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Field, R.N. and R.H. Prysock

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16. ABSTRACT

In December of 1963, the U.S. Bureau of Public Roads requested that the California Division of Highways specify the use of aluminum as an alternate to steel on future beam guard rail contracts or provide justification for continuing to specify steel only.

The general policy of the California Division of Highways has been to specify the most appropriate material in critical applications where the different materials available affect the performance of a structure by their different physical characteristics. It was felt that the considerable difference in certain physical and mechanical characteristics of steel and aluminum raised substantial doubts as to their interchangeability as barrier member, even by substitution of a heavier gage of aluminum alloy for the 12 gage steel currently used.

A structurally safe guard railing or barrier is of primary importance to highway traffic safety, as evidenced by traffic accident studies and the comprehensive research California has maintained in this field for the past twelve years.

From past experience with full scale dynamic impact tests on metal beam railing and median barriers, it was found that pocketing during dynamic impact was the one major factor that spelled the difference between a successful guard railing and a failure (Ref. 1). For instance, under static loading tests the steel Tuthill (metal plate) guard railing exhibited the same joint strength as did the steel "W" section beam. However, under the dynamic loading of a controlled vehicle impact, the Tuthill rail pocketed excessively and failed. The effect this pocketing has on the success or failure in the performance of any specific rail material or design can only be determined by controlled dynamic tests or field performance.

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STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

DYNAMIC FULL SCALE IMPACT TESTS

OF

DOUBLE BLOCKED-OUT METAL BEAM BARRIERS

AND

METAL BEAM GUARD RAILING

SERIES X

A STUDY MADE BY THE
CALIFORNIA DIVISION OF HIGHWAYS
IN COOPERATION WITH THE
U.S. DEPT. OF COMMERCE
BUREAU OF PUBLIC ROADS

65-33
DND

State of California
Highway Transportation Agency
Department of Public Works
Division of Highways
Materials and Research Department

February 1965

Exp. Auth. 300149
Proj. W.O. 6337

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is a report of:

DYNAMIC FULL SCALE IMPACT TESTS

OF

DOUBLE BLOCKED-OUT METAL BEAM BARRIERS

AND

METAL BEAM GUARD RAILING

SERIES X

Study made by . . . . . Structural Materials Section
Under the direction of . . . . . E. F. Nordlin
Work supervised by . . . . . R. N. Field
Project engineer . . . . . M. H. Johnson
Photographic instrumentation . . . . . R. M. Souza
Report prepared by . . . . . R. N. Field and R. H. Prysock

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

RNF/RHP:mw
cc: LRGillis
ACEstep
JEWilson
CGBeer

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I. BACKGROUND AND INTRODUCTION

In December of 1963, the U. S. Bureau of Public Roads requested that the California Division of Highways specify the use of aluminum as an alternate to steel on future beam guard rail contracts or provide justification for continuing to specify steel only.

The general policy of the California Division of Highways has been to specify the most appropriate material in critical applications where the different materials available affect the performance of a structure by their different physical characteristics. It was felt that the considerable difference in certain physical and mechanical characteristics of steel and aluminum raised substantial doubts as to their interchangeability as barrier members, even by substitution of a heavier gage of aluminum alloy for the 12 gage steel currently used.

A structurally safe guard railing or barrier is of primary importance to highway traffic safety, as evidenced by traffic accident studies and the comprehensive research California has maintained in this field for the past twelve years.

From past experience with full scale dynamic impact tests on metal beam railing and median barriers, it was found that pocketing during dynamic impact was the one major factor that spelled the difference between a successful guard railing and a failure (Ref. 1). For instance, under static loading tests the steel Tuthill (metal plate) guard railing exhibited the same joint strength as did the steel "W" section beam. However, under the dynamic loading of a controlled vehicle impact, the Tuthill rail pocketed excessively and failed. The effect this pocketing has on the success or failure in the performance of any specific rail material or design can only be determined by controlled dynamic tests or field performance.

Therefore, in order to proof test and provide adequate data to prepare alternate specifications for aluminum alloy metal beam guard rail and median barrier railing, it was requested that a research project consisting of six full scale dynamic tests on aluminum and steel metal beam guard railing and median barriers be added to the 1963-64 Work Program HPR 1(1). Bureau approval was received in February 1964 and subsequent Headquarters W. O. 64-19U51H19 was issued to provide funds for conducting the six dynamic impact tests. In September 1964, after completion of five of the originally scheduled six tests, additional funds were requested and approved for a continuation of the research program.

This report presents test results from the resultant full series of nine full scale dynamic impact tests on steel and aluminum median barriers and guard rails and analysis of the dynamic data recovered during the tests. The angle of impact

in all of the tests was at 25 degrees from the line of the barrier or railing. The speed of the impacting vehicle was approximately 60 mph for the guard rail tests and approximately 68 mph for the median barrier tests.

The blocked-out type of semi-rigid barrier design used in this series of tests on aluminum and steel beams (Exhibit 1) is a result of tests conducted in 1958 and 1959 on a series of several designs (Ref. 1). Although the 1959 study revealed the double blocked-out design to be the most efficient in performing the design function, the test program did not include any high speed tests on the single blocked-out barrier or guard railing design to determine the effects of varying the design parameters.

Tests 101 through 104 (see Exhibits 2 and 3) were conducted on double blocked-out median barriers. The procedure consisted of first proof testing the current California standard design, using steel for the standard "W" beam and the channel rubbing rail to obtain a base for comparison of the other designs. This initial proof test was designated Test 101. The subsequent tests included modifications of the standard design of Test 101 as follows:

1. Test 102 - a 0.125 inch thick aluminum alloy (Alclad 2024-T3) "W" section beam with aluminum channel rubbing rail (6061-T6).
2. Test 103 - a 0.156 inch thick aluminum alloy "W" section beam with aluminum channel rubbing rail.
3. Test 104 - a formed 12 gage steel "hat" section as rubbing rail.

Tests 101, 102, and 103, which were constructed to the same geometric design, permitted comparisons to be made of 12 gage (0.105 inch thick) steel "W" beams vs. 0.125 inch thick aluminum, and 12 gage steel vs. 0.156 inch thick aluminum. Test 104 provided data to compare the difference in performance between the present steel channel rubbing rail and a steel roll-formed "hat" section proposed for use as an alternate rubbing rail (see Exhibit 4).

Test 106 (Exhibits 2 and 3) was conducted on the current single blocked-out metal beam median barrier design. This design is geometrically one-half of the standard double blocked-out median barrier design, the steel "W" beam and channel rubbing rail being mounted only on one side of timber posts at 6'-3" centers.

Tests 105, 107, 108, and 109 (Exhibits 2 and 3) were performed on blocked-out metal beam guard railing designs. The current California standard guard railing design was proof tested in Test 105 in order to obtain base data to compare with test data on other guard railing designs. This design consists

of a standard 12 gage galvanized steel "W" section beam mounted with the top 24 inches above the ground on timber posts spaced 12'-6" on centers. The remaining designs tested included the following modifications of this blocked-out guard railing design:

1. Test 107 - post spacing reduced to 6 ft. 3 in. and the beam height raised to 27 inches.

2. Test 108 - post spacing reduced to 6 ft. 3 in.

3. Test 109 - 0.156 inch thick aluminum alloy Alclad 2024-T3 "W" section beam on posts at 6 ft. 3 in. centers.

The performance comparisons for guard railing made possible by the above modifications include (1) steel vs. aluminum, (2) 6 ft. 3 in. vs. 12 ft. 6 in. post spacing, (3) beam height of 24 in. vs. 27 in. for post spacing of 6 ft. 3 in., and (4) a general comparison of the single blocked-out (30 in. beam height) median barrier design with guard railing designs (see Exhibit 2).

This work was accomplished in cooperation with the U. S. Bureau of Public Roads.

II. OBJECTIVE

The primary objectives of this test series were as follows:

1. To observe the effects of modifying the current blocked-out metal beam median barrier and guard railing designs by varying beam and rubbing rail materials, beam metal thickness, beam height above the ground, spacing between posts, and cross sectional design of the rubbing rail.

2. To determine effective and economical modifications (beam height and post spacing) to make the present standard blocked-out guard railing design a more positive barrier when required. Test results would be used as a basis for design changes on future installations.

A secondary objective of this study was:

To determine the effectiveness of the current California standard blocked-out metal beam median barrier and guard railing in slowing and redirecting vehicles impacting at medium-high to high speeds.

III. CONCLUSIONS

The following conclusions are based on an analysis of the results of the nine impact tests conducted during this series:

MEDIAN BARRIER

1. The results of Tests 101 and 104 proved conclusively that the double blocked-out steel metal beam median barrier with standard "W" beams mounted at an over-all height of 30 inches above the ground and with steel channel lower rubbing rails on timber posts at 6'-3" centers as originally designed in 1958 is effective and efficient in redirecting a vehicle impacting at high speed (68 mph).

2. The single blocked-out steel metal beam median barrier (Test 106) with a standard "W" beam mounted at an over-all height of 30 inches above the ground and with a steel channel lower rubbing rail on timber posts at 6'-3" centers proved to be equally effective in redirecting a vehicle impacting at a medium high speed (60 mph). However, the severity of damage sustained by the single beam barrier as compared to the double was understandably greater.

3. Aluminum alloy 2024-T3 in 0.125 in. thickness is unacceptable (Test 102) and in 0.156 in. thickness is questionable (Test 103) as a substitute for 12 gage (0.105 in. thick) galvanized steel in the "W" section beams of double blocked-out median barriers. Although the 0.156 in. thick aluminum beams of Test 103 did not fail, no definite conclusions regarding the extent of aluminum performance or reliability can be made from the results of this one test based on the manner and time sequence of failure of the 0.156 in. thick blocked-out single aluminum beam in metal beam guard railing Test 109. For this same reason, aluminum alloy 2024-T3 in 0.156 in. thickness is considered unacceptable as a substitute for steel in the "W" section beam of the single blocked-out median barrier.

4. The 12 gage galvanized steel roll-formed "hat" section rubbing rail used in Test 104 did not perform as well as the structural steel or extruded 6061-T6 aluminum channel sections of Tests 101 and 103. The loss of section modulus and beam strength of the "hat" section due to collapse of the section permitted critical pocketing at the first post after impact, a condition that usually leads to wheel entrapment by the posts.

GUARD RAILING

1. The 24 inch over-all height above the ground of the blocked-out beam in the present California standard metal beam

guard railing design is too low when supported on timber posts at 12 ft. 6 in. centers. Long spans decrease the lateral and torsional stability of the beam and increase the tendency of the impacted beam to rotate or lay back about its own axis permitting the impacting vehicle to vault over as in Test 105.

2. Blocked-out guard railing beams mounted at an over-all height of 24 in. and supported at 6 ft. 3 in. post spacing may perform satisfactorily, as indicated by Test 108. However, a review of bumper characteristics of many late model passenger vehicles revealed that under certain conditions it is possible that an impact could occur above the centerline of a 24 inch high beam (see Exhibit 5), resulting in a high speed vehicle vaulting or rolling over the railing.

3. A beam height of 27 inches above the ground with a post spacing of 6 ft. 3 in. (Test 107) appears to be the optimum for blocked-out guard railing without a lower rubbing rail. Guard railing beams should be blocked out at least 8 in. from the posts.

4. Barrier or guard railing installations with metal beams mounted at heights of more than 27 inches, even though blocked-out, require a bottom rubbing rail to prevent wheel entrapment at the posts.

5. The results of Test 109 indicate that 0.156 in. thick Alclad 2024-T3 aluminum alloy is entirely unacceptable as an alternate for 12 gage galvanized steel in blocked-out "W" section beams used in metal beam guard railing installations, including the single blocked-out metal beam median barrier. The greater flexibility of the metal beam guard railing with single blocked-out beam (even at 6 ft. 3 in. post spacing) as compared to the double blocked-out median barriers under dynamic loading, permits deflections at rates and magnitudes incompatible with the mechanical properties of Alclad 2024-T3 aluminum alloy.

IV. RECOMMENDATIONS

A. Median Barrier

1. It is recommended that no changes be made in either the current design or materials for the double and single blocked-out median barrier. Operational studies have been substantiated by the findings of this test series; that the current blocked-out design is not only effective in preventing cross-overs but efficient from a maintenance standpoint.

2. Alclad 2024-T3 aluminum alloy in 0.125 in. thickness should not be used as an alternate for galvanized steel in standard "W" section beams used in single or double blocked-out median barrier designs.

3. Alclad 2024-T3 aluminum alloy in 0.156 in. thickness should not be used in the standard "W" section beam of the single blocked-out median barrier and should be tested further before use in the double blocked-out median barrier.

4. A 6 [3.0 aluminum alloy 6061-T6 rail may be substituted for the 6 [8.2 galvanized structural steel lower rubbing rail on the single or double blocked-out median barrier (Test 103).

B. Guard Railing

1. All guard railing beams should be blocked out at least 8 inches from the posts as currently specified.

2. Post spacing should not exceed 6 ft. 3 in. where guard action rather than guide functions are required.

3. Normally, the over-all height of the blocked-out beam on future metal beam guard railing installations should not be more than 27 inches and preferably not less than 26 inches above the ground. When it is necessary to place the beam height at more than 27 inches, a bottom channel rubbing rail should be used.

4. Post embedment should not be less than 36 inches on flat ground (10:1 slope and less). This would necessitate an increase of 3 inches over the present 60 inch guard rail post. Special consideration should be given to post embedment depth when placement is within 1 foot of a 2:1 or steeper fill slope or where soil conditions dictate the use of longer posts.

5. The most practical and economical method of modifying present guard railing installations located in problem areas would be to install additional posts to bring the railing up to the forementioned proposed standard of 6 ft. 3 in. post spacing. If the existing beam is not blocked-out, this should be done, simultaneously.

6. In more hazardous locations it is strongly recommended that in addition to placing posts at 6 ft. 3 in. centers the over-all beam height be increased from 24 to 27 in. above the ground. If extra long posts (standard 72 in.) long median barrier posts) were used for the additional reinforcement, it is felt that the existing posts could be jacked up 3 inches from their original position without any appreciable loss of stability to the system.

7. Where positive barrier action is required, it is recommended that the single blocked-out metal beam median barrier design with "W" beam at an over-all height of 30 in. above the ground and channel rubbing rail supported on posts 6 ft. 3 in. on centers be used as a guard railing.

8. Alclad 2024-T3 aluminum alloy in 0.156 in. thickness or less should not be used as an alternate for galvanized steel "W" section beams used in guard railing designs.

V. DISCUSSION

A. BEAM HEIGHT

The results of this series of tests confirmed the importance of those design parameters tested in obtaining adequate designs for median barriers and guard railing. The height of the beam above ground, however, appeared to be one of the more significant variables contributing to the effectiveness of the barrier system. This parameter was not varied for the double blocked-out median barriers, a decision based on previous tests (Ref. 1) and satisfactory operational experience (Ref. 2). Tests 101, 103, and 104 supported the decision and indicated the beam height of 30 in. above the ground to be at, or near, optimum for the particular geometric design with rubbing rail currently used for the single or double blocked-out metal beam median barrier.

The beam height was varied from 24 in. to 27 in. above the ground in the blocked-out guard railing test installations. Test 105 revealed the current California standard guard railing design to be ineffective and unreliable in redirecting modern vehicles traveling at high speeds and impacting at an angle of 25 degrees. The low beam height (24 in.) of the guard railing in Test 105 contributed materially in allowing the vehicle to mount and vault the installation. During the first few moments of impact, the beam deflected a small amount horizontally, rotating with the barrier as a whole as it was deflected. However, almost immediately after impact the deflecting barrier system reached a point, where, due to the beam angle and location of impact forces (front bumper) the beam rotated about its own axis and was laid back to a ramp position. As the front wheel of the vehicle retracted upward into the wheel well, it mounted the beam quite easily and smoothly (see Figure 1 below).

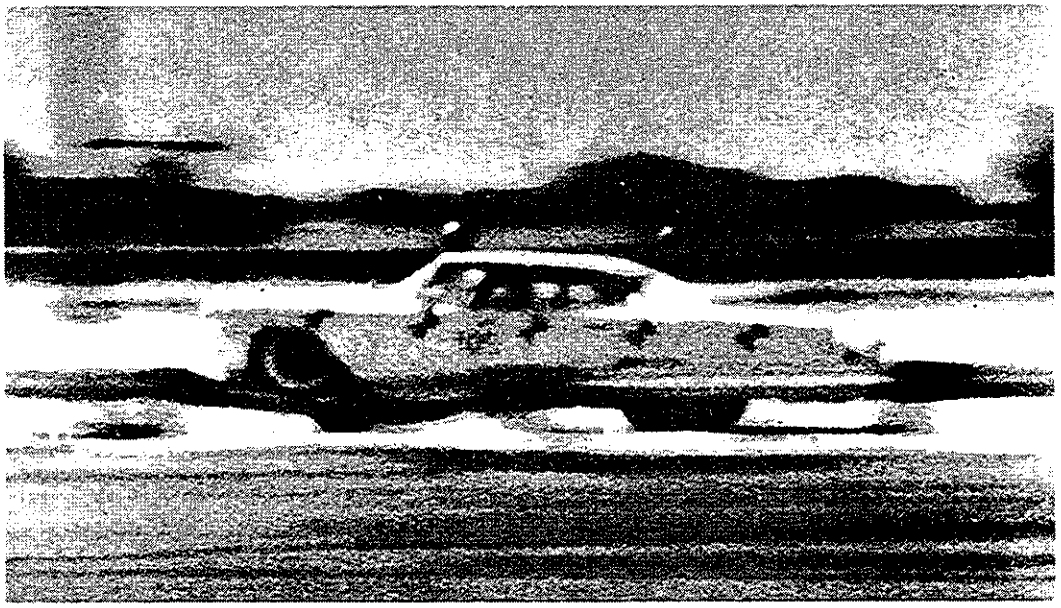


Figure 1

This same 24 inch beam height was retained for Test 108; however, the post spacing was halved to 6 ft. 3 in. The vehicle was successfully redirected because the shorter span increased the lateral and torsional stability of the beam.

Raising the beam height to 27 in. and retaining the 6 ft. 3 in. post spacing for Test 107 produced results very similar to those of Test 108 but there was less pocketing.

The deflection patterns appear to be fairly well defined for beams of different heights. Beams at a height of 30 in. (Tests 101, 103, 104, and 106) deflected laterally and upward (see Exhibit 3).

Upward deflections were the result of the "riding under" tendency of the vehicles. A slight roll to the right or outward from impact was transmitted to each of the vehicles in Tests 101 and 104, and no perceptible roll was transmitted to the vehicles in Tests 103 and 106. The roll was held to a minimum value as the beam provided a restraining force to the upward movement of the left side of the vehicle (see Exhibits 3 and 6).

Although single guard railing beams mounted at lower heights (24 in. to 27 in.) and adequately supported at 6 ft. 3 in. centers did not exhibit as much upward deflection, the lateral deformation was approximately the same as for Tests 101, 103, and 104. It is apparent, however, that the single beams of Tests 107 and 108 would have exhibited deflections larger than those of the double beams of Tests 101, 103, and 104 were they subjected to the higher speed impacts of the latter. Beams at a lower height (24 in. to 27 in.) showed a slight rotation outwardly on their longitudinal axis due to a combination of the deflection behavior of the barrier system and the outward roll of the vehicle. These small outward rotations were not evidenced in the beams mounted at a 30 inch height where the larger upward deflections prevented vehicular roll.

The extent of pocketing in proportion to the vehicle speed, evident at lower beam heights, can also be interrelated to the larger exit angles (see Exhibit 3).

B. RUBBING RAIL

A moderate amount of post damage caused by entrapment was evident in the guard railing tested in Test 107, which indicated 27 in. to be the maximum beam height that could be used without a rubbing rail. The rubbing rail was found to be a major component in installations with beam heights exceeding 27 inches. In Tests 101, 104, and 106 the bottom rubbing rails sustained considerable damage and materially aided the beams in redirecting the vehicles. Although this function is secondary to that of preventing post entrapment,

it contributes considerably to the efficiency of blocked-out barrier performance. Although there was no failure in the "hat" section bottom rail used in Test 104, it exhibited a performance that was inferior to that of the structural steel and extruded aluminum channel sections. The section modulus of the "hat" section was lost entirely in the impact zone when the section was flattened by the vehicle (see Figure 2 below). Static loading tests on this member showed the same lack of ability to support a bending load (see Exhibit 7). The resultant pocketing at the post effected a condition more conducive to wheel entrapment than was experienced in Tests 101 or 103 where steel and aluminum channels were used.

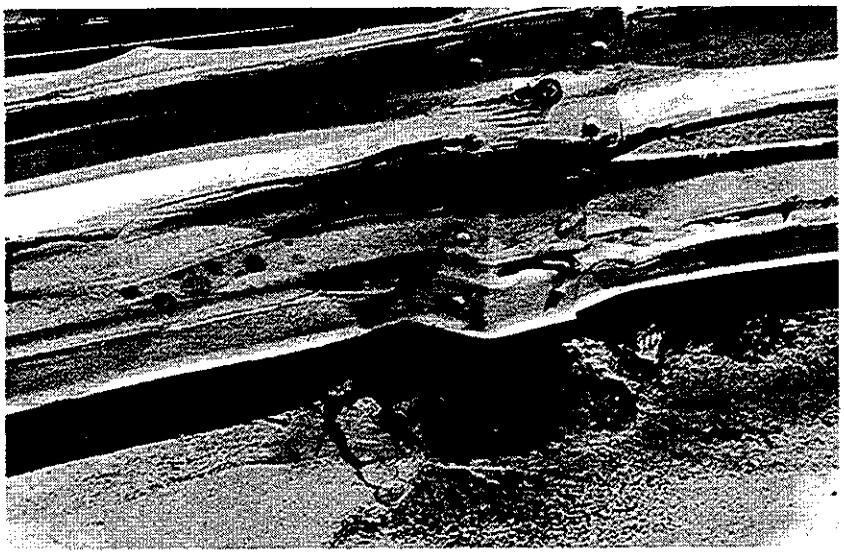


Figure 2

C. BUMPER HEIGHT VS. BEAM HEIGHT

Analysis of the results of Test 105 showed that the vaulting problem on the blocked-out metal beam guard railing was compounded by the front bumper geometrics of the 1962 Chrysler test vehicle (see Figure 3 on the following page).

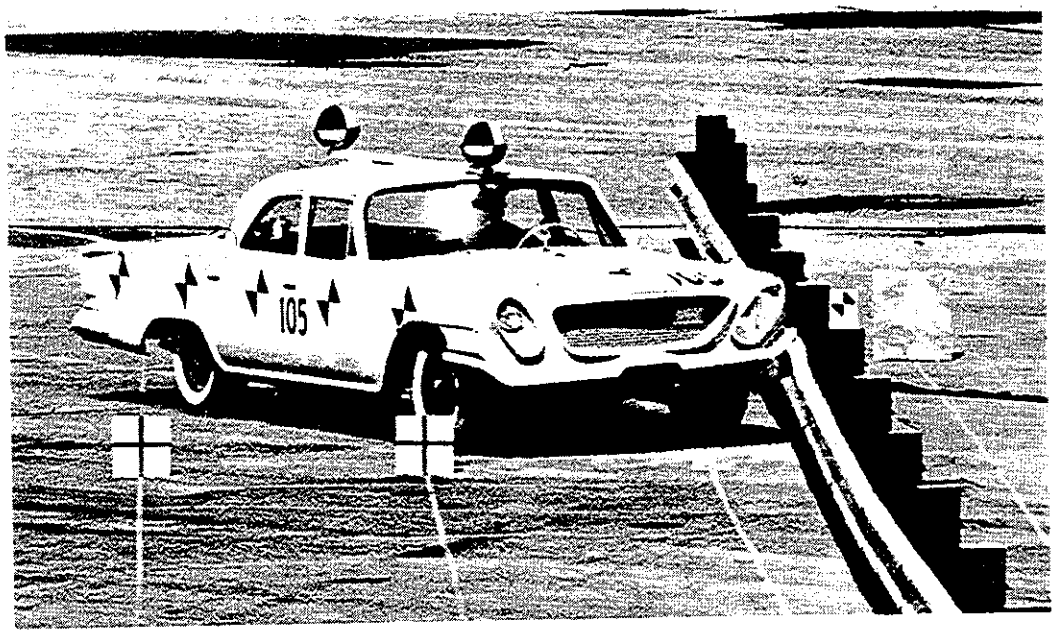


Figure 3

Further investigation of bumper geometrics revealed that a majority of the Detroit manufactured vehicles for the years 1962-65 were equipped with bumpers having characteristics similar to those of the 1962 Chrysler test vehicle. It is possible that this feature of the newer vehicles has contributed to the high incidence of guard rail vaulting reported by the Traffic Department. It may be noted in Exhibit 5 that the bumpers of the newest automobiles from the four leading manufacturers would strike a 24 inch high guard rail above the center of rotation of the beam. This point of impact, in conjunction with the curved, sloped-back design of the bumper, increases the possibility of vaulting. For this reason it is recommended that all future beam type median barriers or guard railings be designed with an over-all height of at least 26 inches above the ground.

D. POST SPACING

The importance of compatibility between beam height and post spacing can be amply demonstrated by comparing Tests 105 and 108. Although three of the posts at close spacing (6 ft. 3 in.) 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 at 12 ft. 6 in., the vehicle readily vaulted the barrier.

Therefore post spacing, as well as beam height, should be considered a major factor affecting barrier performance. The obvious functions of posts within a barrier installation are to transmit forces of impact to the foundation soil and to hold the beam in the designed position. However, in order to function properly, the posts must also lend stability to the beam to allow development of beaming strength.

E. EFFECTIVENESS OF BLOCKED-OUT BARRIERS IN PREVENTING ROLL

The relative effectiveness of the blocked-out barrier or guard railing design in preventing excessive roll of the vehicles may be seen by comparing two tests conducted in 1958 (see Exhibits 8 and 9). During contact with any beam-type barrier, an impacting vehicle attains a roll approximately equal to the angle between the vertical and the plane containing the beam and the post at ground level. Blocking out aids in reducing the angle by maintaining the beam some distance away from the deflected post. For cases in which the lateral post deflections are not excessive, the plane containing the blocked-out beam and the post at ground level is very nearly vertical. The height of the blocked-out beam is maintained or increased slightly during post rotation, as shown below in Figure 4. The effect of the blocking-out is to minimize vehicle roll by providing restraining forces above the center of gravity of the vehicle. In contrast, the height of the non-blocked-out beam immediately decreases during post rotation thereby decreasing the effectiveness of the barrier's restraining forces.

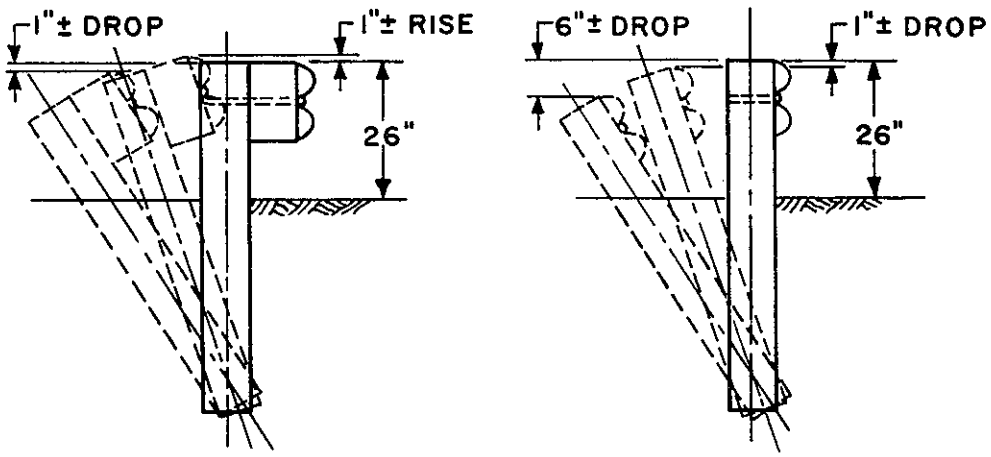


Figure 4

F. BEAM MATERIAL

Satisfactory performance of a barrier may be expected only when materials of sufficient strength are used in conjunction with a proven geometric design. This point was amplified by Tests 101 through 109 in general, and Tests 102, 103, 105, and 109 in particular. Of the three barrier failures in the series, the aluminum beams of Tests 102 and 109 exhibited numerous individual failures through the impact zone. In both tests, failures resulted from longitudinal tensile and bending stresses, or combinations of both, in excess of those capable of being resisted by the beams (see Exhibit 10). The 0.156 in. thick aluminum beam performed satisfactorily in Test 103. Being of thicker material than that used for Test 102 (0.156 in. vs. 0.125 in.), the strength in tension was sufficient to resist the longitudinal forces, thereby allowing the development of a beaming strength adequate for the corresponding deflection. This was not true in Test 109, although the aluminum beam was of the same thickness as that of Test 103. However, in Test 109 a single "W" beam was used whereas in Test 103 double "W" beams as well as rubbing rails were employed. It is therefore concluded that the greater stiffness of the double-beam barrier contributed significantly to the performance by minimizing the magnitudes of the deflections.

Aluminum beam failures generally occurred at posts, either through reduced sections at splice holes or at points of high stress concentration induced by severe bending deformation. Some failures were observed to occur near midspan and are believed to have been initiated by the same type of high stress concentration. These bending stresses, present with large beam deflections, cause local buckling of the top and bottom elements of the beam section. The buckled areas, appearing as ripples along the tops of the beam, are more apparent in steel sections although they do not cause tears as in the aluminum (see Plate 104-D). Failures of aluminum beams, other than those through a reduced section, were observed to begin near the center of a beam cross-section where the bending stresses were the greatest and progress transversely across the beam. 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 Exhibits 7 and 11).

An objectionable characteristic of the aluminum beam is its unpredictable behavior during loading imposed by an impacting vehicle. This characteristic was illustrated by Test 109 where the vehicle, while being redirected in the usual manner, was suddenly ejected from the barrier in an erratic and undesirable trajectory as the beam failed.

Due to the unpredictable manner of load application by the various vehicle components, a beam must be capable of withstanding large localized deformations. Steel beams exhibited

such capability and performed very satisfactorily with no failures that affected the function of the barrier (see Figures 5, 6, and 7 below).

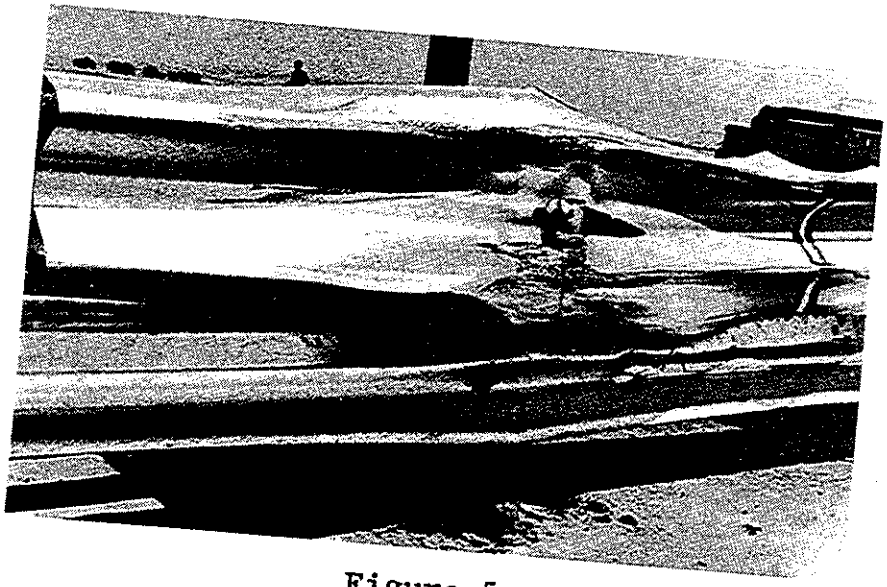


Figure 5

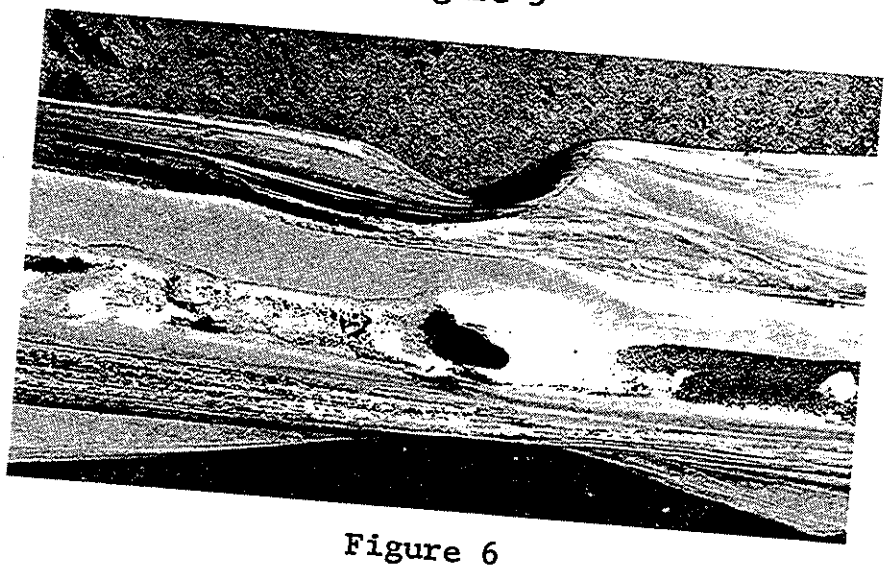


Figure 6

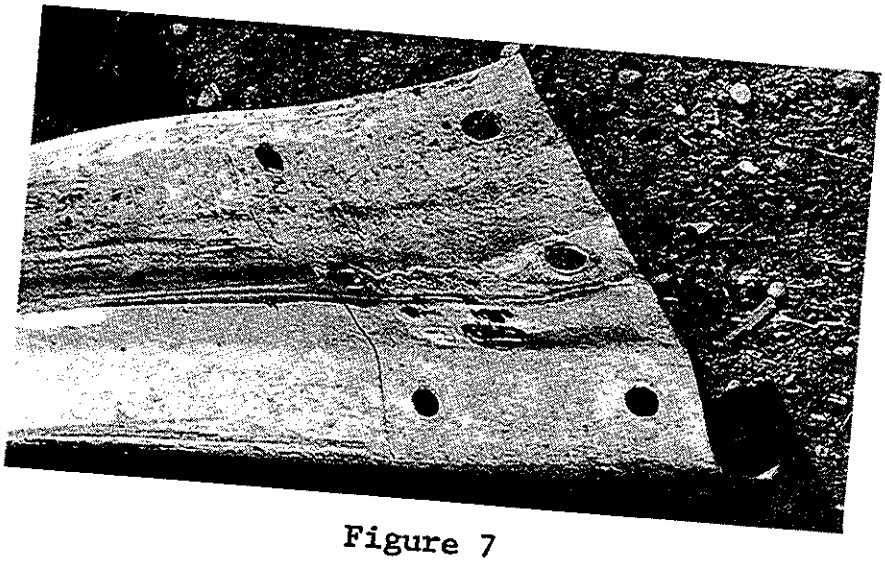


Figure 7

Compare the examples (page 15) of deformed steel beams that were successful in redirecting the vehicle with the examples of aluminum failures shown in Exhibit 10.

G. ENERGY DISSIPATION

The behavior pattern of any semi-rigid type barrier subjected to vehicle impact must include deflections if the barrier is to transmit lower deceleration values and smoother low angle exit trajectories to impacting vehicles than a rigid type barrier. At the instant of impact, the vehicle has a certain amount of kinetic energy which may be resolved into components parallel and perpendicular to the barrier. In order that the vehicle may be redirected effectively, the energy component perpendicular to the barrier must be reduced or dissipated. The energy dissipation is accomplished through bending distortion and crushing of various parts of the vehicle and the barrier, including the foundation soil. A positive redirected trajectory is imparted to 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 type of barrier in this series is referred to as a "beam barrier", the beam itself must be capable of withstanding high axial tensile 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 rail should be developed (Refs. 3 and 4) while others claim by definition that axial tensile stresses may be considered to be negligible (Ref. 5). It is believed that more light should be brought to bear upon this aspect since Tests 102 and 109 illustrate effects that may be expected when the imposed tensile stresses cannot be resisted by the beam.

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 impact area 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, 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. In most instances, some movement still occurs resulting in bending of the bolts. This bending of the bolts results in 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 shearing action of the bolts extended the slot length in the steel beam rail by approximately five inches (see Figure 8 below). However, these severe reactions were limited to the impact zone, where larger strains in the beams were evident.

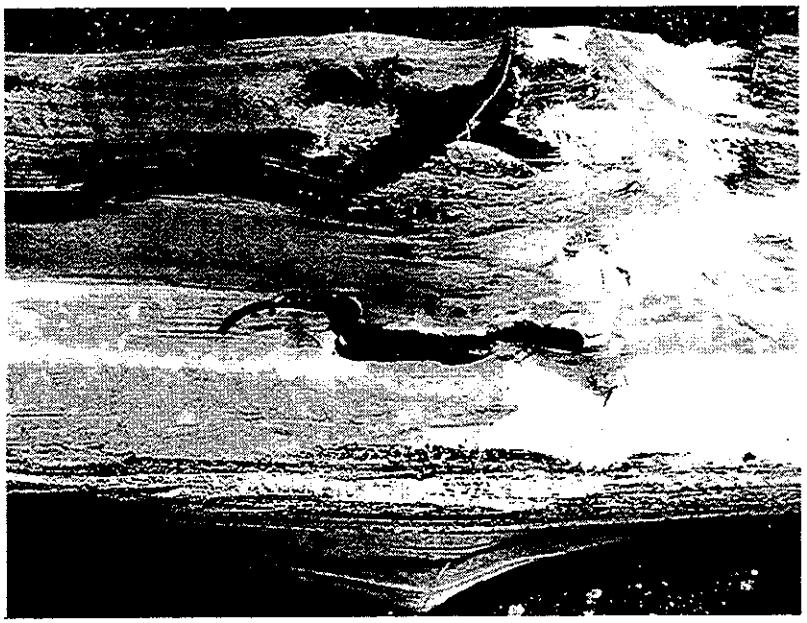


Figure 8

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 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 guard rail installations is fairly common for Douglas fir posts, but unusual for the older installations where redwood posts were used.

