TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TTI-2-10-75-223-1		

4. Title and Subtitle	5. Report Date
Crash Test and Evaluation of a Precast Concrete Median Barrier	October 1975
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
T. J. Hirsch and E. L. Marquis	Research Report No. 223-1
9. Performing Organization Name and Address	10. Work Unit No.
Texas Transportation Institute Texas A&M University College Station, Texas 77840	11. Contract or Grant No. Study No. 2-10-75-223
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	Interim - September, 1974 October, 1975
	14. Sponsoring Agency Code

15. Supplementary Notes

Research done in cooperation with DOT, FHWA.
Study Title: "Crash Test and Evaluation of Precast Concrete Barrier and Remedial Measures for Crash Cushions"

16. Abstract

Median barriers are used on high-volume, high-speed traffic facilities to prevent errant vehicles from crossing a median and conflicting with the opposing traffic stream. A secondary function for some designs of median barriers is to minimize the glare of opposing headlights.

The cast-in-place Concrete Median Barrier (CMB) has proven to be an effective and economical barrier in Texas and other states. Investigation into the use of a precast concrete median barrier stemmed from the interest involved in utilizing a barrier to be prefabricated concurrently with roadway construction. This more effective utilization of work force as well as early project completion and acceptance could provide measurable potential savings to both contractor and the State. In addition, when this barrier is installed on existing facilities the traffic may be disrupted for a considerable period of time if it is cast-in-place. Consequently, there is a need for a Precast Concrete Median Barrier (PCMB) which can be quickly installed on active facilities with a minimum period of traffic disruption.

In order for a precast concrete median barrier to function properly in redirecting vehicles, the relatively short precast sections must be adequately connected together after they are placed in the highway median.

Engineers of the Texas State Department of Highways and Public Transportation and the Texas Transportation Institute developed working drawings for precast sections of a PCMB and two connection details. Full-scale crash tests were conducted on the PCMB and connections in order to verify the stability and strength of the installation.

17. Key Words	18. Distribution Statement
Concrete (Precast), Crash Tests, Highway Safety Median Barriers, Impact, Traffic Barriers.	No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	48	

Form DOT F 1700.7 (8-69)

CRASH TEST AND EVALUATION OF A PRECAST CONCRETE MEDIAN BARRIER

by

T. J. Hirsch
Research Engineer

and

E. L. Marquis
Assistant Research Engineer

Research Report 223-1
Crash Test and Evaluation of Precast
Concrete Barrier and Remedial
Measures for Crash Cushions

Research Study Number 2-10-75-223

Sponsored by
The State Department of Highways
and Public Transportation
in cooperation with
The United States Department of Transportation
Federal Highway Administration

October 1975

Texas Transportation Institute
Texas A&M University
College Station, Texas 77843

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

Concrete (Precast), Crash Tests, Highway Safety Median Barriers, Impact, Traffic Barriers.

ACKNOWLEDGEMENTS

This study was conducted under a cooperative program between the Texas Transportation Institute and the Texas State Department of Highways and Public Transportation. It was sponsored by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration. Liaison was maintained through Mr. John F. Nixon of the Texas State Department of Highways and Public Transportation. The crash tests and evaluation were carried out by personnel of the Highway Safety Research Center of the Texas Transportation Institute.

ABSTRACT

Median barriers are used on high-volume, high-speed traffic facilities to prevent errant vehicles from crossing a median and conflicting with the opposing traffic stream. A secondary function for some designs of median barriers is to minimize the glare of opposing headlights.

The cast-in-place Concrete Median Barrier (CMB) has proven to be an effective and economical barrier in Texas and other states. Investigation into the use of a precast concrete median barrier stemmed from the interest involved in utilizing a barrier to be prefabricated concurrently with roadway construction. This more effective utilization of work force as well as early project completion and acceptance could provide measurable potential savings to both contractor and the State. In addition, when this barrier is installed on existing facilities the traffic may be disrupted for a considerable period of time if it is cast-in-place. Consequently, there is a need for a Precast Concrete Median Barrier (PCMB) which can be quickly installed on active facilities with a minimum period of traffic disruption.

In order for a precast concrete median barrier to function properly in redirecting vehicles, the relatively short precast sections must be adequately connected together after they are placed in the highway median.

Engineers of the Texas State Department of Highways and Public Transportation and the Texas Transportation Institute developed working drawings for precast sections of a PCMB and two connection details. Full-scale crash tests were conducted on the PCMB and connections in order to verify the stability and strength of the installation.

IMPLEMENTATION STATEMENT

Median barriers are used on high-volume, high-speed traffic facilities to prevent errant vehicles from crossing a median and conflicting with the opposing traffic stream. A secondary function for some designs of median barriers is to minimize the glare of opposing headlights.

The cast-in-place Concrete Median Barrier (CMB) has proven to be an effective and economical barrier in Texas and other states. Investigation into the use of a precast concrete median barrier stemmed from the interest involved in utilizing a barrier to be prefabricated concurrently with roadway construction. This more effective utilization of work force as well as early project completion and acceptance could provide measurable potential savings to both contractor and the State. Sections of a PCMB can also be used as a temporary barrier during construction of a new facility since the precast sections are portable and can be moved after the need no longer exists.

In order for a precast concrete median barrier to function properly in redirecting vehicles, the relatively short precast sections must be adequately connected together after they are placed in the desired location.

Engineers of the Texas State Department of Highways and Public Transportation and the Texas Transportation Institute developed working drawings for 30 ft (9.1 m) long precast sections of a PCMB and two connection details. Three sections of the PCMB were precast, hauled to the Texas A&M University Research Annex and installed using two different connection details. Full scale crash tests were conducted on each of the connections developed in order to verify the stability and the strength of the installation. Both tests were successful with the vehicles being smoothly redirected.

The PCMB developed is now being used on IH 35 in Austin, Texas. Design details of the PCMB can be obtained from the Texas State Department of Highways and Public Transportation in Austin, Texas.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

INTRODUCTION

Median barriers are used on high-volume, high-speed traffic facilities to prevent errant vehicles from crossing a median and conflicting with the opposing traffic stream. Current warrants proposed by NCHRP for the installation of median barriers are based on a 2-year traffic projection and the median width (1). Typically the warrants state that for a median width of 20 ft (6.1 m) or less and a predicted ADT (Average Daily Traffic) of 20,000 or more a median barrier should be installed. Facilities with less traffic than this frequently do not have median barriers. If the ADT increases to 20,000 or more it will frequently become necessary to install a median barrier on an existing facility.

Texas median barrier warrants (8) are based on the width of the median. Briefly, the Texas warrants require that for medians up to 24 ft in width a concrete barrier should be used. For medians from 18 to 24 ft in width either the concrete or the double steel beam type should be used. For medians from 24 to 30 ft the double steel beam type should be used.

The cast-in-place Concrete Median Barrier (CMB) has proven to be an effective and economical barrier in Texas and other states. Investigation into the use of a precast concrete median barrier stemmed from the interest involved in utilizing a barrier to be prefabricated concurrently with roadway construction. This more effective utilization of work force as well as early project completion and acceptance could provide measurable potential savings to both contractor and the State. However, when this barrier is installed on existing facilities the traffic may be disrupted for a considerable period of time if it is cast-in-place. Consequently, there is a need for a Precast Concrete Median Barrier (PCMB) which can be quickly installed on active facilities with a minimum period of traffic disruption. In addition, sections of a PCMB can also be used as a temporary barrier during construction of a new facility since the precast sections are portable and can be moved after the need no longer exists.

In order for a PCMB to function properly in redirecting a vehicle, the relative short precast sections must be adequately connected together after they are placed in the desired location. Engineers of the Texas State Department of Highways and Public Transportation (SDHPT) and the Texas Transportation Institute (TTI) developed working drawings for 30 ft (9.1 m) long precast concrete sections of a PCMB and two different connection details.

Three sections of the PCMB were precast, hauled to the Texas A&M University Research Annex and installed using the two different connection details. Full scale crash tests were conducted on each of the connections in order to verify the stability and the strength of the installation.

DESIGN AND INSTALLATION

Design

The cross-section used for the PCMB is shown by Figure 1. This shape is standard in Texas and is essentially the "New Jersey" cross-section with minor modifications.

The concrete median barrier of the New Jersey cross-section has been extensively tested to determine the adequacy of the shape and redirection capabilities. Since that time the CMB has been subjected to testing by numerous organizations including the TTI(4, 5, 6). These reports attested to the sufficiency of the CMB particularly for narrow medians and shallow impact angles. In all of the successful tests the CMB was attached to a simulated bridge parapet (3) or the barrier was long, massive and rigid.

The SDHPT has used precast CMB sections on bridges for some time. These precast sections varied from 15 ft (4.5 m) to 30 ft (9.1 m) in length and were rigidly attached to the bridge deck with anchor bolts at 2 ft (0.6 m) maximum spacing.

California had tested twelve 12 1/2 ft (3.8 m) long precast sections of approximately 5000 lbm (2270 kg) each, and pinned together with a steel rod inserted into eye bolts cast in the ends of the sections to form a 150 ft (45.7 m) barrier free standing on asphaltic concrete (2). Two tests were conducted with a 4800 lbm (2177 kg) vehicle at a nominal speed of 65 mph (104.6 kph). In the first test, which was moderately successful, the vehicle impacted the barrier at 7 degrees. The second test was at a 25 degree impact angle and was less than successful. The barrier rotated and displaced laterally and the vehicle snagged. A second barrier of five 20 ft (6.1 m) sections of approximately 8000 lbm (3630 kg) was constructed and tested at 65 mph (104.6 kph) and 35 degrees, i.e. more than the normal 25 degrees. This test was even less successful than Test No. 2. The barrier segments rotated, displaced laterally and the vehicle rolled over.

In view of the California experience engineers with the Texas SDHPT elected to test precast sections 30 ft (9.1 m) long, of approximately 15,000 lbm (6810 kg) (See Figure 1). This length and weight appeared to be the maximum which could be readily transported and handled.

Two slightly different dowel joint details were used to connect the 30 ft (9.1 m) precast sections together (See Figure 2). The Male-Female dowel connection used three No. 8 dowels (1 in. diam. or 2.54 cm) 18 in. (.46 m) long precast in one end and three mating 2 in. diam. (5.08 cm) tapered holes cast in the opposite end as shown in Figure 2. A pressure grout hole was cast vertically behind the tapered female holes. The second connection used was the Grooved Connection which also used three No. 8 dowels (1 in. diam or 2.54 cm) 18 in. (.46 m) long as shown in Figure 2. The Grooved Connection was believed to be more desirable when the precast sections would be used as a temporary barrier. It was believed that the grout and dowels could be chipped out of the grooved block outs and the precast sections more readily reused. This latter connection detail was arrived at after the precast CMB sections were cast, so these grooves were sawed instead of being precast in as would be desirable.

