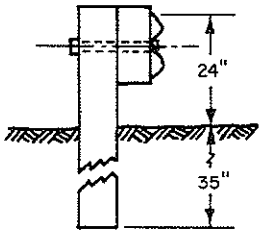


IMPACT + 122 M Sec



IMPACT + 3 M Sec





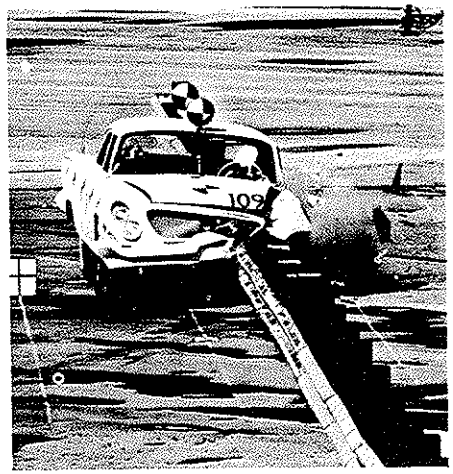
METAL BEAM GUARDRAIL

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"

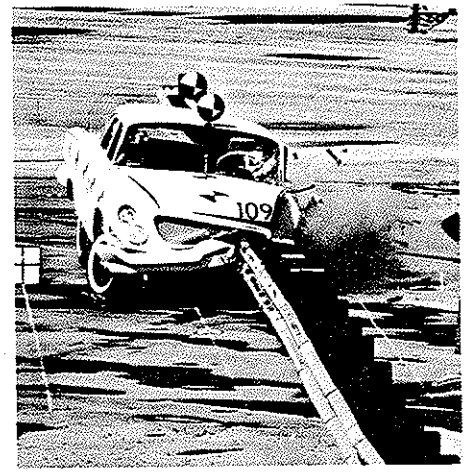
TEST NO.	109
DATE	10-14-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570#
IMPACT SPEED	60 mph
IMPACT ANGLE	25°
EXIT ANGLE	0° at time of failure
DUMMY RESTRAINT	Type 4

TEST 109 PLATE B

Impact + .112 Sec.



I + .241 Sec.



I + .272 Sec.

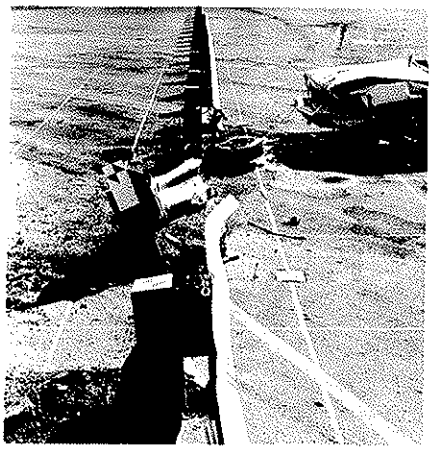
I + .474 Sec.

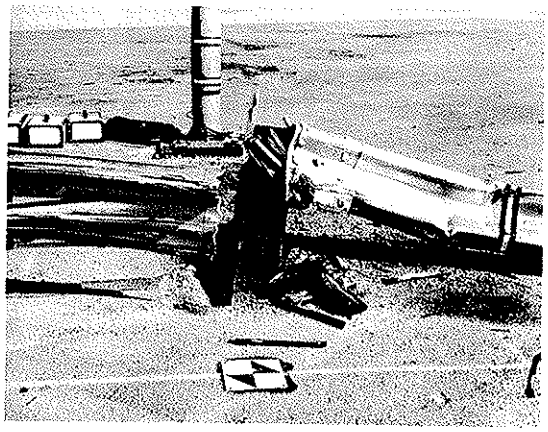
I + .624 Sec.

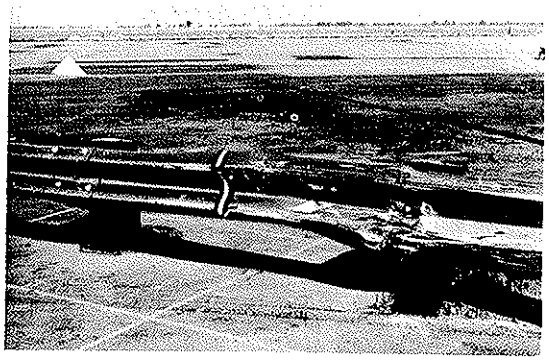
I + 1.618 Sec.

