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Dynamic Tests Of Concrete Median Barrier, Series XVI

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16. ABSTRACT

The results of a series of full scale dynamic impact tests of a concrete median barrier design are reported. The barrier design, developed by the New Jersey Highway Department, consists of a contoured, nonreinforced concrete wall 32 inches high.

It was felt that this barrier design would provide an aesthetically pleasing and maintenance-free barrier for use on very narrow medians.

Three tests were conducted at varying speeds and approach angles. The test barrier effectively contained and redirected the impacting vehicle in all three tests. However, in the third test, a high speed wide angle impact, vehicle damage and passenger deceleration forces were relatively severe. The barrier sustained no appreciable damage from any of the impacts.

It was concluded that the New Jersey concrete median barrier is an effective, low maintenance design suitable for use in narrow flat paved medians free of curbs, dikes, ditches, and sawtooth slopes.

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Dynamic tests, median barriers, barriers, concretes, vehicle dynamics, passengers, kinetics, design

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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

CONCRETE MEDIAN BARRIER

SERIES XVI

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Very truly yours,

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ABSTRACT

REFERENCES: Nordlin, E. F. and R. N. Field, "Dynamic Tests of Concrete Median Barrier, Series XVI", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report No. 636392-III, August 1967.

ABSTRACT: The results of a series of full scale dynamic impact tests of a concrete median barrier design are reported. The barrier design, developed by the New Jersey Highway Department, consists of a contoured, nonreinforced concrete wall 32 inches high.

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KEY WORDS: Dynamic tests, median barriers, barriers, concretes, vehicle dynamics, passengers, kinetics, design..

TABLE OF CONTENTS

I. INTRODUCTION

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

The first concrete median barrier design investigated consisted of precast, reinforced units 96" long and weighing 1600# each. The units were joined with connectors specifically designed to provide continuity. It was felt that these connectors would successfully transfer the shear and moment loads to adjacent units, thus enabling three or more units to act concurrently to develop adequate beaming action. Work on this investigation was conducted under the 1965-66 Work Program HPR 1(3) as Item D-04-41 and was reported on in October 1966[1]. The report concluded, as the result of a single full scale test, that (1) the barrier tested would not redirect an impacting high speed vehicle, and (2) installation and maintenance costs would be considerable.

It was recommended that this initial concrete barrier project be discontinued with the understanding that the Materials and Research Department would undertake a study of the New Jersey concrete median barrier design. This subsequent study was proposed for inclusion in the 1966-67 Work Program HPR 1(4) as Section III, "Dynamic Full Scale Impact Tests on Rails and Barriers". The project was formally approved in June 1966 and was carried as Item D-04-37, Part III, Research.

The first prototype of the New Jersey concrete median barrier design was installed on a test section of that state's highway system in 1955. The over-all height of this prototype barrier was 18 inches. However, after adverse operational experience the height was increased to 24 inches and then in 1959 to the present 32 inches. Accident statistics indicated that this 32 inch high design is performing effectively[2].

In 1963 the General Motors Proving Grounds conducted a series of 21 full scale tests on a concrete bridge parapet design[3] adapted from the New Jersey median barrier design as shown in Figure 1.

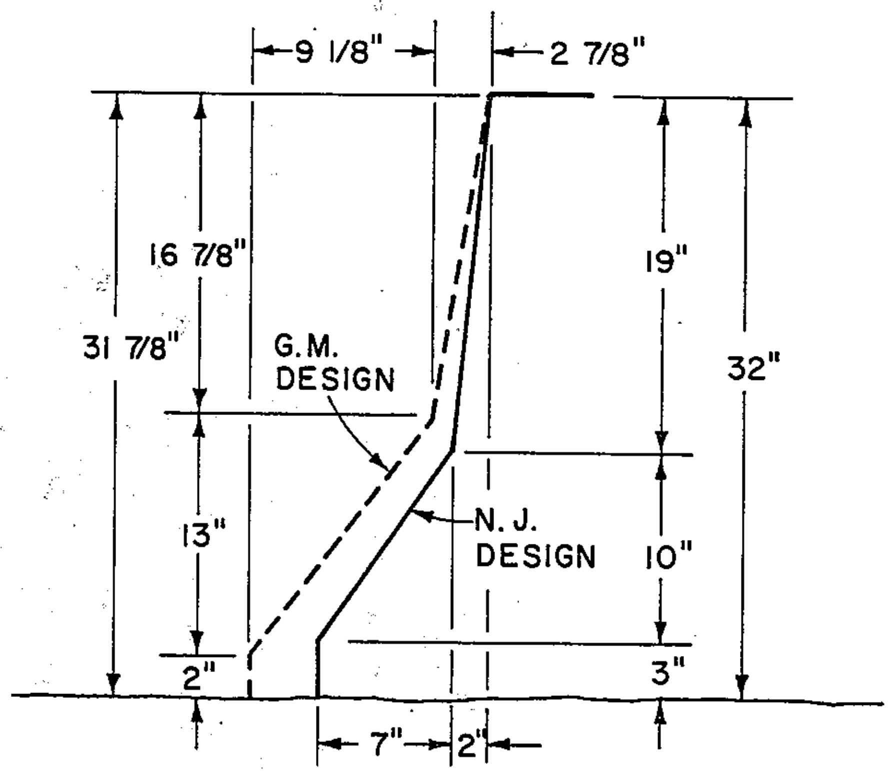

FIGURE 1

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

The State of New Jersey, in order to obtain additional factual accident analysis of their barrier design, commissioned the Stevens Institute of Technology to conduct a research program to "correlate the geometric properties of rigid concrete median barriers and the trajectory parameters of impacting vehicles". These correlations were to be performed by the analysis of high speed movies of automobile-barrier impact simulation done by use of scale model vehicles and barriers. Barrier design modifications were to be proposed as a result of this study. However, Stevens Institute reported that full realization of the intent of their study was not accomplished in that (1) full scale crash data against rigid barriers that would be pertinent to their study could not be located and (2) a complete description of automobiles in terms of all the parameters needed for accurate scaling could not be assembled.

California had proposed in the initial work plan that the latest findings of the Stevens Institute would be utilized in the initial design for the concrete barrier. However, due to their technical difficulties, the Stevens Institute was unable to make any barrier design recommendations. The California tests were therefore conducted on the standard 32 inch high design as originally developed by the State of New Jersey Highway Department.

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads, as Item D-04-37 of Work Program HPR-1(4), Part III, Research. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

II. OBJECTIVE

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

III. CONCLUSIONS

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

1. This barrier design effectively redirects a medium weight sedan impacting at acute angles (less than 10 degrees) with no or minimal vehicle damage and no barrier damage, indicating that this design would be particularly applicable to narrow medians.

2. This barrier design also redirects a medium weight sedan impacting at a high speed (60 mph) wide angle (25 degrees) with little or no barrier damage. However, vehicle damage and passenger deceleration rates can be expected to be relatively severe.

3. Although this concrete barrier design would provide definite maintenance advantages over the California standard metal beam median barrier, placement of this design should be limited to <u>flat</u> paved medians free of <u>curbs</u>, dikes, ditches, and sawtooth slopes.

4. Construction cost of this barrier on one project in Phoenix, Arizona, was $5.88/lin. ft. as compared to the average weighted price of $11.91/lin. ft. for 30,700 ft. of barrier constructed in the State of New Jersey during 1965. Accurate construction costs for California have not been determined.

IV. DISCUSSION

A. Design Tested

The median barrier tested was a contoured, solid concrete wall design as shown below in Figure 2, which was developed by the State of New Jersey Highway Department.

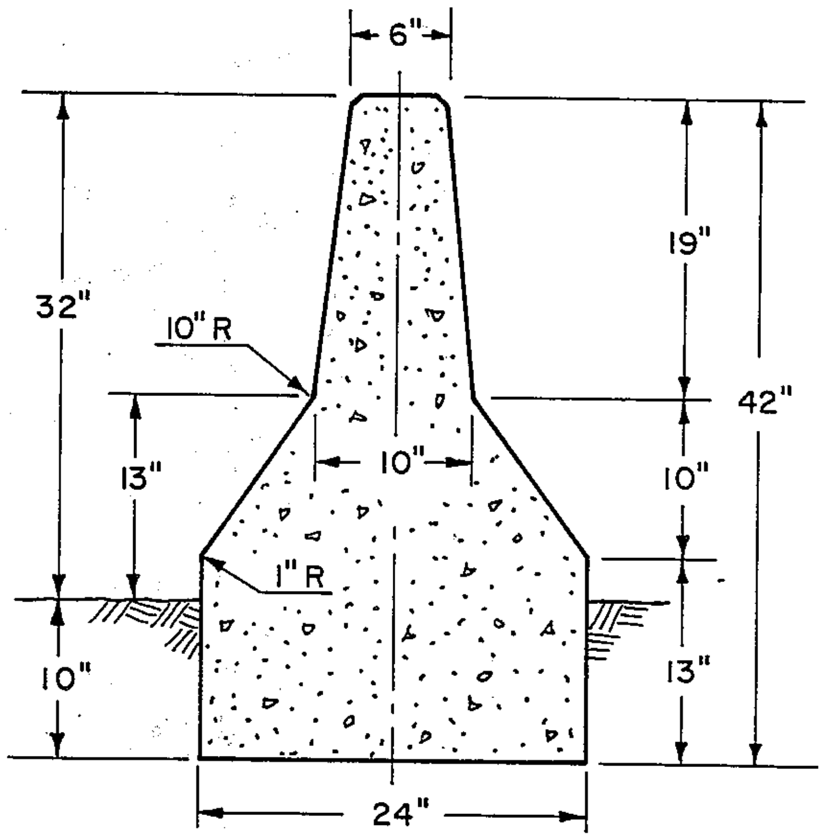

FIGURE 2

The installation consisted of eight 32 inch high, 20 ft. long, nonreinforced, cast-in-place concrete wall sections. Each individual section consisting of a footing and parapet was a single monolithic pour of approximately 3 cubic yards weighing 6 tons. Adjacent sections were not doweled or connected at the expansion joints (Exhibit 1). The strength of the Class A concrete, specified at 3000 psi minimum at 28 days, was in excess of 6200 psi at the time of the impact test.

B. Test Parameters

The test vehicle used in this study was a 1965 Dodge sedan weighing 4540 pounds with dummy and instrumentation. The test impact speeds and angles were as follows:

a. Initial trial test - 20 mph @ 2°.

b. Test 161-A - 38 mph @ 7°.

c. Test 161-B - 65 mph @ 7°.

d. Test 162 - 63 mph @ 25°.

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

The procedures taken to prepare, remotely control, and target the test vehicle are generally similar to those used in past test series and are detailed in previous California reports[5,6].

These test parameters meet the guidelines established by the Highway Research Board Committee on Guardrails and Guide Posts[7].

C. Instrumentation

Photographic and mechanical instrumentation procedures and equipment employed in this test series are generally similar to those used in past test series and are detailed in previous California reports[5,6]. Camera locations and data are shown in Exhibit 2.

Table I, shown on the following page, is a tabulation of dynamic data including readings on the impactograph installed in the chest of the dummy driver during each of the three tests in this series. Included in the exhibit for comparisons are dynamic data from previous tests on semi-flexible box beam barrier, semi-rigid "W" beam median barrier and guardrail, and rigid concrete parapet Type 1 bridge rail.

