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The longitudinally reinforced CMB barrier had a height of 32 in. and weighed 507 plf. The barrier test section, with a length of 150 ft., was not anchored to the ground. A 1-in. layer of hot mix asphalt was placed at the base of the barrier to help resist lateral displacements. Subsequent to the tests, no rotational and lateral permanent set displacements of the barrier was visible.

The relatively minor damage to the truck consisted of sheet metal damage to the front fender and running board of the tractor. Estimated repair cost would be less than 200 dollars.

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TRUCK TESTS
ON
TEXAS CONCRETE MEDIAN BARRIER

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Research Report 146-7
Studies of Field Adaptation of Impact Attenuation Systems

Research Study Number 2-8-68-146

Sponsored by
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College Station, Texas

ABSTRACT

Key Words: Traffic Barriers, Highway Safety, Accidents, Highway Maintenance, Vehicle Damage, Vehicle Decelerations, Injury Probability, Injury Severity.

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Maintenance of the barrier would require at most a light sandblasting job to remove the unsightly tire scrub markings. The small amount of concrete spalling that occurred in the immediate area of impact would require no maintenance. The fence and luminaire pole on top of the barrier were not damaged.

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.

SUMMARY

The rigid Texas concrete median barrier (CMB-70), with inclined surfaces, remained intact in restraining and redirecting a large 48,800 lb. tractor-trailer truck with load under the full-scale impact test conditions of 35 mph/19 deg; 34 mph/16 deg; and 45 mph/15 deg. The truck was remotely controlled from a chase pickup vehicle.

The longitudinally reinforced CMB barrier had a height of 32 in. and weighed 507 plf. The barrier test section, with a length of 150 ft., was not anchored to the ground. A 1-in. layer of hot mix asphalt was placed at the base of the barrier to help resist lateral displacements. Subsequent to the tests, no rotational and lateral permanent set displacements of the barrier were visible.

The truck trailer was loaded with concrete blocks weighing 22,800 lbs. The concrete blocks were staked to an height of about 24 in. over a distance of about two-thirds the length of the trailer. The lumped center-of-mass of the loaded trailer body (excluding the rear tandem wheel assemblies) was located at a height slightly above the top of the concrete blocks and at a height of 72 in. above the level roadway. The location of the lumped center-of-mass of the truck tractor was approximately 31 in. above the level roadway.

Measurements of the tractor-trailer swivel joint showed that the trailer rolling motion was independent of the tractor rolling motion for a differential roll angle of 10 deg. and less. A film analysis revealed that the trailer and tractor rolling motions were independent in the two lower speed 35 and 34 mph tests and dependent in the highest speed 45 mph test. The largest trailer roll angles attained in the two lower speed tests were about 8 deg. In the 45 mph test, the inertia of the tractor was effective in restricting the trailer roll angle to a maximum of 17 deg.

The truck tractor showed no tendency during redirection to climb and vault the barrier. The inner dual tractor wheels did not climb above the lower inclined 55-deg. surface. The highest rise of the tractor bumper above the top of the CMB barrier was 7 in. in the 35 and 34 mph tests and 11 in. in the 45 mph test.

A first attempt was made in this study to evaluate the measured truck accelerations in relation to a severity-index concept. This concept is used by research engineers of the Texas Transportation Institute to investigate automobile roadside traversals and rigid barrier collisions. Predictions on the probability and severity of injuries to an unrestrained occupant were: 45% and on the threshold of major for the 35 mph/19 deg. test; 39% and minor for the 34 mph/16 deg. test; and 57% and major for the 45 mph/15 deg. test.

The relatively minor damage to the truck consisted of sheet metal damage to the front fender and running board of the tractor. Estimated repair cost would be less than 200 dollars.

Maintenance of the barrier would require at most a light sand-blasting job to remove the unsightly tire scrub markings. The small amount of concrete spalling that occurred in the immediate area of impact would require no maintenance. The fence and luminaire pole on top of the barrier were not damaged.

IMPLEMENTATION STATEMENT

This series of tests demonstrated that the Texas concrete median barrier (CMB-70) can be used to restrain and redirect a large size 48,800 lb. tractor-trailer truck, with load, under the impact conditions of 45 mph and 15 deg.

Earlier tests conducted by Hirsch (3) demonstrated that the CMB barrier can be used to restrain and redirect a 4,000 lb. automobile under the impact conditions of 60 mph and 25 deg.

It is to be noted that the 150 ft. longitudinally reinforced CMB barrier test section (see Figure 1) contained no mechanical anchors between the ground and the barrier. A 1 in. layer of hot mix asphalt was placed, however, at the base of the barrier to help resist lateral translations.

The truck tests demonstrated that the maintenance costs of the barrier would be low. At most, maintenance would require a light sand-blasting job to remove the unsightly tire scrub markings (see Figure 14). The small amount of concrete spalling that occurred in the immediate area of impact would require, in the estimation of the writers, no maintenance. The fencing and luminaire pole on top of the barrier were not damaged during the tests.

As of April 1972, the initial construction cost of the CMB barrier for 9,181 L. F. was $13.36. These figures were obtained from an Inter-office THD memorandum from Mr. R. S. Williamson to Mr. John Nixon and Mr. Dave Hustace. The memorandum was dated April 10, 1972.

LIST OF FIGURES

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I. INTRODUCTION

Recent accident information compiled by the Texas Highway Department and reported by Olson (1) shows that the number of trucks involved in traffic barrier fatal accidents has increased from 16 to 21 percent over a period of approximately two years. These accident figures include single unit trucks, combination tractor-trailer trucks, and pickup trucks. Highway engineers are, therefore, very much concerned over the inadequacy of many current types of traffic barriers not having sufficient height and strength to restrain and redirect trucks.

The massive concrete traffic barrier, with a lower inclined surface of about 55 deg., has proven to be under test and field conditions an effective design in restraining and redirecting automobiles. Tests conducted by Lunstrom (2) has further demonstrated that the concrete barrier performed satisfactorily in restraining and redirecting a single unit 16,000 lb. truck, with load, under the impact conditions of 37 mph and 13 deg.

The promising *medium* size truck test results of Lunstrom (2) on the concrete barrier were instrumental in the development of additional research. The objective of this research project was to tentatively determine, based upon a limited number of full-scale tests, the capability of the Texas concrete median barrier (CMB-70) to restrain and redirect a *large* size tractor-trailer truck under typical highway encroachment conditions.

II. DESCRIPTIONS AND PROCEDURES FOR TESTS

Median Barrier

The median barrier used in the full-scale truck tests was the rigid Texas concrete median barrier, designated as CMB-70. Earlier tests conducted by Hirsch (3) demonstrated that the Texas CMB-70 barrier remained intact in restraining and redirecting a standard size 4,000 lb. passenger vehicle under the impact conditions of 60 mph and 25 degrees.

The CMB barrier, shown in Figure 1, has: a weight of 507 plf.; a height of 32 in. above the roadway; a lower 10-in. high inclined surface of 55 degrees; a base width of 27 in.; and a top width of 8 in.

The Texas CMB barrier is similar to the New Jersey Median Barrier (4) except that #5 longitudinal reinforcing steel is used in the Texas barrier whereas none is used in the New Jersey barrier.

The CMB barrier was constructed in two continuous length sections of 50 ft. and 150 ft. as shown in Figure 1. The construction joint between the two sections offers no lateral restraint. The luminaire pole was mounted on top of the shorter 50 ft. section. Three 18-in. diameter drilled concrete shafts were used to support the shorter 50 ft. section against possible overturning due to wind and vibratory forces on the luminaire pole. The longer 150 ft. section, on which the truck tests were conducted, contains no mechanical anchors to the roadway. The 1-in. layer of hot mix asphalt at the base of the CMB barrier was used to provide some restraint to sliding during a vehicle collision. Details of the chain link fabric fence and luminaire pole were discussed by Hirsch (3).

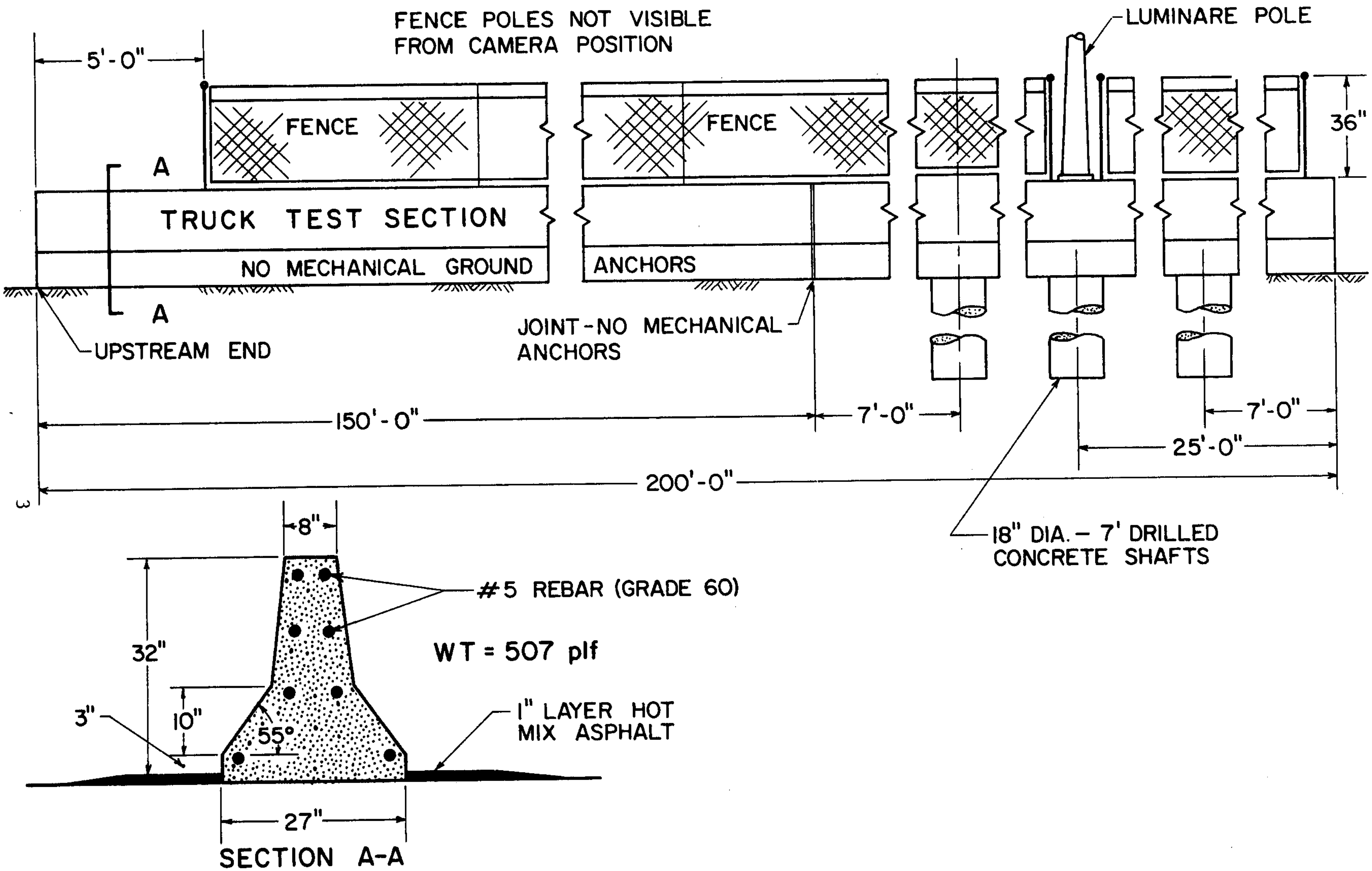


FIGURE 1 TEXAS CONCRETE MEDIAN BARRIER (CMB-70)

Test Vehicle

The test vehicle used in the full-scale tests was a large size tractor-trailer truck weighing 48,800 lbs. with load. Photographs of the truck in a loaded condition prior to the tests are shown in Figure 2. And, pertinent data of the truck are shown in Figure 3.

