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Vehicular Tests Of A 6-Inch High Curbed Gore With and Without a Sand Barrel Crash Cushion

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7. AUTHOR(S)
D.M. Parks, R.L. Stoughton, J.R. Stoker, and E.F. Nordlin

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16. ABSTRACT

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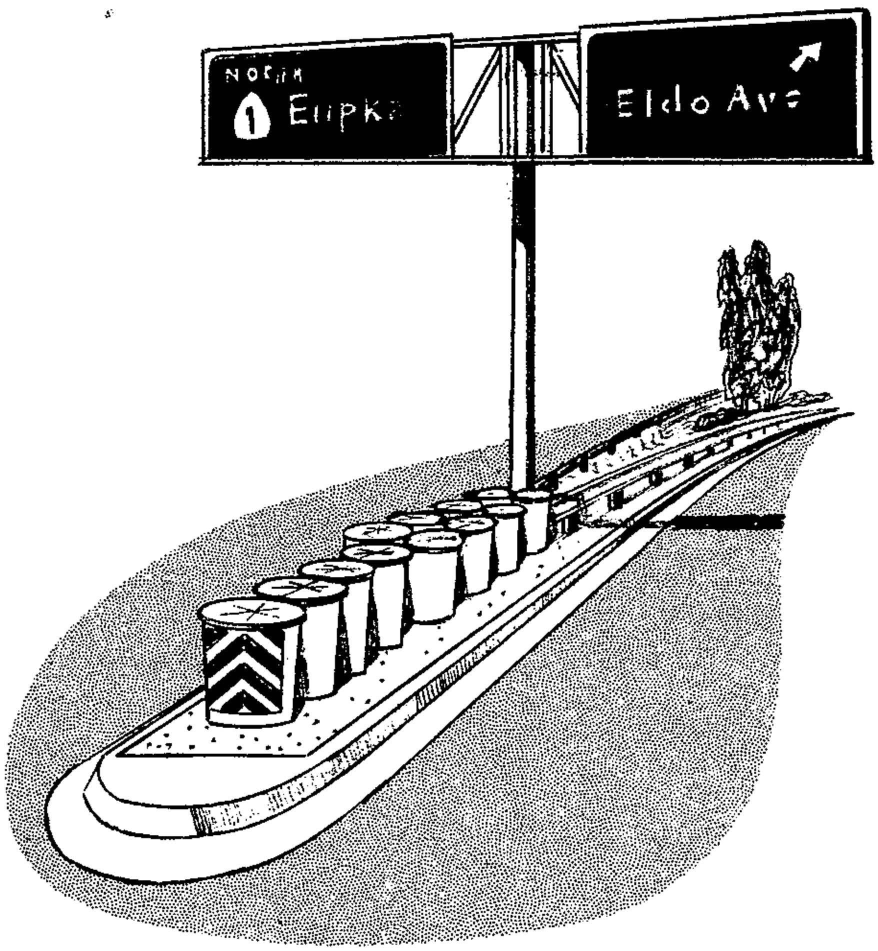
VEHICULAR TESTS OF A 6 INCH HIGH CURBED GORE WITH AND WITHOUT A SAND BARREL CRASH CUSHION



FINAL REPORT
MAY 1979

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

NOTICE

The contents of this report reflect the views of the Office of Transportation Laboratory which is 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 State of California. This report does not constitute a standard, specification, or regulation.

The State of California does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

December 10, 1979

ERRATA

"Vehicular Tests of a 6 Inch High Curbed Gore With and Without a Sand Barrel Crash Cushion"

Report No. CA-TL-79-10 Dated May 1979

1. p.4, second paragraph, sixth line: change 7.5 to 14.5
2. p.5, third paragraph, second line: change 3.5 to 10.2
3. p.6, third paragraph, second line: change 3.1 to 3.2
4. p.39, third paragraph, tenth line: change 12 to 9
5. p.39, third paragraph, twelfth line: change 6.5 to 7.3
6. p.40, second paragraph, seventh line: change 12 to 9
7. p.42, first paragraph, fifth line: change 19 inches to 18 and 15.5 inches respectively
8. p.48, second paragraph, ninth line: change 6.5 to -0.7
9. p.55, third paragraph, fourth line: change "6.5 inches above" to "-0.7 inches below"
10. p.55, fourth paragraph: delete entire paragraph and replace with the following statement:

    "The c.g. height of the test vehicle at the front bumper measuring point (p. 23, Figure 7) remained below not only the c.g. of the sand masses, but the entire sand mass of all the barrels encountered in its trajectory as shown in Figure 37. The top of the six-inch-high front bumper is 2.5 inches lower than the vehicle c.g. height measuring point; hence, the front bumper also stays below the sand masses throughout the vehicle trajectory after impact."

11. p.18, Table 1, Test No. 2: change "Length of Vehicle Diving Mode" from 7.5 to 7.3
12. p.44, Figure 25: Change "3" Tip" to "3" Typ"
13. p.51, Figure 30, "Vehicle Rise": change 6.5 to -0.7

14. p.51, Figure 30, "Vehicle Deceleration, Average": change 3.1 to 3.2

15. p.57, Figure 37: See attached revised figure. The key change was that the Test 349 rise curve was lowered approximately seven inches. Other minor changes were made to improve the readability of the diagrams.

16. p.72, "1974 Ford Gran Torino": The arrow which is labeled "21" Driver's side, etc." should extend to the ground line.

17. p.75, Figure B6: change CAMARA DATA TO CAMERA DATA

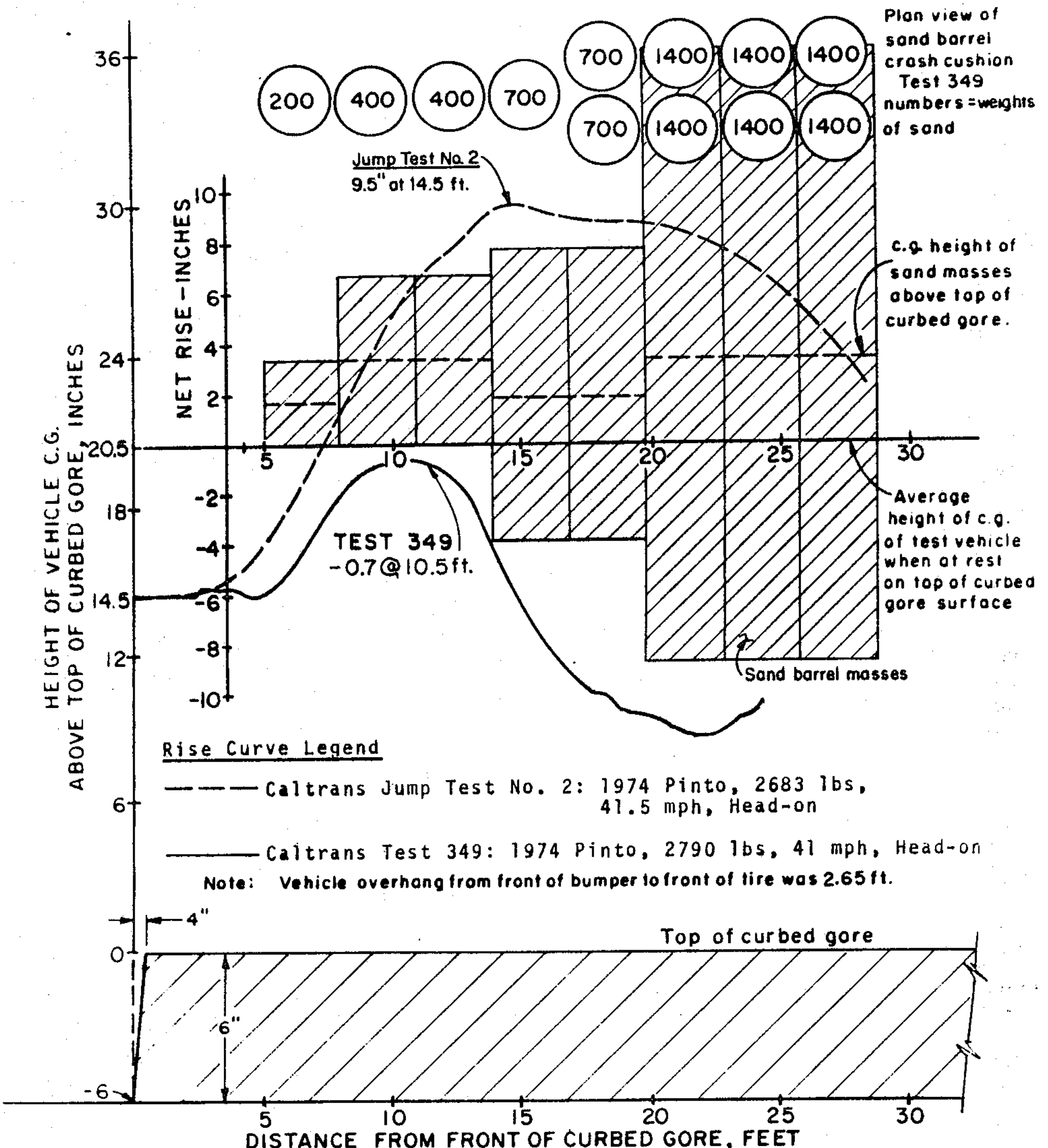
Commentary:

The most significant change in these Errata is the modified rise curve for the car used in Test 349 as shown on the attached revised copy of Figure 37. On the original diagram the six-inch curb height had not been subtracted from the rise data when the curve was drawn. The effects of slight vehicular roll also were incorporated more accurately into the rise curve as had been done for Tests 1, 2, 3, 7, and 8. This lowered the vehicle c.g. rise at the center of the front bumper measuring point an additional one to two inches along the curve.

The conclusion reached after redrawing the rise curve was that the sand in the crash cushion barrels held down the front of the vehicle during impact much more than was originally thought. This is viewed as generally beneficial because it provides extra assurance that a vehicle impacting the curb will not have a chance to vault over the sand-filled barrels.

Although it would be possible to make slight changes in the recommendations for the placement of the crash cushion with respect to the nose of the curbed gore, the original 0-5 foot rule still appears reasonable. Smaller cars with stiffer suspensions than the Pinto might jump more quickly and higher; hence, the 5 ft. maximum setback for the front barrel, although conservative, should be retained. As noted in the text of the report, any negative effects from "submarining" of the Pinto under the sand masses in the barrels were minimal for the test conditions of that test.

Figure 37*, VEHICLE RISE VS DISTANCE FROM NOSE OF CURBED GORE WITH SAND BARREL CRASH CUSHION 5 FT. BACK FROM NOSE, TEST 349



Rise Curve Legend

— — — Caltrans Jump Test No. 2: 1974 Pinto, 2683 lbs, 41.5 mph, Head-on

——— Caltrans Test 349: 1974 Pinto, 2790 lbs, 41 mph, Head-on

Note: Vehicle overhang from front of bumper to front of tire was 2.65 ft.

*Location of plotted point for these curves is identical to the point plotted for Tests 1, 2, 3, 7 and 8 shown in Figure 7.

TECHNICAL REPORT STANDARD TITLE PAGE

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF OPERATIONS
OFFICE OF TRAFFIC ENGINEERING

May 1979

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research report titled:

VEHICULAR TESTS OF A 6 INCH HIGH CURVED GORE WITH AND WITHOUT A SAND BARREL CRASH CUSHION

Study made by .... Transportation Laboratory

Study made for .... Office of Traffic Engineering

Under the direction of .... E. F. Nordlin

Principal Investigator .... J. R. Stoker

Co-Principal Investigator .... R. L. Stoughton

Investigator .... D. M. Parks

Report Prepared by .... D. M. Parks

Very truly yours,

C. P. SWEET, JR.
Chief, Office of Traffic Engineering

ACKNOWLEDGEMENTS

Special appreciation is due the following staff members of the Transportation Laboratory who were instrumental in the successful completion of these tests and in the preparation of this report:

Jim Keesling	In charge of photo and electronic instrumentation data reduction, and preparation of the movie report; also helped conduct the tests.
Roy Steiner	Vehicle preparation and helped conduct crash cushion test.
Robert Mortensen	Data and documentary photography.
Richard Johnson Delmar Gans William Ng	Electronic instrumentation of test vehicles, curb, and dummy for crash cushion test.
David Johnson	Helped construct curbed gore.
Elmer Wigginton	Drafting of barrier plan, tables, and figures.
Larry Stevens	Reproduction of final report.

The authors would like to thank mechanic Howard Martin of the Caltrans Equipment Shop for his assistance during the curbed gore vehicle jump tests. In addition, we thank the District 03 Maintenance crew headed by Jim DeGusta and Wally Yeager who filled the curbed test area with base material and constructed the asphalt concrete surface.

Appreciation is due the following personnel from the California Department of Transportation who were available for technical consultation during the project:

Edward J. Tye	Office of Traffic Engineering
Richard N. Smith	
C. P. Sweet, Jr.	
Ralph Bishop	Office of Structures Design
Philip Hale, Jr.	

We also thank Paul O'Shea, our professional driver, who drove the test vehicles and provided valuable technical assistance during the curbed gore vehicle jump test phase of this research project.

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1. INTRODUCTION

In November 1972, the Federal Highway Administration (FHWA) requested that fixed objects in freeway gores be cleared or shielded with crash cushions. Since that time the California Department of Transportation (Caltrans) has maintained a vigorous gore improvement program concerned with upgrading approximately 1950 freeway gore sites. Through 1977, this work has involved removing many potentially hazardous fixed objects along with installing over 300 crash cushions on California highways.

Some of these freeway off-ramp gores, however, have raised surfaces bounded by curbs. In accidents involving these curbed gores, vehicles may have a tendency either to rise and be launched into the air or to experience a "submarining" effect which causes the center of gravity (c.g.) height of the vehicle to lower. These dynamic motions might pose problems for vehicles impacting crash cushions located on top of curbed gore surfaces. If a vehicle rises drastically, the c.g. height of the vehicle might become higher than the c.g. height of the crash cushion. In this situation, the effectiveness of the crash cushion might be lessened as the vehicle becomes airborne and tries to vault the barrier. Likewise, a vehicle which submarines may travel below the vertical center of load resistance of a crash cushion so that the crash cushion is not fully effective in this case either. However, submarining in general is less critical than launching.

FHWA guidelines concerning the use of crash cushions on Federal-Aid highways (1*) state that curbs in gores over

*Numbers underlined in parenthesis refer to a reference list at the end of this report.

6 inches high should be removed, curbs under 4 inches high may remain and curbs 4 to 6 inches high should be removed unless site conditions and cost of removal warrant leaving them in place.

The Caltrans Office of Traffic Engineering initiated this study to determine whether gore type curbs 6 inches high must be removed when sand barrel crash cushions are used, or what modifications or design practices should be instituted, if any, if the curbs are not removed. Virtually all gore curbs on California highways are 6 inches high.

This project was divided into two parts. In the first part a professional test car driver (termed a "live driver" in this report as opposed to an instrumented anthropomorphic dummy) was employed. He drove both large and small size vehicles head-on over a six inch high curbed gore, clear of fixed objects, at various speeds. These "jump" tests were needed to plot the vertical and horizontal trajectories of the vehicles, and thus, to determine whether vehicle impact tests with sand barrel crash cushions installed on the curbed gore were necessary. The trajectory plots could also be used to estimate the most critical impact conditions. In the second part of this study, an impact test was deemed necessary based on the results of these jump tests and was thus conducted using the same curbed gore and an anthropomorphic dummy.

Although Caltrans (2) and others (3, 4) have conducted vehicle/curb jump tests at impact angles less than 30 degrees, no other testing agency has tested vehicles traversing curbs head-on. The Federal Highway Administration's Structures and Applied Mechanics Division, however, has conducted some HVOSM (Highway-Vehicle-Object Simulation Model) computer runs to determine vehicle trajectories following head-on curb impacts.

A secondary reason for conducting this study deals with the expense and working conditions associated with removing curbed gores. Caltrans estimates the removal of a curbed gore surface costs about $2,500. In addition to being costly, removing curbed gores is also hazardous to both construction workers who are exposed to fast moving highway traffic and motorists who are inconvenienced by lane closures or other traffic control measures. Money saved from not removing curbs could be used for other safety improvements which may have a higher payoff in reducing accident severity.

2. CONCLUSIONS

2.1 Curbed Gore Vehicle Jump Tests

- During the eight live driver curbed gore jump tests conducted at 40 and 60 mph, both the small and the large size passenger vehicles experienced minimal yawing, pitching, and rolling motions. However, some violent jolts were experienced by the test driver. The driver made no effort to control the path of the vehicle after impacting the curbed gore.

- Maximum values of vehicle bumper rise of 8 inches and 9.5 inches over the top of the curbed gore for the large and small size passenger vehicles respectively occurred during head-on impacts with the curbed gore at about 40 mph. Peak rise values in all tests occurred over a wide range from as close as 7.5 ft to 30 ft from the front of the curbed gore. The vehicle bumpers returned to their normal heights above ground at distances ranging from about 27-43 ft beyond the nose of the curb.

- Although the eight live driver curbed gore jump tests conducted for this study produced varying results, it appears that the front barrel of sand barrel crash cushions may be placed within 0-5 ft or over 50 ft from the front of curbed gores 6 inches in height without adversely affecting their performance. The 0-5 ft distance was selected to ensure that a vehicle would remain in its "compression mode", characterized by the wheels recessing into the wheel wells during initial contact with the barrier, instead of starting to jump before making contact. Also, it appears that any tendency for the vehicle to roll would be absorbed by the collision into the crash cushion, if the cushion were placed at this location, since no noticeable vehicle rolling occurred within 5 ft of the nose of the curbed gore in this study. The 50 ft distance was chosen arbitrarily to represent a safe distance beyond the zone of vehicle rising and pitching. No erratic vehicle behavior was observed beyond this point in the tests.

2.2 Impact Test of Sand Barrel Crash Cushion on Curbed Gore

- The performance of the sand barrel crash cushion was not appreciably affected when positioned 5 ft back from the nose on top of a 6 inch high curbed gore, and impacted head-on by a 2790 lb passenger car with a speed of 41 mph.

- The location of the crash cushion helped to reduce the ultimate rise of the test vehicle by about 3.5 inches when compared to the maximum rise for the trajectory of the vehicle impacting only the curbed gore without a crash cushion.

- Vehicle yawing and pitching motions during the test of 12 degrees and -14.5 degrees respectively did not adversely affect the performance of the crash cushion.

- Since the test vehicle remained on top of the curbed gore throughout the impact, the trajectory of the vehicle was not considered hazardous to nearby traffic.

- Barrier debris scattered outside the perimeter of the curbed gore, encroaching about 4 ft into adjacent traffic lanes, could possibly appear hazardous until broken up and dispersed by adjacent traffic or cleaned up by maintenance workers.

- The polyethylene lids tossed in the air and traveling as far as 70 ft during the impact may also appear hazardous to adjacent traffic. This scattering of debris, however, was not accentuated by the location of the crash cushion on the raised gore.

- The maximum 50 millisecond average vehicle longitudinal deceleration of 3.6 g's for this 41 mph test was well below the preferred range of 6 to 8 g's maximum as specified by Transportation Research Circular (TRC) No. 191 (5) for standard 60 mph tests.

- The maximum average vehicle deceleration value at 3.1 g's calculated from the impact speed and the passenger stopping distance using the formula $\frac{V^2}{2gs}$ was also well below the maximum permissible value of 12 g's specified by TRC No. 191 (5) for 60 mph tests.

3. RECOMMENDATIONS

The following recommendations are based on the results of the eight live driver vehicle jump tests involving a 6 inch high curbed gore and the results of a vehicle impact test into a sand barrel crash cushion placed on top of the curbed gore:

- When a sand barrel crash cushion is placed on top of a 6 inch high curbed gore, the front barrel should be located 0-5 ft or over 50 ft back from the nose of the curbed gore to minimize the effects of vehicle vaulting on the performance of the barrier.

- At all locations of the crash cushion on the curbed gore, the barrels on the side of the crash cushion should be 0-3 ft from the curb face measured perpendicular to the face of the curb. This recommendation is based on this test series and previous research (2,3,12).

- On 6 inch high curbed gores where the front barrel in a normal array would be placed more than 5 ft and less than 50 ft back from the nose of the curbed gore, the following guidelines are recommended to bring the front barrel within 5 ft of the nose:

  1. Stretch the crash cushion out to the maximum length possible by allowing 2'-0" maximum between the fixed object and the rear barrels; spacing the barrels 6 inches maximum apart; and adding two 400 lb barrels behind the 200 lb front barrel for a maximum of 10 "rows" of barrels in the crash cushion.

2. Remove part or all of the curbed gore if the front barrel is still over 5 ft from the nose.

- All crash cushion sites are different and should be analyzed independently. If the above guidelines are not easily applied for a given site, the designer should seek expert advice.

- Sand barrel crash cushion lids should be riveted in place to help minimize the scattering of barrier debris during an impact.

4. IMPLEMENTATION

The results of both the curbed gore vehicle jump tests, transmitted as an interim report, and the results of the test of the sand barrel crash cushion placed on top of a 6 inch high curbed gore have been forwarded to Caltrans' Office of Traffic Engineering.

Based on the results of these tests, the Office of Traffic Engineering will now advise to the Districts that the Recommendations in this report are to be followed.

5. TECHNICAL DISCUSSION

PART 1: Curbed Gore Vehicle Jump Tests

5.1 Test Conditions

5.1.1 Test Facility

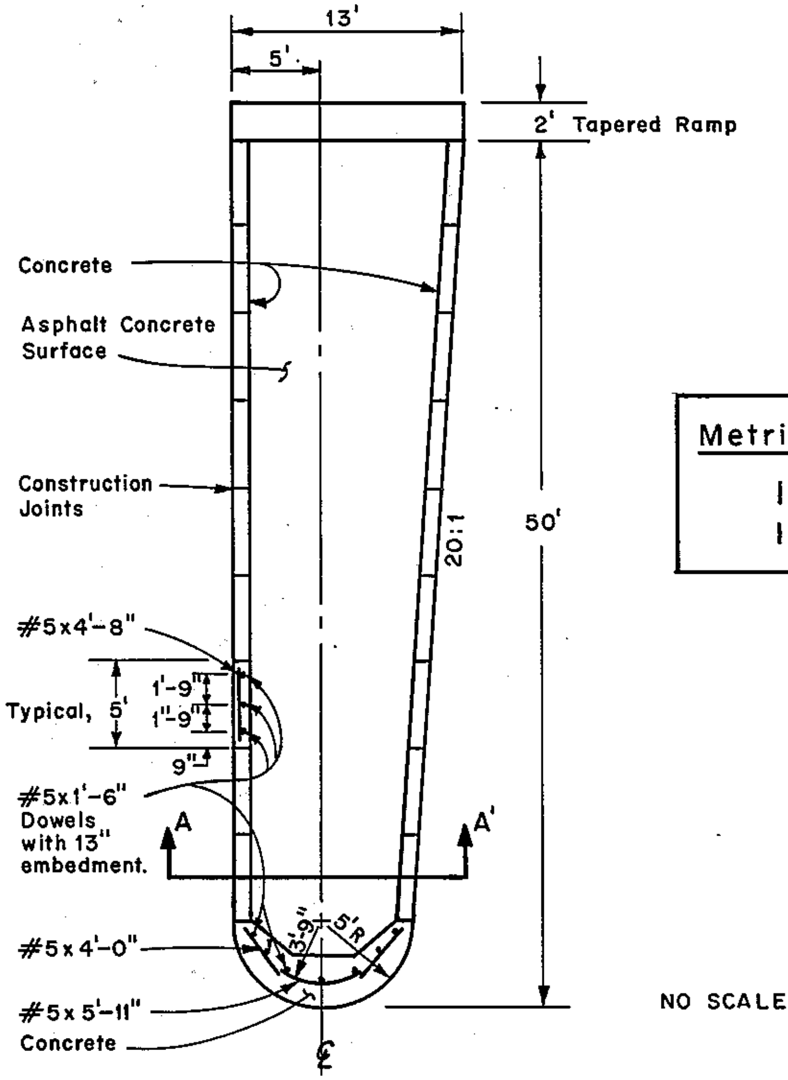
All eight live driver curbed gore jump tests were conducted at the Caltrans Dynamic Test Facility in Bryte, California, near Sacramento. The vehicular crash testing area is a flat asphalt concrete paved surface.

5.1.2 Curbed Gore Design and Construction

Figure 1 shows the curbed gore design used for the live driver jump tests. The gore was 50 ft long, bounded by a 6-inch high California Type B concrete curb. The asphalt concrete top surface of the gore was paved flush with the concrete curb. The front of the curbed gore had a 5 ft radius with a 2:3 sloping face, Figure 2.

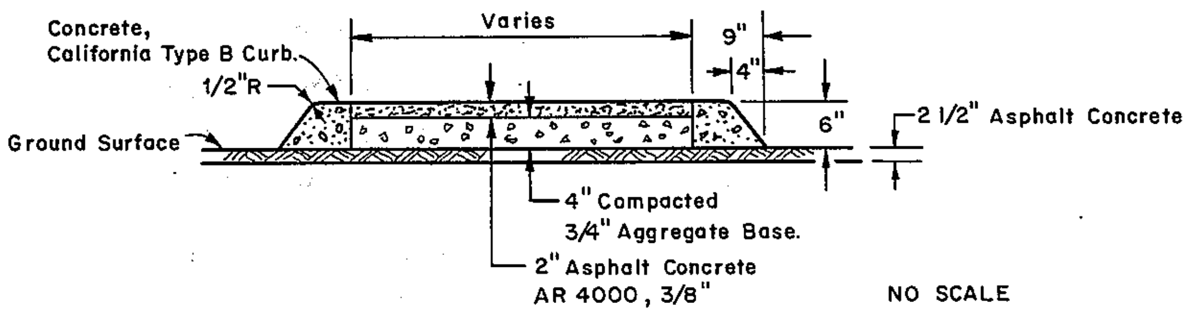
This shape gore design was selected from a 1959 California Highway Planning Manual as being representative of many existing curbed off-ramp gores on California freeways. This design was also used so that three types of headon impacts (see Section 5.1.5, Test Parameters) could be conducted on the same gore installation. It was expected that tests of curbed gores with smaller radii would produce similar results. The standard curbed gores shown in the Design Manuals from 1952-1969 had nose radii ranging from 1 to 5 ft. On the Standard Plan dated March 10, 1969, raised curbed surfaces were eliminated from gores, and this policy is still in effect.