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

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

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

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

DYNAMIC DATA

TABLE I

D. Barrier - Vehicle Performance

1. Energy Dissipation

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

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

TABLE II

THEORETICAL KINETIC ENERGY (Ft. Lbs.)

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

Assuming the brakes are not applied, dissipation of the energy component parallel with the barrier during satisfactory redirection is accomplished through friction force that is developed through (1) vehicle-barrier contact, and (2) wheel-pavement contact. With most barrier designs, the body of an impacting vehicle is in contact with the barrier throughout redirection. However, with the design tested in this investigation, at low angles the only vehicle contact may be that of the impacting front wheel. Thus, the vehicle-barrier friction force may be provided for only by the scrubbing action of this wheel as it climbs and is redirected by the lower sloping parapet face. The wheel-pavement interactions in any vehicular redirection are dependent on factors such as (1) tire condition, (2) weather, (3) weight distribution, and (4) roadway surface material and condition. In these tests the wheel-pavement friction force was generally provided through overcoming (1) "crabbing" of the wheels during redirection, (2) turning force of the tires against the pavement, and (3) normal tire-pavement rolling friction. The surface upon which these tests were conducted is an open grade plant mix bituminous pavement with a coefficient of friction of approximately 0.30. The tires on the test vehicle were near-new 6 ply 7:60-15, and were inflated to 30 psi.

The entire energy component perpendicular to the barrier must be absorbed for effective vehicle retention. This is accomplished through elastic and plastic deformation of the barrier, vehicle, or both. The barrier can transmit a portion of this energy to the structure as in the case of the concrete bridge rail or to the soil such as with the W beam barrier on wood posts. However, with a rigid system, such as this design, if the barrier does not fail, no energy is absorbed by the barrier and very little by the soil. Therefore, the vehicle must absorb or dissipate all the energy.

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

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

It was noted that General Motors experienced similar vehicle reactions in their tests[3]. With a standard size sedan impacting at 50 mph/12°, the vehicle climb was 18 inches and the resulting roll approximately 30° away from the barrier, whereas a truck impacting at 37 mph/13° did not climb the barrier and consequently the roll was toward the barrier.

The Stevens Institute using scale model vehicles was unable to duplicate these vehicle trajectories in their study[4]. In their tests of the General Motors barrier design, the model vehicle climbed much higher; and although the roll was away from the barrier, it was extreme as the vehicle landed on its right rear wheel and appears to have overturned. Stevens' test of the New Jersey barrier design exhibited no correlation as the model vehicle rolls toward the barrier and lands on its left wheels in all tests. Stevens indicated that valid proportioning of the model vehicle, particularly its dynamic response, was the major factor contributing to their lack of correlation with full scale impacts.

2. Preliminary Tests

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

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

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

No damage was sustained by either the vehicle or the barrier (Exhibit 3).

3. Test No. 161-A

This first remote radio controlled test was conducted at an approach angle of 7 degrees and at a speed of 38 mph.

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

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

The vehicle body contacted the upper barrier parapet 3 feet beyond initial impact and for a distance of 6.5 feet. The only damage sustained by the vehicle was slight sheet metal damage and paint scratches in the left front fender area. A close inspection of the steering mechanism and running gear revealed no damage or misalignment that would alter the vehicle's steering characteristics. This vehicle was used without repairs for the succeeding test.

Data film and impactograph recordings of the dummy driver indicates that a live driver would have sustained no injuries.

The barrier sustained no damage.

4. Test No. 161-B

For this test the same 7 degree approach angle was used, but the impact speed was increased to 65 mph.

The vehicle was effectively redirected with a maximum rebound of only 1.4 feet and a maximum roll of 14 degrees away from the barrier.

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

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

Data film and impactograph recordings of the dummy driver indicate that a live driver would have sustained nothing more severe than bruises. The barrier sustained no damage.

5. Test No. 162

This final test was to be conducted at 65 mph/25°, the California Division of Highways standard criteria for proof testing a barrier.

The actual impact speed obtained for this test was 63 mph.

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

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

Although the damage to the vehicle was considered severe, it was comparable to that sustained in similar high-speed, wide-angle tests on the standard blocked-out beam type barrier and a test on a concrete parapet bridge rail (Exhibit 4).

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

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

E. Maintenance and Operation

The results of the flat angle tests indicate that casual impacts, that represent a majority of the freeway median barrier accidents, would result in little or no damage to either the barrier or the offending vehicle. The high-speed wide-angle test indicates that maintenance repairs to this barrier design would be minimal even after a relatively severe impact. This would reflect a maintenance advantage over the beam-type barrier under moderate impact conditions where damaged beams or posts require replacement. However, it should be pointed out that operational studies have indicated that a majority of the casual impacts with the beam-type barrier are unreported and require no maintenance. On the other hand, any impact, however casual, with the cable barrier results in barrier damage usually requiring immediate repairs.

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

The State of Arizona constructed the New Jersey concrete barrier on an existing 6 inch curbed raised median. Operational reports indicate that this raised median presents vaulting problems causing impacting vehicles to initially contact the barrier above the lower sloped face. On two occasions reported, the vehicles vaulted after impacting the curbing and were partially airborne when they struck the upper portion of the barrier parapet knocking out pieces of concrete. A recent accident picture shows a vehicle with the left wheels projecting over the top of the parapet. Tire marks on the face of the barrier indicate that initial contact was made on the upper portion of the parapet approximately 16 inches from the top, and continued for approximately 20 feet at the same elevation before straddling the barrier. Vehicle damage appeared to be relatively moderate, and there was no apparent barrier damage.

These illustrations from operational experience emphasize the importance of placing this barrier on flat medians free of curbs, dikes, ditches, and sawtooth cross sections.

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

V. REFERENCES

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6. Field, R. N. and R. H. Prysock, "Dynamic Full Scale Impact Tests of Double Blocked-Out Metal Beam Barrier and Metal Beam Guardrailing, Test Series X", California Division of Highways, February 1965.

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

VI. APPENDIX

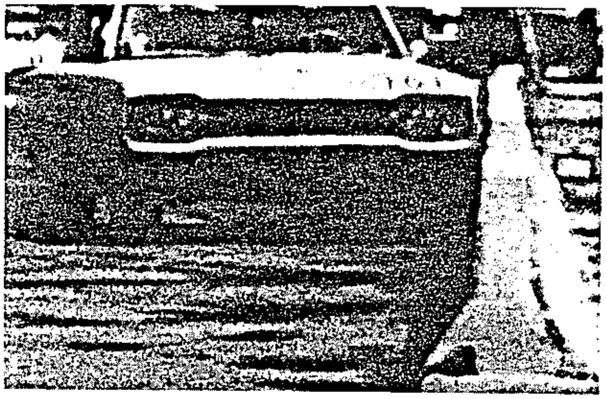
The following groups of plates contain pertinent data and photographs of the impact tests discussed in this report. Each group covers the following:

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

B. A series of sequence pictures from the scaffold mounted camera.

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

TEST 161-A PLATE A



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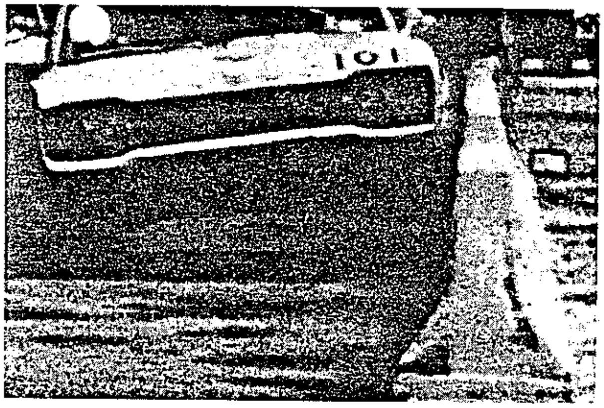

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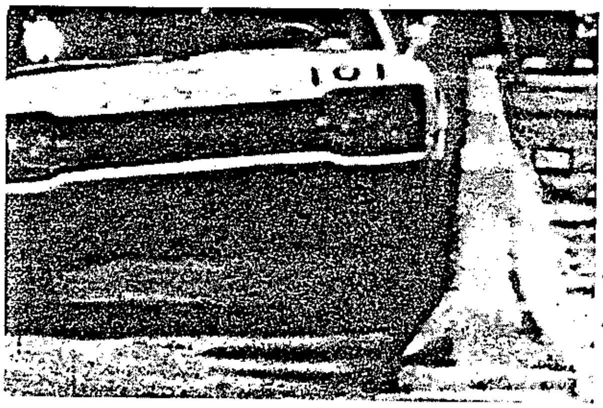

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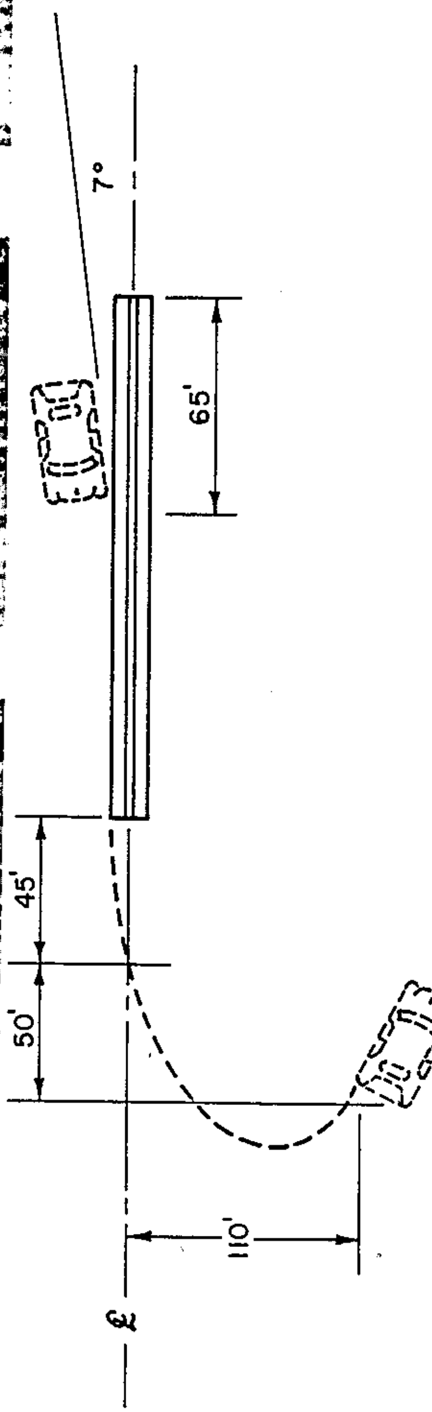
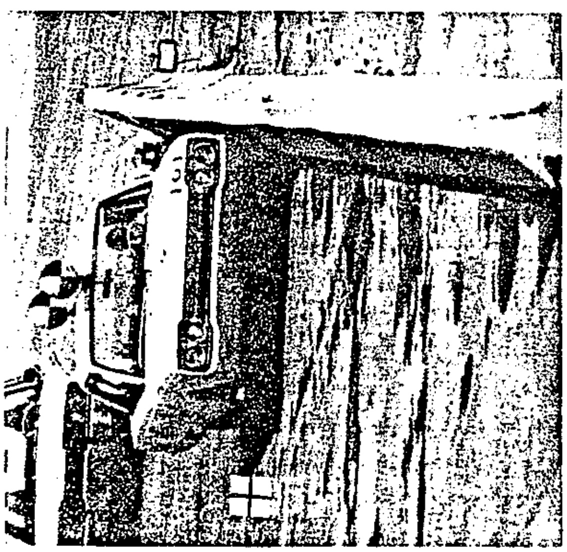