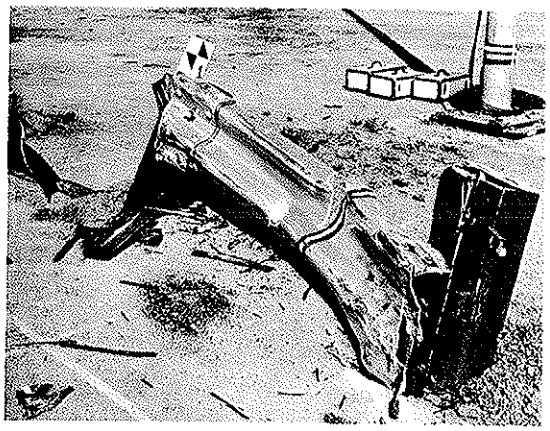
TEST 109 PLATE C

TEST 109 PLATE D

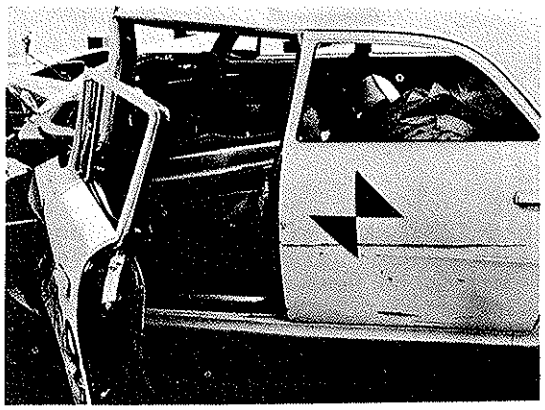








TEST 109 PLATE E



TEST 131 PLATE A

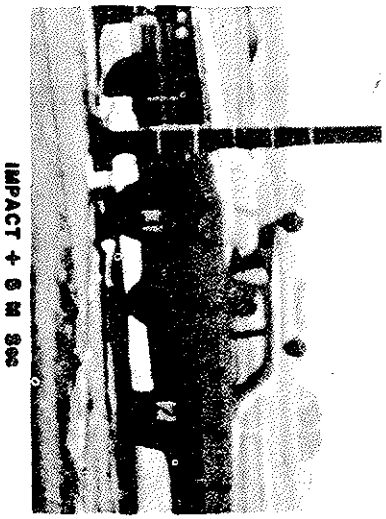
BARRIER: A 37-ft 6-in. unanchored installation of blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 27-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks, on 8- by 8-in. by 5-ft 4-in. treated DF posts spaced 6-ft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