The above discussion on barrier behavior refers mainly to guard rail installations since the added stiffness

of the double blocked-out median barriers tends to contain and restrict severe damage and deformation of barrier components to the immediate impact zone.

2. Post-Soil Reactions:

Reviews of test data film and inspection of the installations after impact indicate that posts are also 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 exceeded final deflections by as much as 50 percent for double blocked-out metal beam median barriers and 150 percent for guard railing. In transmitting the forces to the soil at the test site, a clayey, silty sand, the posts deflected horizontally 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 they appeared to be very near the bottom of the post, which is in agreement with previous findings (Ref. 6) for rigid posts (see Figure 9 below).

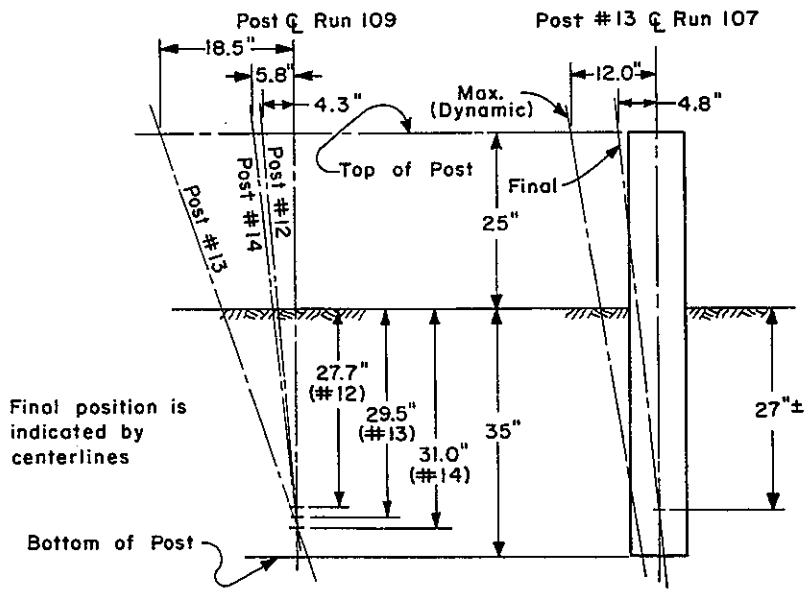


Figure 9

Since the installation was constructed on an airport runway with no imported base material, the two-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 two 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 the limits of shear failure within the soil at the ground surface.

Figure 10 shows soil heave after one of the latter tests. The adjacent asphalt had been removed during recompaction from the previous tests.

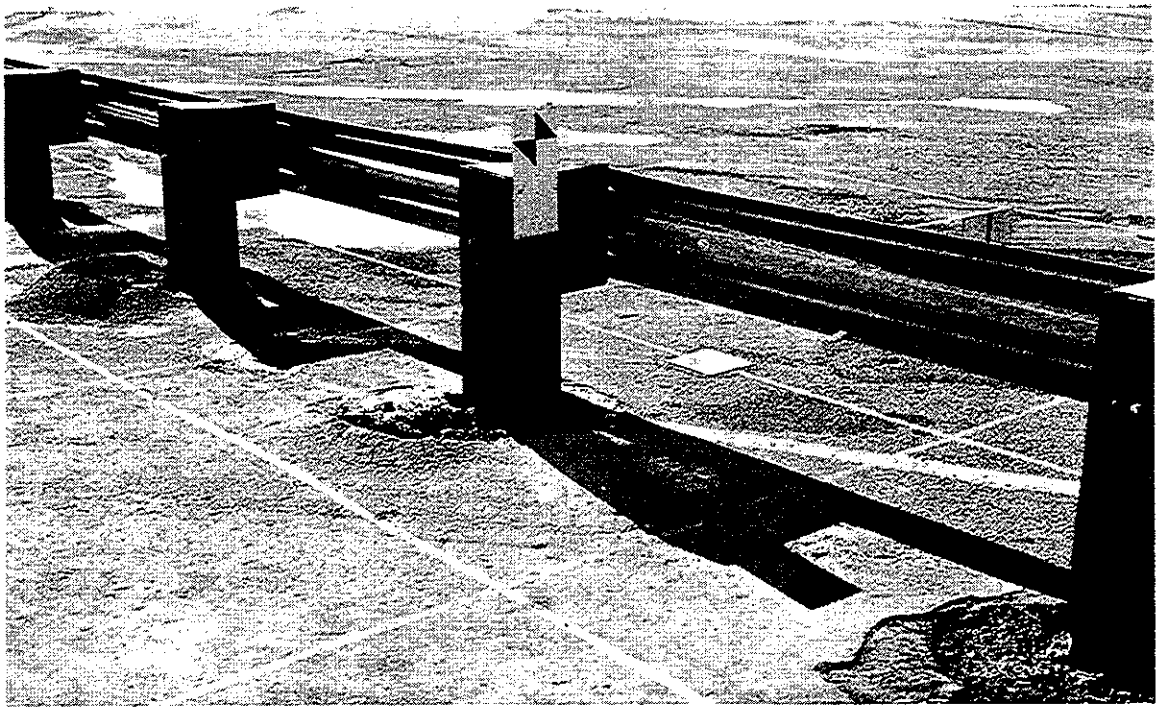


Figure 10

I. OPERATIONAL EXPERIENCE

1. Field Observations:

The blocked-out beam barrier concept has been supported consistently by satisfactory performances of single and double blocked-out metal 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 11 and 12 below.

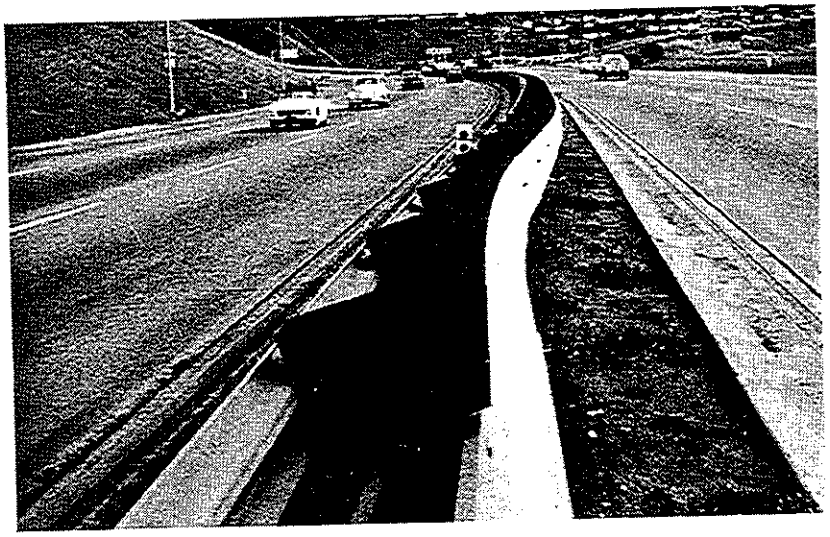


Figure 11

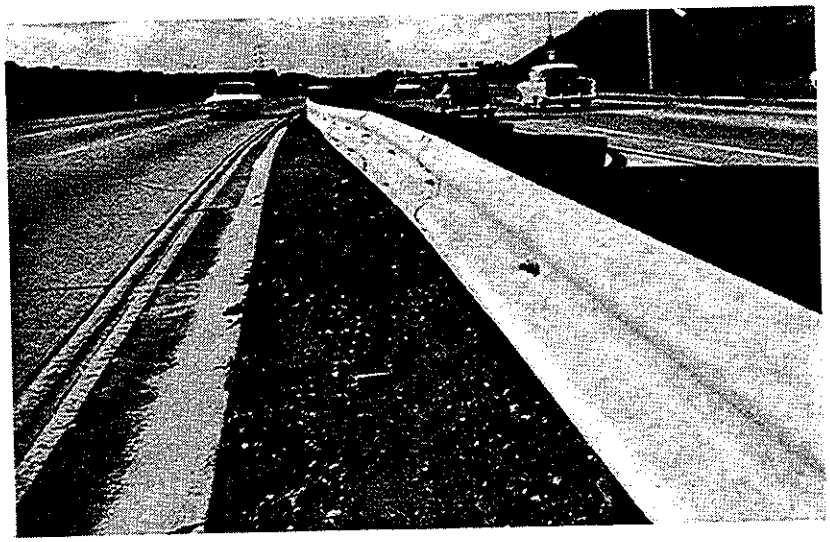


Figure 12

The operational success of the current blocked-out guard railing (at 12 ft. 6 in. post spacing) has not equalled that of the double blocked-out median barrier. However, Test 108 shows that the basic single blocked-out design is effective in redirecting vehicles providing compatible design dimensions such as 6 ft. 3 in. post spacing and 24 in. (preferably 26 to 27 in.) over-all beam height are used.

Observations of damaged short sections of single blocked-out guard rail with posts at 12 ft. 6 in. centers used as obstruction deflectors for sign posts and bridge columns revealed marginal performances by the railings, as illustrated on next page in Figures 13 and 14.

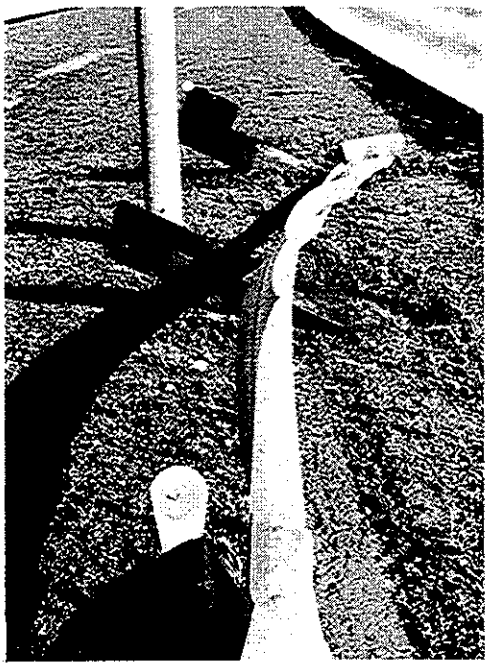


Figure 13

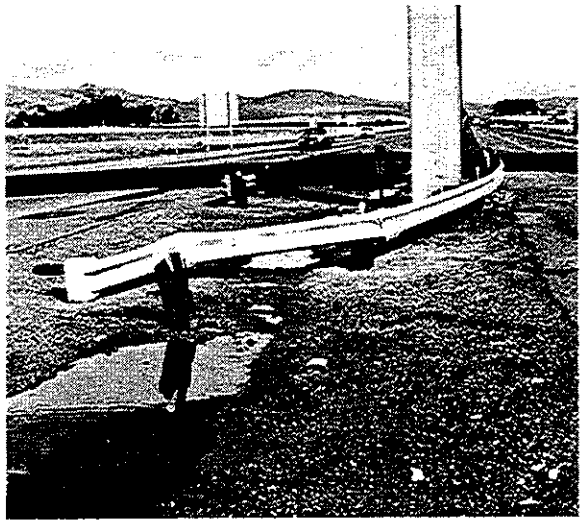


Figure 14

In many instances the barriers were struck near end posts which were knocked flat or dislodged from the beams. This condition results in little or no development of beam action. Occasionally, the free end of the beam is bent in such a manner that it protrudes over a portion of a traffic lane. The hazard must then be removed with the use of a cutting torch (see Figures 15 and 16 below).

Figure 15

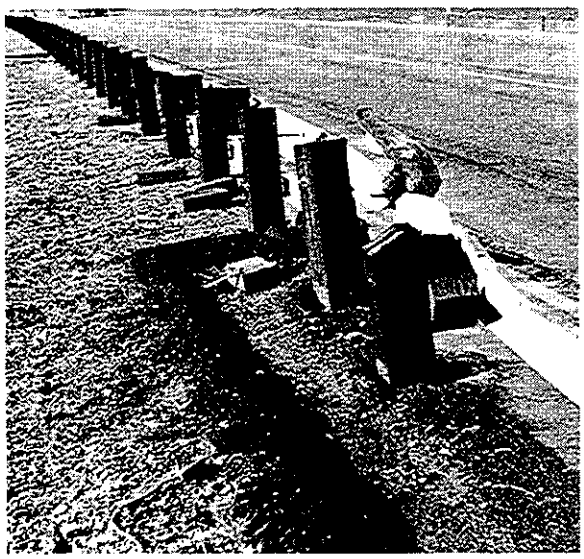


Figure 16

Large lateral post deflections and deformations of the foundation soil around the posts were observed (see Figures 17 and 18).

Figure 17

Figure 18

It was noted that when these deflector guard rail installations were struck near the midpoints, they tended to deflect laterally as a unit with the beams remaining relatively straight. This may be partially due to poorly compacted or saturated soils but would be eased in any event by closer post spacing.

2. General Remarks:

The modifications pertaining to blocked-out guard rail design recommended in this report should result in increased effectiveness of field guard rail installations.

Certain design factors appear to be more significant in short deflector guard rails than in the longer median or guard rail installations. For instance, in short installations the posts must withstand greater loads than those of longer installations which permit some transfer of load to posts at appreciable distances in both directions from the impact point. The tendency of the short barrier to deflect laterally as a unit (Figures 17 and 18) indicates that the resistance of the post-soil system is less than the resistance of the beam to large permanent bending deflections. Improvement of soil resistance may be obtained from better

compaction of backfill around the posts. In field installations, holes at deflected posts were sometimes observed to be lacking a sufficient amount of compacted backfill material. Since the original drilled hole could be distinguished, it was presumed that the backfill material was easily dislocated by the shock of impact (see Figures 19 and 20 below).

Figure 19

Figure 20

Extremely wet weather conditions tend to reduce the strength of the soil surrounding the post. This operational deficiency was also noted on installations of double blocked-out median barrier struck after an extensive wet spell (see Figures 21 and 22).

Figure 21

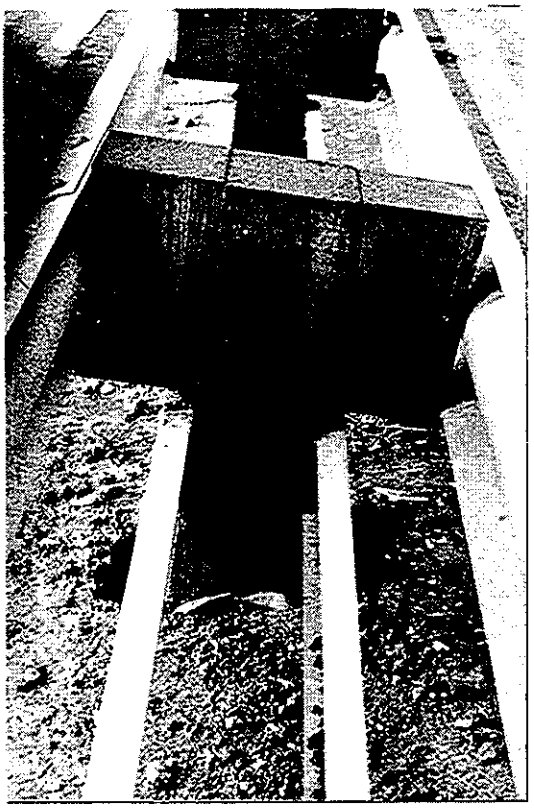


Figure 22

VI. BARRIER TESTS

The following section includes nine groups of plates covering all pertinent data and photographs of the nine impact tests. Each group covers the following:

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

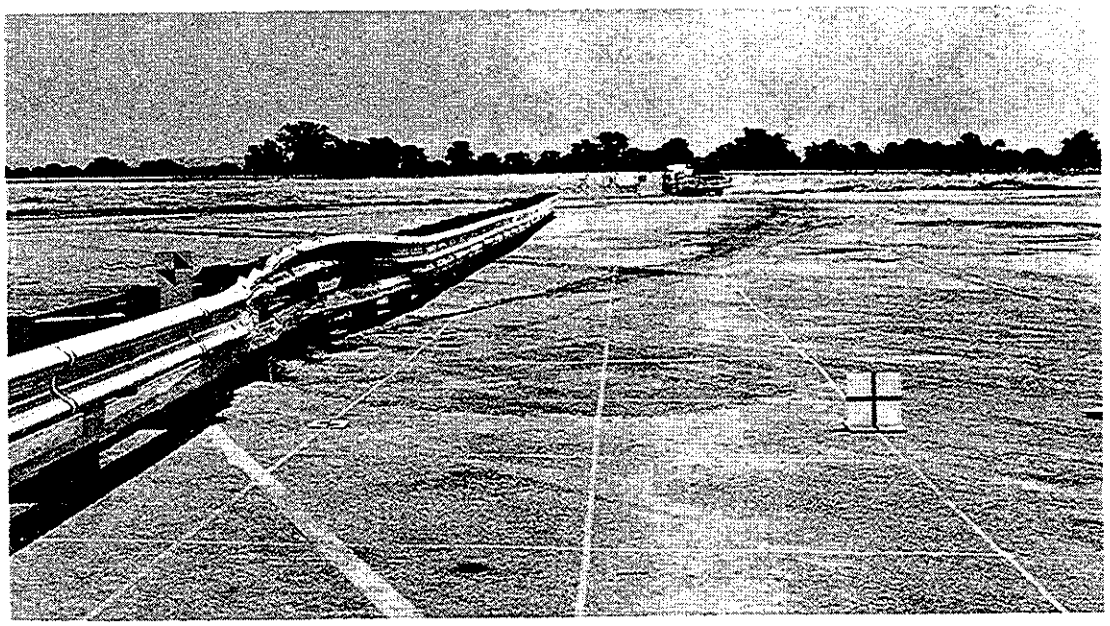
B. A data sheet showing overhead camera views of vehicle through impact and a tabulation of test parameters.

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

D. Detailed photographs of barrier and vehicle damage.

E. Detailed photographs of vehicle damage.

TEST 101 PLATE A



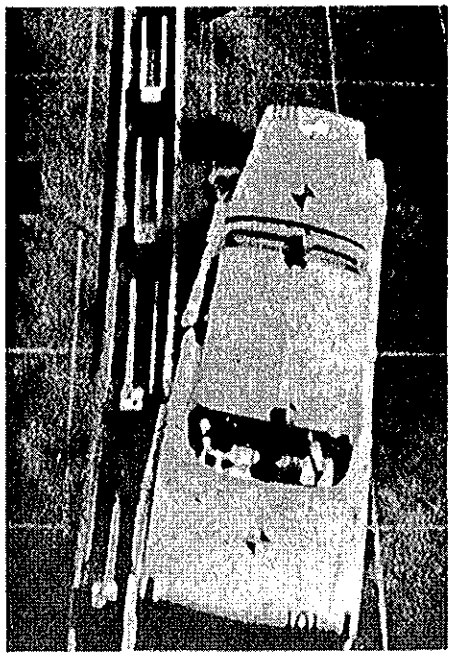
BARRIER: Double blocked-out metal beam median barrier with standard 12 gage (0.105 inch) galvanized steel "W" section beam and 6 [8.2 galvanized steel bottom rubbing rail.

PURPOSE: To proof test the current California standard double blocked-out metal beam median barrier design and serve as a gage of the effectiveness of the aluminum alloy beam and rail components used in Tests 102 and 103 of this series. This test was used also as a base to evaluate the performance of the "hat" section bottom rubbing rail used in Test 104.

PERFORMANCE: The vehicle struck the barrier between posts and remained in contact with the barrier for approximately 18 feet before being redirected to an angle of 15 degrees with the barrier and to a maximum rebound of 23.5 feet. The vehicle traveled 215 feet before crossing the barrier centerline. There was no tendency for the vehicle to jump. A maximum roll of 5 degrees to the right was imparted to the vehicle.

BARRIER DAMAGE: Two 12 ft. 6 in. sections of "W" section beam and two 12 ft. 6 in. sections of bottom rubbing rail on the impact side were damaged, as were one 12 ft. 6 in. section of the beam and one 12 ft. 6 in. section of the bottom rubbing rail on the side opposite impact. Four posts were knocked out of alignment and two block-out blocks were crushed.

VEHICLE DAMAGE: The vehicle was a total loss.



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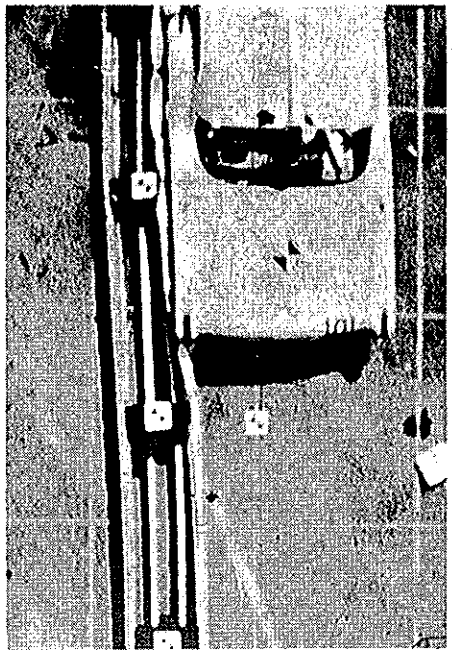

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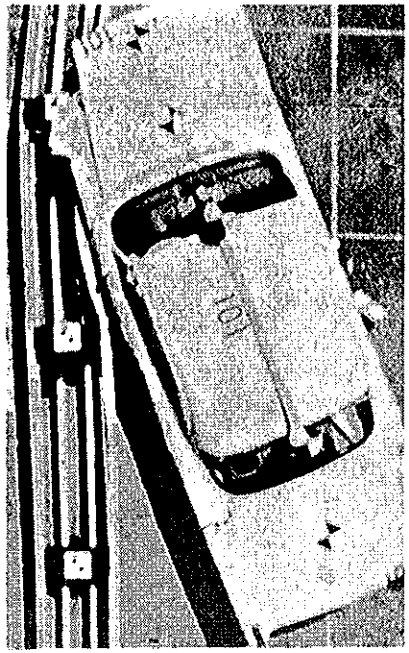

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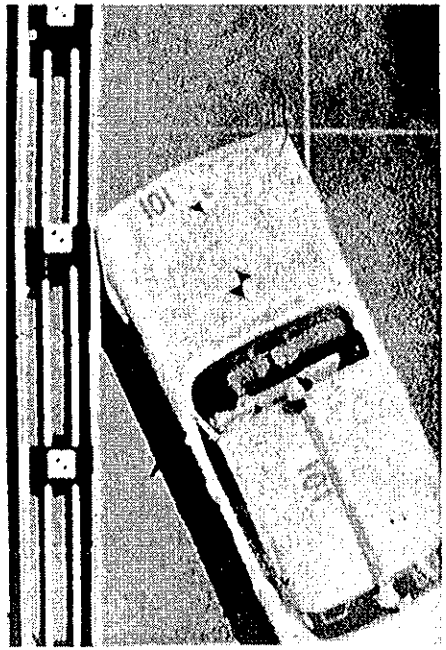
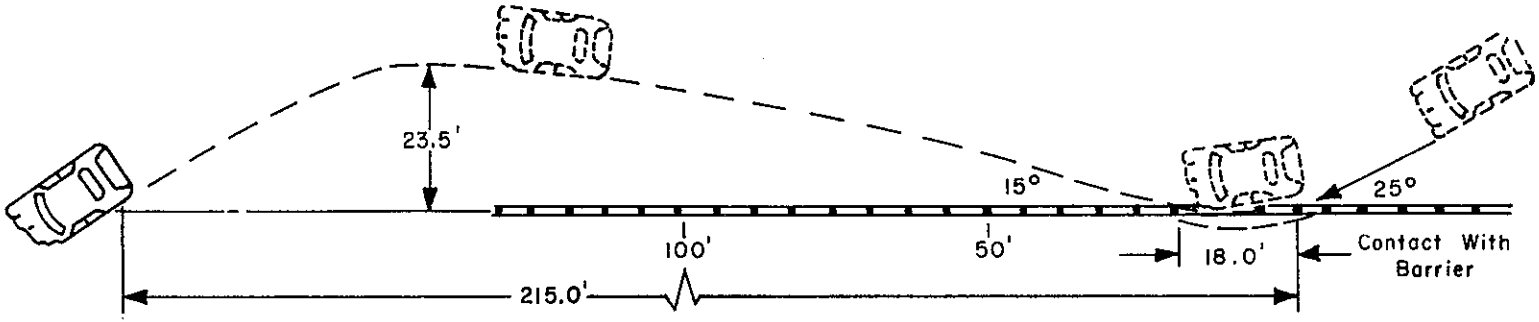
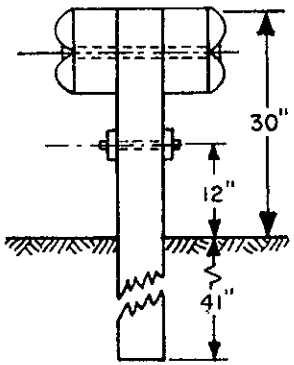


IMPACT + 5 M Sec

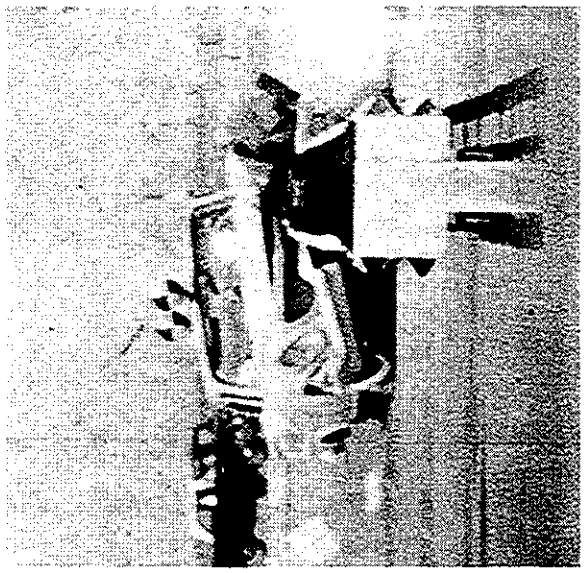




DOUBLE BLOCKED-OUT METAL BEAM BARRIER

BEAM RAIL	12 ga. Galv. Steel x 12'-6"
BOTTOM 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	200'
GROUND CONDITION	DRY
BEAM RAIL DEFLECTION-PERMANENT	15"
BOTTOM RAIL DEFLECTION-PERMANENT	6"

TEST NO.	101
DATE	8-6-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	69 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	15°
DUMMY RESTRAINT	Type I



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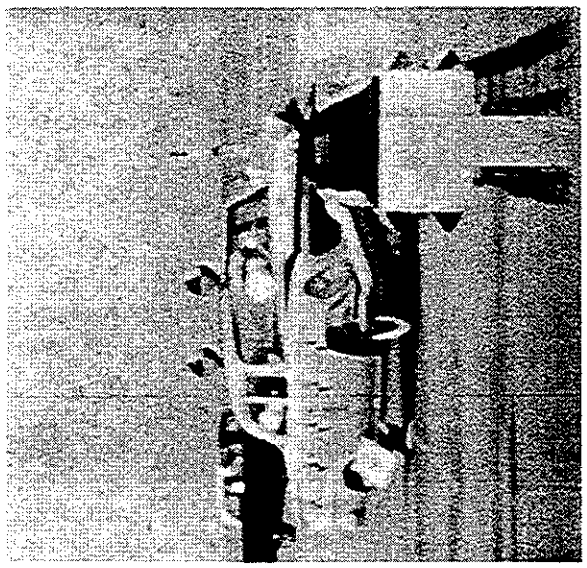

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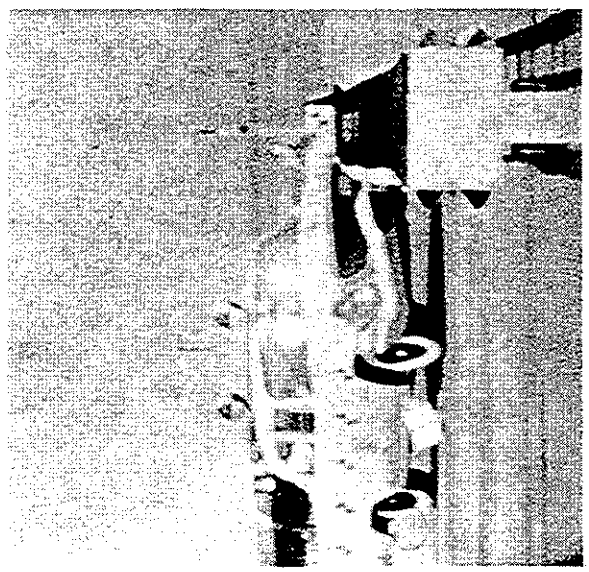

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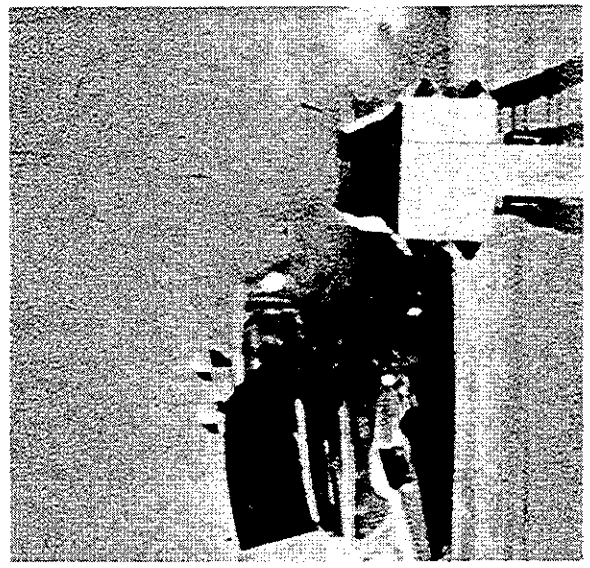
I + .241 Sec.



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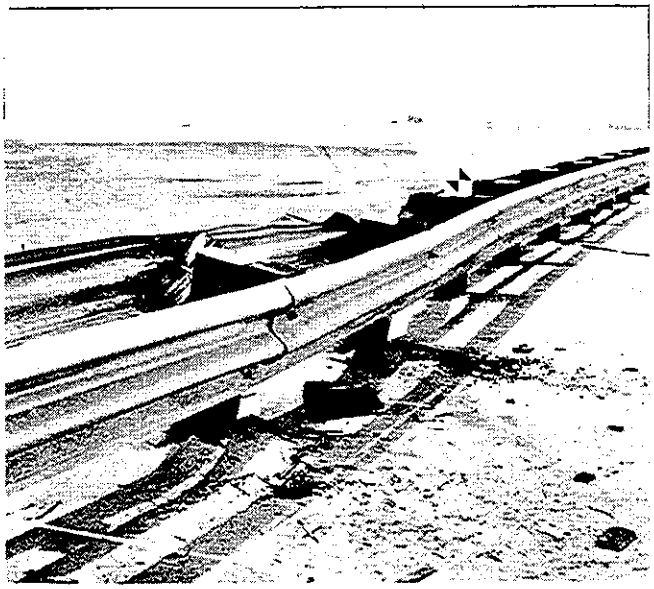
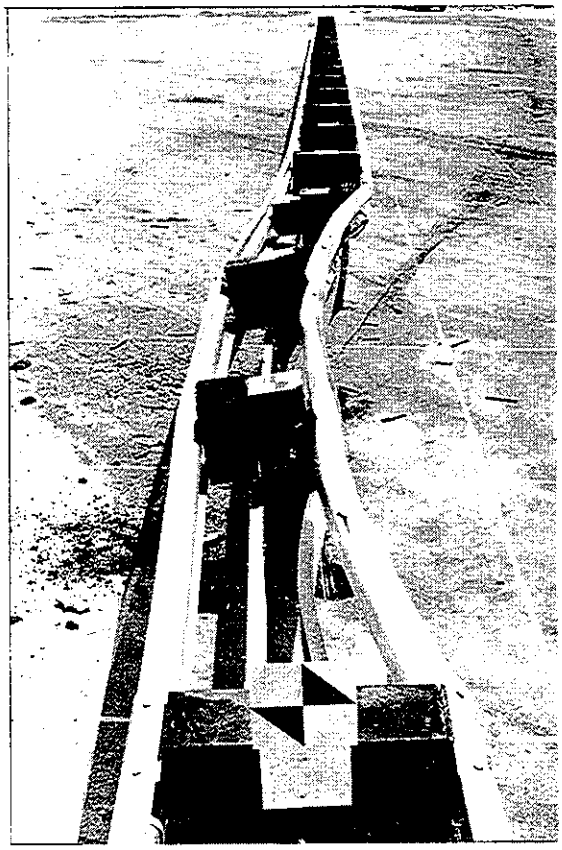
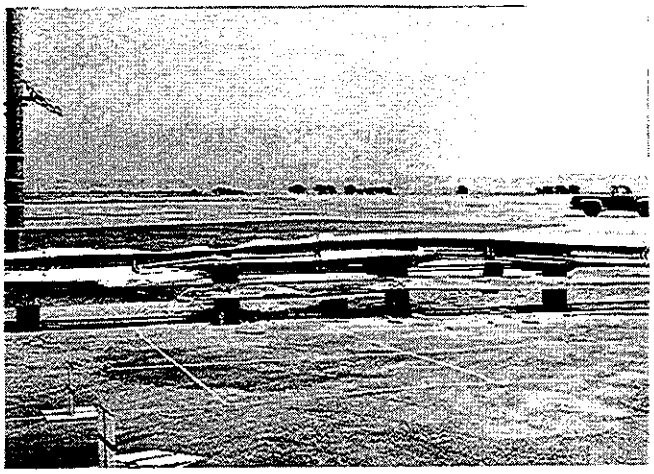
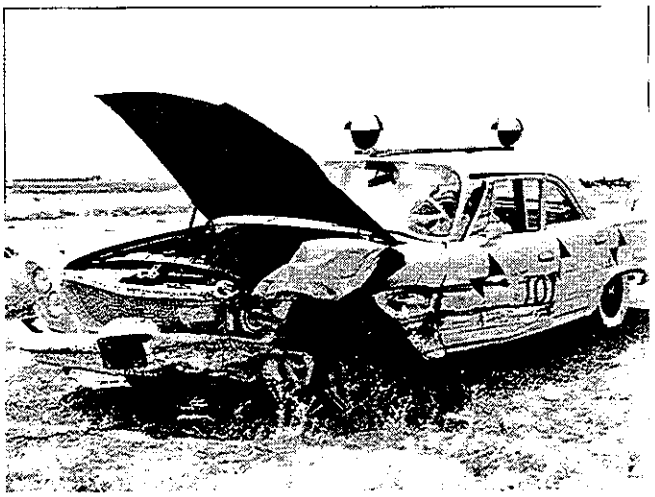
I + .485 Sec.

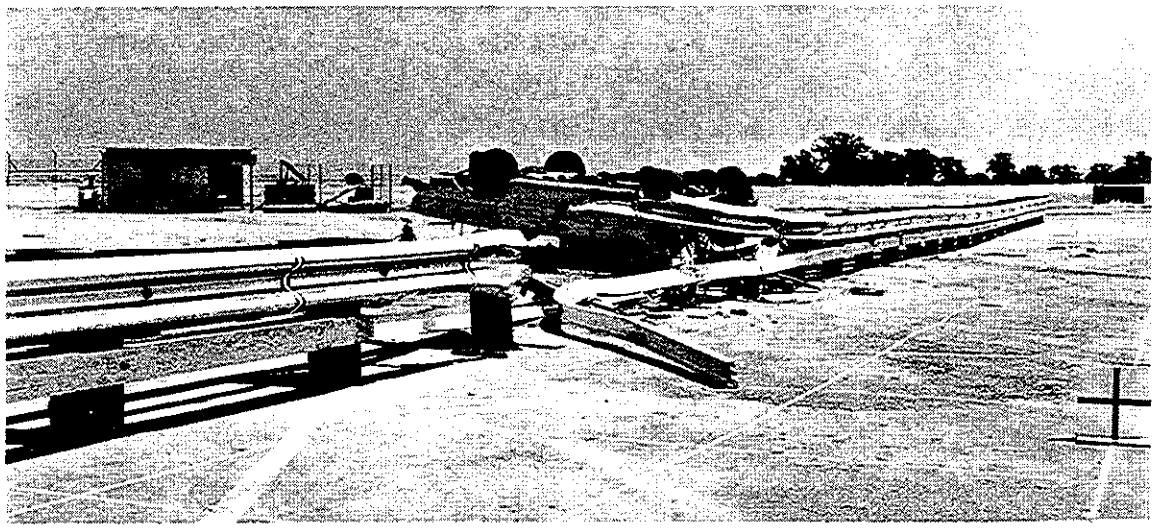








TEST 102 PLATE A



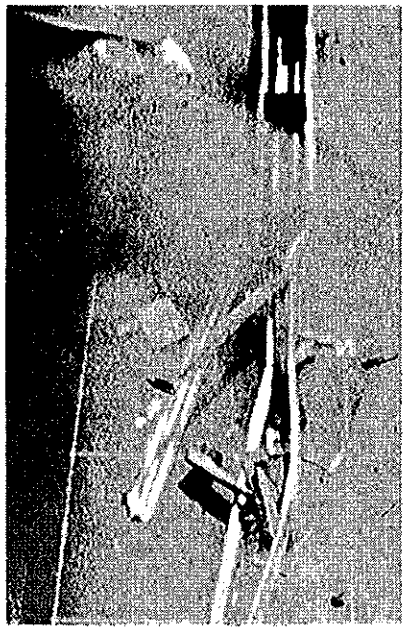
BARRIER: Double blocked-out metal beam median barrier with 0.125 inch thick aluminum alloy Alclad 2024-T3 "W" section beam and 6[3.0 aluminum alloy 6061-T6 bottom rubbing rail. All holes, slots, and splice plates for bottom rubbing rail were fabricated in accordance with California Standard Plan A77-8 (Exhibit 1).

PURPOSE: To test the effectiveness of the current California standard double blocked-out metal beam median barrier design with 0.125 inch aluminum substituted for the standard 12 gage steel "W" section beam and aluminum channel substituted for the structural steel bottom rubbing rail.

PERFORMANCE: The test vehicle struck the barrier at Post 14 and penetrated through both beams. As the vehicle progressed through impact parallel to the barrier, the leading edge of the fractured beam on the impact side penetrated the vehicle body. The vehicle progressed straddling the centerline for 18 feet, pivoted at Post 17 on the damaged right front, and rolled onto its top.

