HIGHWAY RESEARCH REPORT

DYNAMIC TESTS OF BOX BEAM MEDIAN BARRIER SERIES XIV

67-33

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636392-1

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads August, 1967

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

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DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

August 1967

Interim Report
M & R No. 636392

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

DYNAMIC TESTS

OF

BOX BEAM MEDIAN BARRIER

SERIES XIV

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Very truly yours,

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ABSTRACT

REFERENCE: Nordlin, E. F. and R. N. Field, "Dynamic Tests of Box Beam Median Barrier, Series XIV". State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 636392. August 1967.

ABSTRACT: The results of a series of full scale dynamic impact tests of a steel box beam median barrier design are reported. The basic barrier design, developed by the State of New York Department of Public Works, consists of a structural steel box beam 6" x 8" x ¼" mounted 27" high on 3I5.7 steel posts. Resultant data from three dynamic tests of modified post-to-beam connections are presented with a discussion on the dynamics, construction, and maintenance features of the system.

KEY WORDS: Dynamic tests, impact tests, barriers, box beams, vehicle dynamics.

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I. INTRODUCTION

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

The box beam median barrier's "strong beam/weak post" concept was developed during a test series conducted by the New York State Department of Public Works, in cooperation with the Bureau of Public Roads, and was reported in January 1964(3). The report indicated that the box beam type median barrier was particularly effective in regards to vehicle redirection at a low exit angle and with a low deceleration rate.

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

In order to conduct dynamic tests on this barrier design, advance approval was requested in April of 1965 for inclusion in the 1965-66 Work Program HPR 1(3) of a research project titled "Dynamic Full Scale Tests of Tension Box and Beam Box Median Barriers". The project was formally approved in August of 1965 and was carried as No. D-4-37 of Part 2, Research, of the program. Two tests were conducted under this program, the first in December 1965 and the second in March 1966.

In the second quarter of 1966, a proposal which combined this project with two other approved projects (D-4-38 and D-4-39) was prepared and submitted for inclusion in the 1966-67 Work Program HPR 1(4) under the title "Dynamic Full Scale Tests on Rails and Barriers". Approval for this project under No. D-4-37, Section II, was received in July 1966. The third and concluding test of this series was conducted under Section II in September 1966. The tension box portion of this research program was abandoned as it was felt that this barrier would not be a functional improvement over the cable barrier and in addition would be several times as expensive for the initial installation.

All three tests were conducted under the general guidelines established by the Highway Research Board Committee on Guardrails and Guide Posts(4).

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II. OBJECTIVE

The primary objective of this research project was (1) to determine the effectiveness of box beam median barrier for use on narrow (6 ft or less) medians and (2) to determine its maintenance characteristics.

III. CONCLUSIONS

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

1. Due to the dynamic and permanent lateral beam deflections recorded in the impact tests at critical speeds and angles, the minimum median width should be at least 10 feet to contain a box beam barrier located in the center. This minimum median width should be increased if adequate area is to be provided for maintenance vehicles on one or both sides of the barrier.

2. Until further operational or test experience is gained, the use of the box beam should be limited to flat surface medians. The median should be free of curbs, dikes, ditches, and sawtooth slopes in the vicinity of the barrier.

3. Even on flat medians, the box beam barrier may not prove to be as effective as the current California beam-type median barrier in containing trucks and other high center of gravity vehicles because the box beam tends to deflect downwards during impact whereas the blocked-out beam tends to rise.

4. With the same vehicle at the same speed and angle, the impact into the box beam median barrier would be "softer" than into our current blocked-out beam median barrier but "harder" than into our current cable-type barrier.

5. Due to the considerable wheel-to-post involvement observed in the 49 mph 10 degree angle impact test as well as one of the higher speed 25 degree angle impact tests, we should anticipate almost as much

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maintenance repair as we experience with the California cable-type barrier.

6. Although the box beam presents a trim, true profile when first erected, the straight lines of the box beam may be difficult to maintain after a length of barrier has been struck by numerous, even moderate, impacts.

7. Provisions to mount a glare screen on the box beam may present a problem during maintenance repairs since the screen would have to be mounted on the box beam itself, rather than on posts, independent of the beam, as in the case of our current blocked-out beam median barrier.

8. It is estimated that the initial construction cost for the box beam median barrier will range from approximately $8.50 to $11.50 per lin. ft as compared to an average of $2.50 per foot for our current cable type and $8.50 for our current blocked-out beam type median barrier.

9. Recommended design details for the box beam median barrier are shown in Exhibit 5.

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IV. DISCUSSION

A. Design and Performance

Common to the design of each of the three box beam barriers tested were the beams, beam splices, posts, and post footings (see Exhibit 4).

The beams were 8" x 6" x .250" steel tubing ASTM A501, 17'-11½" long. The beam splices utilized a one-piece sleeve-type connection. This exterior connection was selected in lieu of New York's two-piece clamp-type splice in an attempt to increase the beaming strength of the system thus minimizing the lateral deflection. Due to the increased speed anticipated (70 mph vs. New York's 56 mph) and the heavier test vehicles (4500 lbs. vs. New York's 3800 lbs.), it was felt that the two piece clamp might deform under the heavier impact loading conditions.

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

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

Each of the designs tested had a different type of beam to post connection as discussed below. The end anchorage used for Tests 142 and 143 is detailed in Exhibit 3. No end anchorage was used for the Test 141 barrier.

1. Test 141

The installation for Test 141 was a 198' unanchored section of box beam barrier. The decision to test this barrier without anchoring the beam was based upon (1) successful tests of 200' unanchored installations of box beam median barrier in the test series conducted by the State of New York[3] and (2) successful tests of 162½' unanchored sections of guardrail used in the California Series X project[2].

As it was felt that the 1½" x 7" paddle slots in the New York design would permit kinking to occur in the beam under severe impact loading, the post/beam connection was revised in an attempt to effect an

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economic and operational improvement. Figure 1 below is a detail of the angle clip connection used in Test 141.

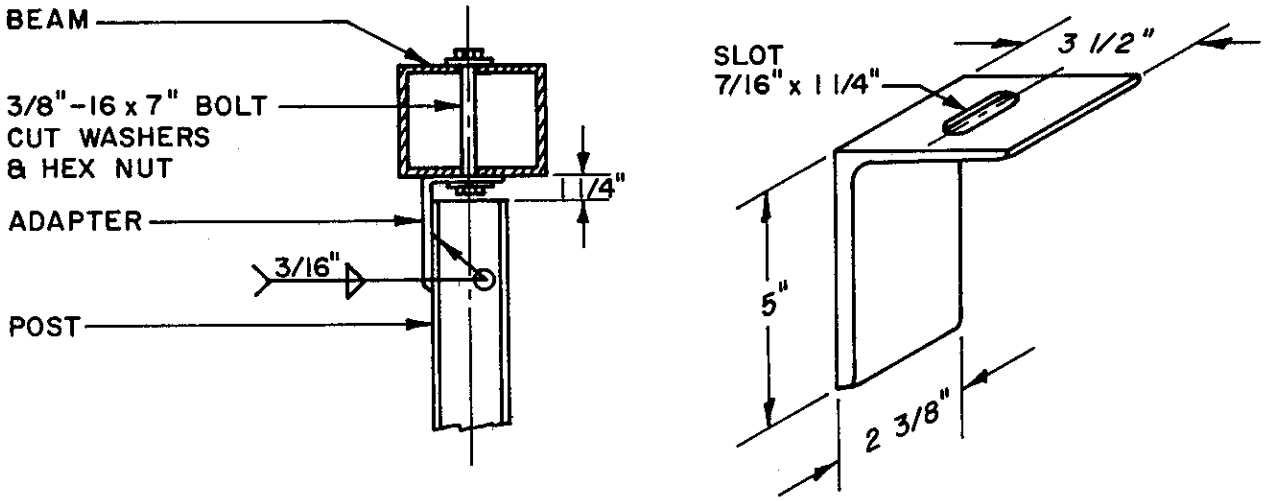

FIGURE 1 (TEST 141)

The barrier failed to retain the vehicle under the 71 mph/25° impact. The box beam was torn free of all posts and thrown more than 50 feet from the original centerline when the 3/8" diameter beam-to-post clip bolts failed in shear and tension. Three 18' sections of beam were damaged beyond economical repair. However, based on the results of the succeeding Test 142, it is felt that an anchored installation with larger or HS beam-to-post bolts would have successfully retained the vehicle.

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

2. <u>Test 142</u>

For Test 142 a 201' installation of anchored box beam barrier utilizing the paddle/slot design shown in Figure 2 on the following page was impacted at 64 mph/25°.

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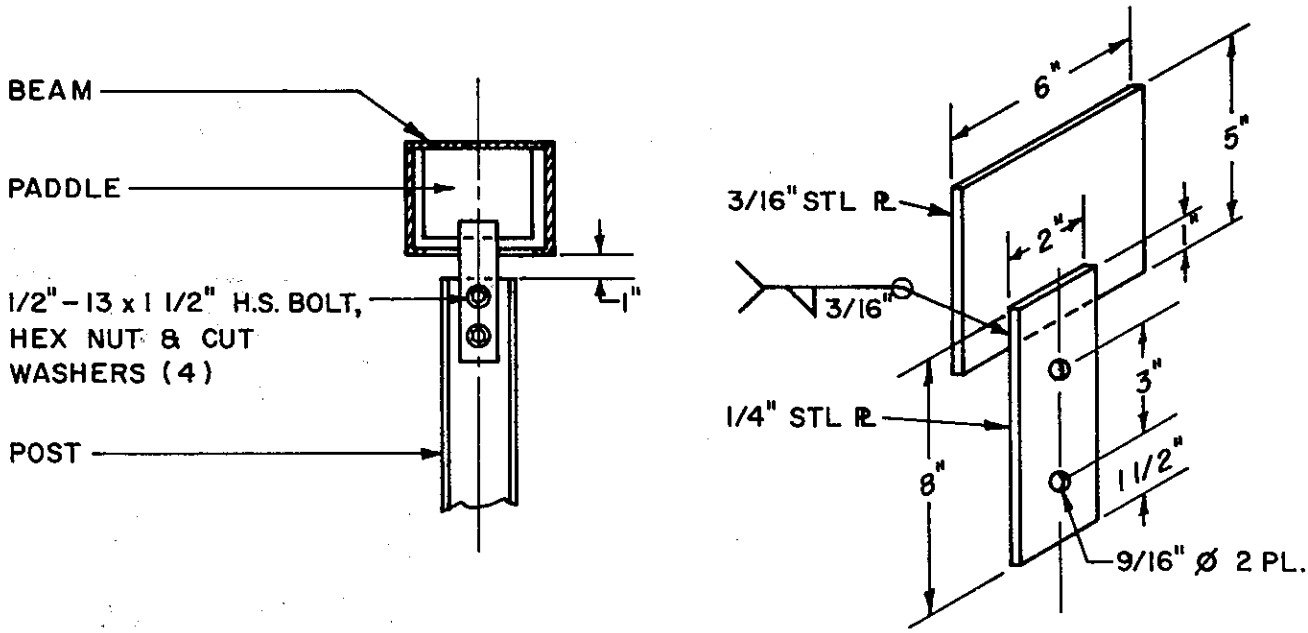

FIGURE 2 (TEST 142)

The vehicle was effectively redirected to an exit angle of 6° during a contact distance of approximately 37'.

However, the 4' dynamic lateral deflection coupled with a considerable loss of beam height (10.5") permitted the vehicle to roll more than 18° into the barrier (Figure 3 below).

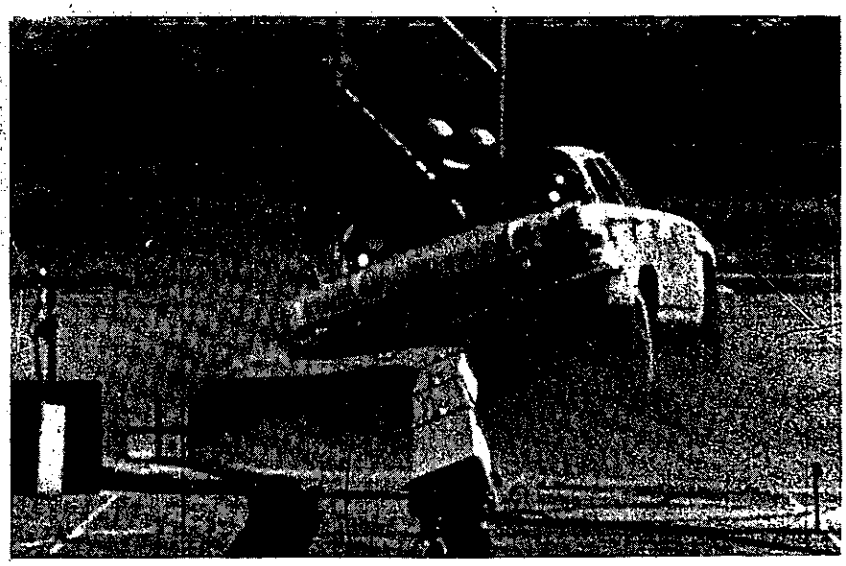

FIGURE 3

This roll was considerably more than has been experienced with a blocked-out system impacted under similar

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conditions. Past impact test experience indicates that this vehicle reaction could result in a roll-over under more severe impact conditions. The 4' lateral deflection would limit the median width upon which this barrier should be installed. Three sections of the beam, 11 posts, and 22 paddles were damaged during the impact and one post was pulled out of the socket. Most of the paddles on the posts that were contacted had damage that indicated they had snagged as they pulled out of the beam slot.