BARRIER	Unreinforced Concrete
LENGTH OF INSTALLATION	160 ft.
UNIT LENGTH	20 ft.
UNIT WEIGHT	13,200 #
GROUND CONDITION	Dry
CONTACT W/BARRIER	95'
MAX. VEHICLE CLIMB	8"
MAX. VEHICLE REBOUND	0

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

TEST 161-A PLATE B



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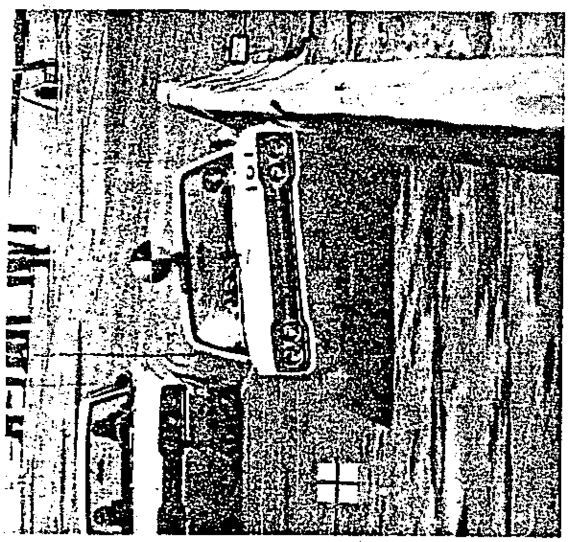

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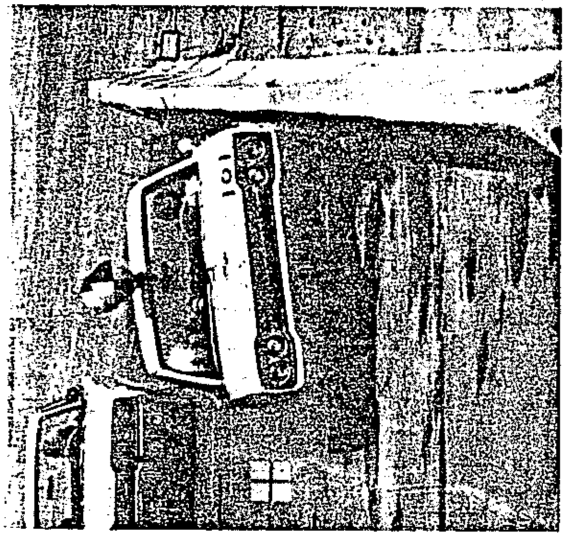

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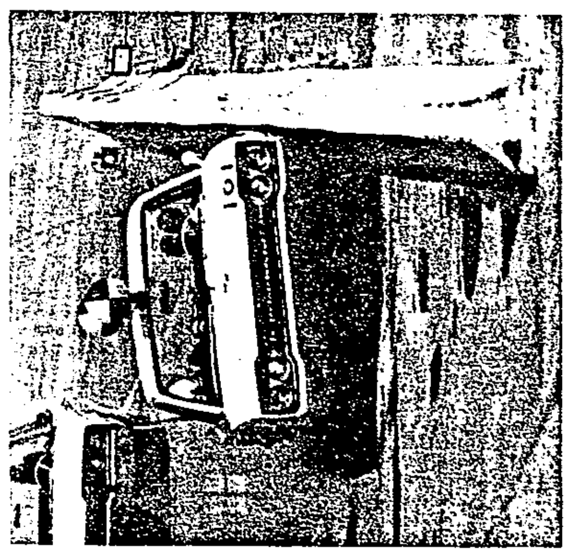

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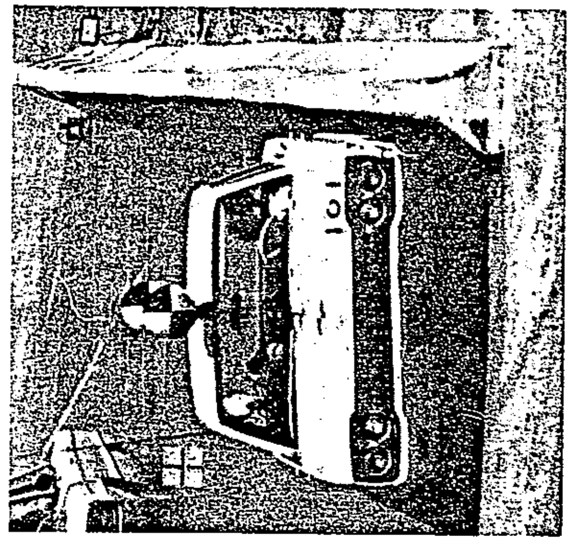

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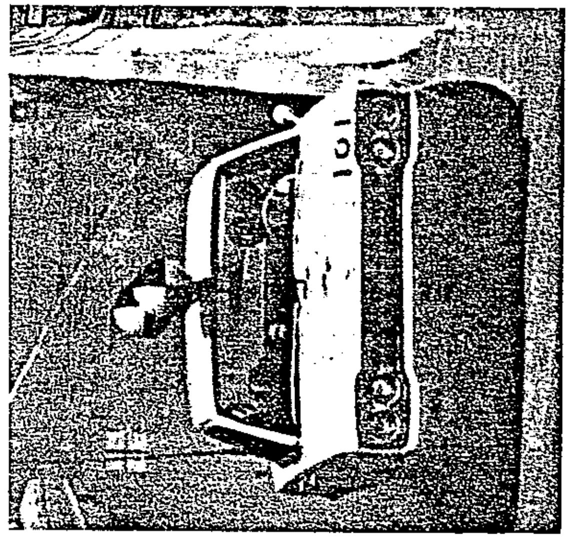
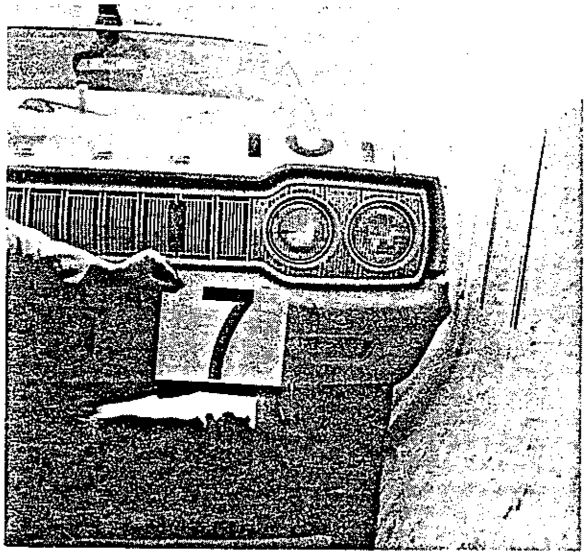
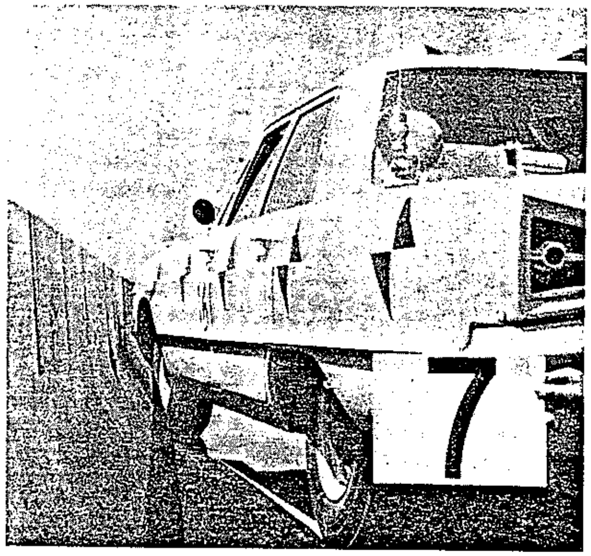
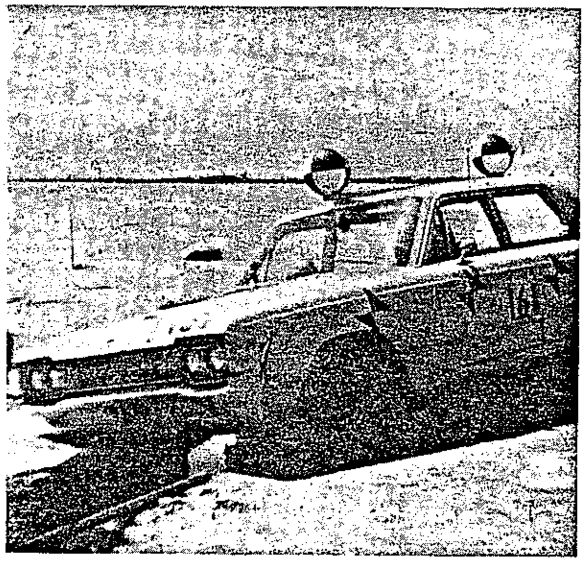
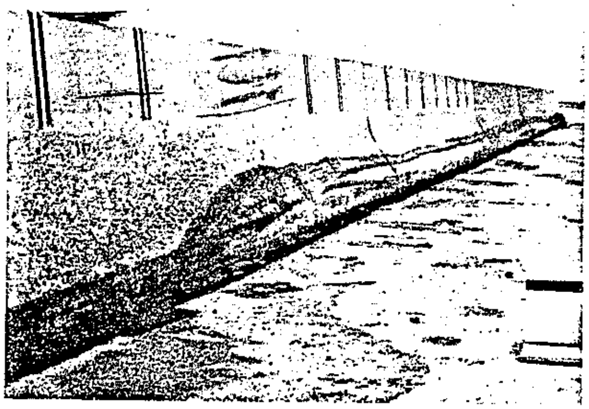
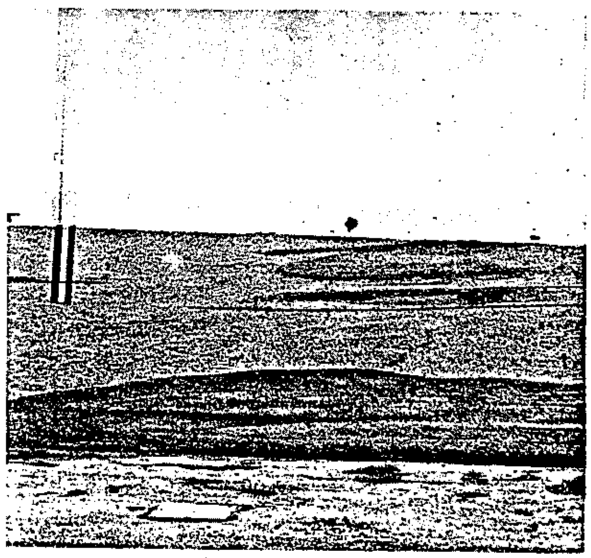


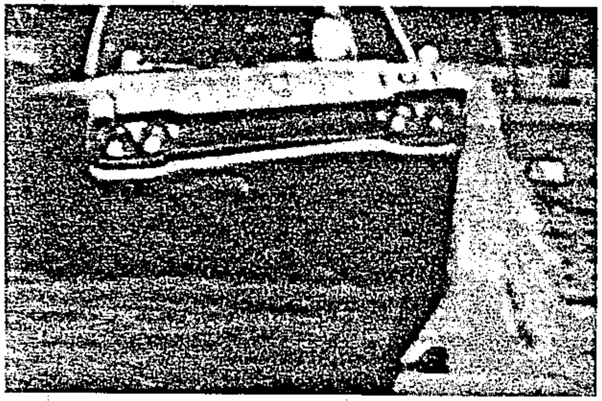
I + 2.50 Sec.

