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Contract No. FH-11-7480

BUMPER COMPLIANCE TEST PROCEDURE EVALUATION

DIGITEK CORPORATION
4818 LINCOLN BOULEVARD
MARINA DEL REY, CALIFORNIA 90291

December 1970
Final Report

Prepared for:

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National Highway Traffic Safety Administration
Washington, D. C. 20590

and no luggage and five passengers and 200 pounds of luggage, respectively. These new weights can give as much as a 25% weight gain and will make a significant difference in bumper performance. Further study in this area is in order before a weighting procedure is picked.

- Determination of Bumper Test Height

Procedures for the determination of the four extreme bumper elevations will encompass various vehicle loadings and the pitch dynamics. These elevations can be acquired using scratch gauges, string pots, or high speed photography. All three methods should be looked into as a technique The one used will be determined by the accuracy needed and the number of cars to be tested. It would seem inappropriate to test the bumper systems without making sure that the bumper does exist on both sides of the datum elevation and that the critical overlap meets the demand for a minimum bearing area. Once the elevation is found, it will be important that this car attitude be duplicated by mechanically pitching the vehicle to the same attitude with respect to the pendulum. This static pitching technique will have some unknown effects when compared to the dynamics of the real world accident. Further work in the above areas might bring to light these effects and make the test technique considerably stronger.

- Determination of the Bumper Surface Load Distributing and Penetrating Characteristics

As explained in Section 4. 4. 1, "Geometric Bumper Considerations", the bumper that gains its invulnerability at the expense of the vehicle it strikes, defeats the purpose and the intent of the standard.

It is at this point in the test procedure that techniques must be developed to evaluate and grade the effectiveness of the corner rounding, and bumper projection which will limit load concentrations and control door beam penetration performance. It is very difficult to design a standard that will insure low door penetration without writing a design specification.

It is not the intent of this standard to dictate design, but there are some general statements that can be made and used to great advantage.

The present door beams give their greatest protection from interior penetration in the fact that they deflect the striking vehicle. To improve this performance it is agreed that the largest corner radius will give the bumper the highest probability of not digging into the door beam and causing entrapment. Entrapment ends any advantage of the deflecting phenomena observed so far.

Secondly, in the present car design the corner sheetmetal and bumper both lie very close to the same intersection of two vertical intersecting planes. This not only allows the sheetmetal to run the risk of door beam entrapment (nondeflection) but it forces the designer of the door beam to spread the door beam too thinly over the vertical range demanded by the bumper fender combination. This brings to light the reasoning for the bumper projection dimensions d_4 and d_5 as well as the rationale behind the standard datum elevation d_1. All three of these dimensions allow the door beam designer to consolidate and gain support for the structure of the door beam. With the door beam stronger and the fender recessed by the bumper projection dimensions, the possibility of catching fender sheetmetal is reduced and the deflection properties of the beam are considerably enhanced both leading to improved occupant protection.

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The report is contained in one volume but a considerable amount of additional information can be found in the photo index, a slide presentation and a documentary movie.

16. Abstract

An automotive test program was conducted to evaluate the capability of a pendulum impacter to perform as an impact simulator of a low speed passenger car impact. The testing included various impacts which intended to evaluate the pendulum's ability to differentiate between a car with good low speed impact characteristics and a car with bad ones.

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FOREWORD

This report was prepared by the Automotive Research Division of the Digitek Corporation, Marina del Rey, California for the National Highway Safety Bureau of the Department of Transportation under Contract FH 11-7480. The work was administered under the direction of the Research Institute, Vehicle Structures Division with Mr. Horace R. Moody as the Contract Manager.

Research performed under this contract has been part of a continuing effort to establish a federal motor vehicle safety standard for low speed impact performance. The results reported here are in one volume but considerable information is included in a photo index, slide presentation, and documentary movie.

The authors gratefully acknowledge the efficient support provided by the Digitek testing staff headed by Mr. J. Kratzke and the cooperation of Mr. H. R. Moody of the National Highway Safety Bureau.

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1.0 INTRODUCTION

Vehicle occupant injury reduction is a major goal of the National Highway Safety Bureau. Although low speed impacts usually do not cause occupant injury, they sometimes cause damage to the vehicle which might cause future more serious impacts that result in occupant injury. Examples of vehicle damage which increase the probability of future accidents are: 1) loss of visibility, or 2) mechanical failures. Driver visibility is lost due to headlight misalignment and vehicle visibility is impaired due to one or more lamps or reflective surfaces not functioning. Mechanical failures, like the hood opening inadvertently or the gas tank leaking and igniting can also lead to more serious accidents.