The immediate entrapment of the left front wheel with the first post contacted can be seen in Figures 4 and 5 below.

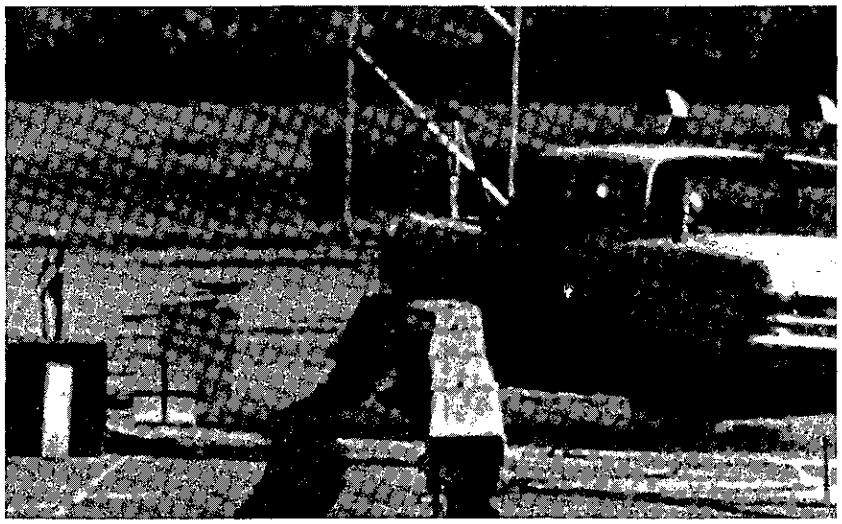

FIGURE 4 (Impact + 0.075 Sec.)

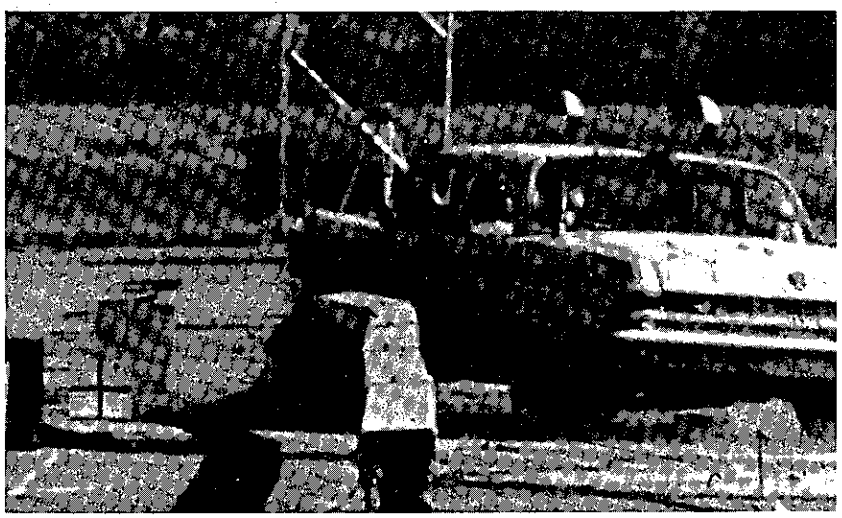

FIGURE 5 (Impact + 0.100 Sec.)

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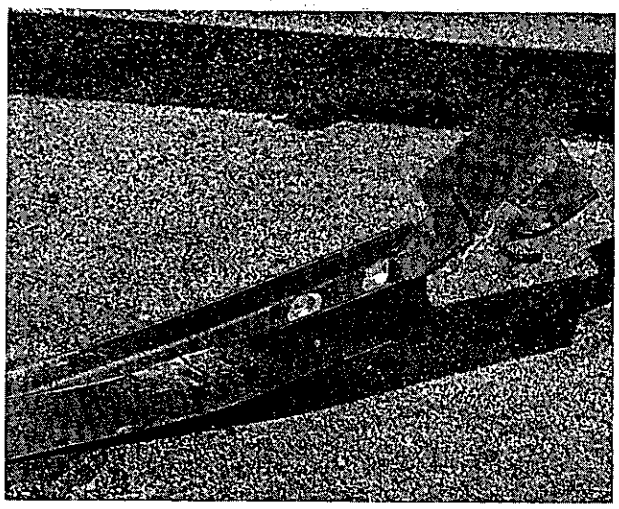
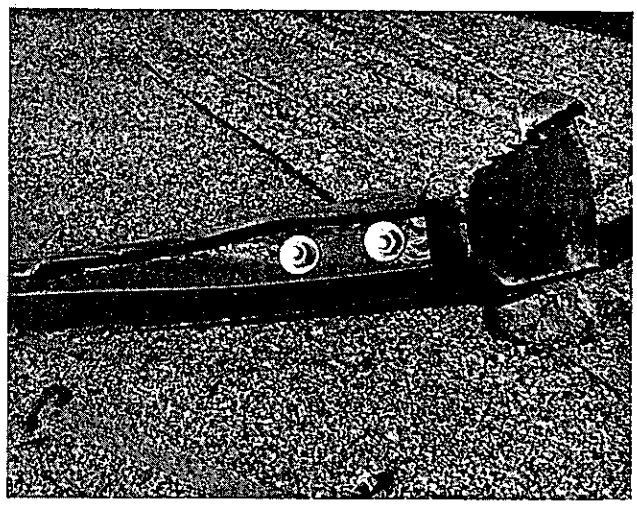
Past experience indicates that this wheel/post involvement is typical of most impacts on 27" high beam-type barriers that are not blocked-out or barriers over 27" high that are not provided with a rubbing rail mounted below the beam. However, with this strong beam/weak post system, it was felt that the relatively light 3I5.7 posts did not affect the smooth progression of the vehicle through impact as would an 8" x 8" timber post or 6" steel "H" post. Further review of the data films indicated that the severe damage to the front wheel and suspension was caused primarily by the paddles hanging up in the beam slots. It is apparent that the post twisted when impacted and the paddle hung up diagonally in the 1½" beam slot, locking the post to the beam. Figures 6a and 6b below show two posts with sheared paddles. For Test 143 the paddles were lengthened and beveled to minimize the snagging.



a



b

FIGURE 6

The two upstream anchor rods in Test 142 were instrumented with SR-4 strain gages mounted and oriented as indicated in Exhibit 3. The barrier was pretensioned to approximately 1000-lb. with the anchorage turnbuckles. During the 64 mph/25° impact, the strain gage instrumentation indicated that a peak load of approximately 32 kips was transmitted through one of the rods to the anchor.

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All of the beam splice bolts (ASTM Designation: A307 steel) used in Test 142 sustained some shear deformation and the top and bottom were sheared completely off one bolt. Figure 7 below shows the head of the splice bolt and the washer just after shearing. This failure occurred at the time of maximum dynamic deflection and is a good example of the magnitude of the tensile forces that can be transmitted a considerable distance downstream as well as upstream from impact on any tension barrier system such as the box beam barrier.

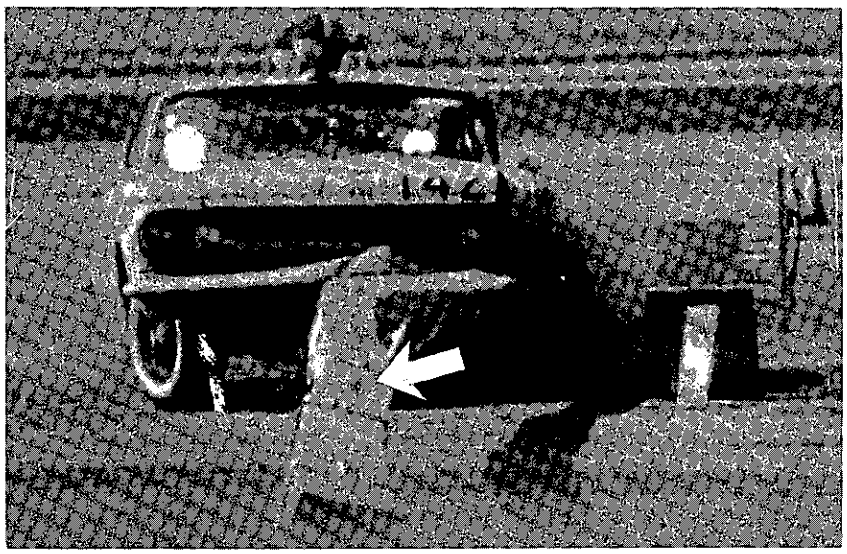

FIGURE 7

Impact + 0.225 sec.

This splice bolt failure had no appreciable effect on the over-all performance of the barrier as the vehicle had almost been redirected and maximum dynamic deflection had occurred. However, for the succeeding test the A307 splice bolts were replaced with high strength bolts.

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

3. Test 143

To correct the deficiencies noted in barrier Test 142, the barrier used in Test 143 incorporated a

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beveled paddle design (Figure 8 below) to minimize the snagging tendency and HS steel beam splice bolts (ASTM Designation: A325) to minimize the splice bolt shear deformation.

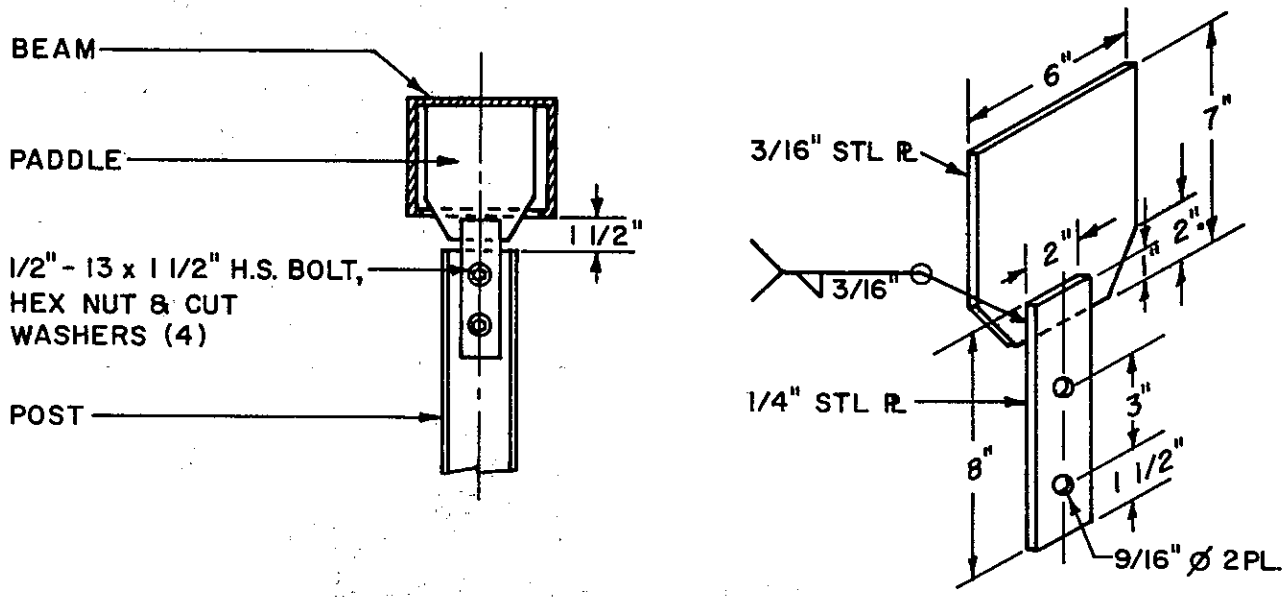

FIGURE 8 (TEST 143)

The impact angle and speed were reduced to 49 mph/10° for Test 143 in order to acquire maintenance data on this type of moderate impact which is considered fairly representative of the majority of freeway median barrier accidents. The 201' installation of box beam barrier used the same end anchorage as was used in Test 142.

The test vehicle impacted the barrier 100' from the upstream end and was redirected to an exit angle of 3° during a contact distance of approximately 21'. The left front tire was ruptured by a post causing the vehicle to curve into a secondary impact with the barrier 42' beyond the initial contact and traveled parallel in contact with the beam for an additional 30' before finally leaving the barrier at a 3° exit angle. Three posts were damaged beyond repair and nine paddles required replacement. However, the beam sustained the impact with no evidence of bending and, as expected, no damage to the 3/4" HS splice bolts. There was no evidence of snagging with the beveled paddle design and no tendency for the vehicle to roll. Repairs to the damaged barrier are discussed under Section C of this report.

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

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

New York's experience with the paddles in a test on an aluminum box beam design[6] indicates that an offset would be desirable in the edge of the paddle to restrain the vertical deflection of the beam upwards under severe impact conditions. This offset as shown in Figure 9 below would tend to restrain the beam until it was firmly embedded in the vehicle body and release before any serious snagging could occur.