Figure 1 , 6" HIGH CURBED GORE PLAN



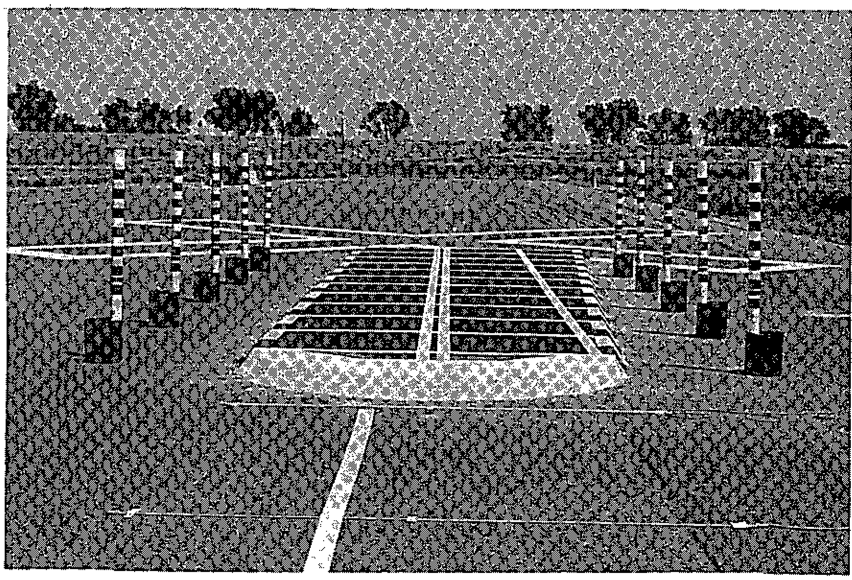
PLAN VIEW

Metric Conversions
1 in = 25.4 mm
1 ft = 0.305 m

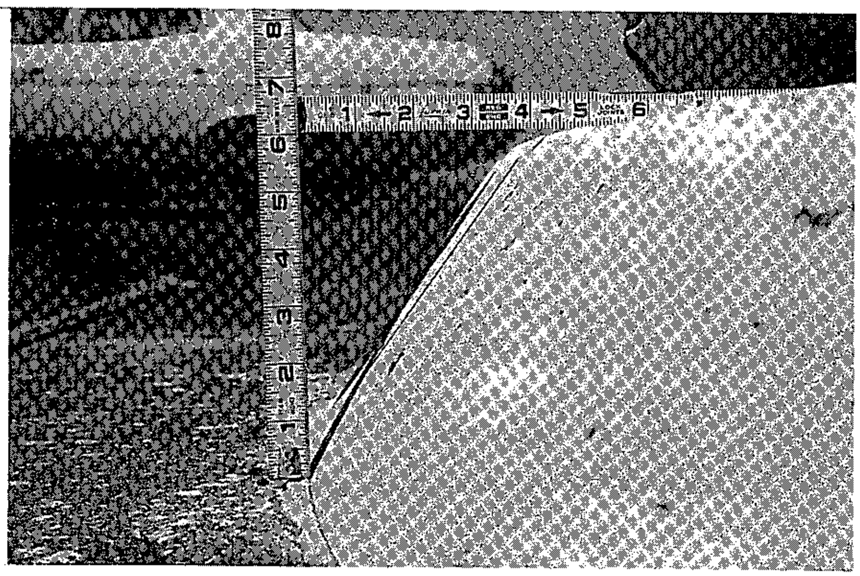


SECTION A – A'

Figure 2. 6 Inch High Curbed Gore



View of Front of Curbed Gore



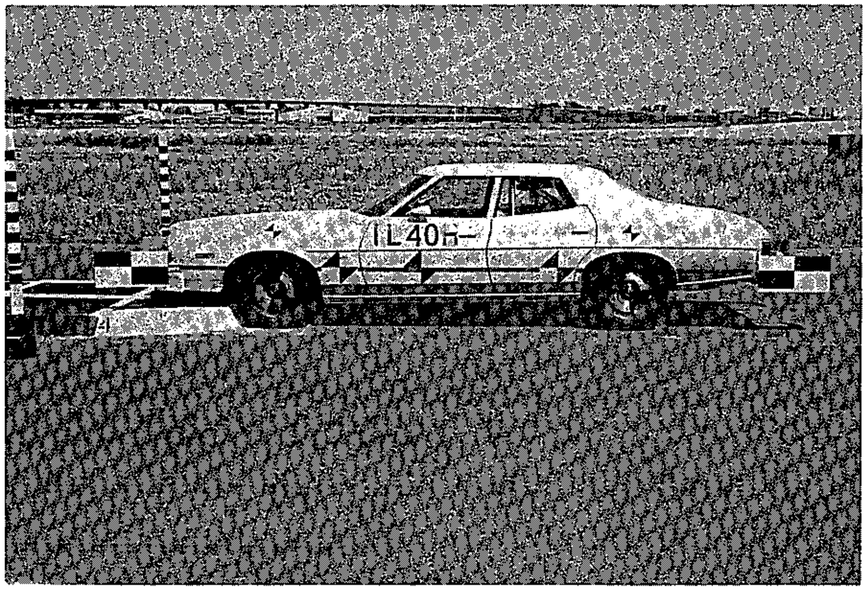
2:3 Front and Side Slopes of Curbed Gore

5.1.3 Test Vehicles

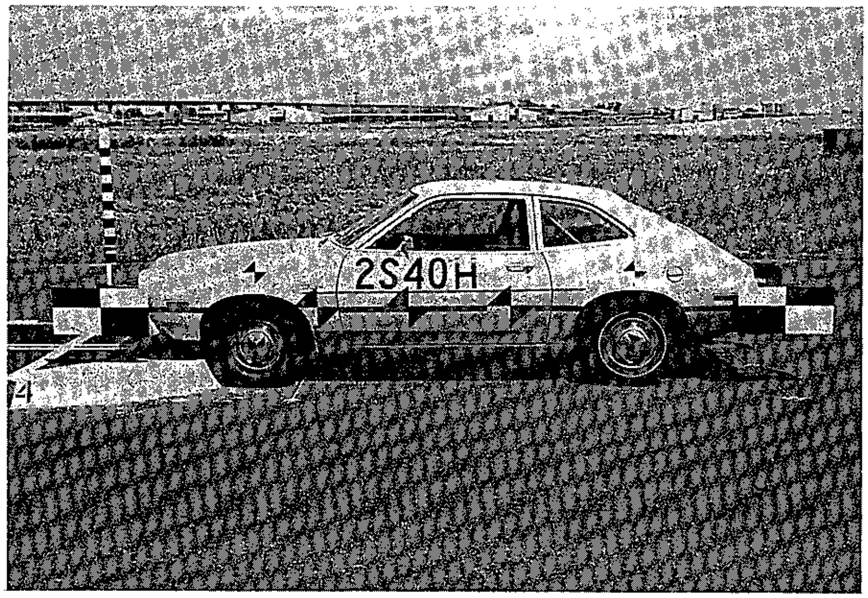
A large and a small size test vehicle were used for the curbed gore vehicle jump tests. The large vehicle was a 1974 Ford Gran Torino weighing 4535 lbs and the small vehicle was a 1974 Ford Pinto coupe weighing 2680 lbs, Figure 3. The vehicle weights included on-board equipment and a professional driver. Both vehicles were in excellent running condition and also free of body damage and missing structural parts.

These test vehicle models were chosen because their weights were fairly representative of large and small size passenger vehicles and also because typical vehicle parameters were available for these cars that could later be used for dynamic computer simulations of crash tests. A list of vehicle parameters along with diagrams and photographs of the vehicle suspension systems are contained in Appendix D.

Both test vehicles were driven by a professional driver, a former race car driver. He is a private consultant who conducts vehicular impact tests and other automotive research. The driver gripped the steering wheel loosely and did not apply any steering input during the tests after impacting the curbed gore. He tried to maintain a constant impact speed during each test without applying the brakes of the vehicle after impact unless it was necessary to avoid running off the end of the paved test site. Driver comments for each of the eight jump tests are contained in Section 5.2.3 of the Test Results.



Large Size Passenger Vehicle:
1974 Ford Gran Torino - 4535 lbs.



Small Size Passenger Vehicle:
1974 Ford Pinto Coupe - 2680 lbs.

Figure 3. Test Vehicles

After each test the vehicles were repaired and aligned. Any structural parts including springs, shock absorbers, wheels and tires, front cross members or other front end parts that were damaged were replaced before the vehicle was reused for any subsequent tests.

5.1.4 Data Acquisition Systems

High speed and normal speed movie cameras and still cameras were used to record the impact events and the conditions of the vehicles and the curbed gore before and after each impact.

The steering wheel of each vehicle was taped every 30 degrees to detect any steering movements during the tests. Cameras mounted inside the test vehicle photographed driver reaction and any steering wheel movements.

Appendices B and C contain a detailed description of the photographic equipment, data collection techniques, electronic instrumentation, and the data reduction methods used for the tests.

5.1.5 Test Parameters

The test vehicles impacted the nose of the curbed gore travelling at 40 and 60 mph at three different head-on attitudes, Figure 4:

- Head-on with both front wheels mounting the curbed gore at the same time;

- Head-on with only the right side wheels mounting the curbed gore; and

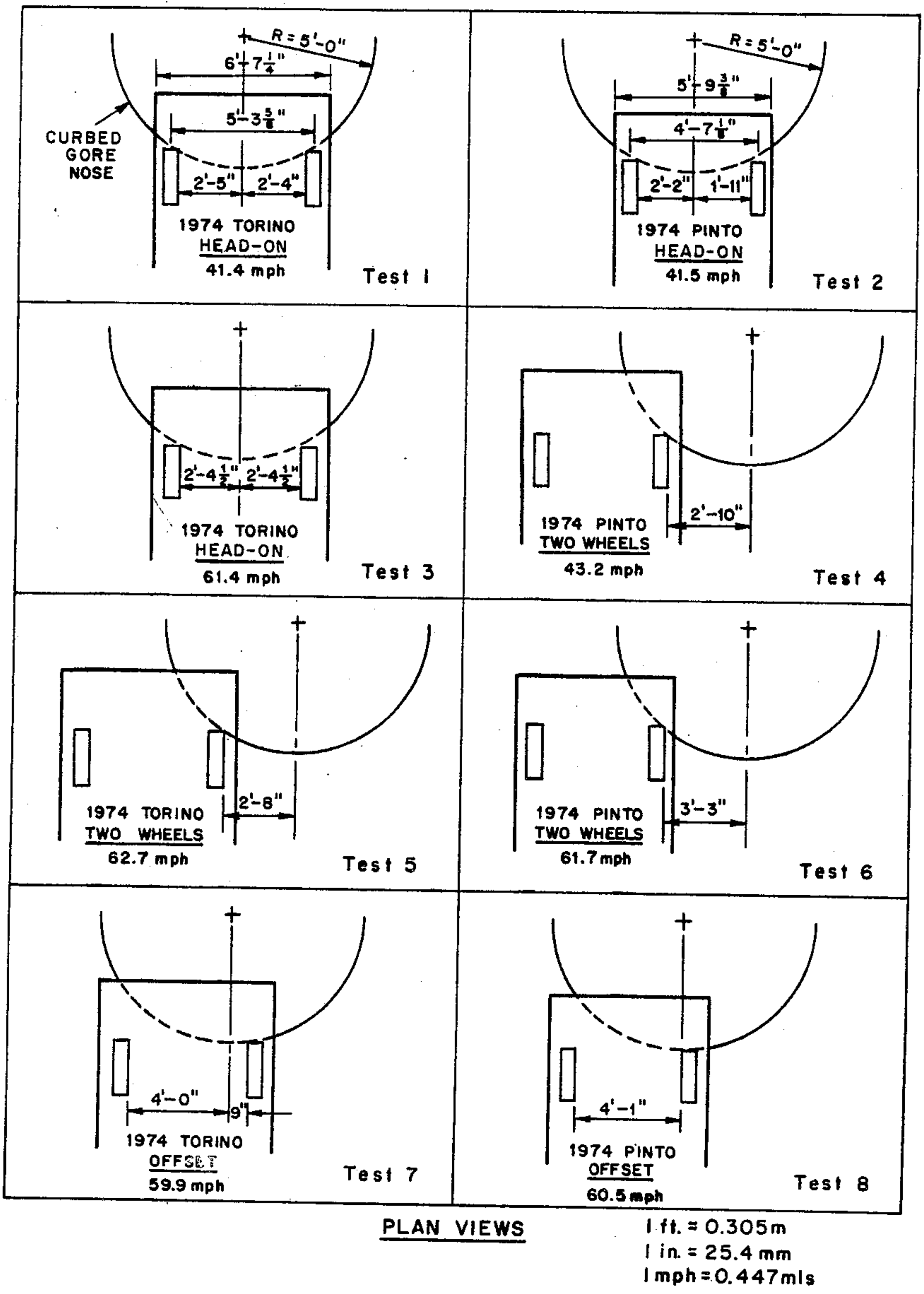


Figure 4, HEAD-ON IMPACT ATTITUDES FOR CURBED GORE VEHICLE JUMP SERIES

- Head-on/offset with the right front wheel mounting the curbed gore before the left front wheel.

Four of the twelve originally planned curbed gore vehicle jump tests were not conducted: 1) small car head-on at 60 mph; 2) large car two right wheels on at 40 mph; and 3) and 4) small and large cars head-on/offset at 40 mph. It was judged that the results from these tests probably would have been similar to and less critical than tests completed earlier in the jump test series.

5.2 Test Results

5.2.1 Summary of Curbed Gore Vehicle Jump Test Results

Table 1 summarizes the results of the eight Caltrans live driver curbed gore vehicle jump tests.

Immediately after impact with the 6-inch high curbed gore, the front wheels of the test vehicle recess into the wheel wells. At this point, the dynamic height of the center of gravity (c.g.) of the vehicle above the top of the curbed gore is lower when compared to its normal height if the vehicle were at rest on top of the curbed gore. For this situation the rise of the vehicle is considered to be negative and the vehicle's suspension system remains in a "compression mode" as long as the front wheels are recessed.

The term "rise" as used herein refers to the difference in heights between the dynamic position of the vertical c.g. of the vehicle and the vertical c.g. of the vehicle measured while the vehicle is at rest on top of the curbed gore.

The rise of the vehicle is considered to be negative as long as the vertical position of the c.g. remains below the at rest position of the c.g. The rise beyond this point becomes positive as the vehicle passes into the "jumping mode" wherein the front suspension becomes extended and the wheels of the vehicle have a tendency to lift off the curbed gore. During the "jumping mode" the height of the vehicle c.g. above the curbed gore exceeds the static or at rest height.

TABLE 1, SUMMARY OF CURBED GORE VEHICLE JUMP TEST RESULTS

TEST NUMBER*	VEHICLE YEAR MAKE, MODEL	VEHICLE WEIGHT lbs	IMPACT SPEED mph	IMPACT ATTITUDE	LENGTH OF VEHICLE DIVING MODE, ft	MAX. VEHICLE RISE & LOCATION**	MAX. PITCH ANGLE deg	MAX. ROLL ANGLE*** deg
1	1974 Ford Gran Torino	4535	41.4	Head-on	9.8	8 in. @ 20 ft	5	-½/0
2	1974 Ford Pinto Coupe	2683	41.5	Head-on	7.5	9.5 in.@ 14.5 ft.	6	-½/1
3	1974 Ford Gran Torino	4535	61.4	Head-on	13.8	4.5 in.@ 26 ft	2.5	-1/½
4	1974 Ford Pinto Coupe	2683	43.2	Head-on/Right Side Wheels Only	9.8	5.5 in.@ 19 ft	2	-9/5
5	1974 Ford Gran Torino	4535	62.7	Head-on/Right Side Wheels Only	13.5	7 in. @ 30 ft	1.5	-11½/1
6	1974 Ford Pinto Coupe	2683	61.7	Head-on/Right Side Wheels Only	12.5	5 in. @ 22 ft	2	-10½/4
7	1974 Ford Gran Torino	4535	59.9	Head-on/Offset Right Front Before Left Front	13	4.5 in.@ 21.5 ft	3	-3/0
8	1974 Ford Pinto Coupe	2683	60.5	Head-on/Offset Right Front Before Left Front	11.8	3.2 in.@ 18 ft.	2	-2/5

*All tests were conducted on a 50 ft long raised gore surface bounded by a 6" high concrete curb with a radius of 5 ft and a front slope of 2:3.

**For Tests 1, 2, 3, 7 and 8 the rise represents the trajectory of a point measured at the intersection of a horizontal line through the c.g. of the vehicle and a vertical line through the leading edge of the front bumper; For Tests 4, 5 and 6 the rise represents the trajectory of a point on the passenger's side of the vehicle measured at the intersection of a horizontal line through the c.g. of the vehicle and a vertical line through the leading edge of the front bumper; the location is measured from the front of the curbed gore.

***Counterclockwise roll/clockwise roll. (Refer to Figure 5, VEHICLE AXIS SYSTEM)

Metric Conversions: 1 lb = 0.454 kg; 1 mph = 0.447 m/s; 1 ft = 0.305 m; 1 degree = 0.0175 rad; 1 in. = 25.4 mm.

During some of the tests the vehicles scraped the asphalt concrete surface of the curbed gore upon returning to the ground. All vehicles, however, continued to travel relatively straight after landing and came to rest about 200 ft downstream from the end of the gore surface. The brakes of the vehicles were not applied until after the vehicles had traveled beyond the end of the curbed gore surface.

Both vehicles attained their maximum rise heights during head-on impacts at 40 mph with both front wheels striking the nose of the curbed gore at the same time, Tests 1 and 2. The small size passenger vehicle (1974 Pinto) rose 9.5 inches, 14.5 feet back from the front of the curbed gore. The large size passenger vehicle (1974 Torino) attained its maximum rise of 8 inches, 20 feet into the curbed gore.

Vehicle pitching was minimal for Tests 3 through 8 with maximum values of 3 degrees or less, Table 1. During the two head-on impacts, Tests 1 and 2, maximum pitch angles were somewhat greater, 5 and 6 degrees respectively for the large and small size vehicles impacting at 40 mph. Figure 5 shows the sign conventions for the vehicle roll, yaw, and pitch axes.

Vehicle roll was negligible for the head-on Tests Nos. 1, 2, and 3, and the head-on/offset Tests Nos. 7 and 8, Figure 6. Values were 3 degrees or less for these tests. Roll angles for the head-on tests where only the right side wheels mounted the curb naturally were higher, but were not excessive. The largest roll angle of -11 1/2 degrees was recorded for Test 5, large size vehicle impacting head-on/right side wheels only at 62.7 mph.

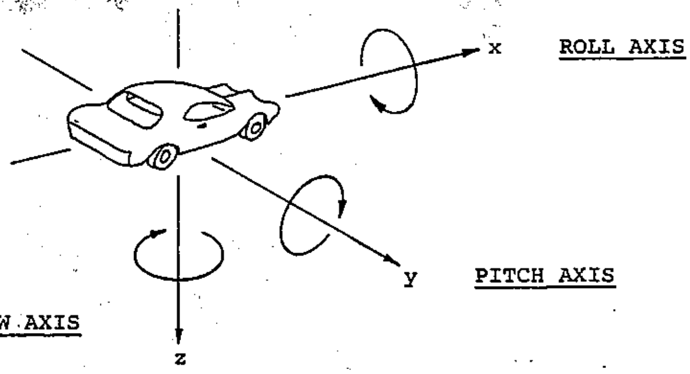


Figure 5. Vehicle Axis System

There was no appreciable vehicle yawing in any of the tests. There was some minor clockwise yawing, however, in Test 7 experienced by the test driver. This test was conducted with the large size passenger vehicle at 59.9 mph head-on/offset with the right front wheel striking the curbed gore before the left front wheel.

The front and rear sheet metal targets fell off the vehicles during some of the tests. These targets were used to delineate the bumpers of the test vehicles. The supporting brackets for these targets were not strong enough to withstand the forces of impact. Also, during most of the tests, the targeted hub caps of the vehicles flew off.

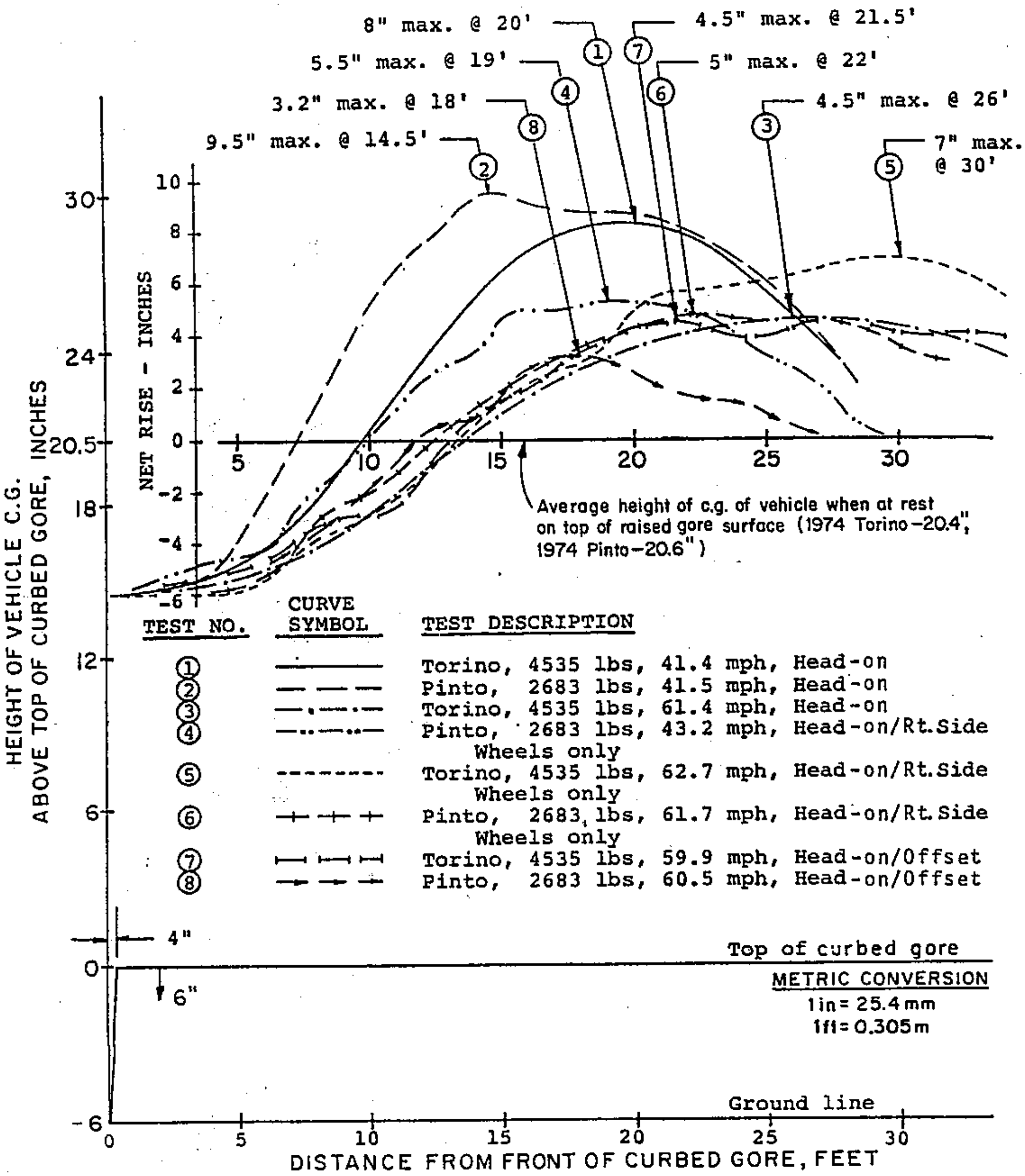
5.2.2 Rise Curves

Most of the summary rise data, Table 1, was taken from the rise curves for the vehicular jump tests plotted with respect to distance from the nose of the curbed gore, Figure 6. Rise measurements for these curves were taken from high speed photographic coverage of each test.

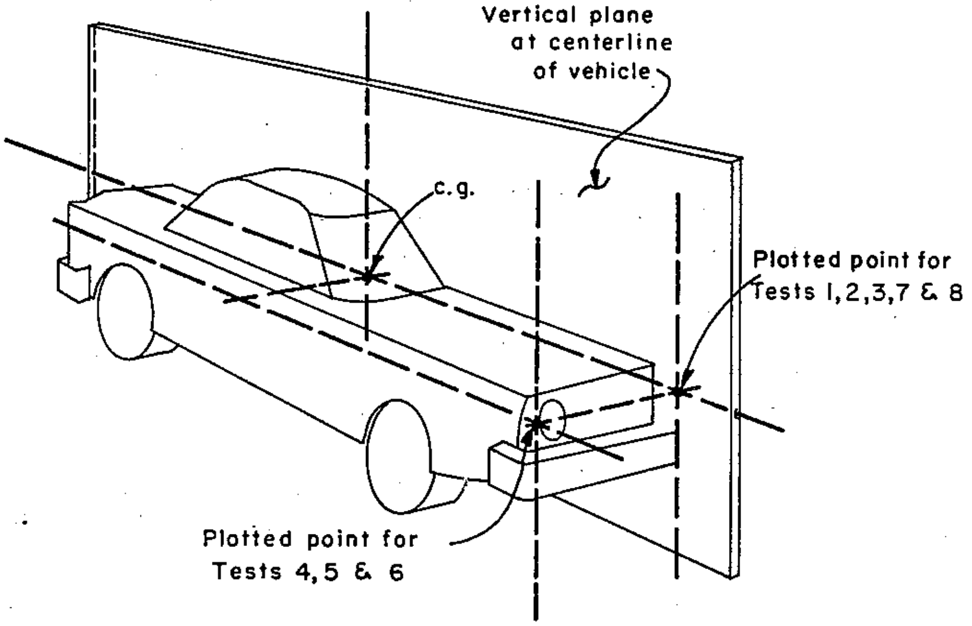
For Tests 1, 2, 3, 7 and 8, the rise curves represent the trajectory of a point measured at the intersection of a horizontal line through the c.g. of the vehicle and a vertical line through the leading edge of the front bumper. For Tests 4, 5 and 6, where only the right side wheels of the vehicle impacted the curbed gore, the trajectory of a point on the right side of the vehicle (passenger's side) measured at the intersection of a horizontal line through the c.g. of the vehicle and a vertical line at the front edge of the front bumper was plotted. Both of these points are shown in Figure 7.