The lower slope dimension on the PCMB sections was increased from 3 in. to 4 in. (7.5 cm to 10 cm) so the section would maintain the

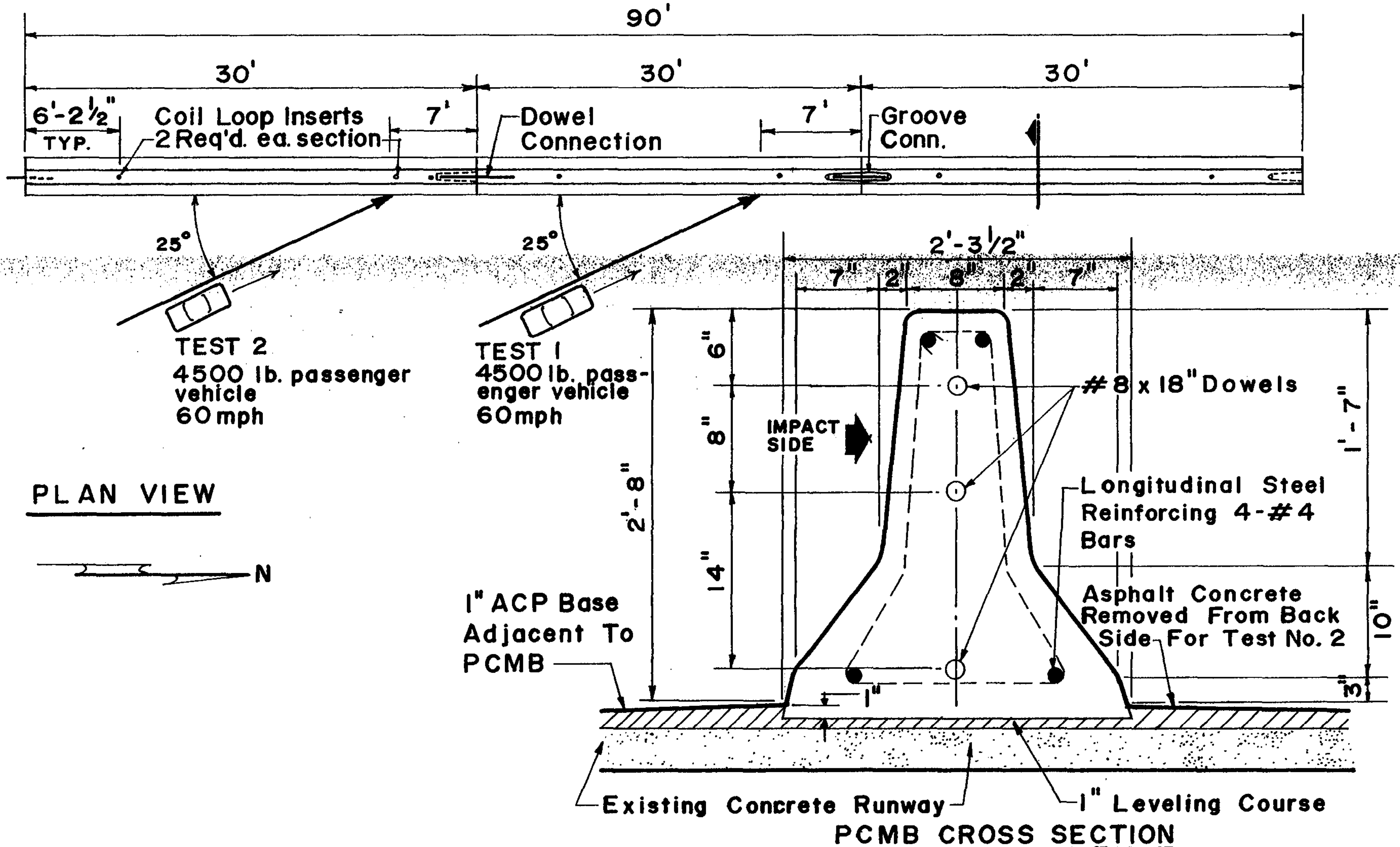


FIGURE 1. PCMB CONNECTION TEST INSTALLATION.

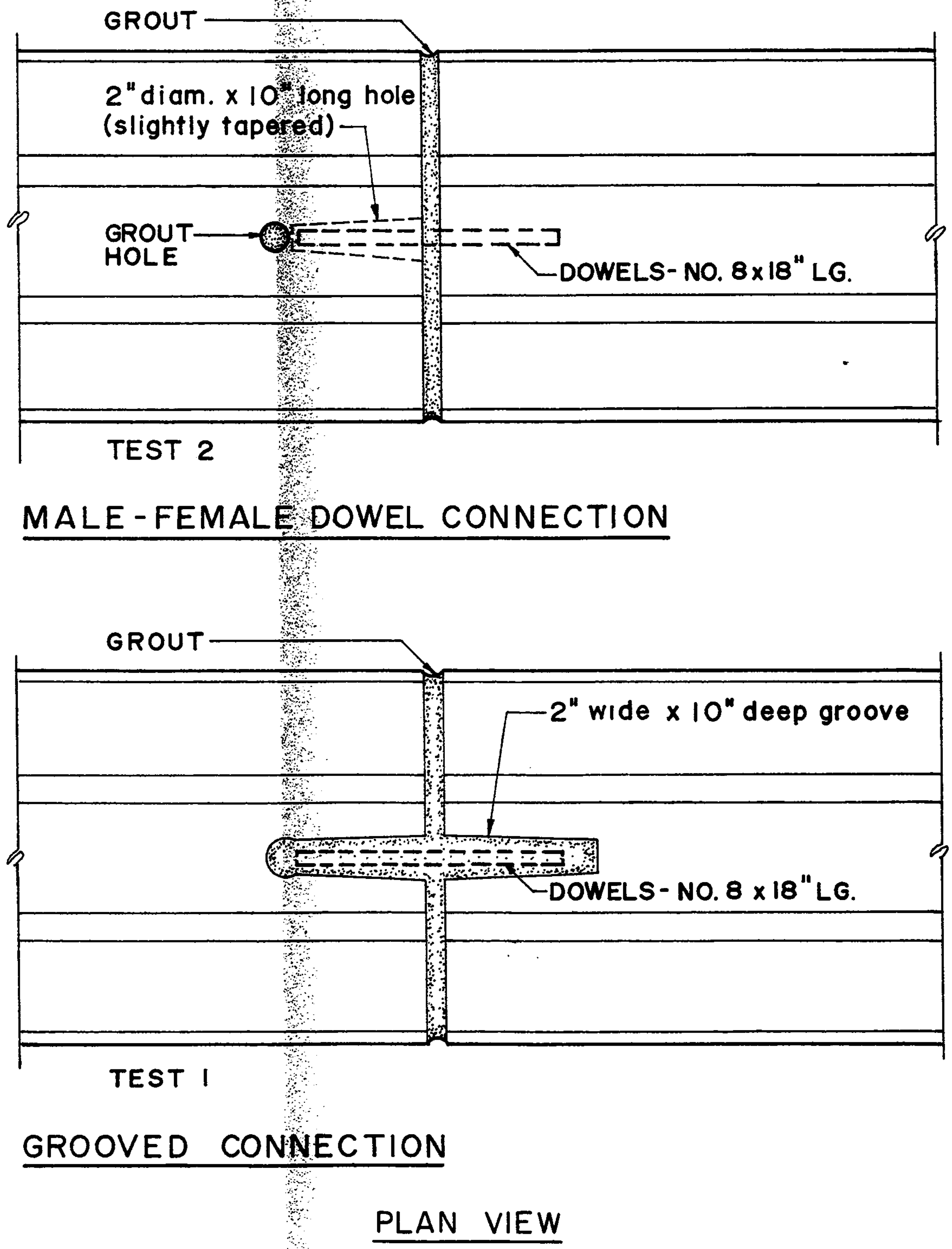


FIG. 2. PCMB TEST CONNECTION DETAILS.

the standard 32 in. (.81 m) height after the 1 in. (2.5 cm) of asphalt concrete fill is placed on the pavement (See Figure 1). This ACP fill is an integral and necessary part of the barrier design for permanent installation since it prevents lateral displacement and cracking at the connections during vehicle impact.

Engineers and precast concrete contractors first indicated that the PCMB units would be cast right side up and lifted at the 1/5 points from each end. An analysis (See Appendix A) of the section indicated that the maximum concrete stress to be expected in tension was 57 psi T (393 kPa) for an uncracked section. This value was well within the limits suggested by ACI-318-71. The recommended safe ultimate concrete stress in tension is $f_t = \sqrt{7.5 f_c'}$ or 410 psi (2827 kPa) for 3000 psi (20685 kPa) concrete. A cracked section analysis was made using No. 4 bars (0.5 in. diam) in each corner of the section. The steel stress would be approximately 1100 psi T (7585 kPa) with the concrete compressive stress less than 120 psi C (827 kPa). All of these values are well within limits published by AASHTO and ACI.

Installation

Three 30 ft (9.1 m) precast sections were installed on the concrete parking apron at the TAMU Research Annex as shown by Figure 1. Figure 3 shows the partial construction sequence for the test barrier. An Asphalt Concrete leveling course was applied; each section, weighing approximately 15,000 lb (6810 kg), was set in place; the two different joints were grouted; and the one inch (2.5 cm) ACP backup fill was placed on both sides of the PCMB. After grouting, the joints were covered with wet

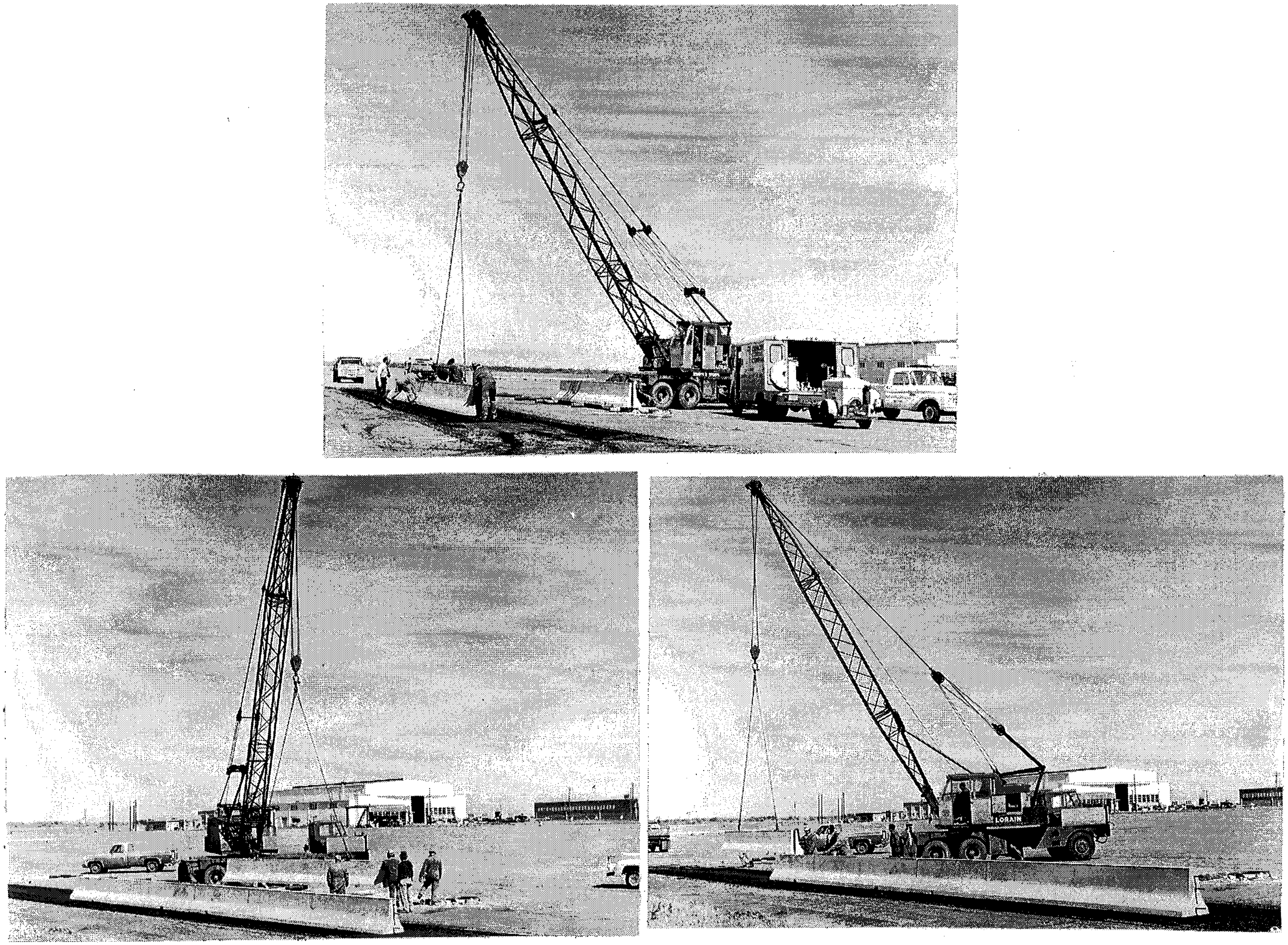


Figure 3. Construction Sequence For PCMB Test Barrier

burlap to aid in curing.