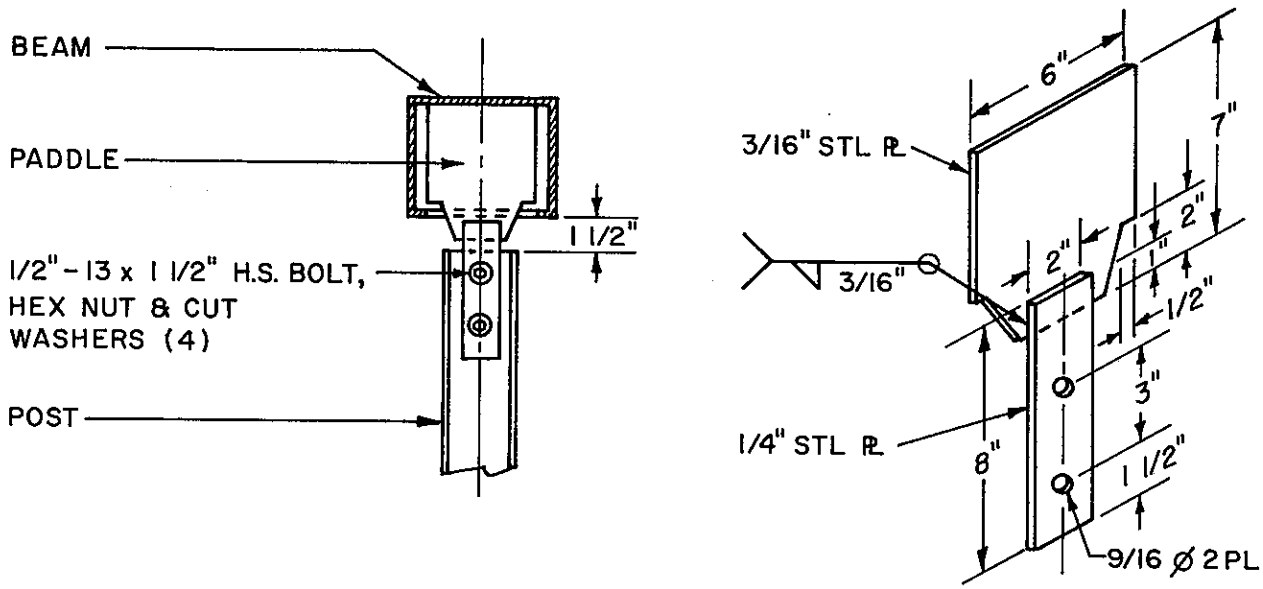

FIGURE 9

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

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B. Test Procedure and Instrumentation

In general, the testing procedure and photographic instrumentation followed that outlined in previous California reports(2)(5). The test vehicles were 1964 Dodge sedans weighing 4540 lbs. with dummy and instrumentation. Utilizing their own power, they were guided into the box beam test installations by radio control. "Sierra Sam", an anthropometric dummy, occupied the driver's seat during each collision as a human simulator. "His" kinematics were recorded by a data camera mounted above the rear seat. A typical photographic instrumentation plan is shown in Exhibit 1.

Two "Impactograph" recorders, each utilizing mechanical stylus type accelerometers recording on a strip chart were used to record the transverse, longitudinal and vertical accelerations during impact. One recorder was mounted in the chest cavity of the dummy and one on the rear floor of the vehicle. Due to the effects of "ringing" caused by transient vibrations through the vehicle frame, the recordings from the vehicle impact recorder were not considered representative of the actual decelerations sustained by the vehicle and are not reported herein. Exhibit 2 is a tabulation of dynamic data including impact readings taken from the dummy for each of the three tests. Included in the exhibit for comparisons are dynamic data from a previous test series on "W" beam barriers.

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

C. Maintenance and Operations

The selection of 200-300 pen asphalt for anchoring the posts to the sockets is based on 8 years operational experience with the cable barrier where posts are embedded in 30" deep sockets. It was found that the 200-300 pen would retain the 2¼ x 4.1# H section posts under severe impact conditions in hot climates (100-120° F) yet were readily removed when damaged. However, damaged posts are difficult to remove from the sockets during the winter season when pavement temperatures approach 30° F. Some experimental work is recommended on the use of 60-70 pen asphalt or even the 85-100 pen asphalt as suggested by other states before considering the heavier grades for the box beam application, even though the box beam posts are only embedded 16 inches.

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In all three tests, records were kept of the time required and the details and difficulties encountered in erecting and repairing the barriers. After Test 143 the damaged posts were readily removed. Two men using a forklift were able to remove and replace the three damaged posts and realign the beam in two hours. It was found that the damaged posts and paddles could be readily replaced without removing the beam splices by lifting the beam free of the paddles for a certain distance each side of the damaged post and holding the beam aside while the repair was made.

The following estimates of repair costs are based on the aforementioned information and should be representative of maintenance costs that can be expected for similar damaged sections in operation:

Test 142, 65 mph/25°

3- beam sections, $67.50 ea.	$ 202.50
11- posts, $2.65 ea.	29.15
22- paddles, $1.10 ea.	24.20
Total Material	$ 255.85
Labor, 12 man hours @ $9.00	108.00
Equipment (boom truck 30 mi. avg. $0.42	12.60
Grand Total	$ 376.45

Test 143, 49 mph/10°

3- posts, $2.65 ea.	$ 7.95
9- paddles, $1.10 ea.	9.90
Total Material	$ 17.85
Labor, 6 man hours @ $9.00	54.00
Equipment (boom truck 30 mi. avg. @ $0.42	12.60
Grand Total	$ 84.45

It is estimated that new construction costs for the box beam median barrier designed as shown in Exhibit 5 will vary from a low of $8.50/lin. ft. to $11.50/lin. ft. dependent upon the proportion of lineal feet constructed on structures where special post anchorages are required and around piers where an envelope design would be required. Recent information from the State of Washington indicates a low bid construction price of $10.50/lin. ft. for 2,279 ft. of painted box beam barrier of the New York design.

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V. REFERENCES

1. Beaton, J. L. and R. N. Field, "Dynamic Full Scale Tests of Median Barriers", California Division of Highways, May 1959.

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

3. McAlpin, G. W., et al, "Development of an Analytical Procedure for Prediction of Highway Barrier Performance", New York State Department of Public Works, Presented at 43rd Annual HRB Meeting, January 1964.

4. Circular 482, "Proposed Full-Scale Testing Procedures for Guardrails", HRB Committee on Guardrails and Guide Posts, September 1962.

5. Nordlin, E. F., R. N. Field, and R. P. Hackett, "Dynamic Full-Scale Impact Tests of Bridge Barrier Rails", California Department of Public Works, Presented at 43rd Annual HRB Meeting, January 1964.

6. Graham, Malcolm D., et al, "New Highway Barriers, The Practical Application of Theoretical Design", New York State Department of Public Works, Presented at the 46th Annual HRB Meeting, January 1967.

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VI. APPENDIX

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

A. A data sheet showing overhead or ground mount data camera views of the vehicle through impact and a tabulation of the test parameters.

B. A series of sequence pictures from the front ground mounted data camera.

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

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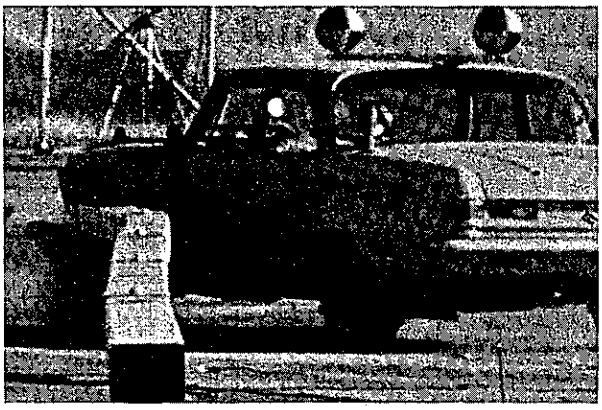
TEST 141 PLATE A



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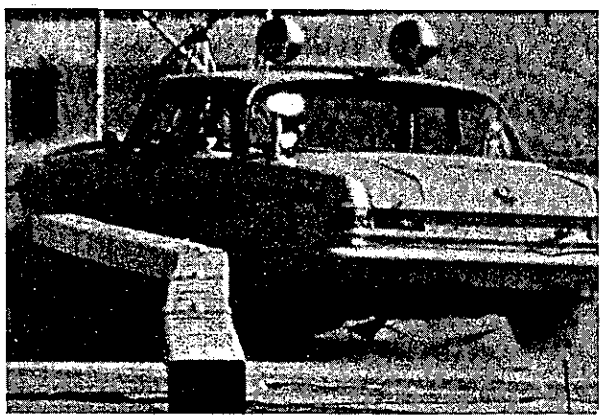

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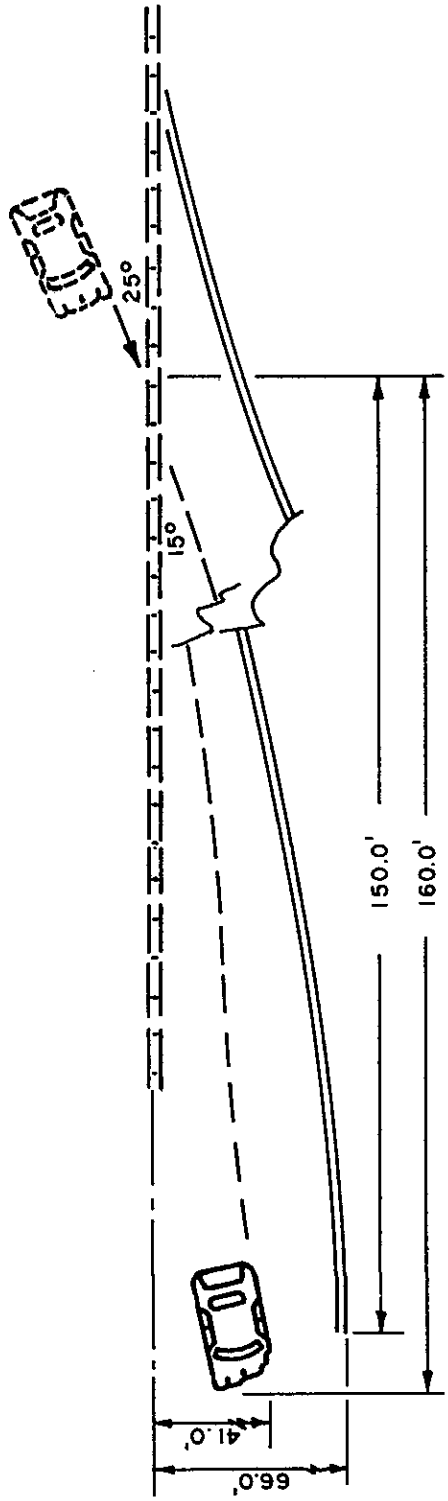

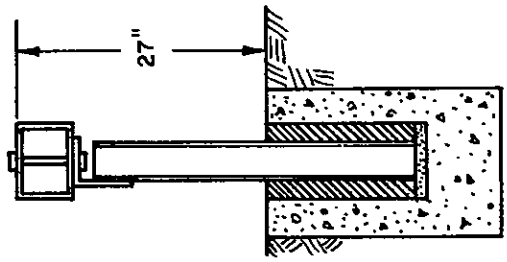

BEAM	6" x 8" x 1/4" x 17'-11 1/2" Steel Tube
SPLICE	6 5/8" x 8 5/8" x 1/4" x 24" Steel
POST	3" I 5.7 # x 36"
POST SPACING	6'-0"
POST EMBEDMENT	16 1/4"
FOOTING	16" dia. x 17" Cl. "A" Conc.
LENGTH OF INSTALLATION	198'
BEAM DEFLECTION - MAXIMUM	NA
BEAM DEFLECTION - PERMANENT	NA

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

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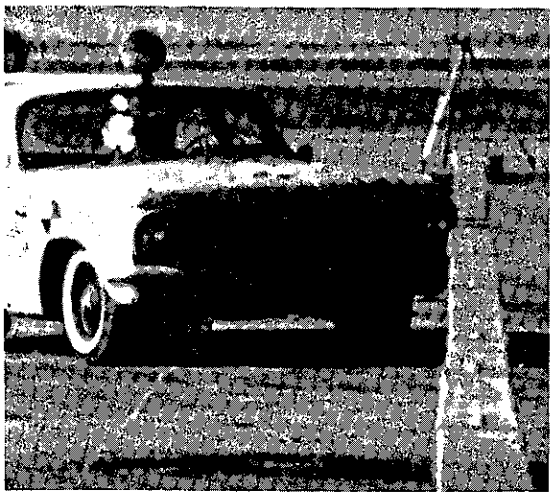
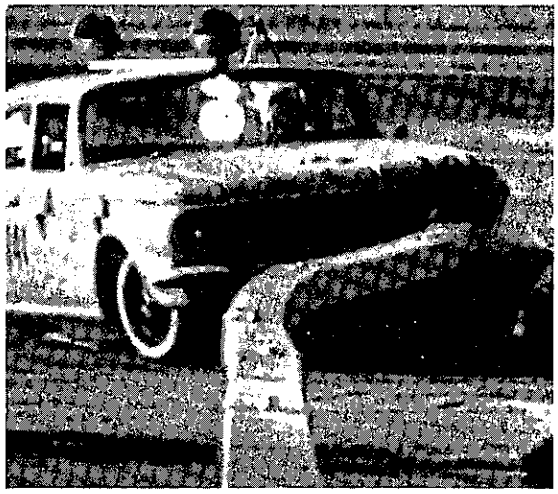
TEST 141 PLATE B