The truck-trailer was loaded with concrete blocks weighing 22,800 lbs. The arrangement of the concrete blocks are shown in the end-view of Figure 2c and the side-view of Figure 3. The blocks were staked to an average height of about 24 in. over a distance of about two-thirds the length of the trailer.

The wheel loads and height measurements of the truck before and after loading are shown in Figure 3. Based on these measurements and an indeterminate analysis, it was possible to determine, without disconnecting the tractor-trailer, the magnitude of the primary lumped-masses of which the trailer was comprised. The lumped center-of-mass of the loaded trailer body (excluding the rear tandem wheel assemblies) is located at a height slightly above the top of the concrete blocks and at a height of 6.0 ft. above the level roadway as shown in Figure 3.

The location of the lumped center-of-mass of the tractor, determined by a trial and error process, is approximately 2.6 ft. above the level roadway as shown in Figure 3. Referring to Figure 2a, the tractor center-of-mass lies about 7 in. below and slightly to the rear of the lower left hand checker-board white square painted on the tractor door.

Truck Control Apparatus

A 5-channel radio remote system was used to control the truck from a *chase* pickup vehicle. The truck control apparatus consisted of:

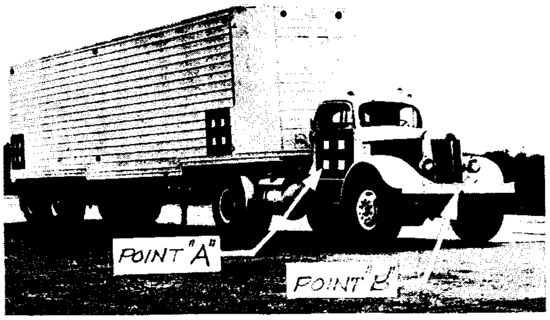


FIGURE 2a
FRONT OBLIQUE VIEW

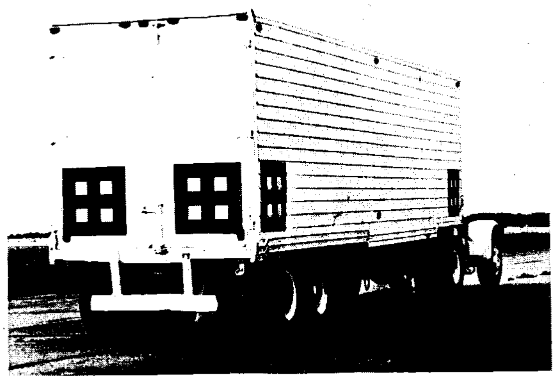


FIGURE 2b
REAR OBLIQUE VIEW

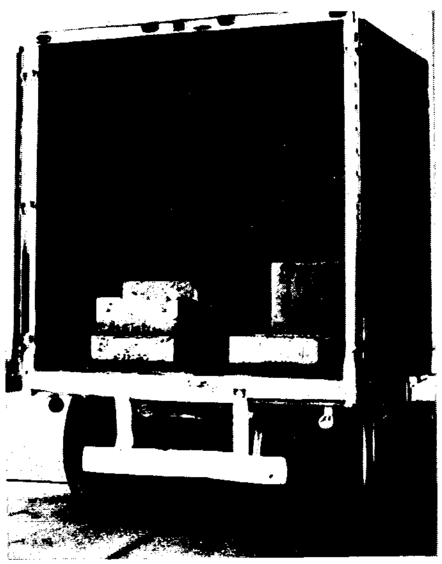
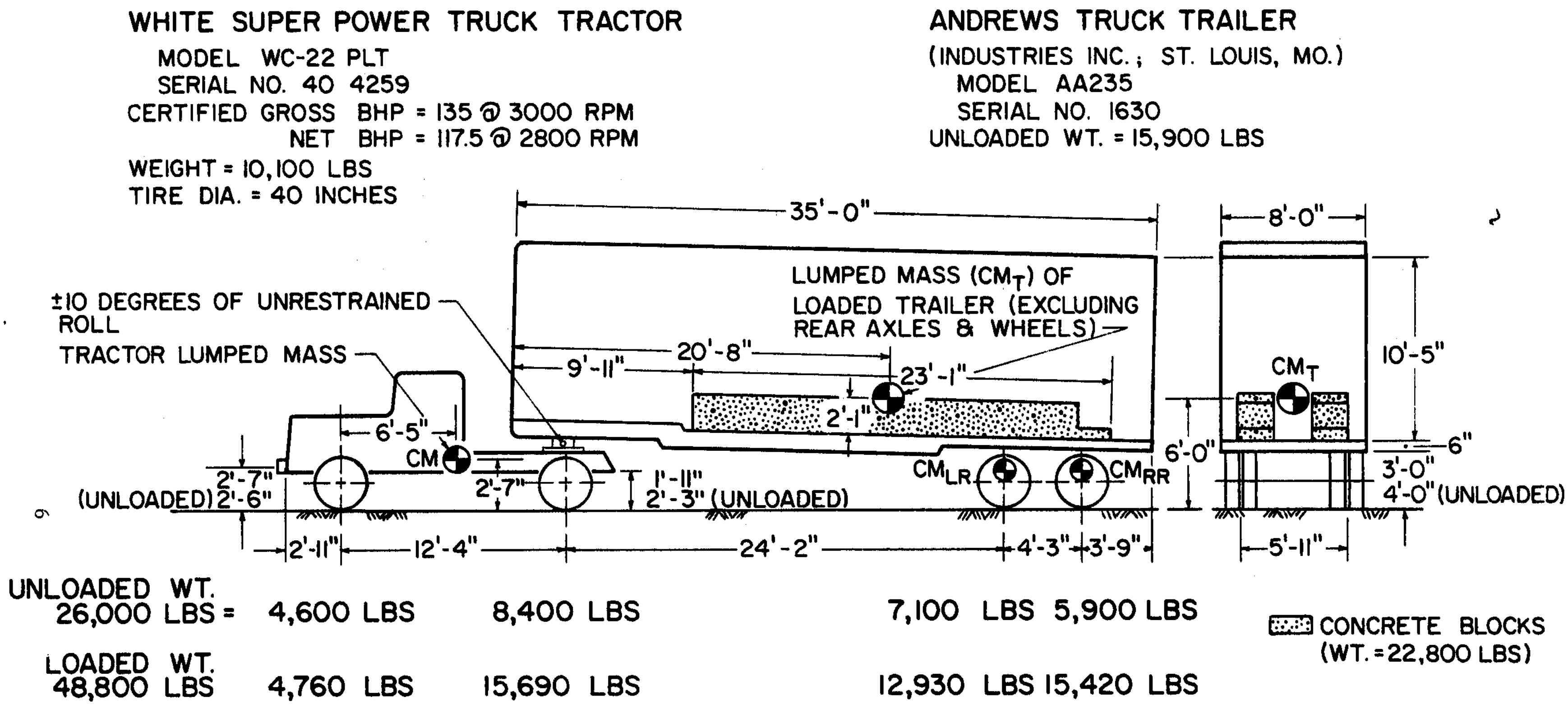


FIGURE 2c
END VIEW ARRANGEMENT OF CONCRETE BLOCKS IN TRAILER

NOTE: AFTER THIS PHOTOGRAPH WAS TAKEN, THE CONCRETE BLOCKS WERE TIED DOWN PRIOR TO TESTS.

FIGURE 2. PHOTOGRAPHS OF TEST TRUCK IN LOADED CONDITION PRIOR TO TESTS



NOTES:

(1) CALCULATED LUMPED MASSES FOR TRAILER:

(a) INTERIOR REAR TANDEM WHEEL ASSEMBLY, CM_{LR} = 176 LB-SEC^2/FT (5,650 LBS)

(b) EXTERIOR REAR TANDEM WHEEL ASSEMBLY, CM_{RR} = 138 LB-SEC^2/FT (4,450 LBS)

(c) TRAILER BODY = 180 LB-SEC^2/FT (5,800 LBS)

(2) TRUCK DIMENSIONS ARE FOR LOADED CONDITIONS EXCEPT AS NOTED

FIGURE 3 PERTINENT TRUCK DATA

1. ON-OFF Steer Control (Hydraulic)
2. ON-OFF Clutch Control (Pneumatic)
3. ON-OFF Trailer Brake Control (Pneumatic)
4. ON-OFF Accelerator Pedal Control (Pneumatic)

The ON-OFF steer control apparatus consisted of a 4-way hydraulic solenoid valve and a double-acting hydraulic cylinder coupled between the front axle and the tie-rod of the truck. A pump, driven by the truck engine, was used as the hydraulic power source. A photograph of the 4-way hydraulic solenoid valve unit, mounted in the tool box of the truck, is shown in Figure 4a.

The ON-OFF clutch and accelerator pedal truck controls each consisted of a 3-way pneumatic valve and a single-acting pneumatic cylinder. The truck air-compressor was used as the pneumatic power source. The single-acting pneumatic cylinders mounted on the clutch and accelerator pedal are visible in the two photographs of Figure 4.

The ON-OFF brake control consisted of a 3-way pneumatic valve spliced into the brake air-lines of the truck trailer. The brakes on the truck tractor were not used in order to minimize the possibilities of jack-knifing.