TEST 161-A PLATE C

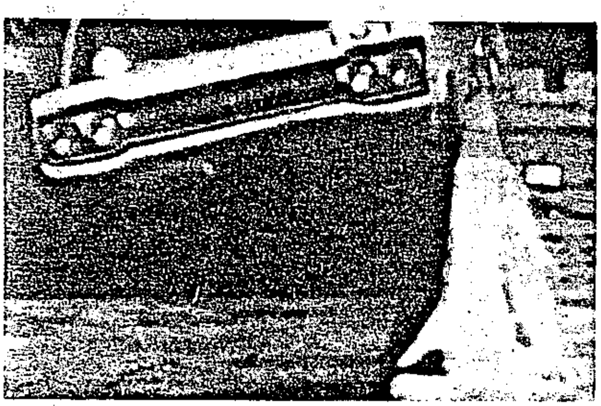




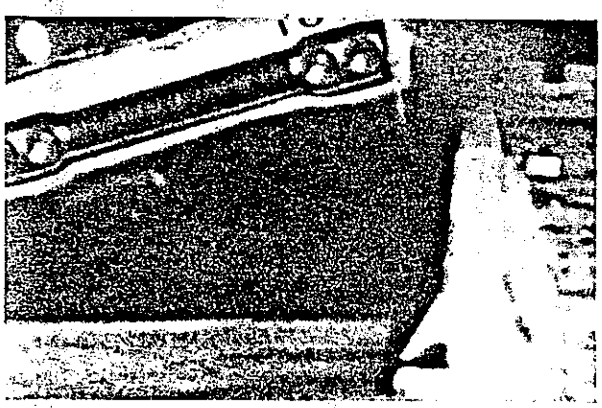
TEST 161-B PLATE A



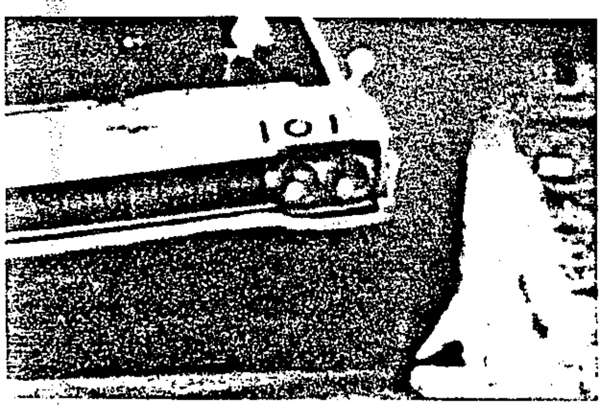
IMPACT +.06 Sec.



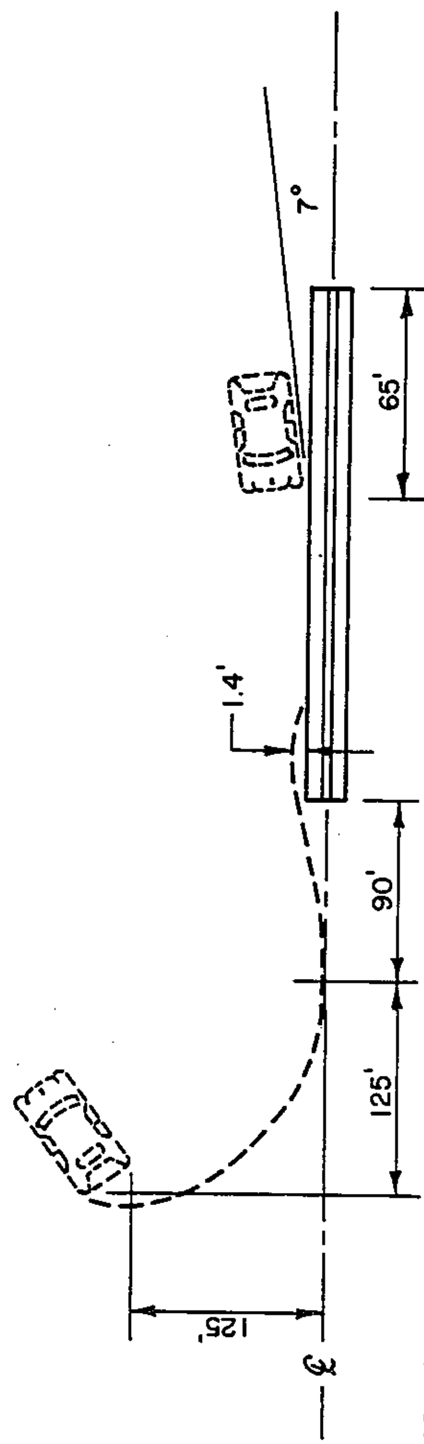
I + .19 Sec.



I + .39 Sec.



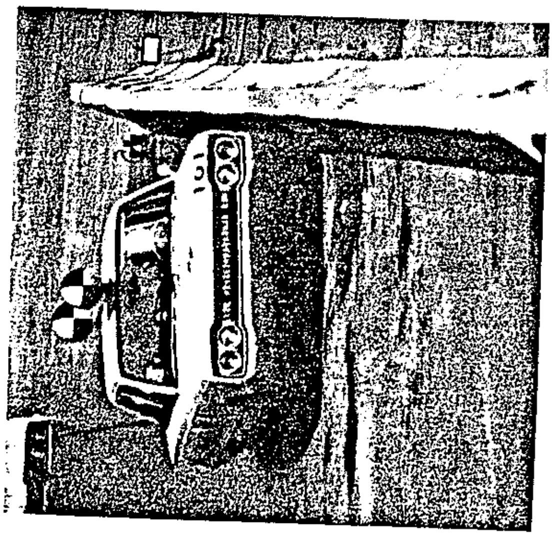
I + .64 Sec.



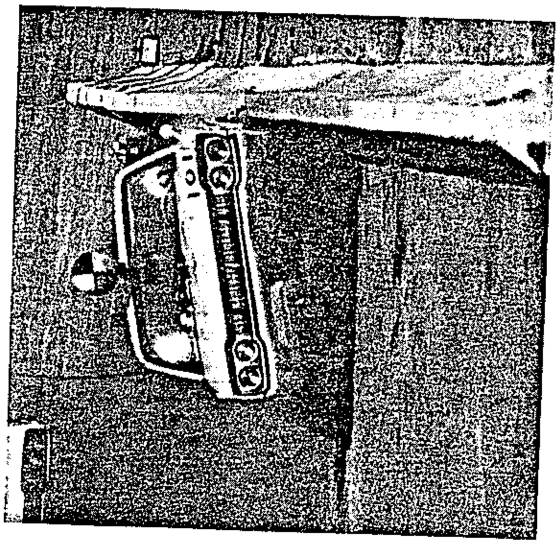
BARRIER	Unreinforced Concrete
LENGTH OF INSTALLATION	160 ft.
UNIT LENGTH	20 ft.
UNIT WEIGHT	13,200 #
GROUND CONDITION	Dry
CONTACT W/BARRIER	35'
MAX. VEHICLE CLIMB	14"
MAX. VEHICLE REBOUND	1.4'

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

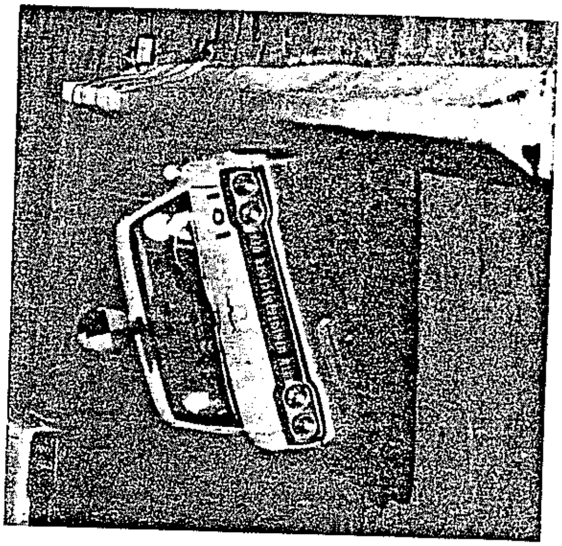
TEST 161-B PLATE B



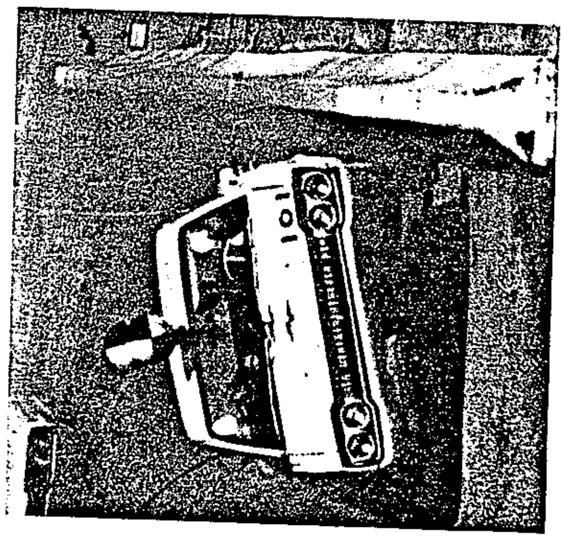
IMPACT



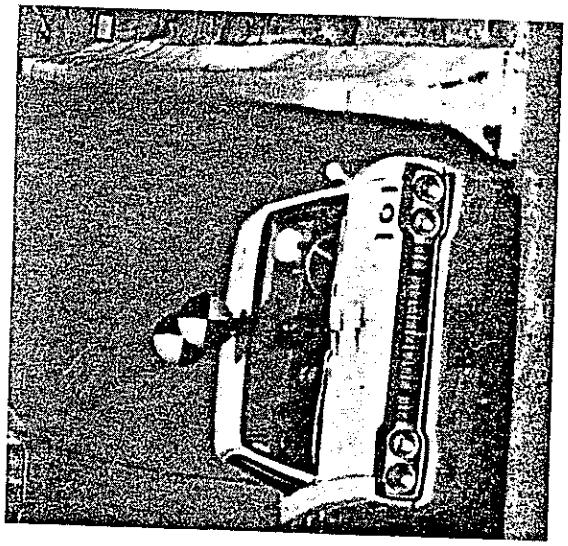
I + .20 Sec.