Impact



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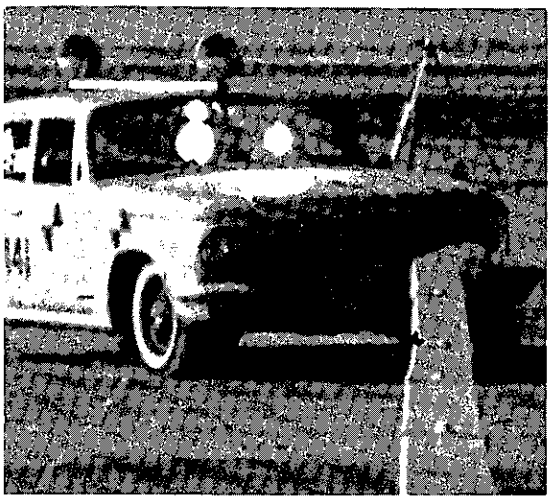

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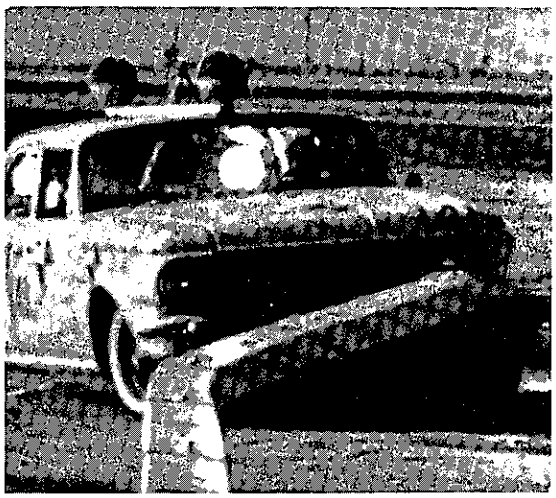
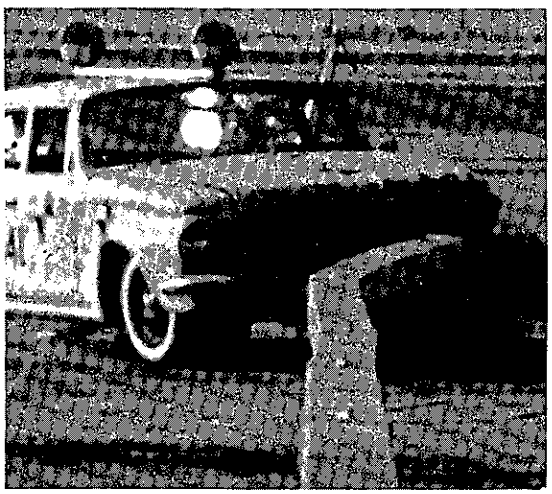


I + .175 Sec.



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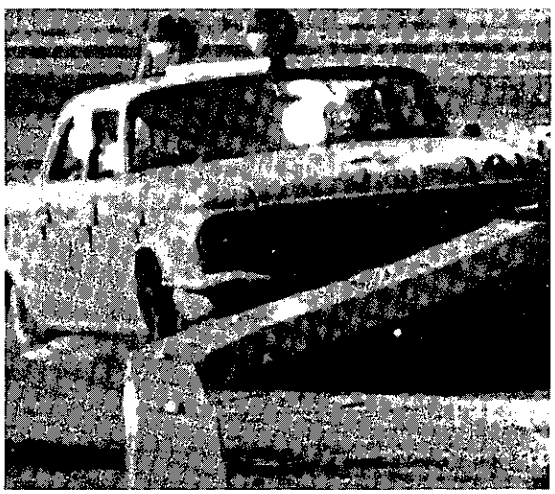

I + .215 Sec.

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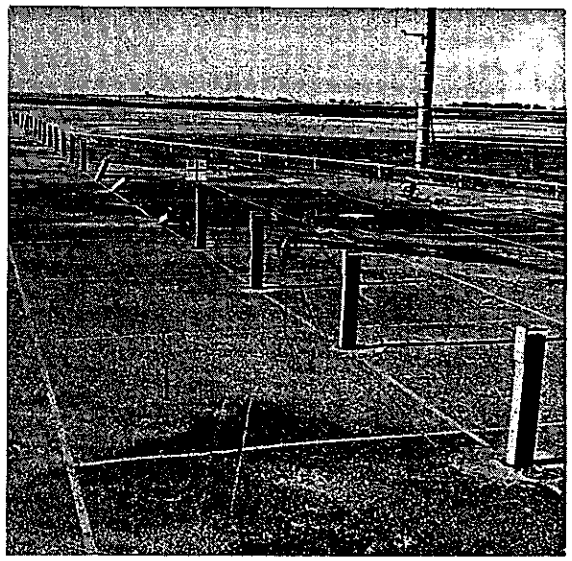
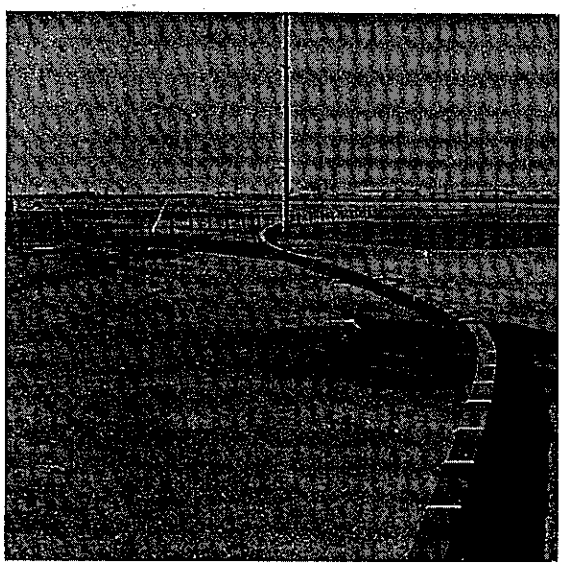
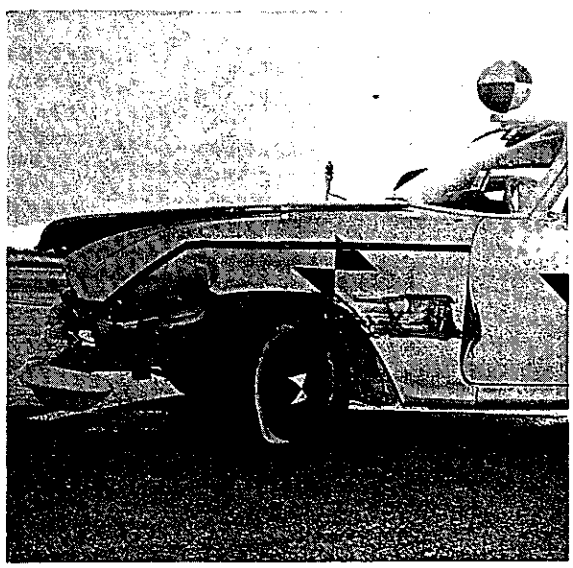
TEST 141 PLATE C







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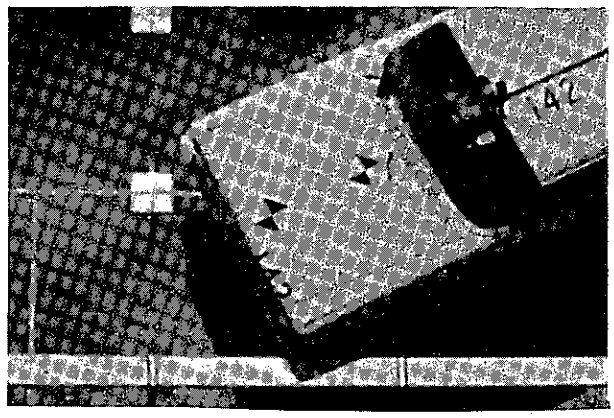
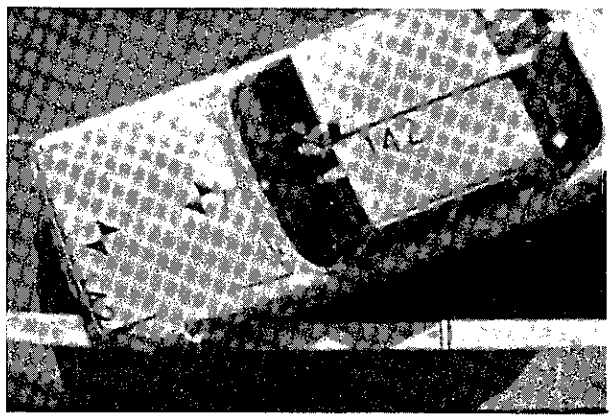
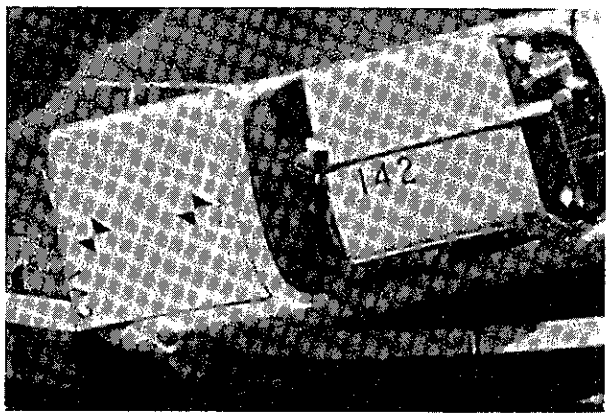
TEST 142 PLATE A



IMPACT



I + .060 Sec.



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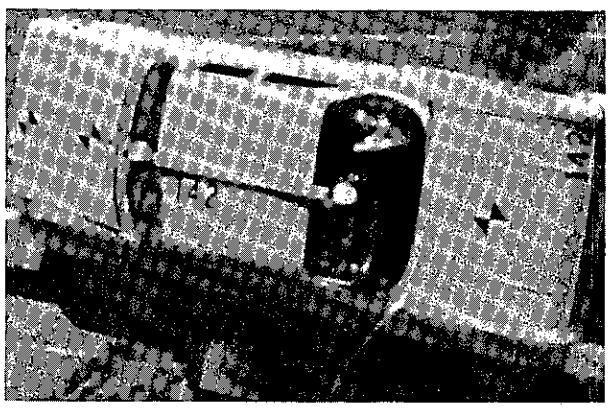

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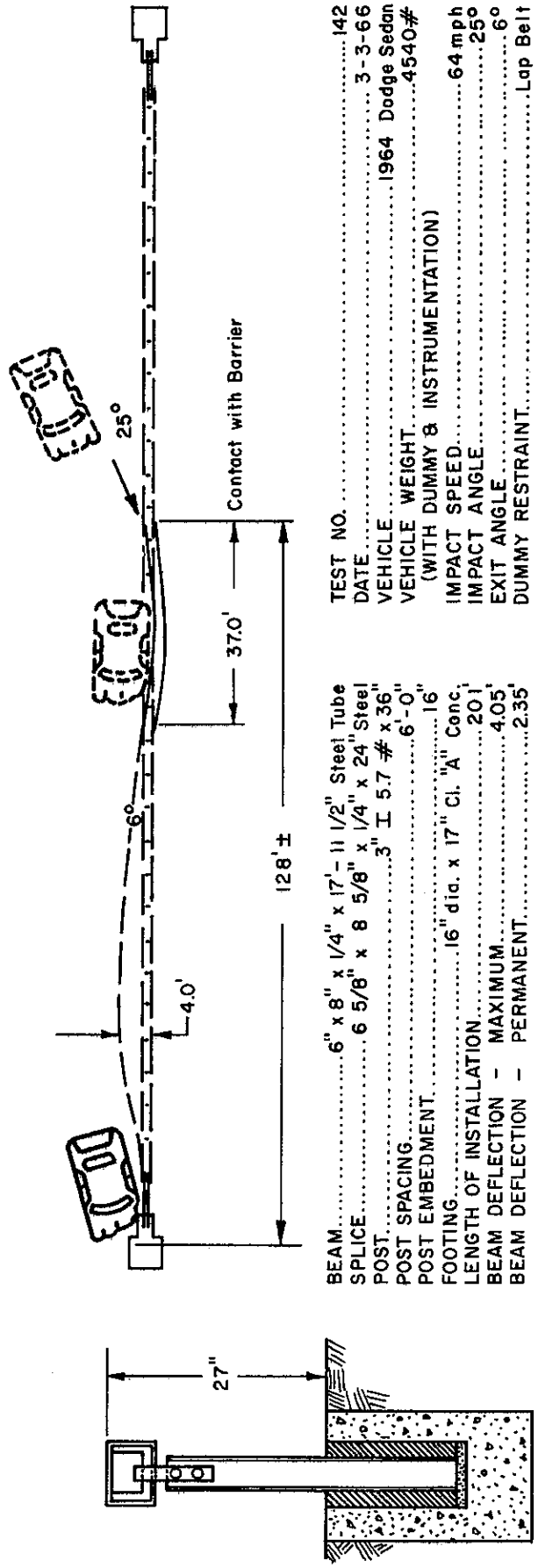