The test truck was started from a rest position by a pushing second vehicle. In the rest position, the truck was in gear with its engine running and its clutch disengaged by the pneumatic control cylinder. After the reaching a sufficient speed, the pushing vehicle reduced its speed and turned away. The clutch of the test truck was then engaged and the truck proceeding on toward the barrier under power and under the control of the *chase* pickup vehicle.

FIGURE 4a

FIGURE 4b

FIGURE 4. PHOTOGRAPHS OF REMOTELY OPERATED ON-OFF TRUCK CONTROLS.

The angle of steer and the accelerator pedal truck controls were held fixed in position subsequent to the instant of barrier contact. The brakes of the truck trailer were applied after the truck was clear of the 200 ft. length barrier test section.

Truck Instrumentation

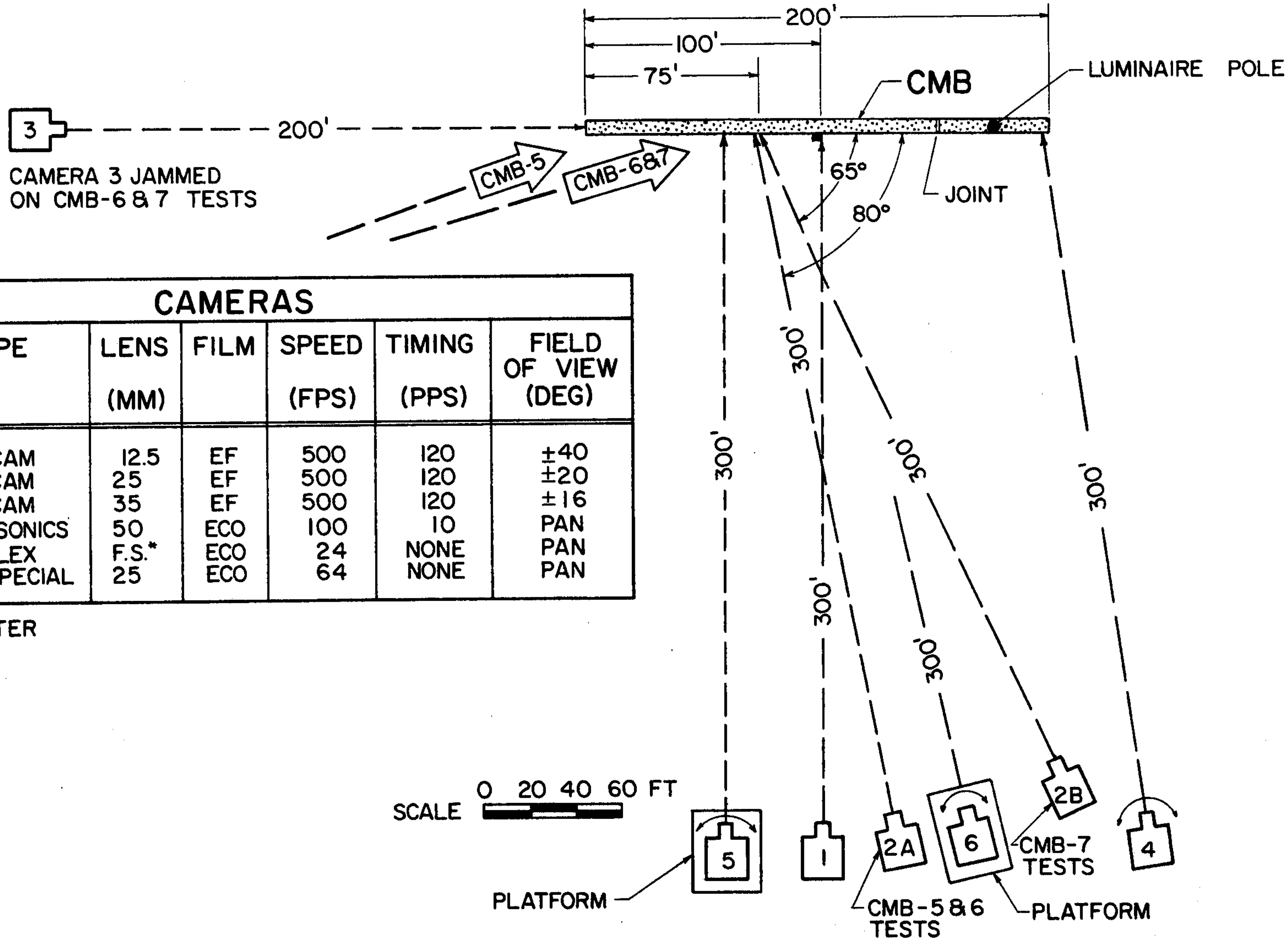
An Impact-O-Graph was used to record the longitudinal, lateral, and vertical acceleration components of the truck tractor compartment at a location on the floor and directly under the passenger occupant. The lower left white square painted on the door of the tractor, and designated as point "A" in Figure 2a, was approximately normal to the location of the Imapct-O-Graph.

The Impact-O-Graph was remotely turned on from the *chase* pickup vehicle just prior to impact with the CMB barrier. The acceleration recordings of the Impact-O-Graph are presented in Figures 13, 14 and 15.

Photographic Coverage

The location of the documentary and high speed cameras relative to the CMB barrier are shown in Figure 5. Pertinent information on the six cameras, such as type and speed, are summarized in a tabular format in Figure 5.

End-view photographic coverage of the CMB-6 and CMB-7 tests was lost as the result of camera no. 3 jamming. The film analysis and sequence photographs presented later in this study were obtained from the panning no. 4 camera.



CAMERAS						
NO	TYPE	LENS (MM)	FILM	SPEED (FPS)	TIMING (PPS)	FIELD OF VIEW (DEG)
1	HYCAM	12.5	EF	500	120	±40
2	HYCAM	25	EF	500	120	±20
3	LOCAM	35	EF	500	120	±16
4	PHOTOSONICS	50	ECO	100	10	PAN
5	BOLEX	F.S.*	ECO	24	NONE	PAN
6	CINE SPECIAL	25	ECO	64	NONE	PAN

*FULL SHUTTER

FIGURE 5 PHOTOGRAPHIC COVERAGE

III. DISCUSSION AND EVALUATION OF TESTS

Barrier Performance

Three full-scale angle collision truck tests, designated as CMB-5, CMB-6 and CMB-7, were conducted on the Texas CMB barrier. The CMB barrier, subjected to the below measured impact conditions, performed satisfactorily in restraining and redirecting the loaded 48,800 lb. tractor-trailer truck. No permanent rotational and lateral displacements of the unanchored and continuously reinforced 150 foot barrier test section were visible.

TEST NO.	IMPACT SPEED (mph)	IMPACT ANGLE (deg)
CMB-5	34.9	19.1
CMB-6	33.8	15.5
CMB-7	44.7	15.0

Truck Kinematics

Sequence panning photographs and graphical displays of the tractor-trailer truck kinematics during the barrier redirection are shown in Figures 6, 7 and 8 for the CMB-5 test; Figures 9 and 10 for the CMB-6 test, and; Figures 11 and 12 for the CMB-7 test. The graphical displays were obtained from an analysis of the high speed film using the Vanguard Motion Analyzer (6) and the IBM 360-65 computer.

End-view sequence photographs of the truck kinematics were not available for the CMB-6 and CMB-7 tests because of a camera malfunction. A comparison of the rolling motion of the truck trailer obtained from an analysis of film from the end-view and side-view cameras is shown in Figure 8 for the CMB-5 test. This comparison indicates that a reasonable estimate of the trailer rolling motion can be obtained from a side-view film analysis.

Measurements of the tractor-trailer truck swivel connection showed that the rolling motion of the trailer was independent of the tractor for angles of about 10 deg. and less. As shown in Figures 8 and 10, the trailer rolling motion in the CMB-5 and CMB-6 tests were less than 8 deg., and hence, independent of the tractor rolling motion. In the CMB-7 test, however, the trailer rolling motion was not independent of the tractor rolling motion. The trailer in the CMB-7 test reached a maximum roll angle of 17 deg. at a time of 1.2 sec. after impact as shown in Figure 12. It can also be seen in the sequence photographs of Figure 11, that at a time of 1.2 sec. the tractor rear dual wheels on the passenger side were lifted off the ground for a height of about 7 in. as a result of the trailer roll angle exceeding the unrestrained swivel roll angle of 10 deg. This observation may be significant for the selected truck under a higher impact speed of say 50 to 55 mph, in that:

1. The inertia of the tractor would greatly assist in minimizing the possibility of rollover provided that the swivel roll pin does not fracture.
2. If the swivel roll pin does fracture, there may be a possibility that the trailer would rollover the CMB barrier.

The vertical motion of a point on the tractor bumper relative to the top of the CMB barrier is shown in Figures 8, 10 and 11 for the three tests. The bumper point selected was located, as shown in Figure 2a, at the midheight of the bumper and at the longitudinal centerline of the tractor. The highest bumper rise above the top of the barrier was about 7 in. for the CMB-5 and CMB-6 tests; whereas, in the CMB-7 test the highest rise was about 11 in.

The vertical motion of a point on the tractor door relative to the top of the barrier is shown in Figures 8, 10 and 11. This point, which is designated as point "A" in Figure 2a, was normal to the Impact-O-Graph mounted on the floor directly under the passenger seat. The highest rise of point "A" above the top of the barrier was about 8 in. for the CMB-5 test; whereas, in the CMB-6 and CMB-7 tests the highest rise was about 18 in.

The sequence photographs and the graphs in Figures 6 through 12 show that the vertical and pitching motions of the tractor continued throughout the entire length of barrier contact as the front and rear dual wheels of the tractor rode up and down on the barrier inclined surfaces. It appears from the film, however, that the rear dual wheels did not climb beyond the top edge of the lower 55 deg. inclined surface. The truck remained in contact with the barrier because the remote control steering system was held in a straight ahead position prior to and subsequent to impact. The vertical and pitching motions were much more pronounced in the 45 mph CMB-7 test than in the two 10 mph slower CMB-5 and CMB-6 tests.

In summary, the three tests demonstrated that the barrier was of sufficient height to prevent the truck from climbing and vaulting the 32 in. high CMB barrier.

Truck Accelerations (Impact-O-Graph)

The longitudinal, lateral and vertical truck accelerations obtained by use of an Impact-O-Graph are shown in Figure 13 for the CMB-5 test; Figure 14 for the CMB-6 test; and, Figure 15 for the CMB-7 test. The Impact-O-Graph was mounted on the floor of the tractor directly under the passenger seat.