BARRIER DAMAGE: The aluminum "W" section beams on both sides of the barrier in the impact area shattered into dozens of fragments varying in area from 6 sq. inches to less than one sq. inch. Six 12 ft. 6 in. sections of aluminum beam were shattered and two 25 foot sections of aluminum channel bottom rubbing rail were damaged beyond repair. Five posts were knocked out of alignment, three of which were broken. Four block-out blocks were crushed. The 6 in. channel bottom rubbing rail on the impact side failed at a splice. However, close study of the data film shows that the aluminum alloy beam was already failing when the rubbing rail splice failed. This deficiency, nevertheless, was corrected in Test 103 by increasing the edge distance to the splice holes.

VEHICLE DAMAGE: As the "W" section beam on the impact side of the barrier separated, it penetrated the bottom of the vehicle, ripping a 6 ft. long gash from the front to rear wheel wells. One three foot long spear-shaped section of the aluminum beam penetrated the floorboard in the front seat and lodged in the edge of the seat on the passenger side. The vehicle was a total loss.



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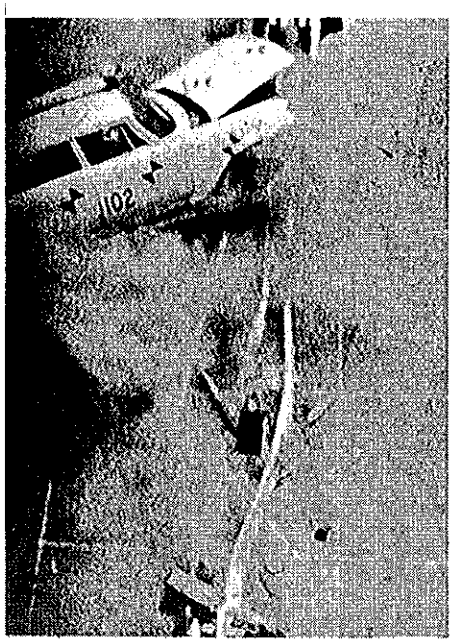

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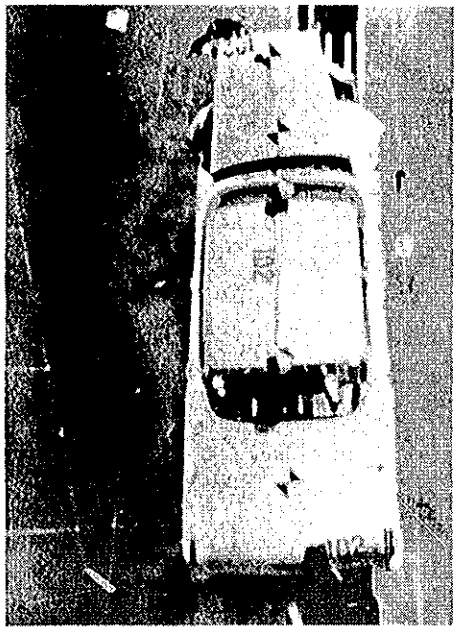

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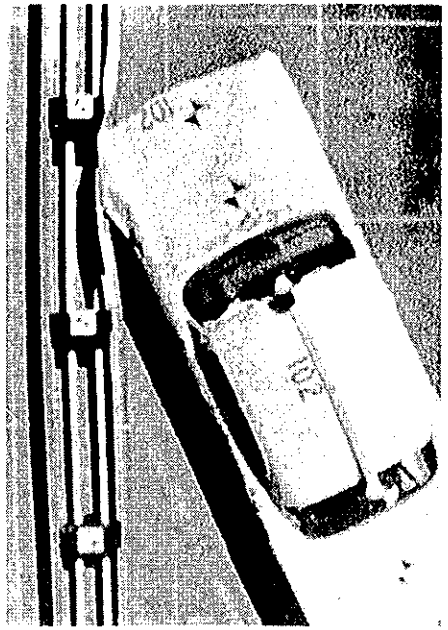

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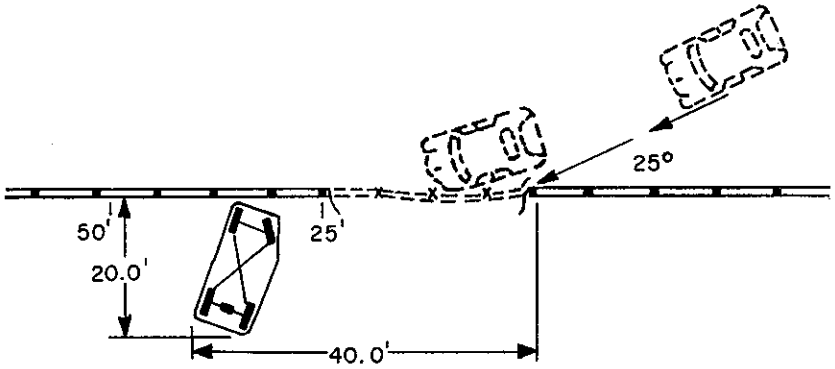
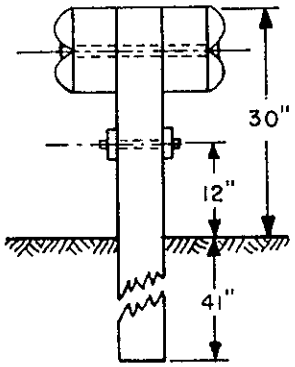


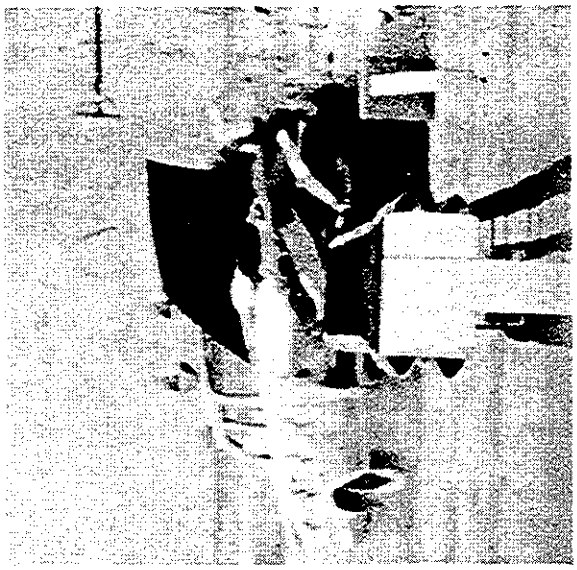


DOUBLE BLOCKED-OUT
METAL BEAM BARRIER

BEAM RAIL	0.125" Aluminum x 12'-6"
BOTTOM RAIL	6 [3.0 Aluminum x 25'-0"
POST	8"x8" Rough D.F. x 6'-0"
POST EMBEDMENT	41"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	200'
GROUND CONDITION	DRY

TEST NO.	102
DATE	8-13-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	67 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	ROLL OVER
DUMMY RESTRAINT	TYPE I

TEST 102 PLATE B



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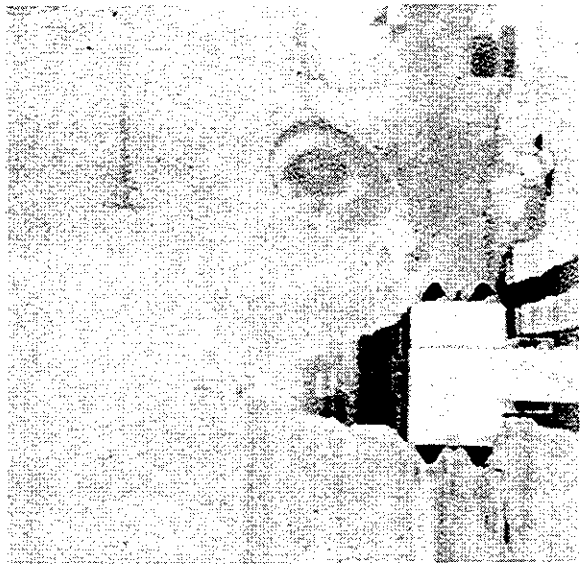

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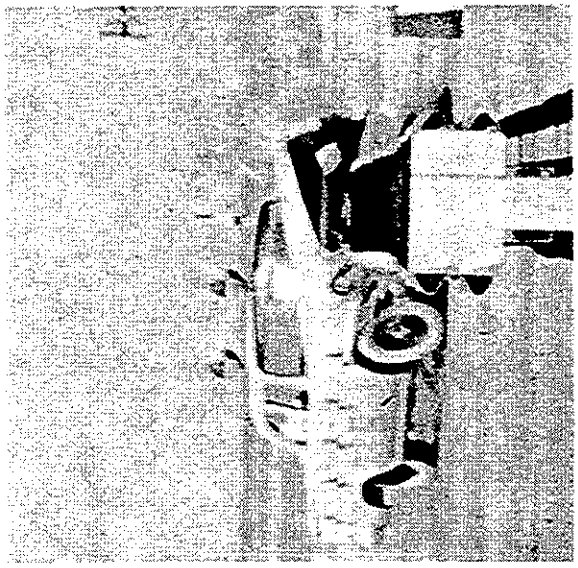

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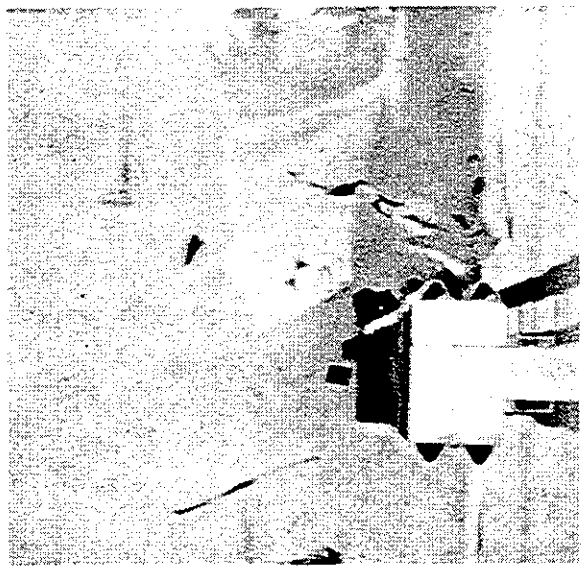

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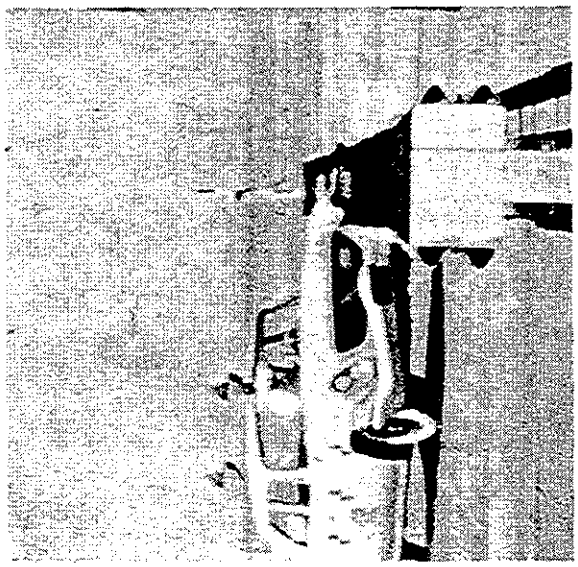

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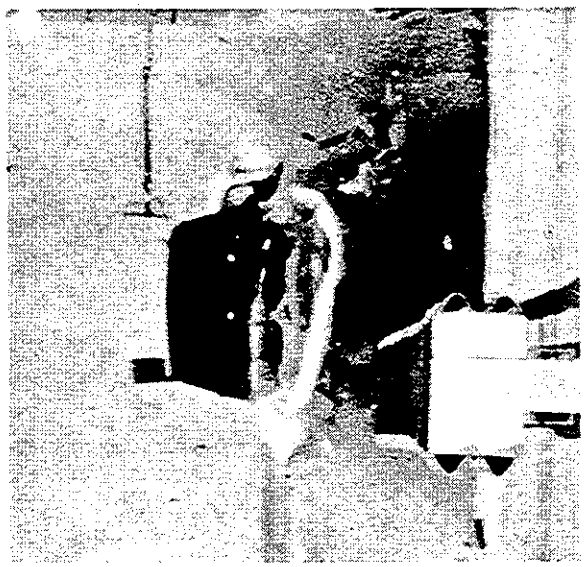
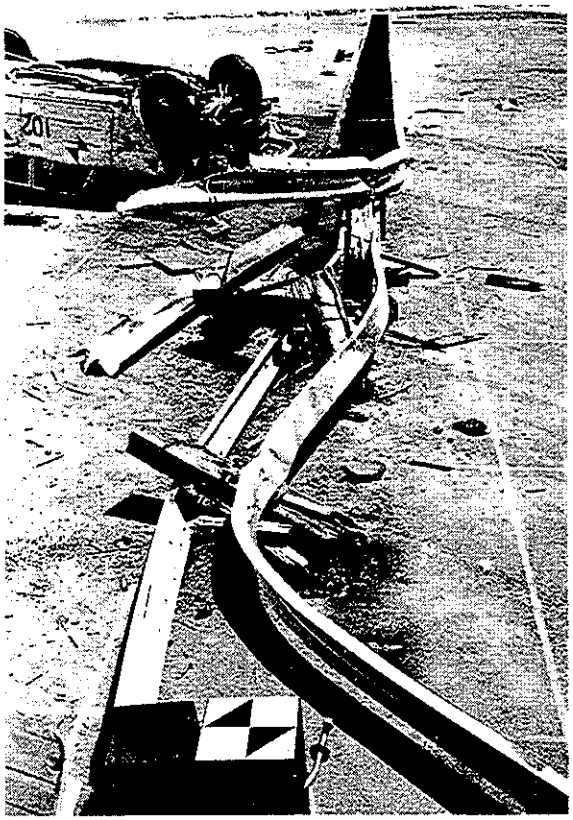
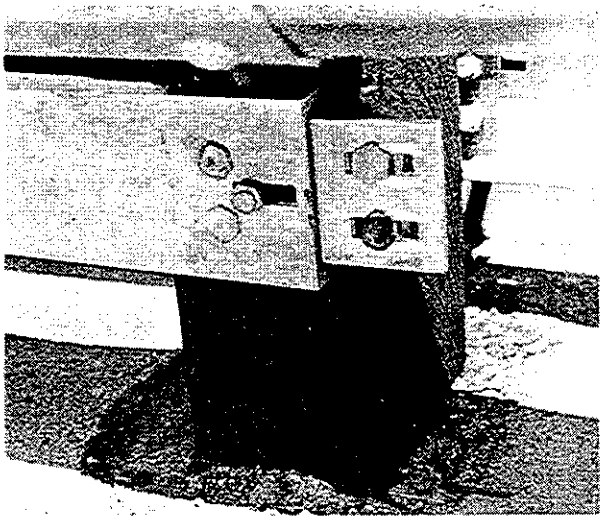
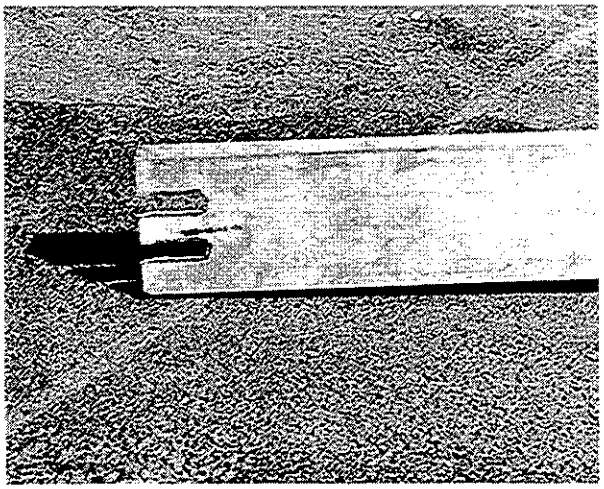
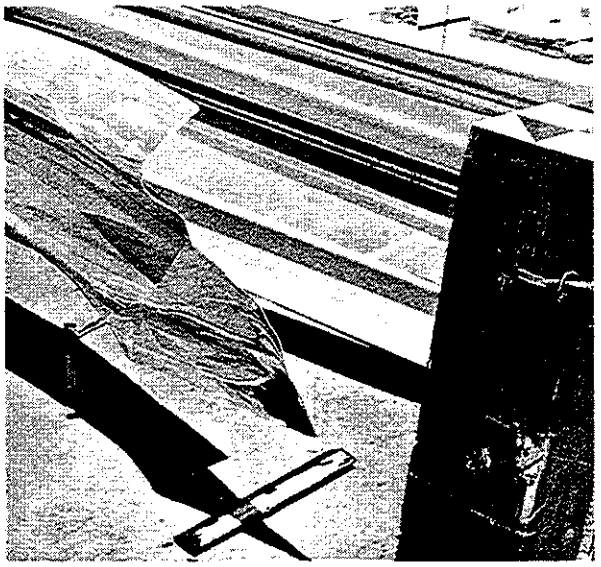


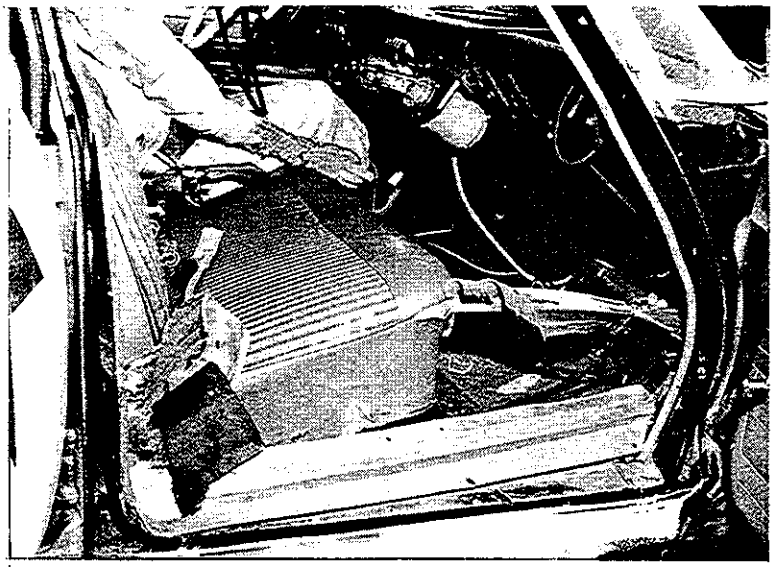
I + .525 Sec.

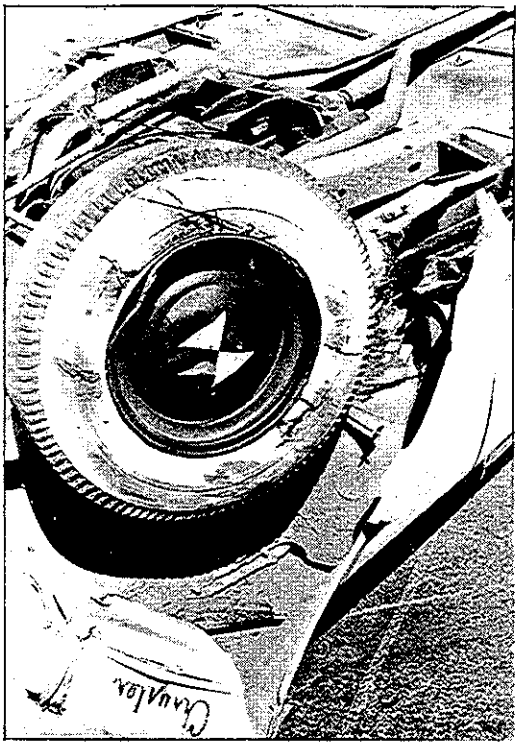


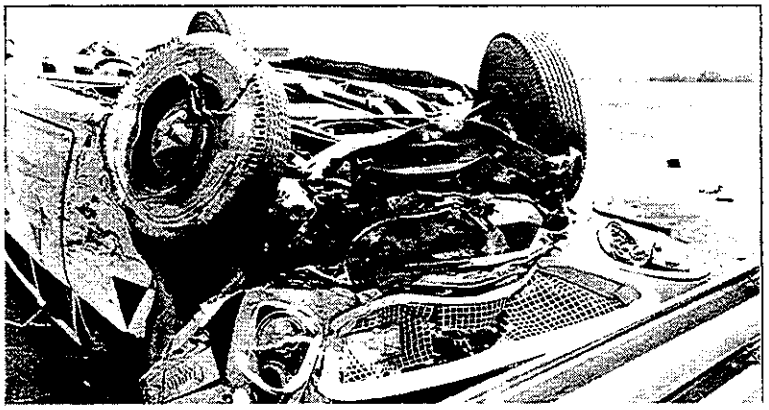


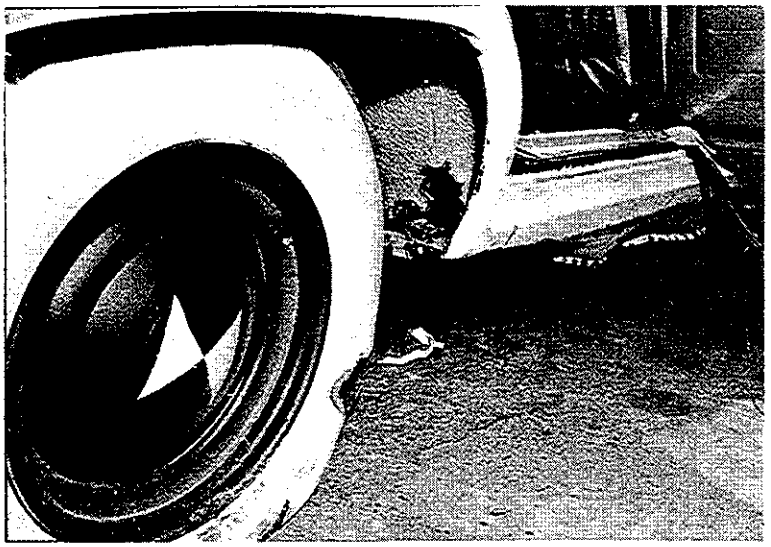




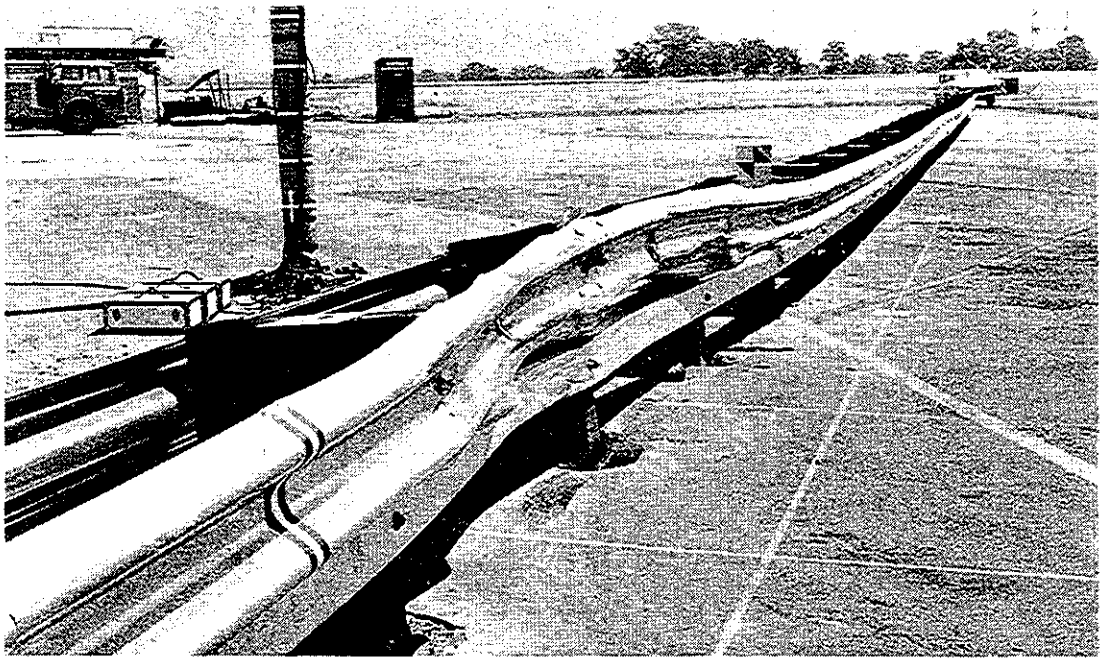








TEST 103 PLATE A



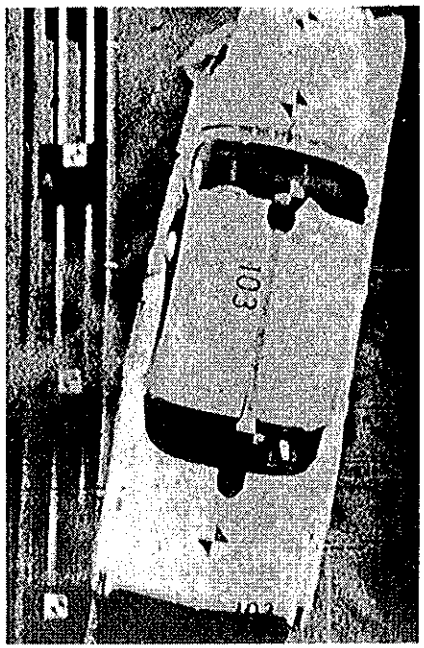
BARRIER: Double blocked-out metal beam median barrier with 0.156 inch thick aluminum alloy Alclad 2024-T3 "W" section beam and 6 [3.0 aluminum alloy 6061-T6 bottom rubbing rail. The bottom rubbing rail was of the same alloy as was used for the bottom rubbing rail in Test 102. However, to prevent the shearing failure at the splice that occurred in the bottom rubbing rail in Test 102, the edge distance for the splice bolt holes was increased from 5/8 in. to 1-5/16 in.

PURPOSE: To test the effectiveness of the current California standard double blocked-out metal beam median barrier design with the thickness of the aluminum "W" section beam in Test 102 increased from 0.125 in. to 0.156 in. and the edge distance of the splice bolt holes in the bottom rubbing rail increased.

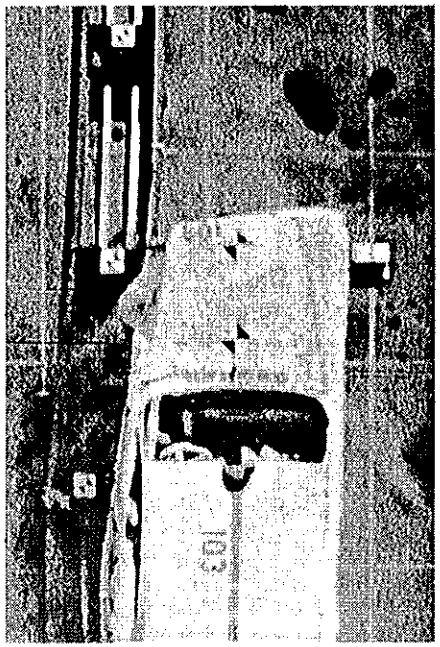
PERFORMANCE: The vehicle struck the barrier between posts and remained in contact with the barrier for approximately 12 feet before being redirected to an exit angle of 14 degrees with the barrier and to a maximum rebound of 14 feet. The vehicle traveled 170 feet before crossing the barrier centerline. There was no tendency for the car to jump or roll.

BARRIER DAMAGE: Two 12 ft. 6 in. sections of aluminum beam and one 25-foot section of aluminum channel bottom rubbing rail were damaged. There was no indication of any failure at the bottom rubbing rail splice joints. Five posts were knocked out of alignment. Two block-out blocks were crushed.

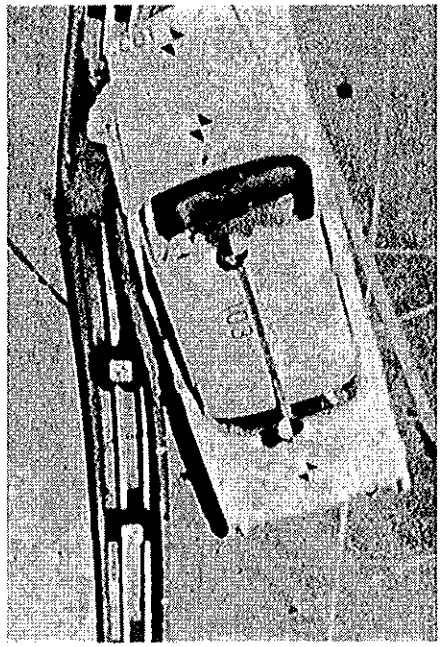
VEHICLE DAMAGE: The vehicle was a total loss.



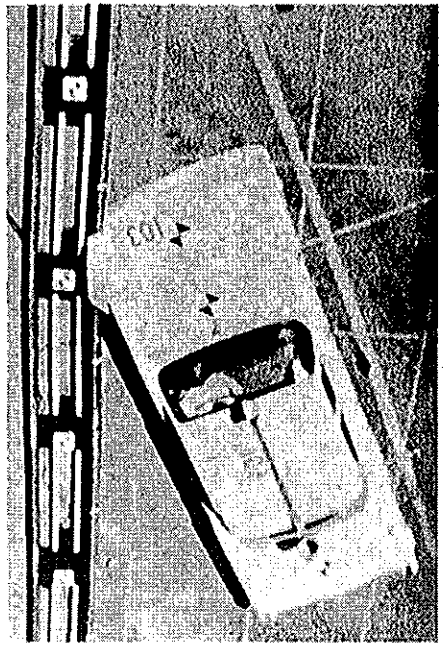
IMPACT + 488 M Sec



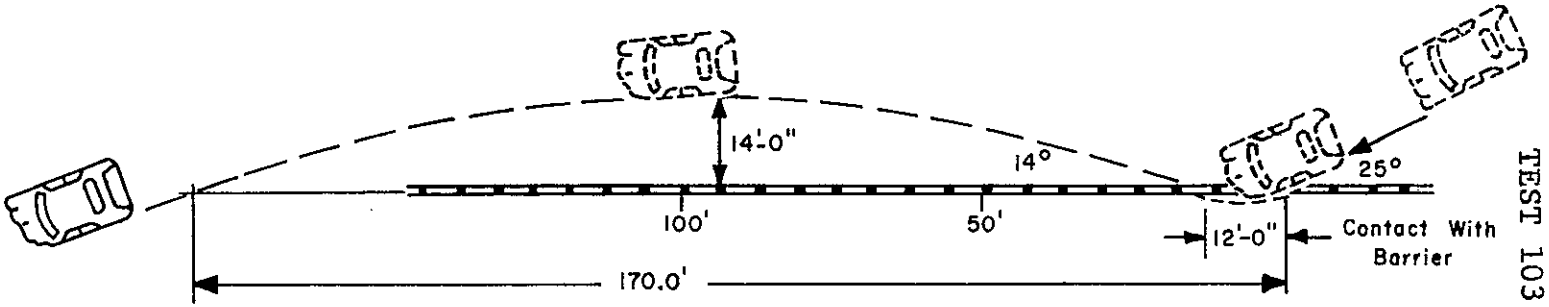
IMPACT + 332 M Sec

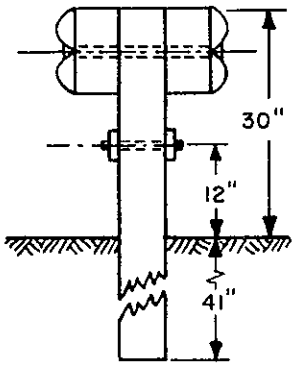


IMPACT + 98 M Sec



IMPACT + 9 M Sec



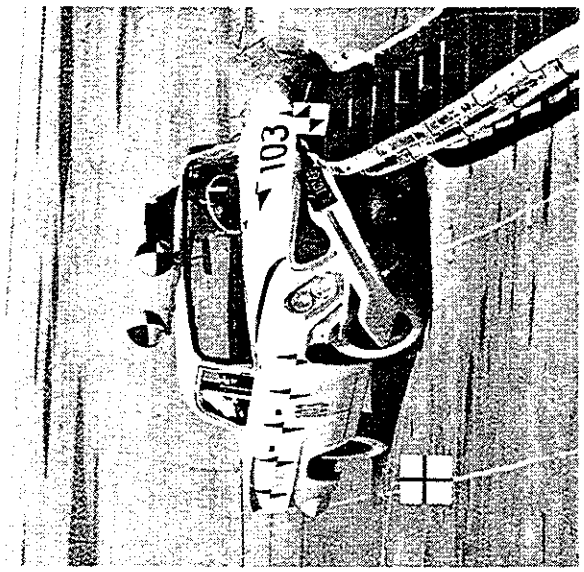


DOUBLE BLOCKED-OUT METAL BEAM BARRIER

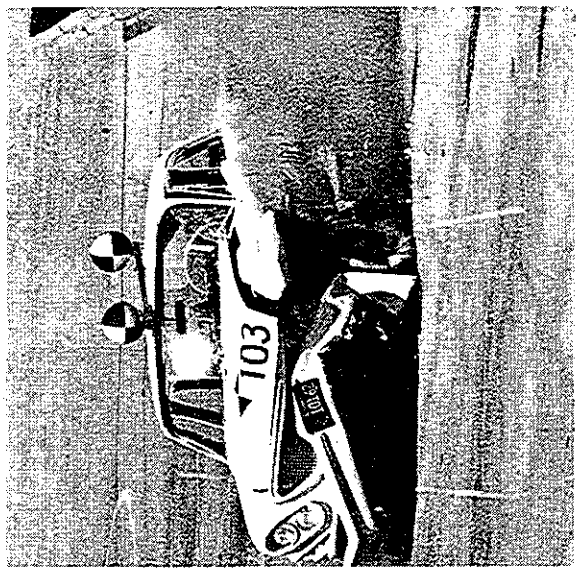
BEAM RAIL	0.156 Aluminum x 12'-6"
BOTTOM RAIL	6 [3.0 Aluminum x 25'-0"
POST	8" x 8" Rough D. F. x 6'-0"
POST EMBEDMENT	41"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	200'
GROUND CONDITION	Dry
BEAM RAIL DEFLECTION-PERMANENT	9"
BOTTOM RAIL DEFLECTION-PERMANENT	7"

TEST NO.	103
DATE	8-20-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	67 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	14°
DUMMY RESTRAINT	Type 4

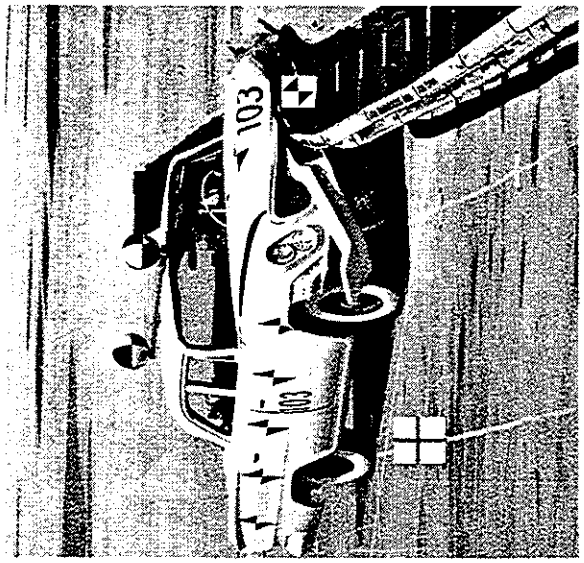
TEST 103 PLATE B



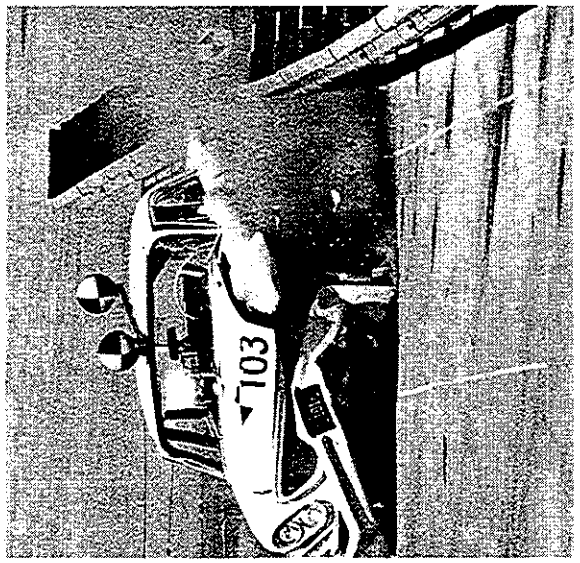
I + .163 Sec.



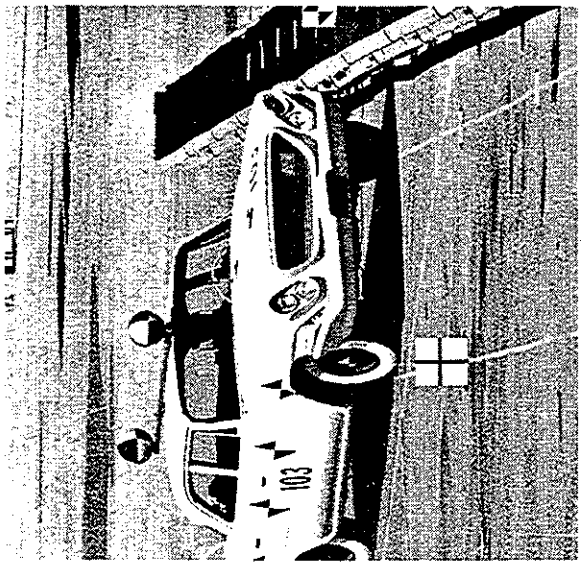
I + .622 Sec.



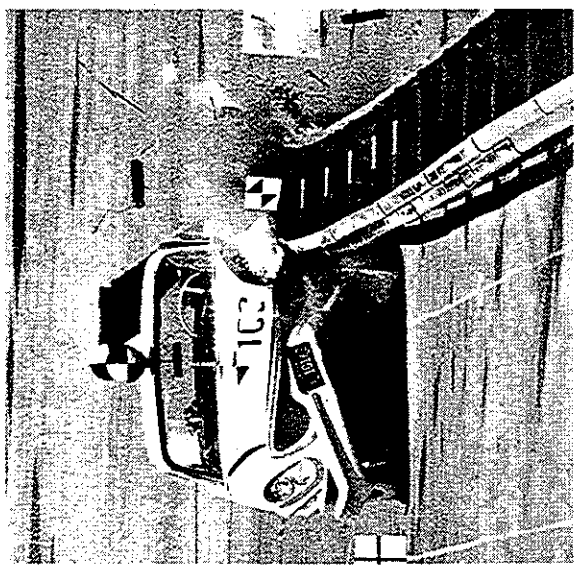
I + .081 Sec.