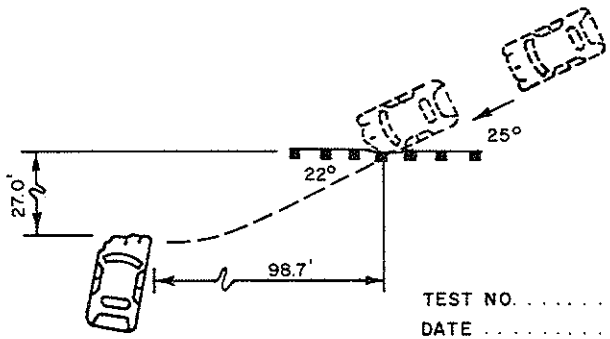


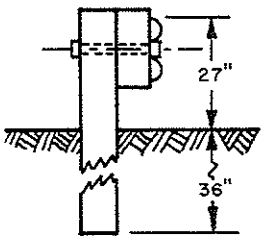
IMPACT + 0 M Sec

IMPACT + 137 M Sec

IMPACT + 375 M Sec

IMPACT + 654 M Sec



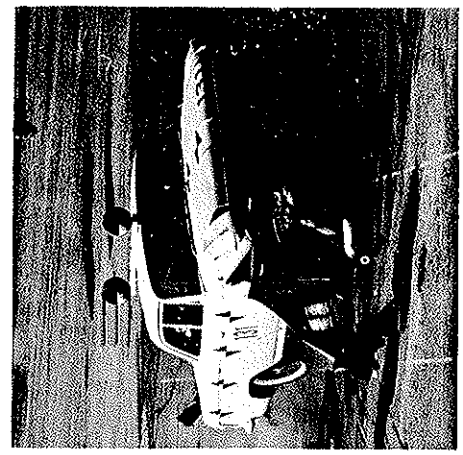


METAL BEAM GUARDRAIL

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

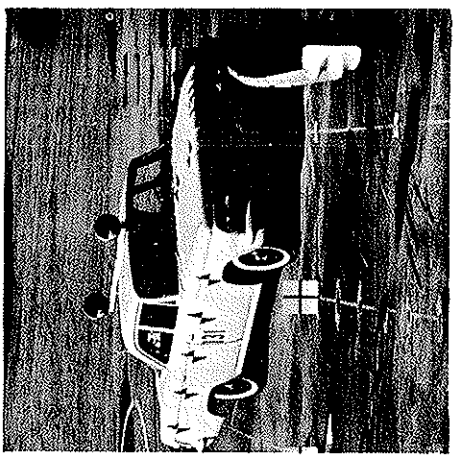
TEST NO.	131
DATE	11-30-65
VEHICLE	1964 Dodge Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4540 #
IMPACT SPEED	63 mph
IMPACT ANGLE	25°
EXIT ANGLE	22°
DUMMY RESTRAINT	Lap Belt

TEST 131 PLATE C

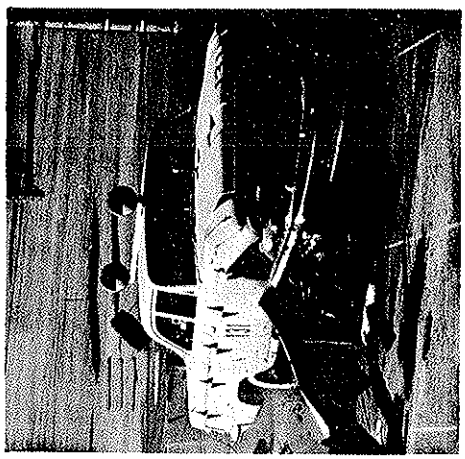


Impact + .032 Sec.

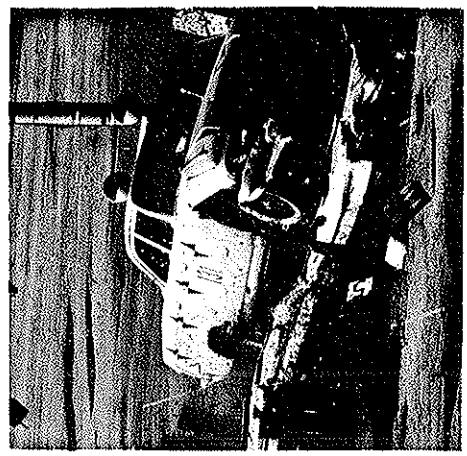
I + .150 Sec



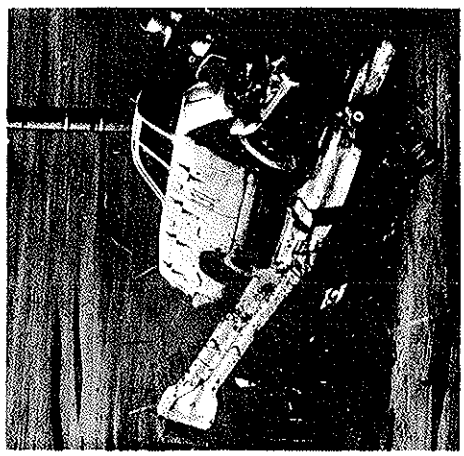
I + .250 Sec



I + .350 Sec.