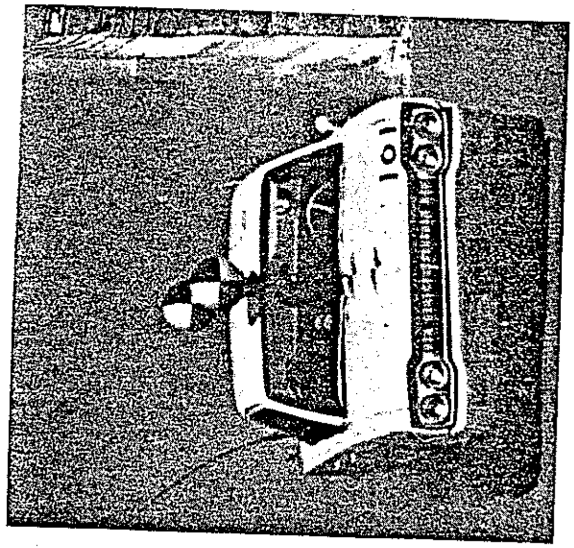
I + .50 Sec.



I + .70 Sec.

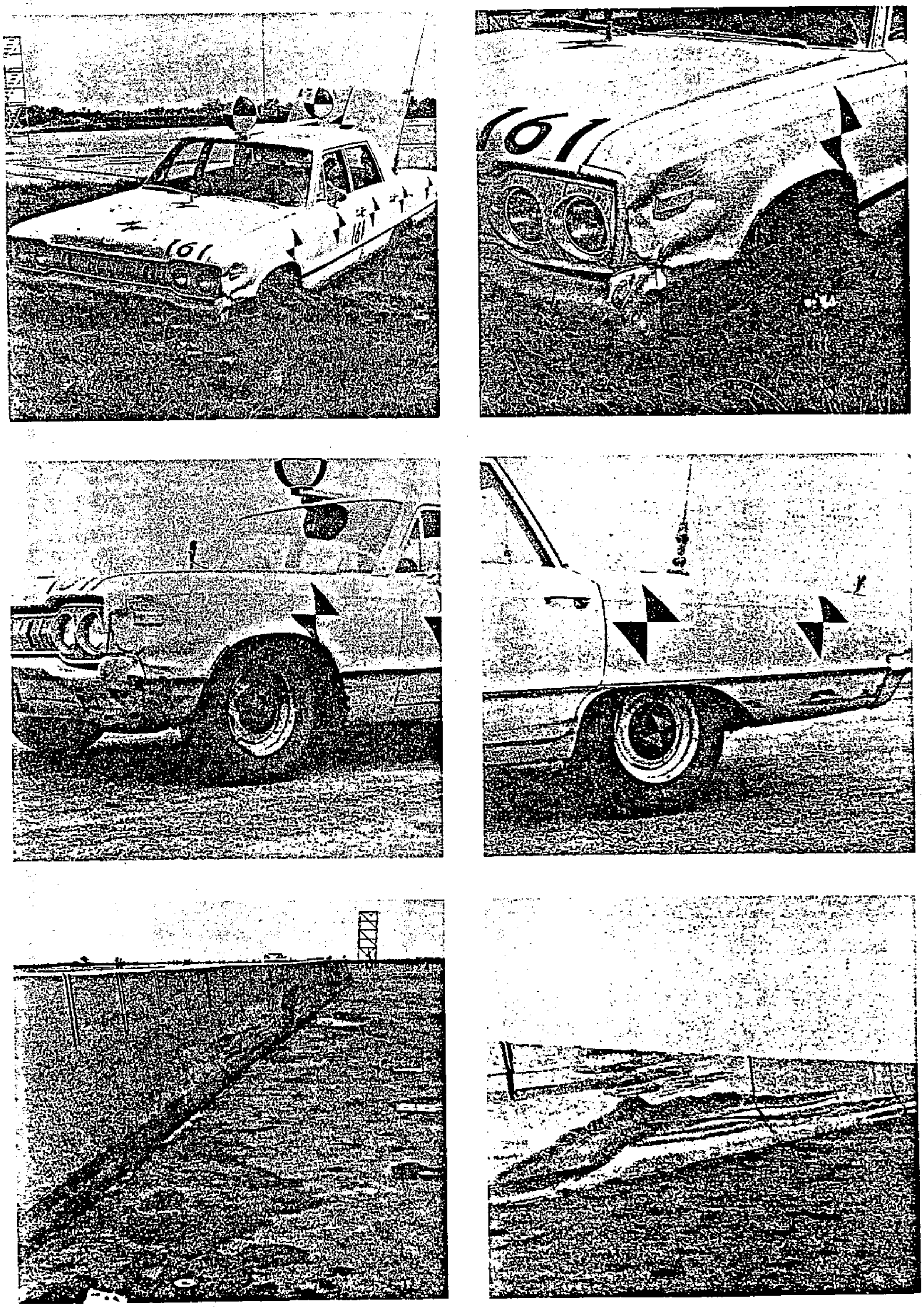


I + .95 Sec.

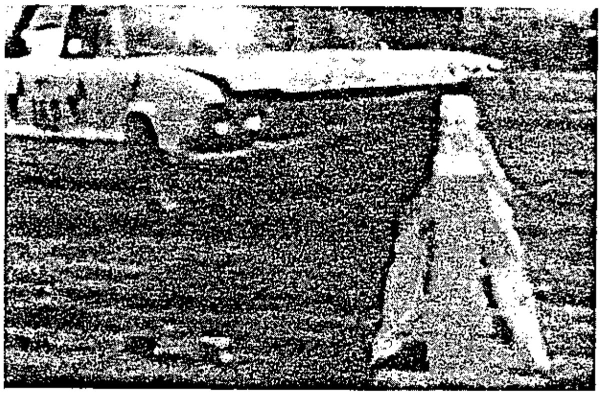


I + 1.35 Sec.

TEST 161-B PLATE C

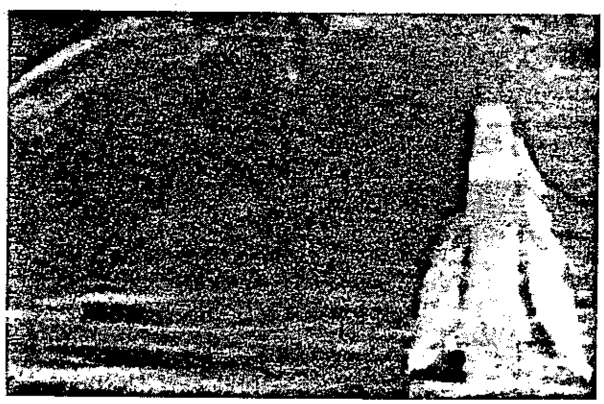


TEST 162 PLATE A



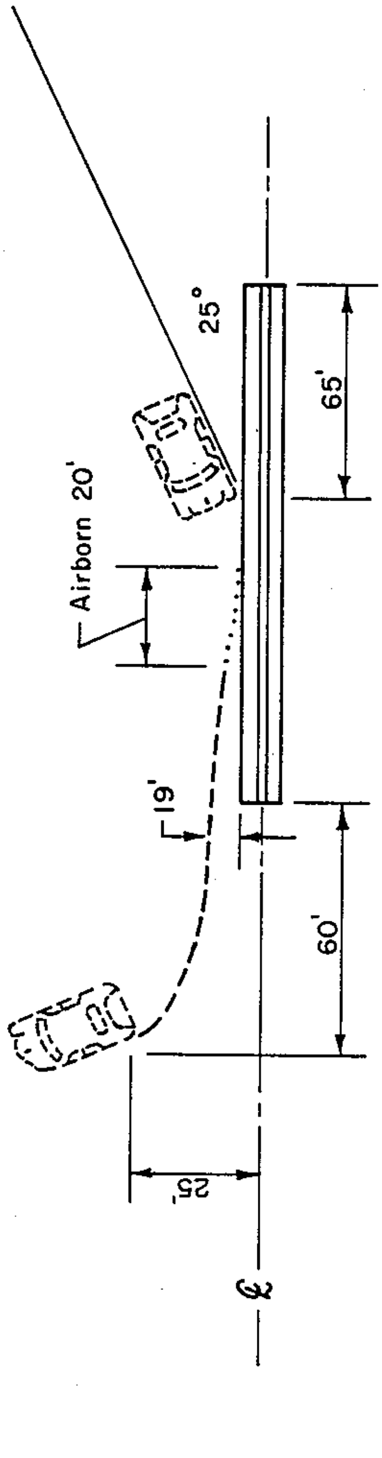
IMPACT + .05 Sec.

I + .17 Sec.



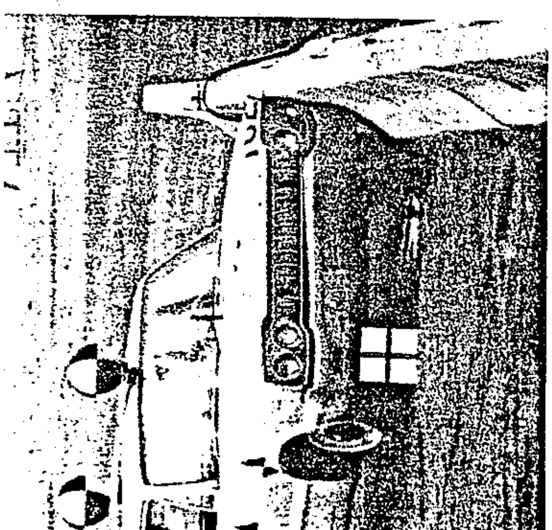
I + .36 Sec.

I + .62 Sec.

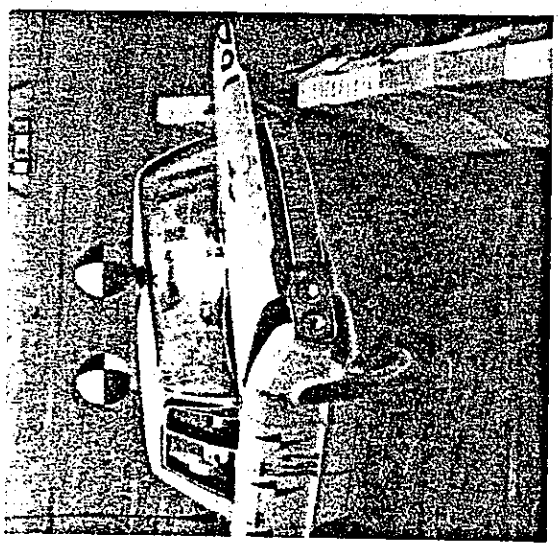


TEST NO.	162
DATE	5-9-67
VEHICLE	1965 Dodge sedan
VEHICLE WEIGHT (W/DUMMY AND INSTRUMENTATION)	4540 #
IMPACT SPEED	63 mph
IMPACT ANGLE	25°
EXIT ANGLE	16°
BARRIER	Unreinforced Concrete
LENGTH OF INSTALLATION	160 ft.
UNIT LENGTH	20 ft.
UNIT WEIGHT	13,200 #
GROUND CONDITION	Dry
CONTACT W/BARRIER	12.5'
MAX. VEHICLE CLIMB	21"
MAX. VEHICLE REBOUND	19.0'