The intent of the bumper testing is to insure that the common low speed impact does not damage the vehicle in such a way as to make it more prone to future accidents and thus unsafe to drive.

The damage noted above is caused by three types of collisions:

1) The square freeway or stop and go accident, with one or both vehicles moving with a differential speed of 10 mph,

2) The parking lot non-square bumper-to-bumper impact, and

3) The car to obstacle impact.

The three types of accidents have been reduced to a closed set of repeatable pendulum impacts which will effect the intended severity and will demonstrate the vehicle's resistance to being reduced to an unsafe state. This report is an evaluation of the proposed technique in it's effort to accomplish this end.

2.0 TESTING CHRONOLOGY

The tests performed can be divided into four groups

2.1 Pendulum System Pretest Checkout (Cadillac T1, T2, T3)

2.2 Non-Impact Testing (GTO - Ford)

2.3 Vehicle Restrained Testing (GTO 1, 2, 3)

2.4 Vehicle Unrestrained Testing (GTO 4, 5, 6, 7 - Ford 8, 9, 10, 11)

2.1 PENDULUM SYSTEM PRETEST CHECKOUT

2.1.1 Apparatus and Procedures

The physical test system and procedures used in Test Section 2.1 are as follows:

The test system was constructed as per original contract with modifications to insure the intent below.

The intent of the first pendulum was to be able to impact a 3000 to 4000 pound vehicle with an equivalent mass at a speed of 5 mph and at two elevations - 14 and 20 inches above ground. The vehicle was to sit on a flat surface with the transmission in gear, the brake on, and the tires blocked with one inch high chocks. The technique was to simulate a 5 mph barrier impact and was to be advantageous because of the high degree of impact trajectory control (speed, direction and vehicle attitude).

Test components are described below.

1) Frame or Supporting Structure

The supporting structure, Figure 1, is a non-symmetric "A" frame made of 4 inch "I" beams and 3 inch square-thin wall steel tubing. The feet are connected to concrete anchors and have elevation adjustment capabilities of ± 1". There are two pendulum pivot points. The lower pivot point gives the c. g. of the mass an elevation of 14" and the second point gives the c. g. an elevation of 20". The two bull wheels allow the pendulum to:

a) be moved vertically from pivot to pivot, and

b) allow the pendulum to be drawn back or cocked for impact testing.

2) The Pendulum Mass

Because of the need for variability, the pendulum mass has been built in segments, shown in Figure 2, and can vary its mass from 2000 to 4000 lbs.

3) Column

The column connecting the mass to the pivot is a single Standard 6" I-beam. The torsional rigidity is not significant enough to keep the mass in planer motion during impact.

4) Release Mechanism

The release mechanism was a double loop of piano wire which was cut with dikes.