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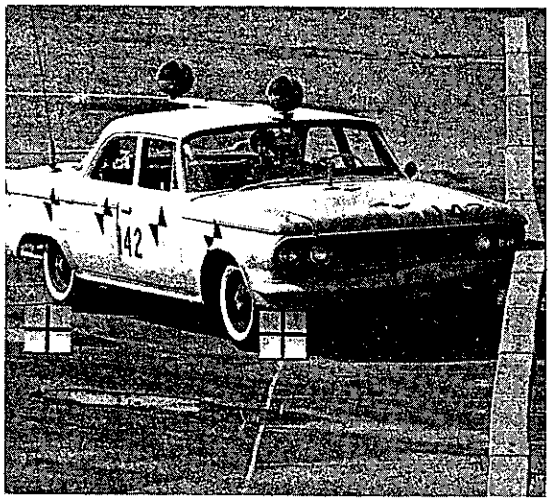
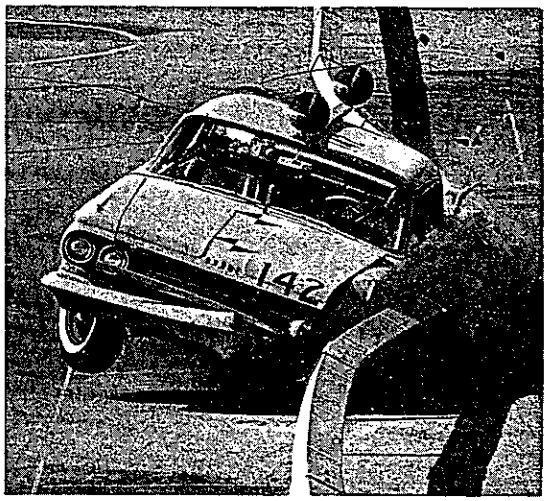
TEST 142 PLATE B



Impact + .020 Sec.



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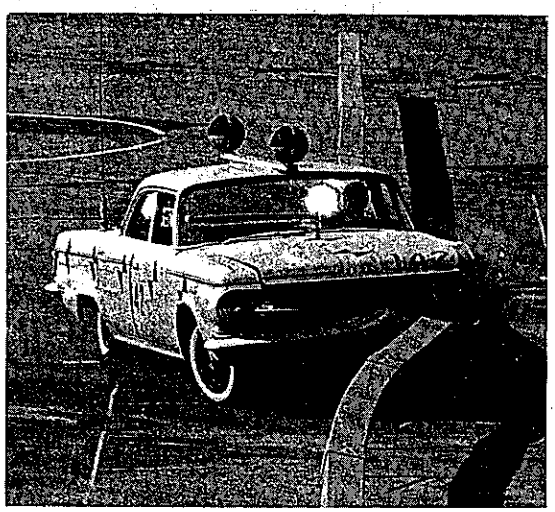

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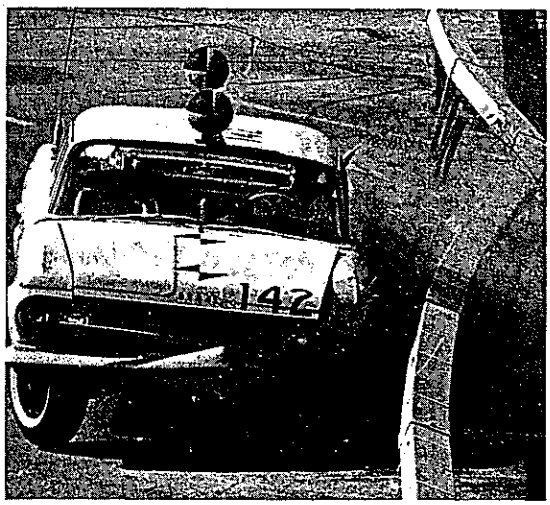

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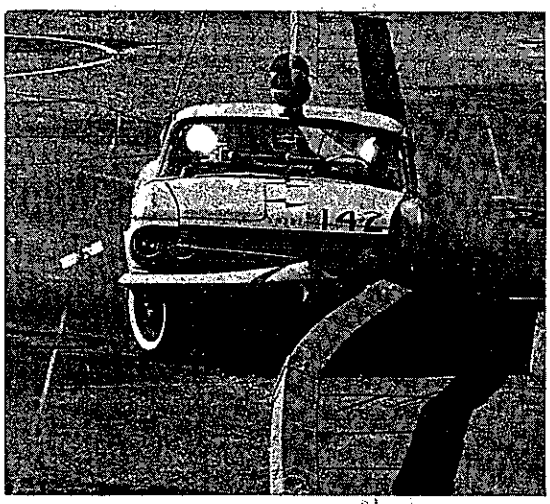

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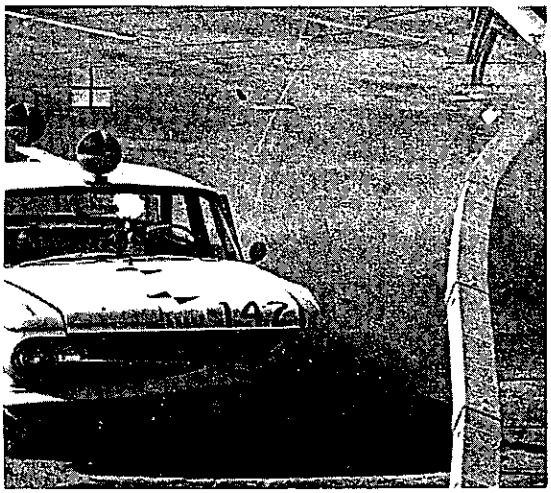

I + 1.060 Sec.

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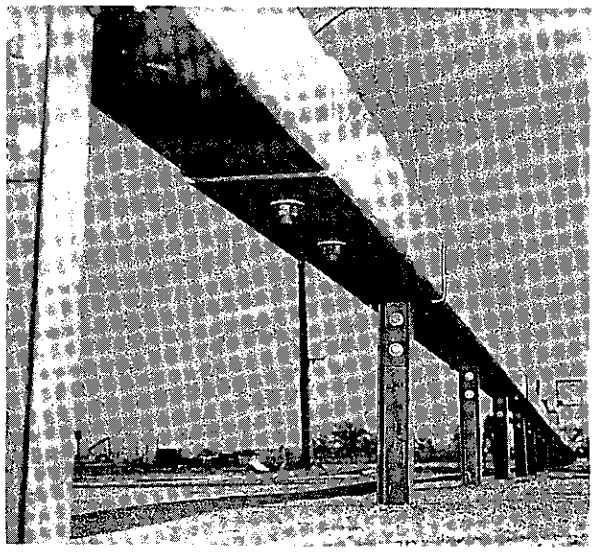
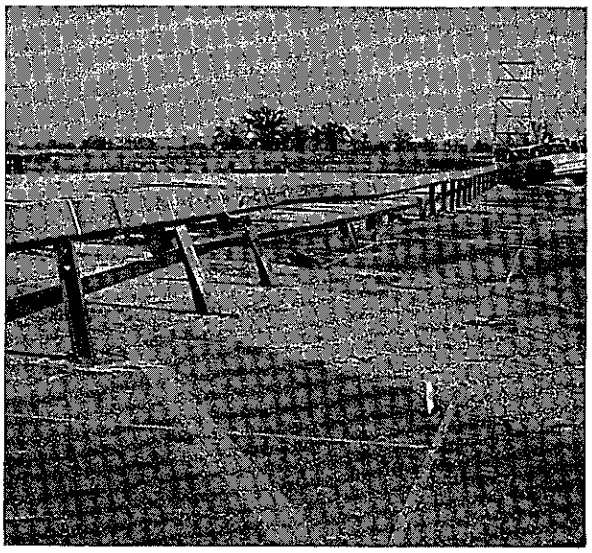
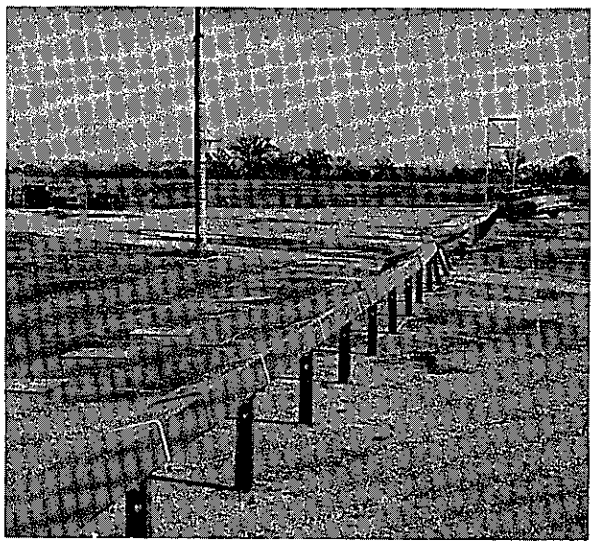
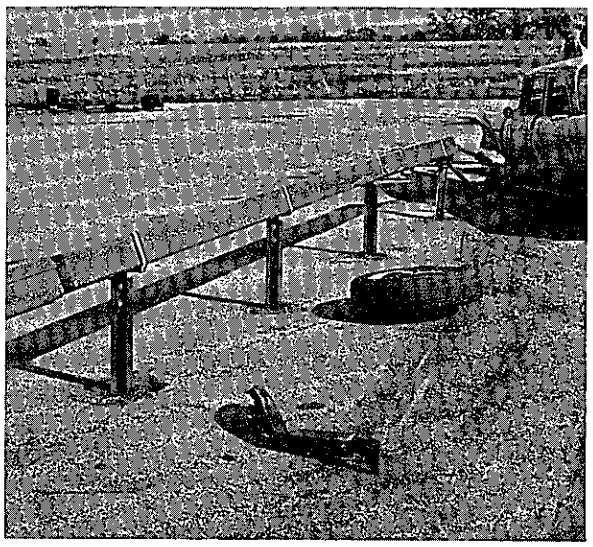
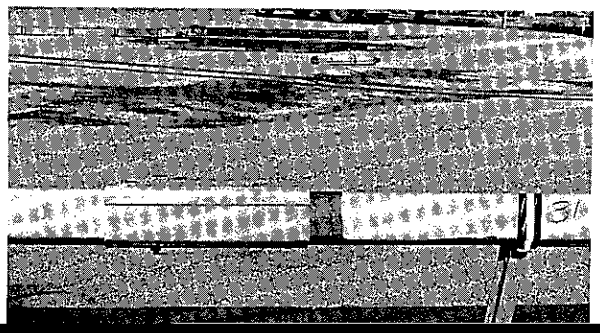
TEST 142 PLATE C