Some significance of the measured truck acceleration components in relation to injury severity may be obtained from a *severity-index* concept used by Weaver (7), Ross (8, 9), and Young (10). The severity-index, expressed by the below equation, takes into consideration the combined effects of the longitudinal (G_{long}), lateral (G_{lat}), and vertical (G_{vert}) truck accelerations.

$$SI = \sqrt{\left(\frac{G_{long}}{G_{XL}}\right)^2 + \left(\frac{G_{lat}}{G_{YL}}\right)^2 + \left(\frac{G_{vert}}{G_{ZL}}\right)^2}$$

The tolerable acceleration components used by the referenced research engineers in studying ran-off-the-road *automobile* traversals of side slopes, ditches, sloping grates, and rigid traffic barriers were:

$$G_{XL} = 7 \text{ G's}$$

$$G_{YL} = 5 \text{ G's}$$

$$G_{ZL} = 6 \text{ G's}$$

These tolerable acceleations, which are referenced to a right-hand coordinate axes system moving with the vehicle, were used for unrestrained occupants.

Up until recently, a severity-index value of *unity* or greater was literally interpreted to mean that an unrestrained occupant in an automobile mishap would be seriously or fatally injured. Combining the work of Olson (1) and Michalski (11) on injury probability and injury severity with the severity-indices computed from the output of the HVOSM vehicle model on the CMB barrier (10), Post and Young (12) refined the interpretation of the severity-index concept as follows:

1. The probability of injury (P) and the severity-index (SI) were linearly related and can be expressed as:

   $$P(\%) = 30\ SI$$

2. A severity-index of 1.5 represents a division between minor and major injuries.

An evaluation of the truck Impact-O-Graph accelerations in relation to severity-index, probability of injury, and injury severity is presented in Table 1. The probability of injury and severity of injury were: 45% and on the threshold of major for the CMB-5 test; 39% and minor for the CMB-6 test; and, 57% and major for the CMB-7 test.

The Impact-O-Graph acceleration traces in Figures 13, 14 and 15 appear to be fairly accurate judging from the magnitude of the computed severity-indices in Table 1. That is, one could have predicted that the severity-index in the CMB-6 test would have been slightly lower than the severity-index of the CMB-5 test because of the flatter 4 deg. impact

TABLE 1

EVALUATION OF TRUCK ACCELERATIONS*
IN RELATION TO INJURY SEVERITY

CMB TEST NO.	IMPACT SPEED (MPH)	IMPACT ANGLE (DEG)	ACCELERATIONS AVERAGED OVER 50 MILLISECONDS			SEVERITY INDEX	PROBABILITY OF INJURY (Unrestrained Occupant) (%)	INJURY SEVERITY (Unrestrained Occupant)
			G_{LONG} (G's)	G_{LAT} (G's)	G_{VERT} (G's)			
5	34.9	19.1	3.3	6.4	4.4	1.5	45	THRESHOLD OF MAJOR
6	33.8	15.5	1.9	5.5	4.3	1.3	39	MINOR
7	44.7	15.0	3.0	7.0	7.4	1.9	57	MAJOR

*ACCELERATIONS OBTAINED BY AN IMPACT-O-GRAPH angle. Similarly, one could have predicted that the severity-indices of the CMB-5 and CMB-6 tests would have been lower than the severity-index of the 10 mph higher speed CMB-7 test.

Computed Vertical Accelerations

In addition to the Impact-O-Graph accelerations, the vertical accelerations of the truck were computed by taking the *second central differences* of the vertical displacements obtained from a high speed film analysis. As discussed earlier, the vertical displacements were measured for a point on the tractor door designated as point "A" in Figure 2a. This point was selected because it was normal to the Impact-O-Graph mounted on the floor under the passenger seat. Graphs of the computed accelerations are shown in Figures 8, 10 and 12. The straight line segments connect the midpoints of the acceleration differences averaged over a time duration of 50 milliseconds as illustrated in Figure 12.

The highest vertical accelerations occurring near the time interval over which the severity-indices were computed earlier were: 2.5 G's for the CMB-5 test; 4.0 G's for the CMB-6 test; and, 3.8 G's for the CMB-7 test. It can be seen that the average vertical accelerations from the Impact-O-Graph in Table 2 and vertical accelerations computed from a film analysis do not differ appreciably when one takes into consideration the difference in the reference coordinate systems. The Impact-O-Graph accelerations were measured relative to a coordinate system attached to and moving with the truck; whereas, the vertical accelerations from the film analysis always lie in vertical plane parallel to the tractor and normal to the roadway. Therefore, the vertical accelerations from the film will differ because there was no way to include the vertical components of the longitudinal and lateral accelerations resulting from the roll and pitch motions of the truck.

Truck Damage

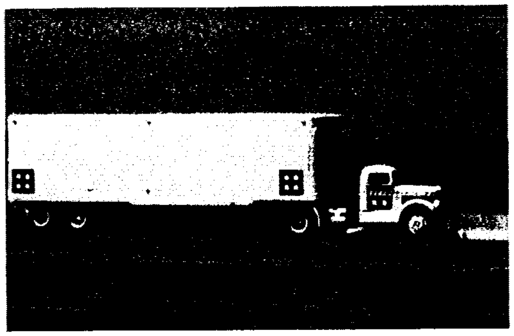
The damage to the truck was relatively minor. The sheet metal damage of the tractor after the CMB-5 test is shown in Figure 16a. And, the sheet metal and bumper damage of the tractor after the CMB-5, CMB-6 and CMB-7 tests is shown in Figure 16b. Damage to the trailer consisted of several small indentations near the rear tandem wheels. The window on the side of the passenger was damaged prior to testing.

The estimated cost required to repair the fender, bumper and running board of the tractor would be most likely less than 200 dollars.

Barrier Damage

Photographs of the CMB barrier after testing are shown in Figure 17. Maintenance of the barrier would require at most a light sand-blasting job to remove the unsightly tire scrub markings. The small amount of concrete spalling that occurred would, in the estimation of the writers, require no maintenance. It can also be seen in the photographs that the fencing and luminaire pole on top of the barrier were not damaged.

The tire scrub markings extend over the entire length of the barrier beyond the points of impact because, as mentioned earlier, the front wheels were locked in a straight ahead steering position subsequent to impact.



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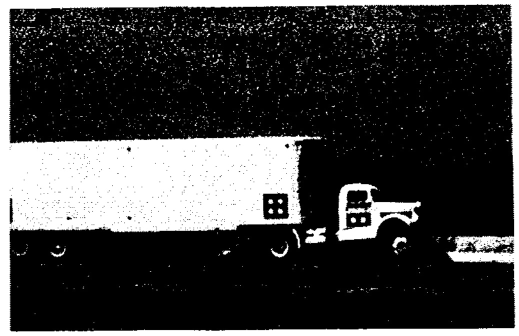

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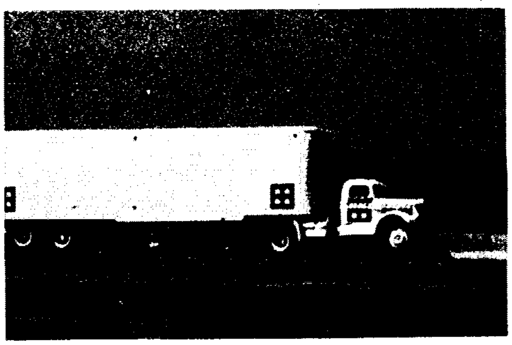

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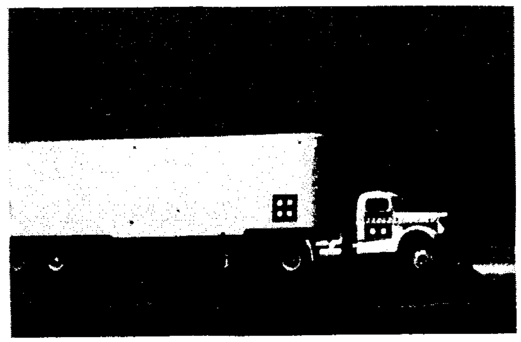

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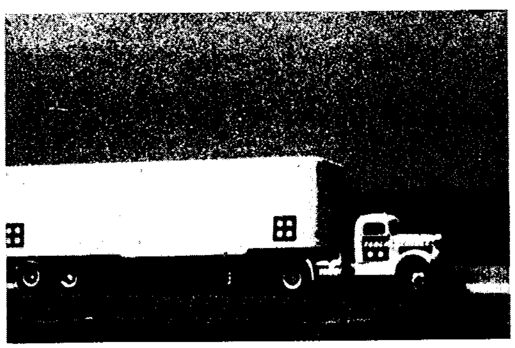
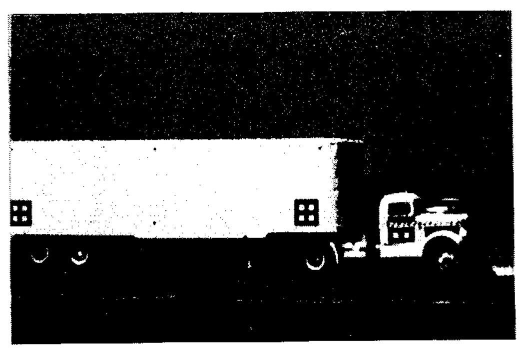
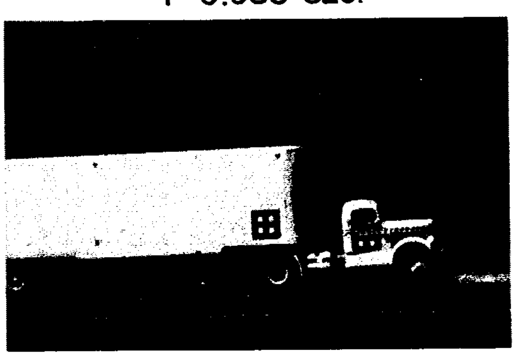


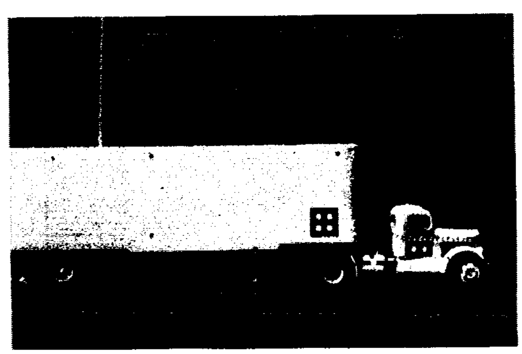
T = 0.983 SEC.



T = 1.558 SEC.