A concrete grout of about a 4 in. (10 cm) slump composed of 33 lb (15 kg) of Portland Cement, 100 lb (45 kg) sand and 15 lb (6.5 kg) water was used to grout the groove joint. The same mix was used for the dowel connection except that the slump was increased to 6 in. (15 cm). Two 4 in (10 cm) cylinders were cast from the mix used to grout each joint. These were cured and tested in compression just prior to each impact test. The five-day strength of the cylinders placed in the groove joint was 5400 psi (37200 kPa). The samples from the dowel joints tested 5740 psi (33830 kPa) at 6 days of age.

Crash Test 1 was conducted on the Groove Connection with the 1 in. ACP located on both sides of the PCMB to prevent lateral displacement of the barrier under the vehicle impact. Since this test proved successful, it was decided to remove the ACP from behind the barrier for Crash Test No. 2 on the Male-Female dowel connection. This test would give an indication as to how the doweled connection would behave if the precast sections were used as a temporary barrier with no ACP backup.

VEHICLE CRASH TESTS

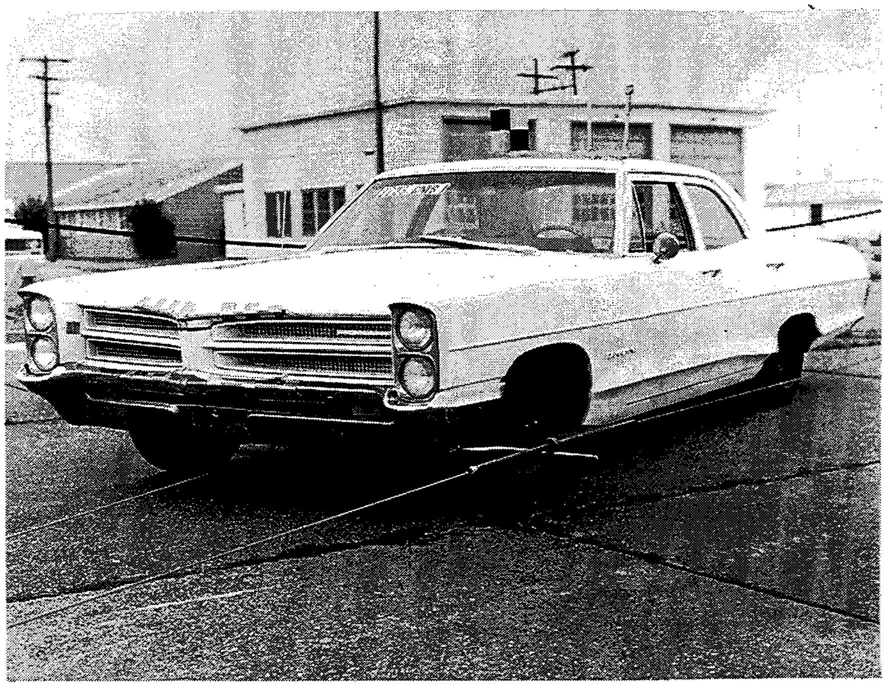
Test 1 Grooved Joint Connection

The vehicle used for Test 1 was a 1966 Pontiac 4500 lbm (2040 kg). The impact point of the left front fender and the barrier occurred 7 ft (2.1 m) upstream from the groove joint as shown in Figure 1. The actual impact angle was 23.5 degrees and the actual impact velocity was 60.5 mph (97.3 kph). The top picture in Figure 4 shows the vehicle before impact while the lower picture shows the vehicle after impact. The vehicle was smoothly redirected and the exit angle was 7 degrees. The maximum vehicle roll angle of 18 degrees occurred while the vehicle was in contact with the barrier. The vehicle remained upright during the test. The front wheel and steering linkage were damaged and the vehicle was inoperable after the impact. Sequence photographs showing the impact are shown in Figures 5 and 6 from the overhead camera and parallel camera respectively.

The average lateral deceleration taken from the high speed film data was 7.5 g's taken over 206 milliseconds. The average longitudinal deceleration over the same period was 1.6 g's. The barrier did not roll or slide laterally. Figure 7 shows closeup views of the joint before and after impact. A hairline or shrinkage crack had appeared in the vertical face before impact. There was no evidence that this crack was altered after impact or any other cracking at the connection during impact. Damage to the precast barrier and joint was nil.

Test 2 Male-Female Joint

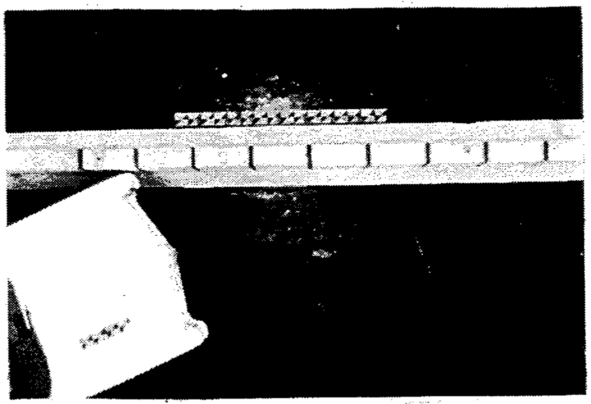
The asphaltic concrete base was removed from the back side of the PCMB prior to Test 2 in order to determine if it was necessary to



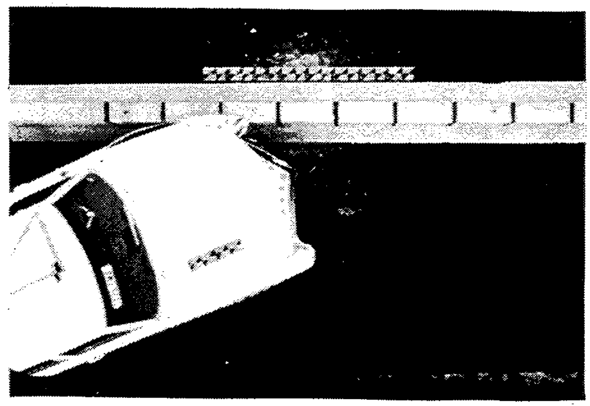
a) Before Impact

b) After Impact

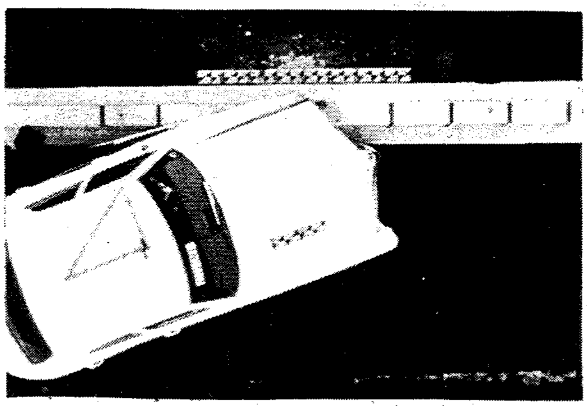
Figure 4. Test 1 Vehicle Before and After Impact.



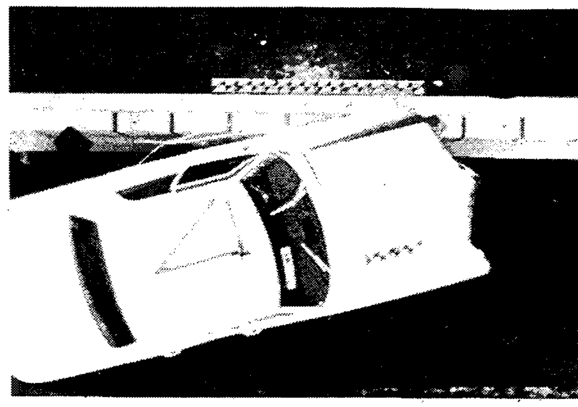
t = 0.000 sec



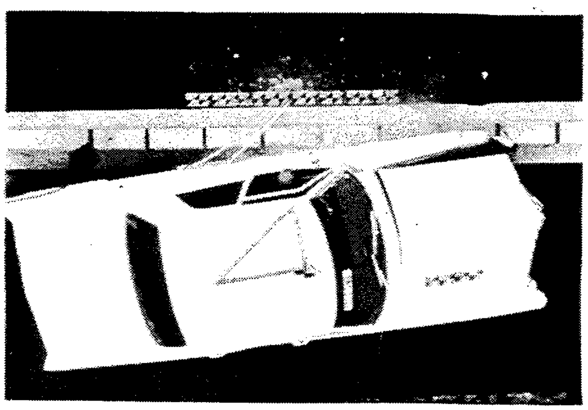
t = 0.039 sec



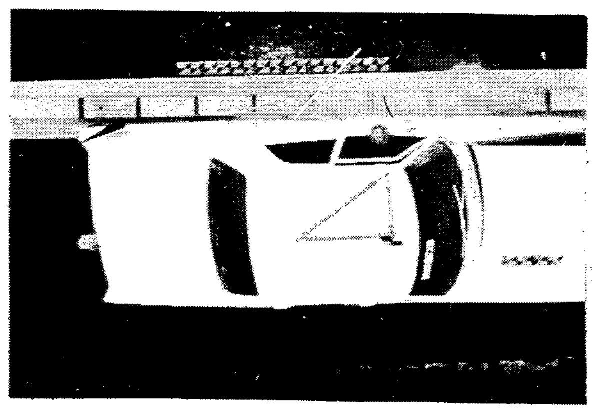
t = 0.078 sec



t = 0.117

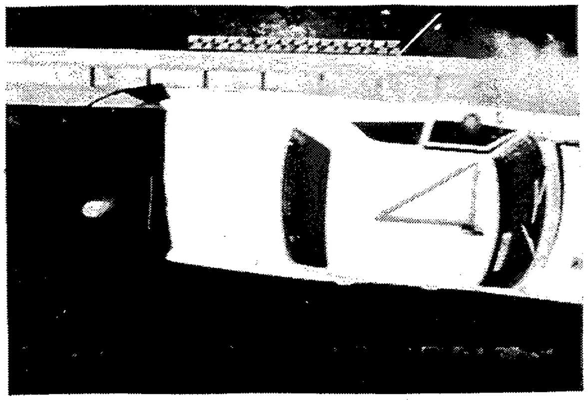


t = 0.156 sec

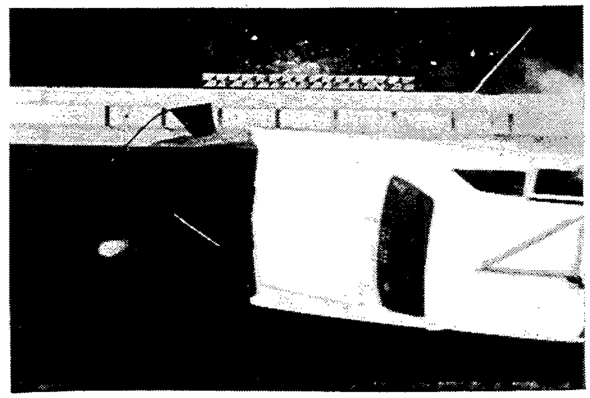


t = 0.198 sec

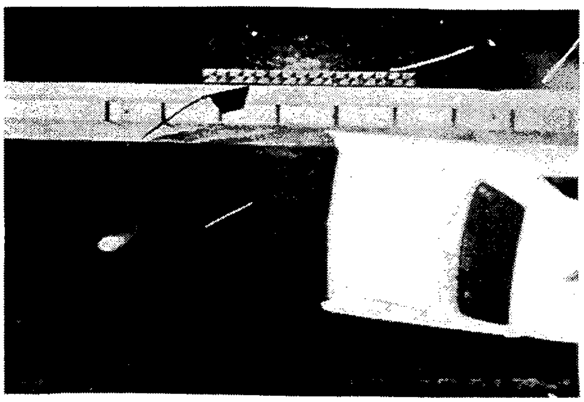
Figure 5 . Sequence Photographs of Test 1.
(Overhead View of Concrete Median Barrier)