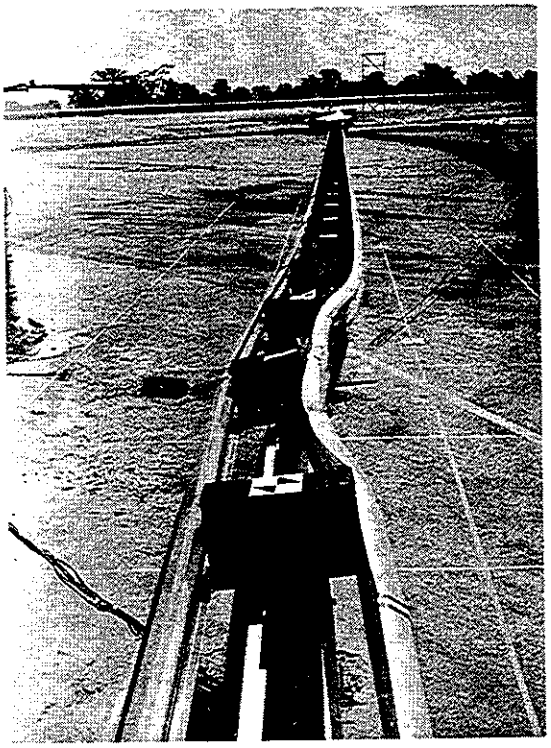
I + .395 Sec.

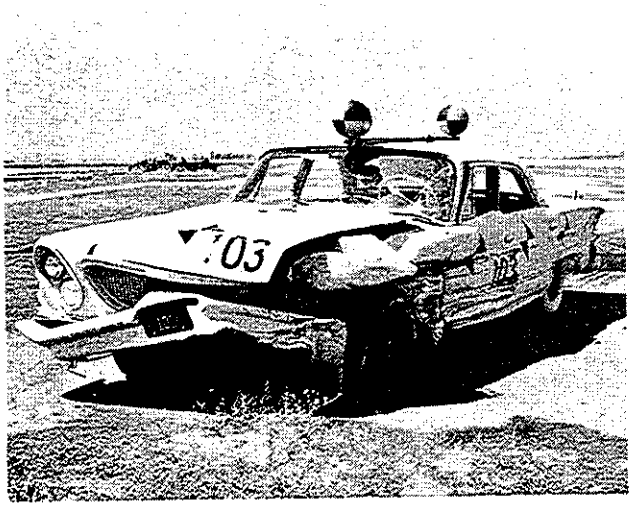


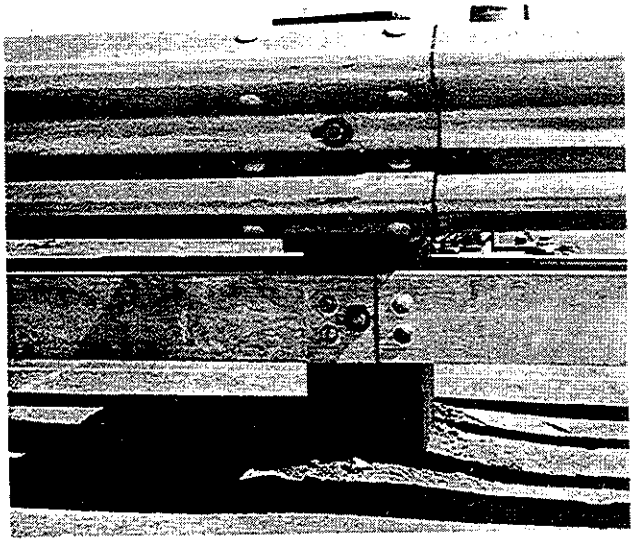
Impact



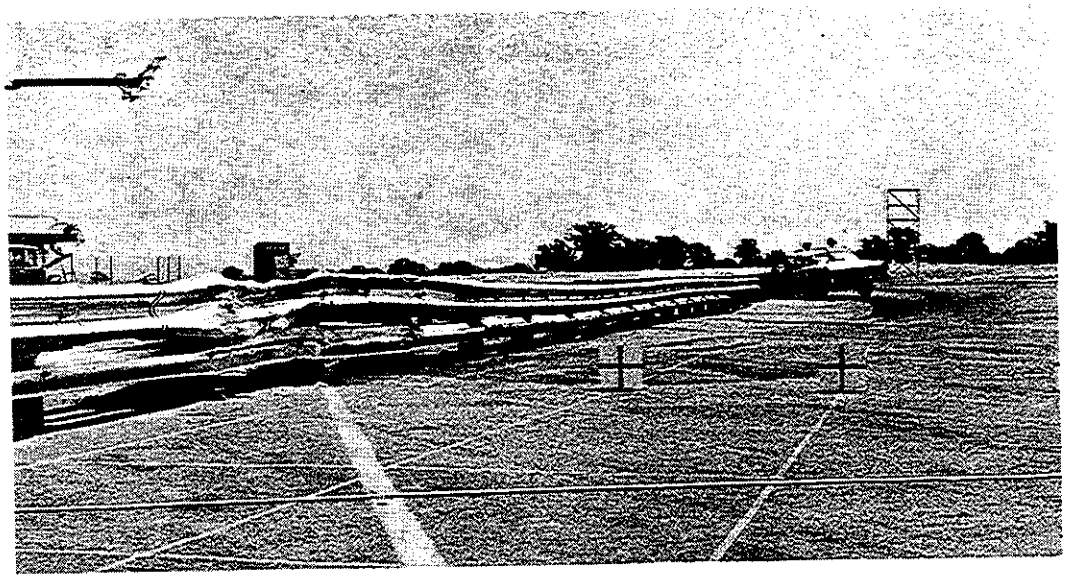
I + .243 Sec.




103



TEST 104 PLATE A



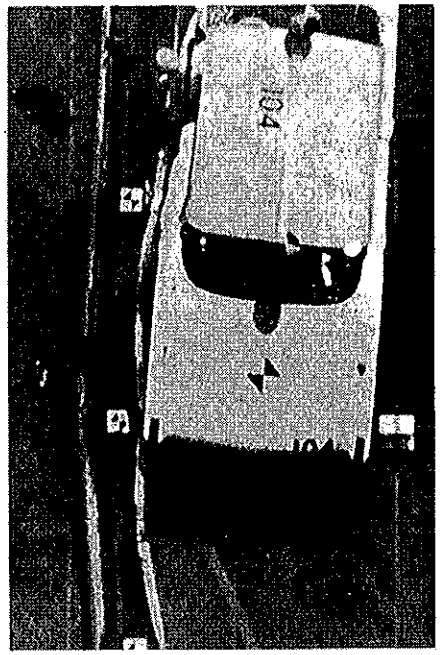
BARRIER: Double blocked-out metal beam median barrier with standard 12 gage (0.105 inch) galvanized steel "W" section beam and 12 gage galvanized steel roll formed "hat" section bottom rubbing rail.

PURPOSE: To test the effectiveness of the current California standard double blocked-out metal beam median barrier design with the 12 gage galvanized steel "hat" section replacing the standard structural steel channel bottom rubbing rail.

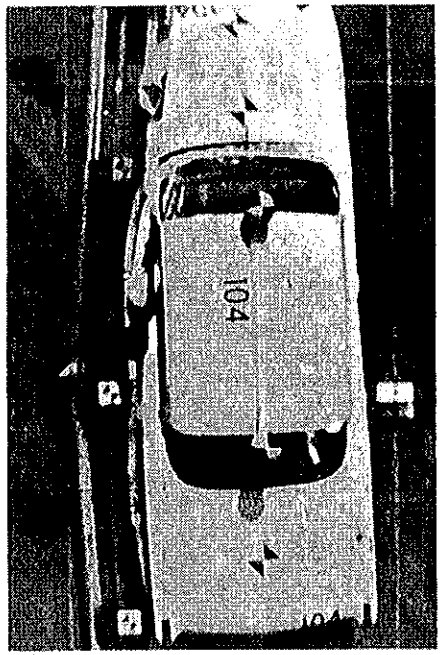
PERFORMANCE: The vehicle struck the barrier between posts and remained in contact with the barrier for approximately 14 feet before being redirected to an exit angle of 14 degrees with the barrier and to a maximum rebound of 9.5 feet. The vehicle traveled 120 feet before crossing the barrier centerline. There was no tendency for the vehicle to jump. A maximum roll of 3.5 degrees to the right was imparted to the vehicle.

BARRIER DAMAGE: Two 12 ft. 6 in. sections of beam rail and two 25-ft. 0 in. sections of bottom rubbing rail on the impact side were damaged, as were one 12 ft. 6 in. section of the beam rail and one 25-foot section of bottom rubbing rail on the side opposite impact. Seven posts were knocked out of alignment and one block-out block was crushed. There was evidence of a moderate amount of pocketing in the "hat" section bottom rail.

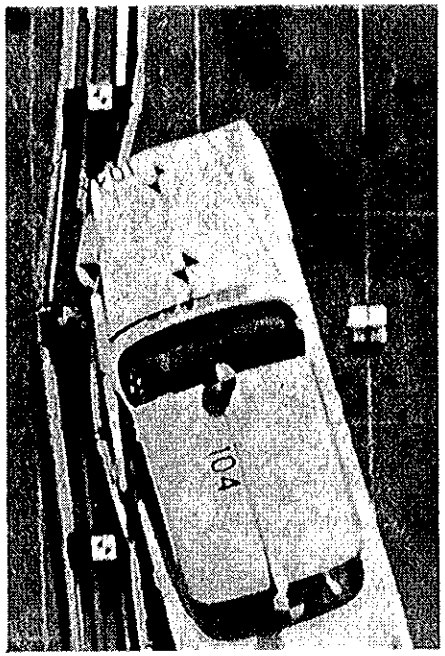
VEHICLE DAMAGE: The vehicle was a total loss.



IMPACT + 306 M Sec



IMPACT + 216 M Sec



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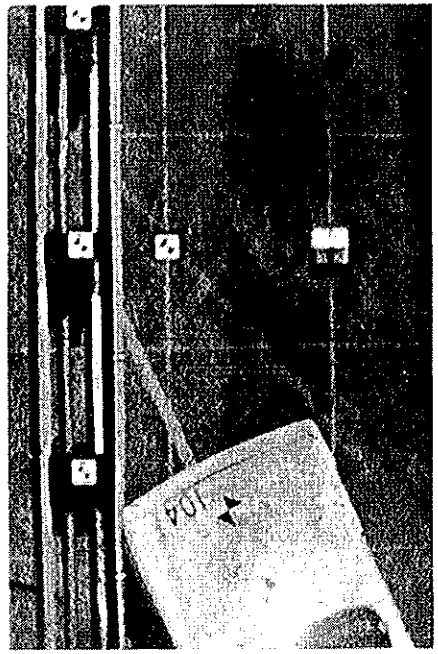
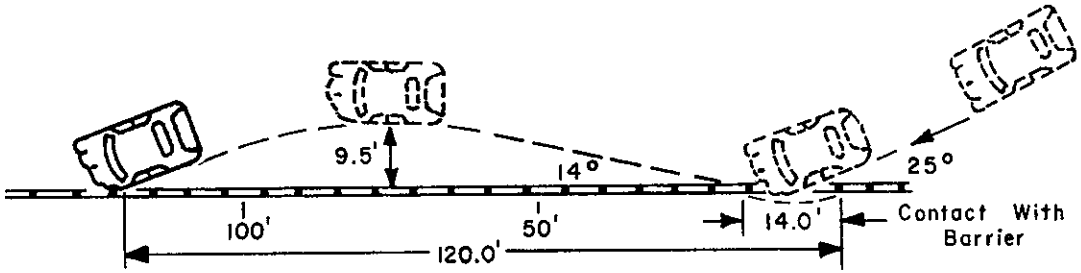
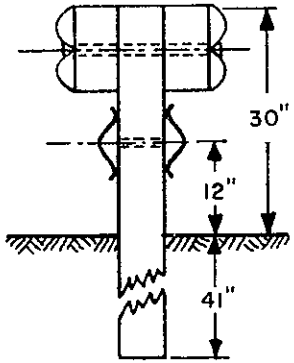


IMPACT



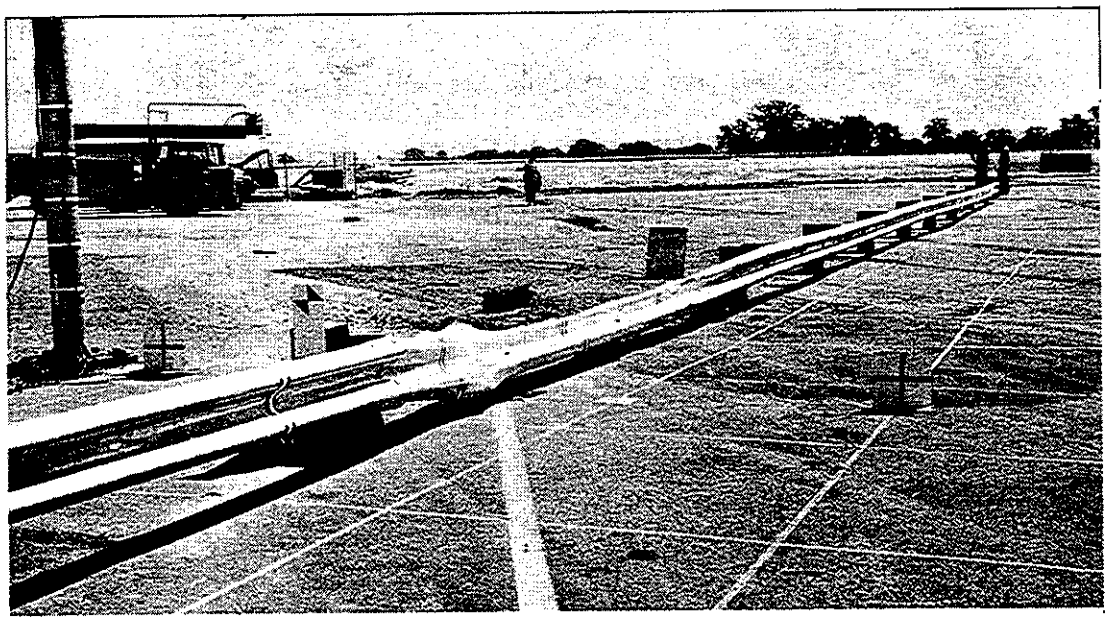


DOUBLE BLOCKED-OUT METAL BEAM BARRIER

BEAM RAIL	12 ga. Galv. Steel x 12'-6"
BOTTOM RAIL	12 ga. Galv. Steel "Hat" Sect. x 25'
POST	8" x 8" Rough D.F. x 6'-0"
POST EMBEDMENT	41"
POST SPACING	6'-3"
LENGTH OF INSTALLATION	200'
GROUND CONDITION	DRY
BEAM RAIL DEFLECTION-PERMANENT	12"
BOTTOM RAIL DEFLECTION-PERMANENT	8"

TEST NO.	104
DATE	8-27-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	68 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	14°
DUMMY RESTRAINT	None

TEST 105 PLATE A



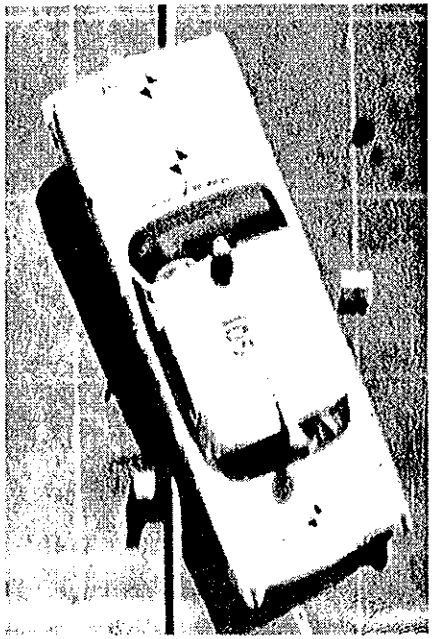
BARRIER: Blocked-out metal beam guard railing with standard 12 gage (0.105 inch) galvanized steel "W" section beam mounted at an over-all height of 24 inches above the ground on 8 in. by 8 in. timber posts spaced 12 ft. 6 in. on centers.

PURPOSE: To proof test the current California standard blocked-out metal beam guard railing design and serve as a gage of the effectiveness of the aluminum alloy beam rail component of Test 109 of this series.

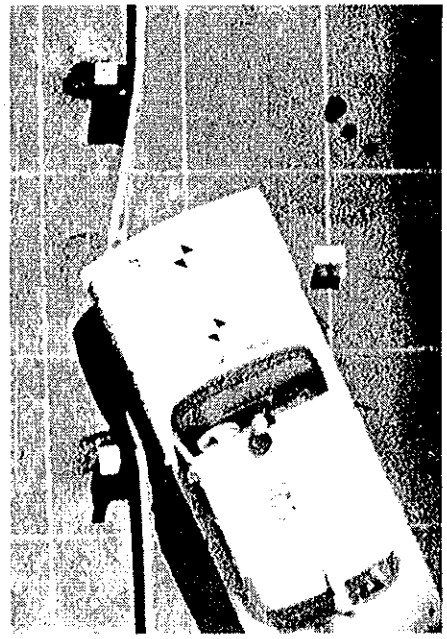
PERFORMANCE: The vehicle struck the guard railing between posts. The bumper rotated the "W" section beam axially into a ramp position, enabling the car to vault the barrier. The vehicle rose to a maximum height of 30 inches and was airborne for 25 feet.

BARRIER DAMAGE: Two 12 ft. 6 in. 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. There was no indication of failure at the splices.

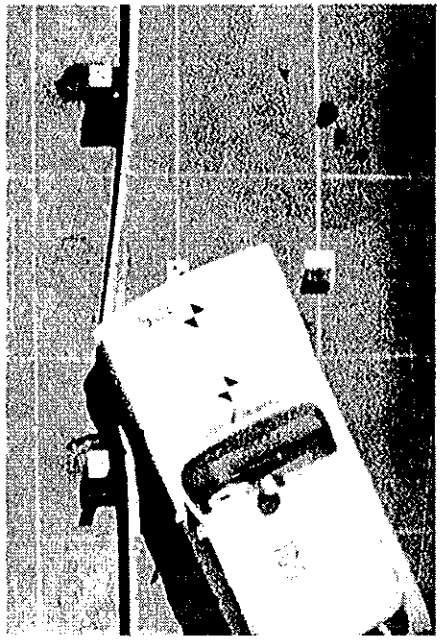
VEHICLE DAMAGE: The vehicle sustained moderate damage to the radiator and undercarriage of the front of the car. This vehicle was repaired for $250 and used as the impact vehicle in Test 109.



IMPACT + 130 M Sec



IMPACT + 57 M Sec



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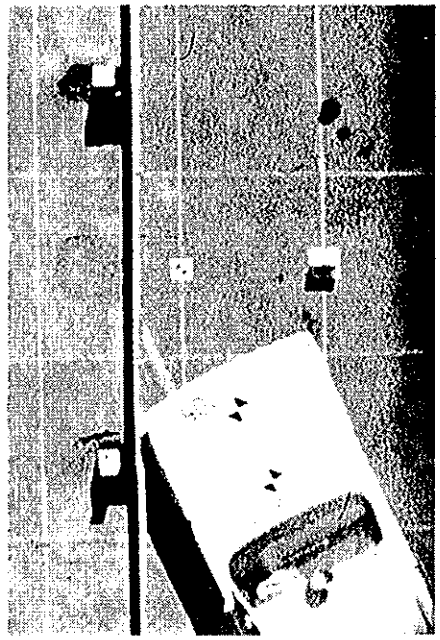
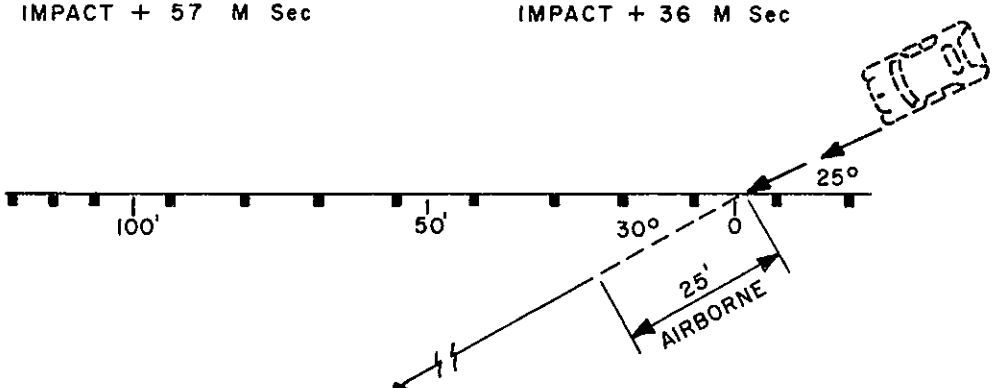
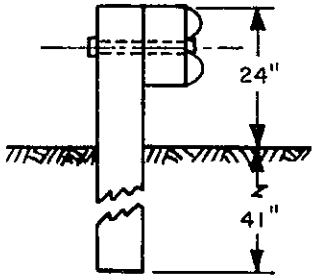


IMPACT

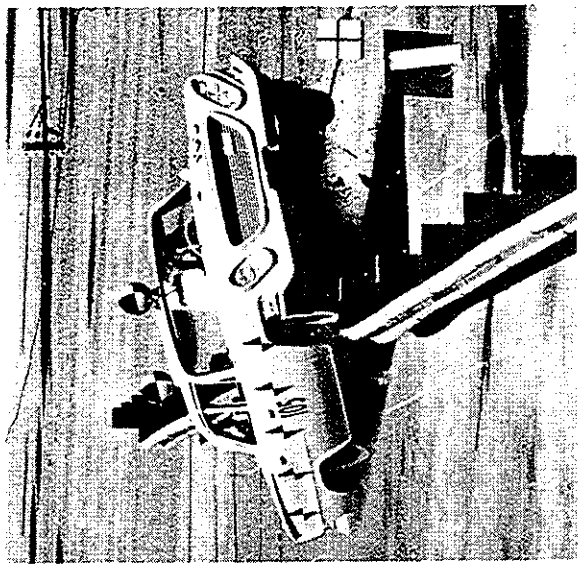




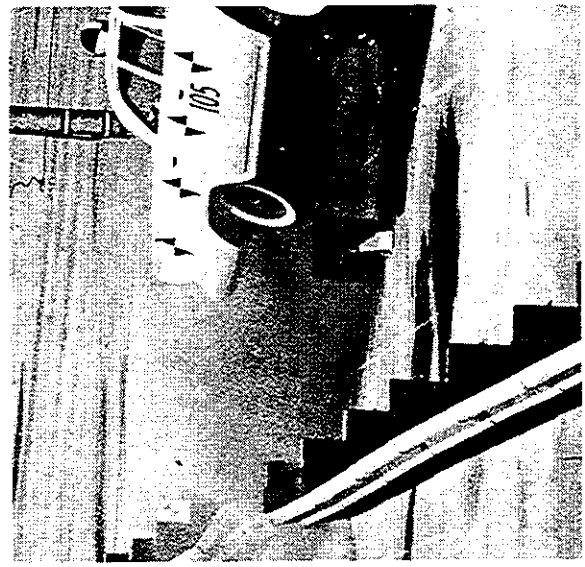
METAL BEAM
GUARD RAILING

BEAM-RAIL	12 ga. Galv. Steel x 12'-6"
BOTTOM 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"

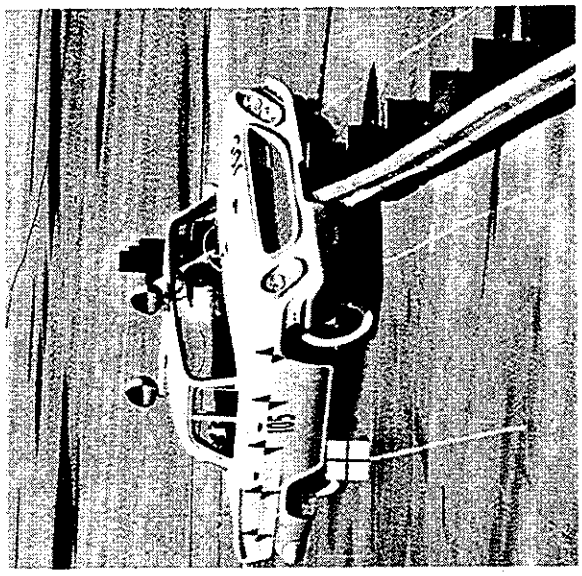
TEST NO.	105
DATE	9-9-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570#
IMPACT SPEED	58 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	30°
DUMMY RESTRAINT	Type 4



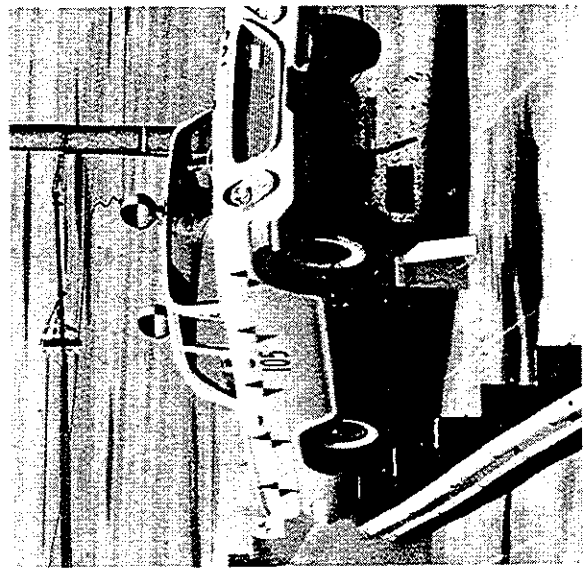
I + .252 Sec.



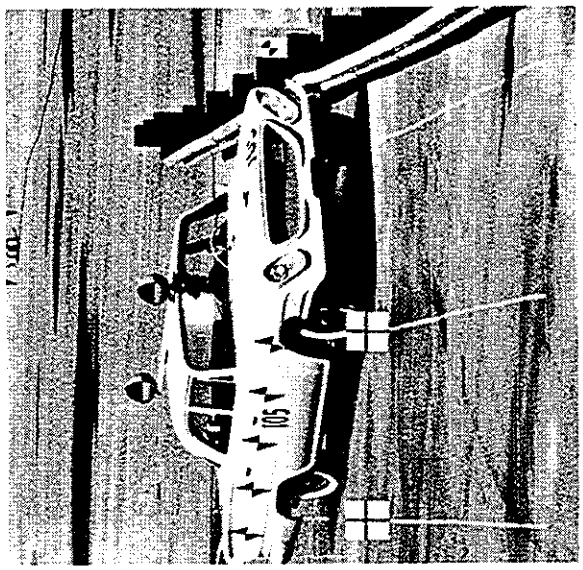
I + .646 Sec.



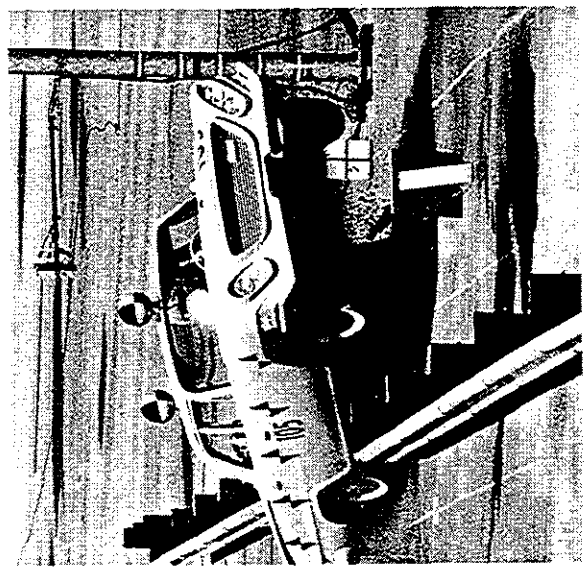
I + .102 Sec.



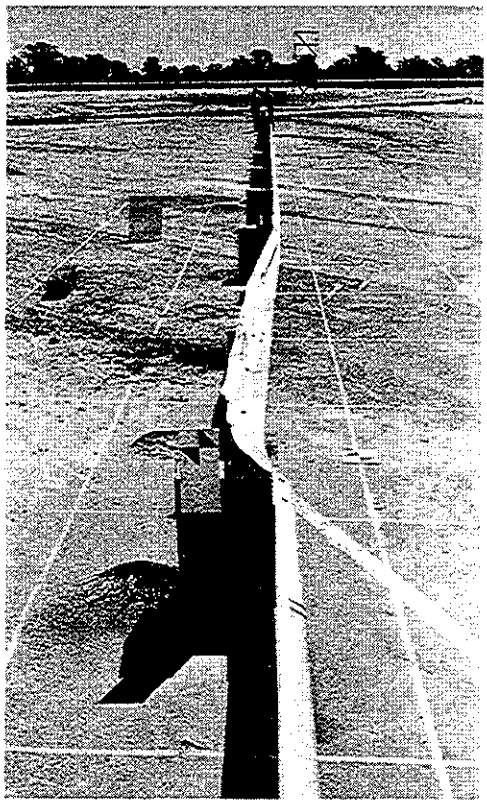
I + .451 Sec.

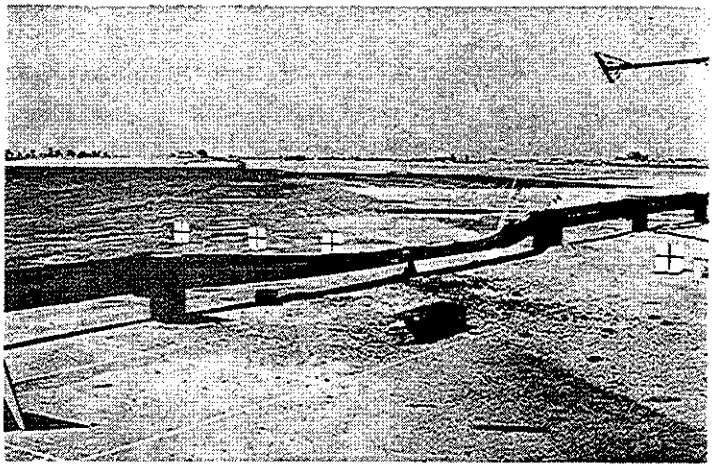


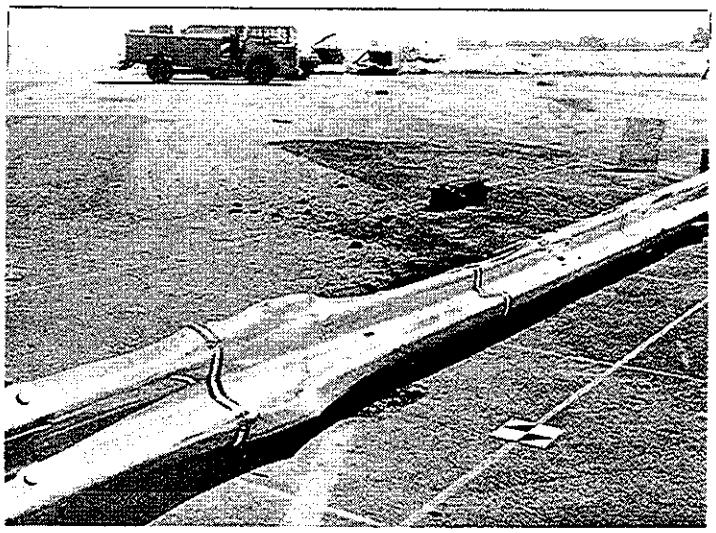
Impact

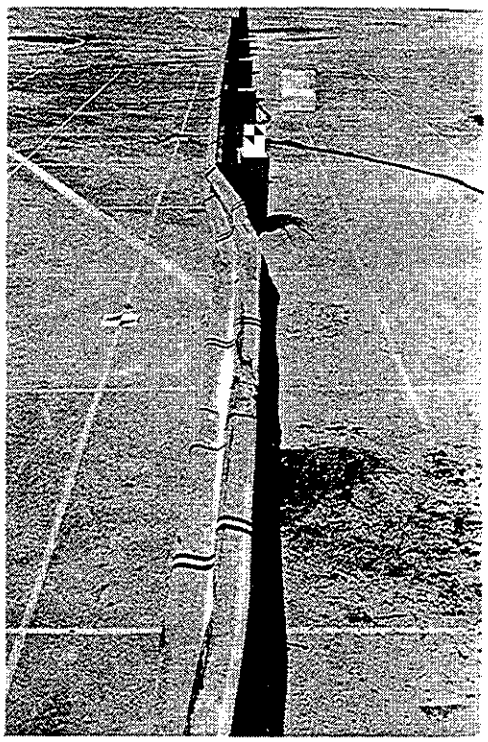


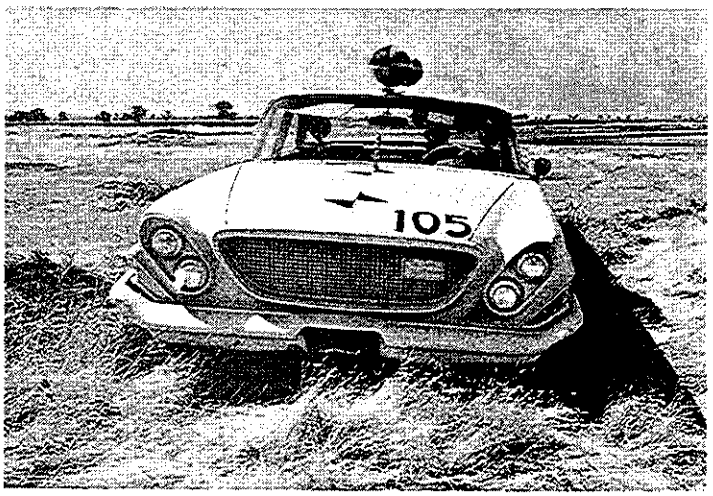
I + .331 Sec.



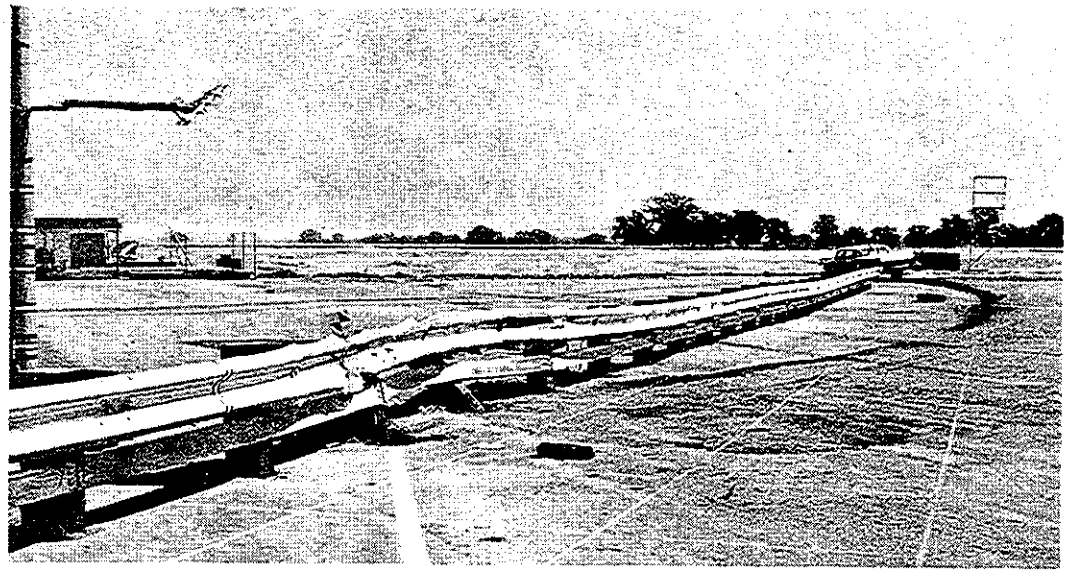







105

TEST 106 PLATE A



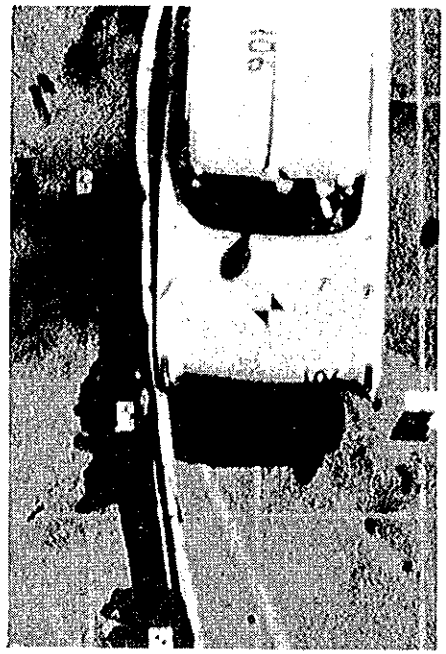
BARRIER: Single blocked-out metal beam median barrier with standard 12 gage (0.105 inch) galvanized steel "W" section beam mounted at an over-all height of 30 inches above the ground and 6 [8.2 galvanized steel bottom rubbing rail on 8 in. by 8 in. timber posts spaced at 6 ft. 3 in. centers.

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

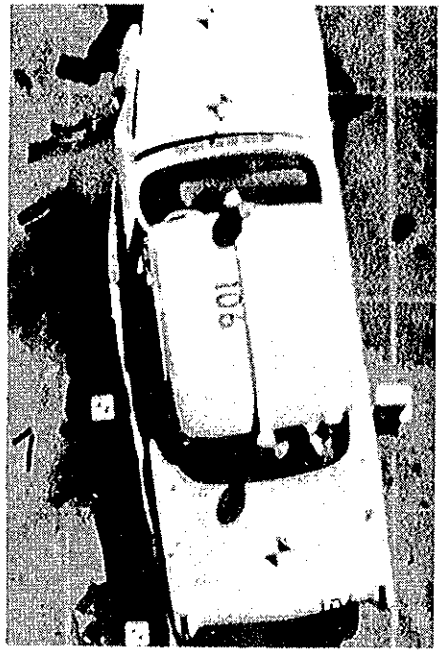
PERFORMANCE: The vehicle struck the barrier at a post and remained in contact for approximately 19 feet before being redirected to an exit angle of 13 degrees and to a maximum rebound of 11 feet. The vehicle traveled 160 feet before crossing the barrier centerline. There was no tendency for the vehicle to jump or roll.