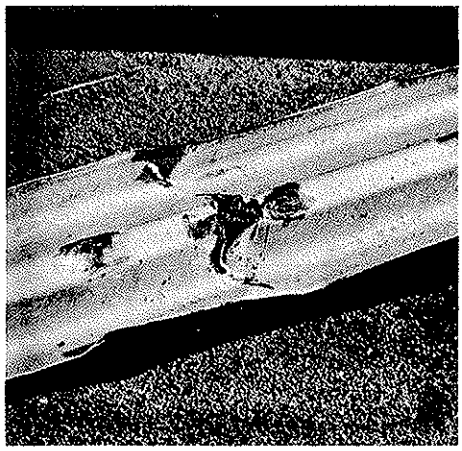


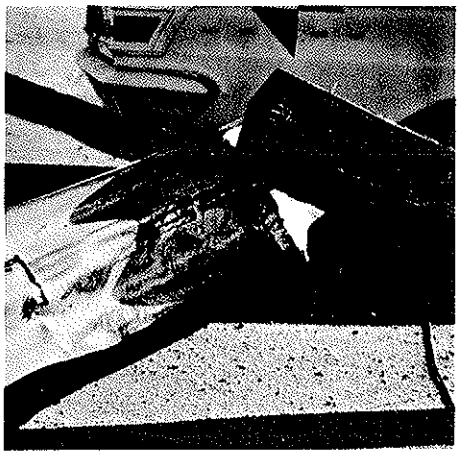
I + .550 Sec.



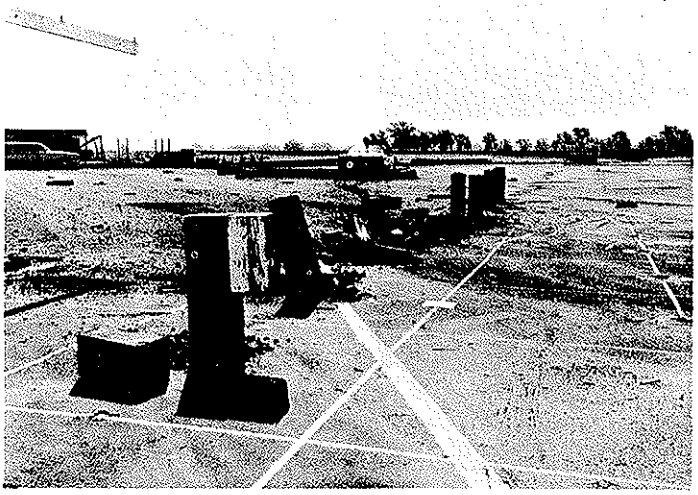
I + .650 Sec.

TEST 131 PLATE D





TEST 132 PLATE A



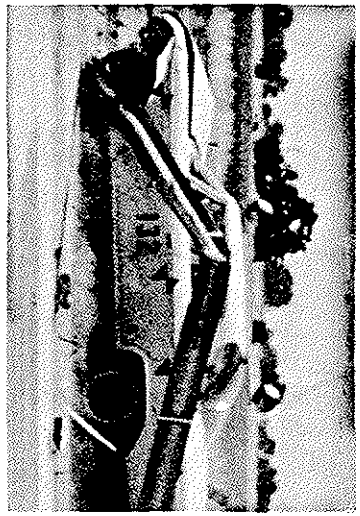
BARRIER: A 62-ft 6-in. unanchored installation of blocked-out metal beam guardrail with galvanized 12 gage (0.105-in.) steel corrugated beam mounted 27-in. high (top edge of beam to ground), blocked-out with 8- by 8- by 14-in. treated DF blocks (except as noted below), on 8- by 8-in. by 5-ft 4-in. treated 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.