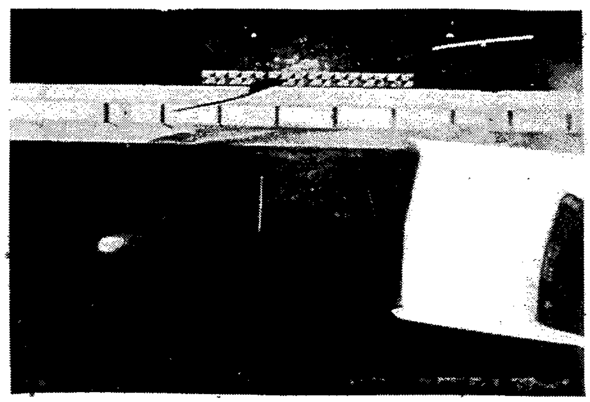
t = 0.233 sec



t = 0.272 sec

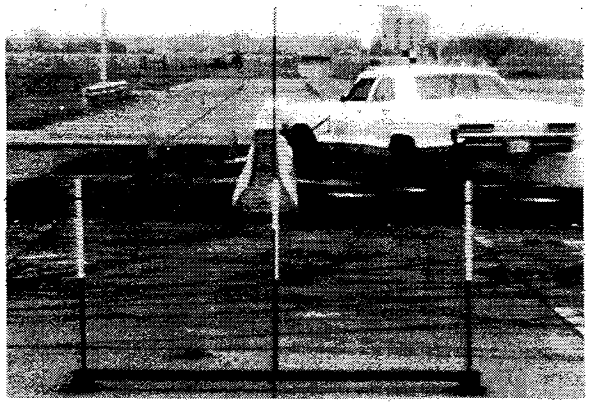


t = 0.311 sec



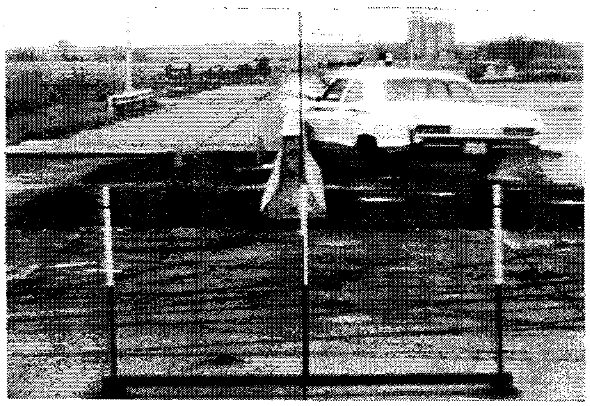
t = 0.350 sec

Figure 5 . Sequence Photographs of Test 1 (continued).
(Overhead View of Concrete Median Barrier)



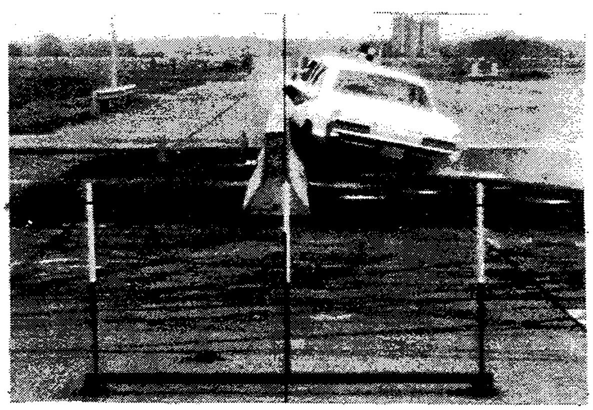
t = 0.000 sec

t = 0.037 sec

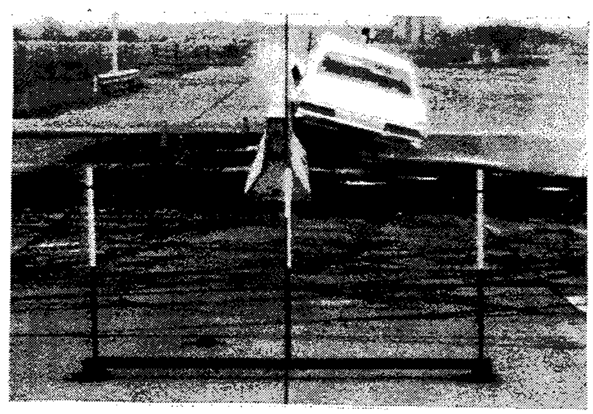


t = 0.074 sec

t = 0.111 sec

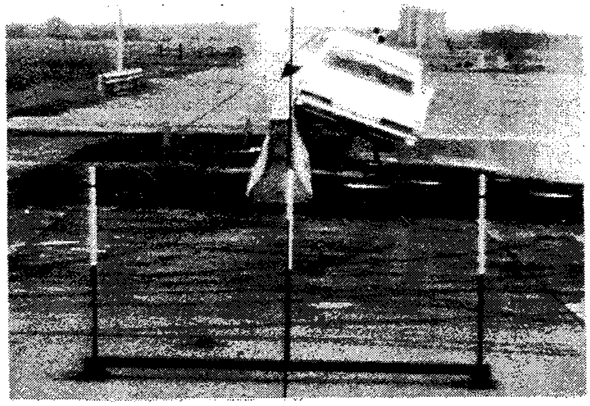


t = 0.148 sec

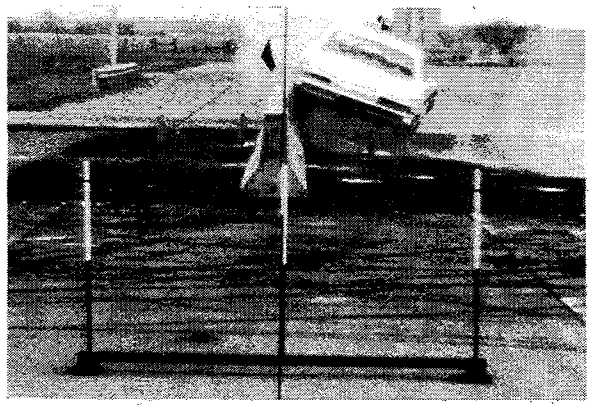


t = 0.198 sec

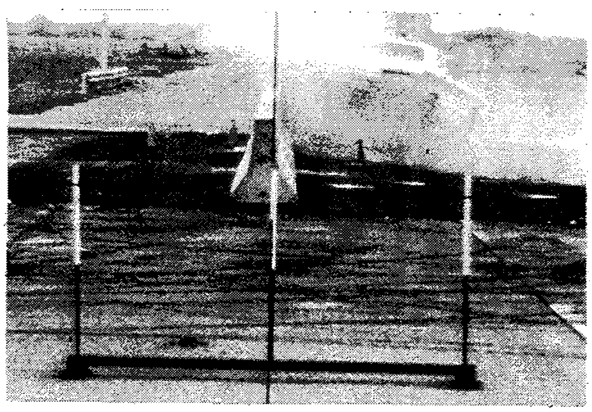
Figure 6 . Sequence Photographs of Test 1[illegible]
(View Parallel to Concrete Median Barrier)



t = 0.249 sec

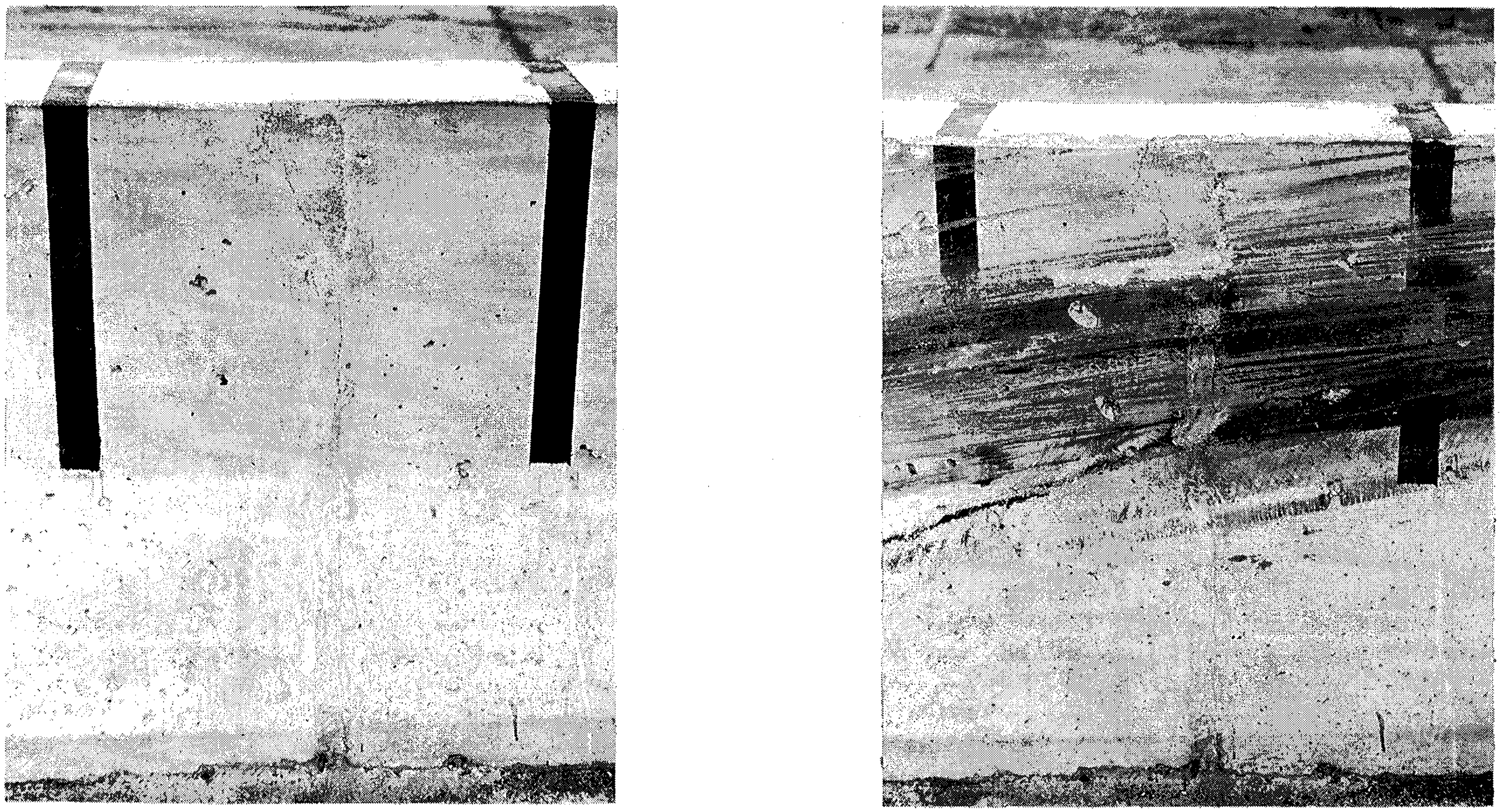


t = 0.309 sec



t = 0.674 sec

Figure 6 . Sequence Photographs of Test 1 (continued).
(View Parallel to Concrete Median Barrier)



a) Before Impact

b) After Impact

Figure 7. Groove Joint Before and After Test 1.