BARRIER DAMAGE: Three 12 ft. 6 in. sections of beam and two 12 ft. 6 in. sections of bottom rubbing rail were damaged. Six posts were knocked out of alignment, one of which was broken and one of which was split. Three block-out blocks were splintered and two were split.

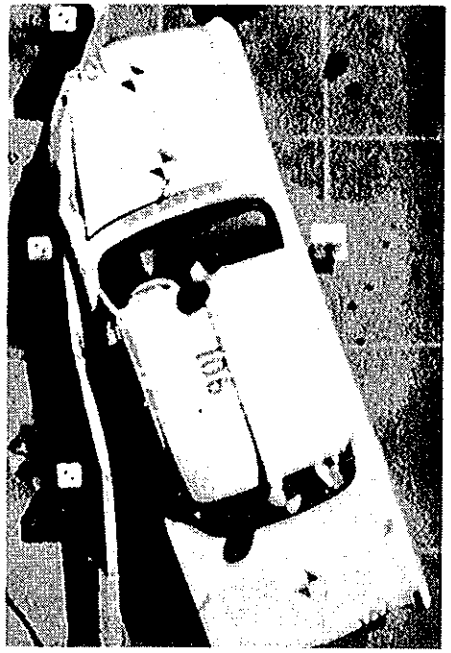
VEHICLE DAMAGE: The vehicle was a total loss.



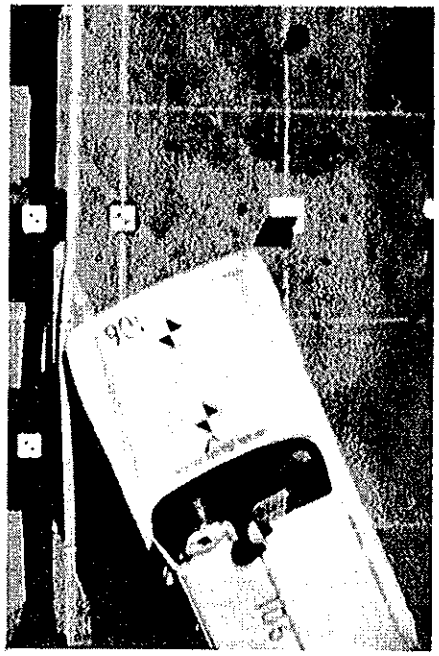
IMPACT + 312 M Sec



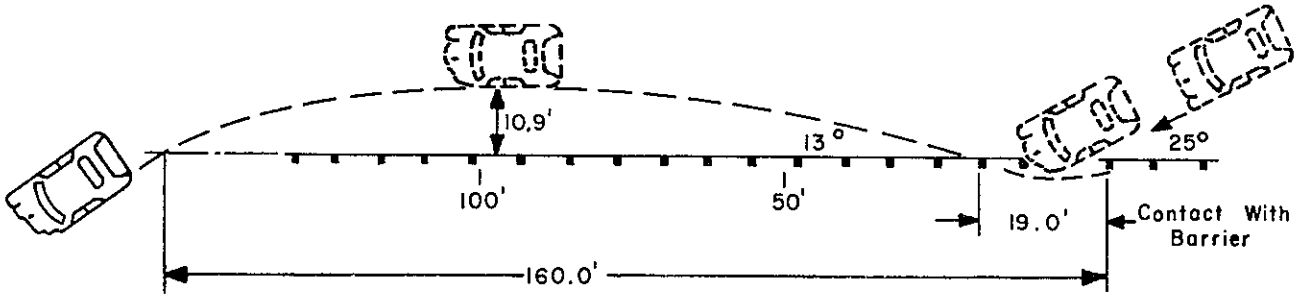
IMPACT + 179 M Sec

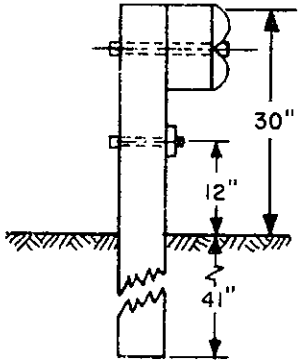


IMPACT + 93 M Sec



IMPACT + 2 M Sec

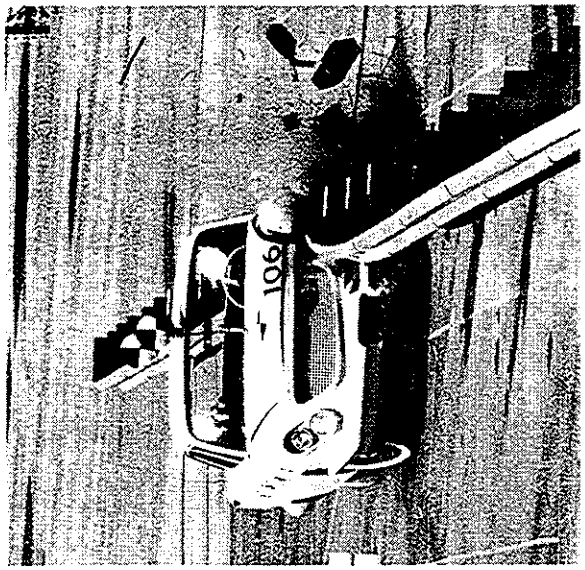




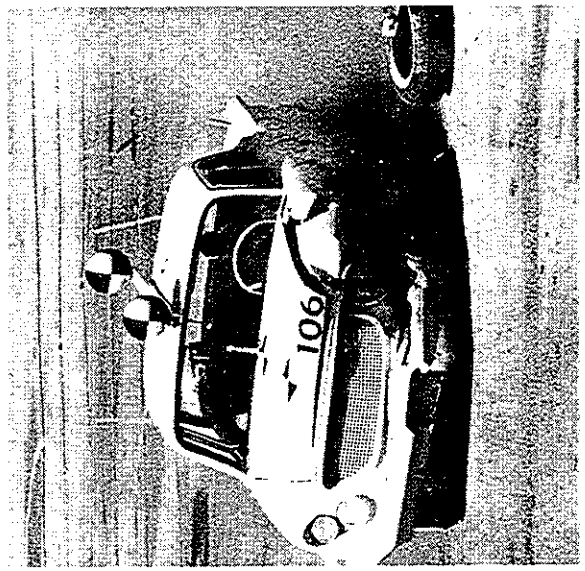
SINGLE BLOCKED-OUT METAL BEAM BARRIER

BEAM RAIL	12 ga. Galv. Steel x 12'-6"
BOTTOM 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"
BOTTOM RAIL DEFLECTION-PERMANENT	17"

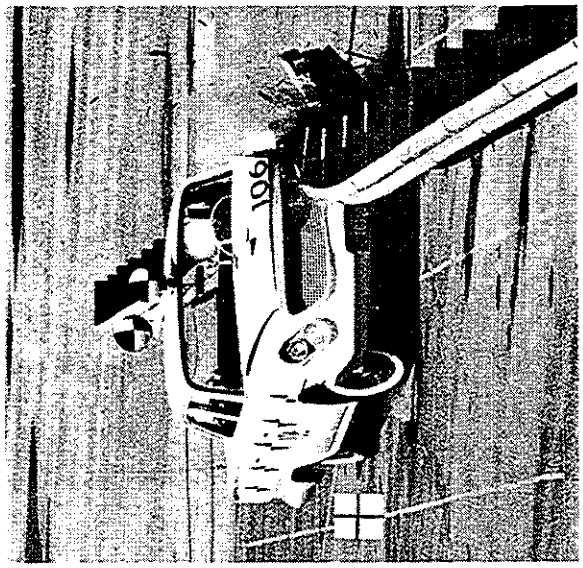
TEST NO.	106
DATE	9-25-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	60 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	13°
DUMMY RESTRAINT	Type 4



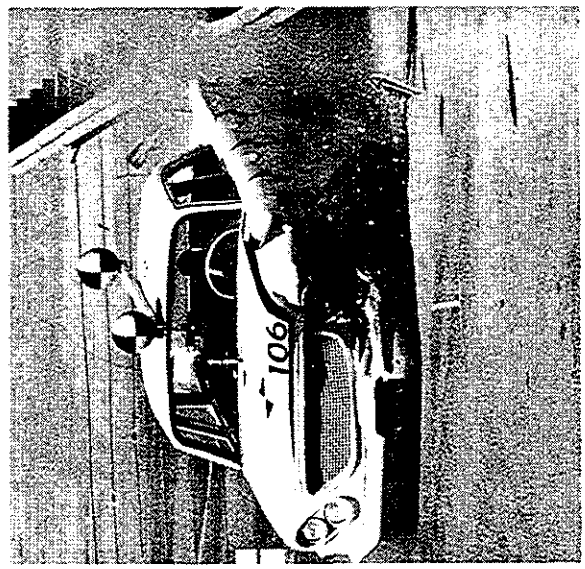
I + .243 Sec.



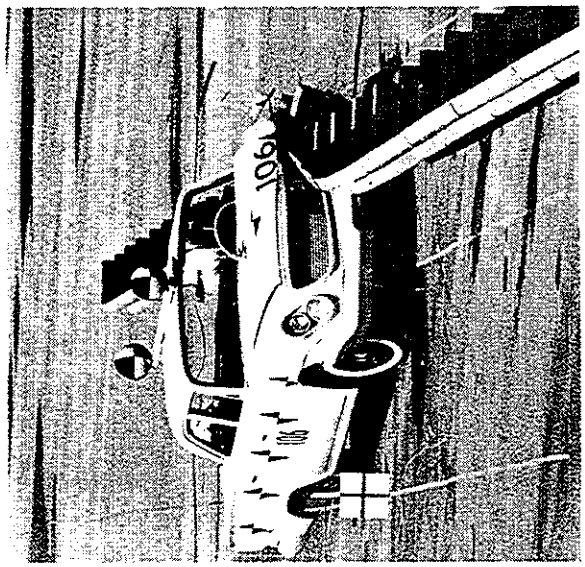
I + .889 Sec.



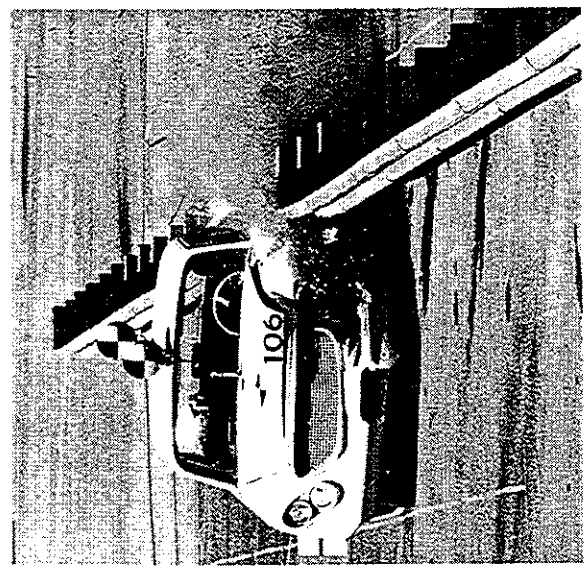
I + .181 Sec.



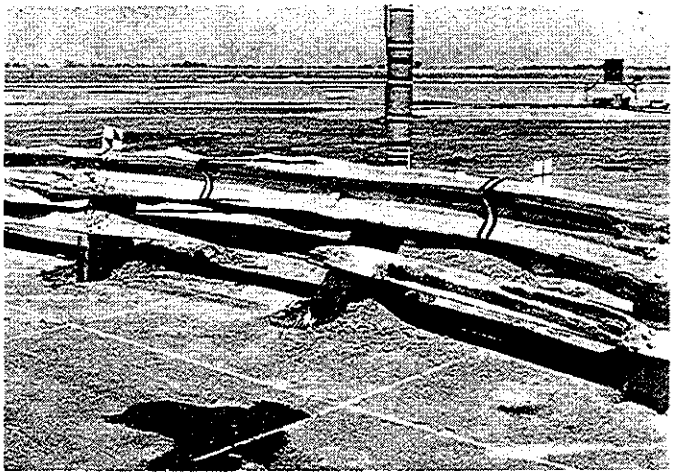
I + .624 Sec.

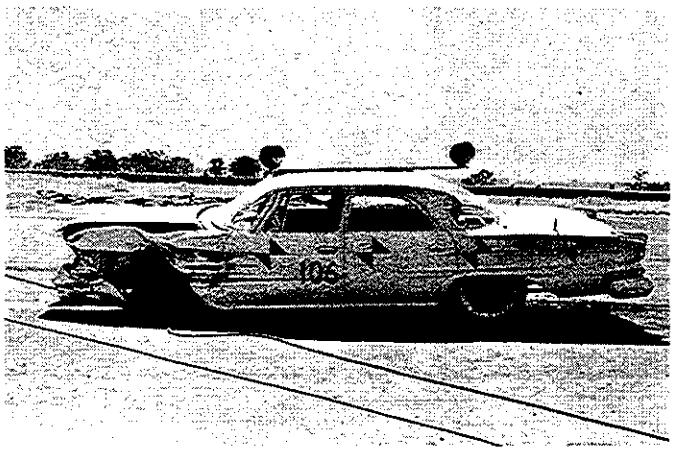


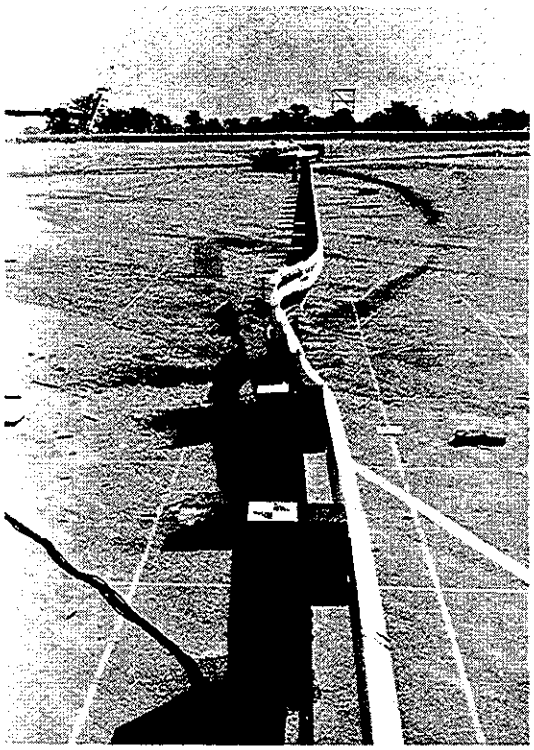
Impact + .082 Sec.

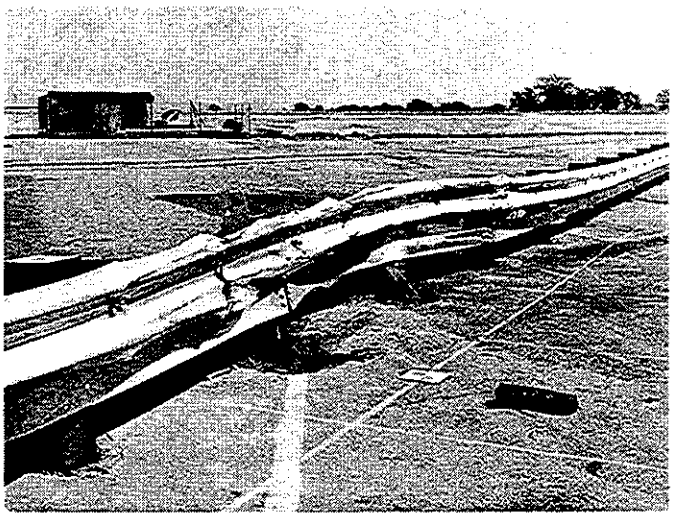


I + .373 Sec.

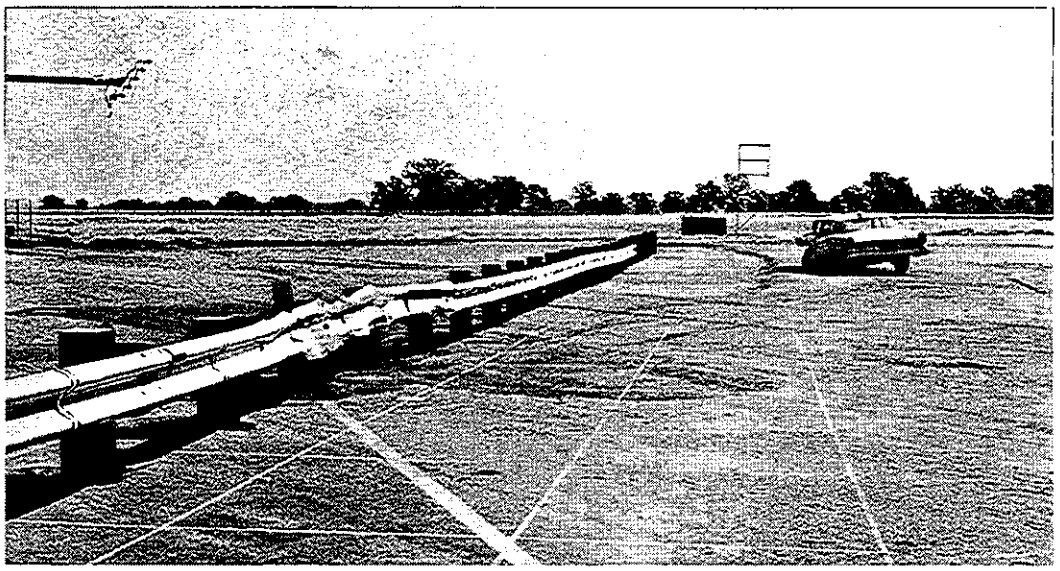



106





TEST 107 PLATE A



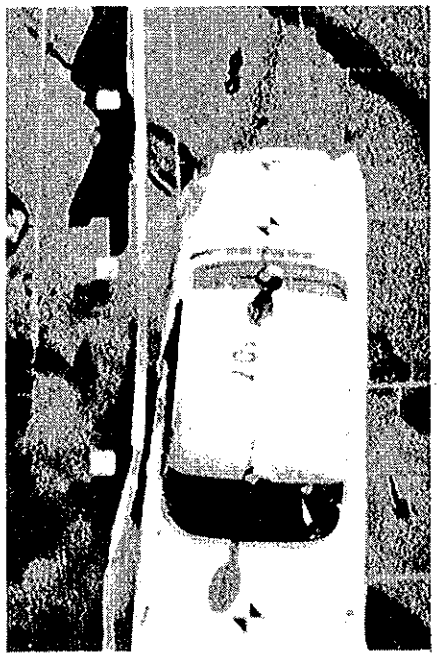
BARRIER: Blocked-out metal beam guard railing with standard 12 gage (0.105 inch) galvanized steel "W" section beam mounted at an over-all height of 27 inches above the ground on 8 in. by 8 in. timber posts spaced at 6 ft. 3 in. centers.

PURPOSE: To test the effectiveness of the current California standard blocked-out metal beam guard railing design with the beam over-all height increased from 24 in. to 27 in. and the post spacing decreased from 12 ft. 6 in. to 6 ft. 3 in.

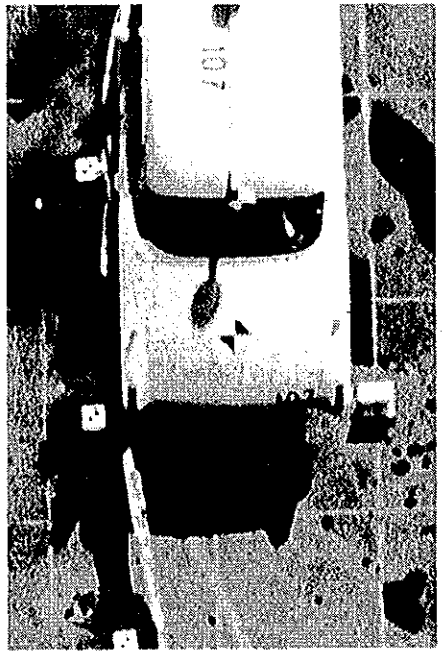
PERFORMANCE: The vehicle struck the railing at a post and remained in contact for approximately 13 feet before being redirected to an exit angle of 17 degrees and to a maximum rebound of 19 feet. The vehicle came to rest approximately 78 feet from the point of impact. There was no tendency for the vehicle to jump or roll.

BARRIER DAMAGE: Three 12 ft. 6 in. sections of beam were damaged. Four posts were knocked out of alignment and two additional posts were split. Two block-out blocks were splintered and three were split.

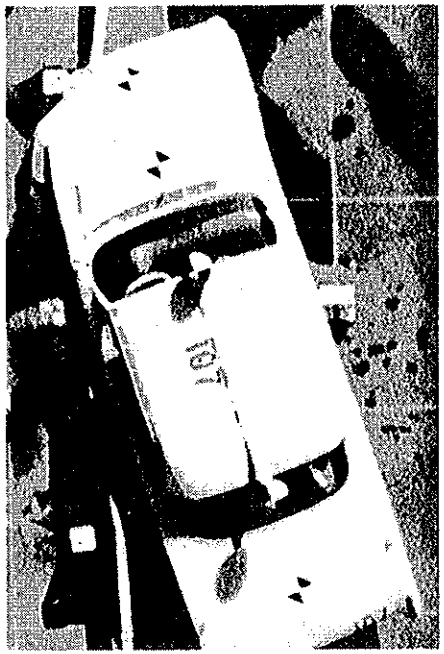
VEHICLE DAMAGE: The vehicle was a total loss.



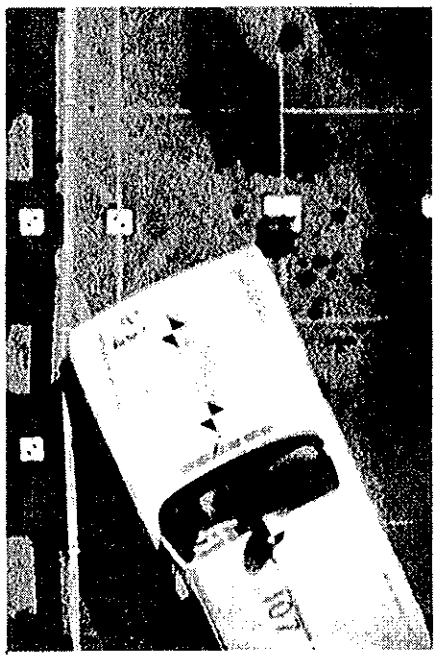
IMPACT + 384 M Sec



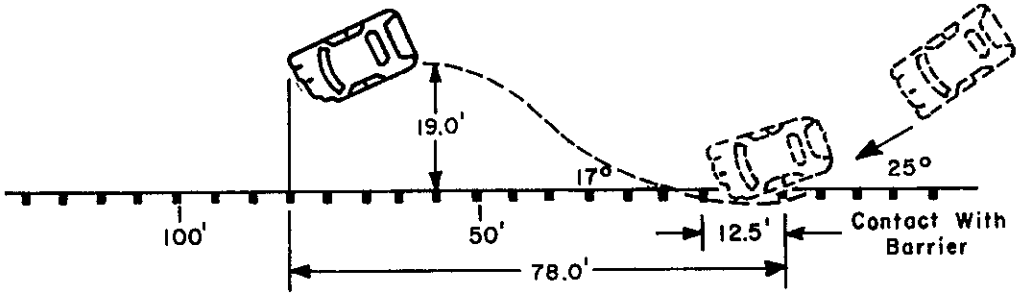
IMPACT + 280 M Sec

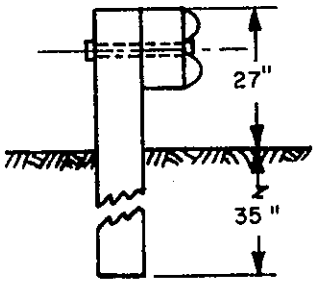


IMPACT + 112 M Sec



IMPACT

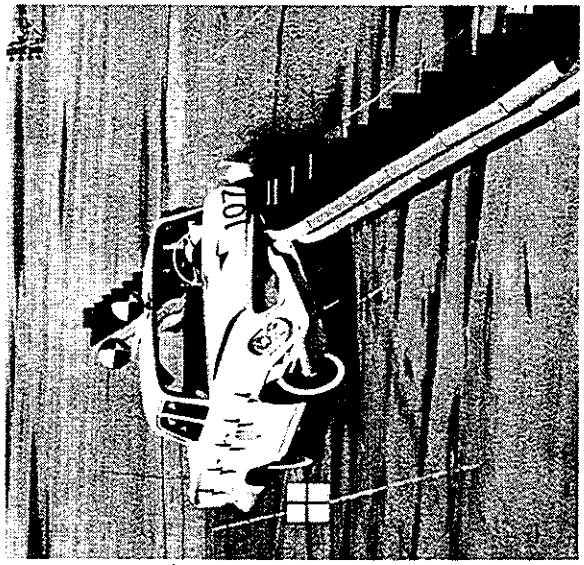




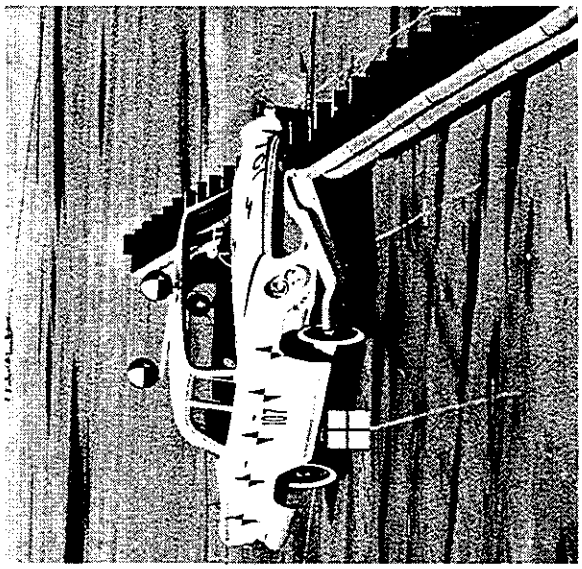
METAL BEAM GUARD RAILING

BEAM RAIL	12 ga. Galv. Steel x 12'-6"
BOTTOM 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"

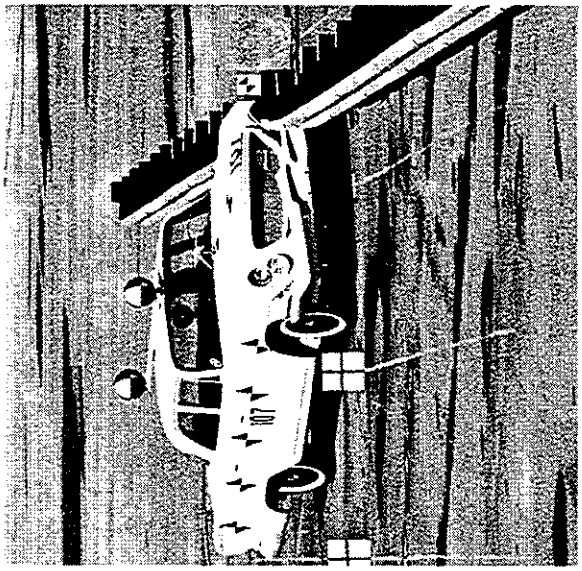
TEST NO.	107
DATE	10-1-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570#
IMPACT SPEED	60 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	17°
DUMMY RESTRAINT	Lap Belt



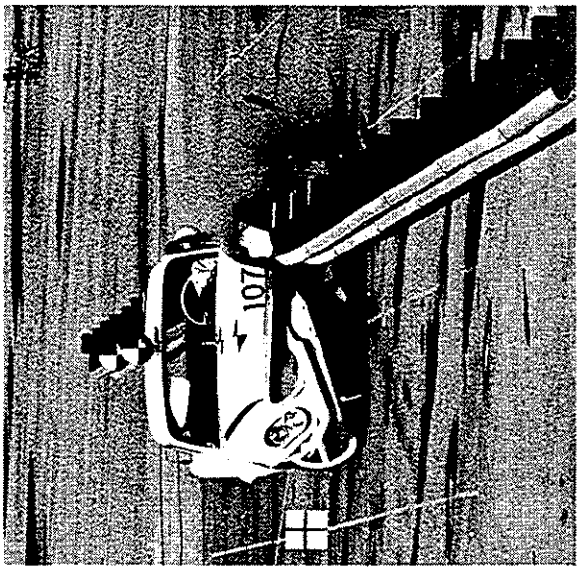
Impact + .045 Sec.



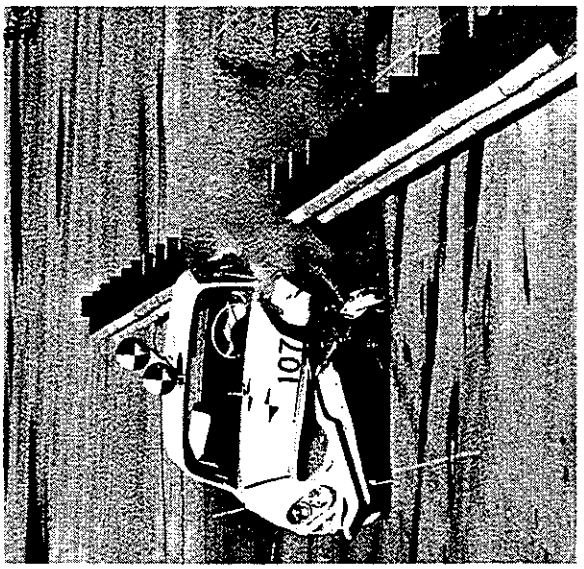
I + .090 Sec.



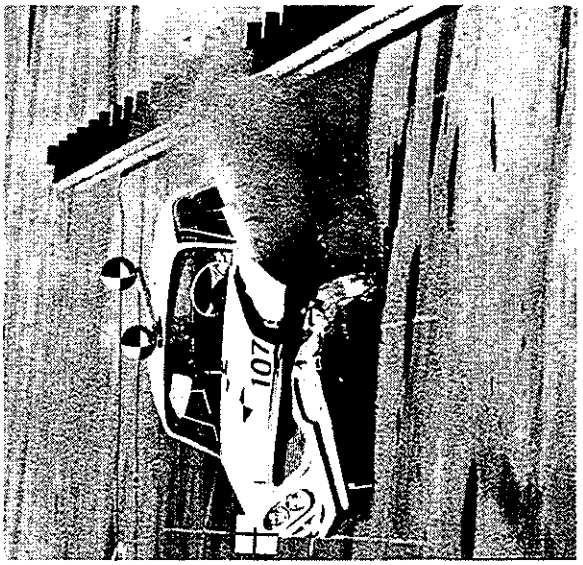
I + .180 Sec.



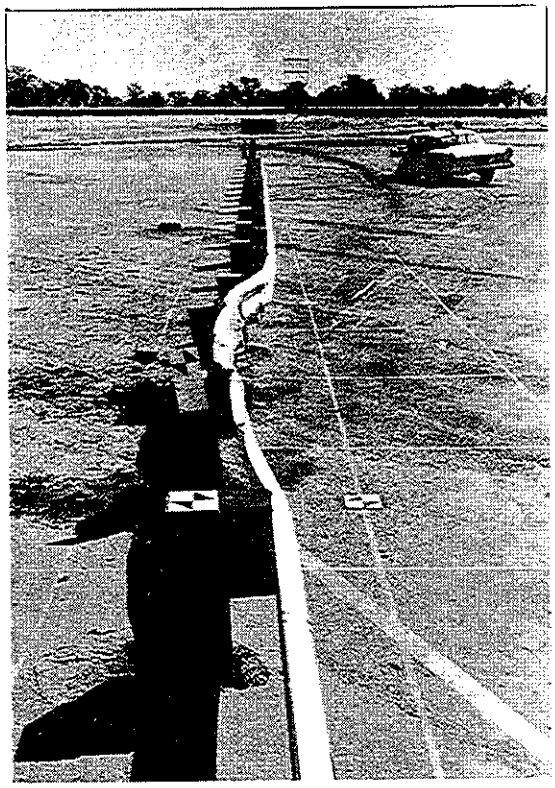
I + .360 Sec.

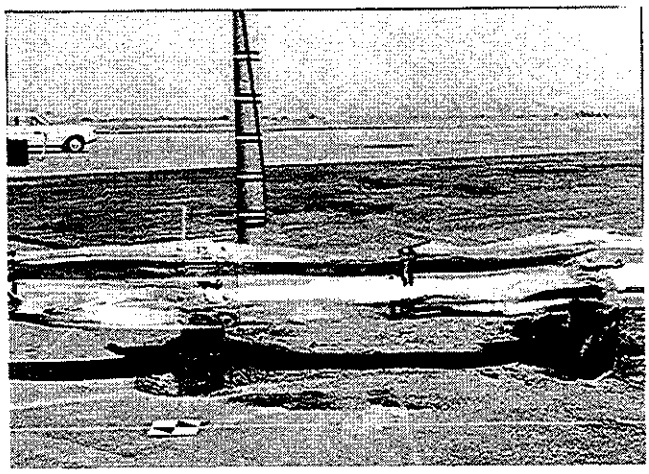


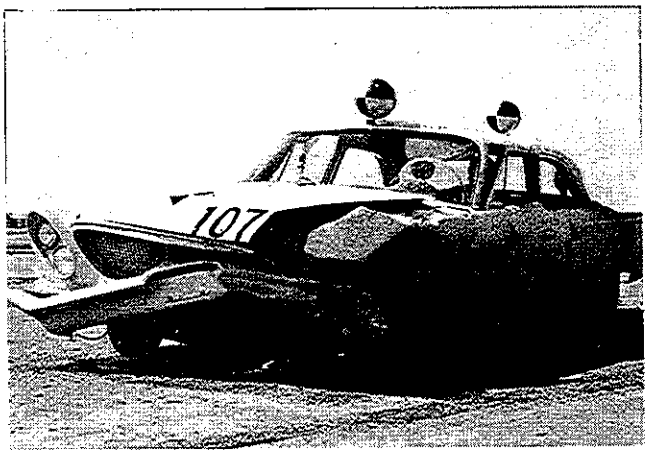
I + .405 Sec.



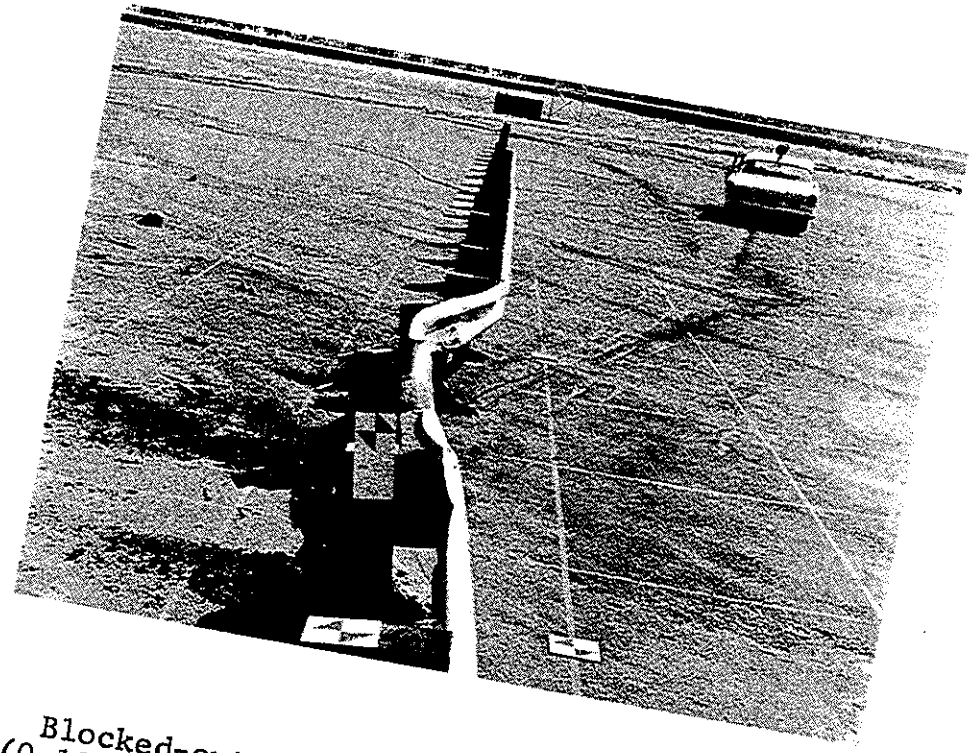
I + .601 Sec.






107

TEST 108 PLATE A



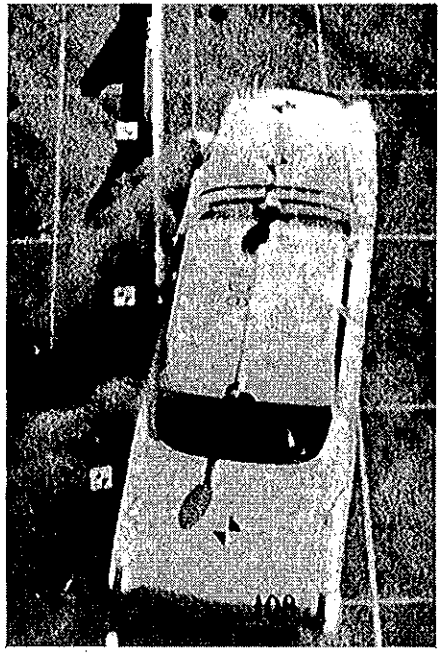
BARRIER: Blocked-out metal beam guard railing with standard 12 gage (0.105 inch) galvanized steel "W" section beam rail mounted at an over-all height of 24 inches above the ground on 8 in. by 8 in. timber posts spaced 6 ft. 3 in. on centers.

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

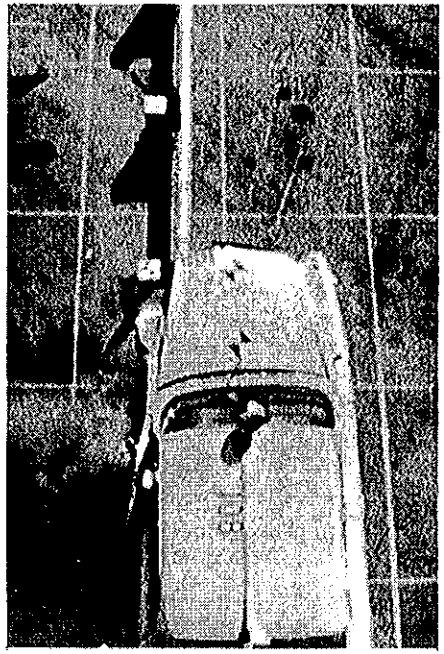
PERFORMANCE: The vehicle struck the railing between posts and remained in contact for approximately 13 feet before being redirected to an exit angle of 19 degrees and to a maximum rebound of 19 feet. The vehicle came to rest approximately 84 feet from the point of impact. There was no tendency for the vehicle to jump. A maximum roll of 5 degrees to the left was imparted to the vehicle.