FIGURE I GENERAL TEST SET-UP

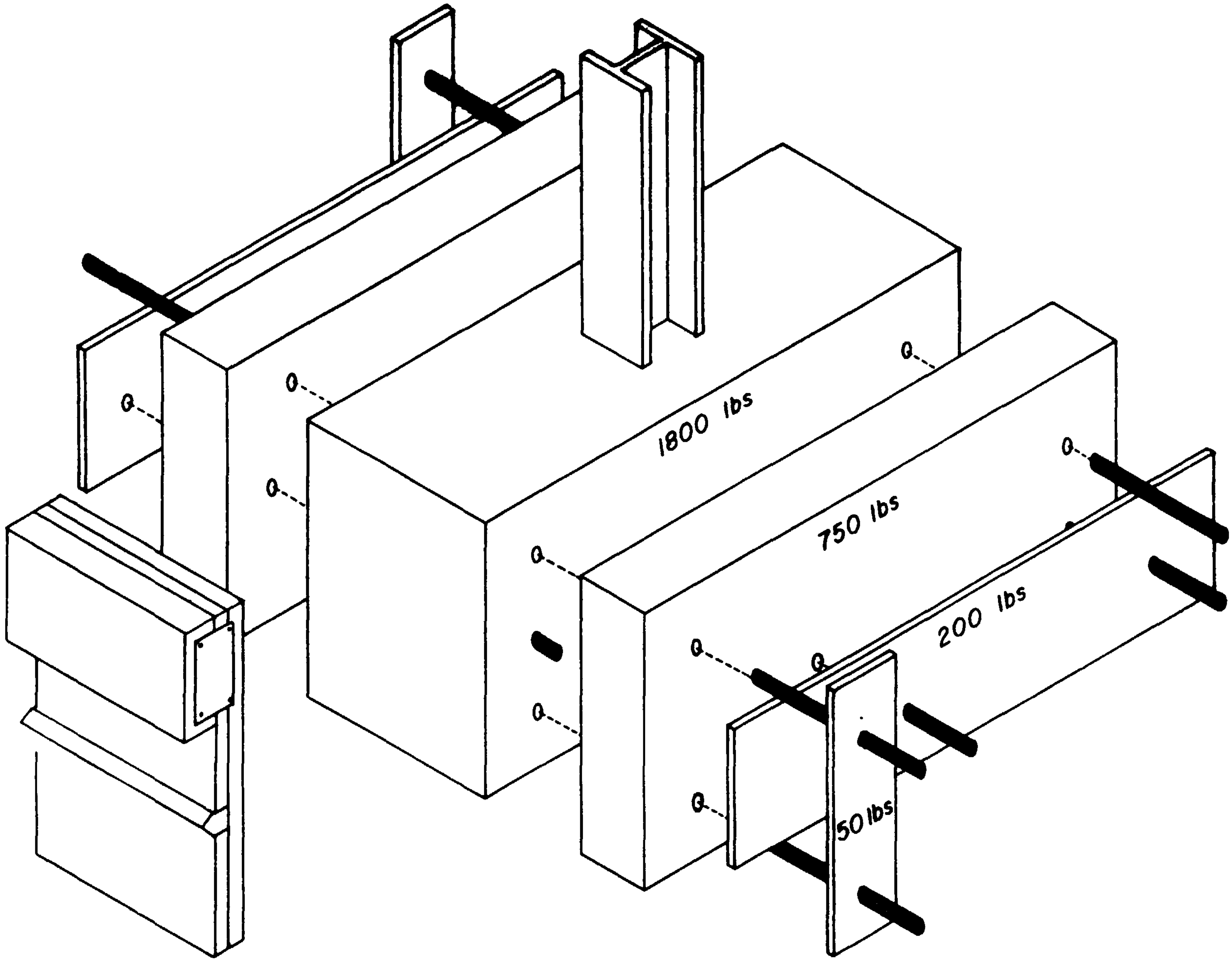

FIGURE 2 – PENDULUM MASS ADJUSTMENT CAPABILITY

5) <u>The Pad and Tie-Down Device</u>

The original system for pendulum impact of the vehicle was designed and built to impact a vehicle that was blocked so that it would not move. Brakes on, transmission in gear, and one-inch high wheel "chocks" were the required restraints

Under preliminary evaluation it became clear that another hold-down mechanism was needed to hold the car perfectly rigid if the 5 mph simulation was going to be accurate. The first suggestion was to block the car up and connect its frame to the ground. This was rejected because it removed the suspension movement in a vertical mode and thus effecting under/override characteristics. The next suggestion was to back the car up using a rigid barrier behind the rear bumper. This idea was rejected because damage and deformation would be produced at both ends at the same time and a true measurement of pass/fail would not be obtained. The solution adopted was to brace the car so that it would not move backward on impact, by placing the four wheels in a vise. This was done and the first testing was done using the apparatus in Figure 3.

6) <u>Instrumentation and Documentation</u>

During the first tests all output from the system was in optical format. Four high-speed (200 fps) and two real time (24 fps) cameras were used. The cameras were placed and had approximate fields as shown in Figure 4.