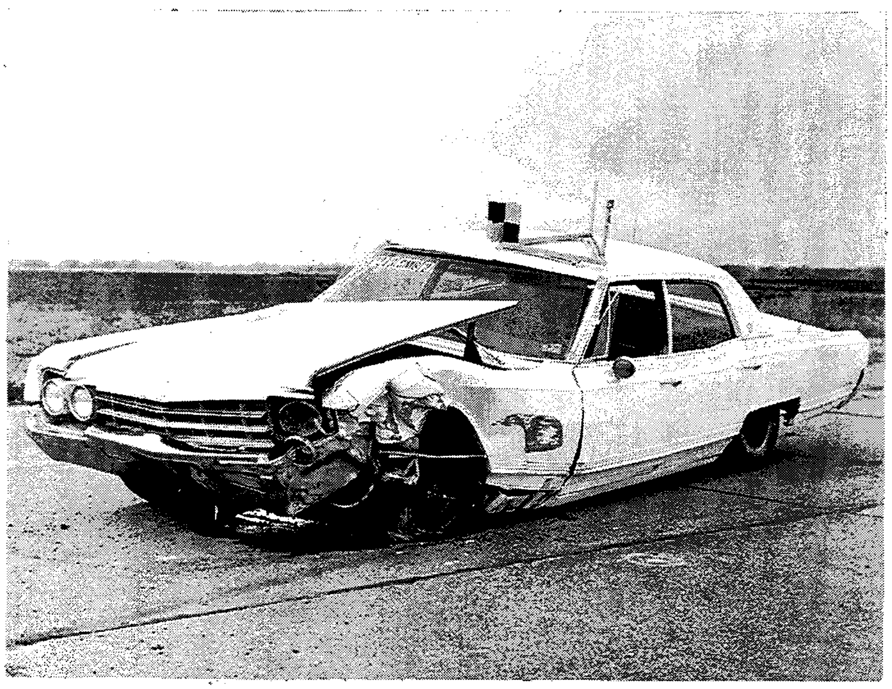
stabilize the barrier when used as a temporary installation.

The vehicle used for Test 2 was a 1965 Oldsmobile 4540 lbm (2060 kg). The impact point of the left front fender occurred 7 ft (2.1 m) upstream from the male-female dowel joint as shown in Figure 1. The actual impact angle was 24.2 degrees and the actual impact velocity was 59.8 (96.2 kmh). The top picture in Figure 8 shows the vehicle before impact while the lower picture shows the vehicle after impact. The vehicle was smoothly redirected and the exit angle was 3 degrees. Again the maximum vehicle roll angle of approximately 18 degrees occurred while the vehicle was in contact with the barrier. The vehicle remained upright during the test. The left front wheel and steering linkage were damaged and the vehicle was inoperable after the impact. Sequence photographs showing the impact are shown in Figures 9 and 10 from the overhead camera and parallel camera respectively.

The average lateral vehicle deceleration taken from the film was 6.3 g's over 223 milliseconds. The average longitudinal deceleration over the same period was 1.1 g's. The barrier did not roll or rotate during the impact. The precast barrier did displace 13 1/2 in. (34.3 cm) laterally at the connection during vehicle redirection with significant cracking of the concrete apparent on both the tension and compression sides of the joint (See Figure 11). The joint held together however and smoothly redirected the vehicle.

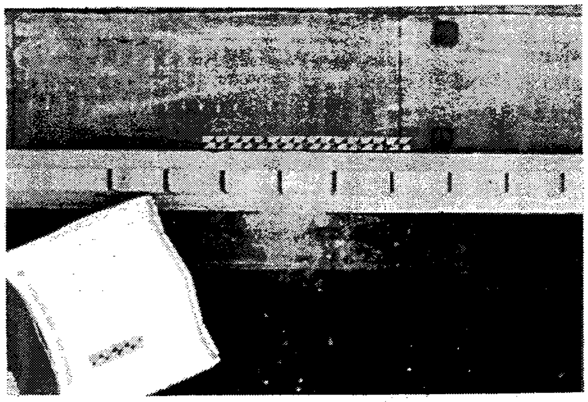
The groove joint downstream 30 ft (9.1 m) was fractured also (See Figure 12). This allowed the center section to rotate slightly in the horizontal plane between the two joints. The last section downstream from the groove joint (Figure 1) did not move at all.

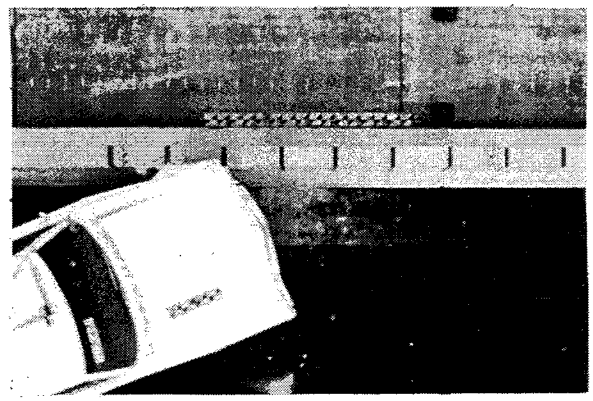
a) Before Impact



b) After Impact

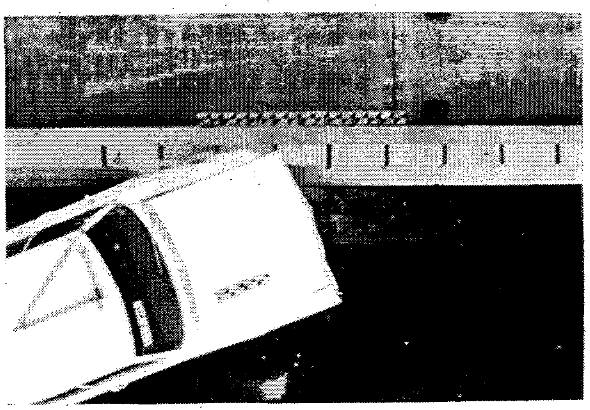
Figure 8. Test 2 Vehicle Before and After Impact

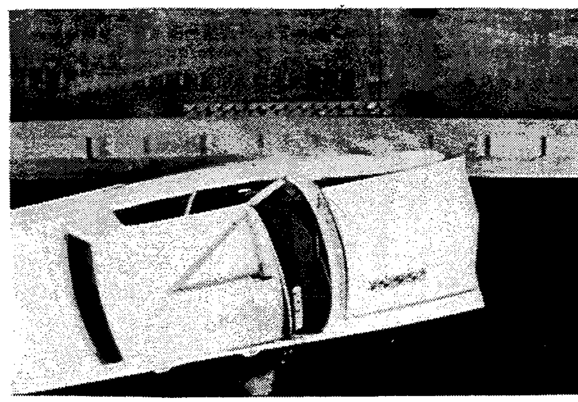




t = 0.000 sec

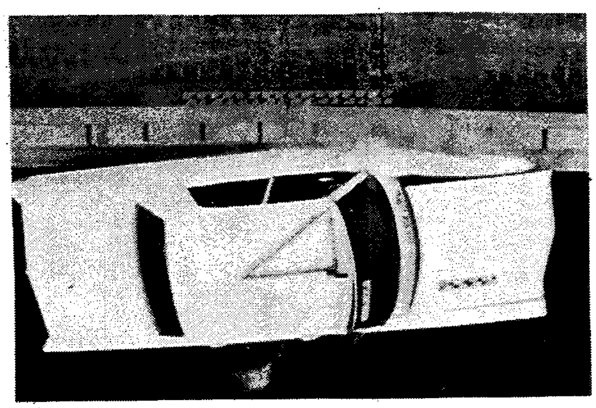
t = 0.034 sec

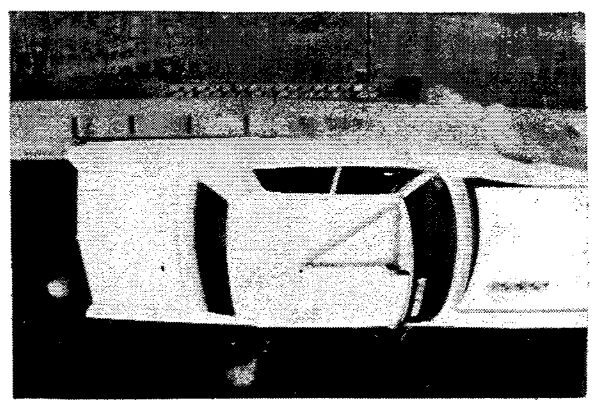




t = 0.057 sec

t = 0.135 sec

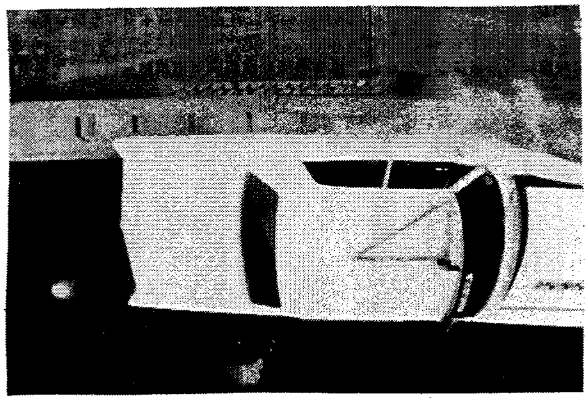




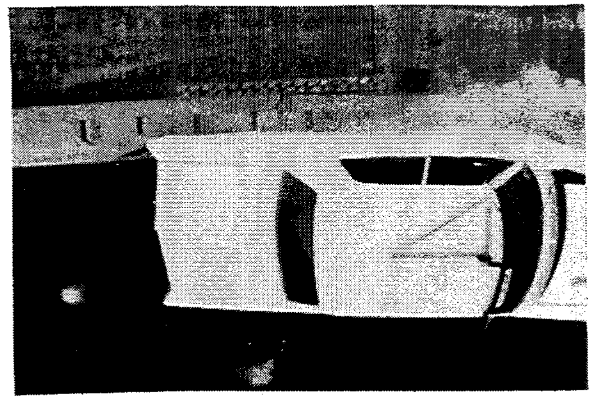
t = 0.169 sec

t = 0.203 sec

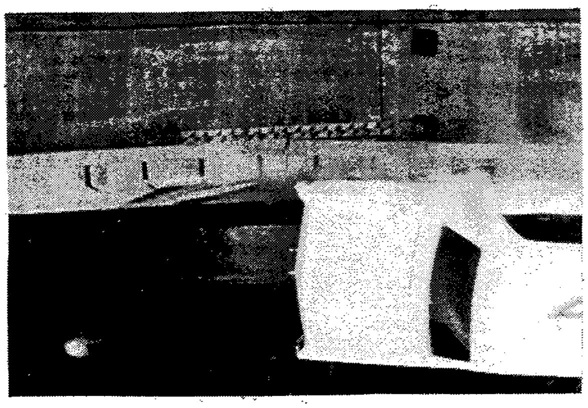
Figure 9. Sequence Photographs of Test 2.3-2.
(Overhead View of Concrete Median Barrier)