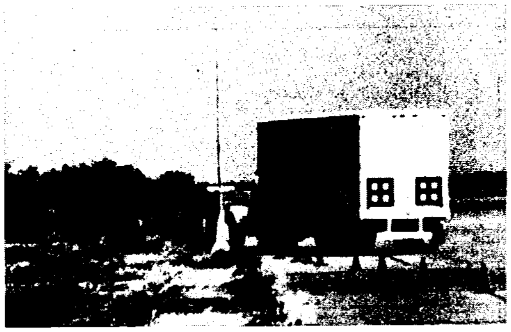


T = 3.169 SEC.

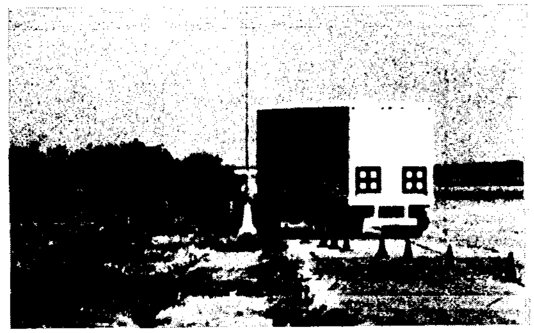


T = 5.177 SEC.

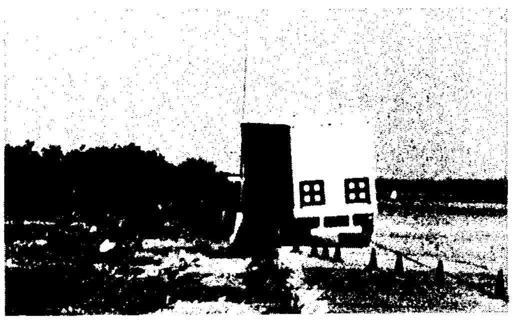
FIGURE 6 SEQUENCE PHOTOGRAPHS OF CMB—5 TEST.



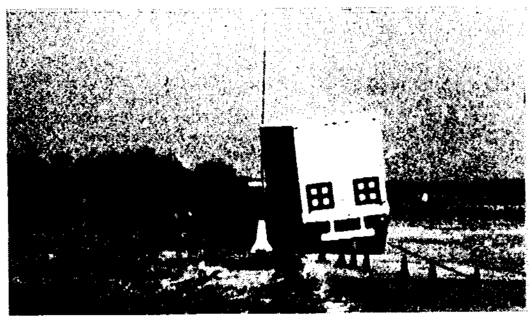
T=0.000 SEC. (IMPACT)



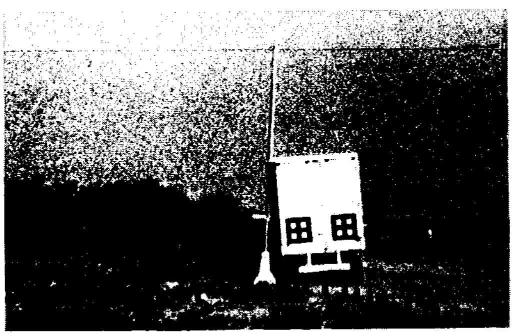
T=0.253 SEC.



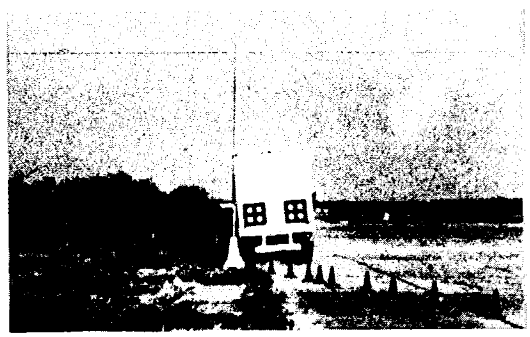
T=0.539 SEC.



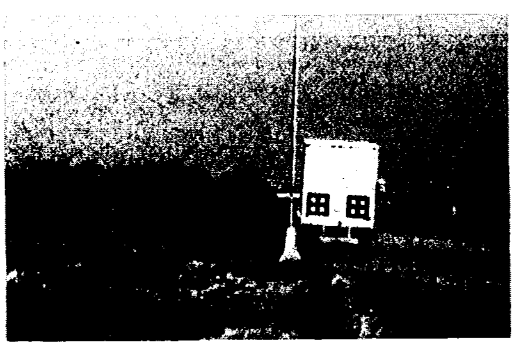
T=0.650 SEC.



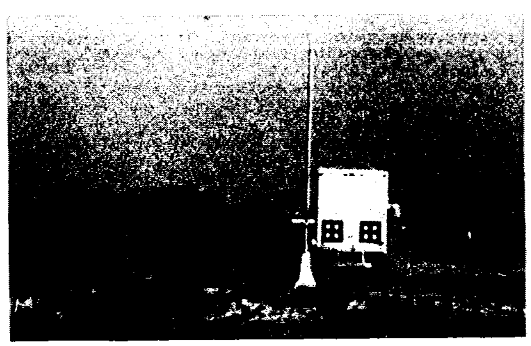
T=0.900 SEC.



T=1.110 SEC.



T=1.700 SEC.



T=2.000 SEC.

FIGURE 7 SEQUENCE PHOTOGRAPHS OF CMB-5 TEST.

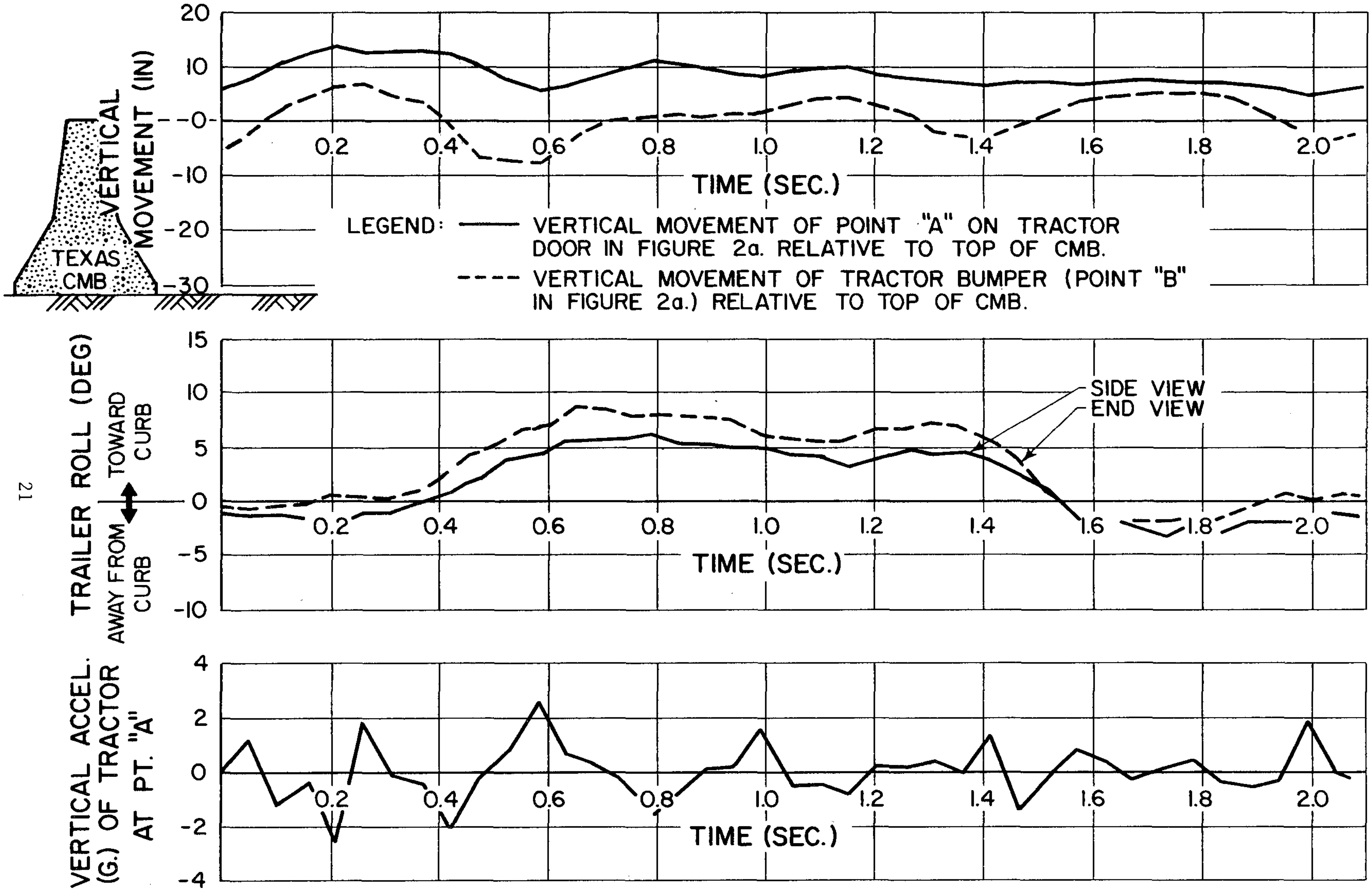
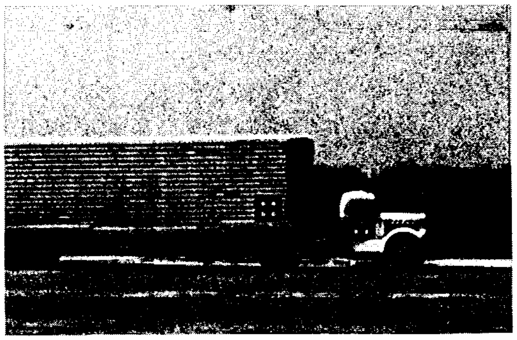
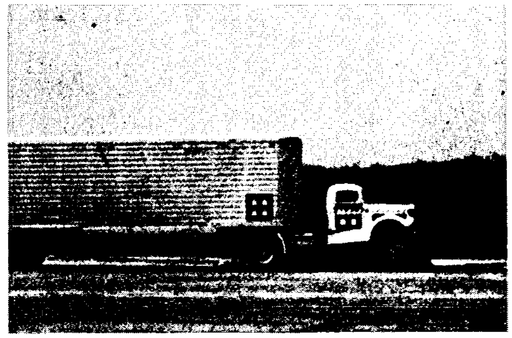


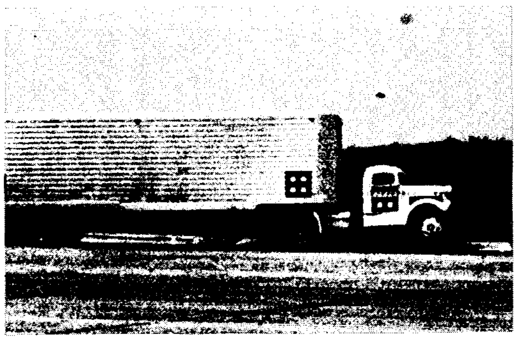
FIGURE 8 CMB-5 RESULTS FROM FILM ANALYSIS



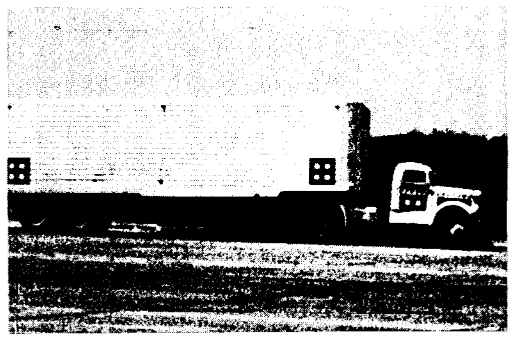
T = 0.000 SEC. (IMPACT)



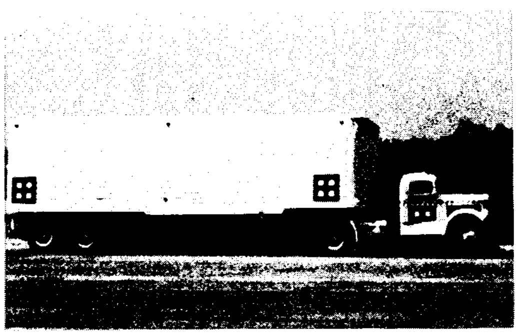
T = 0.271 SEC.