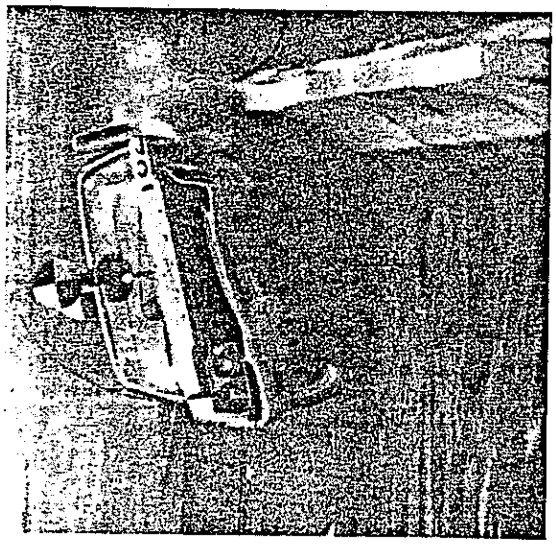
TEST 162 PLATE B



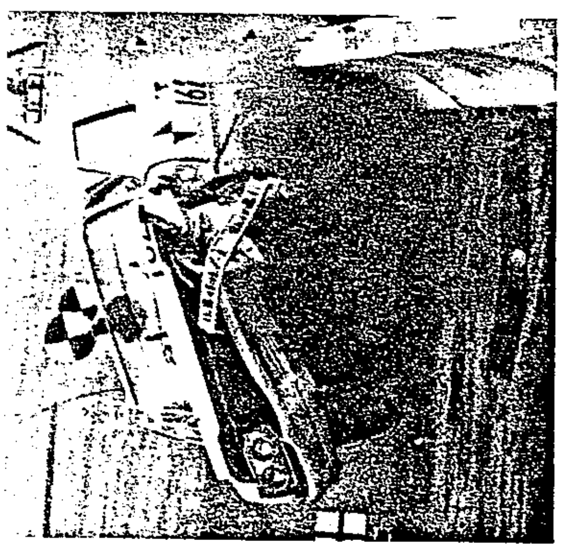
IMPACT



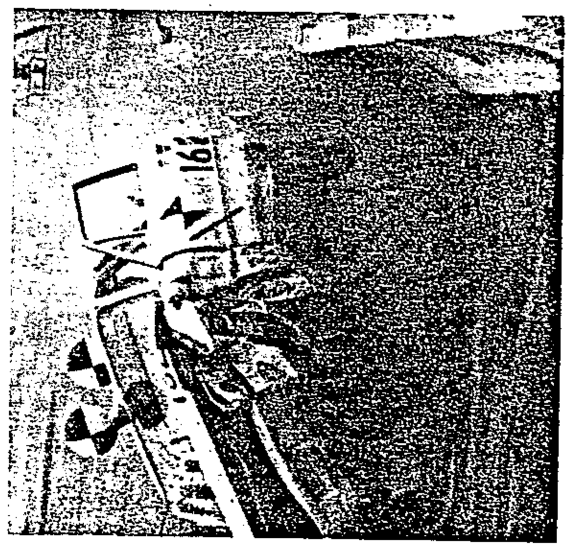
I + .10 Sec.



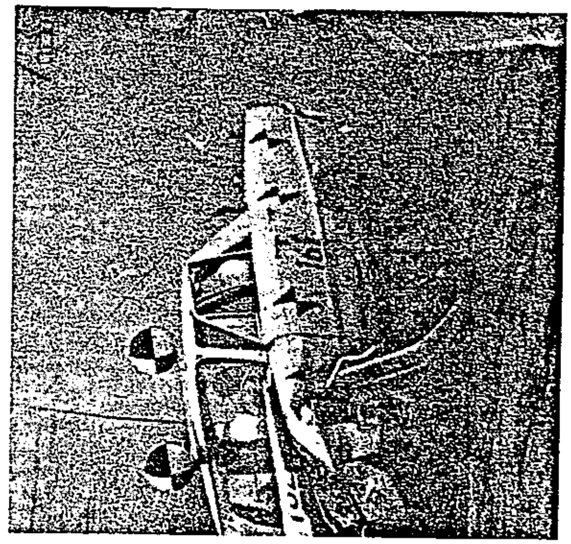
I + .20 Sec.



I + .40 Sec.

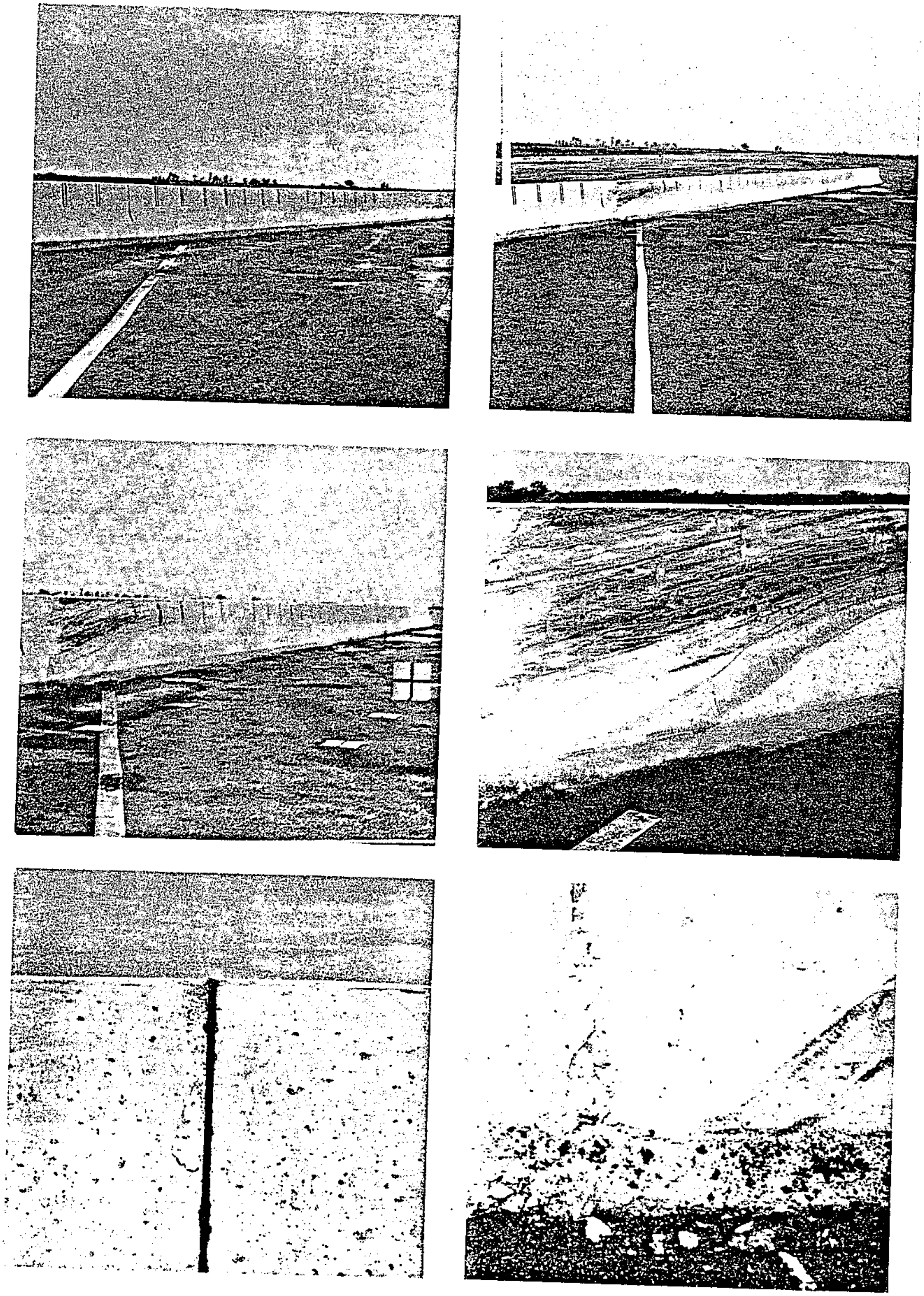


I + .60 Sec.



I + .80 Sec.

TEST 162 PLATE C



TEST 162 PLATE D

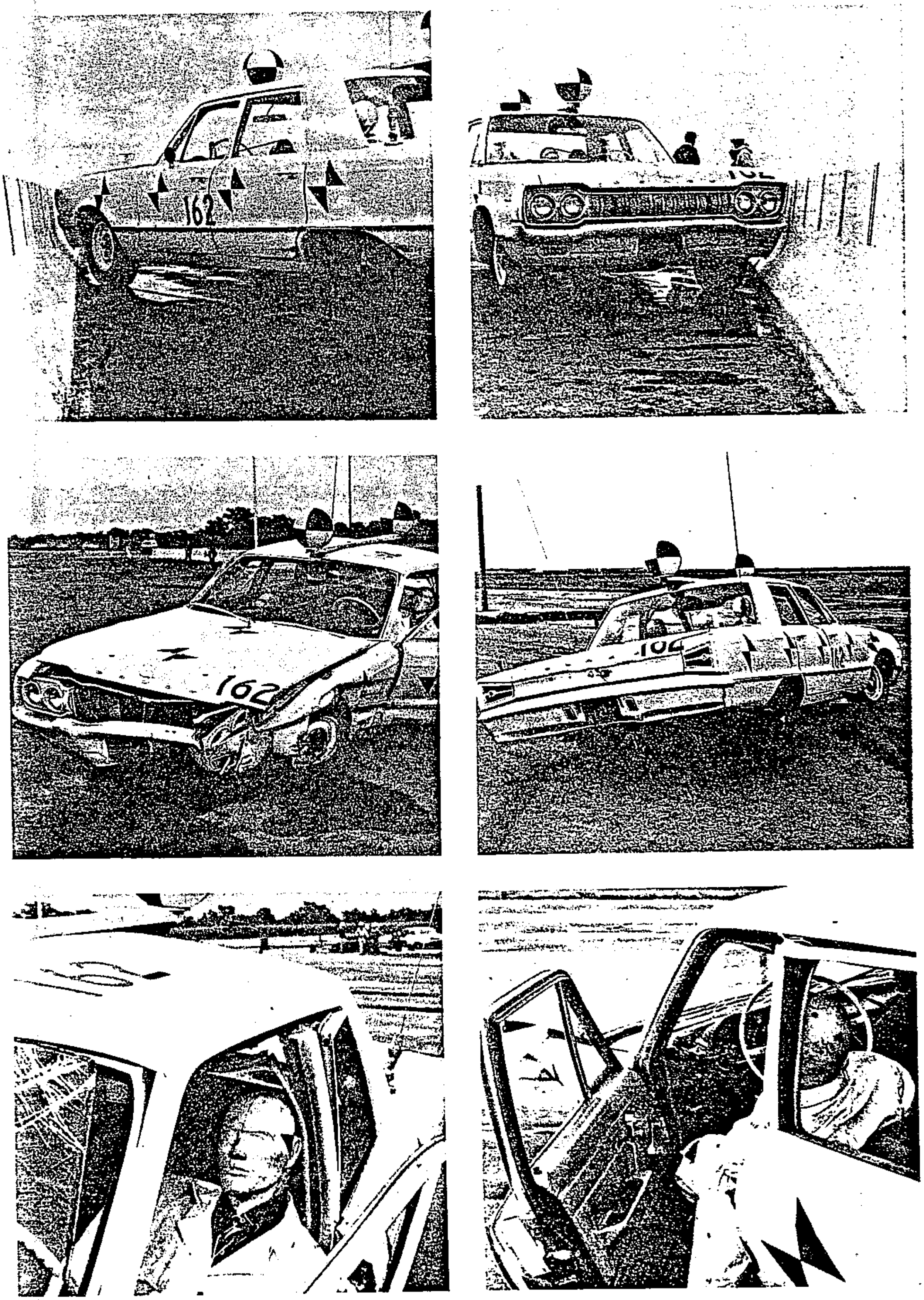
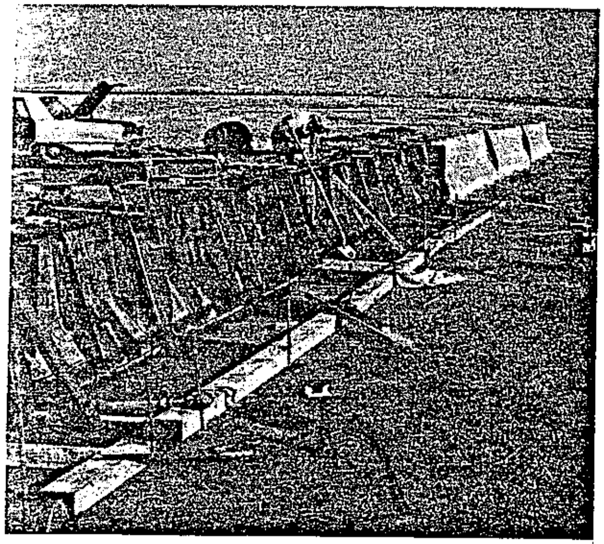