BARRIER DAMAGE: Three 12 ft. 6 in. sections of beam were damaged. Five posts were knocked out of alignment and five additional posts were split. Two block-out blocks were splintered and four were split.

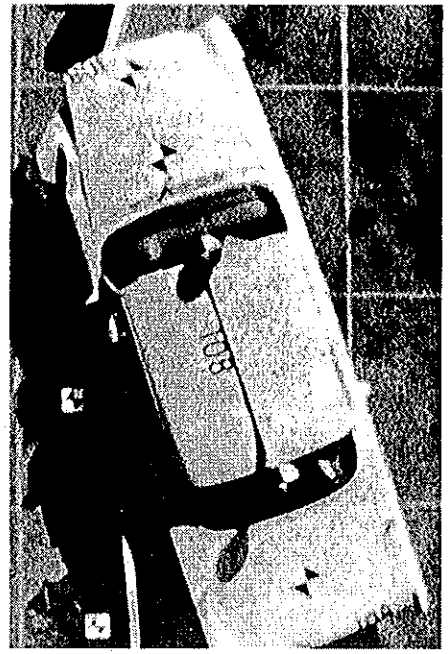
VEHICLE DAMAGE: The vehicle was a total loss.



IMPACT + 317 M Sec

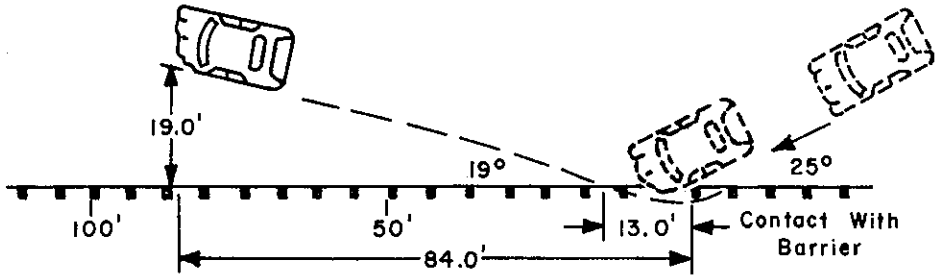


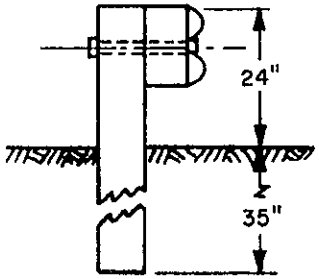
IMPACT + 177 M Sec



IMPACT + 125 M Sec

IMPACT

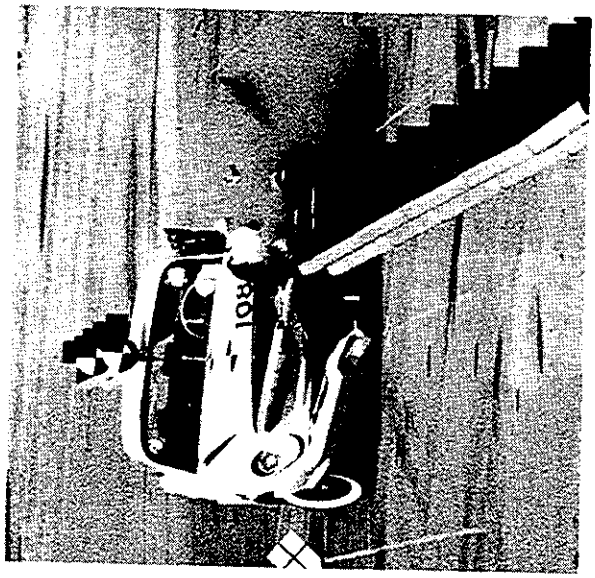




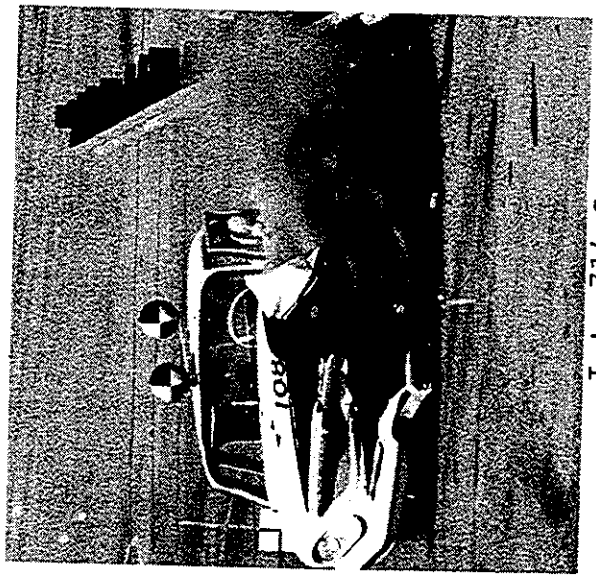
METAL BEAM GUARD RAILING

BEAM RAIL	12 ga. Galv. Steel x 12'-6"
BOTTOM 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"

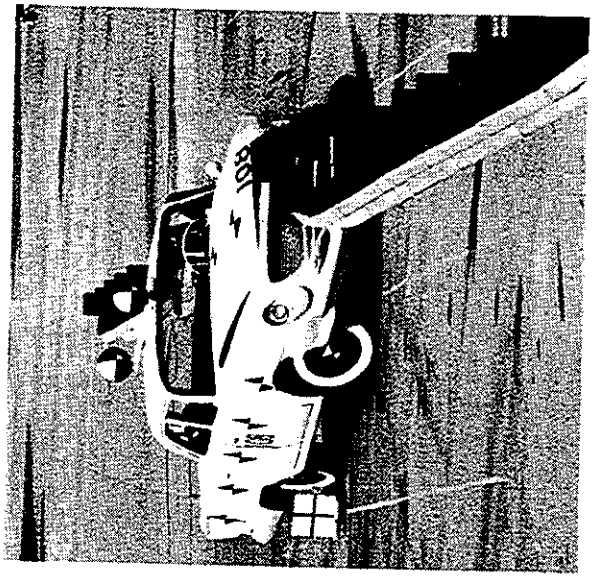
TEST NO.	108
DATE	10-7-64
VEHICLE	1962 Chrysler Sedan
VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION)	4570 #
IMPACT SPEED	59 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	19°
DUMMY RESTRAINT	Lap Belt



I + .304 Sec.

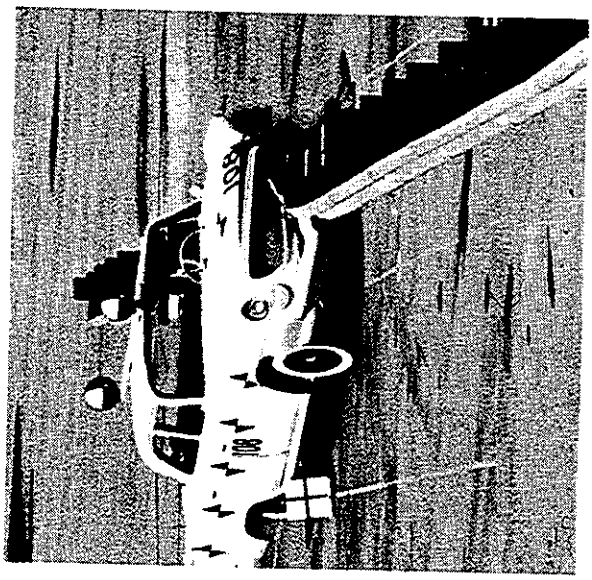


I + .714 Sec.

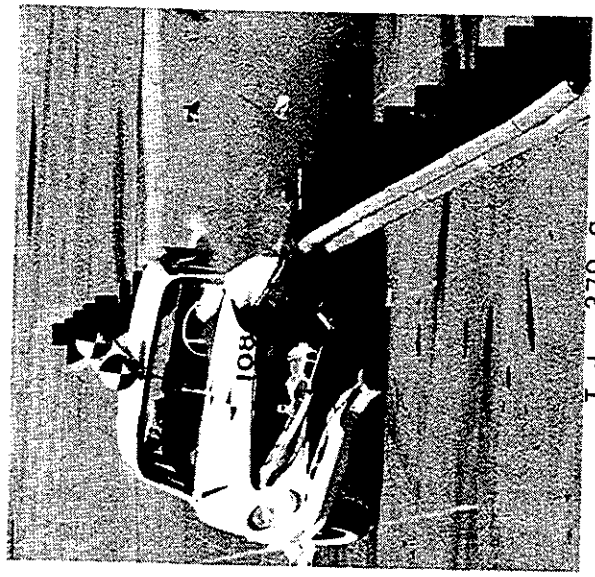


I + .171 Sec.

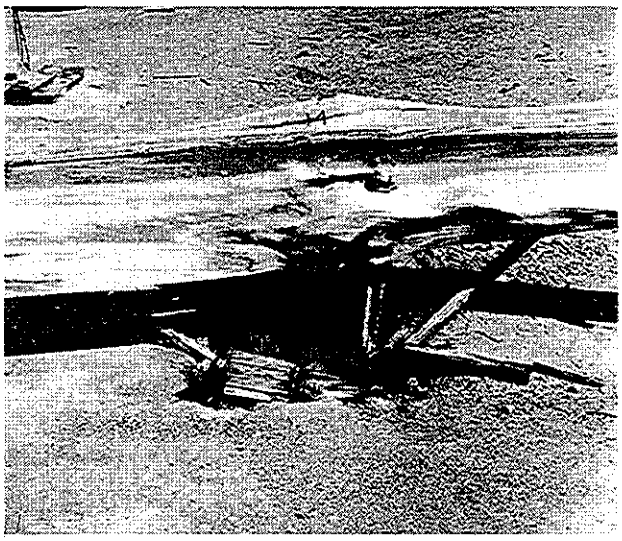
I + .536 Sec.

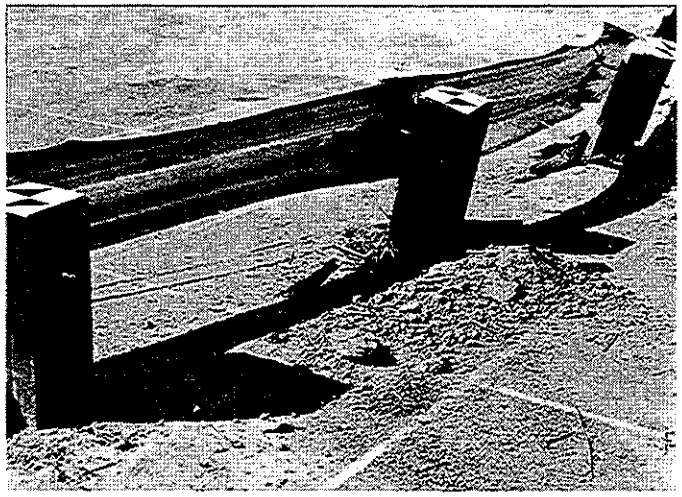


Impact + .118 Sec.



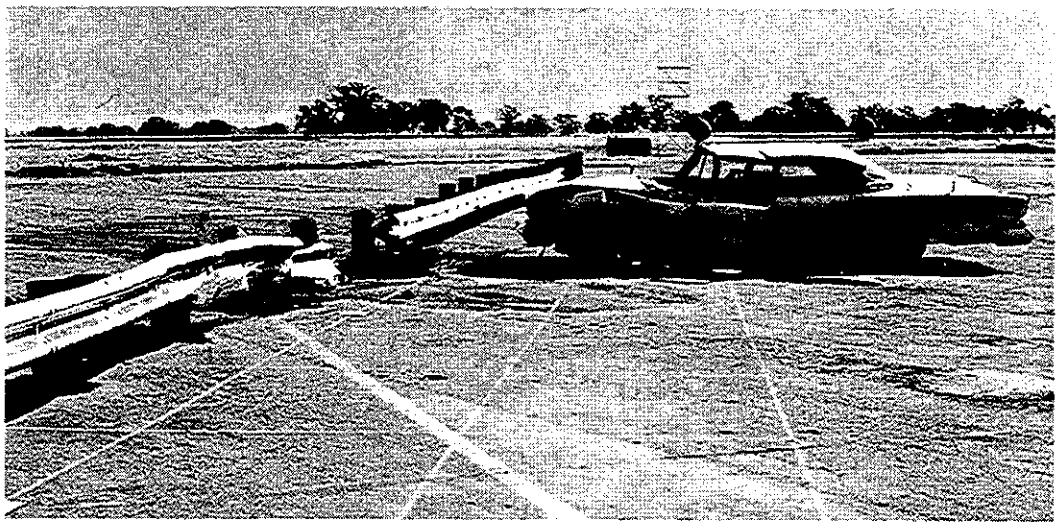
I + .379 Sec.





108

TEST 109 PLATE A



BARRIER: Blocked-out metal beam guard railing with 0.156 in. thick aluminum alloy Alclad 2024-T3 "W" section beam mounted at an over-all height of 24 inches above the ground on 8 in. by 8 in. timber posts spaced 6 ft. 3 in. on centers.

PURPOSE: To test the effectiveness of the current California standard blocked-out metal beam guard railing design with 0.156 inch aluminum substituted for the standard 12 gage (0.105 inch) steel "W" section beam and the post spacing decreased from 12 ft. 6 in. to 6 ft. 3 in. centers.

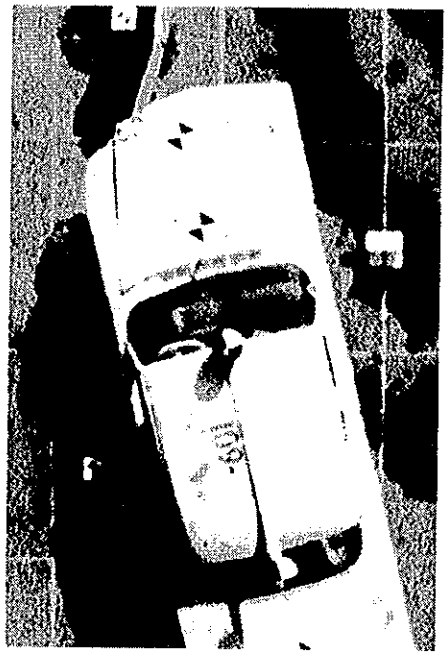
PERFORMANCE: The vehicle struck the railing between posts and remained in contact for approximately 12 feet before the beam separated, causing a violent 100 degree spin-out. As the aluminum beam failed, one 8 foot section penetrated into the passenger compartment through the wheel well and floor boards, impaling the dummy. The vehicle pivoted about this section of beam which subsequently broke off near the wheel well.

BARRIER DAMAGE: Two 12 ft. 6 in. sections of aluminum beam were destroyed. The aluminum 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 damage to the front end, dash board, and front of the passenger compartment. The vehicle was considered a total loss.

IMPACT + 524 M Sec

IMPACT + 330 M Sec



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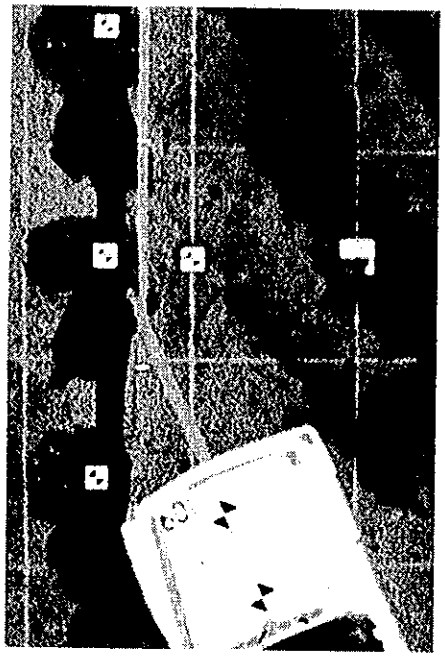

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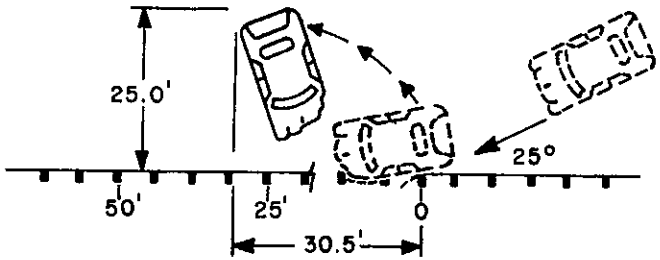
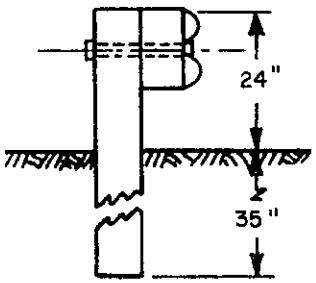
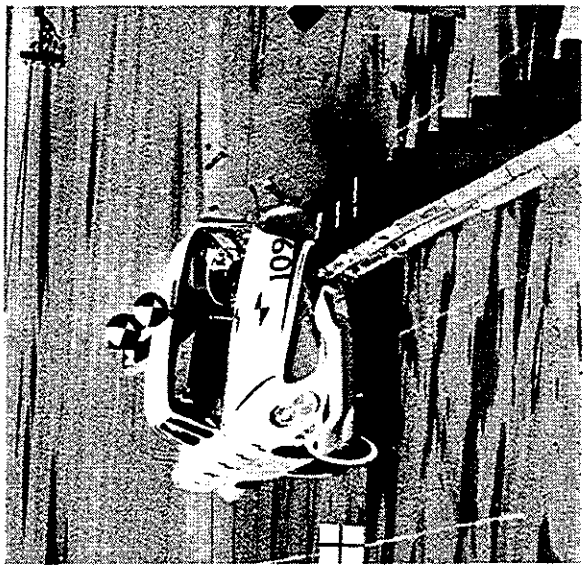




METAL BEAM GUARD RAILING

BEAM RAIL	0.156" Aluminum x 12'-6"
BOTTOM 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 m.p.h.
IMPACT ANGLE	25°
EXIT ANGLE	0° at time of failure
DUMMY RESTRAINT	Type 4



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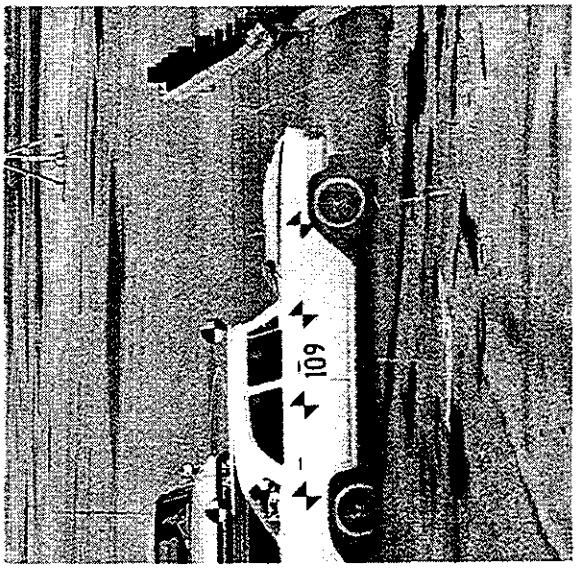

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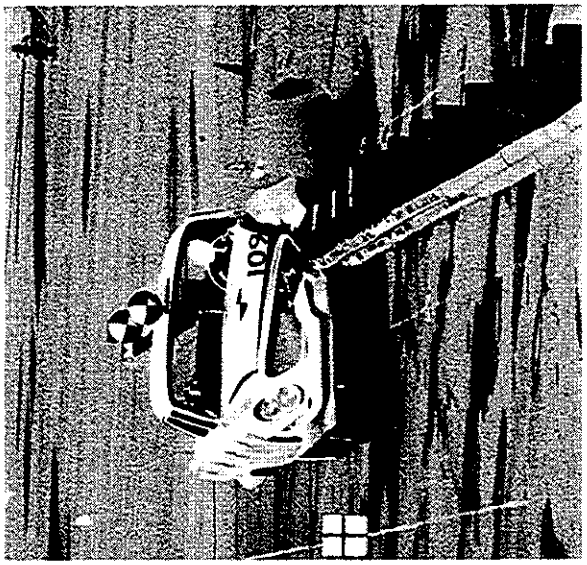
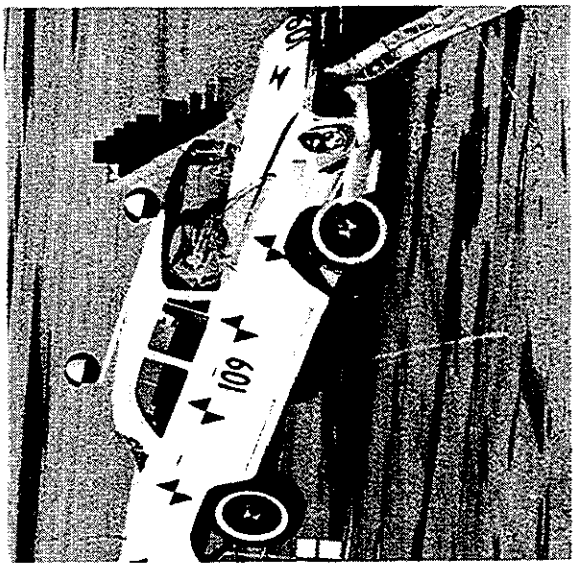


I + .241 Sec.



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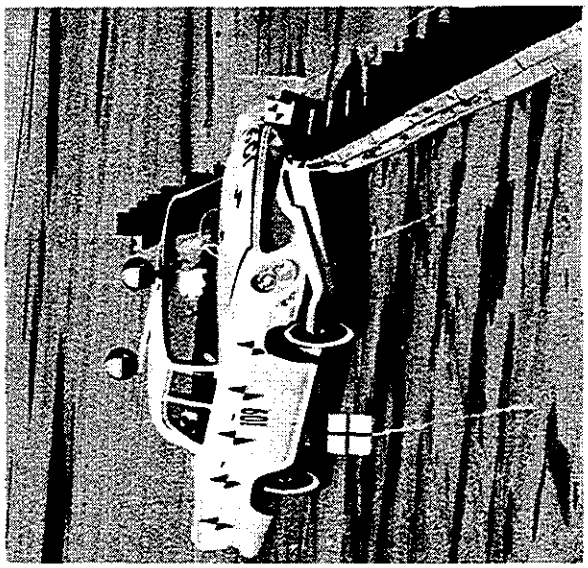

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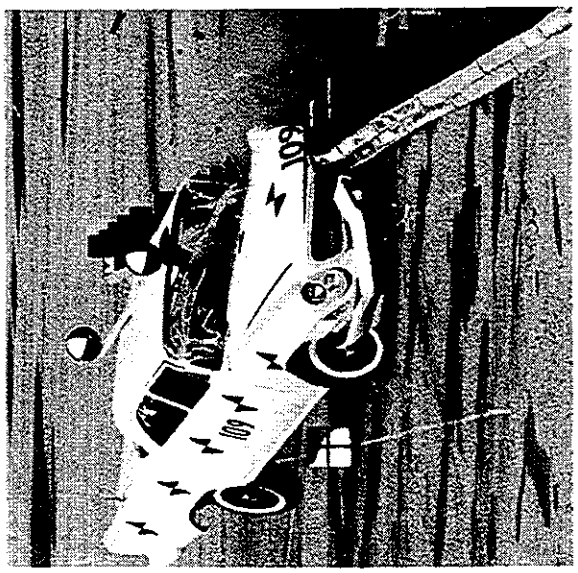

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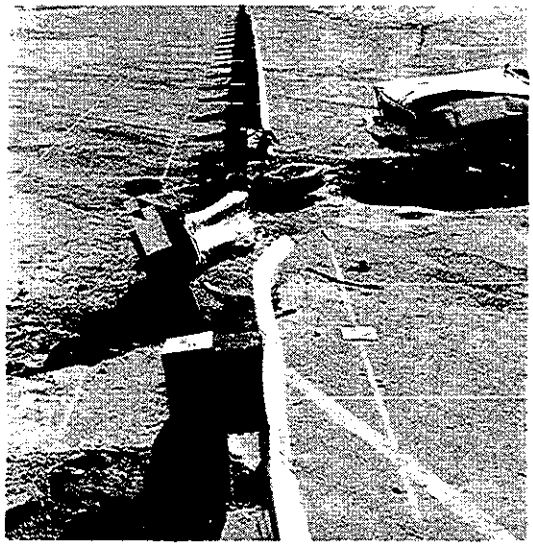
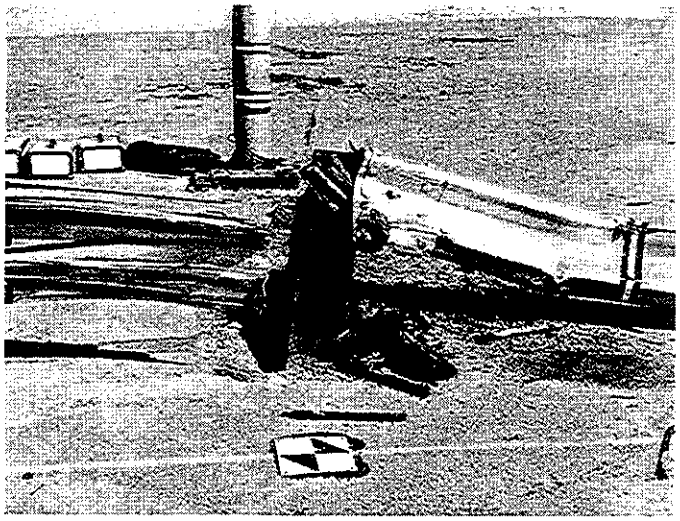
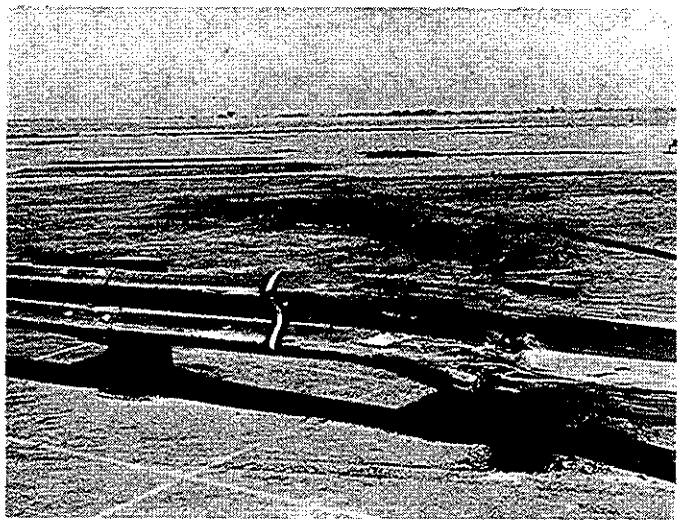
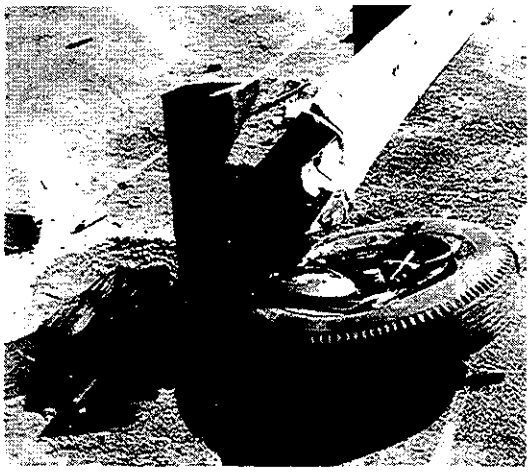
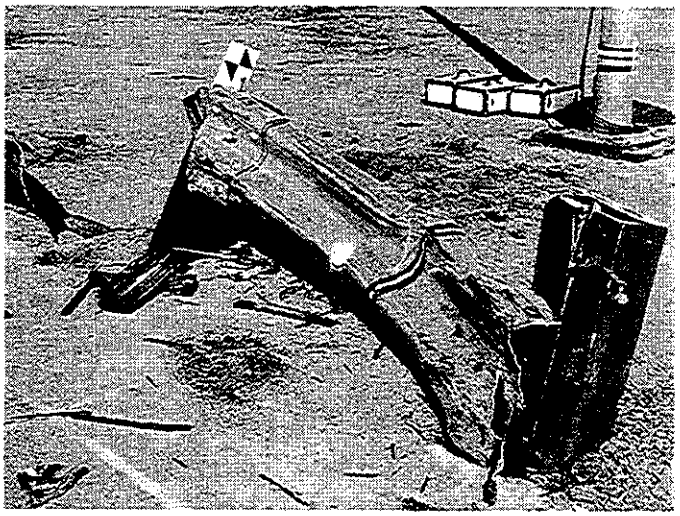
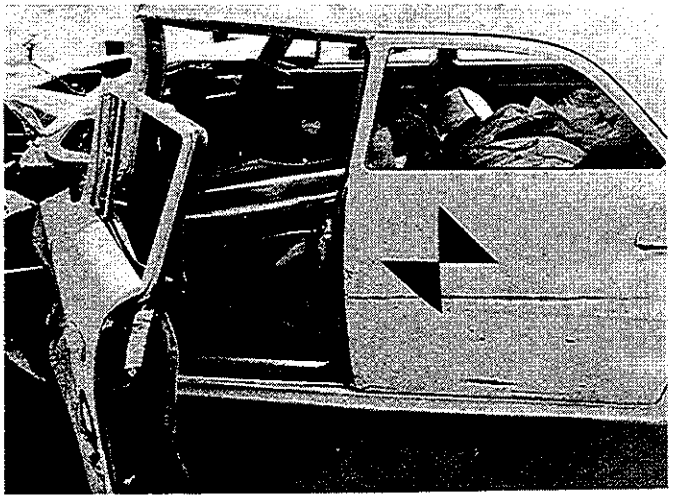


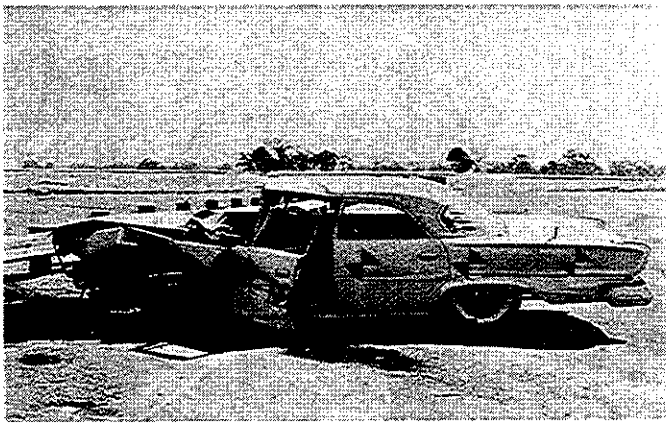












VII. TEST PROGRAM

This series of full scale dynamic impact tests was conducted on a closed runway of the City of Lincoln airport located approximately 32 miles north of Sacramento. The closed portion of the runway is 300 ft. wide and approximately 1500 ft. long. There is no imported base material under the 2 inch thick plant mix bituminous surface.

A. Test Parameters

1. Construction: Each of the four double blocked-out median barrier installations was 200 ft. long. The first three posts (Posts 1, 2, and 3) and the last three posts (Posts 31, 32, and 33) were embedded in concrete to provide added strength to the installation and more closely simulate an infinite length. The test section was shortened to approximately 165 feet for the guard railing tests to simulate a length more closely related to those of problem field installations. However, the concrete embedded Posts 1, 2, and 3 were retained for the guard railing tests to reduce the possibility of an end failure adversely affecting the test results should the test vehicle miss the target point (Post 13) and impact upstream (say at Post 5 or 6). The remainder of the posts for all guard railing tests were embedded in compacted native soil. Many of the posts, particularly those downstream from impact, survived the entire series of nine tests without damage. Some of the posts showed no movement in the soil and required no recompaction during the series.

   As the nine tests were conducted during the dry season, a close correlation could be obtained on the lateral stability of the various designs tested. After each test the soil around those posts loosened during impact was thoroughly recompacted and all damaged posts, block-out blocks and mounting hardware were replaced. Compaction of the backfill for the timber posts was considered equal to or better than that obtained in the field.

2. Test Vehicle: The selection of the retired CHP 1962 Chyrsler sedan for a test vehicle was based on the following requirements established after more than 100 full scale impact tests over a period of ten years.

   a. The vehicle should be equipped with an automatic transmission and be in good mechanical condition for attaining the required impact speeds (60-70 mph) in a minimum distance (600-800 ft.) so that a minimum of radio control guidance would be required.

b. The vehicle should be representative of the average one or two year old standard size passenger vehicle.

VEHICLE	CURB WEIGHT
1962 Chrysler V8	3990 lbs.
1963 Ford Galaxie V8	3990 lbs.
1963 Pontiac Catalina V8	3975 lbs.
1963 Chevrolet V8	3665 lbs.
1963 Buick Le Sabre V8	4120 lbs.
1963 Olds 88	4185 lbs.
1963 Mercury Monterey V8	4150 lbs.

Although the full size V8 is not exactly representative of the average vehicle weight, it does represent the average of the heavier type passenger vehicles that would normally be encountered on our freeways. It would not be practical to use a compact or medium weight vehicle for proof testing a barrier design unless there were specific operational problems involving a particular type or weight passenger sedan. (For instance, small foreign sports cars were used in a recent test series to check on their penetration under cable type median barriers.)

c. All test vehicles should be identical and in the same general mechanical condition. Selection of retired CHP vehicles from a surplus of more than 50 assured us of an ample supply of cars that would meet this condition.

3. Aluminum Alloy: The final selection of Alclad 2024-T3 aluminum for the "W" section beams was confirmed by the Aluminum Association Committee on Highway Applications. The Aluminum Association indicated that their recommendations were based on the results of the industry sponsored Lehigh University impact test program (Ref. 7). The engineering report on the Lehigh test series on aluminum and steel indicated that the aluminum alloy 2024-T3 "W" section beams in 0.125 inch thickness performed satisfactorily in guard railing designs. (It should be noted that the Lehigh tests were conducted at a maximum impact angle of 15 degrees and at 54 to 63 mph impact speed with medium weight (3140-3465 lbs.) passenger sedan test vehicles of 1950 to 1954 vintage.)

The selection of the 6 ⊏ 3.0 aluminum alloy 6061-T6 channel section for the bottom rubbing rail on the double blocked-out median barrier tests was based on the section modulus being approximately the same as that for the current steel channel used as a rubbing rail on the California standard blocked-out beam type median barrier design. A comparison of the two materials is as follows:

Property	Steel 6" 8.2#	Aluminum 6" 3.0#
Area	2.39 in.^{2}	2.55 in.^{2}
Web Thickness	0.200 in.	0.225 in.
Flange Width	1.920 in.	1.945 in.
Sxx	4.30 in.^{3}	4.52 in.^{3}
Syy	0.50 in.^{3}	0.51 in.^{3}

Steel - A-7, F_y = 33,000 psi

$F_a = 0.60\ F_y$ = 19,800 psi

Aluminum - 6061-T6, F_y = 35,000 psi (ASCE)

F_a = 23,000 psi (ASCE suggested specs for aluminum alloys)

Although the 0.125 inch thick aluminum "W" section beam was proposed as thick enough for the double blocked-out median barrier, preliminary analysis of the test parameters (viz: speed, angle, vehicle weight) proposed for this series compared to those used for the Lehigh tests indicated that the aluminum beam thickness should be increased, particularly when used in the blocked-out guard railing design. The next higher gage aluminum in alloy 2024-T3 that was readily obtainable was 0.156 in. thick.

4. Test Procedure: The guard rail portion of this test series was conducted in accordance with the test parameters outlined in Highway Research Board Circular Letter 482 dated September 1962 entitled "Full Scale Testing Procedures for Guard Rails" (Ref. 8). The following test parameters, extracted from Circular 482, have been in use by the California Division of Highways since 1958 and have established a uniformity of testing that aids researchers conducting full scale impact tests under these test procedures:

"The test section of guard rail shall be erected as follows:

1. The rail shall be installed straight and level.

2. Post embedment shall be typical of that expected in the field.

3. The approach surface shall be smooth and stabilized or paved.

4. The minimum length of test section shall be 150 ft., complete with vertical supports, horizontal members and end anchorages, as necessary.

   The test vehicle shall be of standard design, weighing 4000 lbs. plus or minus 200 lbs., with load, and have a center of gravity approximately 21 in. above the pavement.

   Tests shall be made at a speed of 60 mph at impact angles of 7 and 25 degrees."

As this impact series was conducted to proof test the two blocked-out designs, the 7 degree impact angle was not considered severe enough and was deleted from the program. All tests were therefore conducted at a 25 degree impact angle.

The median barrier portion of the test series was conducted in accordance with the above with one exception. An impact speed of 65 to 70 mph was considered more realistic for simulating the more severe type of median barrier impacts that are encountered on California's freeways and expressways. However, the guard rail tests were conducted at speeds of 58 to 60 mph.

It is interesting to note that while the selection of 60 mph/25 degree test impact for this project is based on review of many accident reports, New York made the same selection through logic.

The following excerpt from the State of New York Research Report 63-2, page 6 (Ref. 11) is reprinted below as an excellent technical explanation for the selection of the 60 mph/25 degree impact test conditions:

"In reviewing the impact conditions, it was realized that when a car is traveling parallel to a barrier and suddenly turns towards the barrier, there is a minimum radius of curvature which the vehicle is capable of negotiating. The vehicle is unable to make a sharper turn simply because the tires will not develop enough centripetal force to provide the necessary radial acceleration. Therefore, by assuming a reasonable coefficient

of friction (.7) and instantaneous full steer into the barrier, the maximum probable impact angle can be computed. These impact angles have been computed for speeds 30, 40, 50 and 60 mph on highways of various widths and are tabulated in Table 2. On a 2-lane highway, the vehicle might cross a 10-foot shoulder before impacting the guard rail, or cross the on-coming lane and then the shoulder for a lateral distance of 25 feet. On a 3-lane highway, the vehicle might cross an additional 15 feet, thus traveling a distance of approximately 40 feet laterally. Based on the above figures, an impact condition of 60 mph at 25° was selected to represent a comparatively severe accident which could be encountered on the highway."