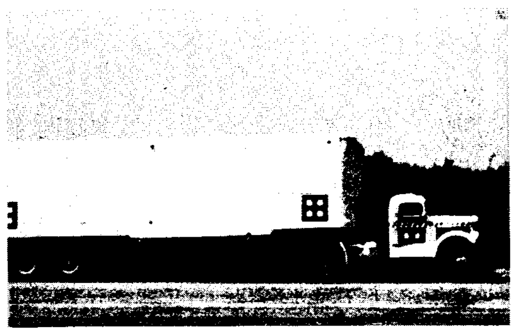
T = 0.417 SEC.



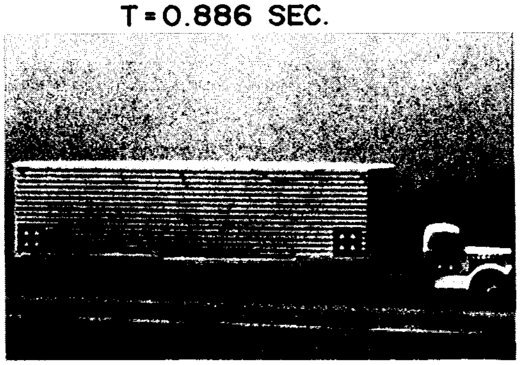
T = 0.563 SEC.



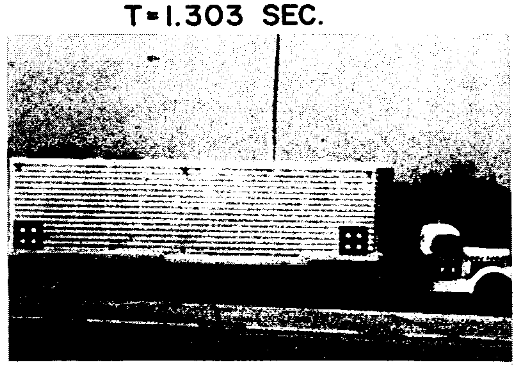
T = 0.886 SEC.



T = 1.303 SEC.



T = 1.626 SEC.



T = 3.147 SEC.

FIGURE 9 SEQUENCE PHOTOGRAPHS OF CMB–6 TEST.

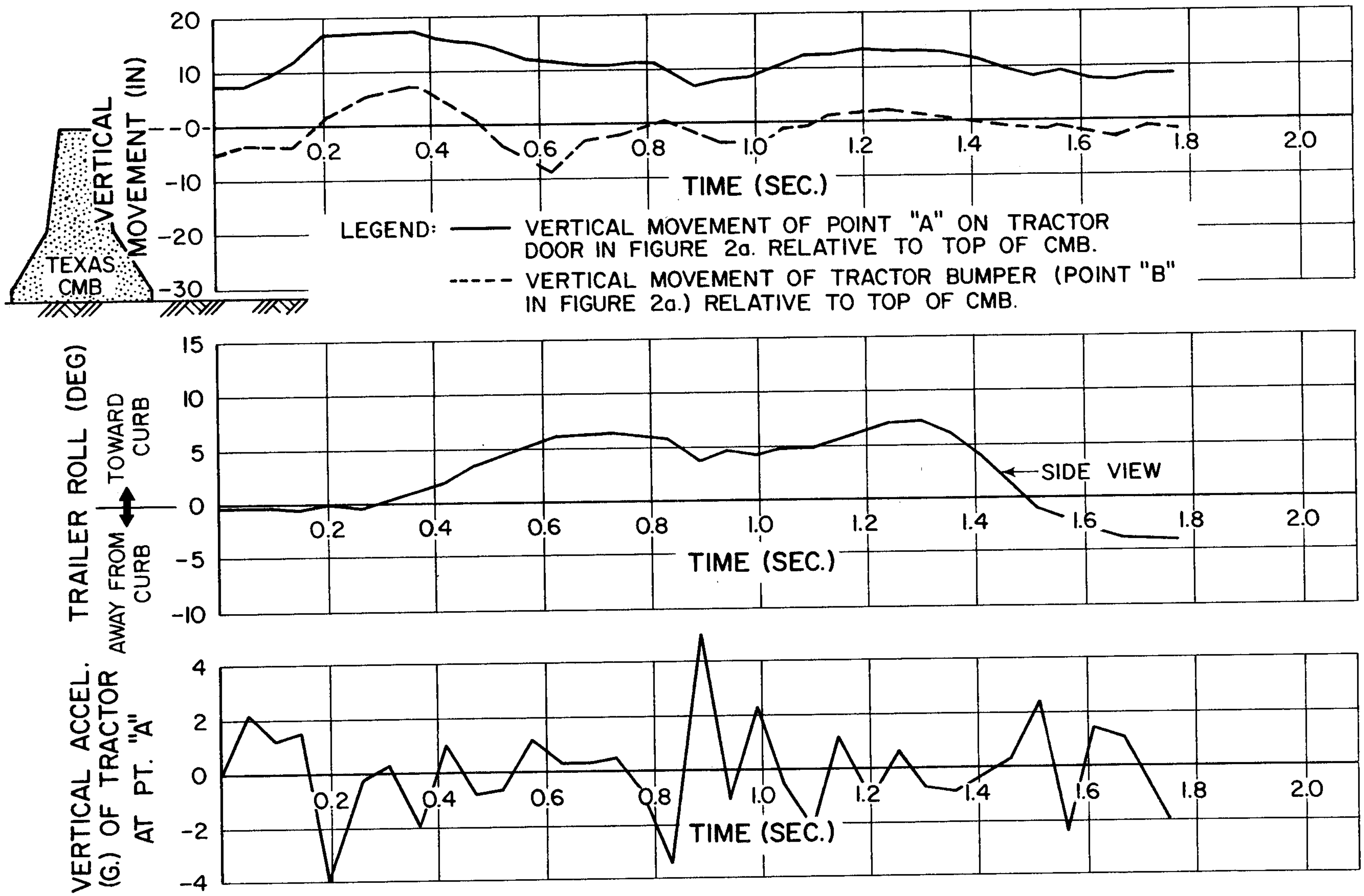
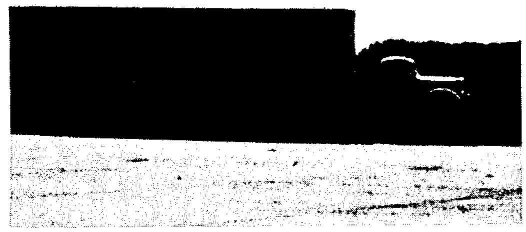


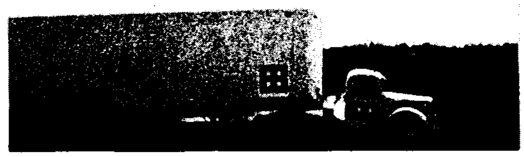
FIGURE 10 CMB-6 RESULTS FROM FILM ANALYSIS

T = 0.000 SEC. (IMPACT)

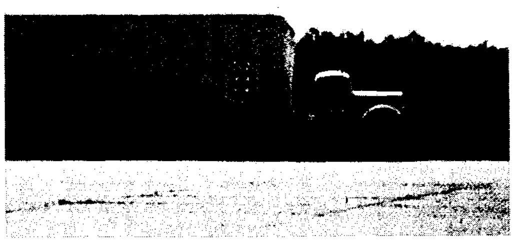


T = 0.260 SEC.

T = 0.364 SEC.

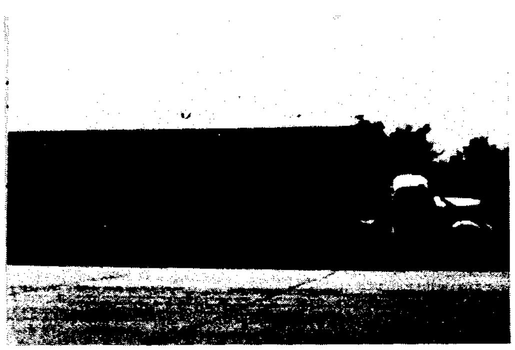


T = 0.584 SEC.

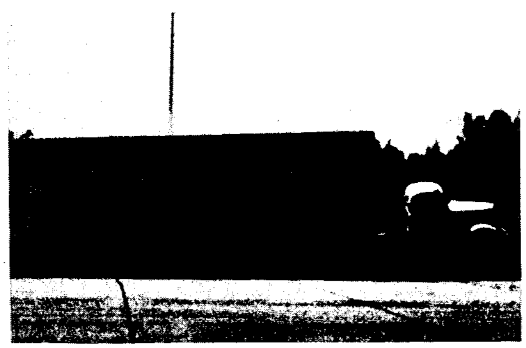


T = 0.968 SEC.

T = 1.200 SEC.



T = 1.915 SEC.



T = 2.727 SEC.

FIGURE 11 SEQUENCE PHOTOGRAPHS OF CMB-7 TEST.