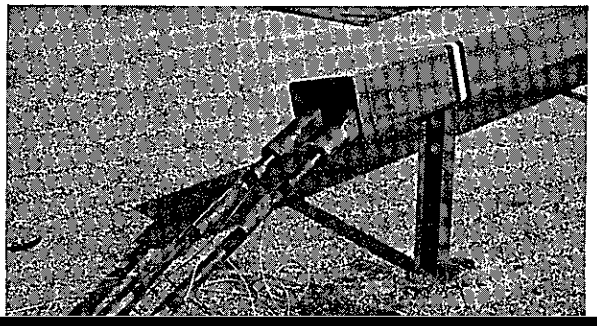












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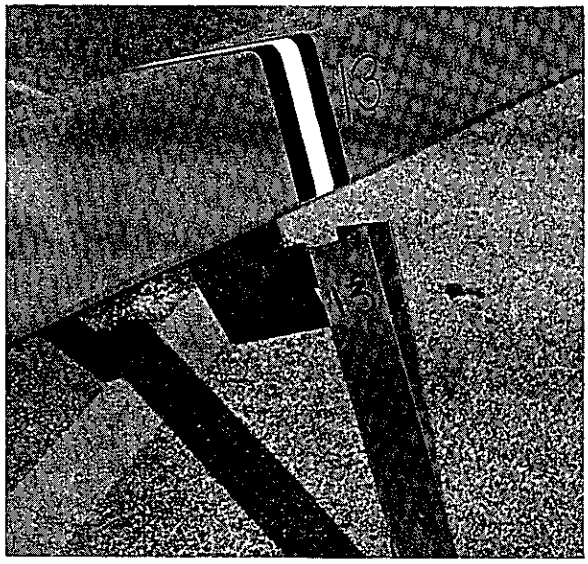
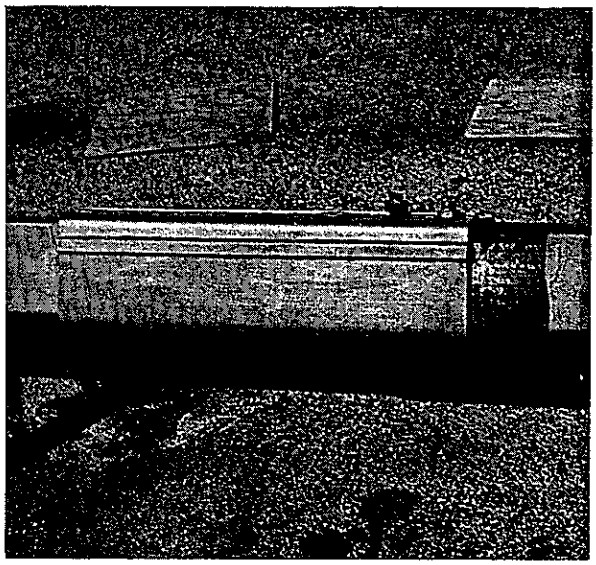
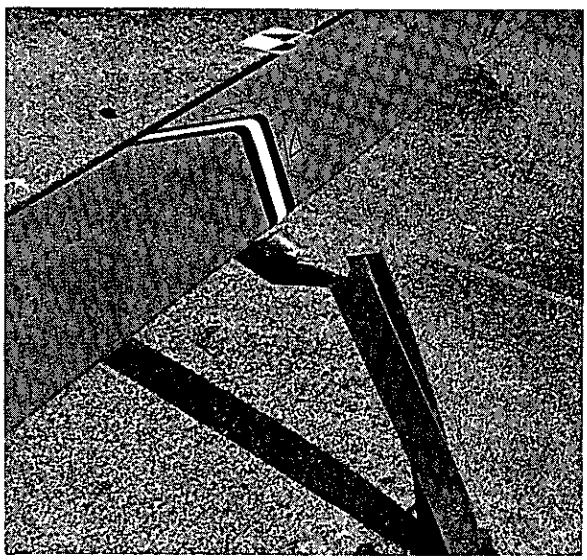
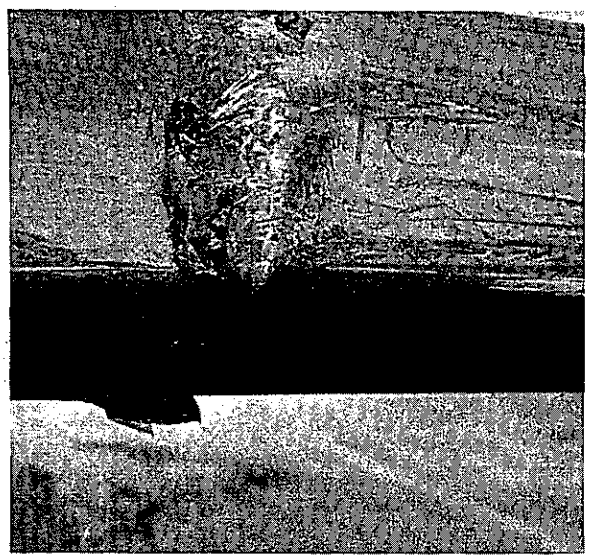
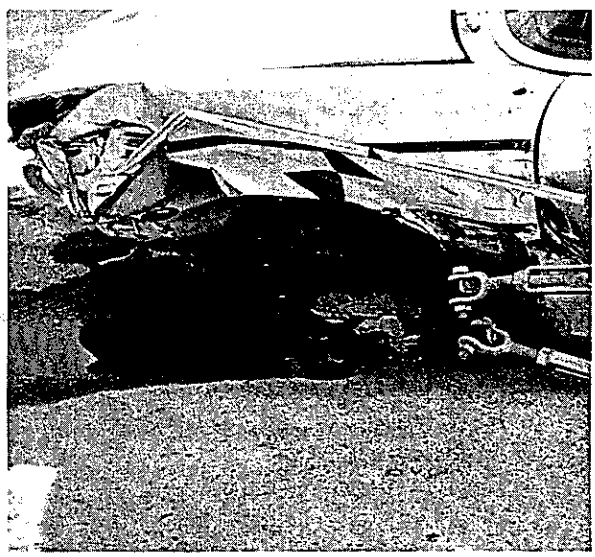
TEST 142 PLATE D











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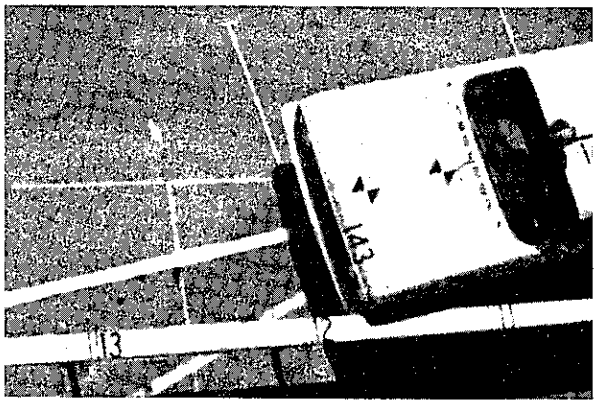
TEST 143 PLATE A



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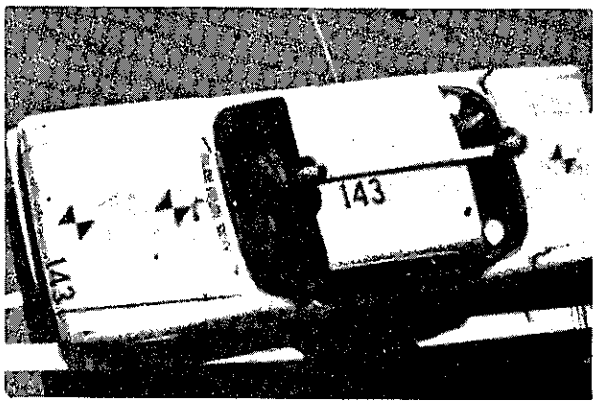

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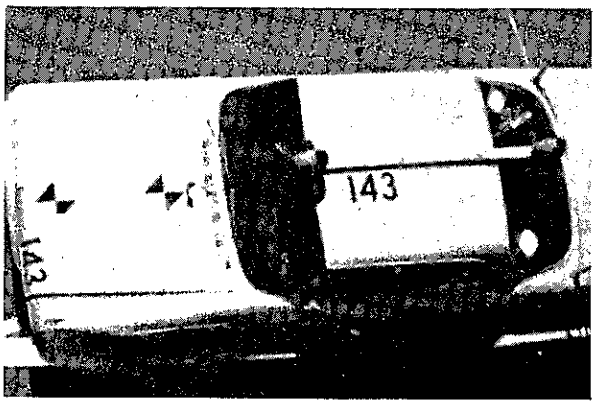

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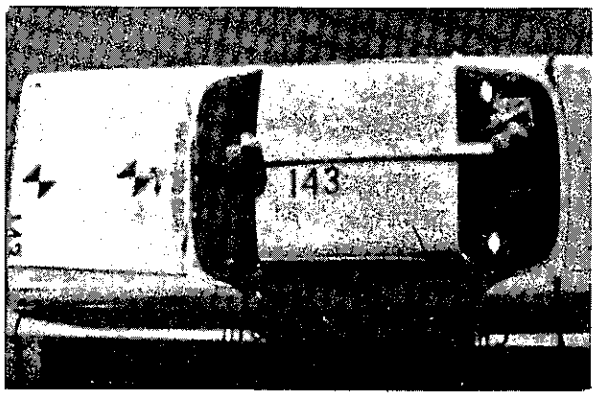

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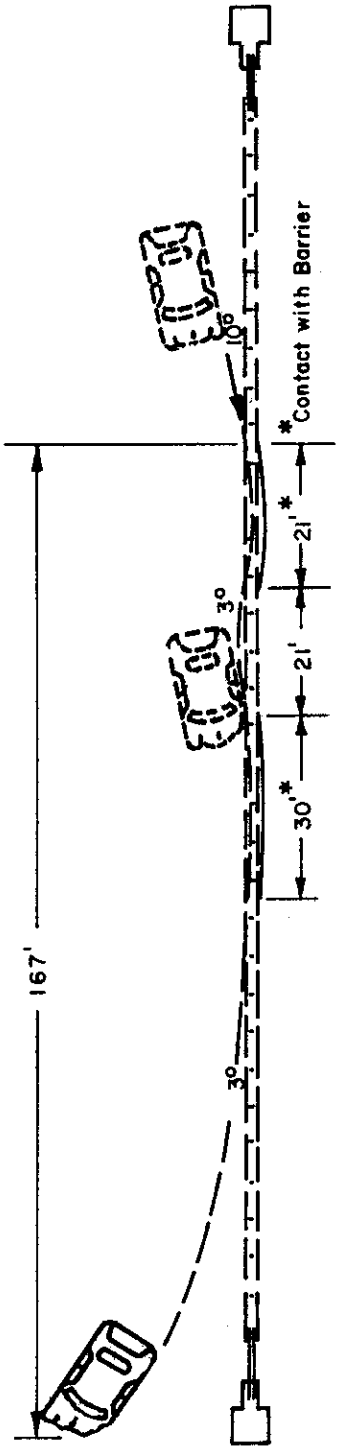
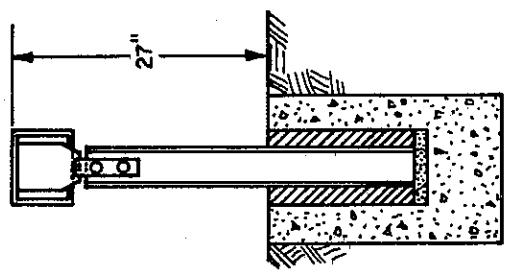


TEST NO. 143
DATE 9-22-66
VEHICLE ..... 1964 Dodge Sedan
VEHICLE WEIGHT ..... 4540#
(WITH DUMMY & INSTRUMENTATION)
IMPACT SPEED ..... 49 mph
IMPACT ANGLE ..... 10°
EXIT ANGLE ..... 3°
DUMMY RESTRAINT ..... Lap Belt

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



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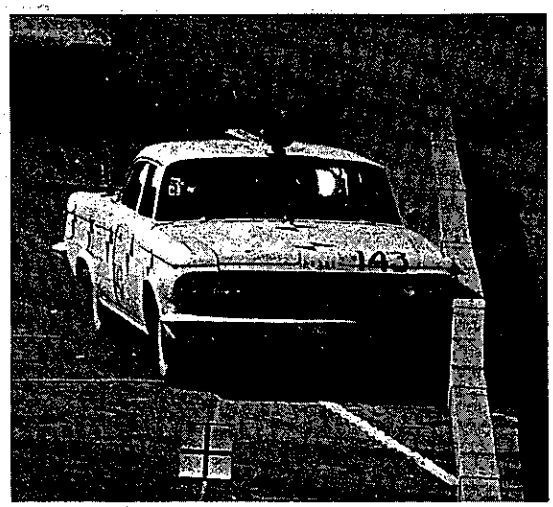
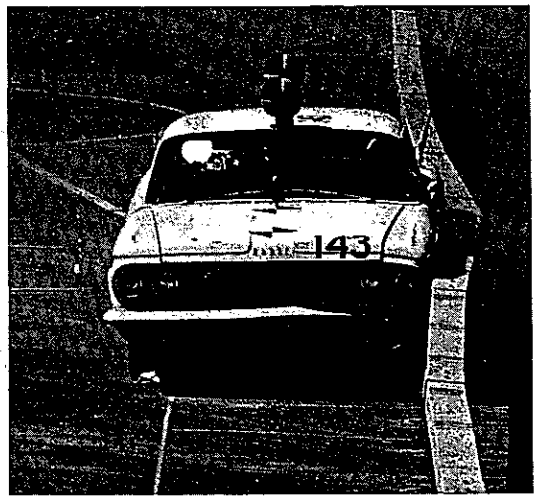
TEST 143 PLATE B



Impact + .055 Sec.