EXHIBIT 1



CALIFORNIA TEST INSTALLATION

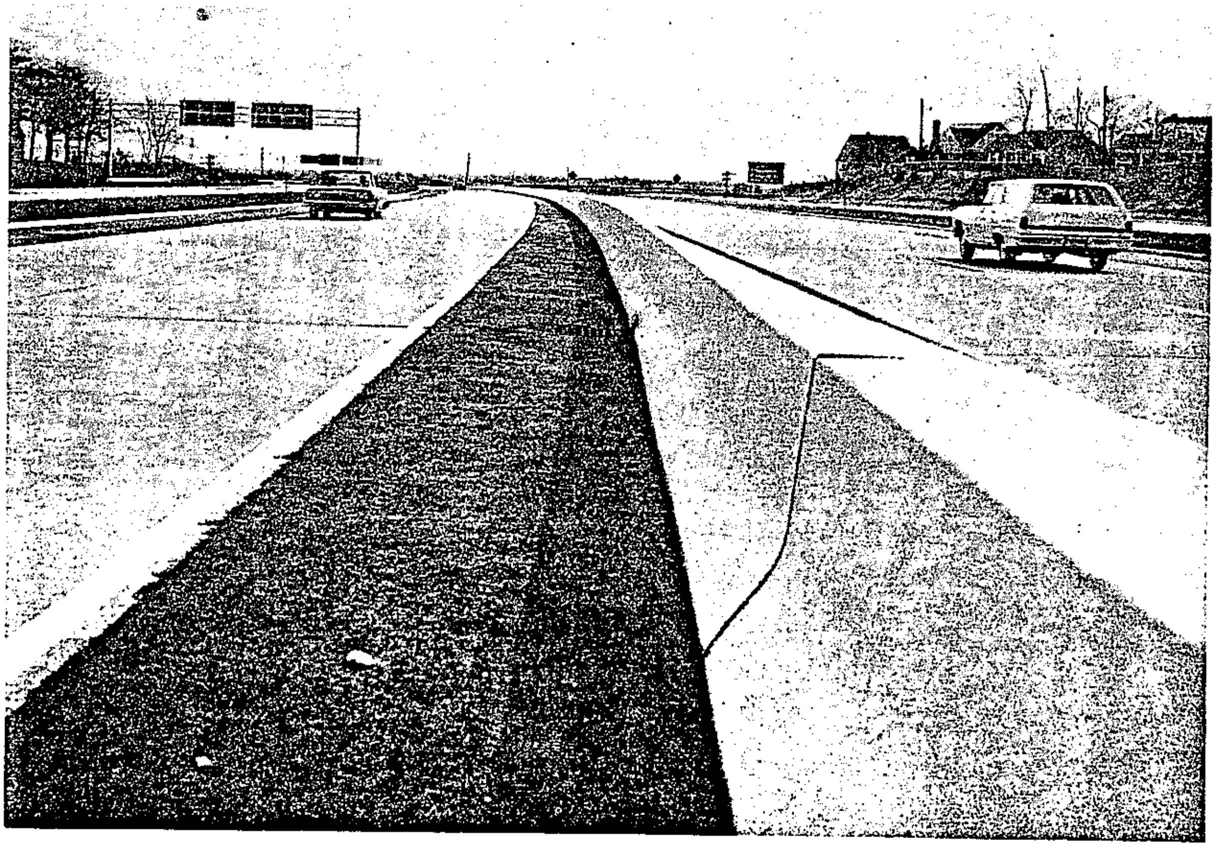
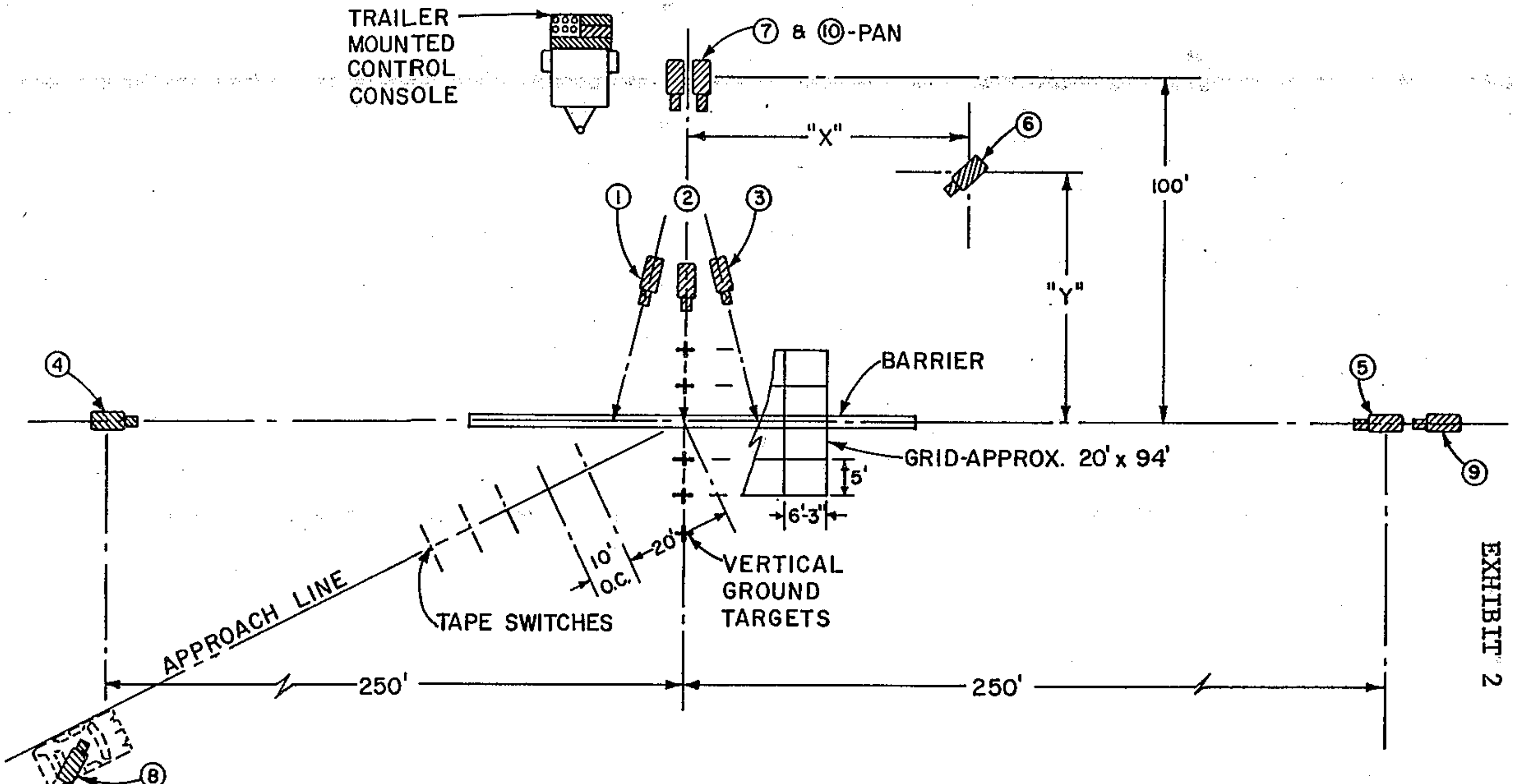


EXHIBIT 2



CAMERA DATA

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

④⑤ PHOTO-SONICS, 4" LENS, 380 FPS.

⑥ PHOTO-SONIC, 2" LENS, 380 FPS.

⑦ PHOTO-SONIC, 2" LENS, 380 FPS.

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

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

⑩ BOLEX, 1" LENS, 24 FPS.

* FRAMES PER SECOND.

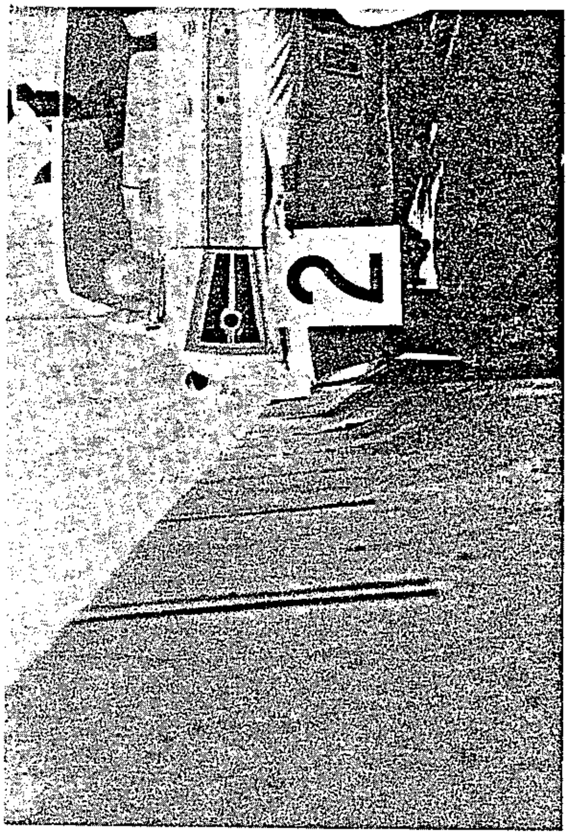
NOTE:

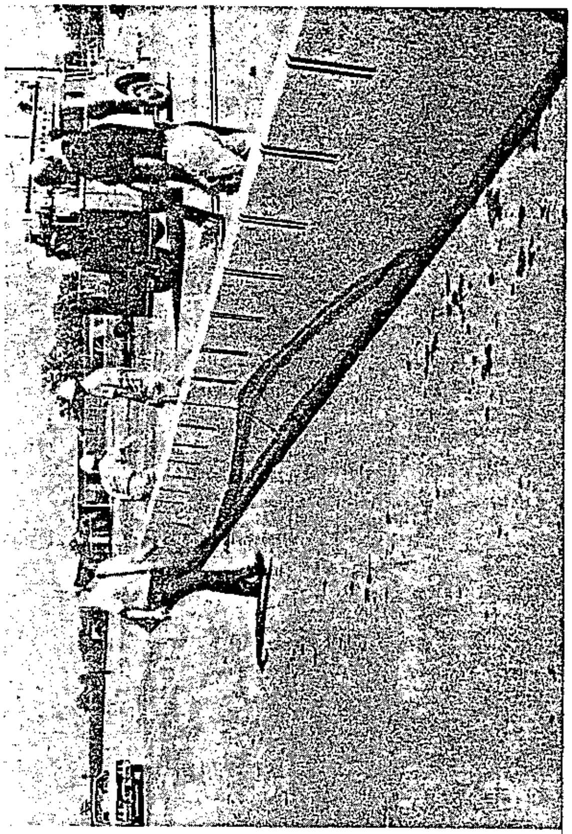
CAMERAS 4 AND 5 HAVE THEIR HORIZONTAL AXES ALIGNED ON A PLANE 5' ABOVE GRADE AS MEASURED AT THE DESIRED POINT OF IMPACT.