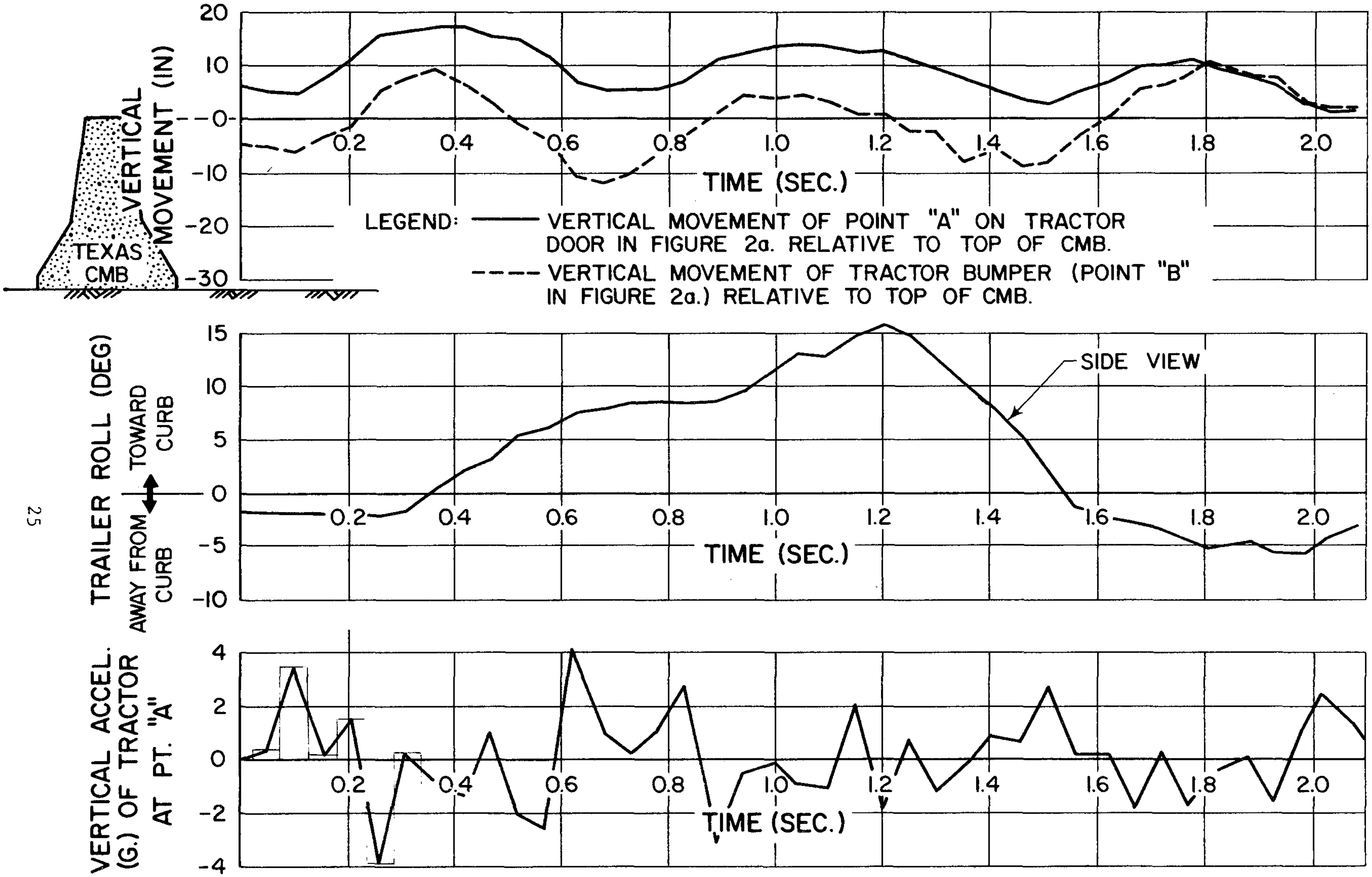


FIGURE 12 CMB-7 RESULTS FROM FILM ANALYSIS

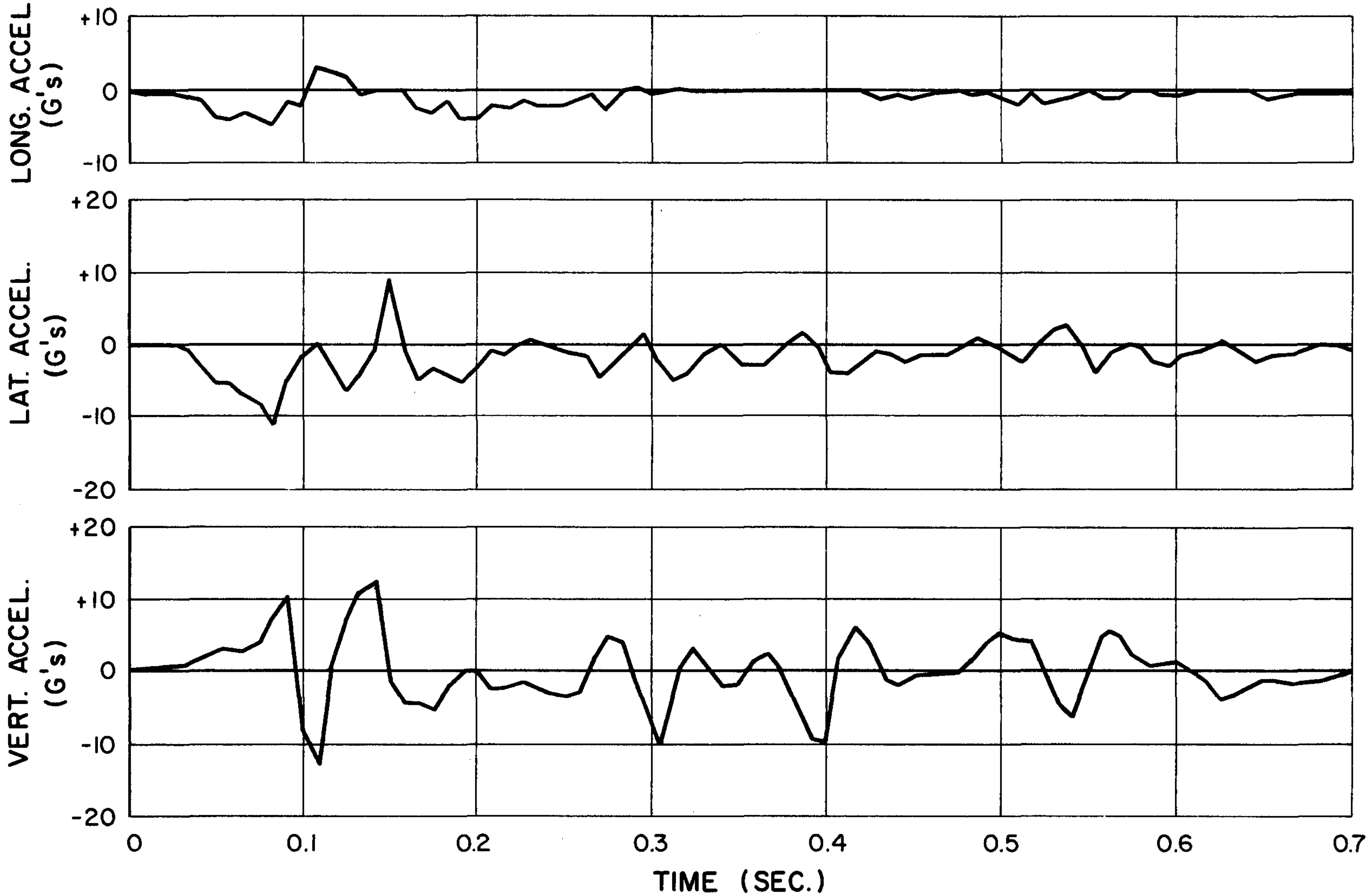


FIGURE 13 TRUCK-TRACTOR ACCELERATION COMPONENTS DURING CMB-5 TEST (IMPACT-O-GRAPH)

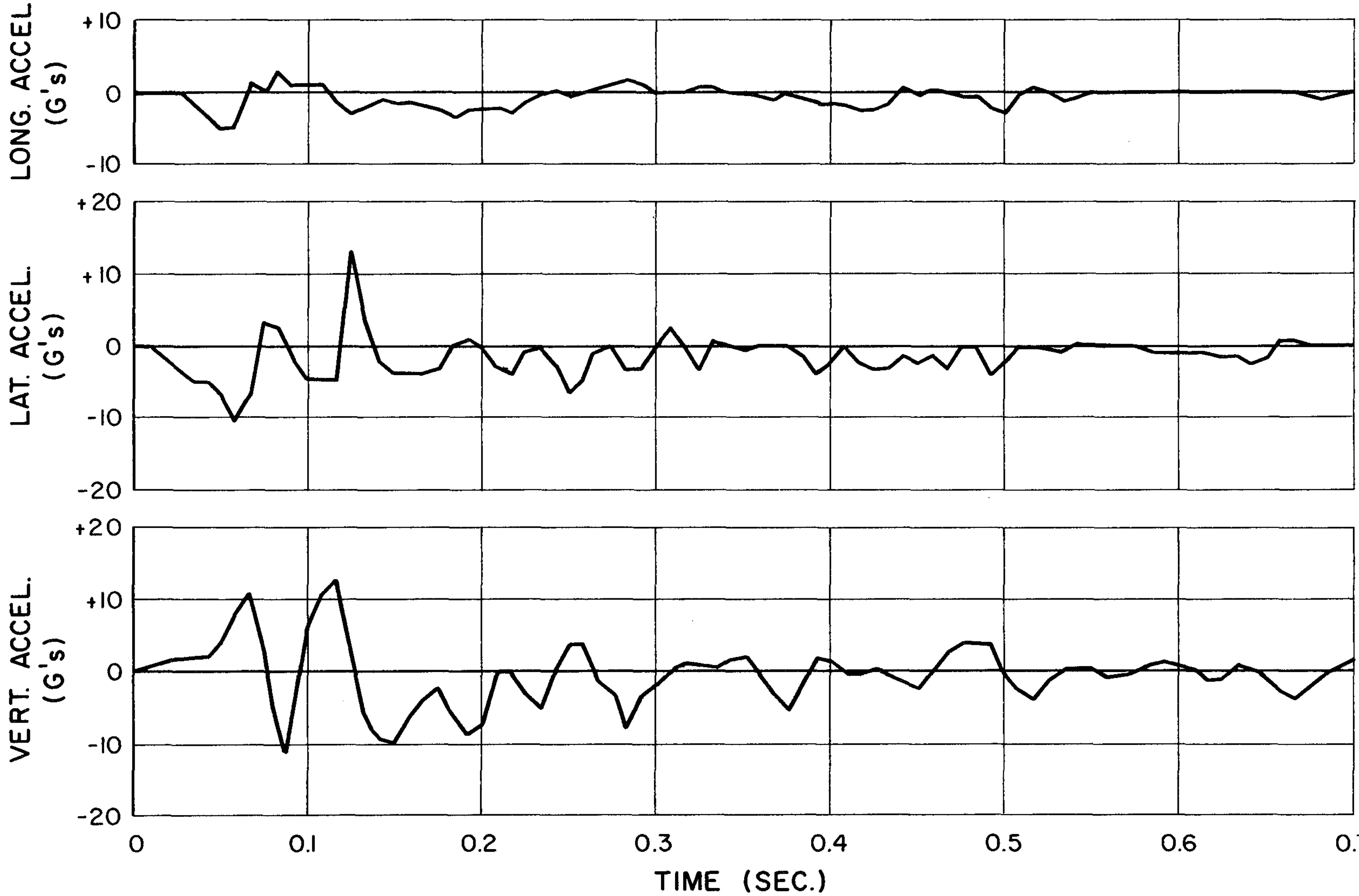


FIGURE 14 TRUCK-TRACTOR ACCELERATION COMPONENTS DURING CMB-6 TEST (IMPACT-O-GRAPH)