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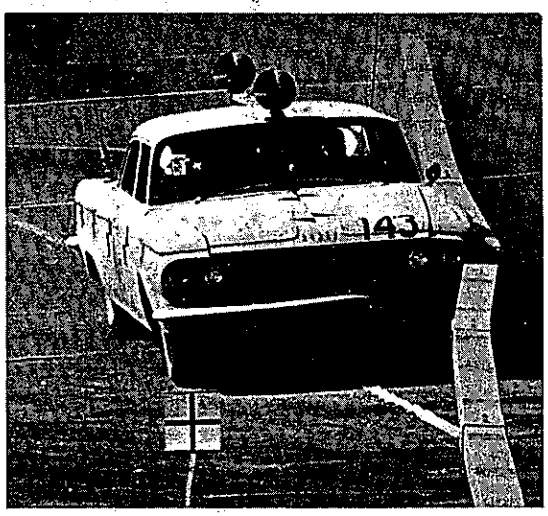

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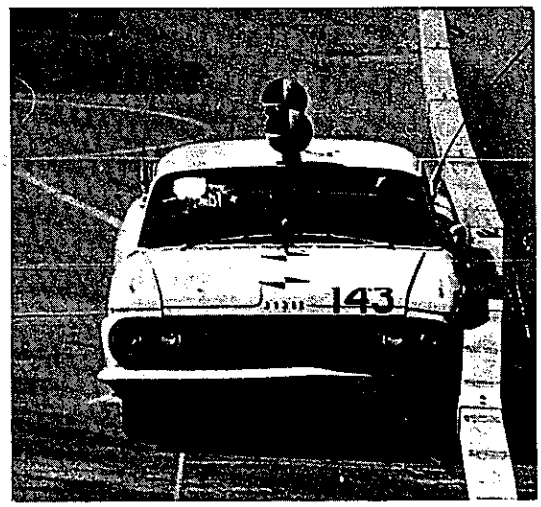

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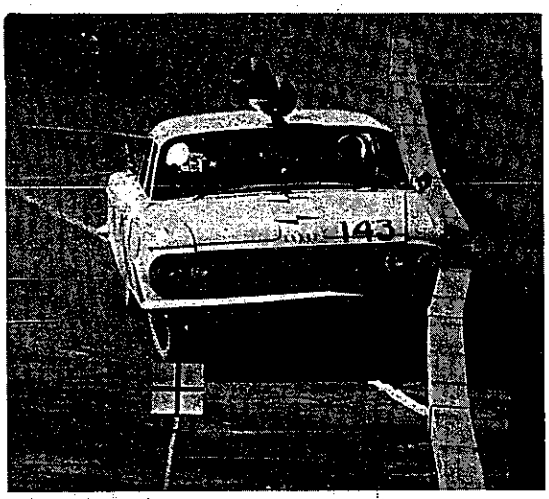

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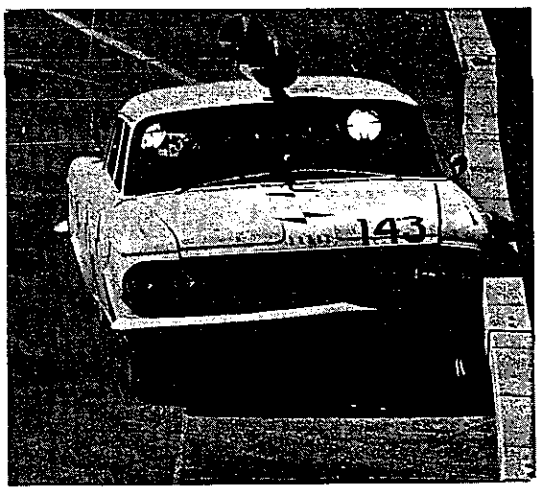

I + .760 Sec.

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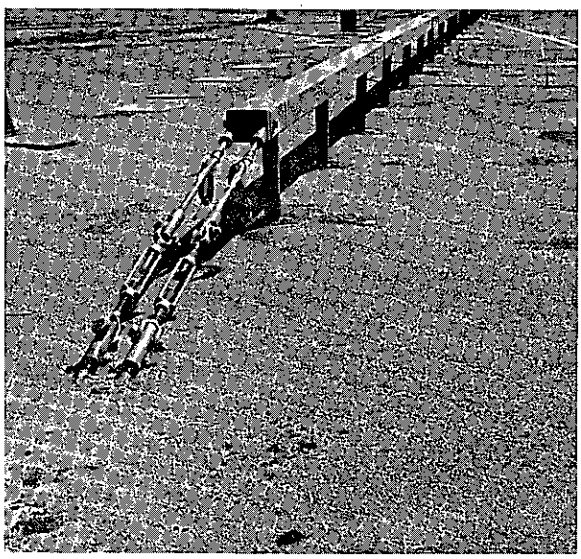
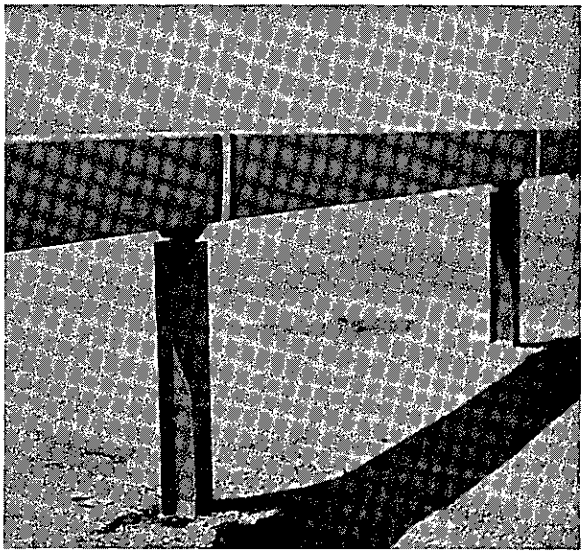
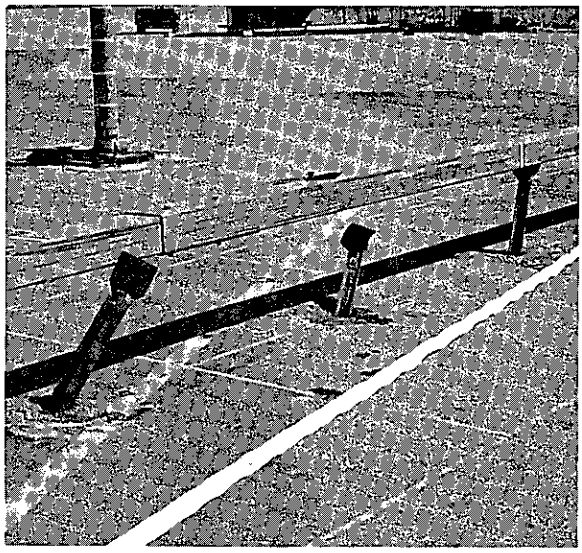
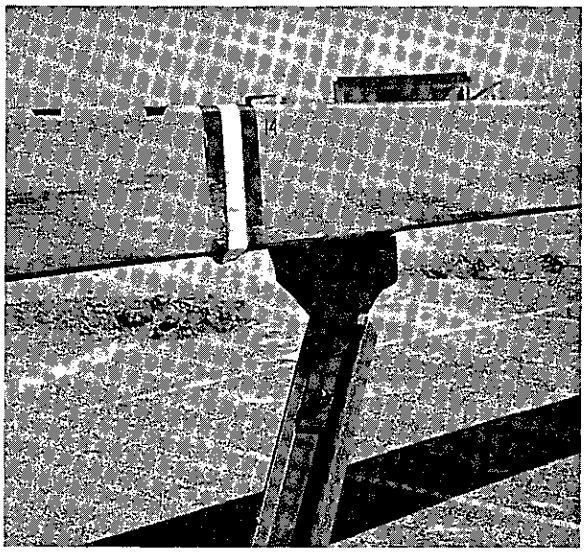
TEST 143 PLATE C









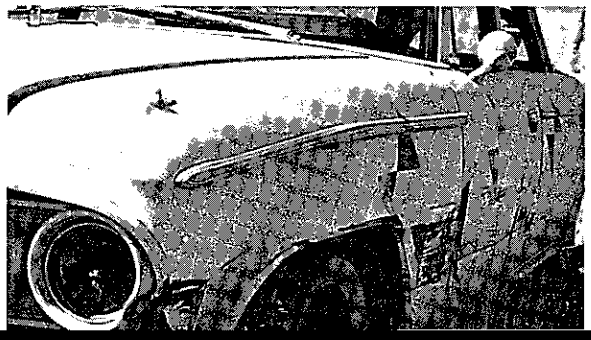


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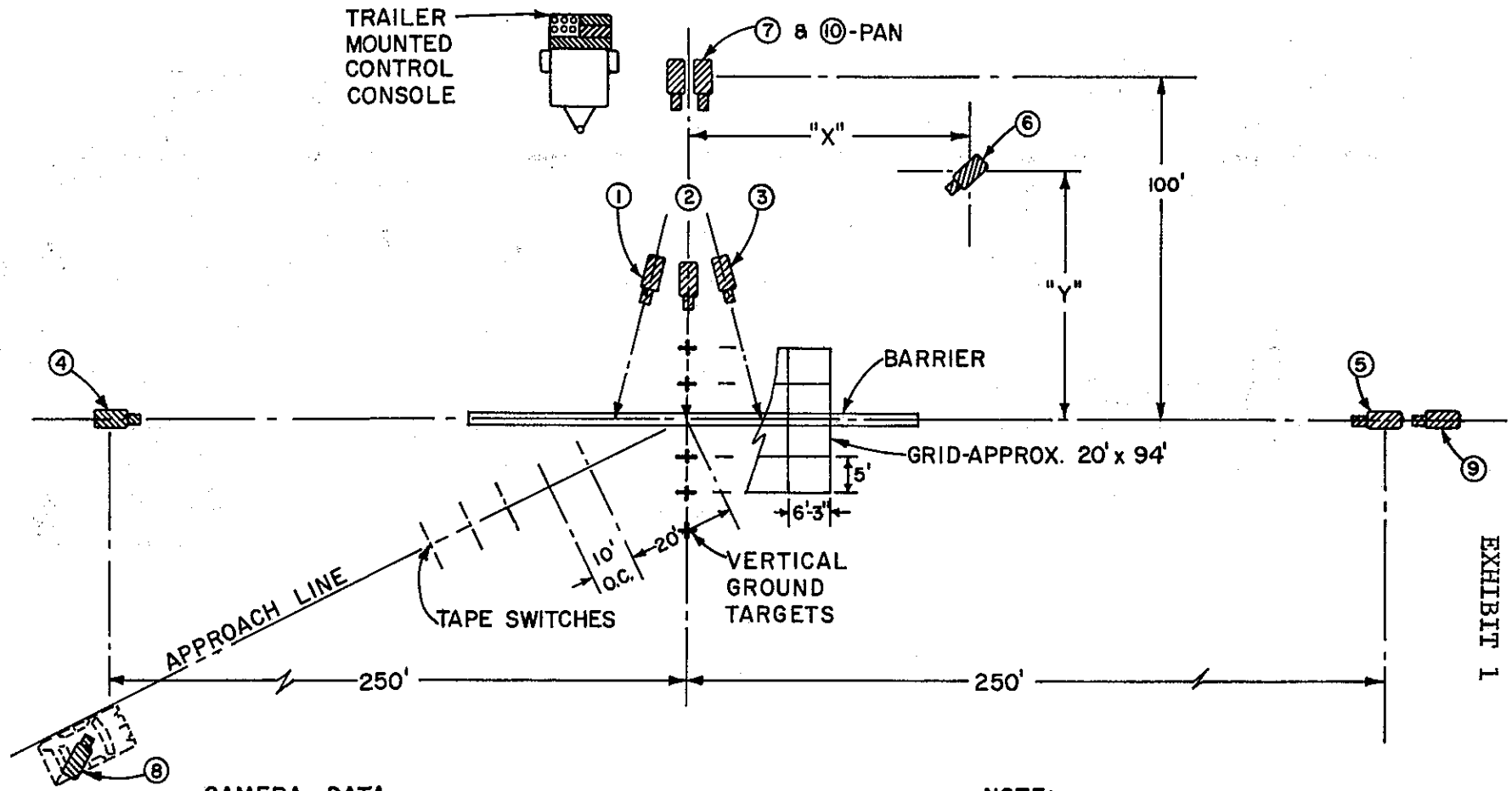
EXHIBIT 1



CAMERA DATA

①②③ PHOTO-SONICS, 13.0 MM LENS, 380 FPS,* MOUNTED ON 35' TOWER AND ORIENTED TO COVER THE AREAS INDICATED ABOVE.

④⑤ PHOTO-SONICS, 4" LENS, 380 FPS.

⑥ PHOTO-SONIC, 2" LENS, 380 FPS.

⑦ PHOTO-SONIC, 2" LENS, 380 FPS.

⑧ PHOTO-SONIC, 5.3 MM WIDE ANGLE LENS, 200 FPS, INSIDE TEST CAR.

⑨ HULCHER, 70 MM SEQUENCE CAMERA, 12" LENS, MOUNTED ABOUT 12' HIGH ON SCAFFOLD.

⑩ BOLEX, 1" LENS, 24 FPS.

* FRAMES PER SECOND.