Also worth noting is the difference in scales between the horizontal and vertical coordinate systems for these rise curves, Figure 6. The compressed scale for distance along the curbed gore exaggerates the slopes along the rise curves.

Figure 6,* VEHICLE RISE VS DISTANCE FROM NOSE OF 6" HIGH CURBED GORE



*Refer to Figure 7 for location of plotted point with respect to the test vehicle for each rise curve.



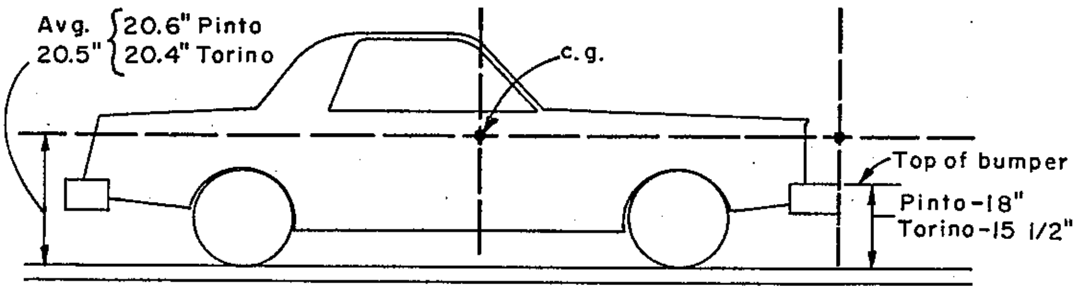


Figure 7, LOCATION OF POINTS USED TO PLOT RISE CURVES IN Figure 6

5.2.3 Professional Driver Comments

In addition to the analytical data already presented, the following comments were provided in writing by the professional driver after the tests were completed. The most violent impact, according to this assessment, was the small car impact head-on at 40 mph, Test 2. There was a loud sound at impact and a rather violent jolt in the vehicle.

The vehicle pitched noticeably, but was tolerable from the driver's point of view. The maximum vehicle rise occurred during this test.

- Test 1: 4535 lb Veh/41.4 mph/Head-on

The impact between wheels and curbed gore produced a moderate jolt to the driver, through the seat. There was no unusual feed-back through the steering wheel and no excessive noticeable pitch in the inside of the vehicle.

Directional stability was easily maintained with control braking and turning excellent. There was no loss of air in the tires.

- Test 2: 2680 lb Veh/41.5 mph/Head-on

The impact between vehicle and curbed gore produced a loud sound and a rather violent jolt in the vehicle.

The vehicle maintained more or less a straight ahead direction but it was impossible to change its direction. All four wheels of the vehicle were bent and lost air. Also, some damage was sustained by the vehicle's undercarriage.

The vehicle pitched rather excessively but was tolerable.

- Test 3: 4535 lb Veh/61.4 mph/Head-on

The feeling was a little bit more severe than for Test 1. However, none were as great an impact as Test 2. This test was very tolerable.

- Test 4: 2680 lb Veh/43.2 mph/Head-on - only right side wheels impact curbed gore.

There was a slight jolt. No problems were experienced. There was no vehicle pitching or yawing.

- Test 5: 4535 lb Veh/62.7 mph/Head-on - only right side wheels impact curbed gore.

There was more jolt than in Test 4, however, steering was easy and there were no control problems.

- Test 6: 2680 lb Veh//61.7 mph/Head-on - only right side wheels impact curbed gore.

There was a large jolt. The vehicle went straight for a short time. Eventually there was loss of steering due to wheel damage on the right side of the vehicle. The vehicle veered to the right. After approximately 100 to 150 ft, the vehicle lost its steering due to loss of air in the tire on the right side.

- Test 7: 4535 lb Veh/59.9 mph/Head-on/Offset - Right front wheel impacts curbed gore before left front wheel.

There was a slight difference between offset and head-on impacts.

Inside (the vehicle) two impact reports (sounds) could be detected, however, this could be the front and rear wheels of the vehicle. The vehicle displayed a slight clockwise yawing motion and some pitching during impact.

The control of the vehicle was easily maintained and the interior jolt was minimal for these impact conditions.

- Test 8: 2680 lb Veh/60.5 mph/Head-on/Offset - Right front wheel impacts curbed gore before left front wheel.

There was a rather large jolt in the vehicle with the feeling of considerable pitch. Directional stability remained quite stable. Control of the vehicle could be maintained. The overall evaluation was very tolerable.

5.2.4 Vehicle Damage and Repair Costs

Vehicle damage consisted primarily of bent wheels, loss of air in tires, front springs which were replaced after Tests 1 and 2, large and small size car head-on at 40 mph, and leaking oil pans in Test 1 and Test 8, small car head-on/offset at 60 mph. The front end of each vehicle was aligned before each test. The front cross member and the frame had to be straightened after Test 2, small car head-on impact at 40 mph. The front cross member was also straightened after Test 5, large car head-on/right side wheels at 60 mph. There was no apparent damage to the shock absorbers in any of the tests.

Vehicle damage and repair cost estimates for each test are shown in Table 2.

TABLE 2 - VEHICLE DAMAGE & REPAIR COST ESTIMATES

TEST NUMBER	VEHICLE REPAIR DESCRIPTION	REPAIR COST $*
1	2 Front springs, front end alignment	114
2	4 Wheels, 2 tires, 2 front springs, straighten frame & front cross member, front end alignment, hole in oil pan	320
3	2 Front wheels, straighten right rear wheel, front end alignment	120
4	2 Right side wheels, 1 tire, battery hold down plate, front end alignment	98
5	Bent front right wheel, straighten cross member, front end alignment	59
6	2 Right side wheels, 1 tire, 3 wheel covers, front end alignment	142
7	Right front & left rear rims bent, loss of air in tires, front end alignment	120
8	Oil pan smashed - oil leak, possible engine damage, right front, & right rear wheels bent, loss of air in tires, front end alignment	400

*Parts & Labor

5.2.5 Vehicle and Curbed Gore Damage Photographs

The following photographs in Figures 8-24 show tire marks on the curbed gore, vehicle damage, and the position of the vehicles after the tests. The concrete curb was repainted after each test.

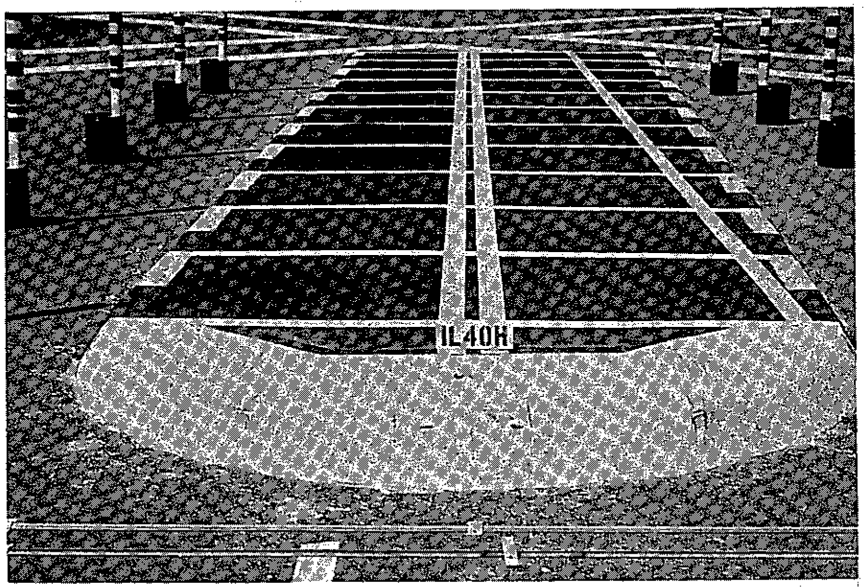


Figure 8. TEST 1: Tire Marks on Curbed Gore
Large Car/41.4 mph/Head-on

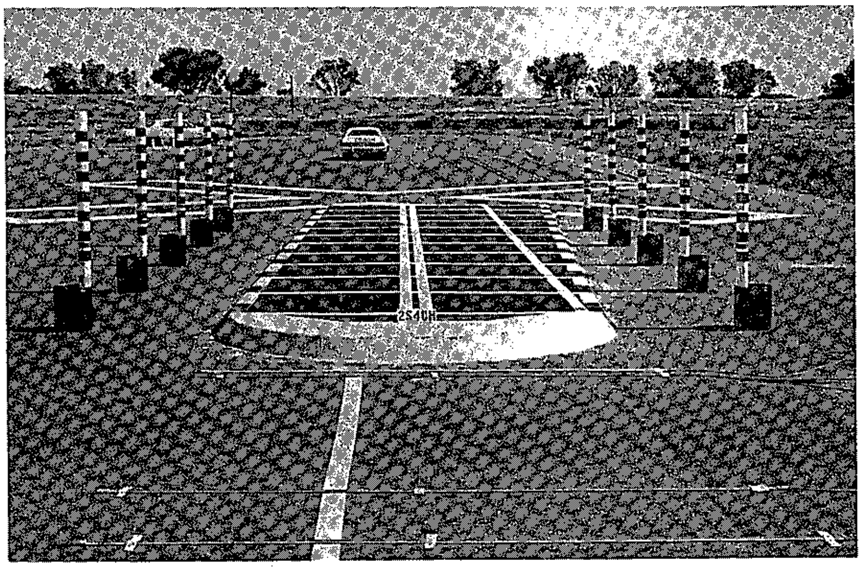


Figure 9. TEST 2: Tire Marks on Curbed Gore
Small Car/41.5 mph/Head-on

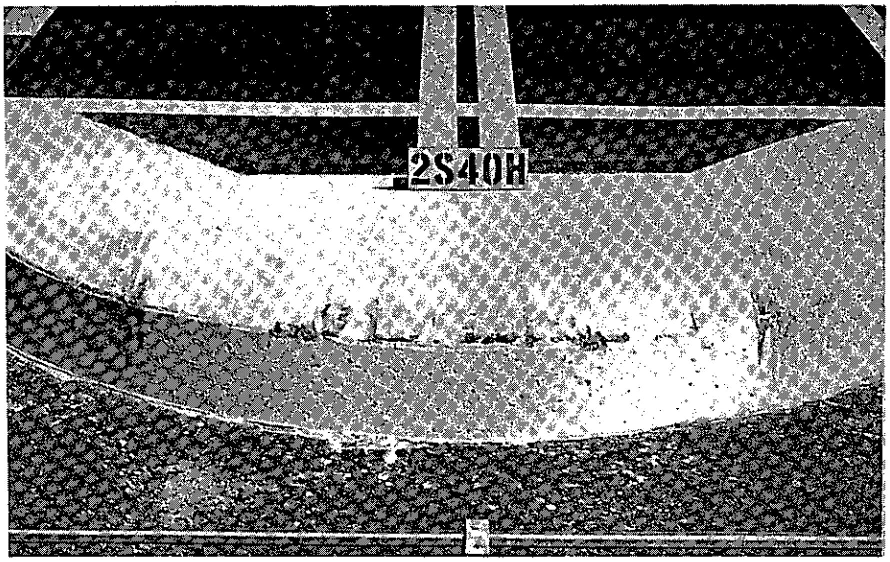


Figure 10 TEST 2: Tire and Scrape Marks on Curbed Gore; Small Car/41.5 mph/Head-on

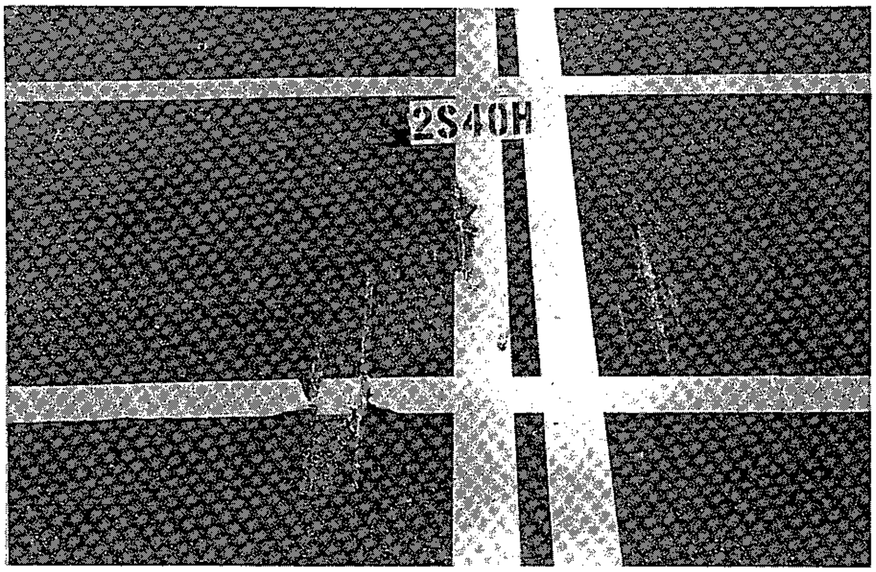


Figure 11 TEST 2: Gouge in Top A.C. Layer of Curbed Gore 32 ft from Front of Nose

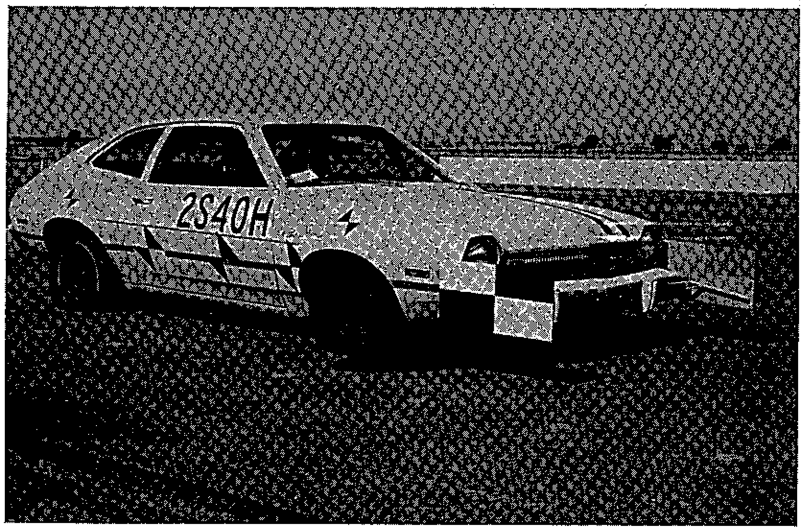


Figure 12. TEST 2: Vehicle Damage - All Four Wheels Bent, Tires Flat; Small Car/41.5 mph/Head-on

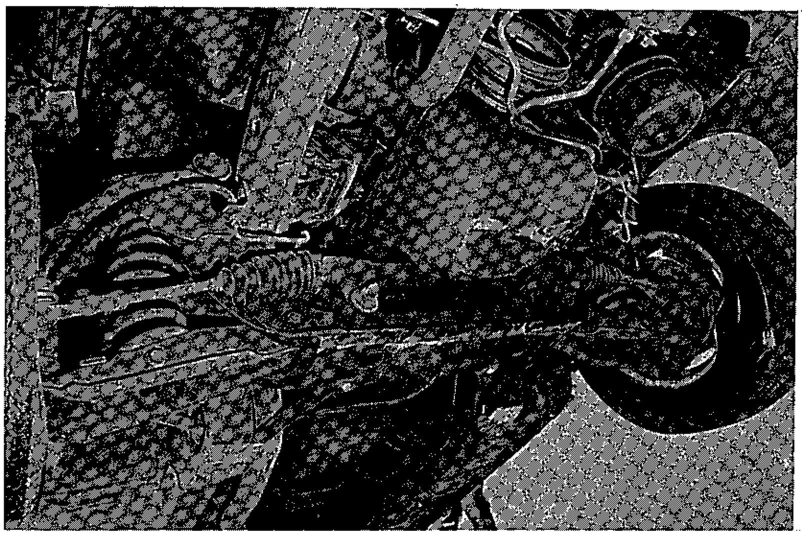


Figure 13. TEST 2: Undercarriage Damage - Note Oil Pan Damage and White Paint Marks from Curbed Gore on Front Cross Member

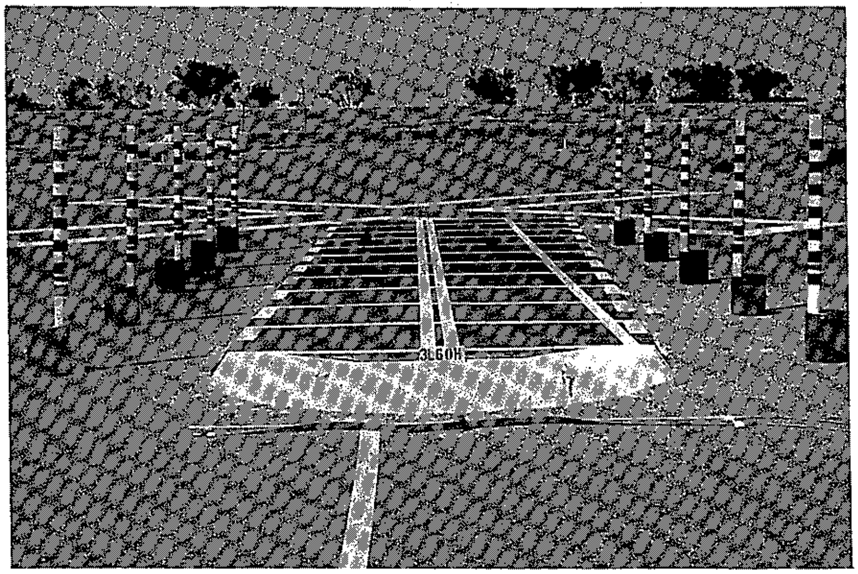


Figure 14. TEST 3:

Tire Marks on
Curbed Gore
Large Car/61.4 mph/
Head-on

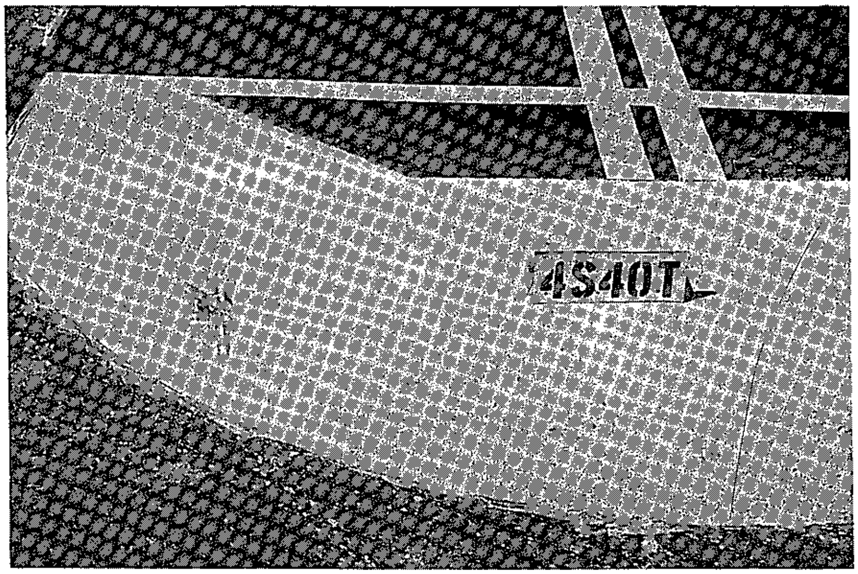


Figure 15. TEST 4:

Tire Marks on
Curbed Gore
Small Car/43.2 mph/
Head-on - Right Side
Wheels Only

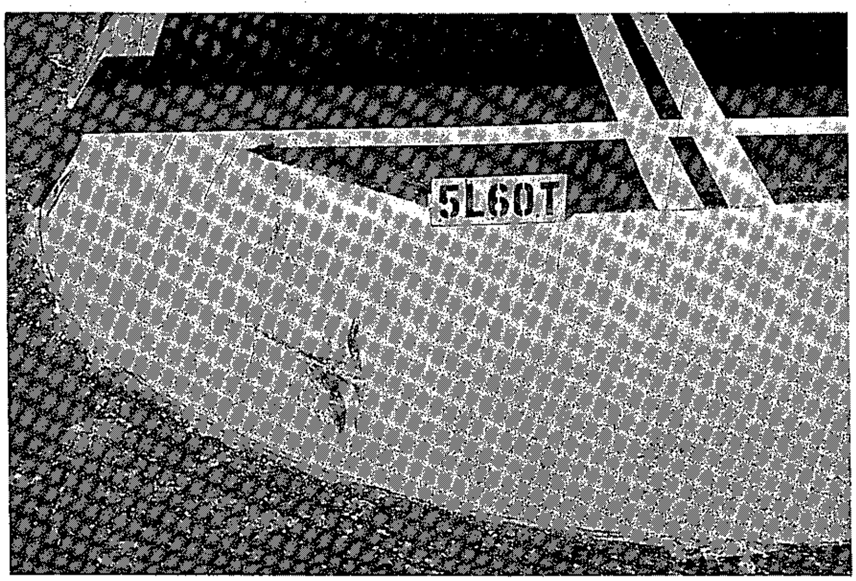


Figure 16. TEST 5:

Tire Marks on
Curbed Gore
Large Car/62.7 mph/
Head-on - Right Side
Wheels Only

Figure 17. <u>TEST 5</u>:

Bent Front Right Wheel;
Large Car/62.7 mph/
Head-on - Right Side Wheels Only

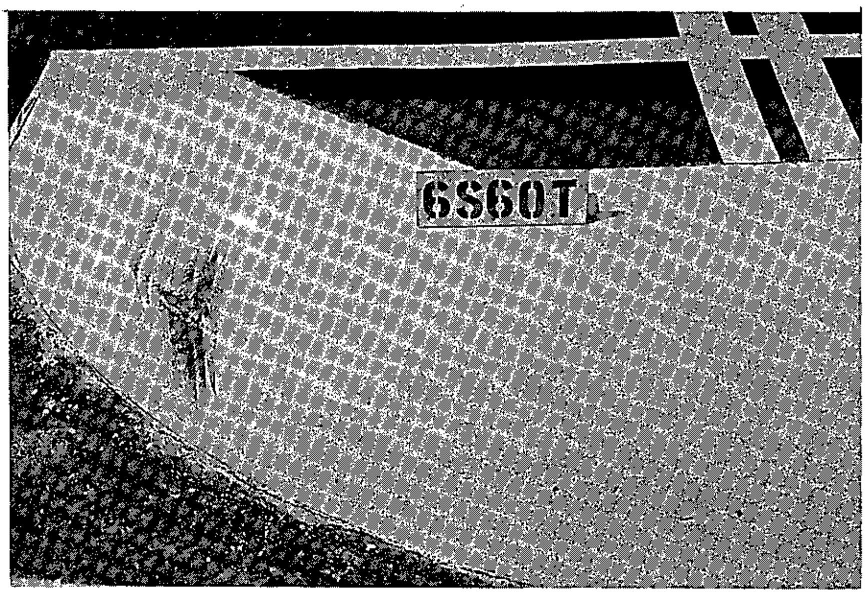


Figure 18. <u>TEST 6</u>:

Tire Marks on Curbed Gore;
Small Car/61.7 mph/
Head-on - Right Side Wheels Only

Figure 19. <u>TEST 6</u>:

Vehicle Damage - Two Right Side Wheels and One Tire Replaced

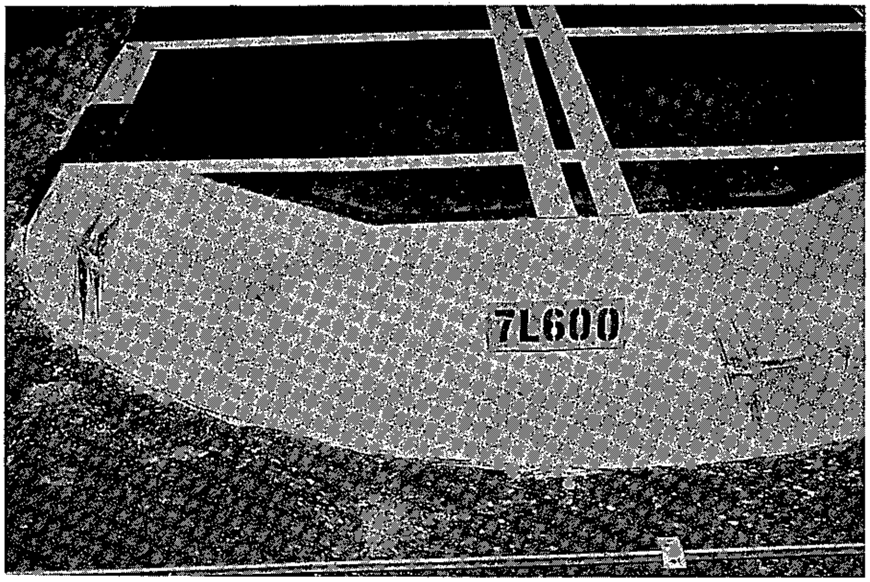


Figure 20. TEST 7: Tire Marks on Curbed Gore
Large Car/59.9 mph/Head-on/Offset -
Right Front Before Left Front Wheel