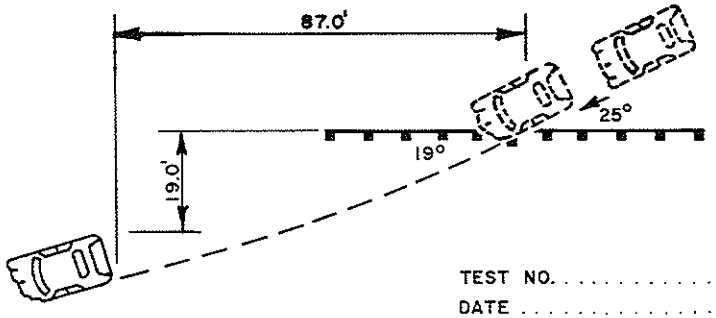


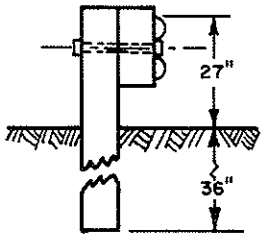
IMPACT + 2 M Sec

IMPACT + 167 M Sec

IMPACT + 446 M Sec

IMPACT + 908 M Sec



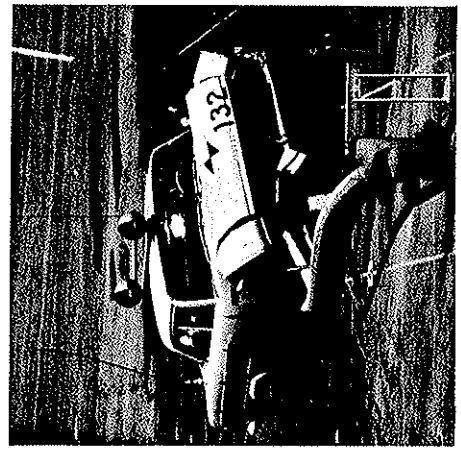


METAL BEAM GUARDRAIL

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

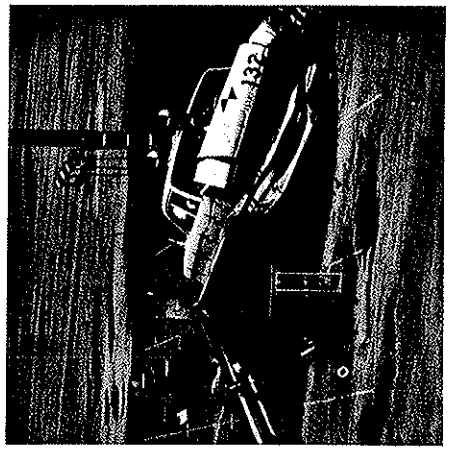
TEST 132 PLATE B



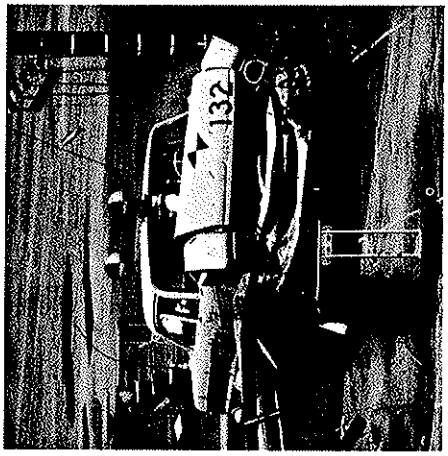
I + .200 Sec.

I + .100 Sec.

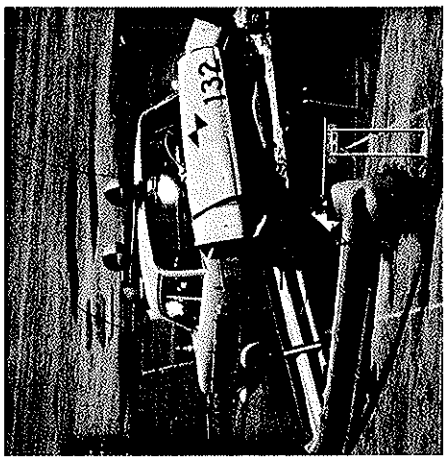
Impact + .042 Sec.



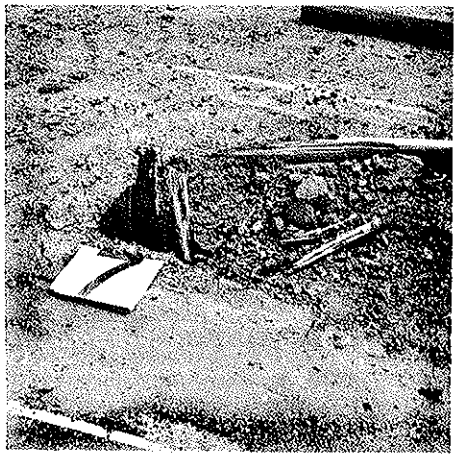
I + .600 Sec.



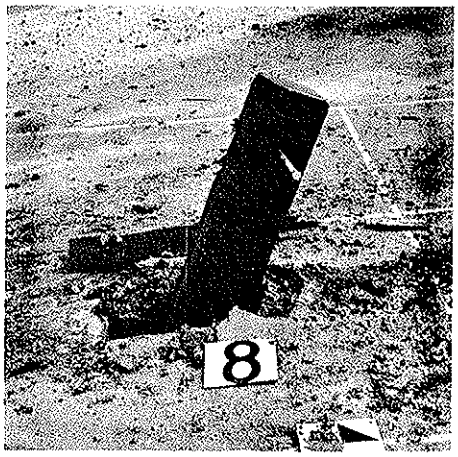
I + .400 Sec.



I + .300 Sec.


7


6


8


7


3


132
132