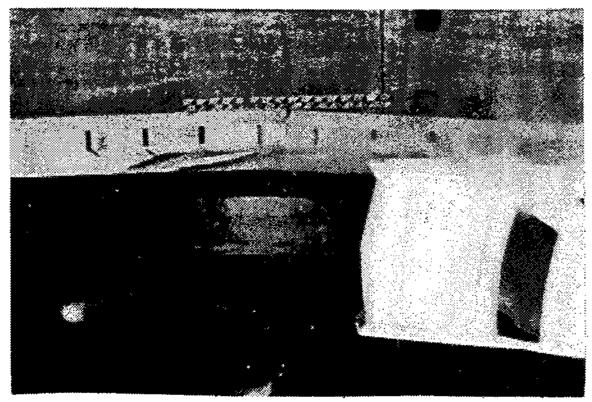
t = 0.223 sec



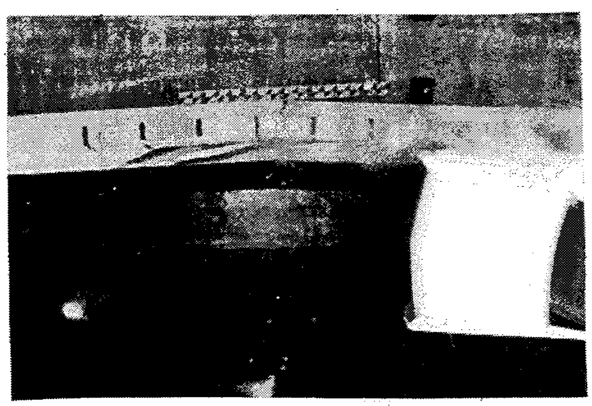
t = 0.237 sec



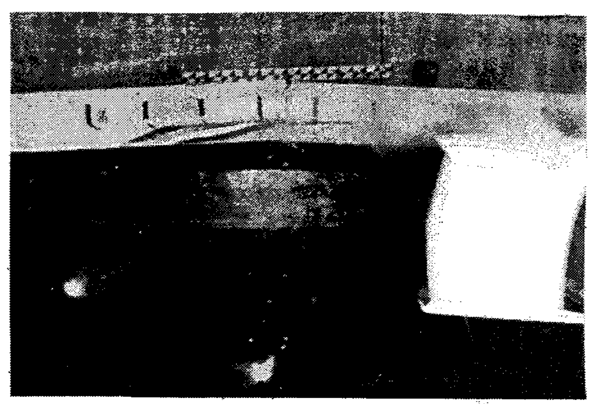
t = 0.304 sec



t = 0.338 sec

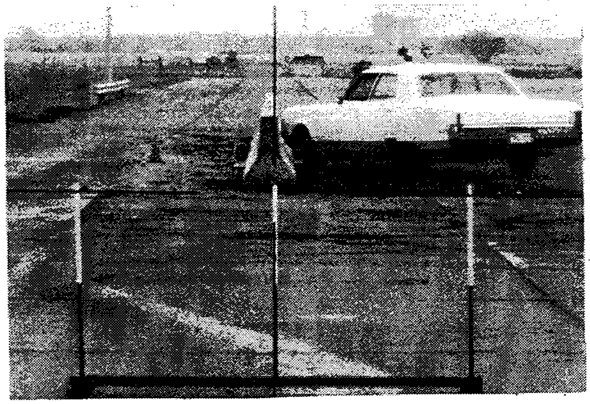


t = 0.362 sec



t = 0.368 sec

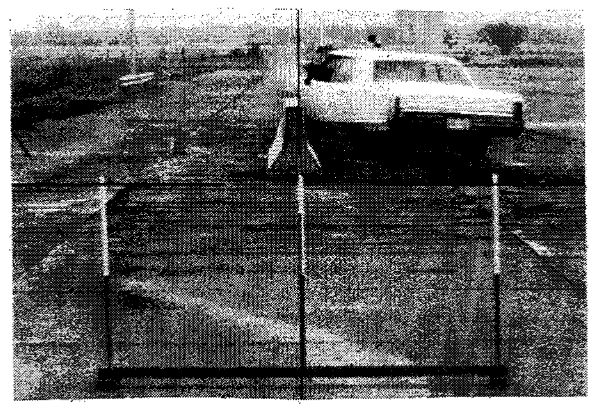
Figure 9. Sequence Photographs of Test 2 (continued).
(Overhead View of Concrete Median Barrier)



t = 0.000 sec

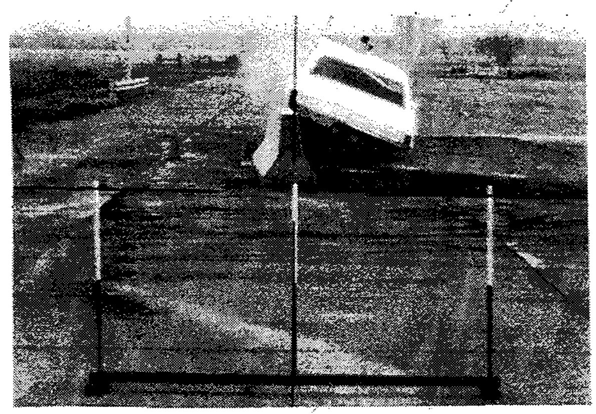
t = 0.025 sec

t = 0.050 sec



t = 0.098 sec

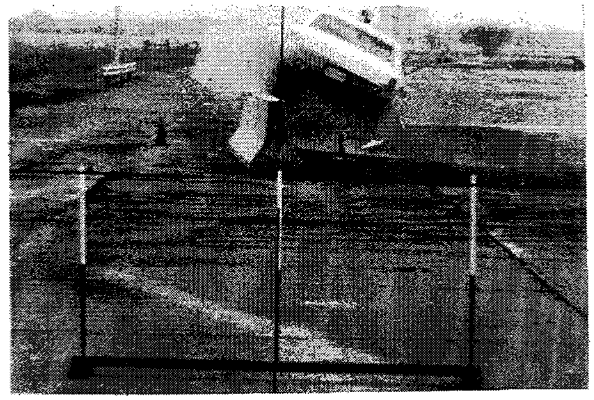
t = 0.184 sec



t = 0.223 sec

Figure 10. Sequence Photographs of Test 2.3-2
(View Parallel to Concrete Median Barrier)

t = 0.362 sec



t = 0.432 sec

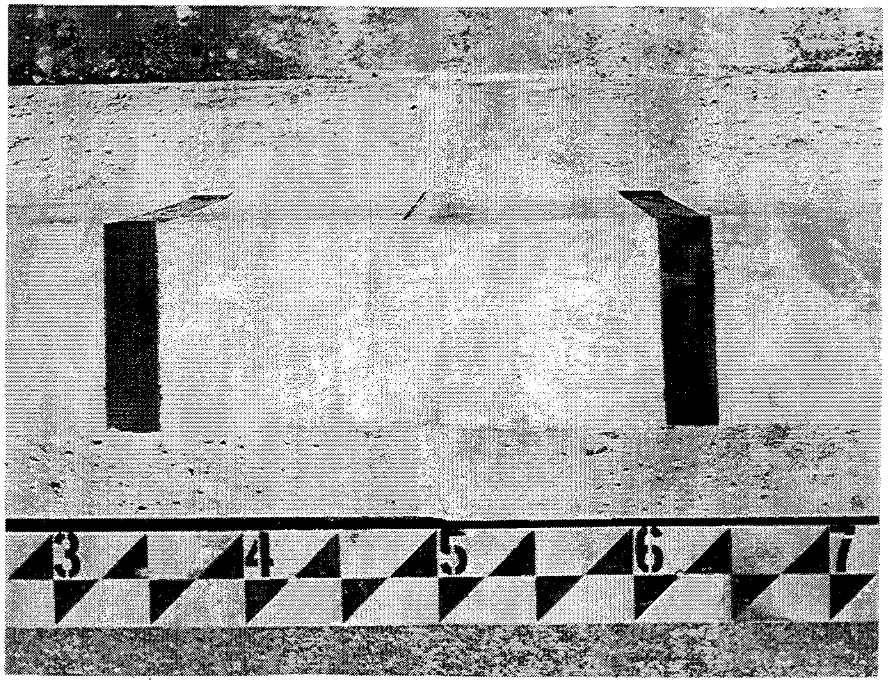
t = 0.659 sec

t = 0.757 sec

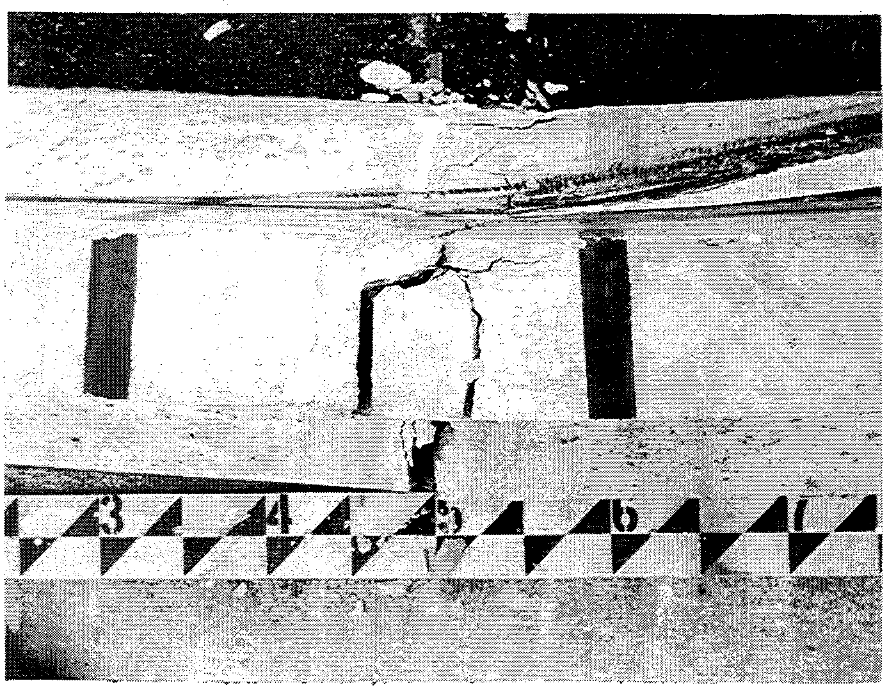
t = 0.857 sec

t = 1.099 sec

Figure 10. Sequence Photographs of Test 2 (continued).
(View Parallel to Concrete Median Barrier)

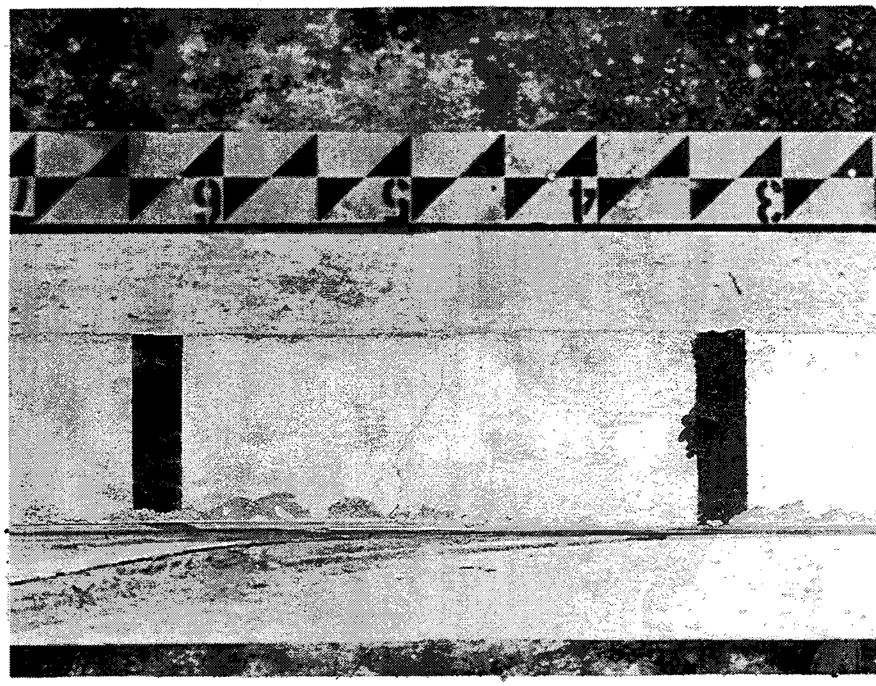


a) Before Impact

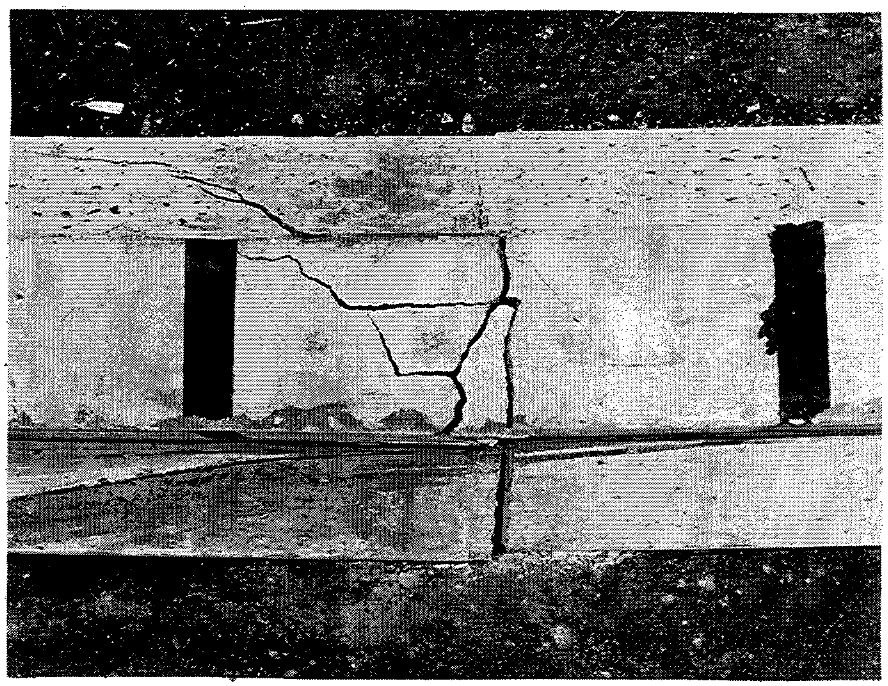


b) After Impact

Figure 11. Dowel Joint Before and After Test 2.



a) Before Impact



b) After Impact

Figure 12. Groove Joint Before and After Test 2.