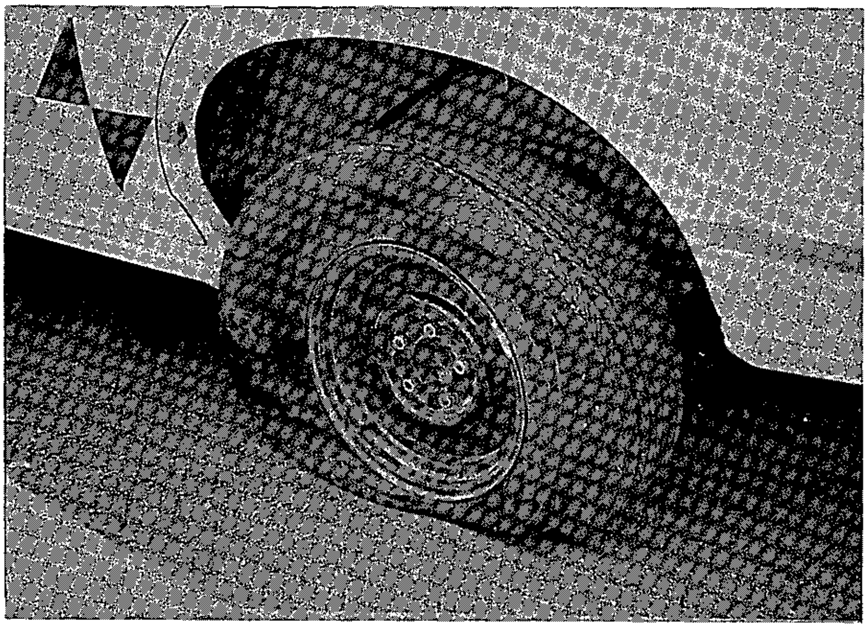


Figure 21. TEST 7: Vehicle Damage - Left Rear Wheel;
Right Front Wheel Also Bent

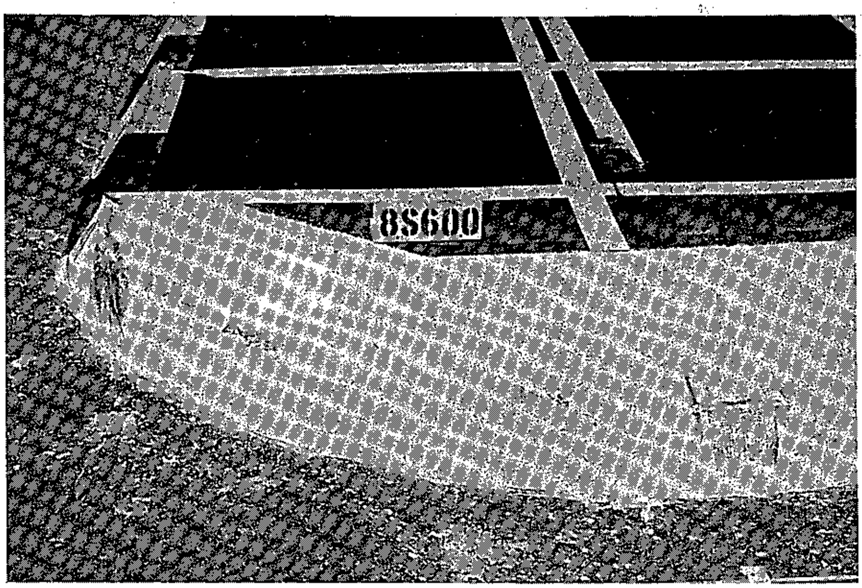


Figure 22. TEST 8:

Tire Marks on Curbed Gore. Small Car/60.5 mph/ Head-on/Offset - Right Front Wheel Before Left Front Wheel

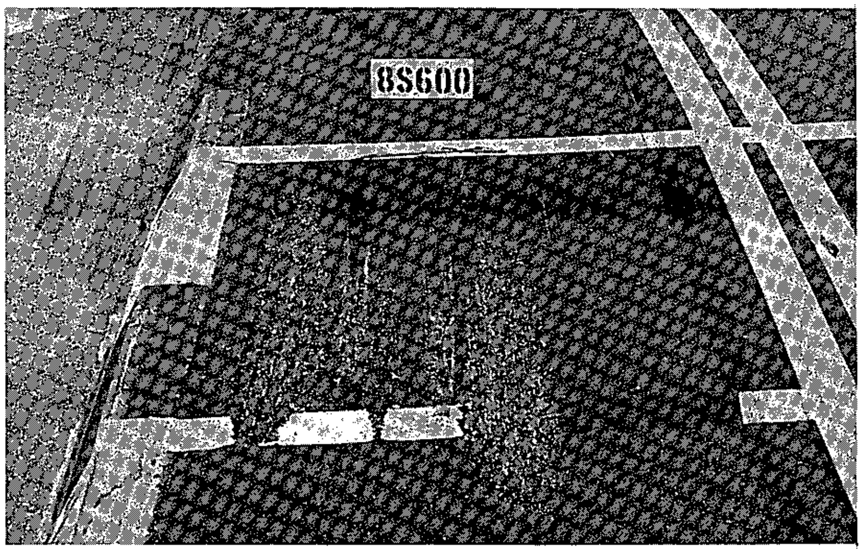


Figure 23. TEST 8:

Gouges in Top A.C. Layer of Curbed Gore

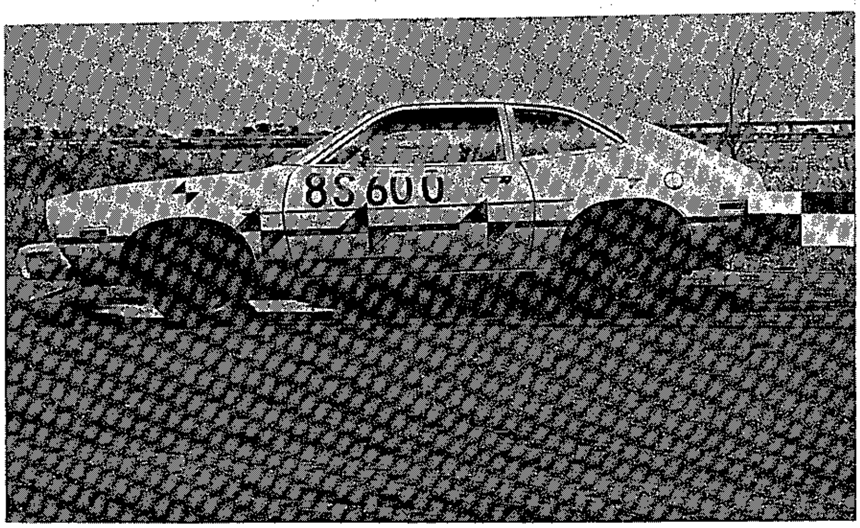


Figure 24. TEST 8:

Vehicle Damage - Oil Pan Leak; Right Front and Right Rear Wheels Bent

5.3 Discussion of Test Results

The trajectory of the two types of vehicles used in the curbed gore jump tests can be divided into two modes, a compression mode and a jumping mode. During the compression mode, the vehicle's front suspension system compresses, lowering the c.g. of the vehicle. This happens because the vehicle is slow to react to the height of the curbed gore during the initial phase of the impact. As the suspension system of the vehicle recovers, the car enters its jumping mode characterized by a positive rise of the c.g. above the static or at rest c.g. of the vehicle.

Both vehicles used for this project have similar coil spring suspension systems, Figures D1 through D4 of Appendix D. Dimensions, mass parameters, and suspension parameters for both vehicles are also shown in Appendix D, Table D1.

The compression mode distances of the small car (Pinto) were shorter than the corresponding values of the large car (Torino) for the same test conditions, Table 1, Section 5.2.1. This probably can be attributed to the stiffer suspension system in the small car (larger suspension front wheel stop and spring rates), Table D1, Appendix D. Also, the vertical travel of the front wheels (jounce) is 20% less for the Pinto than the Torino, 3.37 inches compared to 4.24 inches.

The compression mode distances for the 60 mph tests were longer than those values for the 40 mph tests, an average of 12.9 ft compared to 9.0 ft. When the tests were classified according to impact attitude, i.e., head-on, head-on/two wheels, etc., the tests with the longer compression mode distances also required greater distances to reach their maximum rise attitudes.

Maximum vehicle rise values occurred in a range from 14.5 ft to 30 ft with an average distance of 21.4 ft back from the nose of the curbed gore. Some of the rise curves (Tests 3, 5, 6, 7), Figure 6, Section 5.2.2 did not begin to flatten out until as far back as 30 ft from the front of the curbed gore. Crash cushions located 30 ft back of the nose of the curbed gore might be sensitive to vehicle ramping for these types of impact conditions. In long gores, crash cushions should be placed 50 ft or more back of the nose of the gore. No erratic vehicle behavior was observed beyond this point in the tests.

The Structures and Applied Mechanics Division of the Federal Highway Administration conducted HVOSM (Highway-Vehicle-Object Simulation Model) computer runs to determine vehicle trajectories following head-on impacts into curbs. It is interesting to compare the results of those runs with the Caltrans curbed gore vehicle jump tests conducted as part of this study. Vehicle trajectory vs. distance from curb graphs for six different curb heights (4.0, 4.5, 5.0, 5.5, 6.0, and 9.0 inch) were plotted. Similar to the results of Caltrans Test 1, Figure 6, the 6-inch HVOSM curb simulation test vehicle attained its maximum rise of 11.75 inches about 18 ft back from the front of the curb. All of the simulation tests were conducted at 55 mph with a 1963 Ford Galaxie weighing 4200 lbs with a bumper height and depth of 21.25 and 9 inches respectively.

The Caltrans curbed gore vehicle jump tests were conducted to determine if guidelines could be developed for the placement of crash cushions on curbed gore areas without seriously diminishing the effectiveness of the crash cushion, i.e., its ability to bring the impacting vehicle to a reasonably safe stop.

In order to evaluate the effect of vehicle ramping (jumping mode) or submarining (compression mode) on the placement of crash cushions at different positions along the curbed gore, a transparent elevation view of a standard sand barrel crash cushion commonly used by Caltrans, composed of twelve barrels, was overlayed on the rise curve for each jump test. Using this technique, the interaction of the curb induced vehicle dynamics and crash cushion effectiveness was evaluated. The crash cushion array examined had a 200 lb first barrel followed by a column of two 400 lb barrels, a 700 lb barrel, a row of two 700 lb barrels, and three rows of two 1400 lb barrels. See Figures 25 and 26. This sand barrel crash cushion array was chosen because it is typical of sand barrel arrays being deployed. Also, no other types of crash cushions are placed on curbed gores in California.

The current California guidelines, in effect when this project was initiated, for placing crash cushions on curbs were as follows according to a Caltrans Office of Traffic Engineering memorandum concerning the Gore Improvement Program dated January 7, 1975:

- Curbing may remain in place where more than 25 feet of space will remain between the front of the crash cushion and the gore nose curb.

- Curbing may remain in place when the front of the crash cushion is within 8 feet of the gore nose curb.

- The performance of a crash cushion with the foremost module between 8 ft and 25 ft behind a gore nose curb is questionable.

Now, suppose the sand barrel crash cushion array just mentioned is placed on top of the curbed gore used for this project, 8 ft back from the nose according to the 1975 Caltrans guidelines. For this situation and by using the test parameters that created the largest vehicle rise value, Caltrans Test 2, small car/41.5 mph/head-on, the vehicle's maximum c.g. height above the c.g. of the crash cushion would probably be about 7 inches. This would occur as the vehicle was hitting the first 700 lb sand barrel which is located 12 ft into the barrier. For these test conditions the vehicle would have started to rise (enter its jumping mode) 6.5 ft after impacting the curbed gore, before initially striking the crash cushion.

Similarly, if the same jump test conditions were used and the crash cushion was placed at the nose of the curbed gore so that there was no distance between the nose and the first barrel of the crash cushion, a maximum vehicle c.g. rise at the front bumper would probably be about 6 inches above the c.g. of the crash cushion. This value would occur at the first row of 1400 lb sand barrels located about 15 ft from the front of the cushion. For this situation the vehicle would travel under the c.g. of each of the first three sand barrels before starting to rise.

The distance the vehicle submarines while impacting the first few sand barrels should help prevent vehicle ramping. The sand displaced during this "submarining" action should help hold down the front of the vehicle and reduce its ultimate rise. However, if this submarining distance was too great, the effectiveness of the crash cushion might be reduced. The vehicle would not benefit by slowing down gradually. Instead, the vehicle would likely experience greater deceleration forces imparted by the larger sand masses of the sand barrels located towards the back of the crash cushion.

A distance of 0-5 ft was chosen as a guideline for placing sand barrel crash cushions back from the nose on top of a 6 inch high curbed gore. For the case of a crash cushion located 5 ft in back of the curbed gore nose, an impacting vehicle might still rise about 7.5 inches above the c.g. of the crash cushion. This would occur at the fourth barrel, 12 ft into the crash cushion. However, the submarining effect of the impact would be minimal.

As the vehicle traveled through the first three barrels of a crash cushion placed according to the above guideline the tendency for the vehicle to rise would be lessened. During this phase of the impact, the vehicle would be hitting these barrels approximately at the c.g. heights of their sand masses. In addition, the accumulation of sand on top of the vehicle at this point would also help exert a downward force on the vehicle restricting its tendency to rise.

Any tendency for the vehicle to roll would also be absorbed by the collision into the crash cushion, if the cushion were placed 0-5 ft from the curbed gore nose. No noticeable vehicle rolling occurred within that 5 ft space in any of the jump tests.

A vehicle impact test using the test parameters of Caltrans jump Test 2 (worst case), small car/40 mph/head-on, was conducted to verify the validity of this proposed 0-5 ft guideline. The results of this test, Test 349, are discussed in the remaining sections of this report.

It is rather fortunate that the maximum vehicle rise values for the jump tests occurred for the 40 mph head-on impacts with both vehicle sizes. At 40 mph only 44% of the kinetic energy of a 60 mph impact must be absorbed by the crash cushion. At this lower energy level, it will take less resisting force to prevent vehicle rising.

Even though the vehicle rise was measured for a variety of curbed gore jump conditions, it is uncertain what value of rise would cause a vehicle to vault a crash cushion if the crash cushion is placed on top of a 6 inch high curbed gore. In other words, it is unknown precisly how high the center of gravity of the vehicle must be in relationship to the center of gravity of the crash cushion before vehicle ramping and undesirable vehicle behavior occurs.

A wide range of bumper heights and bumper depths of the vehicle population also could affect this unknown critical rise value. Top of bumper heights at the center of the small and large size passenger vehicles used for this project were approximately 19 inches. Assuming all frontal forces are distributed by the bumper, vehicle rise might be influenced by the shape of the bumper and its ability to distribute these forces. Many bumpers slope back toward the vehicles. These types of bumper configurations might encourage vehicle ramping.

It is assumed that vaulting and ramping are much less desirable than submarining when a vehicle impacts a sand barrel type crash cushion. However, a vehicle which wedges under the sand in the first three or four modules of a crash cushion may be decelerated less rapidly at first, then experience higher than normal decelerations when it contacts 700 or 1400 lb barrels of sand located at the middle and back half of the cushion respectively.

6. TECHNICAL DISCUSSION

PART 2: Impact Test of Sand Barrel Crash Cushion on Curbed Gore

6.1 Test Conditions

6.1.1 Test Facility

The vehicular crash test, Test 349, was also conducted at the Caltrans Dynamic Test Facility in Bryte, California.

6.1.2 Sand Barrel Crash Cushion Design and Construction

A sand barrel crash cushion was placed on top of the 6-inch high curbed gore surface, Figure 1, used for the vehicular jump tests described in Part 1 of this report. The twelve barrel array was positioned 5 ft back from the nose of the curbed gore surface as shown in Figure 25 to minimize the effect of vehicle jumping on its performance. This location was chosen as a result of the curbed gore vehicle jump test series previously described.

The sand barrel crash cushion used for this test was a standard array commonly used by Caltrans to shield fixed objects in gores at locations where impact speeds may reach 60 mph. Barrel weights of 200, 400, 700, and 1400 lb were used, Figure 25. Recently developed expanded polystyrene cores, located inside the barrels, placed the sand layers at their correct elevations in each barrel.

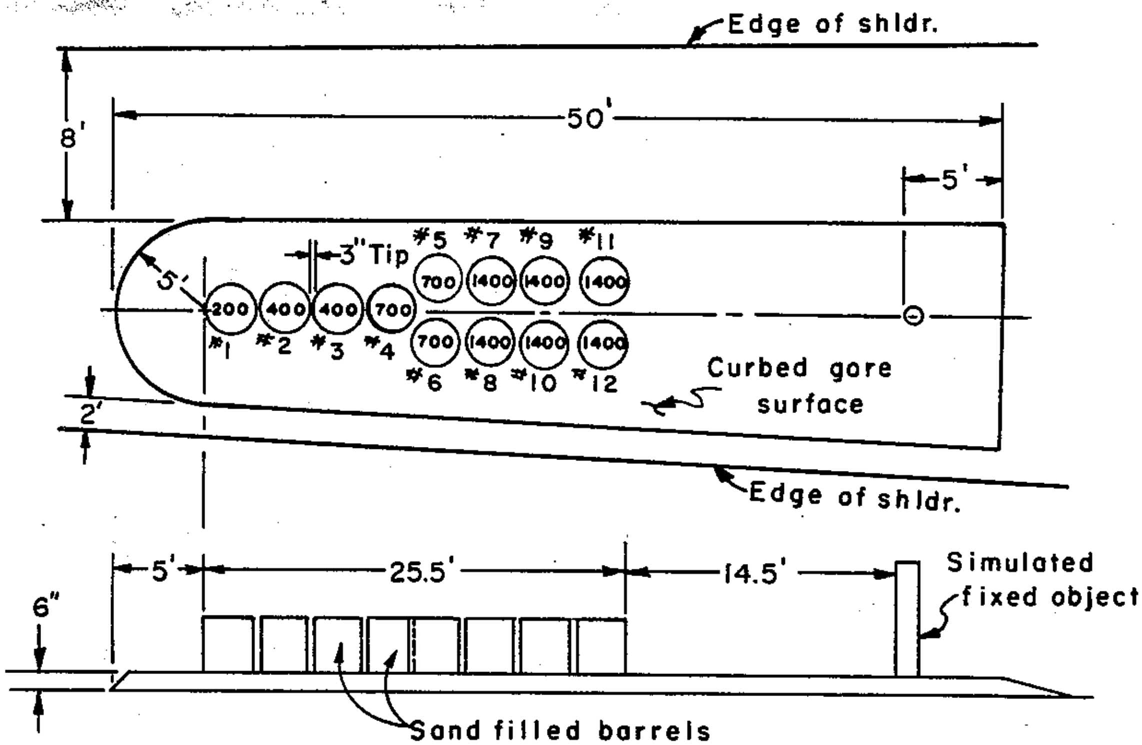


Figure 25, PLAN AND ELEVATION VIEWS OF SAND BARREL CRASH CUSHION ON 6" HIGH CURBED GORE, TEST 349

METRIC CONVERSION

1 ft. = 0.305 m
1 in. = 25.4 mm
1 lb. = 0.454 kg

The polyethylene lids were not riveted to each barrel as recommended by the manufacturer to deter vandalism. Instead, it was decided to study the trajectory of the lids during impact to determine if they posed a possible safety hazard to adjacent traffic. Each lid weighed about 8 to 10 lbs. These newly designed lids were heavier than those previously used.

Clean, dry bagged sand of commercial quality was used to fill each barrel to its desired weight.

Photographs of the test barrier are shown in Figures 26 and 27.

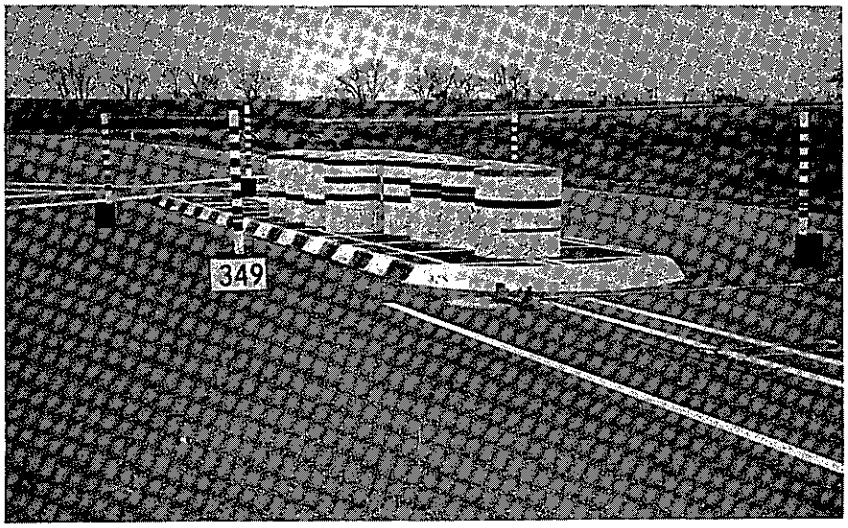


Figure 26. Sand Barrel Crash Cushion on Top of Curbed Gore.

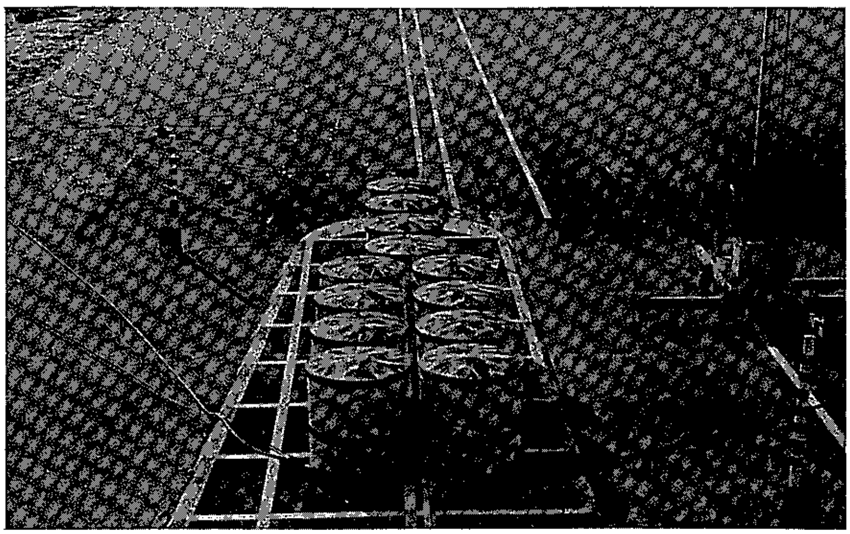


Figure 27. Rear View of Sand Barrel Crash Cushion on Top of Curbed Gore.

6.1.3 Data Acquisition Systems

High speed and normal speed movie cameras and still cameras were again used to record the impact events and the conditions of the test vehicle, the curbed gore, and the sand barrel crash cushion before and after the impact.

An anthropomorphic dummy with accelerometers mounted in its head cavity was placed in the driver's seat to obtain motion and acceleration data. The dummy, Sierra Stan, Model P/N 292-850, manufactured by the Sierra Engineering Company, is a 50th percentile male weighing 165 lbs. The dummy was restrained with a standard lap belt during the test.

Accelerometers oriented in the longitudinal (direction of vehicle travel), lateral, and vertical directions, were also mounted on the floorboard of the test vehicle. Acceleration data were collected to judge impact severity and to evaluate vehicle occupant injury tolerances.

Appendices B and C contain a detailed description of the following: photographic equipment and data collection techniques; electronic instrumentation and data reduction methods; and instrumentation records.

6.1.4 Test Parameters

A 1974 Ford Pinto coupe, weighing 2790 lbs (including instrumentation and the anthropomorphic dummy) was used for the crash test. This vehicle had previously been used for the curbed gore jump test series. Before it was reused for this test, it was completely repaired including wheel and front suspension damage.

The planned impact speed/angle were 40 mph/0° (head-on). These test parameters were selected because they represented the conditions for creating the highest value of vehicle rise during the curbed gore vehicle jump test series. Also, accident data indicates that 70% of gore impacts are head-on.

Photographs of the test vehicle and its relationship to the sand barrel crash cushion are shown in Figures 28 and 29. The height of the vehicle's bumper above the top of the 6 inch high curbed gore was 1 ft when parked adjacent to the curb.

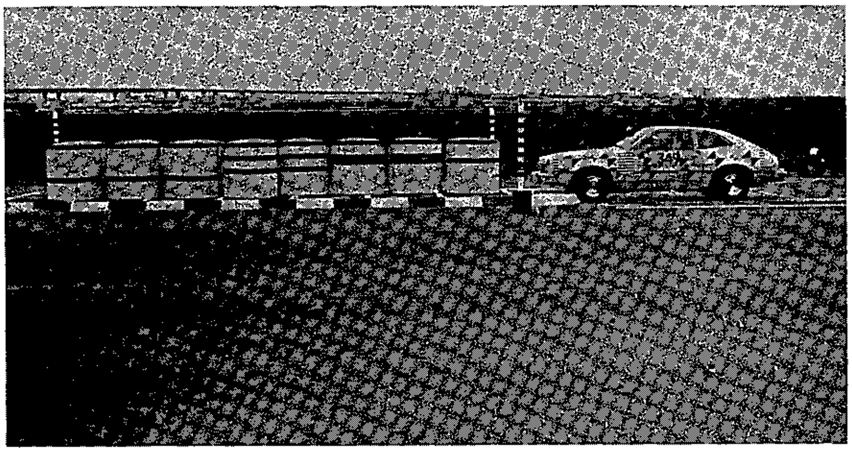


Figure 28. Vehicle/Barrier Relationship.

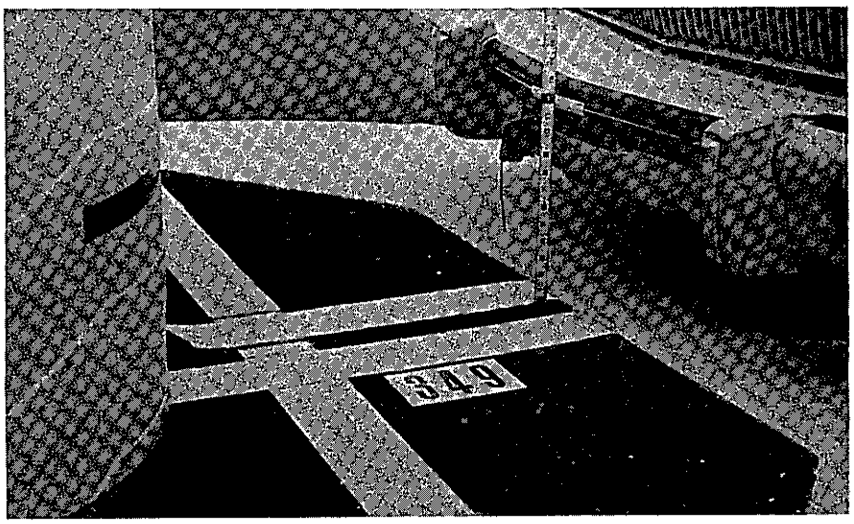


Figure 29. Close-up View of Vehicle Against Nose of 6-inch High Curbed Gore. Bumper Height Above Top of Gore is 1 foot.