TABLE 2

Computed Impact Angles

Speed (MPH)	Lateral Distance from Car to Barrier: Straight Road				Curved Road (5°)			
	10'	20'	30'	40'	10'	20'	30'	40'
30	28°	40°			29°	41°		
40	21°	29°	37°		22°	31°	39°	
50	17°	24°	28°	34°	18°	26°	32°	37°
60	14°	20°	24°	28°	16°	22°	27°	32°

B. Instrumentation

1. Photographic

For this tenth series of impact tests, photographic instrumentation methods were again used as a primary method of data gathering. Since first used early in 1958, this methodology has been successfully employed although refined considerably. For this Series X test program, improvements in the method of orienting the cameras were adopted, similar to that originated by the Cornell Aeronautical Laboratories for their impact research (Ref. 5). The three ground mounted data cameras (Cameras 4, 5, and 6) were positioned at the same elevation as the sphere targets on the vehicle. This provided greater ease and accuracy in determining vehicle trajectory and deceleration for correlation of data from all nine tests. Exhibit 12 is a dimensional layout of the data cameras including ground targeting and grids. Exhibit 13 is a detailed photograph of the test site impact zone showing tape switches, flash bulbs, and ground targeting. The flash bulb images on the data film provide average vehicle speed over the last 50 ft. before impact.

For plotting the x-y coordinates of the vehicle image through impact from the data films, a Vanguard film analyzer was used. Exhibit 14 shows exit speed and angle in the immediate impact zone, reduced from these coordinates. Butterfly targets mounted on the hood, trunk, and sides of the test vehicle and the 10 in. diameter spheres mounted on an aluminum beam on the top of the vehicle provided excellent targets for plotting (see Exhibit 15). All metallic surfaces of the vehicles were painted with a light grey non-reflective paint to reduce glare and provide maximum contrast for the data camera records.

The flash bulb mounted on the hood of the crash vehicle was fired on impact by a "g" switch mounted on the dashboard. The image from this flash bulb provided an event mark for time correlation of all data cameras including the data camera mounted in the crash vehicle. The pulse from the "g" switch also activated an event marker on the two impact recorders in the crash vehicle to provide time correlation of the impact recordings with all photographic data recordings.

A thorough description of the photographic instrumentation can be found in the engineering report from Series VIII (Ref. 10).

2. Test Vehicles

The eight vehicles used for this test Series X were 1962 Chrysler sedans with 383 cu. in. V8 engines and automatic transmissions. The following preparation procedures were used to modify the vehicles for remote radio control:

a. The back seat, spare tire, and gas tank were removed.

b. A remote operated CO_2 system was installed to activate the brakes on radio command. The ignition was interlocked with the brakes to cut-out when brakes were remotely applied.

c. The foot throttle was attached to an actuator manually activated through a switch (located on the rear trunk deck) by the test coordinator.

d. A one gallon gas tank provided fuel for the crash car.

e. Steering was controlled by a 250 ounce-inch step motor mounted on the dash through a "V" belt drive to the steering wheel.

f. The transistorized radio control unit and translator for the steering motor were mounted on a chassis in the trunk of the vehicle. (It is interesting to note that the radio control unit survived the nine impacts

with no evidence of damage or any failures.). See Exhibits 16-A and B for detailed photographs of the remote control radio equipment.

3. Acceleration

It was believed that significant deceleration data could be obtained from the crash vehicle and the anthropometric dummy by use of mechanical stylus type "Impactograph" recording instruments (Exhibits 16-C and D). However, due to the complexity of the decelerations, and the relatively low frequency response of the stylus assemblies on the impact recorders, no valid comparisons between impact and actual "g" forces could be extrapolated from the test charts recorded during impact. The readings tabulated in Exhibit 14 indicate the relative peak impacts sustained by the vehicle and dummy through collision. The magnitudes are not to be construed as linear. However, when comparing these impact values with door deformation, caused by dummy impact, impact speeds, and types of dummy restraints, a fair indication of the relative intensities of the nine impacts can be determined. The direction of the maximum impact forces for each test appear to be valid substantiated by the damage sustained by the left shoulder of the dummy when the vehicle was violently redirected as in Tests 101, 103, and 104. The high lateral impacts (to the left) on the dummy in Test 109 would be expected as the vehicle was partially redirected before the barrier failed. The extremely high longitudinal impact reading for the dummy on Test 109 was a result of the beam rail element contacting the lower abdomen of the dummy and driving "him" into the back seat of the vehicle. Needless to say, this last test proved fatal to "Sierra Sam".

4. Dummy Restraints (see Exhibits 17 and 18)

The body restraint systems used on the anthropometric dummy for this series were furnished and installed by the California Highway Patrol for the purpose of evaluating the various harnesses under severe impact conditions. The slotted "T" bar bracket mounted on the back of the front seat was developed during Test Series VIII but not fully evaluated at that time. It was found that in order to retain the driver in the car during an oblique collision, a positive method of holding the shoulder straps in position was required.

A full evaluation of the various harnesses used for dummy restraint during the last three test series will be available at a later date.

VIII. REFERENCES

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

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

3. Lundstrom, L. C. and P. C. Skeels, "Full-Scale Appraisals of Guardrail Installations by Car Impact Tests", Highway Research Board Proceedings, Volume 38, 1959.

4. Finkbiner, N. M., "Highway Guard Fence", Oregon State Highway Department Technical Bulletin No. 21, April 1950.

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

6. Davisson, M. T. and S. Prakash, "A Review of Soil-Pole Behavior", HRB 39, 1964.

7. Institute of Research of Lehigh University, "Dynamic Tests of Aluminum Guard Rail".

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

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

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

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

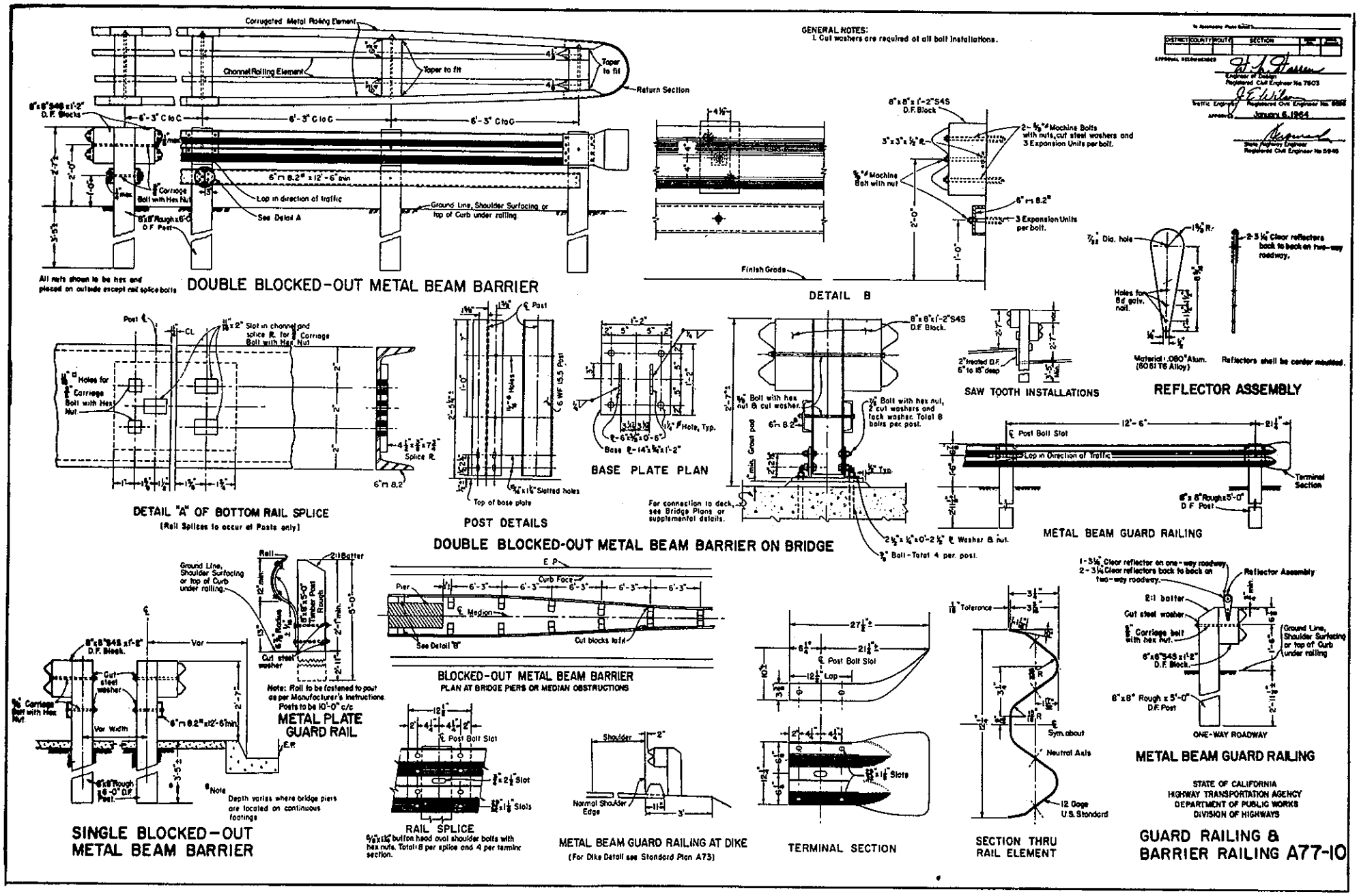
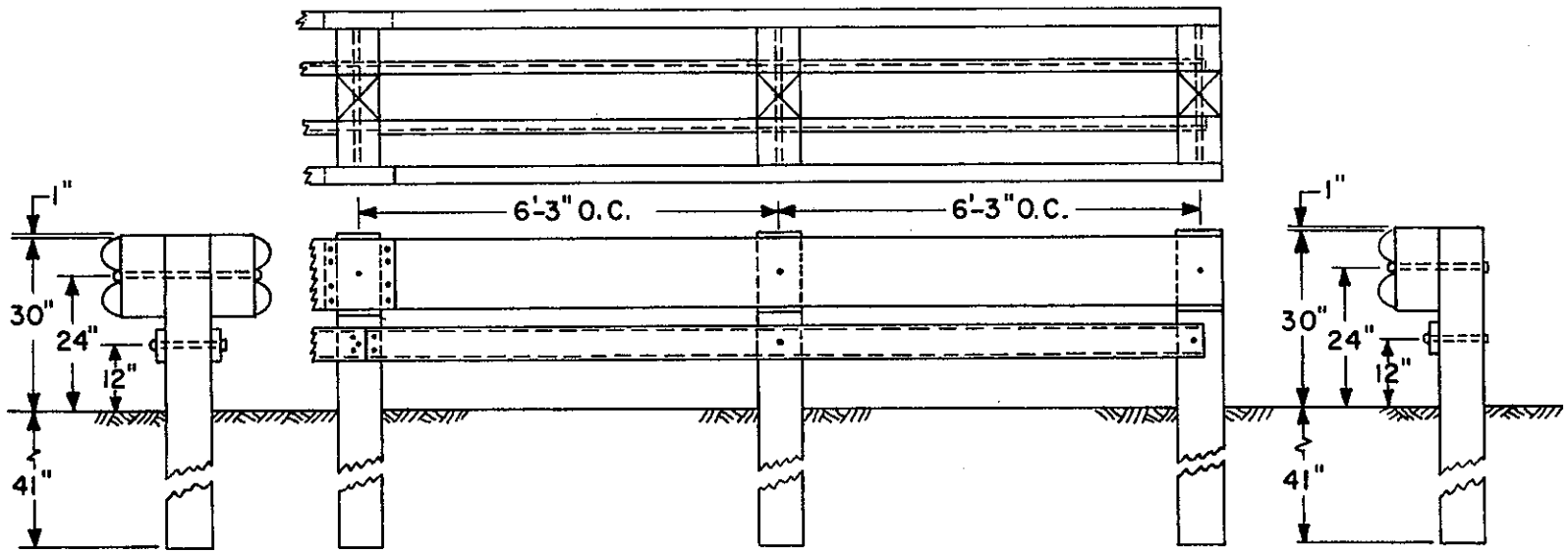

GENERAL NOTES:
1. Cut washers are required at all bolt installations.
DOUBLE BLOCKED-OUT METAL BEAM BARRIER
All nuts shown to be hex and placed on outside except rail splice bolts
DETAIL B
DETAIL "A" OF BOTTOM RAIL SPLICE
(Rail Splices to occur at Posts only)
POST DETAILS
BASE PLATE PLAN
DOUBLE BLOCKED-OUT METAL BEAM BARRIER ON BRIDGE
SAW TOOTH INSTALLATIONS
REFLECTOR ASSEMBLY
METAL BEAM GUARD RAILING
BLOCKED-OUT METAL BEAM BARRIER
PLAN AT BRIDGE PIERS OR MEDIAN OBSTRUCTIONS
METAL PLATE GUARD RAIL
SINGLE BLOCKED-OUT METAL BEAM BARRIER
RAIL SPLICE
METAL BEAM GUARD RAILING AT DIKE
(For Dike Detail see Standard Plan A73)
TERMINAL SECTION
SECTION THRU RAIL ELEMENT
ONE-WAY ROADWAY
METAL BEAM GUARD RAILING
STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
GUARD RAILING & BARRIER RAILING A77-10

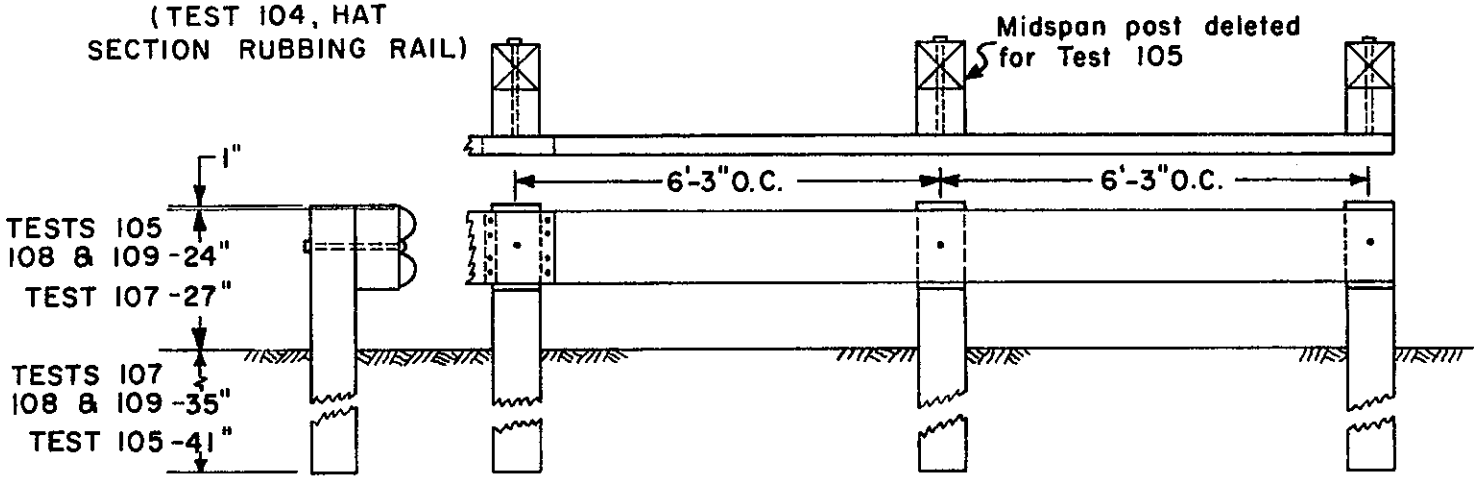
EXHIBIT 1



DOUBLE
TESTS 101, 102
& 103
(TEST 104, HAT
SECTION RUBBING RAIL)

BLOCKED-OUT METAL BEAM BARRIER

SINGLE
TEST 106



NOTE:

All posts and blocks are 8" x 8" D. F. treated.

BLOCKED-OUT METAL BEAM GUARD RAILING
CONSTRUCTION DETAILS FOR TEST SERIES X

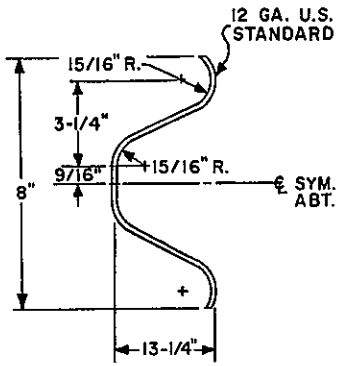
EXHIBIT 2

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			
101	Double Blocked-out Median Barrier	12 ga. Galv. Steel	15"	30"	36"	—	5°	69 m.p.h.	15°	18'
102	Double Blocked-out Median Barrier	0.125" Aluminum	—	30"	Failed	Roll Over		67 m.p.h.	—	—
103	Double Blocked-out Median Barrier	0.156" Aluminum	9"	30"	35"	— Flat —		67 m.p.h.	14°	12'
104	Double Blocked-out Median Barrier	12 ga. Galv. Steel	12"	30"	34"	—	3.5°	68 m.p.h.	14°	14'
105	Single Blocked-out Guard Rail	12 ga. Galv. Steel	5"	24"	16"	— Jump —		58 m.p.h.	30°	—
106	Single Blocked-out Median Barrier	12 ga. Galv. Steel	21"	30"	34"	— Flat —		60 m.p.h.	13°	19'
107	Single Blocked-out Guard Rail	12 ga. Galv. Steel	18"	27"	29"	— Flat —		60 m.p.h.	17°	13'
108	Single Blocked-out Guard Rail	12 ga. Galv. Steel	18"	24"	28"	5°	—	59 m.p.h.	19°	13'
109	Single Blocked-out Guard Rail	0.156" Aluminum	—	24"	Failed	8° Before Failure	—	60 m.p.h.	—	—

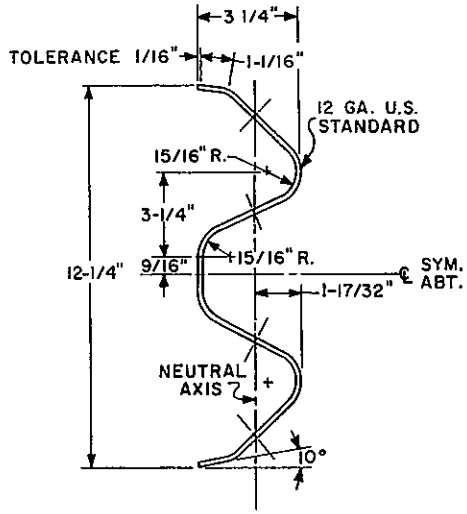
* Exit angle measured as vehicle leaves barrier.

EXHIBIT 3

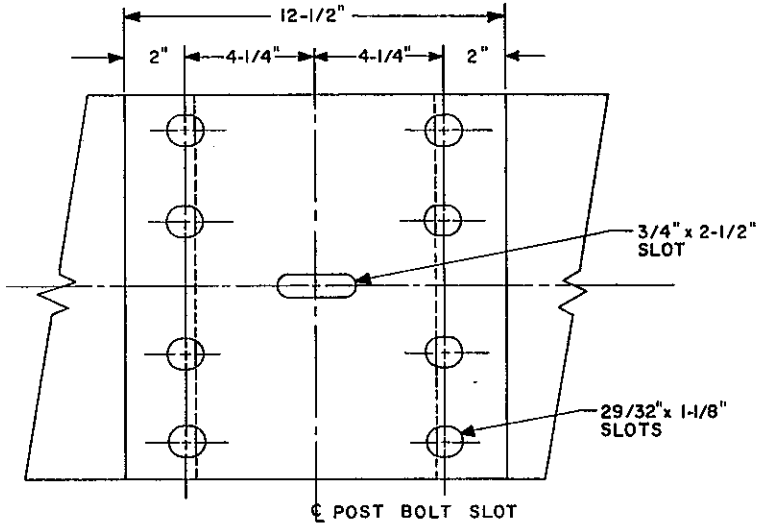


ROLL FORMED "HAT" SECTION RAIL ELEMENT

(Proposed for rubbing rail)

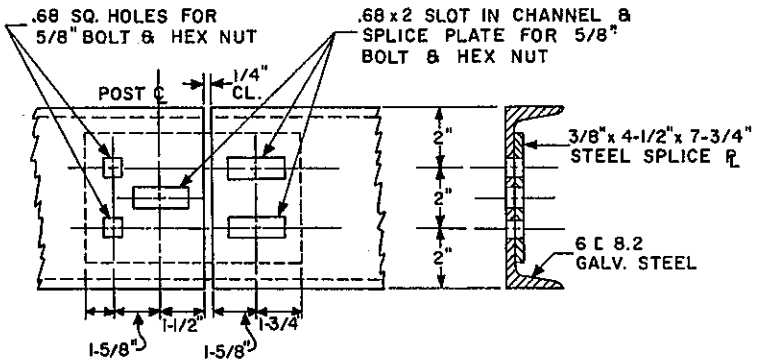


SECTION THRU BEAM ELEMENT

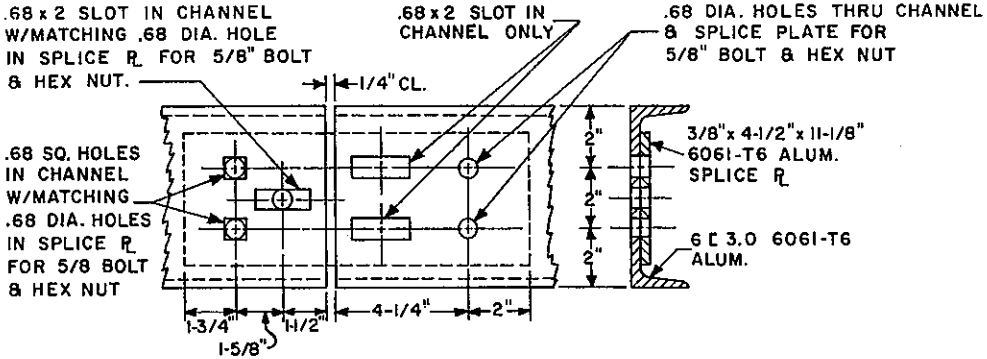


BEAM SPLICE

5/8" x 1-1/4" button head oval shoulder bolts with hex nuts.
Total: 8 per splice and 4 per terminal section.



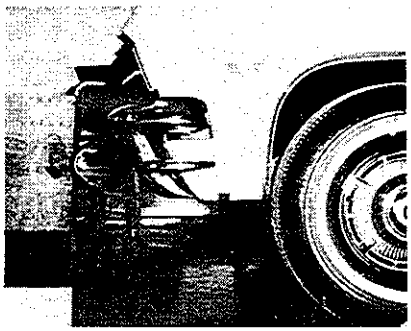
SPLICE DETAIL — STEEL RAIL



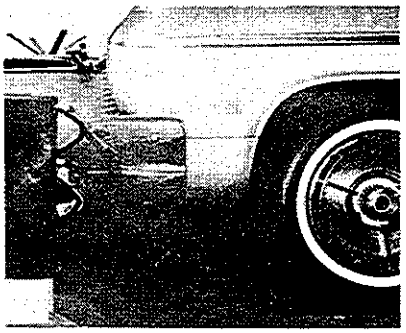
SPLICE DETAIL — ALUMINUM RAIL

SPLICE DETAILS FOR SERIES X

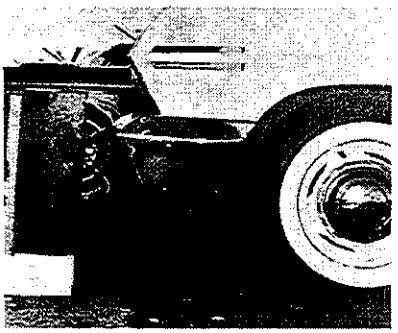
EXHIBIT 4



1965

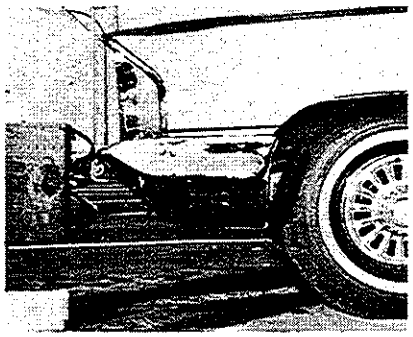


1964

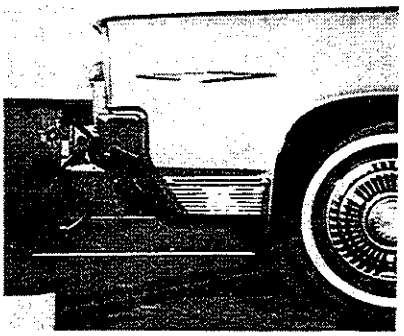


1963

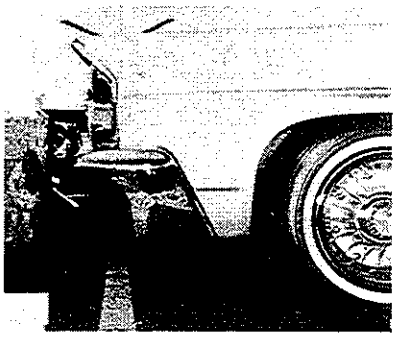
CHEVROLET



1965

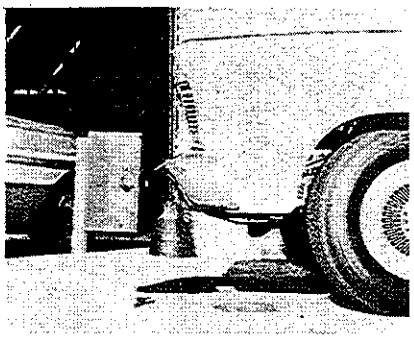


1964

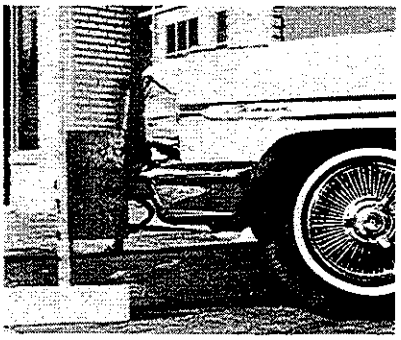


1963

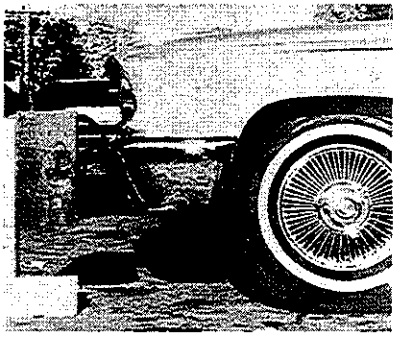
PONTIAC



1965

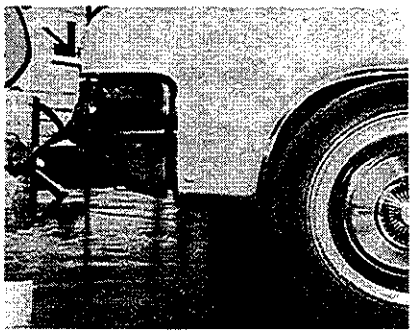


1964

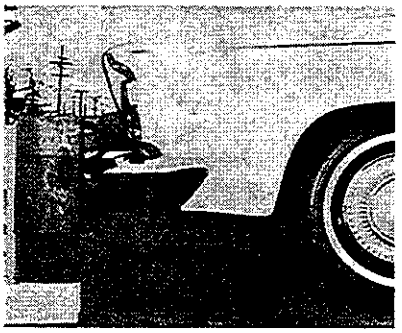


1963

FORD



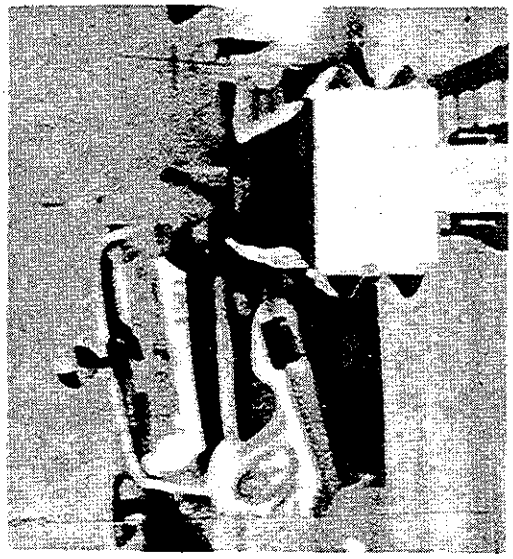
1965



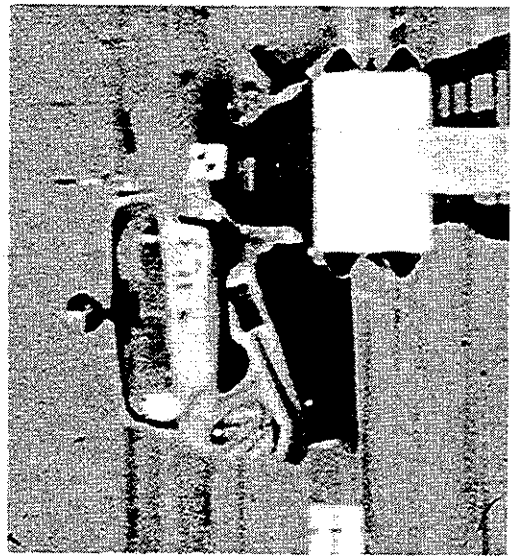
1963 & 1964

CHRYSLER

Comparison of vehicle bumper heights to standard 24 inch high guard rail.



Test 101



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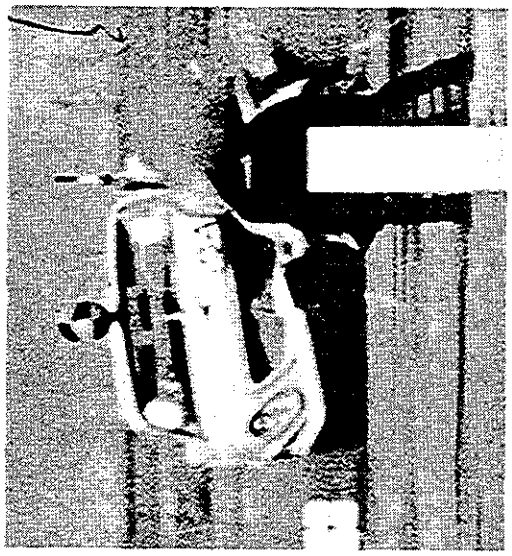

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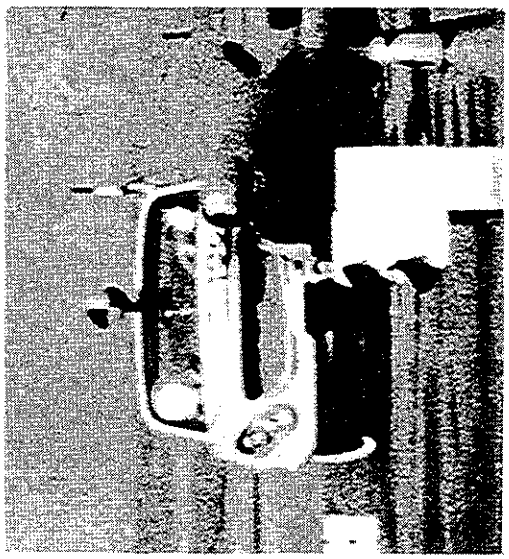

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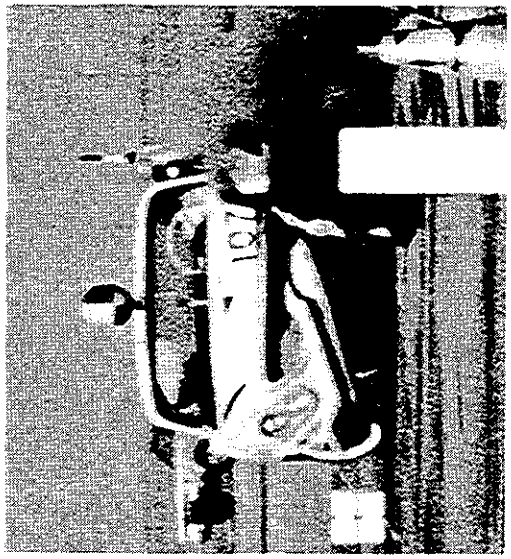
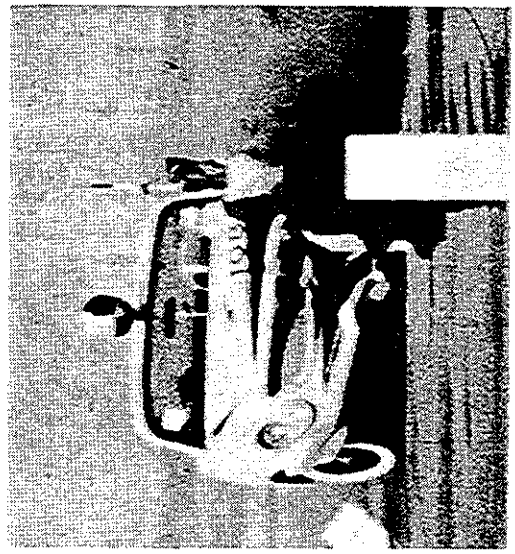
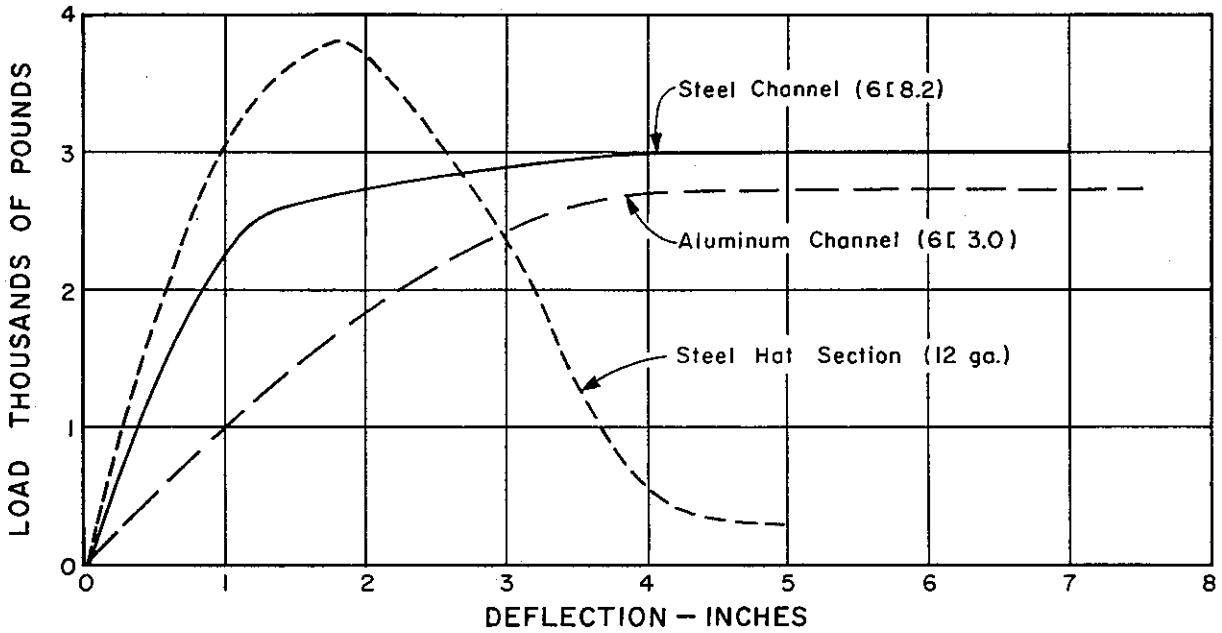