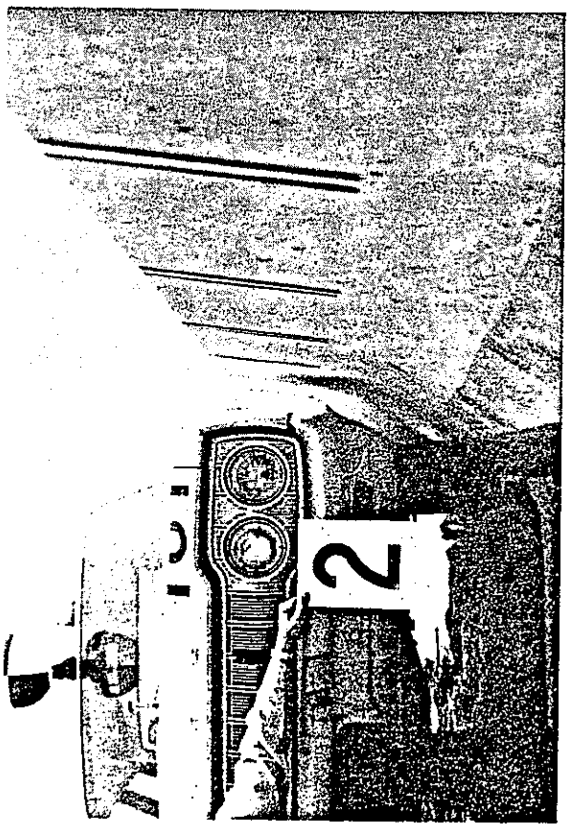
DIMENSIONS "X" & "Y" DEPEND UPON BARRIER LENGTH, AND IMPACT ANGLE.

DYNAMIC FULL SCALE BARRIER TESTS
PHOTOGRAPHIC INSTRUMENTATION – TYPICAL PLAN

EXHIBIT 3







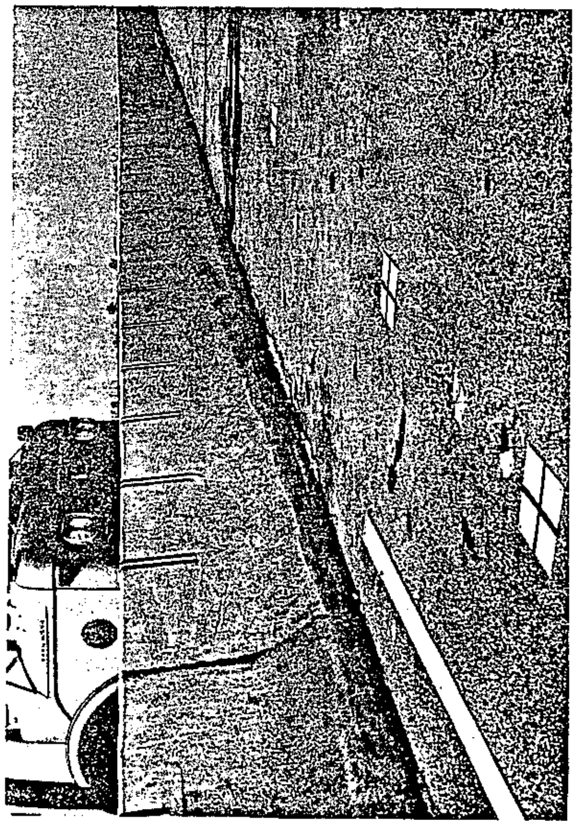
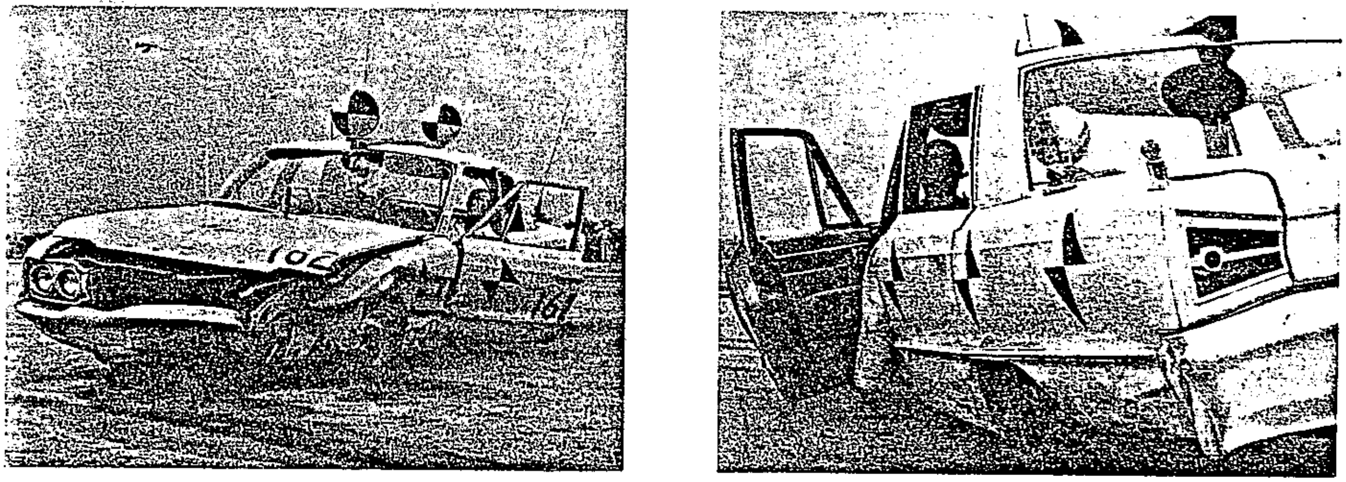
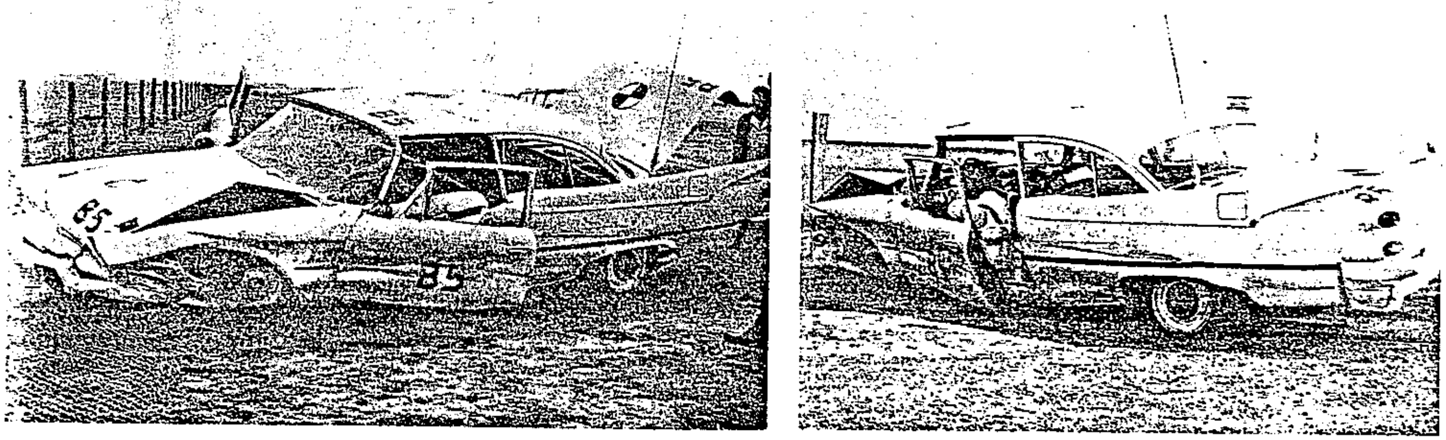


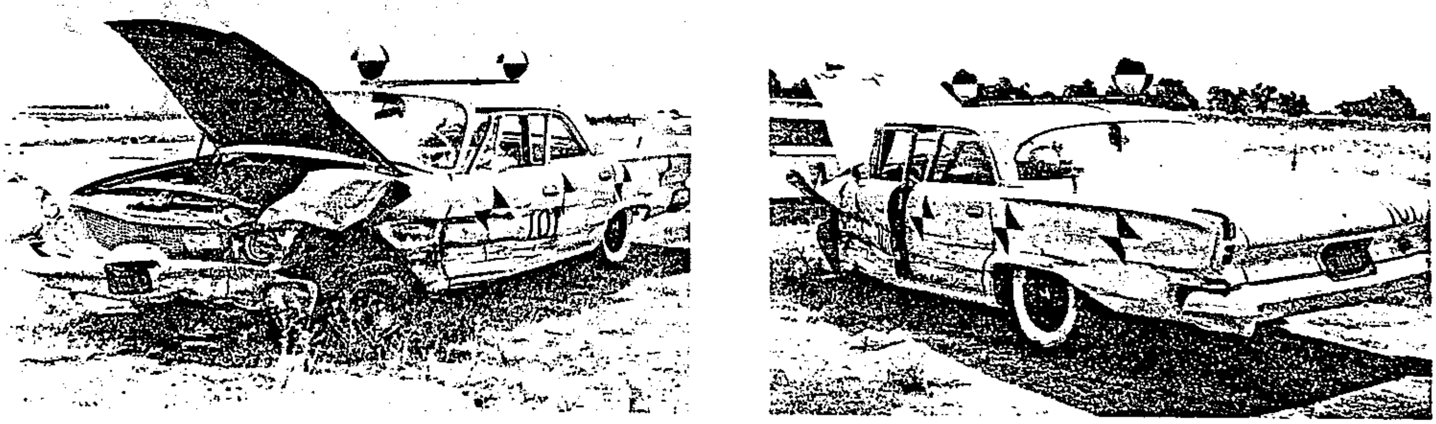
EXHIBIT 4



TEST 162 - NEW JERSEY CONCRETE MEDIAN BARRIER



TEST B-5 CONCRETE PARAPET BRIDGE RAIL (TYPE I)



TEST 101 - "W" BEAM MEDIAN BARRIER

COMPARISON OF VEHICLE DAMAGE ON THREE BARRIER TYPES