6.2 Test Results

Test photos and a summary of test data are contained in Figures 30 through 33 following the Test Results Section.

6.2.1 Impact Description

The test vehicle impacted the curbed gore head-on about 3 inches offset from the center line of the gore toward the passenger side of the vehicle at 41 mph. The vehicle yawed counterclockwise about 12 degrees as it plowed into the sand barrel crash cushion and came to rest on top of the gore surface 22.5 ft from the nose of the curbed gore. During the impact the vehicle also rolled counterclockwise 2 degrees and attained a maximum rise height of 6.5 inches, 10.5 ft from the nose of the curbed gore. The vehicle also pitched about -14.5 degrees, nose down, during the impact. The final position of the vehicle after impact is shown in Figure 30.

6.2.2 Barrier Damage

Seven of the twelve sand barrels were destroyed during the impact. The five remaining barrels, all containing 1400 lbs of sand, were essentially intact, but were moved out of position as shown in Figure 30.

The lids on barrels 9 and 10 were jarred loose but remained on top of the barrels. These lids were designed to snap onto the tops of the barrels. The top four pop rivets failed along one seam of barrel 10.

Barrier debris and sand were scattered to both sides and to the back of the curbed gore. Three of the barrel lids - numbers 1, 5, and 6 - flew a considerable distance from the main pile of debris and sand, Figure 30. Three nearly whole barrel shells were pushed off the sides of the curbed gore during the impact.

The majority of the sand fell within the outlined area shown in Figure 30; however, some sand was scattered as far back as the end of the 50 ft gore surface.

Photographs showing the barrier damage and the scattered debris are shown in Figures 31 through 33.

6.2.3 Vehicle Damage

The test vehicle was damaged from impacting the curbed gore as well as from hitting the sand barrel crash cushion. All four tires deflated and the oil pan was scraped as the vehicle mounted the curbed gore.

The vehicle's front bumper was not damaged during the impact. The front of the vehicle was slightly damaged above the top of the bumper. The grill was broken and the hood was pushed inward for a width of about 3 ft extending back to a maximum crush of 12 inches, forming a triangular indentation. The top of the radiator was also pushed back to the fan.

The passenger compartment was not damaged. There was no intrusion of vehicle parts or barrier components into the passenger compartment.

Vehicle damage assessments according to the Traffic Accident Scale (TAD)(6) and to the Vehicle Damage Index (VDI)(7) were FC-3 and 12FCMW1 respectively.

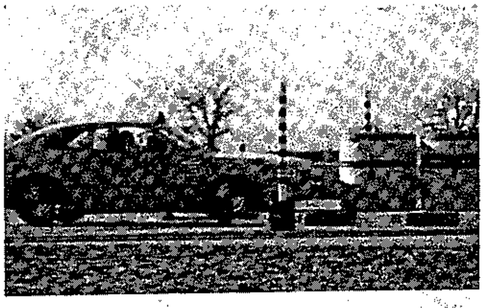
Vehicle damage photographs are shown in Figures 34 through 36.

6.2.4 Anthropomorphic Dummy Behavior

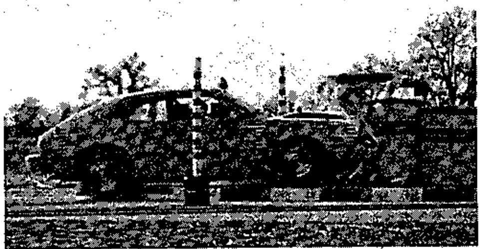
The dummy was restrained by a lap belt. During impact the dummy pivoted about its waist, moved forward, and hit its head at the bridge of the nose on the steering wheel of the vehicle. The dummy's head remained on the steering wheel momentarily, then its upper body leaned over towards the passenger side of the vehicle and remained there until the vehicle came to rest.

Accelerometer and lap belt load data from the dummy are included in Appendix C, Figure C4 and C5.

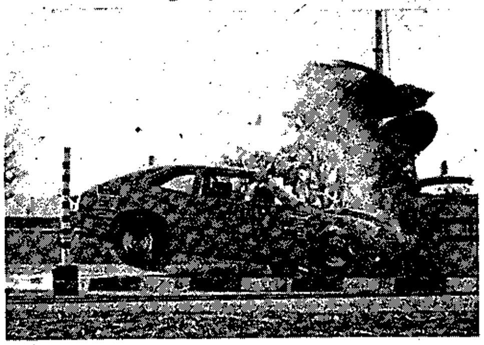
Figure 30, DATA SUMMARY SHEET



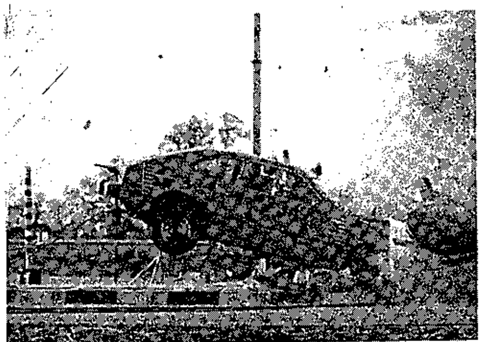
Impact + 0.03 Sec



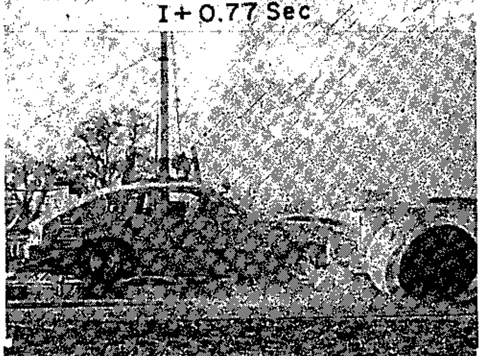
I + 0.14 Sec



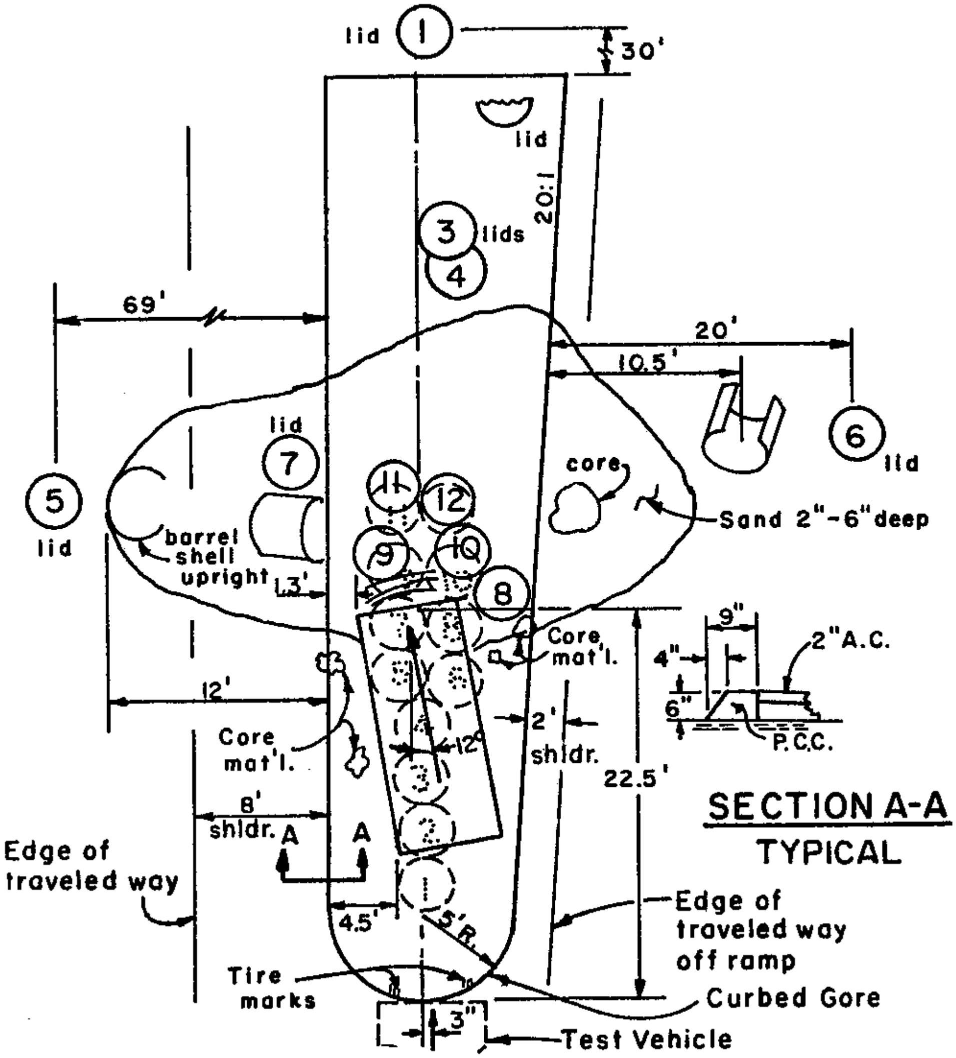
I + 0.32 Sec



I + 0.77 Sec



I + 1.18 Sec



TEST 349 DATE OF TEST: 1-20-78

BARRIER . . . . Sand Barrel Crash Cushion On Curbed Gore
- No. of Barrels 12
- Barrel Weights . . 1-200 lbs, . 2 & 3-400 lbs, . 4,5, & 6-700 lbs, . 7 thru 12-1400 lbs.
- Barrel Spacing . . . . 3 in.
- Distance From Front of Curbed Gore . . . . 5 ft.
- Length of Curbed Gore . . . . 50 ft.
- Length of Crash Cushion . . . . .25.5 ft.

VEHICLE . . . . 1974 Ford Pinto Coupe
- Weight (w/Dummy & Instr.). . . . . . 2790 lbs.
- Dummy Restraint . . . . Lap Belt

IMPACT VELOCITY . . . . .41 MPH

IMPACT ANGLE . . . . 0°(Head-on)

VEHICLE DECELERATION (Max. 50 msec, avg.)
- Longitudinal . . . . 3.6 g
- Lateral . . . . 0.9 g
- Average ($v^2/2\ gs$) . . . . 3.1 g

DECELERATION DISTANCE . . . . 17.5 ft.

VEHICLE RISE . . . . 6.5 in.

VEHICLE ROLL/PITCH/YAW . . . . -2°/-14.5°/-12°

VEHICLE DAMAGE
- TAD FC-3
- VDI . . . . 12 FCMWI
- Max. Crush at Vehicle . . . . .12 in.
- No. of Damaged Barrels 7

METRIC CONVERSION

1 in. = 25.4 mm; 1 ft = 0.305 m
1 mph = 0.447 m/s; 1 lb = 0.454 kg
1 deg (°) = 0.0175 rad.

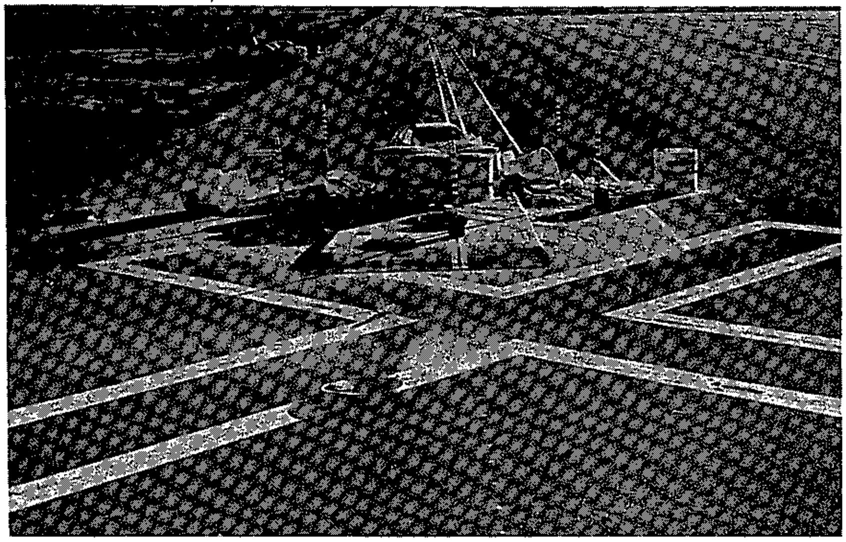


Figure 31.
Barrier Damage Viewed from Back of Curbed Gore.

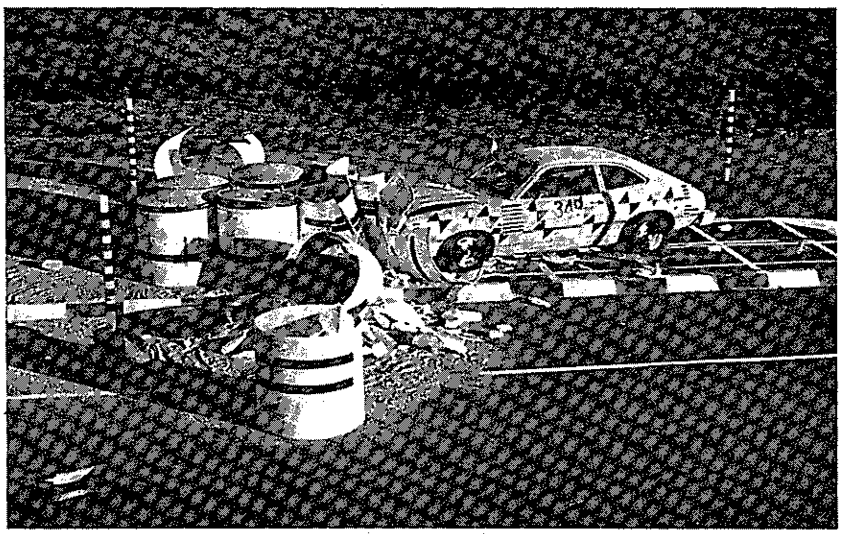


Figure 32.
Barrier Damage Viewed from Driver's Side of Vehicle

Figure 33.
Barrier Damage Viewed from Passenger's Side of Vehicle

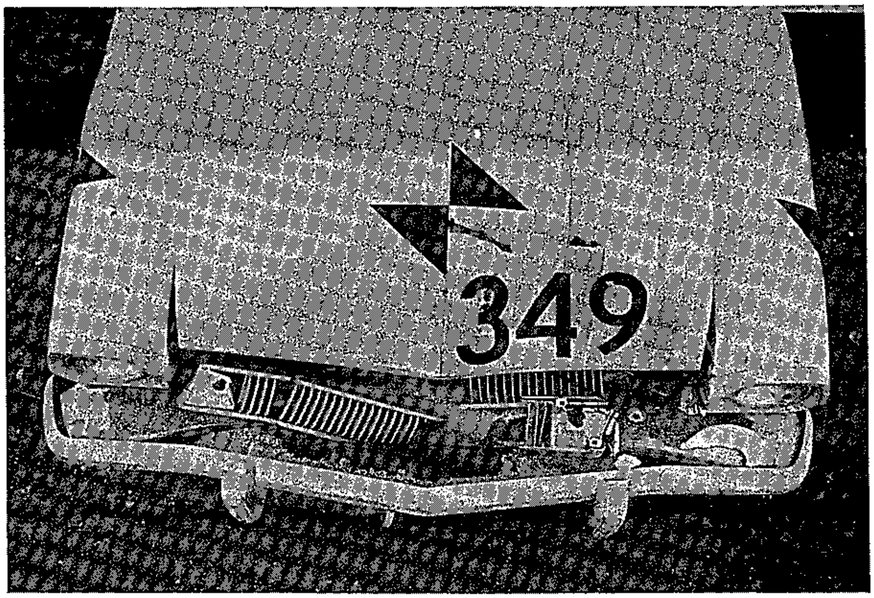


Figure 34.

Plan View of Front of Damaged Test Vehicle.

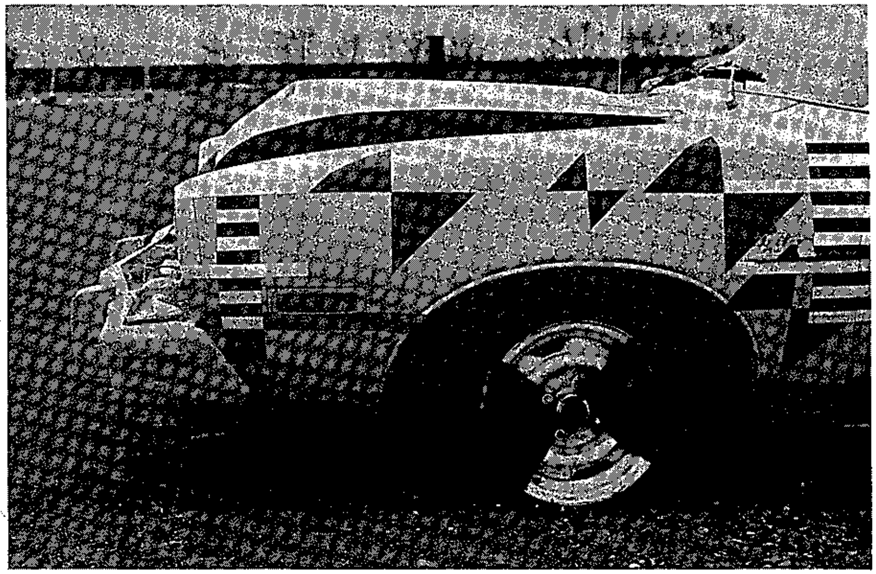


Figure 35.

Side View of Front of Damaged Test Vehicle, Test 349.

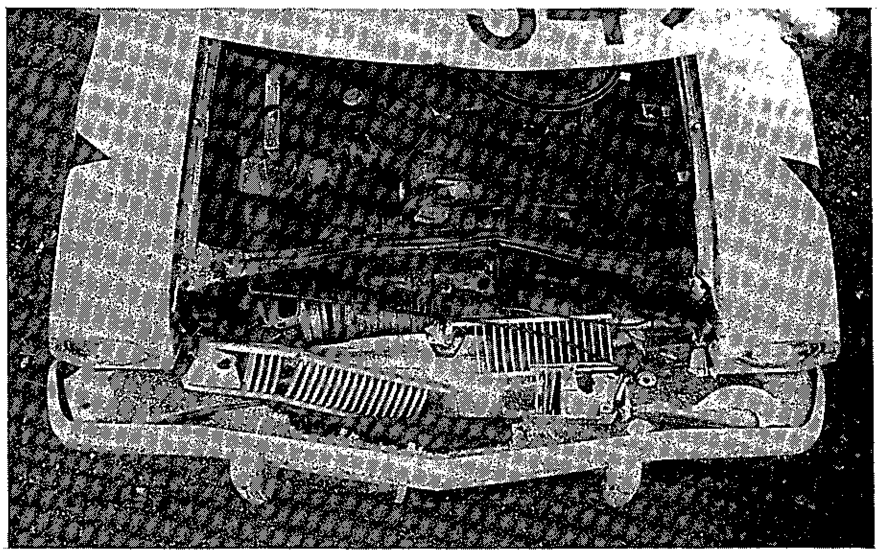


Figure 36.

Plan View of Damaged Test Vehicle with Hood Open, Test 349.

6.3 Discussion of Test Results

The safety performance appraisal factors that will be used as a guide for discussing the results of Test 349 are structural adequacy, impact severity, and vehicle trajectory hazard. These criteria are outlined in Transportation Research Circular (TRC) No. 191 "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenences" (5).

The Test 349 impact parameters, 2790 lb vehicle/41 mph/head-on, were selected because they produced the largest value of vehicle rise during the Caltrans curbed gore vehicle jump test series.

The objective of the crash test was to verify that the placement of a sand barrel crash cushion 5 ft away from the nose of the curbed gore would minimize any vehicle vaulting and would not adversely affect the performance of the crash cushion.

Ordinarily, crash cushions are evaluated at 60 mph as specified in TRC No. 191 (5). The lower test speed of Test 349 reduced the severity of the impact considerably.

6.3.1 Structural Adequacy

The performance of the sand barrel crash cushion was not affected by its location on top of the curbed gore surface. The crash cushion adequately stopped the test vehicle. The crash cushion did not snag or pocket the vehicle causing it to spinout or stop abruptly.

Vehicle roll during impact was negligible. The vehicle yawing of 12 degrees during the test may have happened because the vehicle hit the curved nose of the curbed gore and the first sand barrel at a slightly eccentric attitude. This yawing, however, did not lessen the effectiveness of the crash cushion. The moderate vehicle pitch of -14.5 degrees, nose down, which also occurred during impact did not seem to affect the performance of the crash cushion. Maximum pitch occurred as the front bumper of the vehicle came into contact with the first row of 1400 lb barrels. At this instant the vehicle had traveled about 20 ft past the nose of the curbed gore.

In comparison, a Volkswagen used in an earlier Caltrans test, Test 242 (8), on a sand barrel crash cushion had a negative pitch angle of 10 degrees. That barrier was composed of 17 sand barrels placed on grade, not on a curbed gore. The Volkswagen impacted the crash cushion head-on at 59 mph.

The Test 349 vehicle remained relatively stable, except for its moderate pitching motion during the test. The maximum rise of the c.g. at the front bumper of the vehicle during the test was 6.5 inches above its static or at rest c.g. location. This maximum rise value occurred when the vehicle had traveled 10.5 ft beyond the nose of the curbed gore.

The c.g. of the test vehicle rose above the c.g. of the sand masses of the first three sand barrels of the crash cushion as shown in Figure 37 during the test. The mid-height of the front bumper of the test vehicle, however, remained below the c. g. of these barrels at all times. Only the top of the 6 inch high front bumper which is 2.5 inches below the c.g. of the vehicle rose above the c.g. of the first 400 lb sand barrel of the crash cushion during Test 349.

The maximum rise trajectory of the test vehicle impacting the curbed gore without a crash cushion, Caltrans Jump Test No. 2, is also plotted on Figure 37 so that the rise curves could be compared. Test parameters (2370 lb vehicle/40 mph/head-on) were identical for both Caltrans Test 349 and Caltrans Jump Test No. 2.

During the impact, the passenger compartment of the vehicle remained intact. There was no intrusion of barrier or vehicle components.

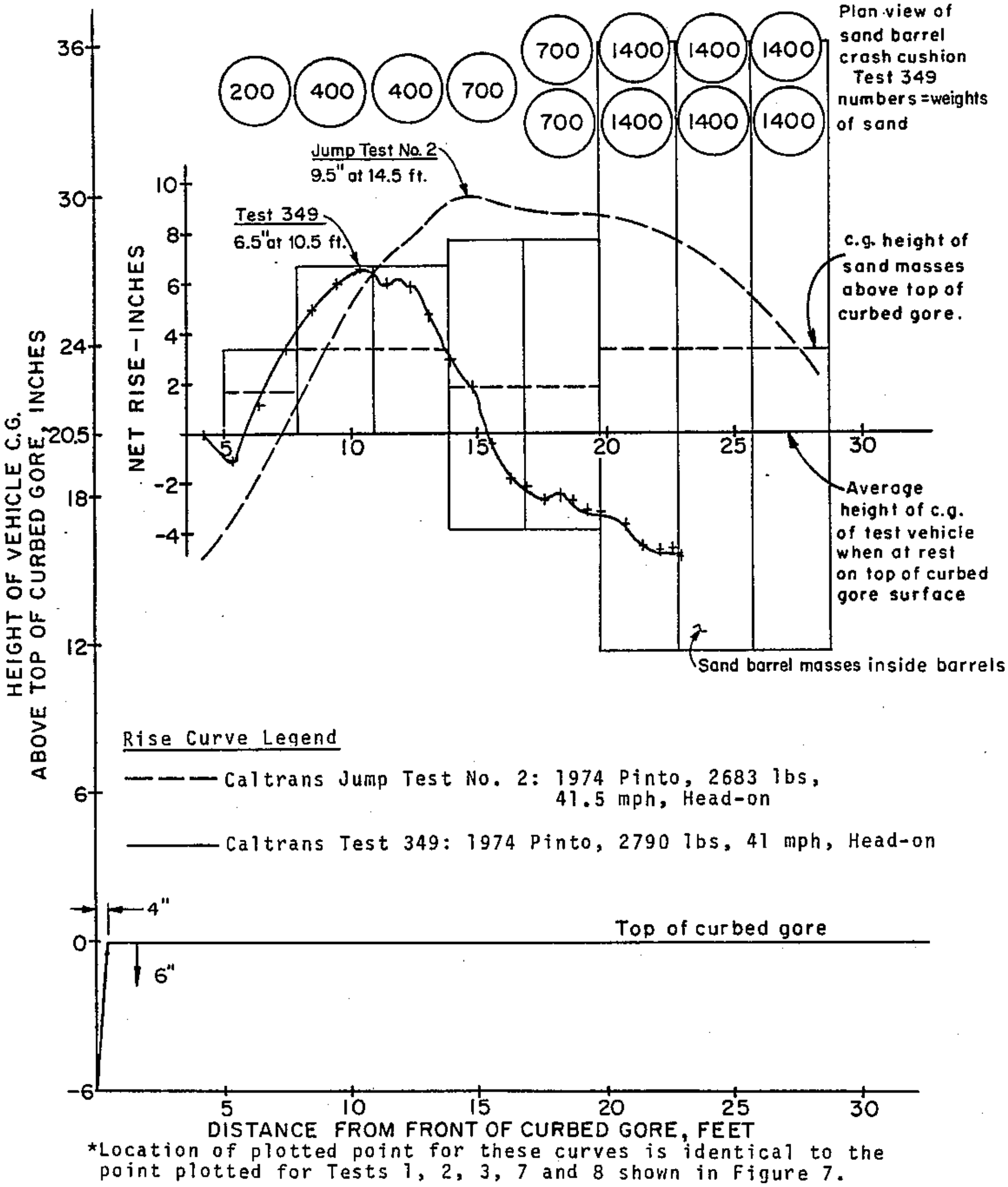
The vehicle remained on top of the curbed gore during impact. Loss of air in all four tires which occurred as the vehicle mounted the curb helped prevent the vehicle from rolling off the gore surface.

6.3.2 Impact Severity

Due to the low impact speed of 41 mph, the severity of the impact was reduced substantially. Only about 44% of the kinetic energy of a 60 mph impact was absorbed by the curbed gore and sand barrel crash cushion test.