DISCUSSION OF TESTS

A brief summary of the test data is shown in Table 1. In both tests the vehicle was smoothly redirected and remained upright. The barrier did not rotate in either tests.

When the PCMB was supported laterally by the 1 in. (2.54 cm) thick asphaltic paving material (Test 1), it did not displace laterally and no damage was inflicted on the precast concrete segments or connection. For a permanent installation the 1 in. (2.54 cm) thick asphaltic paving material or some other lateral support should be used so that maintenance or repair cost would be small or nil.

If the PCMB is to be used as a temporary barrier, Test 2 indicates that lateral support by the 1 in. (2.54 cm) asphaltic concrete is not absolutely necessary. However, the barrier can be expected to displace laterally under vehicle impact approximately 1 ft (.3 m) and significant cracking of the concrete will occur at the segment joints. Under low speed and/or low angle impacts the lateral displacement and cracking of the concrete would probably be minimal.

One can conclude from these two tests that the precast concrete median barrier (PCMB) will function as designed when the 30 ft (9.1 m) sections are connected by either of the two connection used and backed up with 1 in. (2.54 cm) of ACP. This type of installation is recommended for permanent installations. If the PCMB is used as a temporary installation either connection should be acceptable, however considerable maintenance can be anticipated if the ACP or some other backup is not used to prevent sliding.

TABLE 1. SUMMARY OF TEST DATA.

DATA		BARRIER TEST CMB-1	BARRIER TEST CMB-2
VEHICLE			
	Year	1966	1965
	Make	Pontiac	Olds
W,	Weight (lb)	4500	4540
	(kg)	2040	2060
θ,	Impact Angle (deg)	23.5	24.2
FILM DATA			
V_I,	Initial Impact Speed (mph)	60.5	59.8
	(kph)	97.3	96.2
V_P,	Speed at Parallel (mph)	48.0	49.3
	(kph)	77.2	79.3
S_{long},	Longitudinal Distance to Parallel (ft)	15.0	16.5
	(m)	4.57	5.02
D,	Permanent Barrier Displacement (ft)	0	1.1
	(m)	0	0.34
S_{lat},	Lateral Distance to Parallel (ft)	2.6	3.2
	(m)	0.55	0.98
Δt,	Time to Parallel (sec)	0.206	0.223
G_{long},	Average Longitudinal Deceleration (G's) (Parallel to Barrier)	1.6	1.1
G_{lat},	Average Lateral Deceleration (G's) (Normal to Barrier)	7.5	6.3
	Departure Angle (deg)	7.0	3.0
VEHICLE DAMAGE CLASSIFICATION			
	TAD	FL-5.5	FL-4.5
	SAE	11FLEW3	11LFEW2

CONCLUSIONS

Past experience has shown that the Concrete Median Barrier (CMB) is an economical and effective traffic barrier. Investigation into the use of a precast concrete median barrier stemmed from the interest involved in utilizing a barrier to be prefabricated concurrently with roadway construction. This more effective utilization of work force as well as early project completion and acceptance could provide measurable potential savings to both contractor and the State. When installing this barrier on existing facilities, it is frequently desirable to precast the concrete median barrier (PCMB) so the units can be quickly installed during low traffic volume periods. The 30 ft (9.1 m) long sections with grouted dowel connections and the 1 in. asphalt concrete paving (ACP) fill material behind the barrier proved to be an effective barrier in redirecting 4500 lbm (2040 kg) vehicles impacting at 60 mph (96.5 km/hr) and 25 degrees.

If the 1 in. ACP or some other backup device is not used to prevent lateral sliding the doweled connections tested here appear to be adequate, however considerable maintenance can be anticipated after high speed, high angle impacts. This type installation (without backup device) should only be used as a temporary barrier.

Four #4 longitudinal reinforcing bars are adequate for handling and lifting requirements provided that the sections are cast right side up. Where the units will be cast bottom side up (for simpler form design and removal) four #5 longitudinal bars are recommended provided two pickup points located approximately 6 ft 2½ in. (1.9 m) from each end are used.

The recommendations for reinforcing steel are intended to produce added safety during installation and reduced maintenance when in service. These concrete sections could have been designed as plain unreinforced concrete members.

REFERENCES

1. Michie, J. D., and Bronstad, M. E., "Location, Selection, and Maintenance of Highway Traffic Barriers," NCHRP Report 118, 1971.

2. Bronstad, M. E. Personal Conversation on July 18, 1975.

3. Lundstrom, L. C., Skeels, P. C., Englund, B. R., and Rogers, R. A., "A Bridge Parapet Designed for Säfety," Highway Research Record No. 83, HRB, 1965, pp. 169-183.

4. Young, R. D., Post, E. R., and Ross, Jr., H. E., "Simulation of Vehicle Impact with Texas Concrete Median Barrier: Test Comparisons and Parameter Study," Highway Research Record No. 460, HRB, 1973, pp. 61-72.

5. Post, E. R., Hirsch, T. J., Hayes, G. G., and Nixon, J. F., "Vehicle Crash Test and Evaluation of Median Barriers for Texas Highways," Highway Research Record No. 460, HRB, 1973, pp. 97-113.

6. Ross, Hayes E. Jr., "Impact Performance and a Selection Criteria for Texas Median Barriers," TTI Research Report 140-8, Texas A&M University, April 1974.

7. Bronstad, M. E., and Michie, J. D., "Recommended Procedures for Vehicle Crash Testing of Highway Structures," NCHRP Report 153, 1974.

APPENDIX A

HANDLING STRESSES

APPENDIX A

HANDLING STRESSES

Handling stresses are extremely important in the design of precast concrete units. The design of precast concrete members should consider service loads as well as temporary lifting, storage, hauling and installation loads. Brittle failure of an unreinforced precast concrete unit during handling operations would be dangerous to construction personnel. Plain concrete stresses for dead load only with lifting points 6.2 ft (1.9 m) from each end would be 56.8 psi T (392 kPa). According to AASHTO-PCI design criteria for precast concrete piling and beams and impact factor of 1.5 is reasonable for such designs. Applying this as an impact factor gives a maximum anticipated stress of 85 psi T (588 kPa).

According ACI 318-71 a safe ultimate stress for concrete in tension is $7.5\ \sqrt{f'_c}$ which for 3000 psi (20685 kPa) concrete at 28 days would be

$$f_{allow\ 28} = 7.5\ \sqrt{3000} = 410 \text{ psi T (2826 kPa) or at 7 days}$$

$$f_{allow\ \ 7} = 7.5\ \sqrt{2250} = 355 \text{ psi T (2448 kPa)}$$

The factor of safety against cracking or brittle failure for plain concrete for handling units right side up would be $\frac{355}{85} = 4.2$. The addition of the four reinforcing bars is added safety. An acceptable method to designers and possibly a less expensive method of manufacturing is to cast the 30 ft sections of median barrier upside down. These sections are next removed from the forms by lifting with coil loop inserts or cables cast into the bottom of barrier approximately 6 ft - 2½ in. (1.9 m) from each end. The barrier section will then be set back on the surface bottom side up and allowed to cure. The curing procedure should conform to job specifications. Next the barrier section is laid on its side and attachments are made to inserts cast in the narrow top of the barrier or to choker cables wrapped around the barrier at pickup points. The barrier section is then righted by lifting (sideways) on the inserts and the unit then moved to a storage location or truck bed and hauled to the job site.

Lifting from the bottom and righting induces completely different handling stresses than occur when the barrier is cast right side up. The critical stresses occur when the barrier is on its side. Assuming lifting points at 6.2 ft (1.9 m) from each end of the section, the maximum bending stress for plain concrete would be 104.3 psi T (719 kPa). Using an impact factor of 1.5- and 7-day old concrete the factor of safety would be $\frac{355}{104.3 \times 1.5} = 2.3$. Any symmetrical placement of reinforcing would increase this factor of safety without causing any over stress in the steel.

Should a cracked section be encountered during handling then the concrete stress would be increased to 461 psi C (3180 kPa) which is well within the 7-day limits of 2250 psi C (15,500 kPa) of 3,000 psi C (20,700 kPa) concrete. Steel stresses for four #5 bars are 13,940 psi T (96,120 kPa). The factor of safety for failure due to yield for Grade 40 steel is:

$$\text{F.S.} = \frac{40,000}{13,940 \times 1.5} = 1.9$$

and for Grade 60 steel

$$\text{F.S.} = \frac{60,000}{13,940 \times 1.5} = 2.9$$

It is believed that these precast concrete members should contain some steel for safety during construction and to reduce maintenance during inservice operations.