Test 107



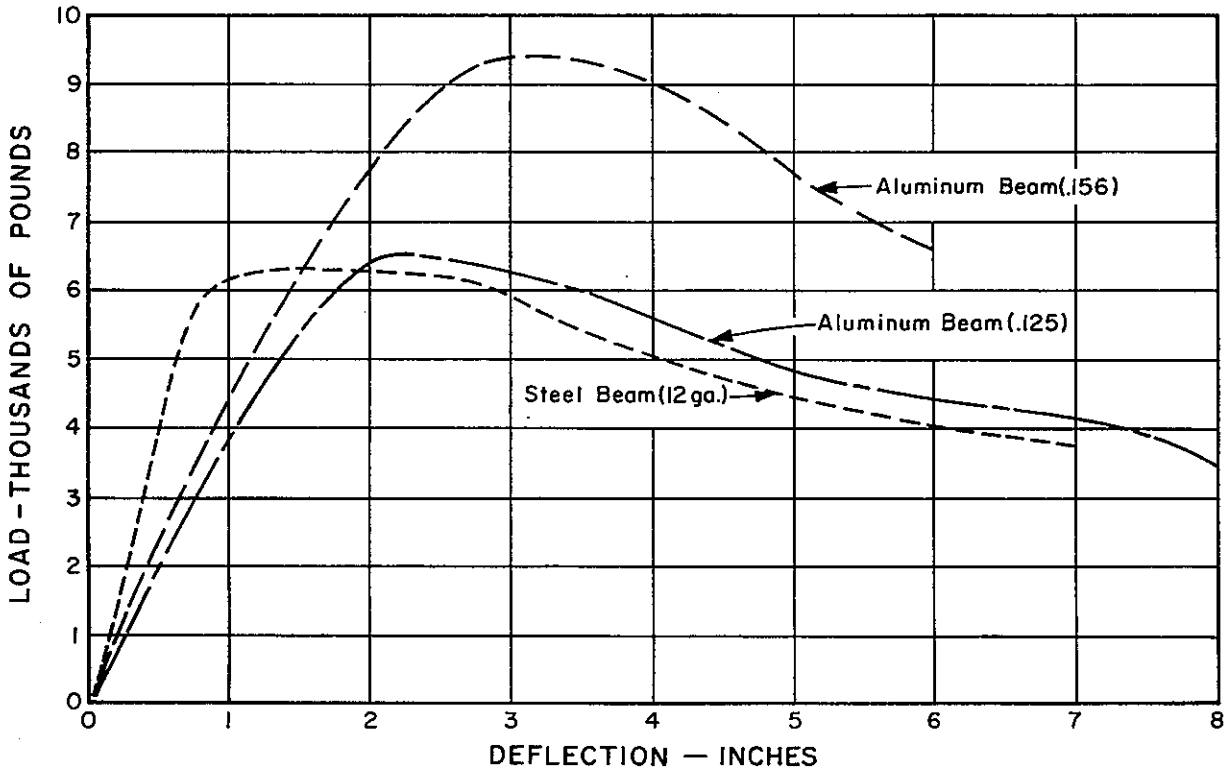
Test 108

CHANNEL DEFLECTIONS

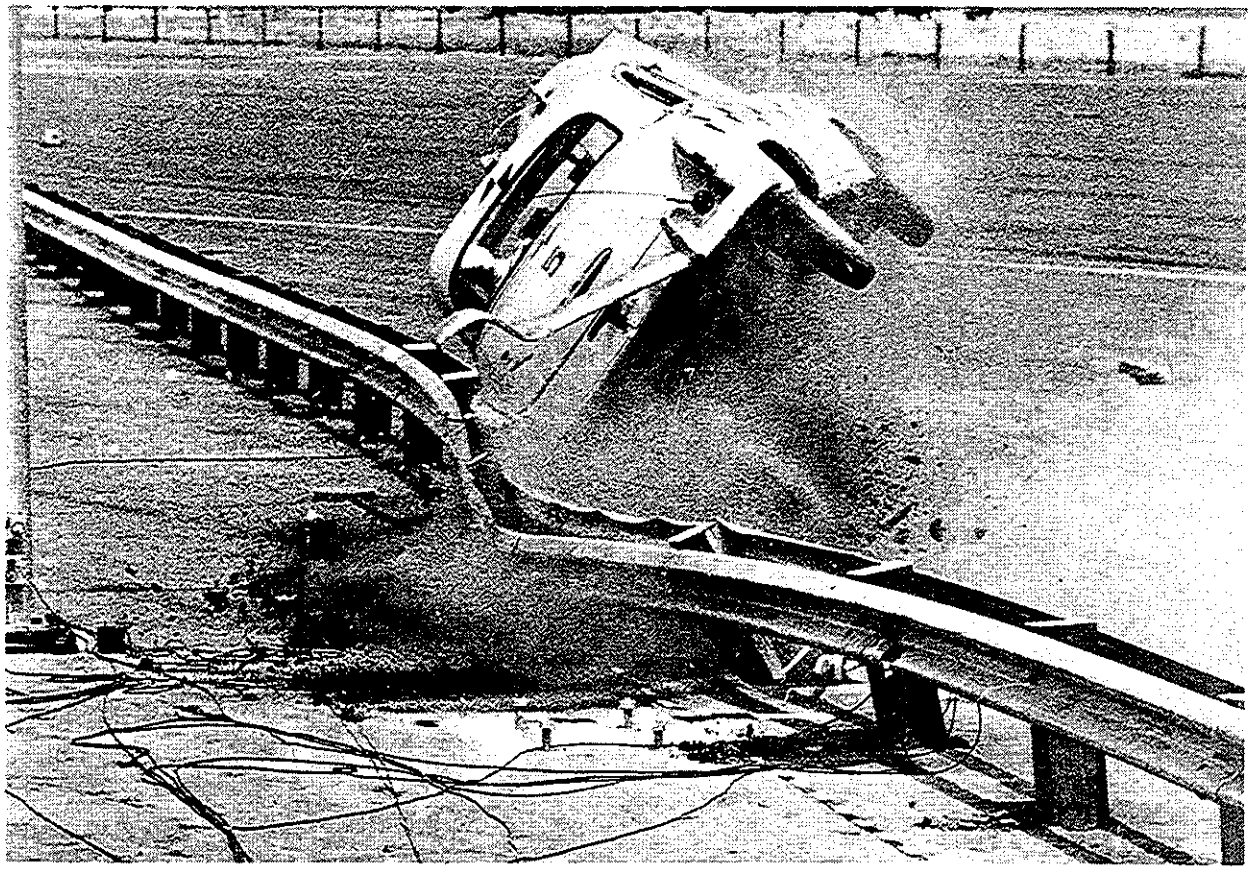


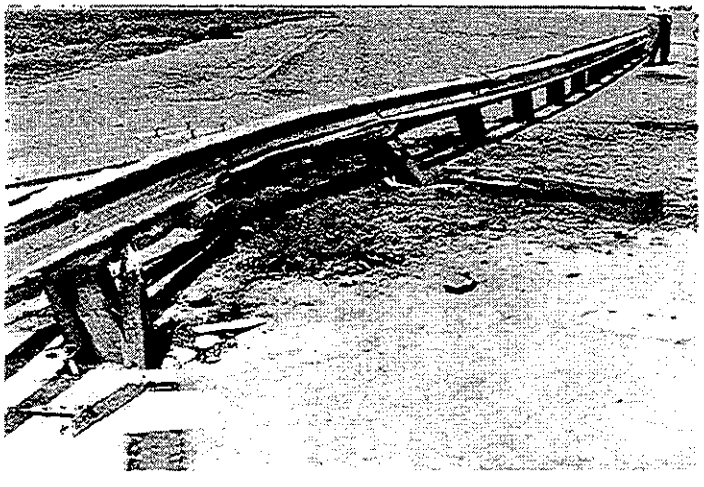
STATIC LOADING OF 6 FT 3 IN. CHANNEL SECTIONS
CONCENTRATED LOAD AT CENTER

BEAM DEFLECTIONS



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

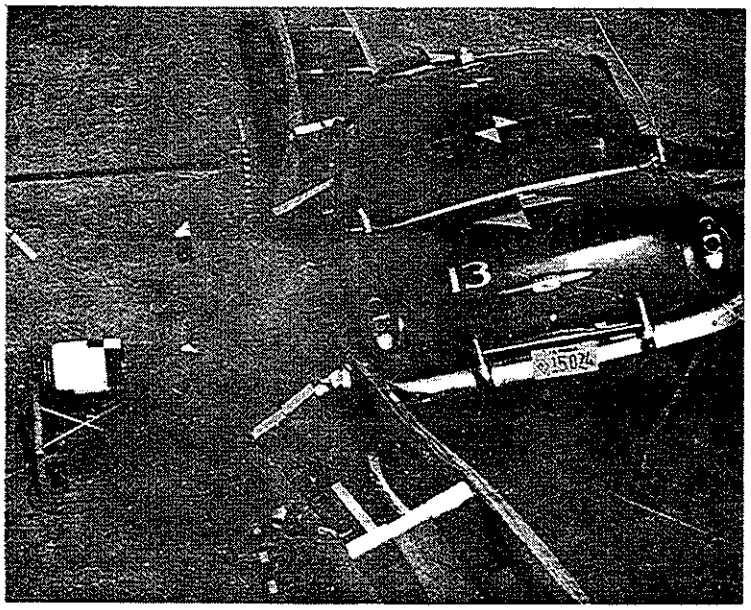


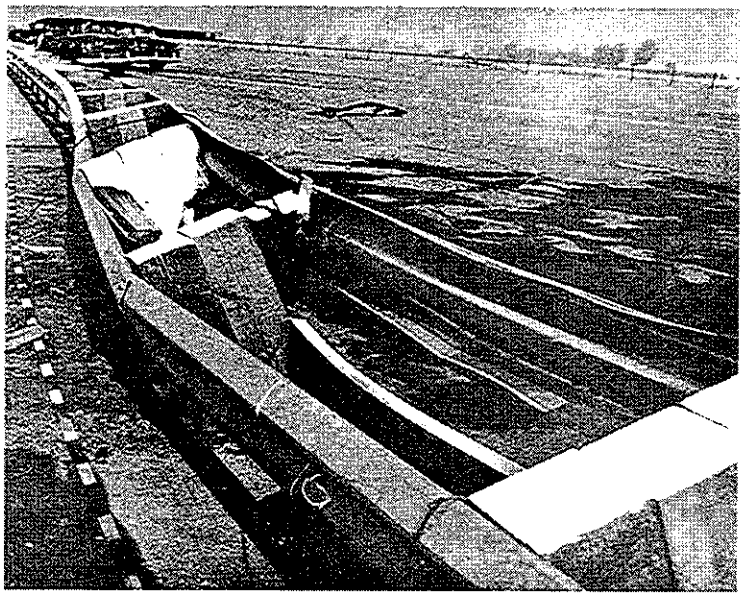


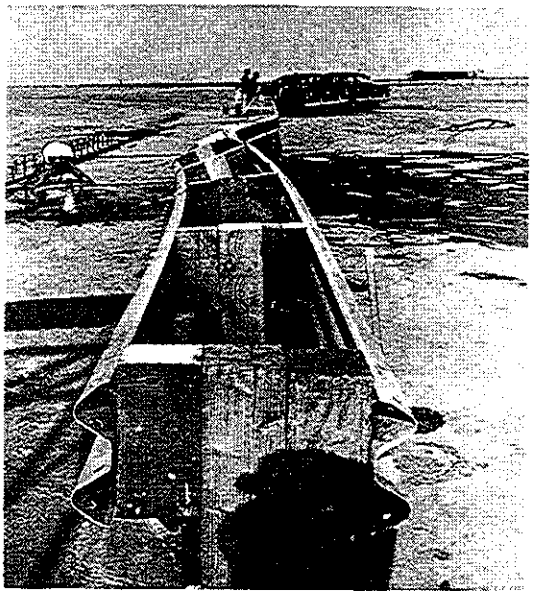
TEST 505 19 8

Double Beam Type "W" Section Rail mounted on 8- x 8- in. D. F. posts at 6 ft. 3 in. centers.

Impact speed	58 mph
Impact angle	31 deg.
Beam height	25 in.



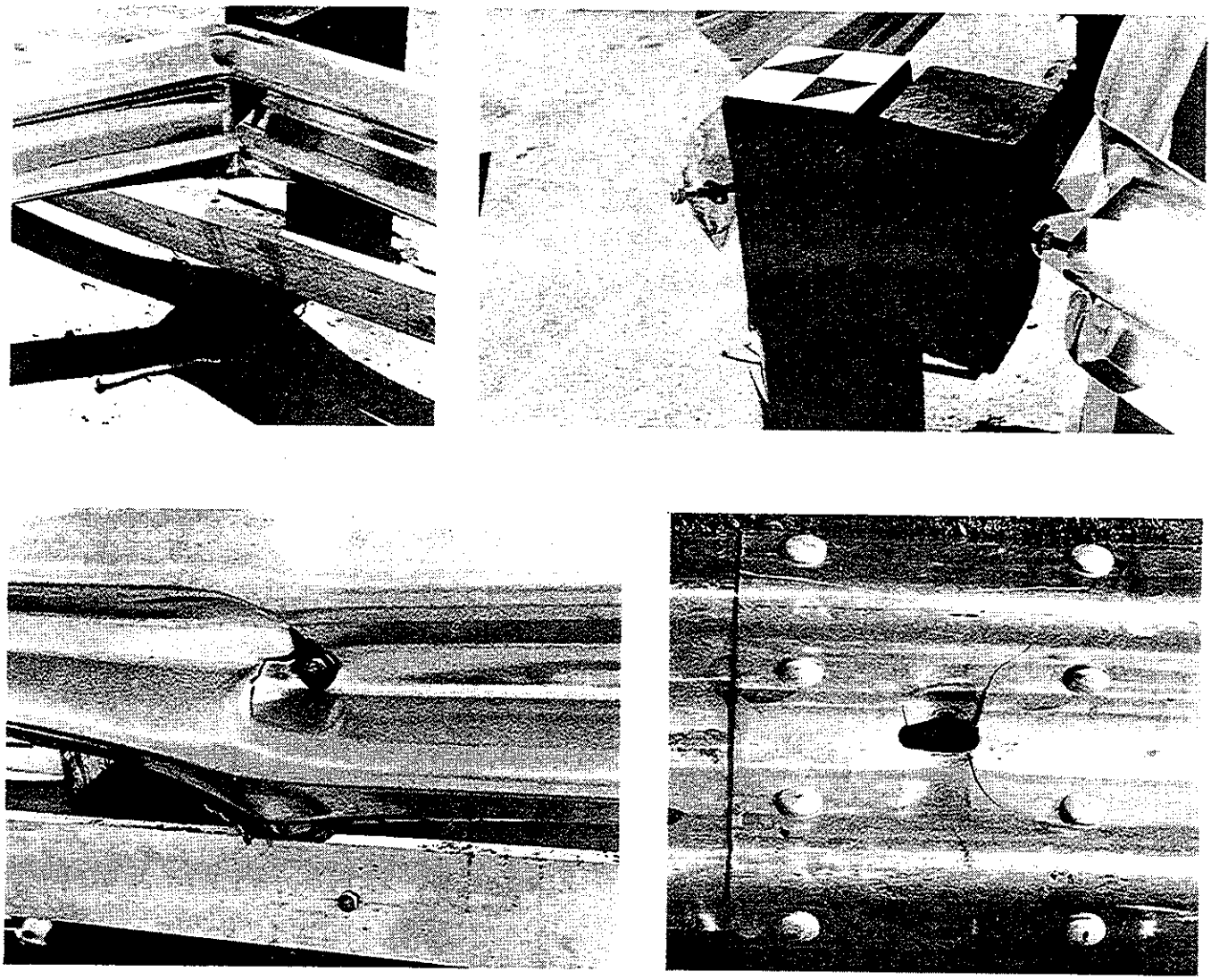




TEST 513 1958

First test on blocked-out metal beam barrier design. 8- by 8- in. D.F. posts on 6 ft. 3 in. centers.

Impact speed	60 mph
Impact angle	32 deg.
Beam height	30 in.



0.125 aluminum failures from Test 102

0.156 aluminum failures from Test 109

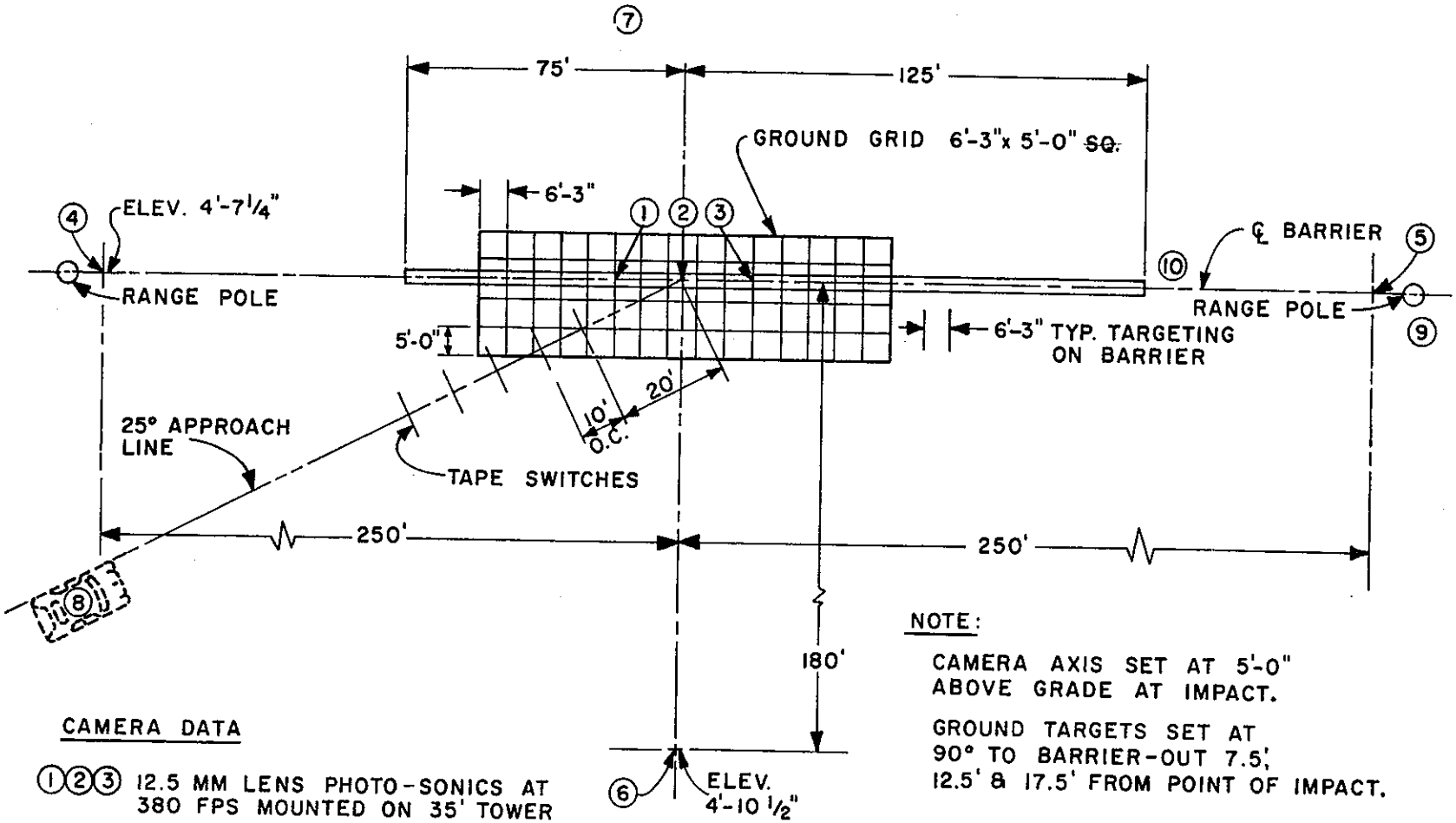
PHYSICAL TEST AVERAGES
ON SERIES X BARRIER AND GUARD RAIL MEMBERS

SPECIMEN	SAMPLE NUMBER	YIELD POINT PSI	ULTIMATE PSI	ELONG. %
Steel Beam	101	54,403	70,313	20.3
	104	54,907	74,047	20.7
	105	54,122	71,491	21.1
	106	56,396	75,078	20.2
	107	57,203	77,160	19.8
	108	53,003	71,147	20.8
Aluminum Beam (.125)	102	56,195	66,973	14.2
Aluminum Beam (.156)	103	60,852	67,330	15.7
	109	59,415	67,080	16.0
Steel Channel	101	45,695	66,510	24.5
	106	47,370	65,297	24.3
Steel Hat Section	104	56,903	68,627	19.3
Aluminum Channel	102	44,050	46,893	10.0
	103	45,323	48,690	10.0

NOTE:

All samples taken from rails in immediate impact area.
Sample Number indicates Run Number.

EXHIBIT 11



NOTE:

CAMERA AXIS SET AT 5'-0" ABOVE GRADE AT IMPACT.

GROUND TARGETS SET AT 90° TO BARRIER-OUT 7.5', 12.5' & 17.5' FROM POINT OF IMPACT.

CAMERA DATA

1 2 3 12.5 MM LENS PHOTO-SONICS AT 380 FPS MOUNTED ON 35' TOWER

4 5 4 IN. LENS PHOTO-SONICS AT 380 FPS

6 1 IN. LENS PHOTO-SONICS AT 380 FPS

7 PAN 2 IN. LENS PHOTO-SONICS AT 380 FPS

8 5.3 MM LENS PHOTO-SONICS AT 200 FPS IN CAR

9 14 IN. LENS 70 MM HULCHER SEQUENCE-CAMERA ON SCAFFOLD

10 3 IN. LENS ROBOT 35 MM SEQUENCE AT 7 FPS

DYNAMIC FULL SCALE IMPACT TESTS — SERIES X

CAMERA & TARGET LOCATIONS FOR VEHICLE TRAJECTORY

EXHIBIT 12

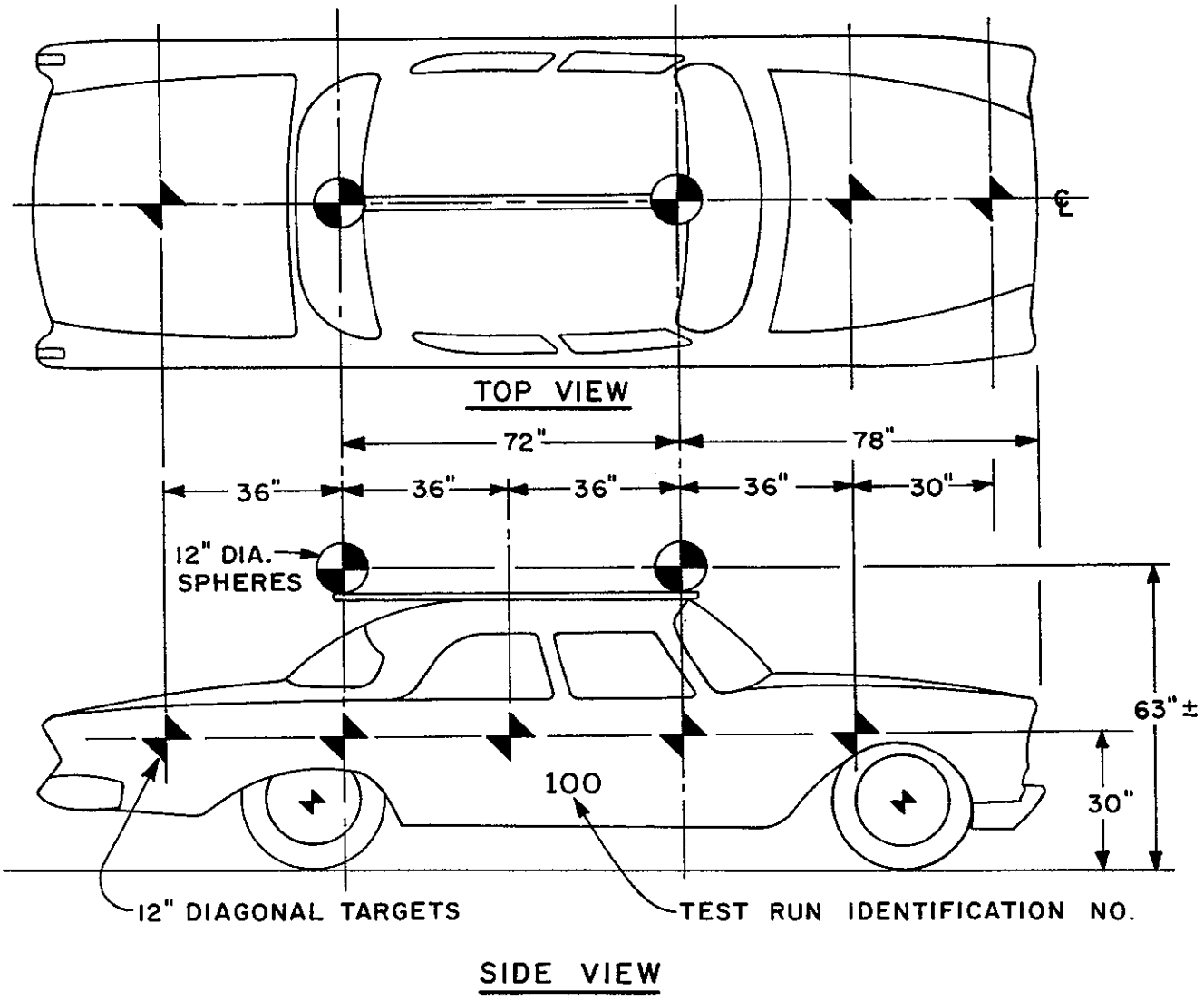
Series X Test Site: Showing camera grid, ground targets, tape switches, camera scaffold, camera tower and test barrier.

DYNAMIC DATA ON VEHICLES

TEST NO	DOOR DEFORMATION	DUMMY RE-STRAINT	DOOR OPENED CLOSED	DUMMY DECEL.						VEHICLE DECEL.						VEHICLE TRAJECTORY					
				TRANSV.		LONG.		VERT.		TRANSV.		LONG		VERT.		ANGLE		SPEED		* DIST. FROM IMPACT	IMPACT LOCATION
				L	R	FWD	BCK	UP	DN	L	R	FWD	BCK	UP	DN	ENT.	EXIT	ENT.	EXIT		
101	1/2"	TYPE 1	OPENED	3.5		2.3			1.5	NO		READINGS				25°	15°	69	41	38'	@ POST #13
102	1"	TYPE 1	CLOSED	1.7	.8	2.4			3	2		2		5		25°	–	67	0	–	@ POST #13+3'
103	4-3/4"	TYPE 4	CLOSED	3.5		1.8		.8	1.2	2	1.4	2.7		1	1.2	25°	14°	67	44	30'	@ POST #10
104	5"	NONE	OPENED	4.2		2.2		2.4		1.2		2		2		25°	14°	68	41	30'	@ POST #12
105	0	TYPE 4	CLOSED	.5		.2		.5	.4	2.1	1.8	1		1.8	1.5	25°	JUMP	58	55	25'	@POST #12+2'
106	1/2"	TYPE 4	CLOSED	2.9		1.6			.2	1.4		1.5		1.6		25°	13°	60	43	25'	@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	25'	@POST #12+4'
108	2"	LAP BELT	OPENED	3.3		2.4		1.8		1.0		1.8		1.5		25°	17°	59	35	25'	@ 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	–	@ POST #12

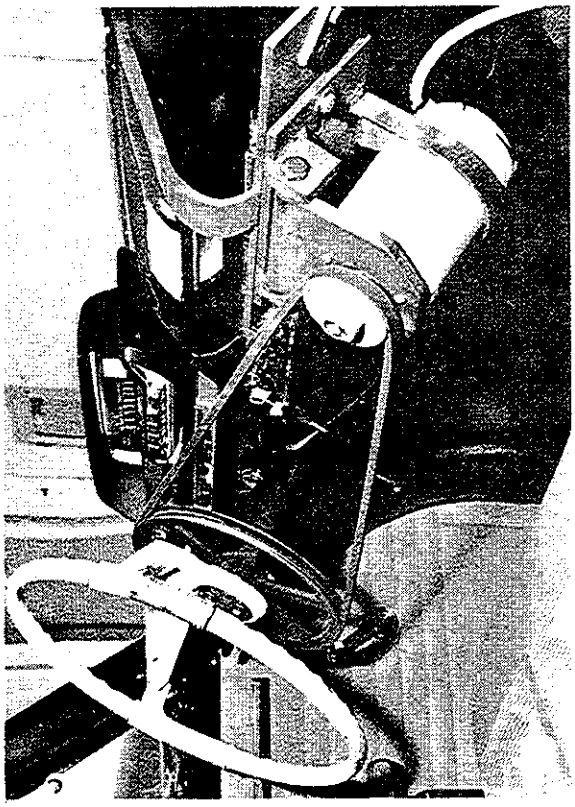
*Distance at which exit angle and exit speed were measured.

EXHIBIT 14



TEST VEHICLE TARGETING SKETCH
1962 CHRYSLER SEDAN

EXHIBIT 16



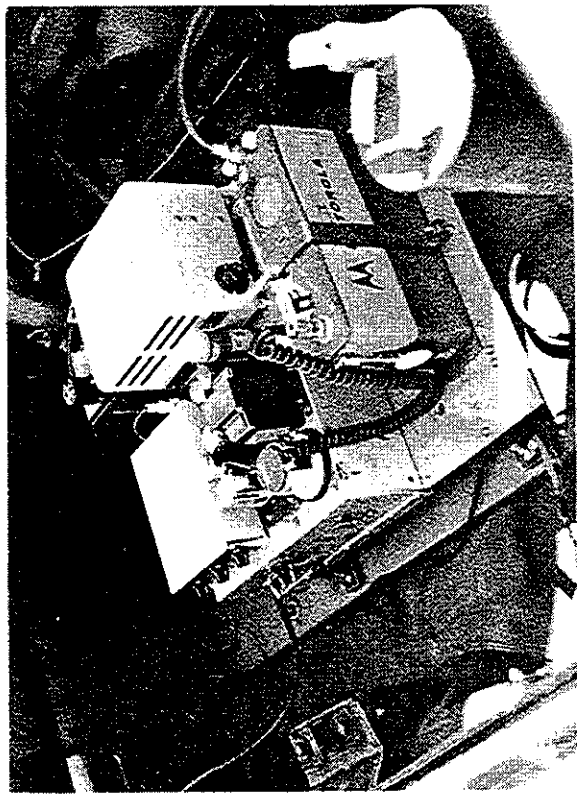


Figure 1

Figure 2

CROSS CHEST TYPE 1

This restraint system consists of a conventional lap belt and a cross-the-chest belt. The cross-the-chest belt attaches to the lap belt at the buckle (see Figure 1) and is bolted at the other end to the vehicle door frame near the driver's left shoulder by a 5/8 inch eye bolt (see Figure 2).

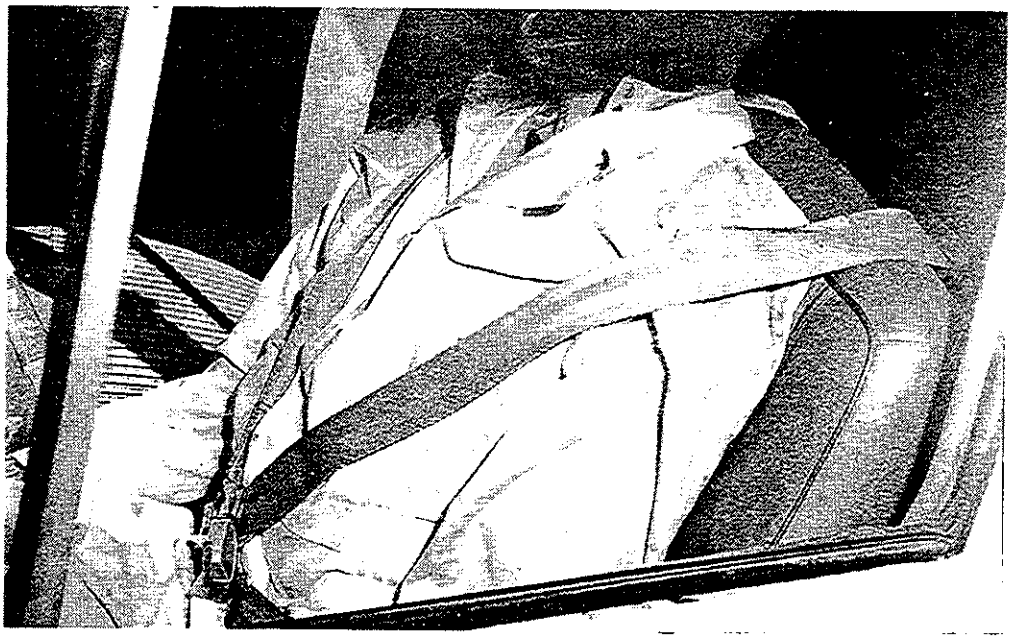


Figure 1

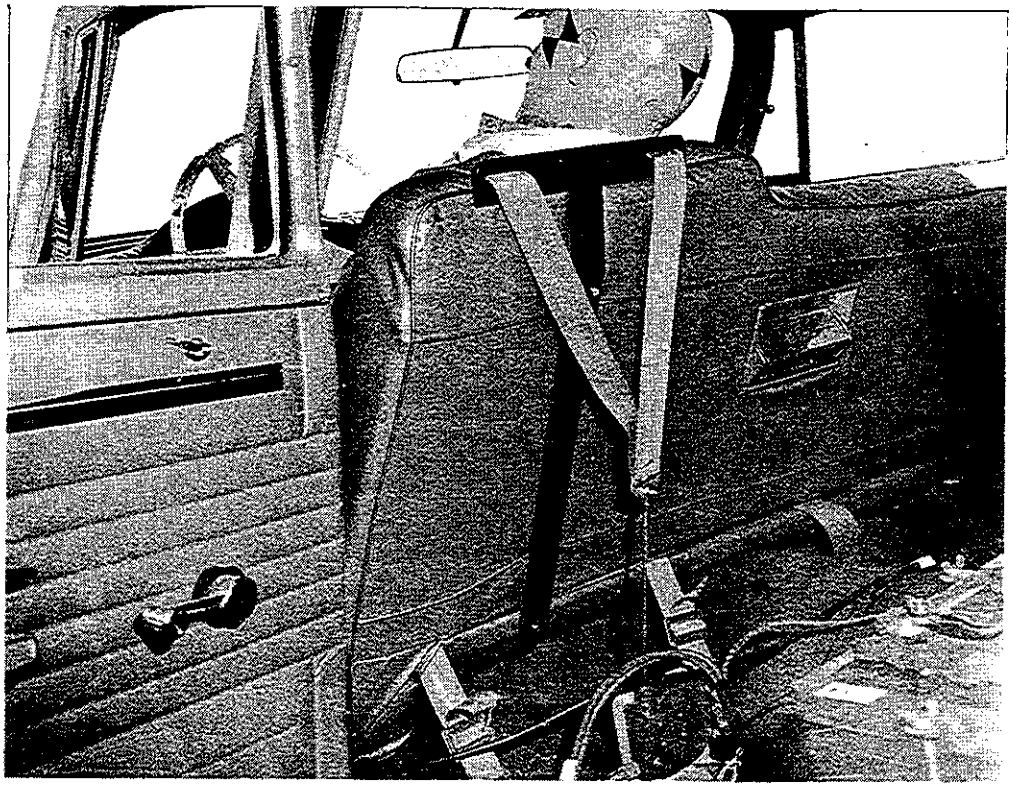
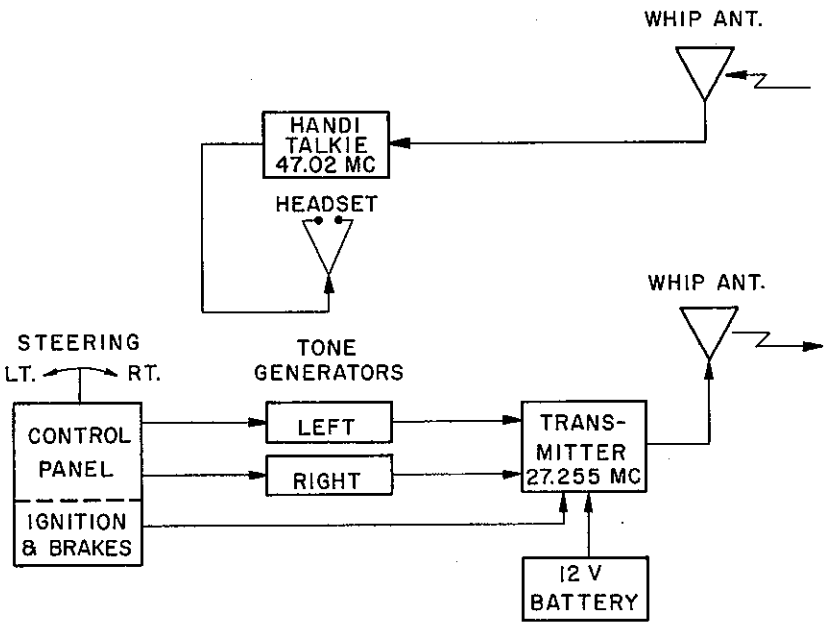


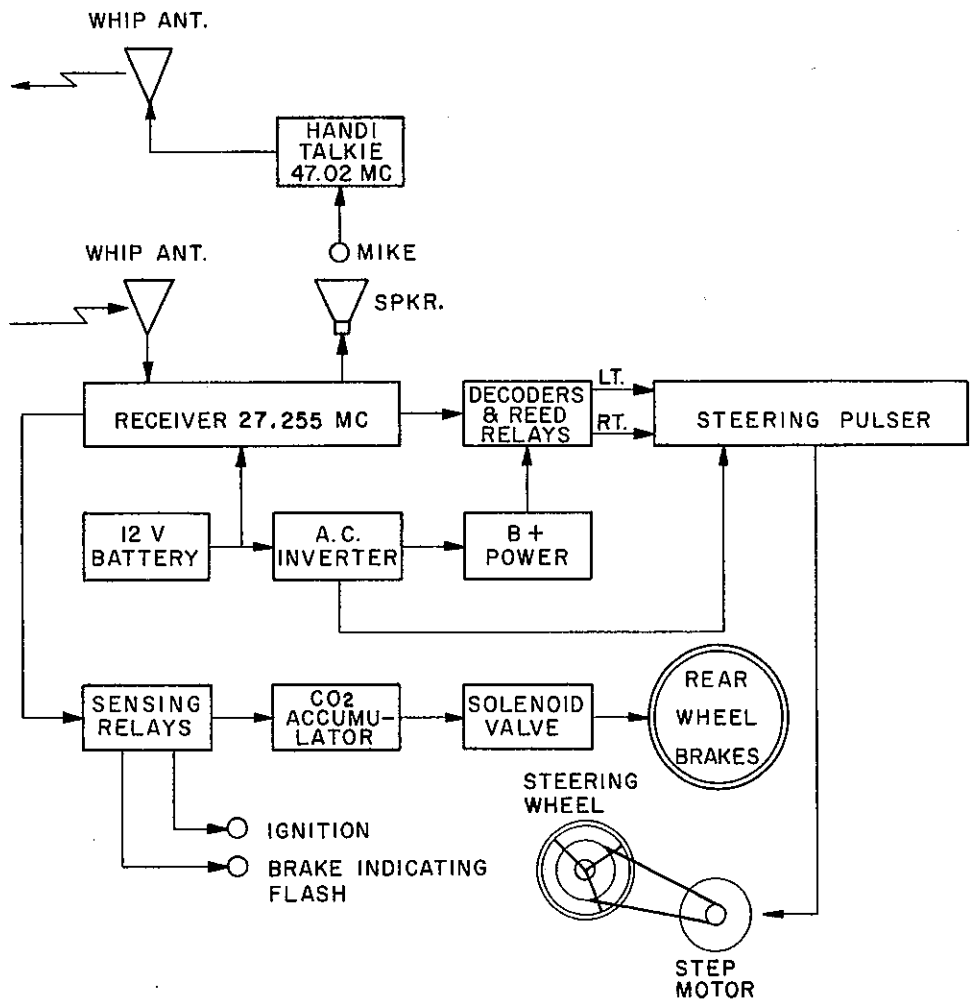
Figure 2

INERTIA REEL - T BAR TYPE 4

This restraint system consists of a conventional lap belt and a shoulder harness. The shoulder harness attaches to the lap belt at the multiple buckle (see Figure 1), passes over the back of the front seat, through slots in the T-Bar and is secured to the vehicle floor in the rear seating compartment by the inertia reel (see Figure 2).



REMOTE CONTROL CAR BLOCK DIAGRAM



CRASH CAR STEERING AND BRAKES BLOCK DIAGRAM

EXHIBIT 19