The actual vehicle decelerations were well within the maximum vehicle deceleration values specified by TRC No. 191 (5). Maximum 50 millisecond vehicle decelerations in the longitudinal and lateral directions were 3.6 g's and 0.9 g's respectively. These values are much less than the recommended maximum values of 6 to 8 g's. Also the average deceleration value of 3.2 g's for the vehicle calculated from the formula $\frac{V^2}{2gs}$ where s is the stopping distance of the passenger compartment and V is the impact velocity is substantially less than the maximum permissible value of 12 g's. Accelerometer records of vehicle deceleration are contained in the Appendix, Figure C3.

Figure 37,* VEHICLE RISE VS DISTANCE FROM NOSE OF CURBED GORE WITH SAND BARREL CRASH CUSHION 5 FT. BACK FROM NOSE, TEST 349



*Location of plotted point for these curves is identical to the point plotted for Tests 1, 2, 3, 7 and 8 shown in Figure 7.

Electronic data responses from the anthropomorphic dummy lap belted in the driver's seat during the impact give a further indication of impact severity. Acceleration versus time traces for accelerometers mounted in the head cavity of the dummy are included in the Appendix C as Figure C4. A lap belt load vs. time trace is also included, Figure C5.

The lap belt load did not exceed the 5000 lb (222 kN) limit specified by Federal Motor Vehicle Safety Standard 208 (9) which is a guideline cited in TRC No. 191 (5).

6.3.3 Vehicle Trajectory Hazard

The trajectory of the test vehicle during and after the impact would not be hazardous to adjacent traffic. The test vehicle remained on top of the curbed gore after the impact.

Barrier debris spread to the sides of the curbed gore crash cushion site, however, may be hazardous to nearby traffic. The debris diagram, Figure 30, for the test shows two nearly whole polyethylene sand barrel shells located approximately 12 ft and 10.5 ft on either side of the curbed gore surface. In addition a potential hazard also exists from flying sand barrel lids. These new lids are heavier than those previously approved for use. They weigh about 8 to 10 lbs each. Whole lids were found 20 ft, 30 ft, and as far as 69 ft away from the sides of the curbed gore. This potential flying lid hazard probably would have been lessened if the lids had been riveted on to the barrels before the test.

6.3.4 Construction Considerations

On 6 inch high curbed gores where the front barrel in a normal array would be placed more than 5 ft and less than 50 ft back from the nose of the curbed gore, the following guidelines are recommended to bring the front barrel within 5 ft of the nose.

1. Stretch the crash cushion out to the maximum length possible by allowing 2'-0" maximum between the fixed object and the rear barrels; spacing the barrels 6 inches maximum apart; and adding two 400 lb barrels behind the 200 lb front barrel for a maximum of 10 "rows" of barrels in the crash cushion.

2. Remove part or all of the curbed gore if the front barrel is still over 5 ft from the nose.

At all locations of the crash cushion on the curbed gore, the barrels on the side of the crash cushion should be 0-3 ft from the curb face measured perpendicular to the face of the curb. This recommendation is based on this test series and previous research (2,3,12).

All crash cushion sites are different and should be analyzeed independently. If the above guidelines are not easily applied for a given site, the designer should seek expert advice.

7. REFERENCES

1. Federal Highway Administration, "Use of Crash Cushions on Federal-Aid Highways", FHWA Notice N5040.8, U.S. Department of Transportation, June 11, 1975.

2. Beaton, J. L. and R. N. Field, "Final Report of Full Scale Dynamic Tests of Bridge Curbs and Rails", Report No. 88-R-6012, California Division of Highways, August 1957.

3. Olson, R. M., et al., "Effect of Curb Geometry and Location on Vehicle Behavior", National Cooperative Highway Research Program Report 150, Transportation Research Board, 1974.

4. Dunlap, D. F., "Barrier - Curb Redirection Effectiveness", and "Curb-Guardrail Vaulting Evaluation", Highway Research Record No. 460, pp. 1-19.

5. Transportation Research Board, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", Transportation Research Circular No. 191, February 1978.

6. "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project Bulletin No. 1, National Safety Council, 1968.

7. "Collision Deformation Classification, Recommended Practice J224a", 1973 Handbook, Society of Automotive Engineers, New York, 1973.

8. Nordlin, E. F., et al, "Dynamic Tests of an Energy Absorbing Barrier Employing Sand-Filled Frangible Plastic Barrels, Series XXIV", Report No. 636405-4, California Division of Highways, July 1971.

9. U.S. Department of Transportation, "Occupant Crash Protection in Passenger Cars", FMVSS 208, Federal Register, DOT NHTSA (49 CFR Part 571).

10. Basso, G. L. "Functional Derivation of Vehicle Parameters for Dynamic Studies", LTR-ST747, National Research Council of Canada, Ottawa, Canada.

11 Rasmussen, R. E., F. W. Hill, and P. M. Riede, Typical Vehicle Parameters for Dynamics Studies", Report No. A-2542, General Motors Proving Ground, Milford, Michigan, April 1970.

12. Nordlin, E. F. et al, "Dynamic Full Scale Impact Tests of Cable Type Median Barriers, Test Series IX", California Division of Highways, June 1965.

APPENDIX A: Test Vehicle Equipment and Guidance Methods

A.1 Test Vehicle Equipment

A.1.1 Curbed Gore Vehicle Jump Tests

The following modifications were made to the two vehicles used for the eight live driver tests:

- The test vehicle gas tank was disconnected from the fuel supply line and drained. Shortly before the test, dry ice was placed in the tank as a safety precaution to drive out the gas fumes. A one-gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line, Figure A1.

- Two 12-volt wet cell motorcycle storage batteries, Figure A2, were mounted in the trunk to supply power to a high speed camera located inside the vehicle.

- A six point roll bar was welded to the frame of the test vehicle to provide protection for the driver.

- A three point safety harness including a lap belt, shoulder straps, and a submarine strap was also installed for the driver's safety.

A.1.2 Test of Sand Barrel Crash Cushion on Curbed Gore

Vehicle modifications for the crash test are itemized as follows:

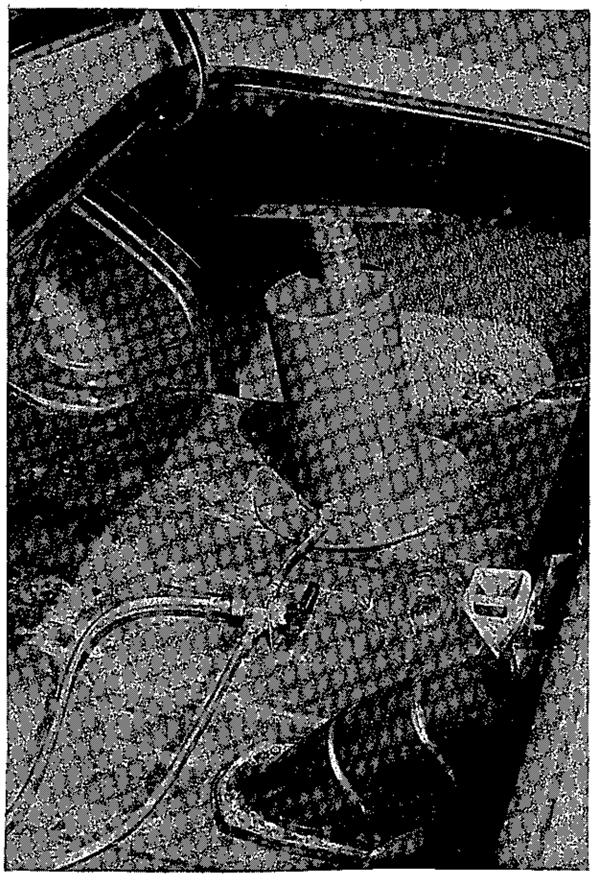


Figure A1. 1 Gallon Safety Gas Tank

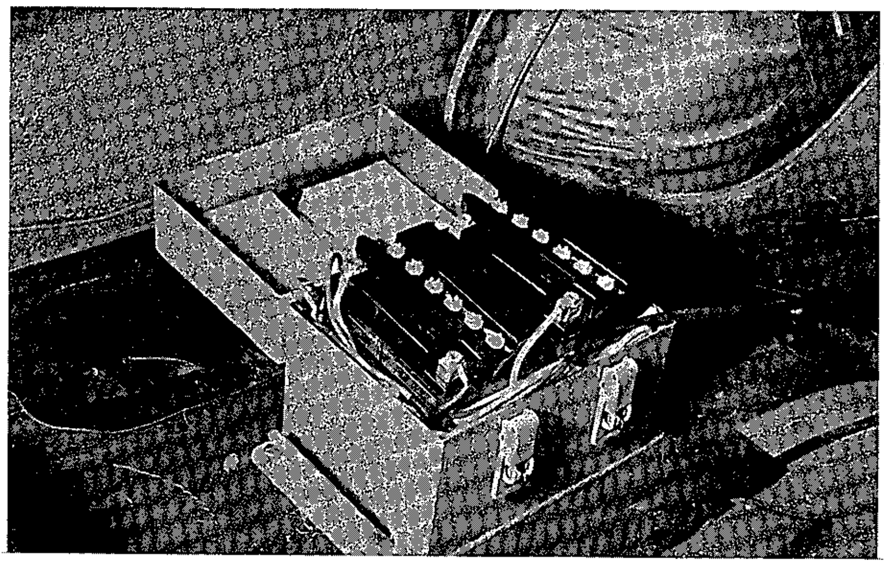


Figure A2. 12-Volt Wet Cell Motorcycle Batteries

- The test vehicle gas tank was disconnected from the fuel supply line and drained. Shortly before the test, dry ice was placed in the tank. A one-gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

- Four 12-volt wet cell motorcycle storage batteries were mounted on the floor of the rear seat compartment to supply power for the accelerator motor and the solenoid-valve brake system.

- A solenoid-valve actuated CO_2 system was connected to the brake line for remote braking. With 700 psi in the accumulator tank, the brakes could be locked in less than 100 milliseconds after activation. Brakes were activated by remote control.

- The ignition system was connected to the brake relay in a failsafe interlock system. When the brake system was activated, the vehicle ignition was switched off.

- A micro switch was mounted below the front bumper and connected to the ignition system. A trip line installed near impact triggered the switch, thus opening the ignition circuit and cutting the vehicle motor prior to impact.

- The accelerator pedal was linked to a small electric motor which, when activated, opened the throttle, Figure A3. The motor was activated by a manually thrown switch mounted on the top of the rear fender of the test vehicle.

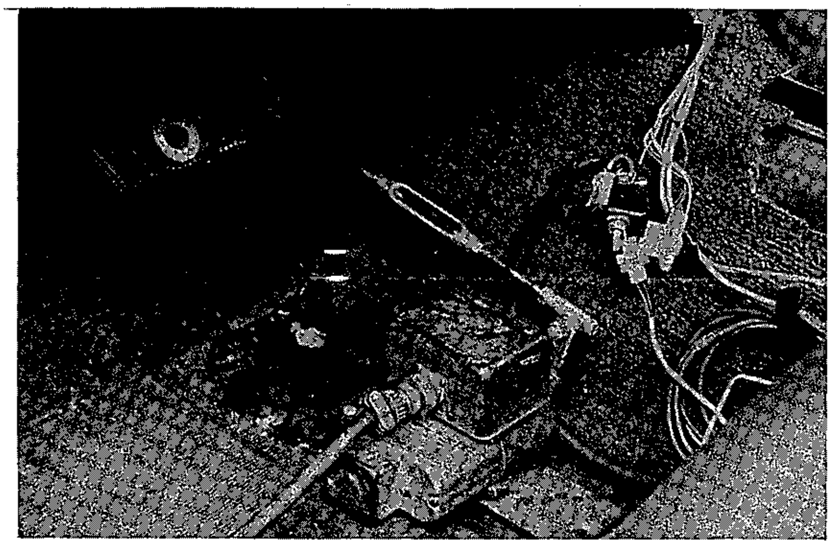


Figure A3. Accelerator Motor

- A speed control device connected between the negative side of the coil and the battery of the vehicle regulated the speed of the test vehicle based on engine revolutions per minute. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tapeswitches set a known distance apart connected to a digital timer.

A.2 Vehicle Guidance Control System

This system was only used for the vehicular crash test of the sand barrel crash cushion placed on top of the 6 inch (152 mm) high curbed gore.

A cable guidance system was used to direct the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path, passed through a slipbase guide bracket,

Figure A4, bolted to the spindle of the left front wheel of the vehicle. A steel angle bracket, Figure A5, anchoring the end of the cable closest to the barrier to a concrete footing, projected high enough to knock off the guide bracket, thereby releasing the vehicle from the guidance cable prior to impact.

The remote brakes were controlled at the console trailer, located adjacent to the impact area, by using an instrumentation cable connected between the vehicle and the electronic instrumentation trailer, and a cable from that trailer to the console trailer. Any loss of continuity in these cables caused the brakes to activate automatically.

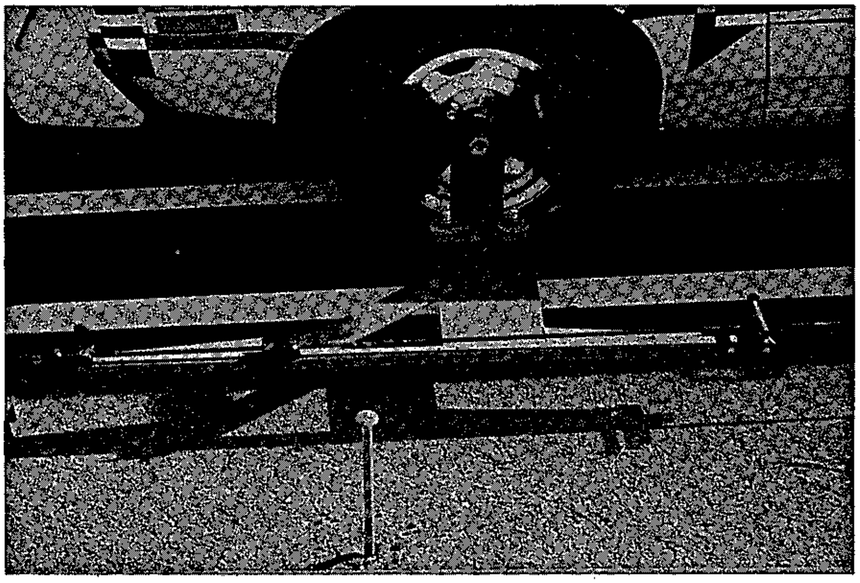


Figure A4. Slipbase Guide Bracket

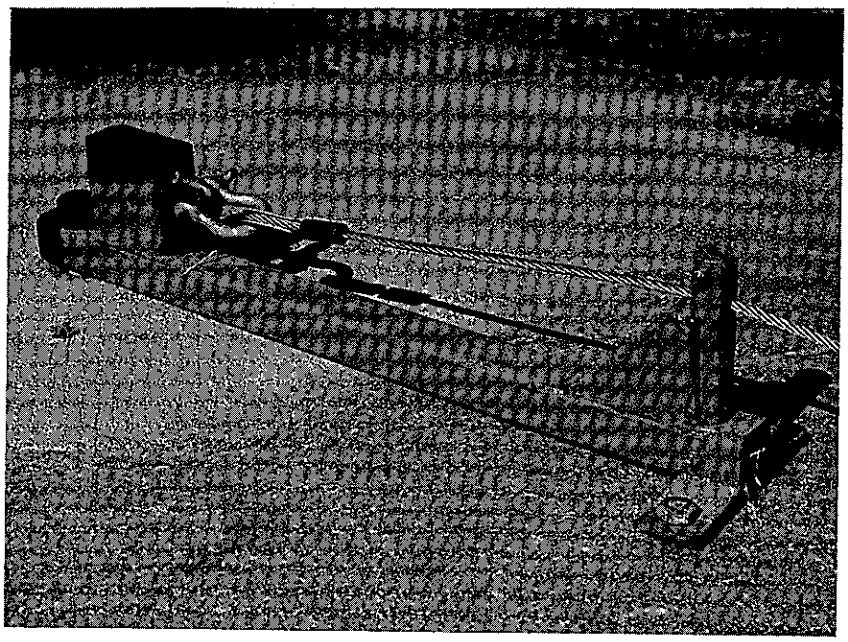


Figure A5. Steel Knockoff Bracket

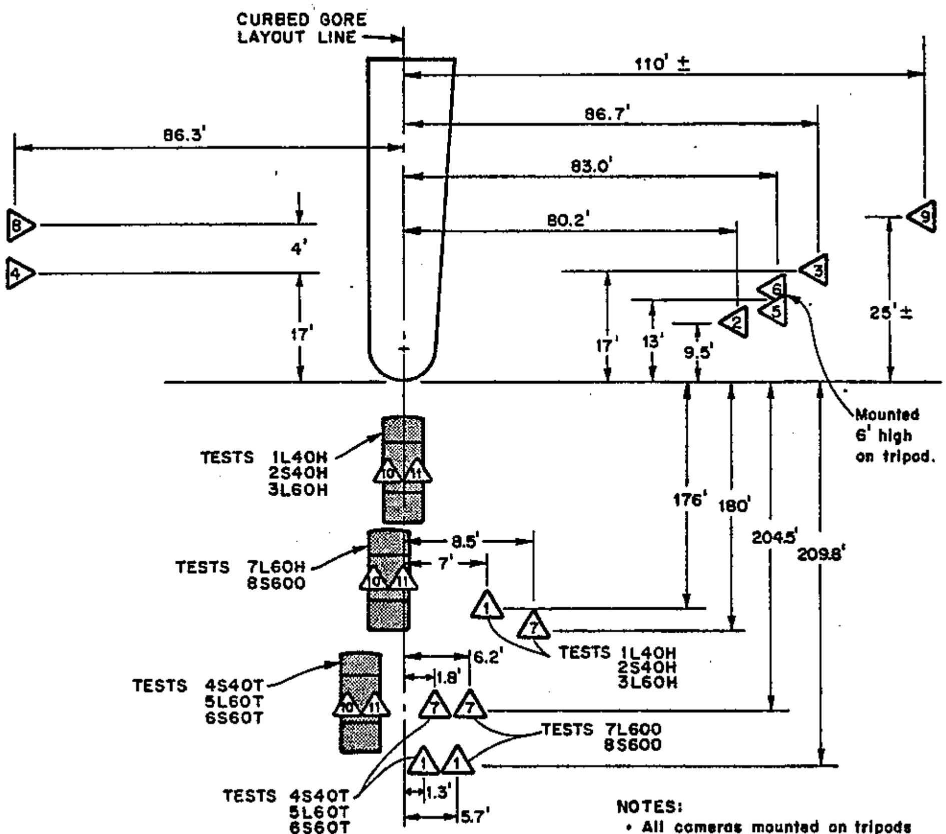
APPENDIX B: Photo-Instrumentation and Analysis Techniques

B.1 Curbed Gore Vehicle Jump Tests

Data film was obtained by using four high speed Photo-Sonics Model 16mm-1B cameras, 200-400 frames per second (fps) and two high speed Redlake Locam cameras, 500 fps. These field cameras were located around the barrier as shown in Figure B1, Camera Layout. All field cameras were electrically actuated from a central control console located adjacent to the impact area.

In addition to the field cameras a high speed Photo-Sonics Model 16mm-1B camera and a Bolex camera were mounted on a bracket inside the test vehicle, Figure B2. Two Mini Pro 650 watt heads provided light for the cameras mounted inside the vehicles. These light sources were each powered by a 30-volt battery belt. The interior cameras and lights were actuated by four toggle switches mounted on a board and secured to the front seat of the test vehicle, Figure B2.

All high speed cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships. Additional coverage of the impacts was obtained by a 70mm Hulcher sequence camera and a 35mm Hulcher sequence camera (both operating at 20 frames per second). Documentary coverage of the tests consisted of normal speed movies and still photographs taken before, during, and after each impact. Data from the high speed movies was reduced on a Vanguard Motion Analyzer, Figure B3.



CAMERA DATA

NOTES:
- All cameras mounted on tripods 27" above top of curb surface unless noted other wise.
- 1 Ft. = 0.305 m ; 1 in = 25.4 mm
- fps = Frames per second

(1) - Redlake Locam 16mm, 100 mm lens, 500 fps.
(2) - Redlake Locam 16mm, 25 mm lens, 500 fps.
(3) - Photo-Sonics model 16 mm-1B, 13 mm lens, 300-350 fps.
(4) - Photo-Sonics model 16 mm-1B, 13 mm lens, 200 fps.
(5) - Photo-Sonics model 16 mm-1B, 2" lens, 300-350 fps, Pan camera.
(6) - Bolex, 1" lens, 24 fps, Pan camera.
(7) - Photo-Sonics model 16 mm-1B, 100 mm lens, 300-350 fps.
(8) - 35 mm Hulcher, 45 mm lens, 20 fps, sequence - color slides.
(9) - 70 mm Hulcher, 13 mm lens, 20 fps, black & white sequence photos.
(10) - Bolex, 16 mm, 1" lens 24 fps. Inside test vehicle.
(11) - Photo-Sonics model 16 mm-1B, 13 mm lens, 200 fps. Inside test vehicle.

Figure B 1 , CAMERA LAYOUT

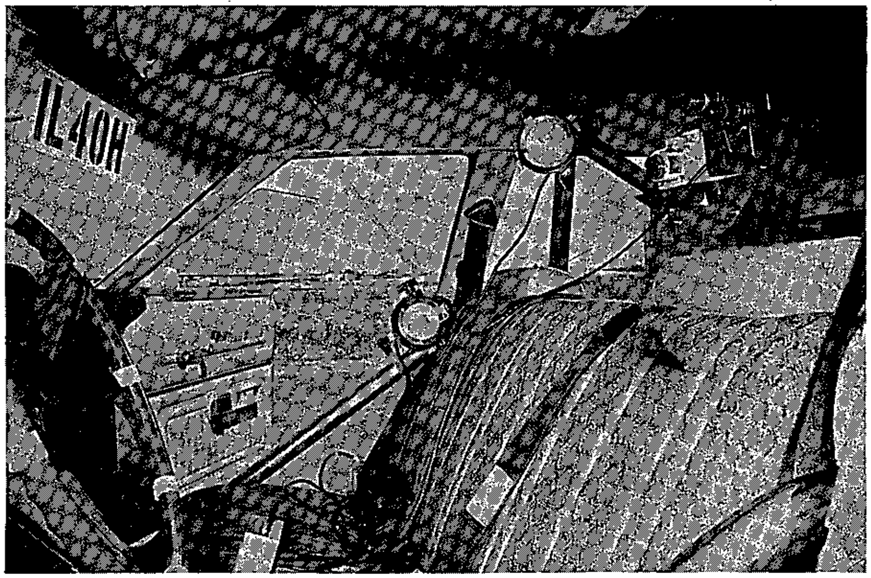


Figure B2. Photo-Sonics and Bolex Cameras; Mini Pro 650 Lights; and Taped Steering Wheel

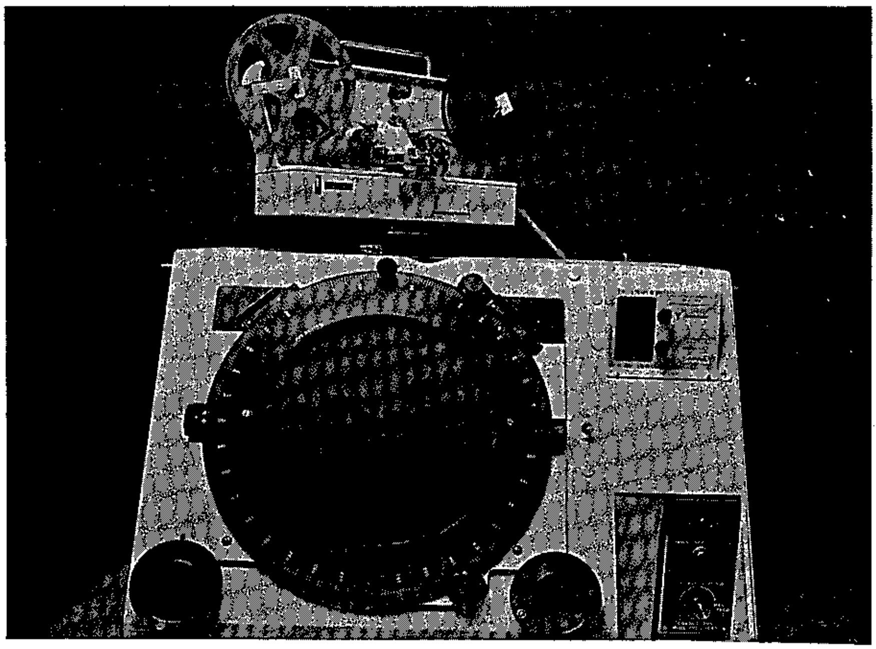


Figure B3. Vanguard Motion Analyzer

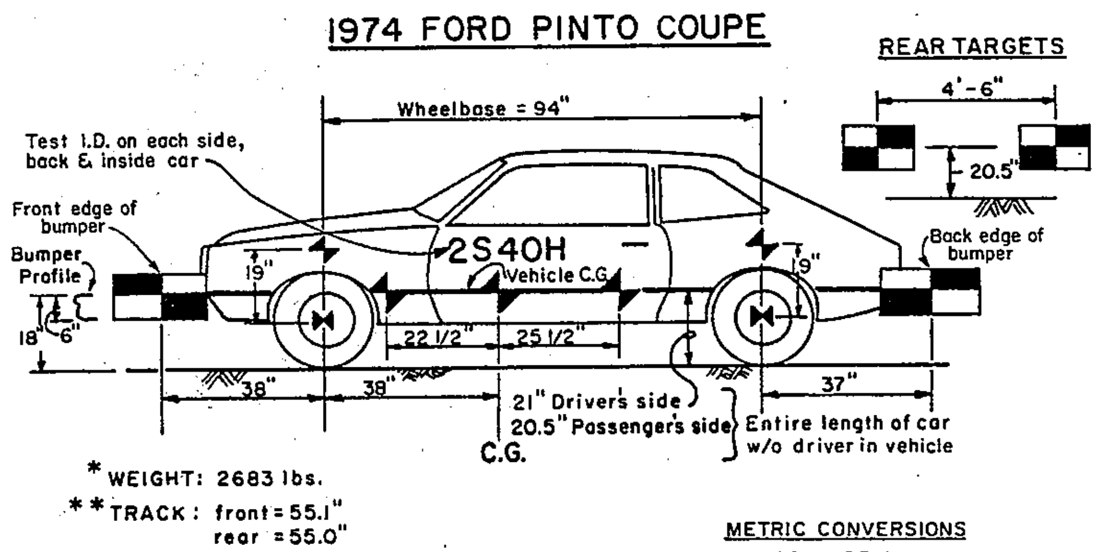
Some procedures used to facilitate data reduction for the test are listed as follows:

1. Targets were attached to the vehicle body and to the barrier, Figures B4 and B5.

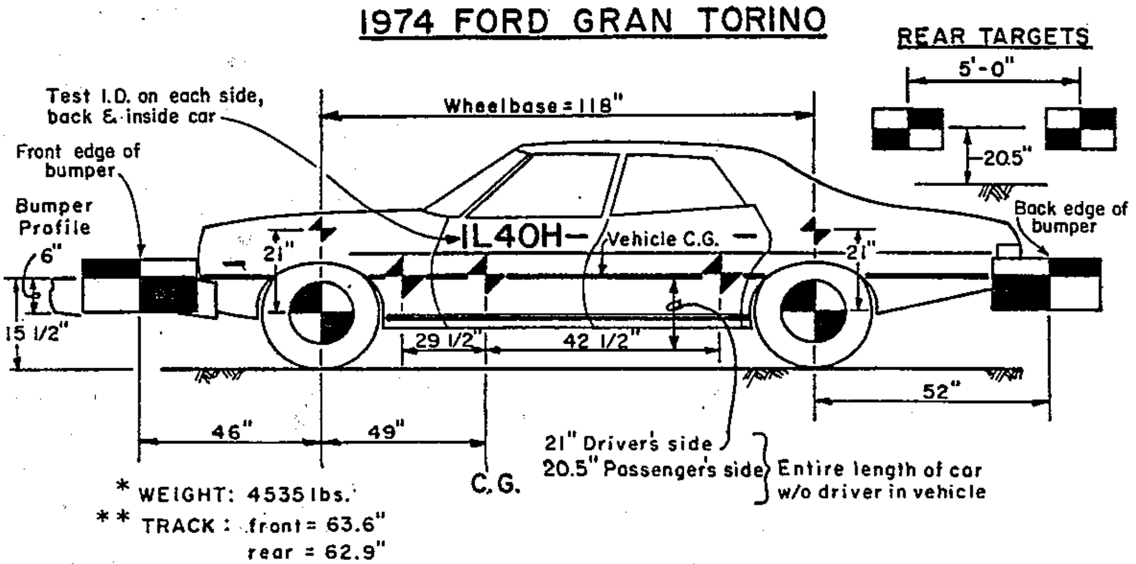
2. Five tape switches, placed at 10 ft intervals, were attached to the ground perpendicular to the path of the impacting vehicle beginning 1 ft from impact, Figure B5. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of all the data cameras and was used to correlate the cameras with the impact events.