NOTE:

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

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

DYNAMIC FULL SCALE BARRIER TESTS
PHOTOGRAPHIC INSTRUMENTATION – TYPICAL PLAN

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EXHIBIT 2

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

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

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

DYNAMIC DATA ON BARRIER AND VEHICLES

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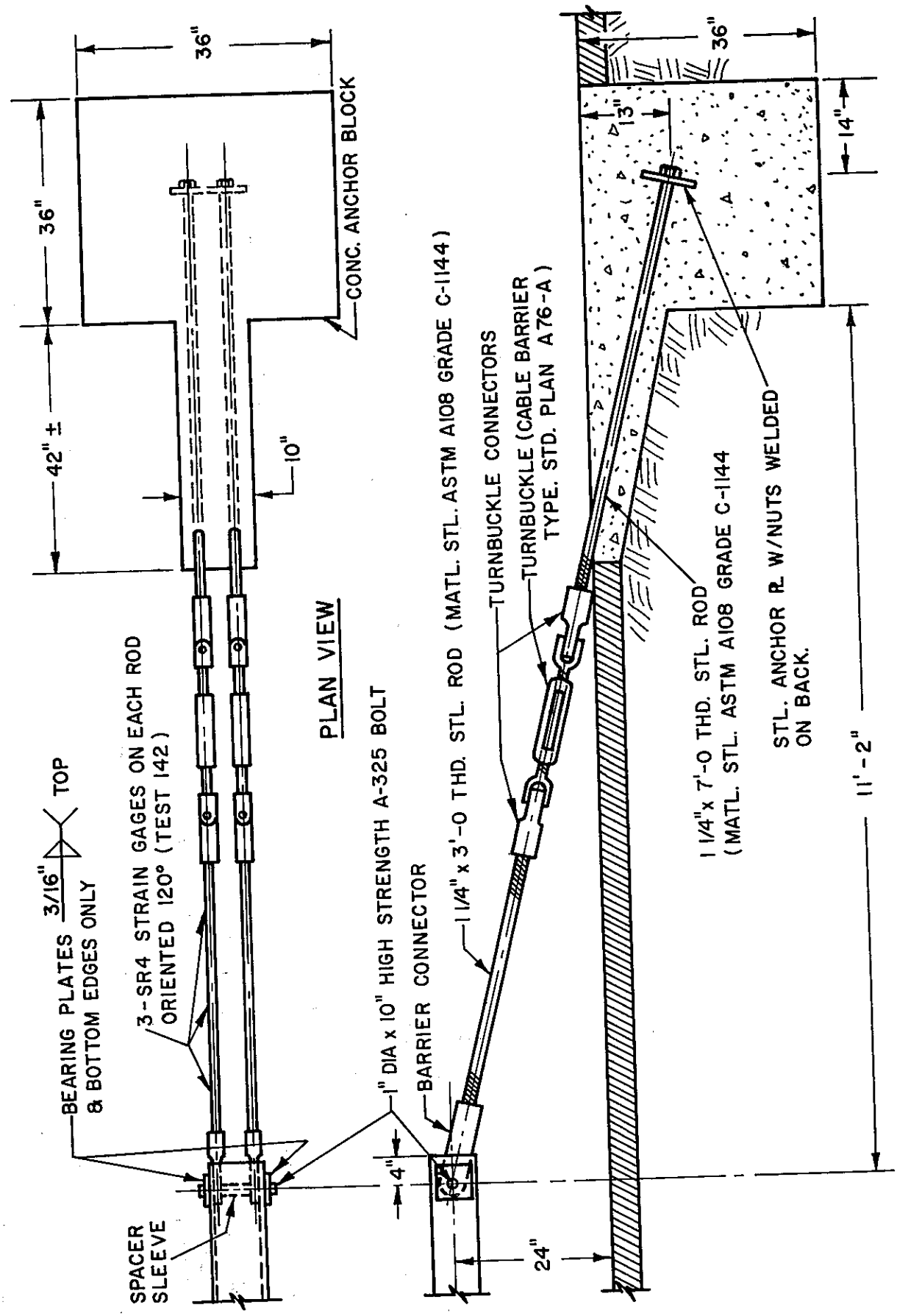
EXHIBIT 3



END ANCHOR ASSEMBLY
TESTS NO. 142 & 143

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EXHIBIT 4

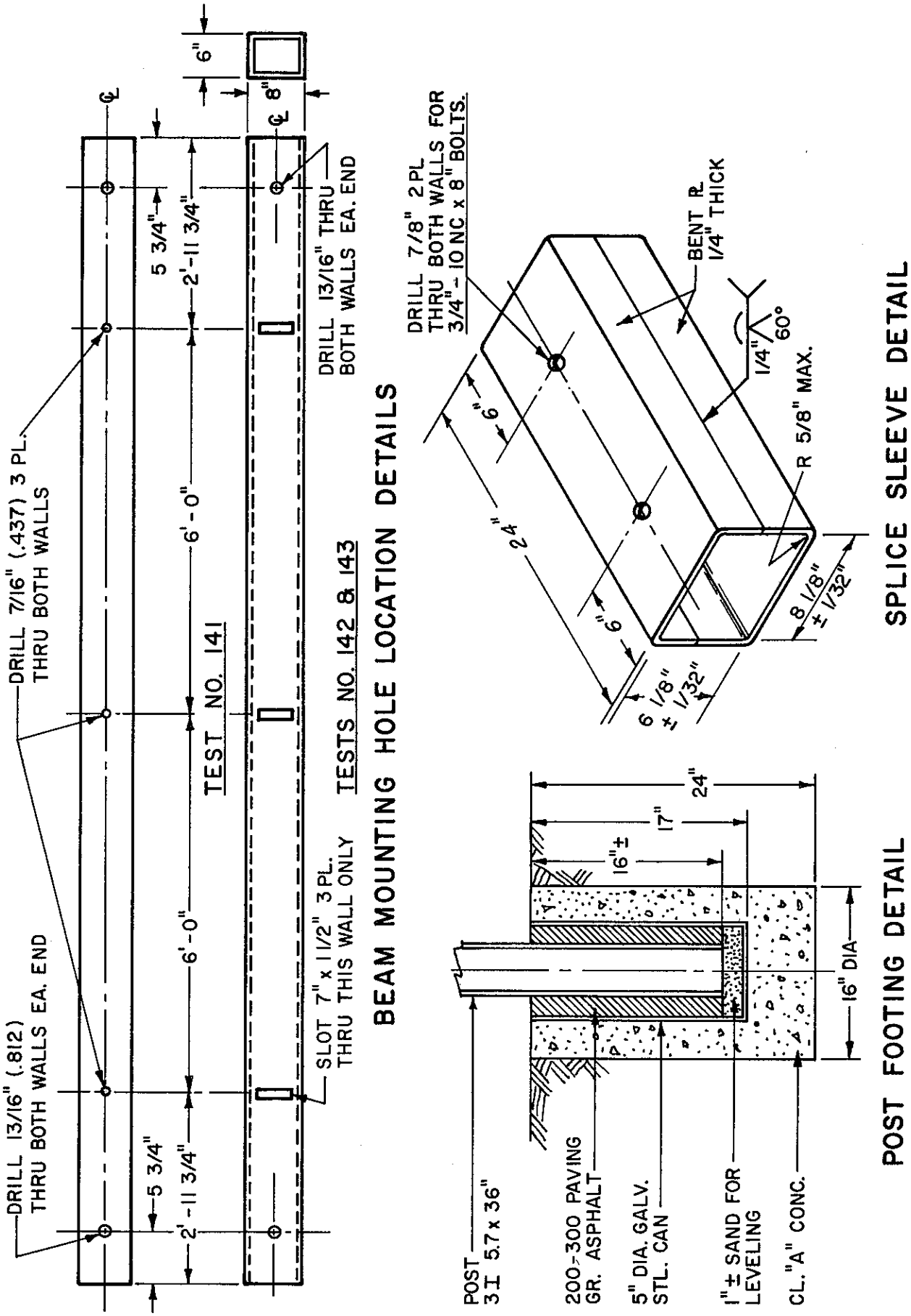

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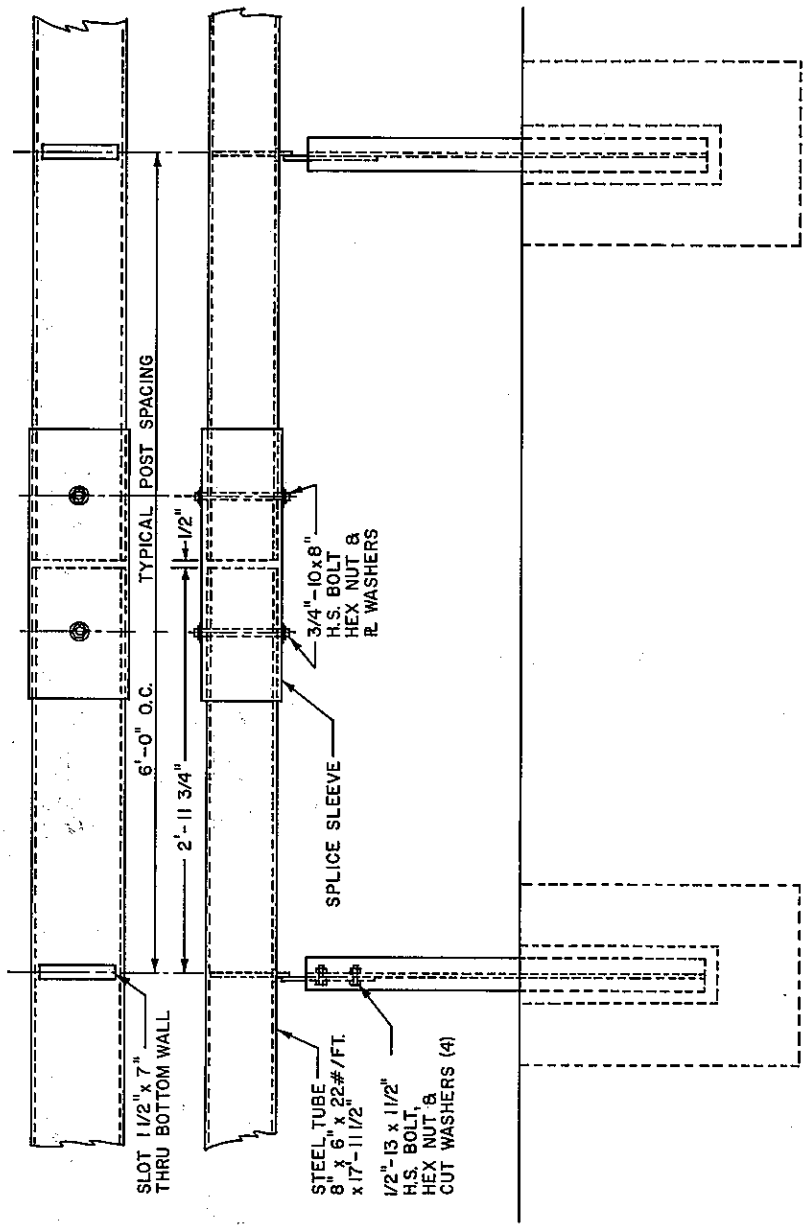
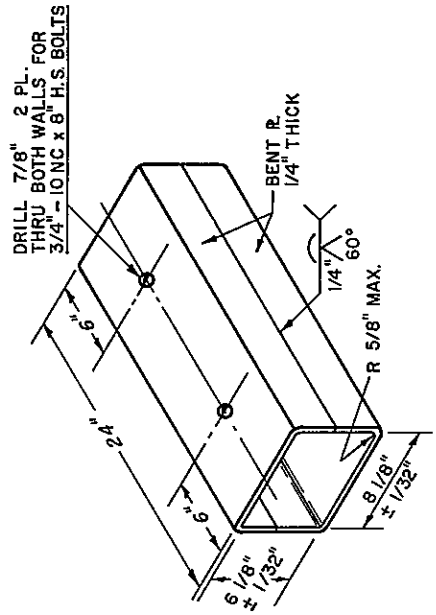
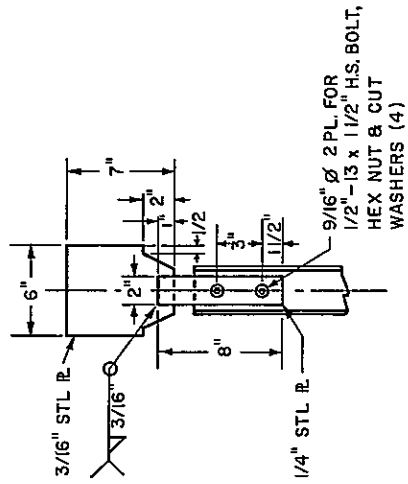
EXHIBIT 5



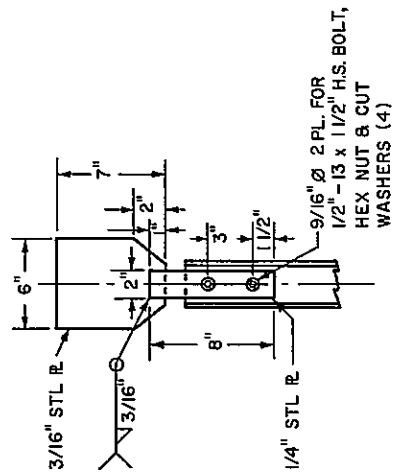
TYPICAL INSTALLATION



SPLICE SLEEVE DETAIL

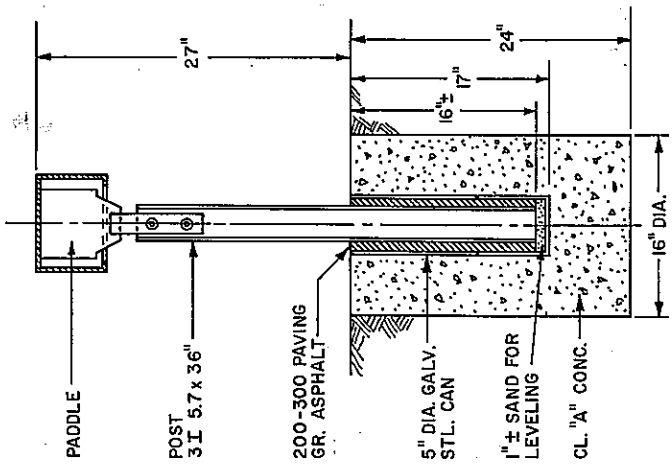


ALTERNATE DESIGN



DESIGN TESTED TEST NO. 143

PADDLE DETAILS



TYPICAL SECTION

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