APPENDIX B

FILM DATA

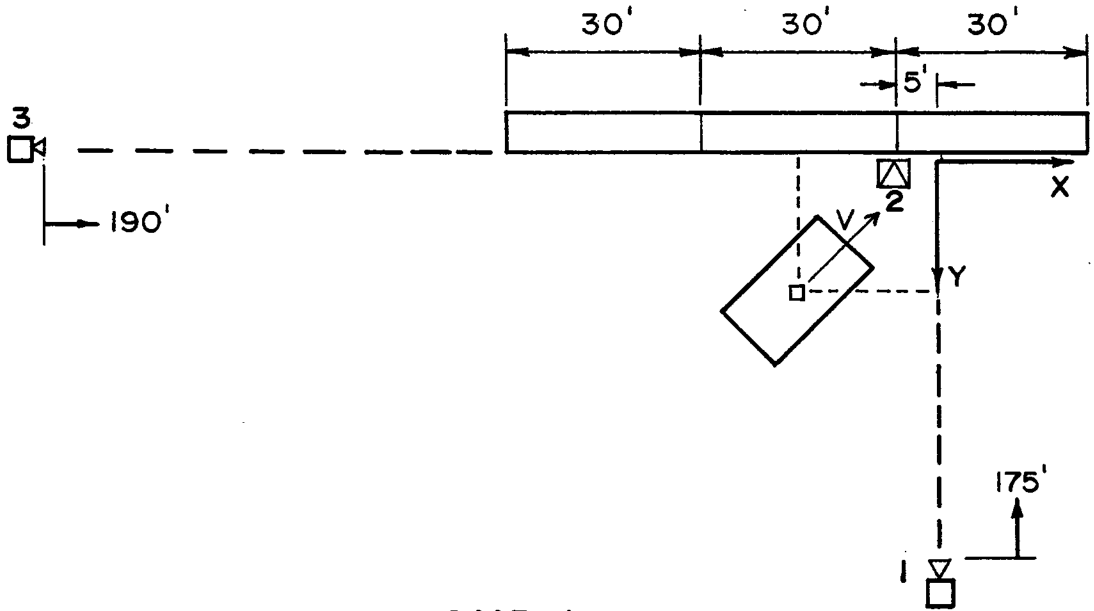
APPENDIX B

INSTRUMENTATION

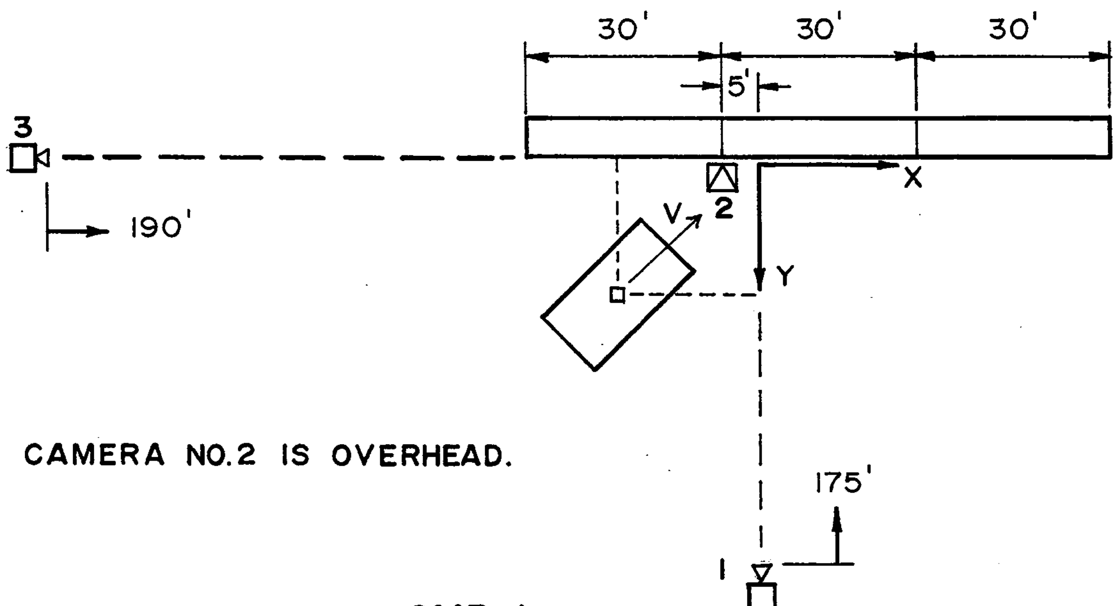
The instrumentation used for both tests consisted primarily of three high speed cameras located as shown in Figure B-1. One camera was located perpendicular to and 175 ft (53.3 m) from the face of the barrier. The perpendicular line of site was 5 ft (1.5 m) downstream from the joint being impacted. An overhead camera was located directly above the joint being impacted. The third camera was in line with and parallel to the barrier located 190 ft (58.1 m) from the upstream end of the barrier. In addition, a documentary camera was located in the vicinity of camera no. 1. A flash bulb, operated by a tape switch and located on top of the vehicles, was used to synchronize the films from the high speed cameras. Each of the cameras were further controlled by timing lights.

Stadia markers were placed on top of each vehicle as shown in Figure B-2. Each marker was coded so that position, roll pitch and yaw could be determined from the two ground mounted cameras.

The determination of the strength and stability of the barrier is a primary objective of this study. The overhead camera, no. 2, and the parallel camera, no. 3, were used to measure lateral displacement and barrier roll. A stadia board was placed behind the barrier at the joint impacted to aid in the measuring of lateral displacement.



CMB-1



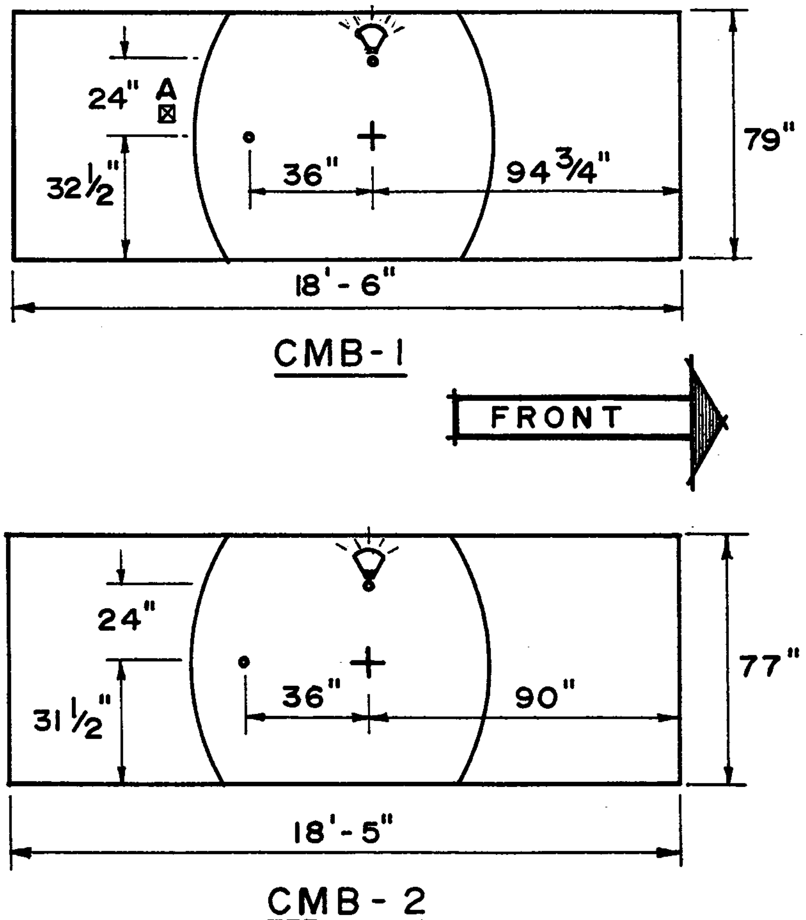
CAMERA NO. 2 IS OVERHEAD.

CMB-1

X-Y COORDINATES: Shown in relation to median barrier and camera placement.

FIGURE B-1. HIGH SPEED CAMERA LOCATIONS FOR TESTS.

ROOF TARGETS: Shown in relation to vehicle.



A = Impact-O-Graph in trunk; TEST CMB-1 only.

FIGURE B-2. DATA POINTS FOR TRIANGULATION.

TABLE B-1

TRIANGULATION DATA FOR CMB1 BARRIER TEST

The x,y coordinates are of the center of gravity. Point x=0 and y=0 is 5.0 ft north of the joint on the front face of the barrier. (See Figures)

Time (msec)	x (ft)	y (ft)	Time (msec)	x (ft)	y (ft)
-50	-19.2	7.7	210	0.1	3.14
-40	-18.3	7.3	220	0.8	3.11
-30	-17.6	6.9	229	1.5	3.19
-20	-16.8	6.6	239	2.2	3.28
-10	-16.0	6.2	249	2.9	3.40
0	-15.2	5.7	259	3.6	3.53
10	-14.3	5.4	269	4.3	3.61
20	-13.6	5.1	279	4.9	3.70
30	-12.8	4.7	289	5.6	3.73
40	-12.0	4.5	299	6.4	3.82
50	-11.2	4.2	309	7.1	3.91
60	-10.4	4.0	319	7.8	4.00
70	- 9.7	3.8	329	8.5	4.09
80	- 8.9	3.6	339	9.3	4.20
90	- 8.2	3.4	349	9.9	4.25
100	- 7.5	3.4	359	10.7	4.29
110	- 6.8	3.30	369	11.4	4.40
120	- 6.1	3.30	379	12.0	4.49
130	- 5.4	3.32	389	12.8	4.58
140	- 4.7	3.25	399	13.5	4.62
150	- 4.0	3.23	409	14.1	4.72
160	- 3.2	3.21	419	14.8	4.82
170	- 2.6	3.18	429	15.5	4.91
180	- 2.0	3.14	439	16.2	5.01
190	- 1.3	3.13	449	16.9	5.06
200	- 0.6	3.13			

TABLE B-2

TIME DISPLACEMENT DATA FOR CMB1 BARRIER TEST

Time (msec)		Displacement (ft)	Time (msec)	Displacement (ft)
-50		-4.5	210	15.7
-40		-3.6	220	16.4
-30		-2.7	229	17.1
-20		-1.8	239	17.7
-10		-0.9	249	18.5
0	IMPACT	0.0	259	19.2
10		0.9	269	19.9
20		1.7	279	20.5
30		2.6	289	21.3
40		3.4	299	22.0
50		4.2	309	22.7
60		5.1	319	23.4
70		5.9	329	24.1
80		6.1	339	24.9
90		7.3	349	25.6
100		8.0	359	26.3
110		8.8	369	27.0
120		9.4	379	27.7
130		10.1	389	28.4
140		10.9	399	29.1
150		11.6	409	29.8
160		12.3	419	30.5
170		12.9	429	31.2
180		13.6	439	31.9
190		14.3	449	32.6
200		14.9		

TABLE B-3

TRIANGULATION DATA FOR CMB2 BARRIER TEST

The x,y coordinates are of the center of gravity. Point x=0 and y=0 is 5.0 ft north of the joint on the front face of the barrier. (See Figures)

Time (msec)	x (ft)	y (ft)	Time (msec)	x (ft)	y (ft)
-50	-19.4	7.4	231	1.9	2.48
-40	-18.6	7.0	241	2.6	2.54
-30	-17.7	6.7	251	3.4	2.57
-20	-16.9	6.3	261	4.1	2.60
-10	-16.2	6.0	271	4.9	2.63
0	-15.4	5.6	282	5.6	2.63
10	-14.5	5.3	292	6.3	2.67
20	-13.7	5.0	302	7.1	2.70
30	-12.9	4.7	312	7.8	2.73
40	-12.1	4.4	322	8.6	2.77
50	-11.3	4.1	332	9.3	2.79
60	-10.5	3.8	342	10.1	2.84
70	- 9.7	3.6	352	10.8	2.87
80	- 8.9	3.4	362	11.5	2.94
90	- 8.2	3.3	372	12.3	2.96
101	- 7.5	3.2	382	13.0	2.99
111	- 6.8	3.19	392	13.8	3.03
121	- 6.0	3.09	402	14.5	3.07
131	- 5.2	2.99	412	15.2	3.07
141	- 4.3	2.94	422	16.0	3.14
151	- 3.8	2.89	432	16.7	3.19
161	- 3.0	2.82	442	17.5	3.25
171	- 2.4	2.77	452	18.3	3.28
181	- 1.7	2.70	463	19.1	3.31
191	- 1.0	2.61	473	19.8	3.34
201	- 0.3	2.60	483	20.5	3.42
211	0.4	2.53	493	21.3	3.43
221	1.2	2.46	503	22.1	3.53

TABLE B-3 (Continued)

TRIANGULATION DATA FOR CMB2 BARRIER TEST
(CONTINUED)

Time (msec)	x (ft)	y (ft)	Time (msec)	x (ft)	y (ft)
513	22.8	3.59	563	26.6	3.69
523	23.6	3.59	573	27.4	3.71
533	24.3	3.61	583	28.1	3.75
543	25.1	3.65	593	28.9	3.77
553	25.9	3.68			

TABLE B-4

TIME DISPLACEMENT DATA FOR CMB2 BARRIER TEST

Time (msec)		Displacement (ft)	Time (msec)	Displacement (ft)
-50		-4.4	282	21.3
-40		-3.6	292	22.0
-30		-2.6	302	22.8
-20		-1.7	312	23.5
-10		-0.9	322	24.3
0	IMPACT	0.0	332	25.0
10		0.9	342	25.8
20		1.8	352	26.5
30		2.7	362	27.2
40		3.5	372	28.0
50		4.3	382	28.7
60		5.2	392	29.5
70		6.0	402	30.2
80		6.8	412	31.0
90		7.5	422	31.7
101		8.3	432	32.4
111		9.0	442	33.2
121		9.8	452	34.0
131		10.5	463	34.8
141		11.2	473	35.6
151		12.0	483	36.3
161		12.7	493	37.0
171		13.4	503	37.8
181		14.1	513	38.6
191		14.8	523	39.3
201		15.5	533	40.1
211		16.2	543	40.8
221		17.0	553	41.6
231		17.6	563	42.4
241		18.3	573	43.1
251		19.1	583	43.9
261		19.8	593	44.7
271		20.6		