3. The steering wheel of each vehicle was taped every 30 degrees to detect any steering motions during the tests.

Figure B4, VEHICLE DIMENSIONS, PARAMETERS & TARGETING



METRIC CONVERSIONS
1 in. = 25.4 mm
1 ft. = 0.305 m
1 lb = 0.454 kg



* Includes driver and instrumentation
** Lateral distance between the centers of tire contact of a pair of wheels.

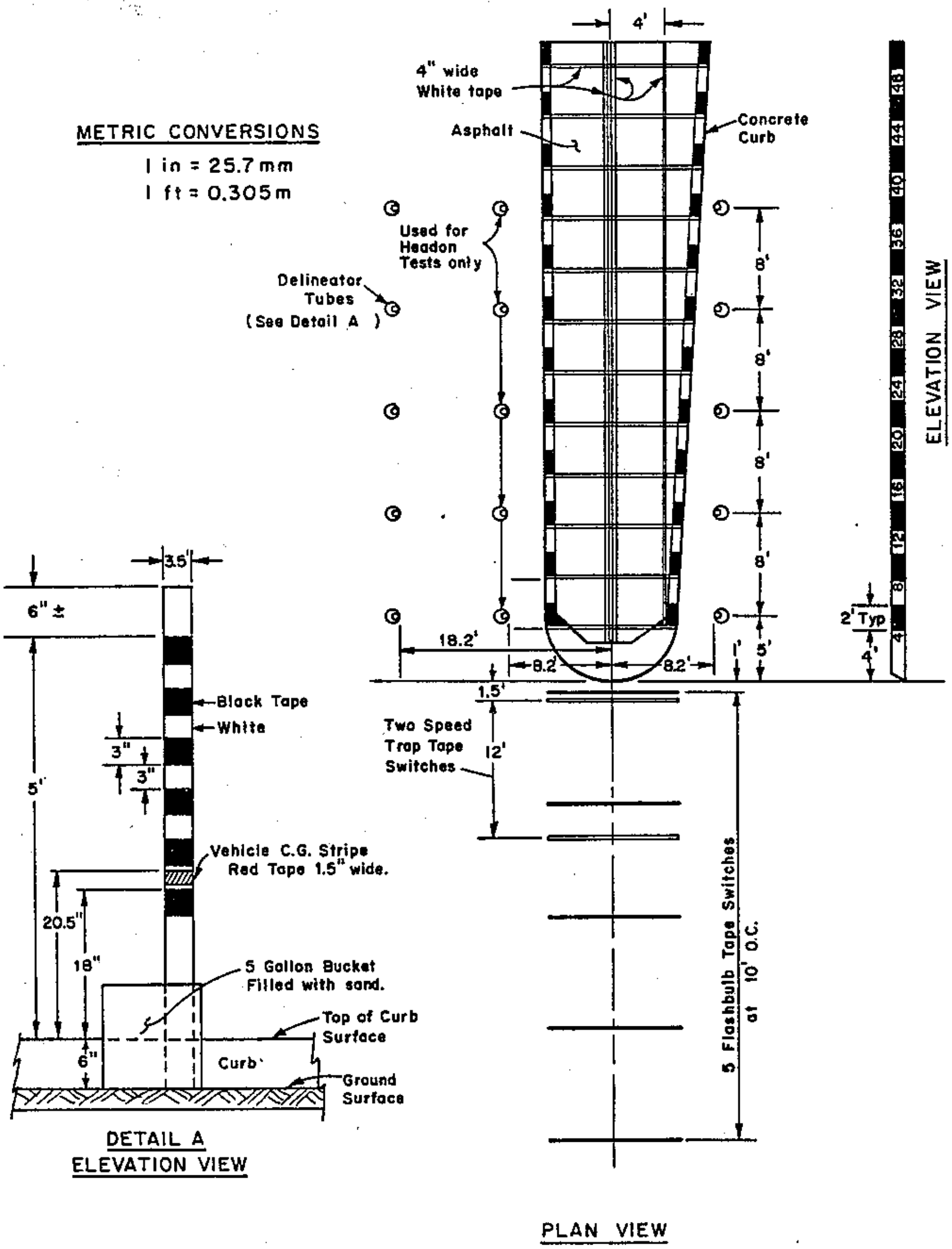


Figure B5 , BARRIER TARGETING & INSTRUMENTATION
CALTRANS CURBED GORE JUMP TESTS

B.2 Test of Sand Barrel Crash Cushion on Curbed Gore

Data film was obtained by using eight high speed Photo-Sonics Model 16 mm-1B cameras, 200-400 frames per second (fps), and three high speed Redlake Locam cameras, 500 fps. These cameras were located around the barrier as shown in Figure B6. These cameras were electrically actuated from a central control console located adjacent to the impact area.

All cameras were equipped with timing light generators and additional coverage of the impact was obtained with 70 mm and 35 mm Hulcher sequence cameras as explained in Section B.1.1. Normal speed movies and still photographs also served to document the test.

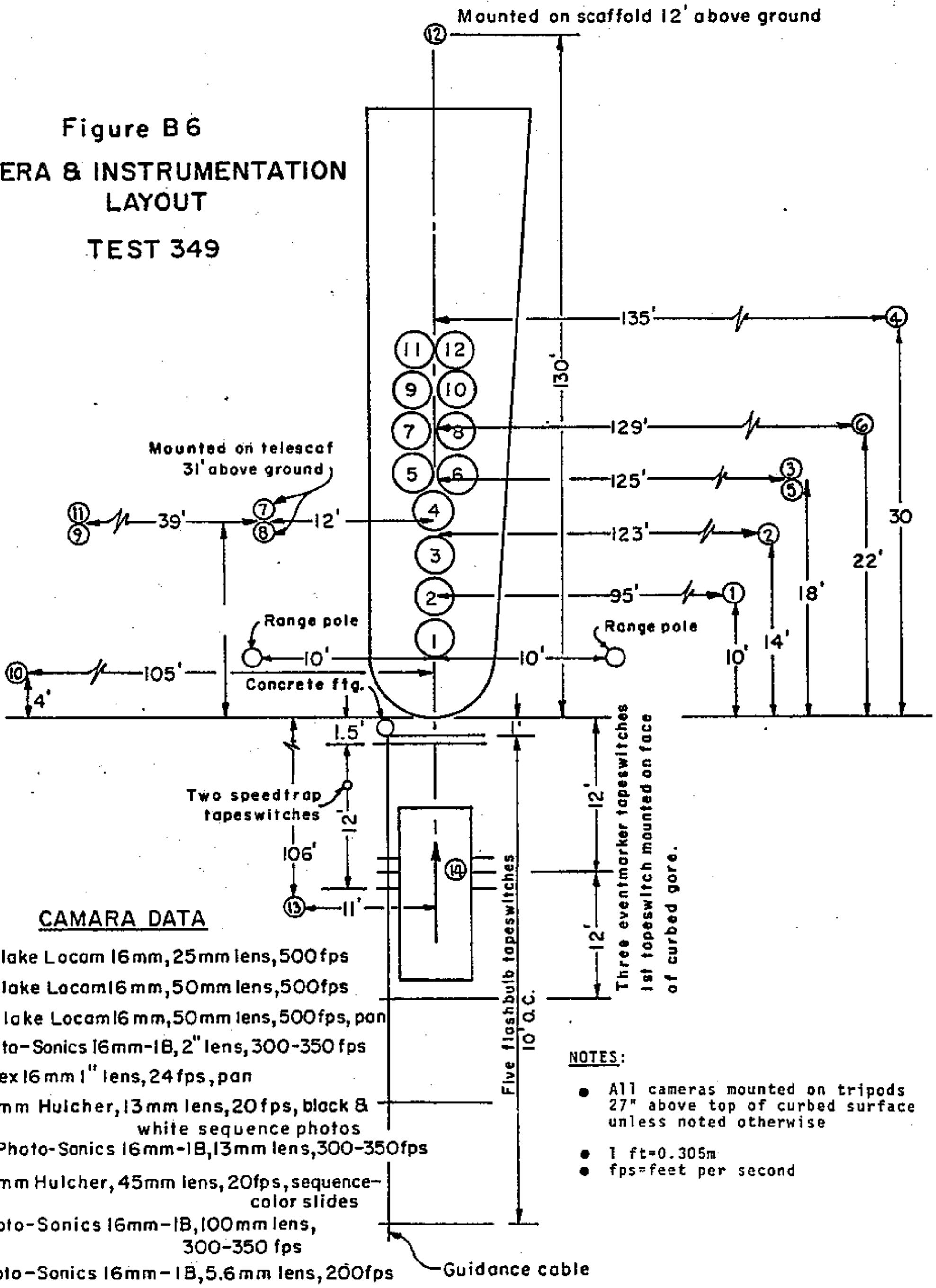
The test vehicle was targeted as shown in Figure B7 to facilitate data reduction. In addition, flashbulbs, mounted on the test vehicle, were electronically flashed to establish initial vehicle/barrier contact and the application of the vehicle's brakes. These flashbulbs have a delay of several milliseconds before lighting up.

Five tape switches, Figure B6, were also attached to the ground in the path of the impacting vehicle as explained in Section B.1.1.

Figure B6

CAMERA & INSTRUMENTATION LAYOUT

TEST 349



CAMARA DATA

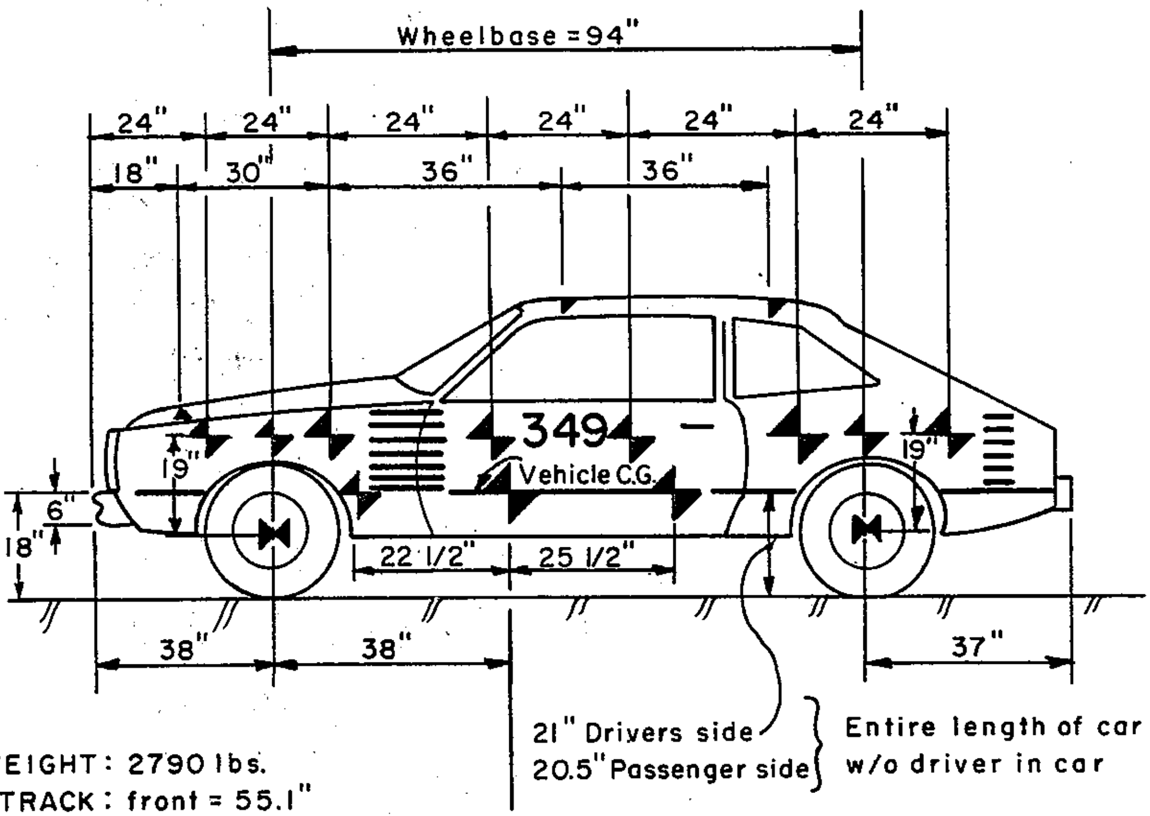
- (1) Redlake Locam 16mm, 25mm lens, 500fps
- (2) Redlake Locam 16mm, 50mm lens, 500fps
- (3) Redlake Locam 16mm, 50mm lens, 500fps, pan
- (4)(10) Photo-Sonics 16mm-1B, 2" lens, 300-350 fps
- (5) Bolex 16mm 1" lens, 24fps, pan
- (6) 70 mm Hulcher, 13mm lens, 20fps, black & white sequence photos
- (7)(8)(9) Photo-Sonics 16mm-1B, 13mm lens, 300-350fps
- (11) 35mm Hulcher, 45mm lens, 20fps, sequence-color slides
- (12)(13) Photo-Sonics 16mm-1B, 100mm lens, 300-350 fps
- (14) Photo-Sonics 16mm-1B, 5.6mm lens, 200fps

NOTES:

- All cameras mounted on tripods 27" above top of curbed surface unless noted otherwise
- 1 ft=0.305m
- fps=feet per second

Figure B7, VEHICLE DIMENSIONS, PARAMETERS & TARGETING

1974 FORD PINTO COUPE



* WEIGHT : 2790 lbs.
** TRACK : front = 55.1"
rear = 55.0"

* Includes dummy and instrumentation

** Lateral distance between the centers of tire contact of a pair of wheels.

(No Scale)

METRIC CONVERSION

1 in	=	25.4 mm
1 ft	=	0.305 m
1 lb	=	0.454 kg

APPENDIX C: Electronic Instrumentation and Data

C.1 Curbed Gore Vehicle Jump Tests

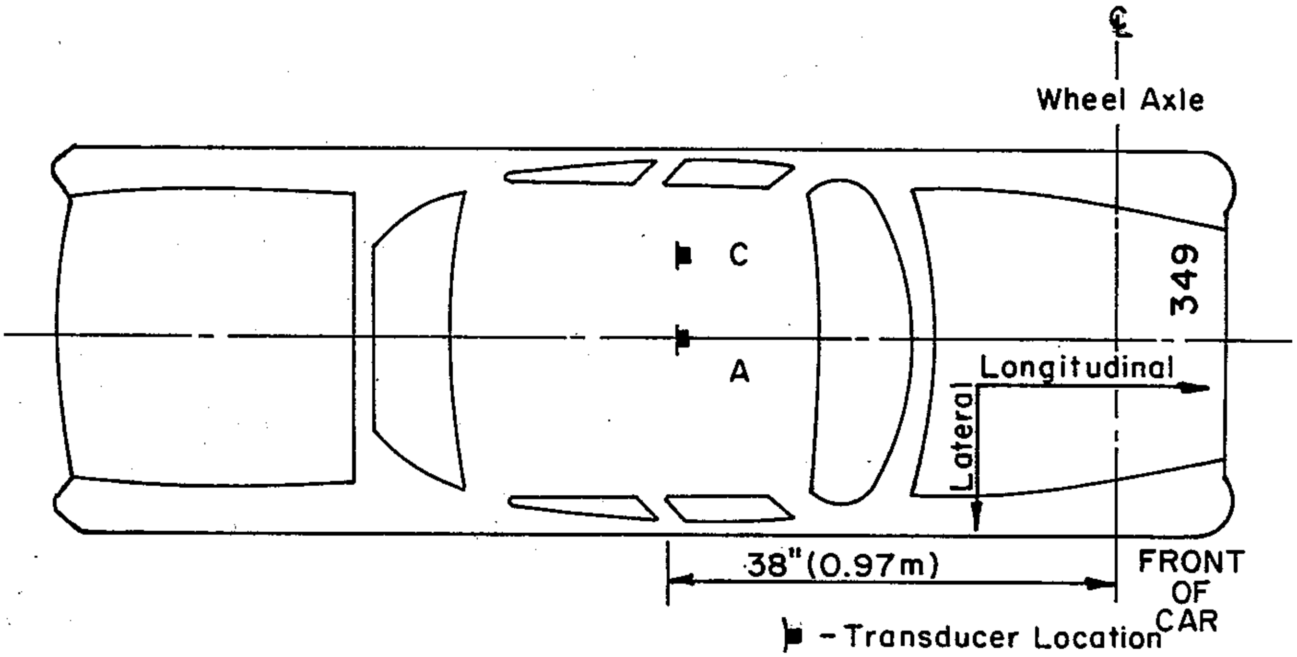
There was no electronic instrumentation mounted in the test vehicles for the eight live driver curbed gore vehicle jump tests. Two tape switches were placed 12 ft apart near the barrier specifically to determine impact speed of the vehicle on test day, Figure B5.

C.2 Test of Sand Barrel Crash Cushion on Curbed Gore

Data from all transducers in the test vehicle were transmitted through a 1000 foot Belden #8776 umbilical cable connecting the vehicle to a fourteen channel Hewlett Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area.

Figure C1 shows the locations of all transducers mounted in the test vehicle. Five Statham accelerometers, of the unbonded strain gage type, and two Endevco Model 2262-200 piezoresistive accelerometers were used for acceleration measurements. Three were mounted in the head cavity of the anthropomorphic dummy. The other accelerometers were mounted on a steel plate welded to the floor over the drive shaft at the horizontal center of gravity of the vehicle as shown in Figure C2. One seat belt transducer was installed on the dummy's lap belt for the test.

Figure C1, VEHICLE INSTRUMENTATION



1974 FORD PINTO COUPE, 2790 LBS. (1267 kg)

CHANNEL NO.	TRANSDUCER		LOCATION	
	TYPE	SER.NO.		
1	Accelerometer	590	C	Stan's head (Dummy) Longitudinal
2	Accelerometer	591	C	Stan's head (Dummy) Lateral
3	Accelerometer	1029	C	Stan's head (Dummy) Vertical
4	Accelerometer	589	A	Floor at C.G. Longitudinal
5	Accelerometer	586	A	Floor at C.G. Lateral
7	Accelerometer	AN92	A	Floor at C.G. Longitudinal
8	Accelerometer	DG66	A	Floor at C.G. Vertical
9	Seat Belt	275	C	Stan's Lap Belt (Dummy)

METRIC CONVERSIONS

1 in = 25.4 mm
1 lb = 0.454 kg

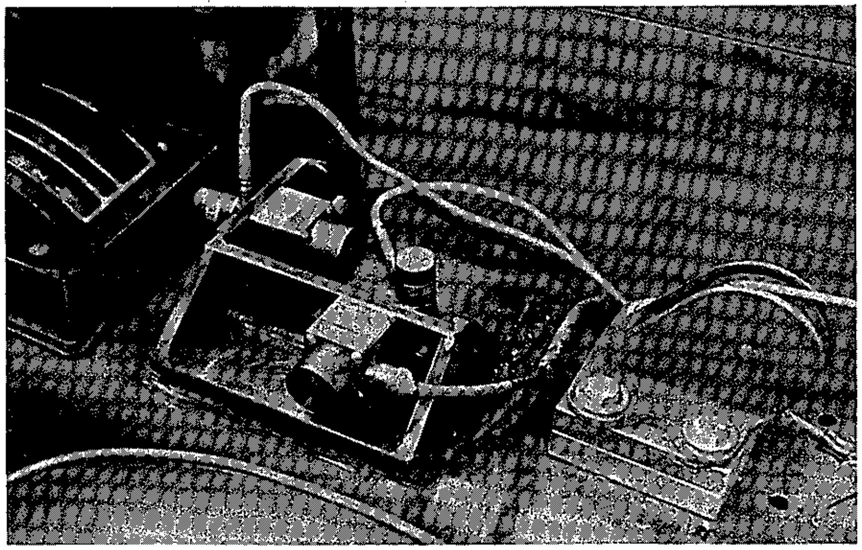


Figure C2. Accelerometers Mounted in Test Vehicle

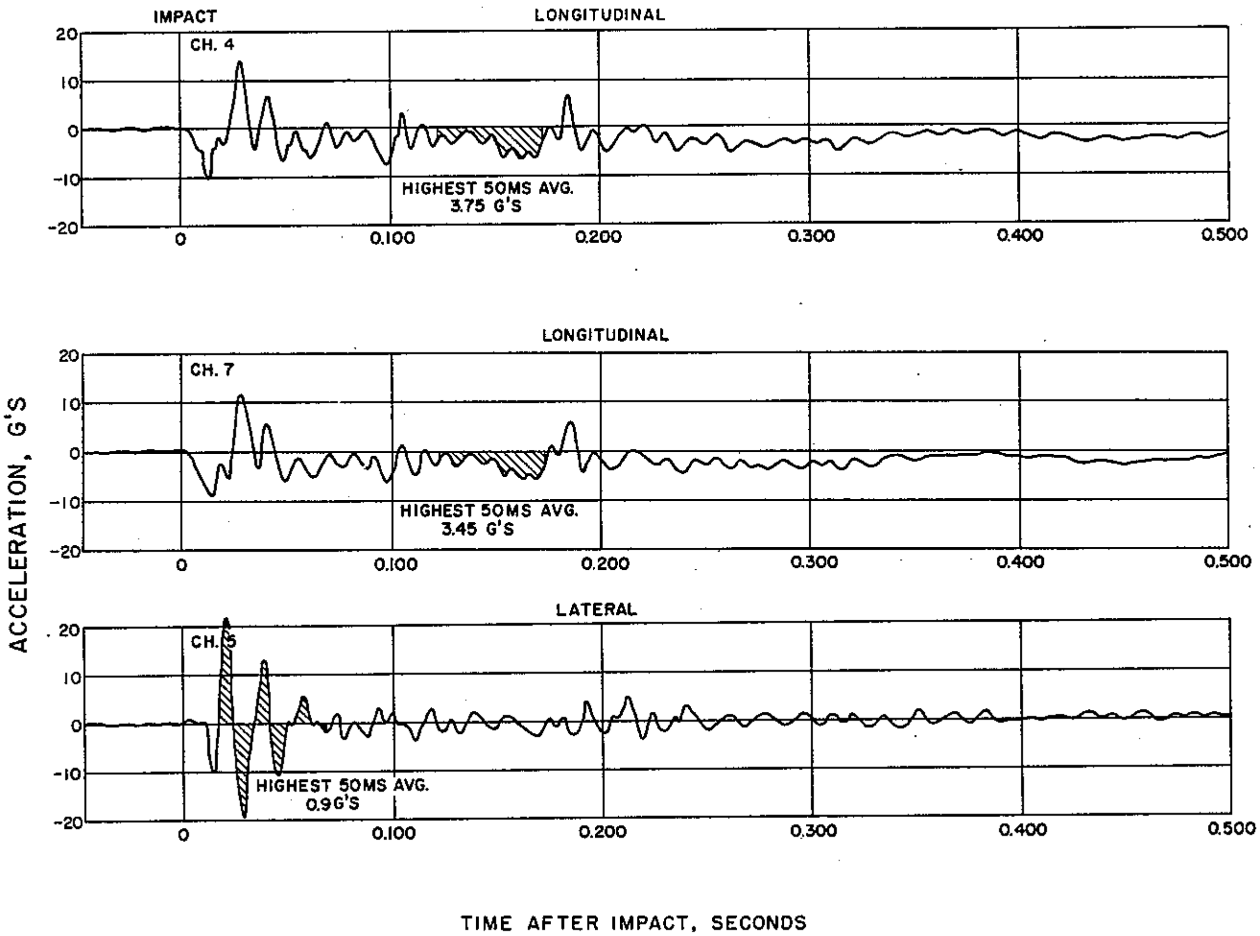
Two pressure activated tape switches attached to the ground and one attached to the front of the curbed gore were spaced 12 ft apart to represent "event markers", Figure B6. A time cycle and two additional speed trap tape switches were also used as explained in Section C.1.