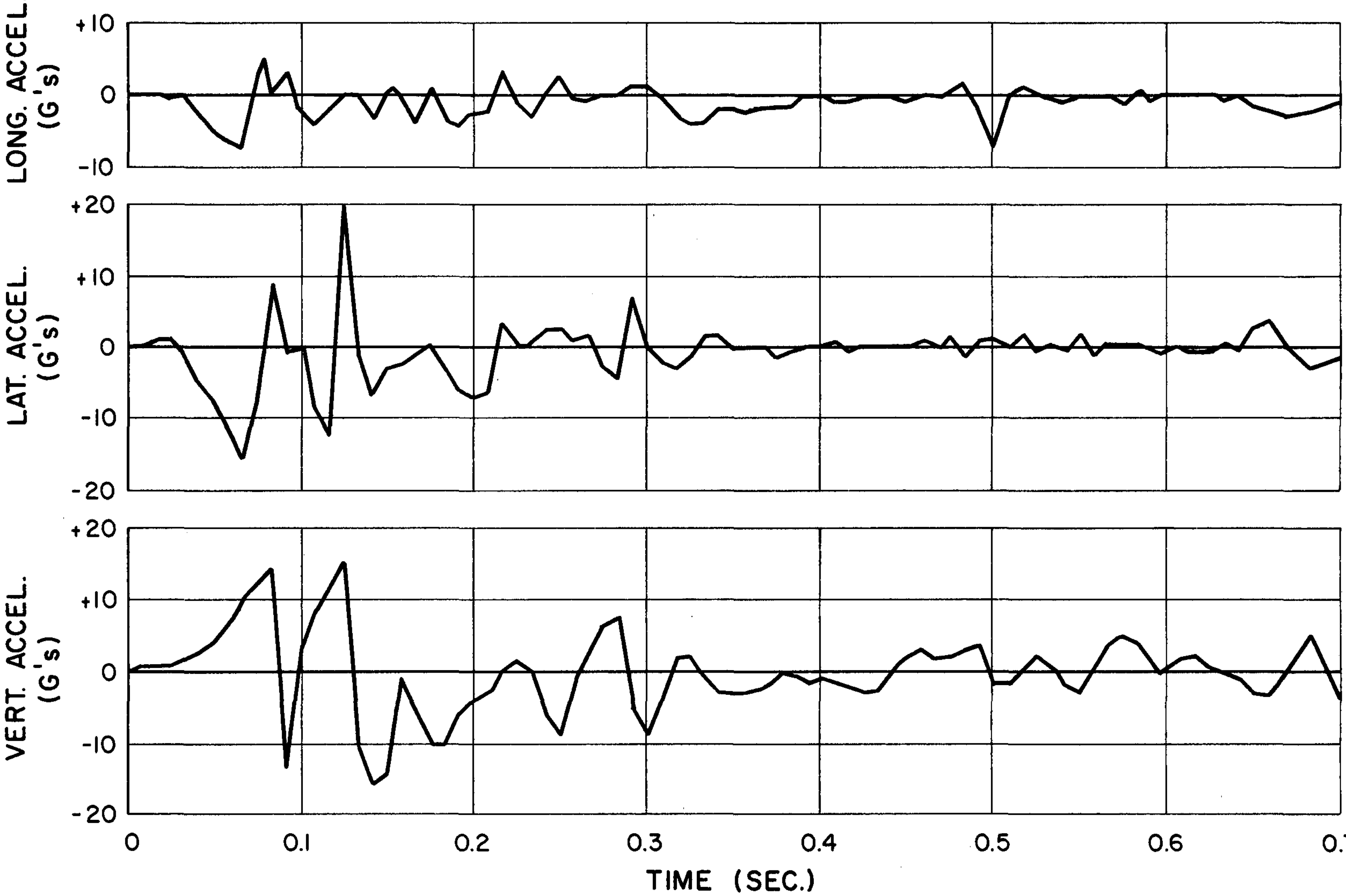


FIGURE 15 TRUCK-TRACTOR ACCELERATION COMPONENTS DURING CMB-7 TEST (IMPACT-O-GRAPH)

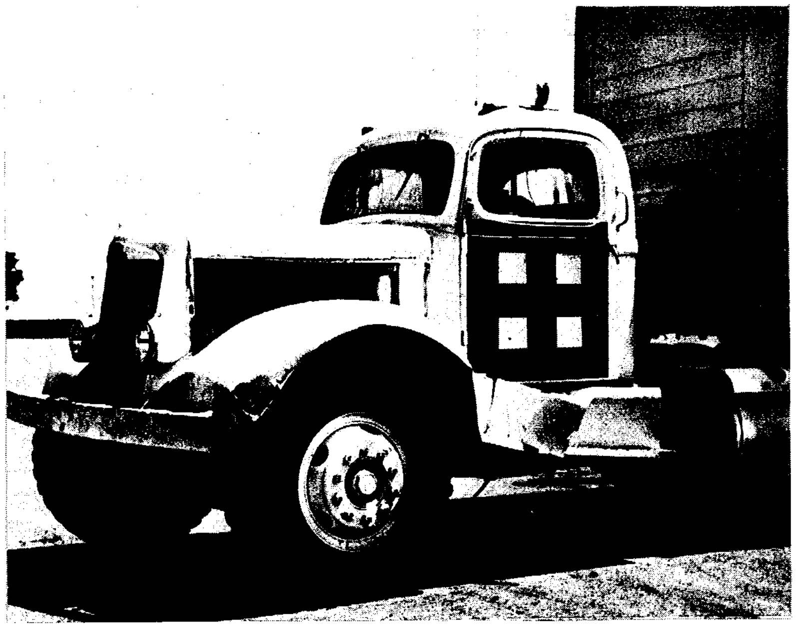


FIGURE 16 a

TRACTOR DAMAGE AFTER CMB-5 TEST

FIGURE 16 b

TRACTOR DAMAGE AFTER CMB-5, CMB-6, & CMB-7 TESTS.

FIGURE 16. TRACTOR DAMAGE DURING CMB TESTS.

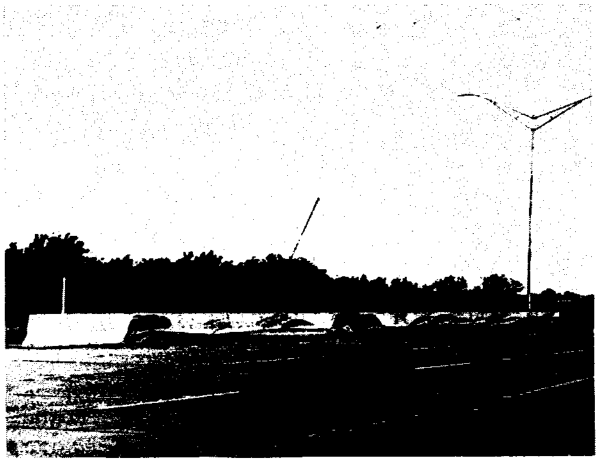


FIGURE 17 a

OVERALL VIEW OF BARRIER AFTER CMB-5, CMB-6, & CMB-7 TESTS.

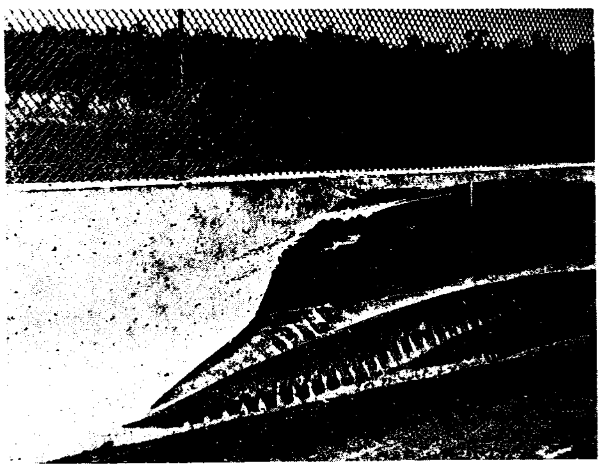


FIGURE 17 b

BARRIER AFTER CMB-5 TEST.

FIGURE 17 c

BARRIER AFTER CMB-6, AND CMB-7 TESTS.

FIGURE 17. CMB BARRIER DAMAGE.

CONCLUSIONS AND NEEDED RESEARCH

This series of truck tests demonstrated that the Texas CMB barrier design (CMB-70) can restrain and redirect a large size 48,800 lb. tractor-trailer truck, with load, under the impact conditions of 45 mph and 15 deg. The tests also demonstrated that barrier maintenance costs would be low. At most, the barrier maintenance would consist of a light sand-blasting job to remove the unsightly tire scrub markings.

The three truck tests conducted in this study and the one test by Lunstrom (2) can be considered, at best, as preliminary in scope. Considering only the *selected* tractor-trailer truck and barrier used in this study, there still remains many unanswered questions. For example,

1. How would the Texas CMB barrier perform under higher impact speeds?
2. What influence would a higher trailer load center-of-mass have on the trailer rolling motion?
3. What influence would a higher impact speed have on the trailer rolling motion. After some unrestrained differential roll, the trailer rolling motion is dependent on the inertia of the truck tractor as long as the tractor-trailer roll pin does not fracture.

In addition to the above variables, there exist other important variables such as different barrier designs and different types of trucks. The writers believe that a three-dimensional mathematical model of a single unit truck and a tractor-trailer truck would, in conjunction with an expanded testing program, prove to be a very valuable tool.* It is possible that the tire and suspension subroutines of the HVOSM model developed by McHenry (13) and modified by Young (10, 14) could be used in developing a truck model.

*HVOSM, with hardpoints added, closely predicted the results of automobiles impacting the Texas CMB. Additional tests were then simulated at a cost much lower than actual testing.

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