After the test the tape recorder data was played back through a Visicorder which produced an oscillographic trace (line) on paper for each channel of the tape recorder. Each paper record contained a curve of data representing one transducer, signals from the three tape switches, and the time cycle markings.

Longitudinal and lateral vehicle acceleration records for Test 349 are shown in Figure C3. The data trace for the vertical accelerometer placed in the vehicle was invalid because it went into oscillications after impact with

Figure C3, VEHICLE ACCELERATION VS TIME

TEST 349, 2790 LB. VEHICLE, 41 M.P.H., 0° (HEAD-ON)
SAND BARREL CRASH CUSHION ON 6" HIGH CURBED GORE



METRIC CONVERSION

1 lb = 0.454 kg
1 mph = 0.447 m/s
1 deg. = 0.0175 rad
1 in. = 25.4 mm

the sand barrel crash cushion. Acceleration responses of the anthropomorphic dummy and the lap belt record for the test are shown in Figures C4 and C5.

Some of the accelerometer data records contained high frequency spikes. This data was filtered at 100 Hertz with a Krohn-Hite filter to facilitate data reduction. The smoother resultant curves give a good representation of the overall deceleration of the vehicle without significantly altering the amplitude and time values of the acceleration pulses.

Figure C4. DUMMY ACCELERATION VS TIME

TEST 349, 2790 LB. VEHICLE, 41 M.P.H., 0°(HEAD-ON), LAP BELT
SAND BARREL CRASH CUSHION ON 6" HIGH CURBED GORE

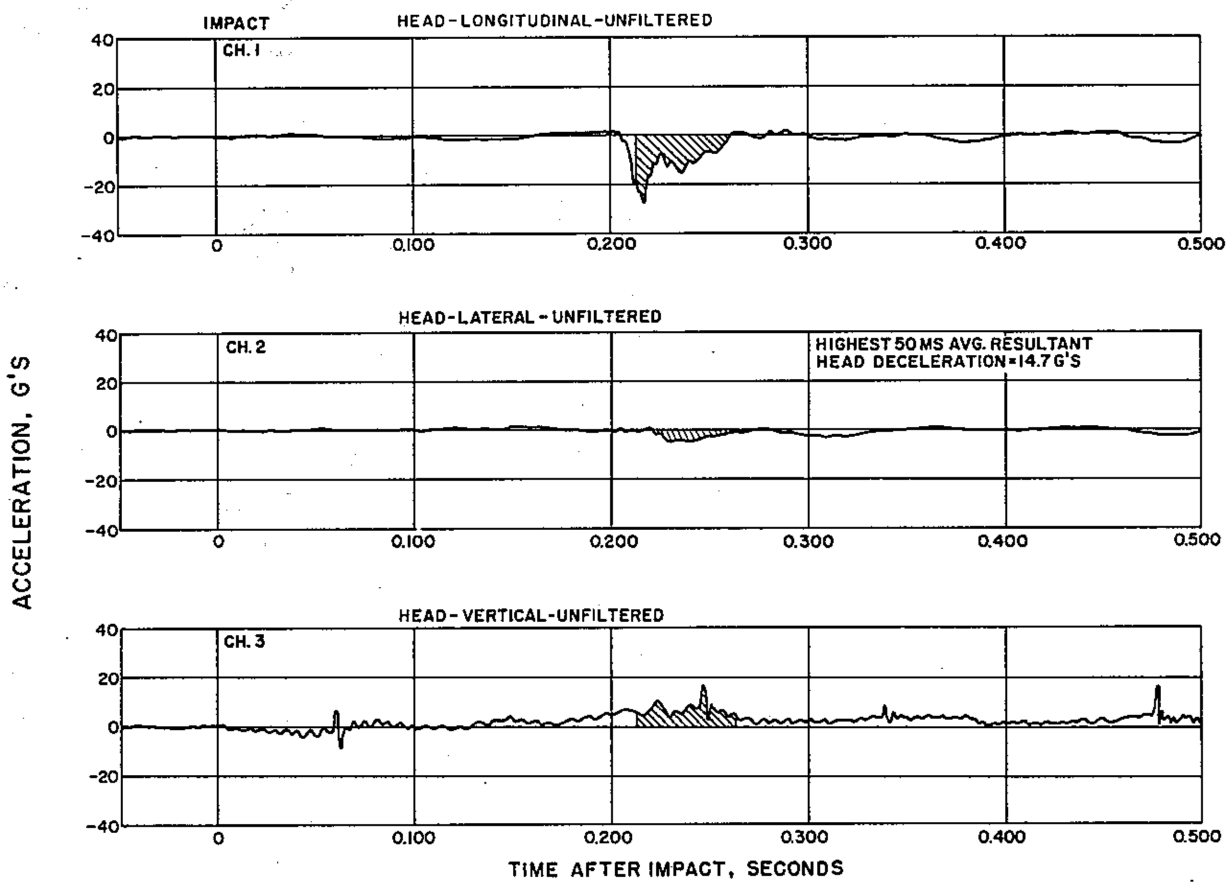
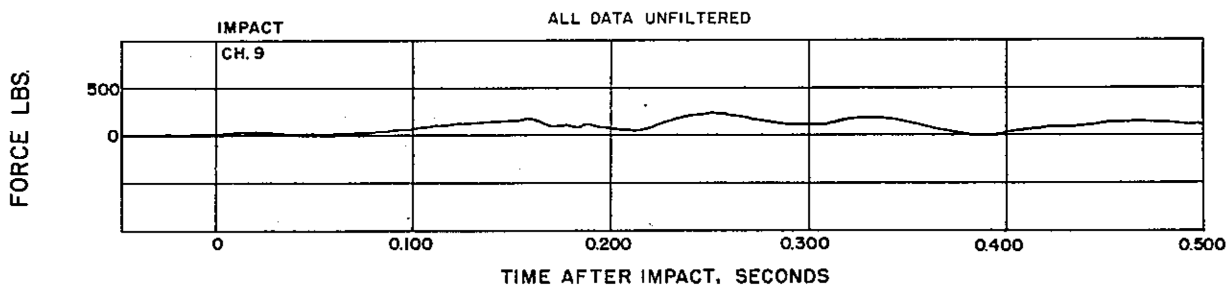


Figure C5. DUMMY LAP BELT LOAD VS TIME

TEST 349, 2790 LB. VEHICLE, 41 M.P.H., 0°(HEAD-ON), LAP BELT
SAND BARREL CRASH CUSHION ON 6" HIGH CURBED GORE



METRIC CONVERSION
1 lb = 0.454 kg
1 mph = 0.447 m/s
1 deg = 0.0175 rad
1 in = 25.4 mm

APPENDIX D: Representative Vehicle Parameters and Suspension Diagrams and Photographs

Table D1 (6) itemizes the more important vehicle parameters including dimensions, mass parameters, moments of inertia, suspension parameters and others for the two vehicles used for this research study.

Figures D1 and D2 show some assembled and disassembled views of the front end and steering section and the rear suspension for the 1974 Ford Pinto and 1974 Ford Gran Torino used for this study. Closeup photographs of the front suspensions for both vehicles are shown in Figures D3 and D4.

TABLE D1* REPRESENTATIVE DATA FOR FORD PRODUCTION MODELS

Parameter	Units	1974 Pinto Subcompact	1974 Torino Intermediate
Dimensions:			
Wheelbase	in	94.2	118
Track: Front	in	55.1	63.6
Rear	in	55.0	62.9
Rear Spring Spacing	in	42.2	33.7
Wheel Centre Height	in	10.7	11.8
Mass Parameters: (Design Load = 1 less than max. no. of passengers)			
Total Weight	lb	2925	4694
Weight distribution: Front	lb	1504	2318
Unsprung Weight: Front	lb	147	257
Rear	lb	219	355
Vertical C.G. (above ground)	in	20.6	20.4
**Moment of Inertia: Roll[1]	$lb\text{-}sec^2\text{-}in$	1970	5530
Pitch[2]	$lb\text{-}sec^2\text{-}in$	12,140	37,260
Yaw[2]	$lb\text{-}sec^2\text{-}in$	19,570	47,570
Suspension:			
Wheel Spring Rate: Rear	lb/in	95	130
Front	lb/in	280	270
Rear Roll Steer	%	9.5	5.7
Roll Stiffness: Front	lb-ft/deg	262	782
Rear	lb-ft/deg	187	138
Wheel Travel (metal to metal)			
Front: Jounce	in	3.37	4.24
Rebound	in	3.63	4.11
Rear: Jounce	in	3.51	3.07
Rebound	in	3.26	5.72
Rear Roll Centre	in	9.4	7.90
Suspension Stop Spring Rate:			
Front	lb/in	1200	500
Rear	lb/in	210	625
Ride Rate: Front	lb/in	111	105
Rear	lb/in	110	130

* This information was obtained from reference 10

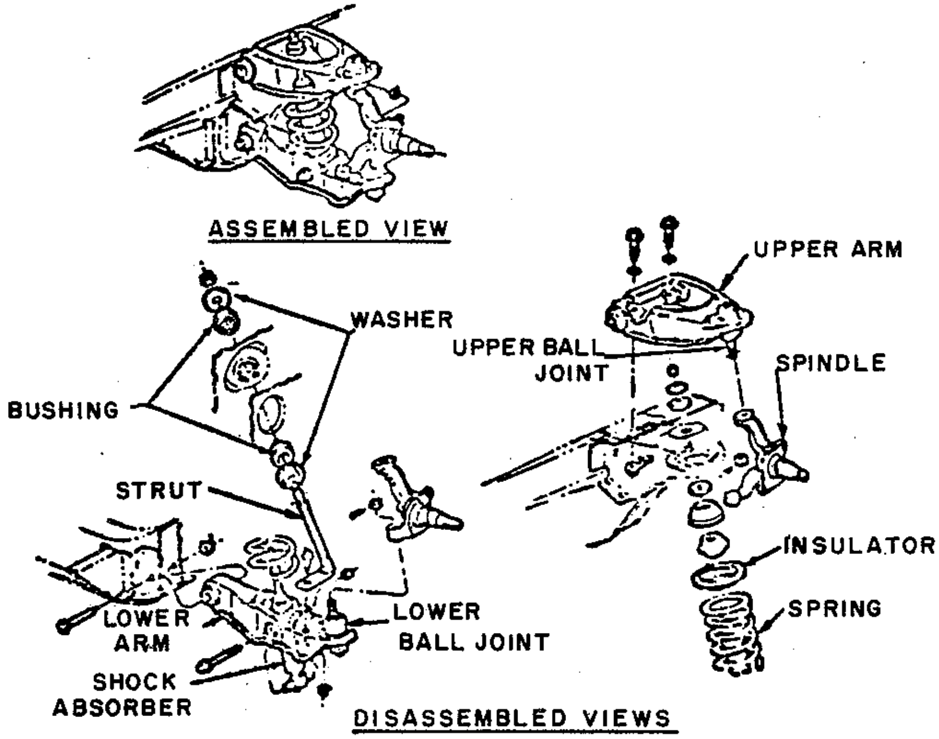
** Estimates based on straight line approximations obtained from reference 11

1. Sprung mass
2. Unsprung mass

Metric Conversions

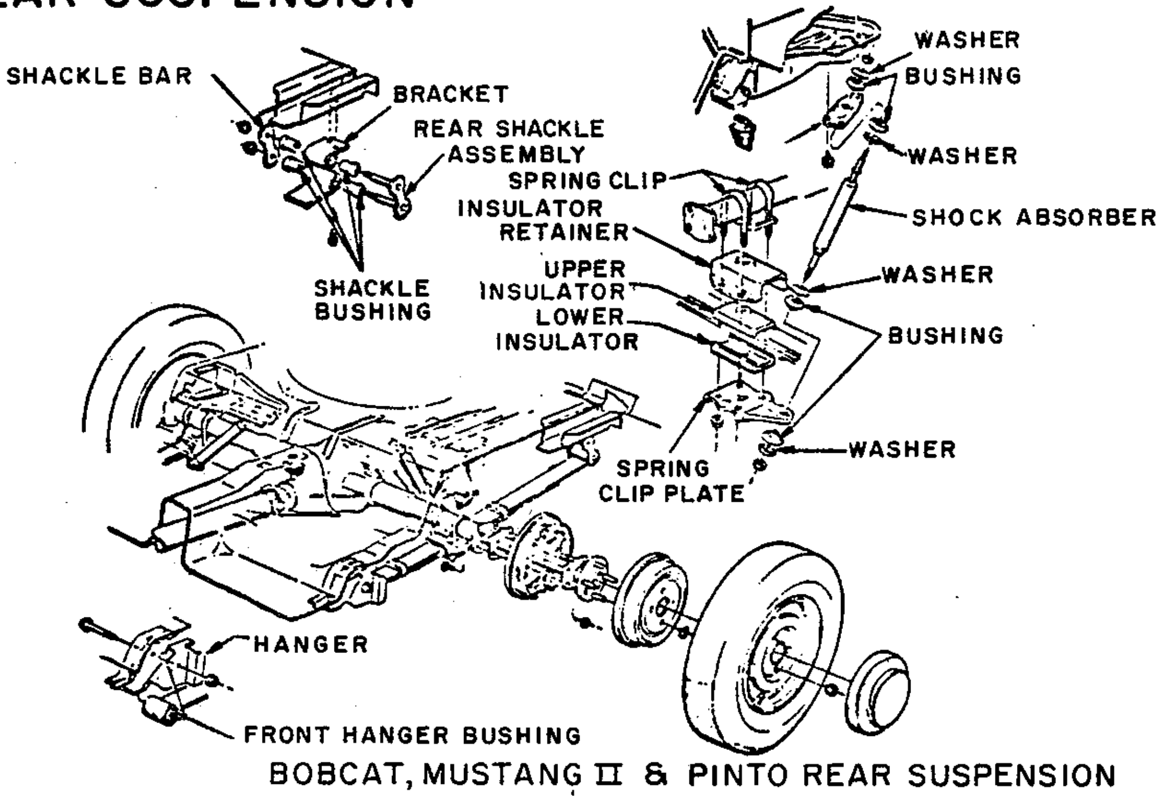
1 in.=25.4mm
1 lb.=0.454kg
1 deg=0.0175 rad.

FRONT END & STEERING SECTION



FRONT SUSPENSION ASSEMBLY-TYPICAL

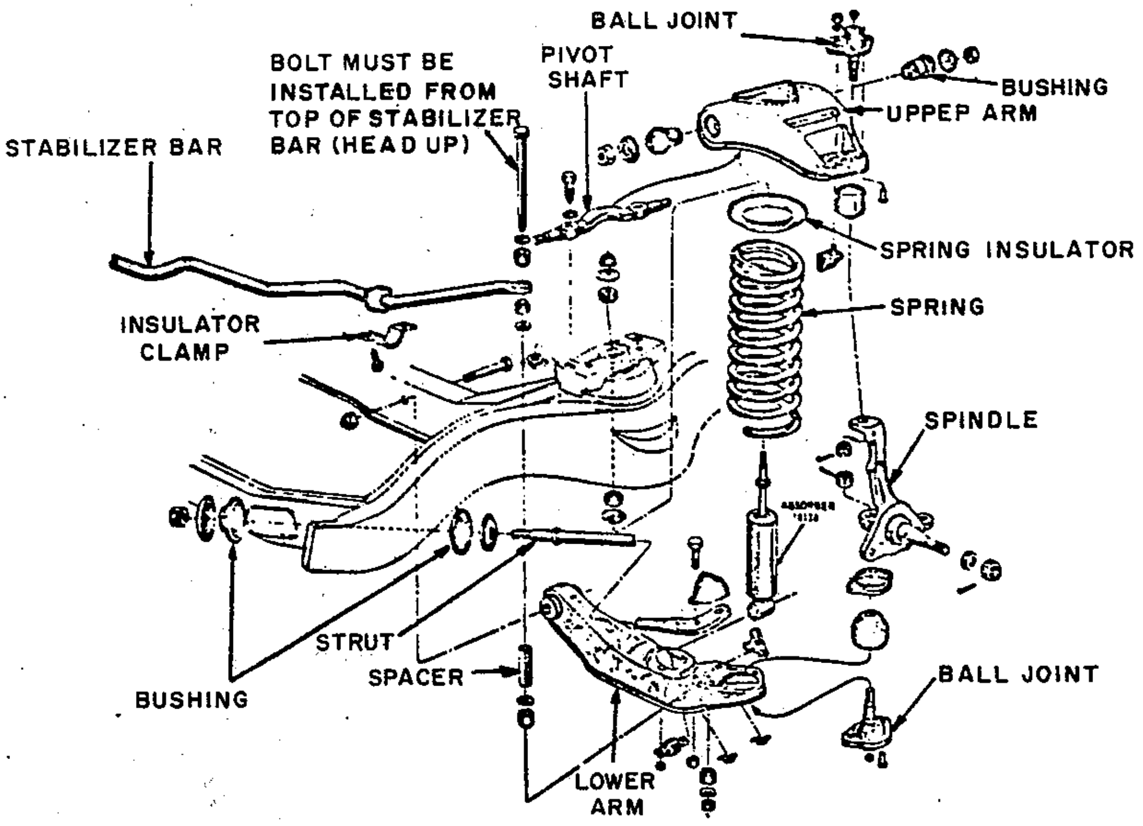
REAR SUSPENSION



BOBCAT, MUSTANG II & PINTO REAR SUSPENSION

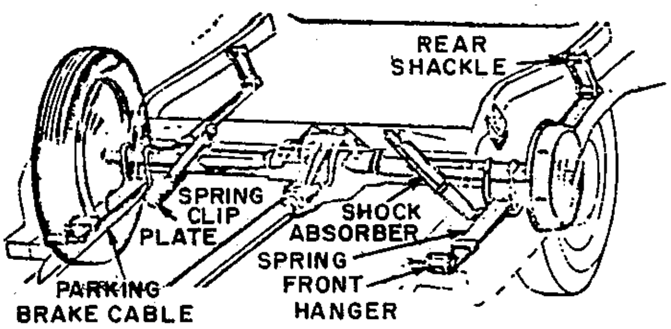
Figure D2, SUSPENSION DIAGRAMS–1974 FORD GRAN TORINO

FRONT END & STEERING SECTION

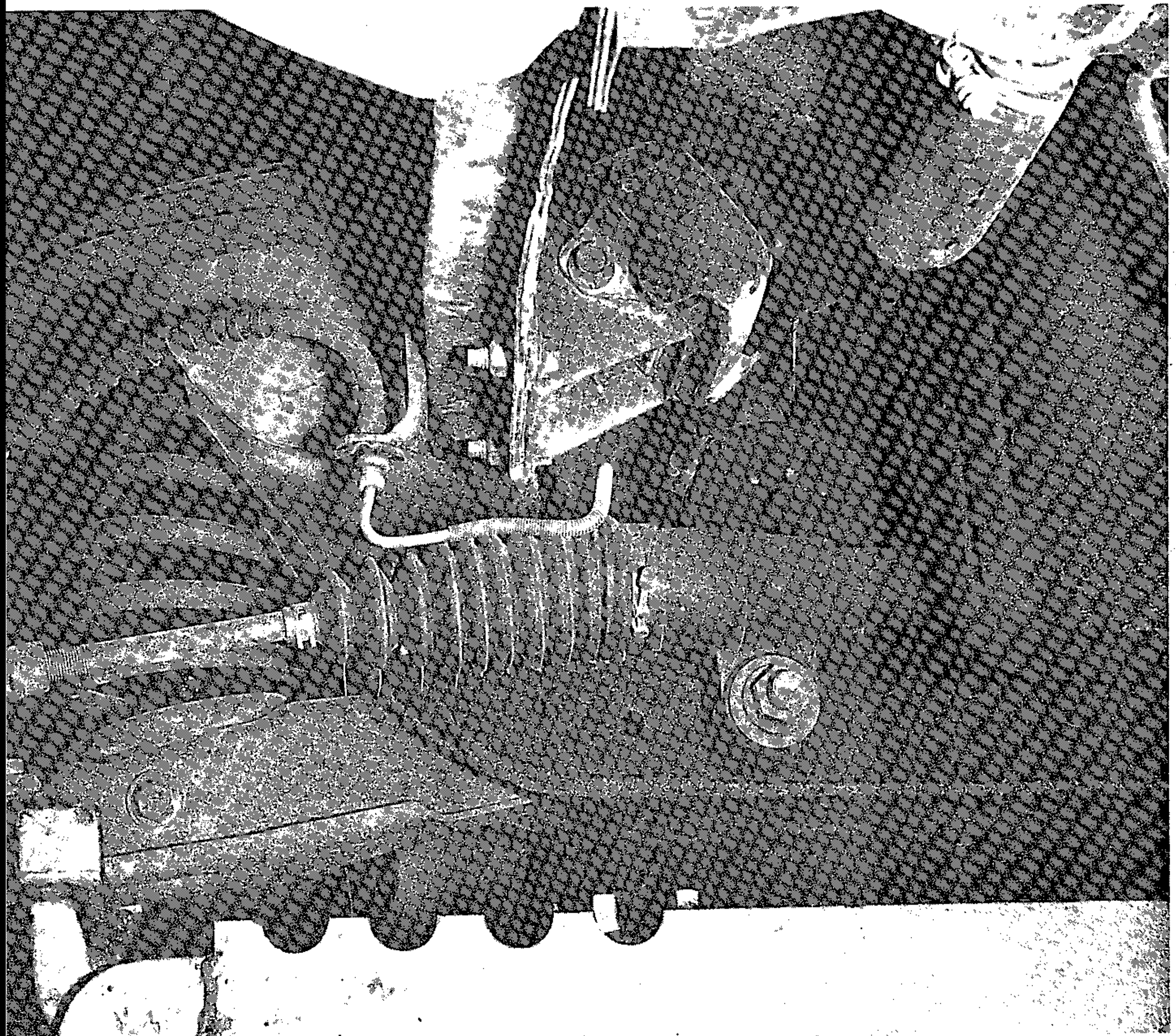


FRONT SUSPENSION. 1972-76 ELITE, MONTEGO, TORINO & 1974-76 COUGAR

REAR SUSPENSION



LEAF SPRING SUSPENSION (TYPICAL)



[redacted]e D3, CLOSE-UP VIEW OF 1974 FORD PINTO COUPE
FRONT SUSPENSION

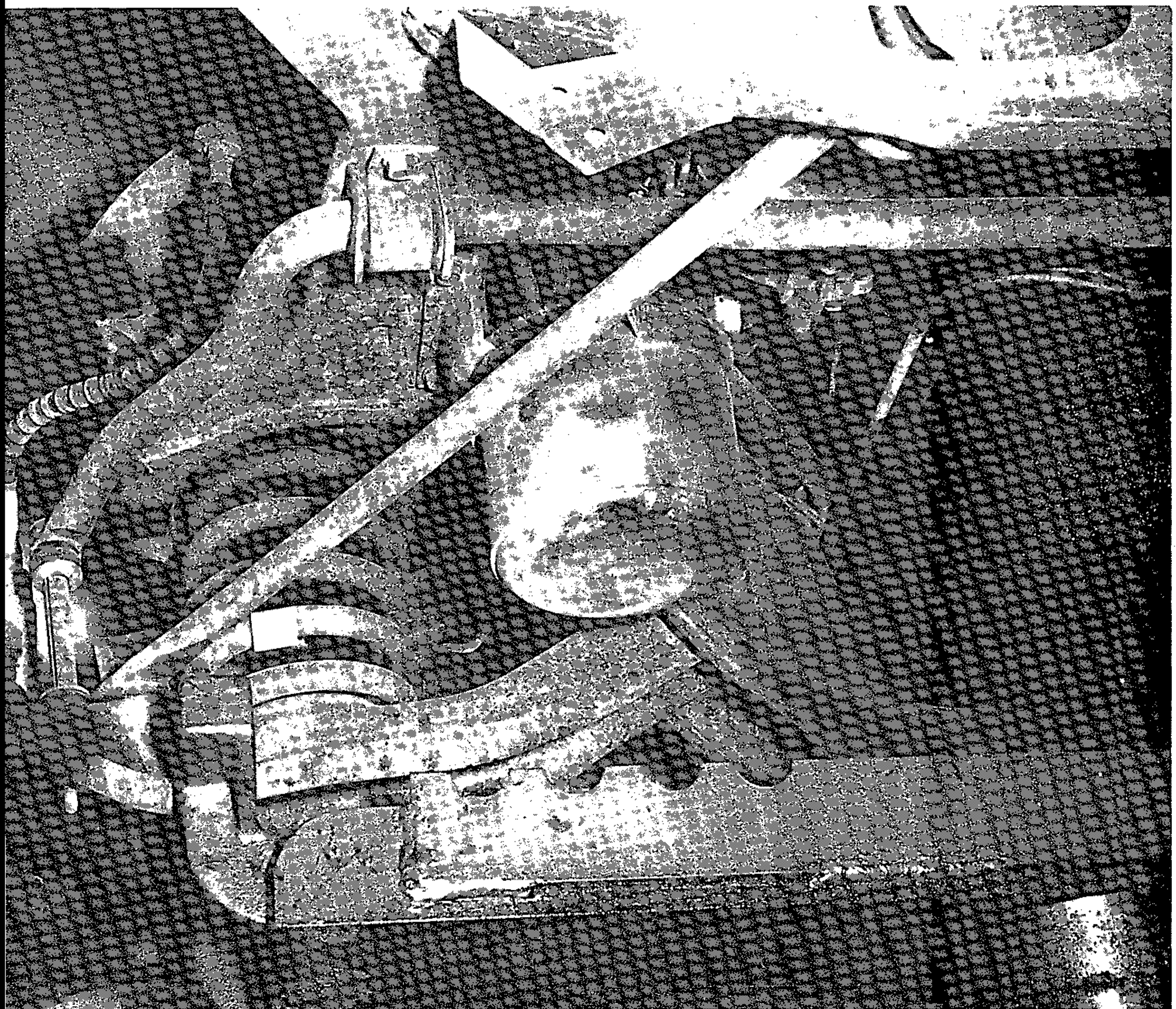


Figure D4, CLOSE-UP VIEW OF 1974 FORD GRAN TORINO FRONT SUSPENSION