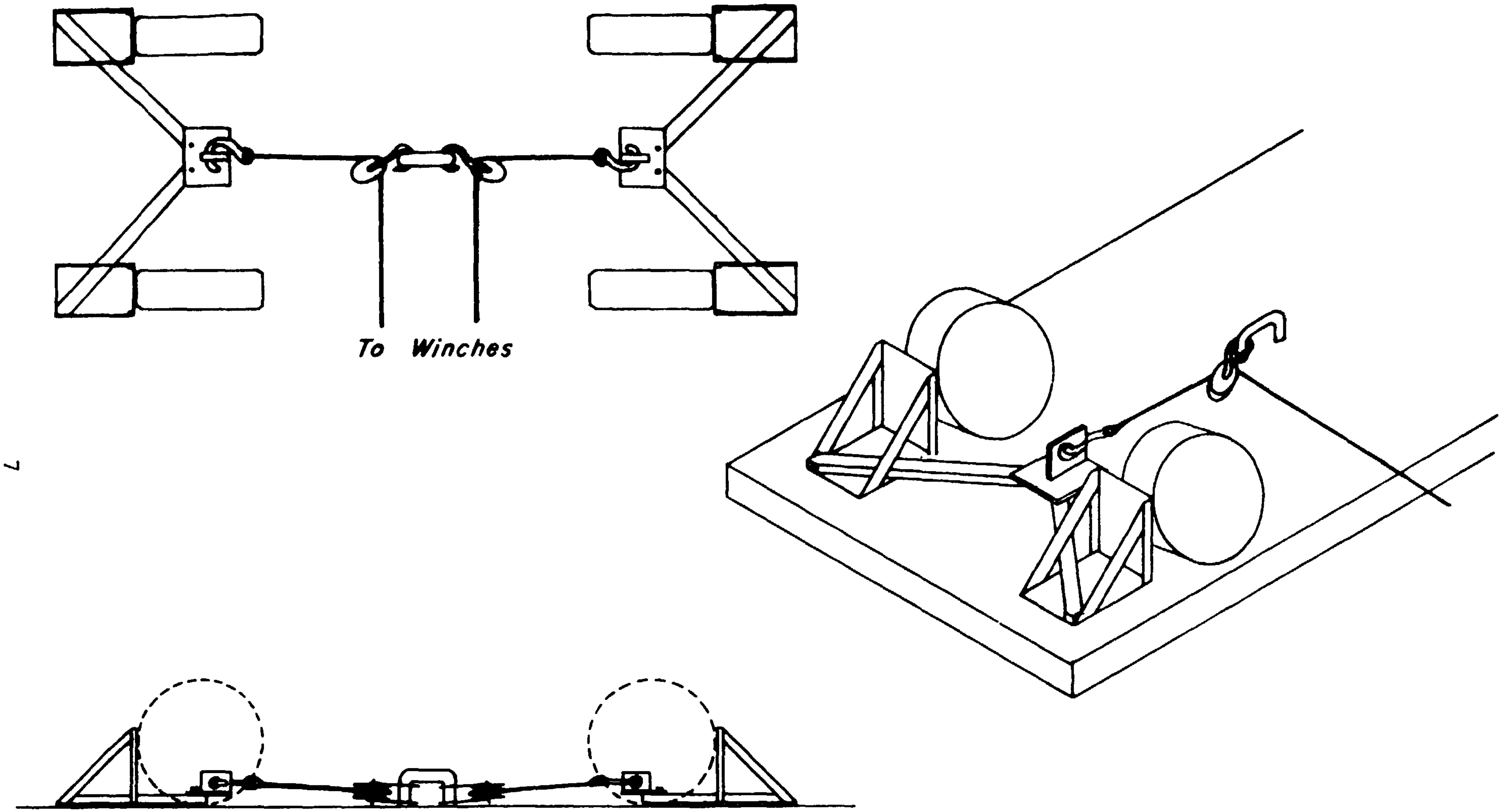

FIGURE 3 – VEHICLE RESTRAINT SYSTEM

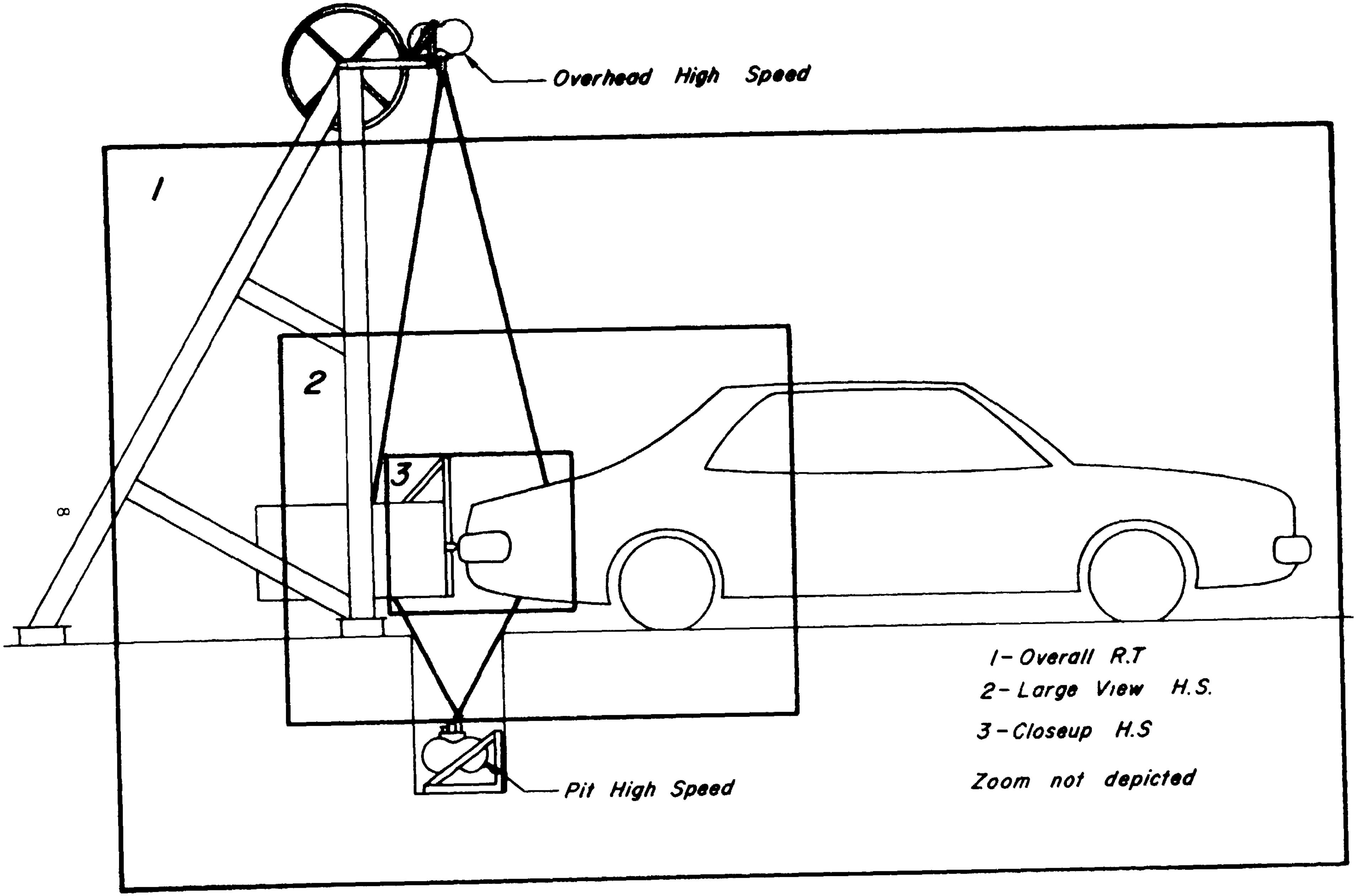

FIGURE 4 – CAMERA FIELDS

Test Procedure

1) Preparation of Test Vehicle

The vehicle shall be at curb weight and on a level, hard surface with the front wheels in a straight-ahead position. Each road wheel shall be equipped with the manufacturer's largest recommended original equipment tires inflated to the vehicle manufacturer's recommended pressure for the indicated loading. The vehicle's parking brakes shall be disengaged and the transmission placed in neutral. In addition, each wheel shall be blocked to keep the vehicle in one test position.*

2) Preparation of Test Device

Prepare a pendulum type impact device containing a mass equal to within ± 20 pounds of the test vehicle's curb weight. The mass shall:

a) Be affixed to one end of a rigid shaft such that the distance between the shaft's axis of rotation and the center-of-percussion of the entire impact pendulum measures 132 ± 1 inches (see Figure 5).

b) Be capable of swinging in a circular arc in a vertical plane and through a prescribed angle.

c) Have affixed to it a steel contoured surface** as shown in Figure 6. Line A of the contoured

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* Modification 1 - use of a vise hold-down was substituted.

** Modification 2 - use of wood for all surfaces other than Line "A".

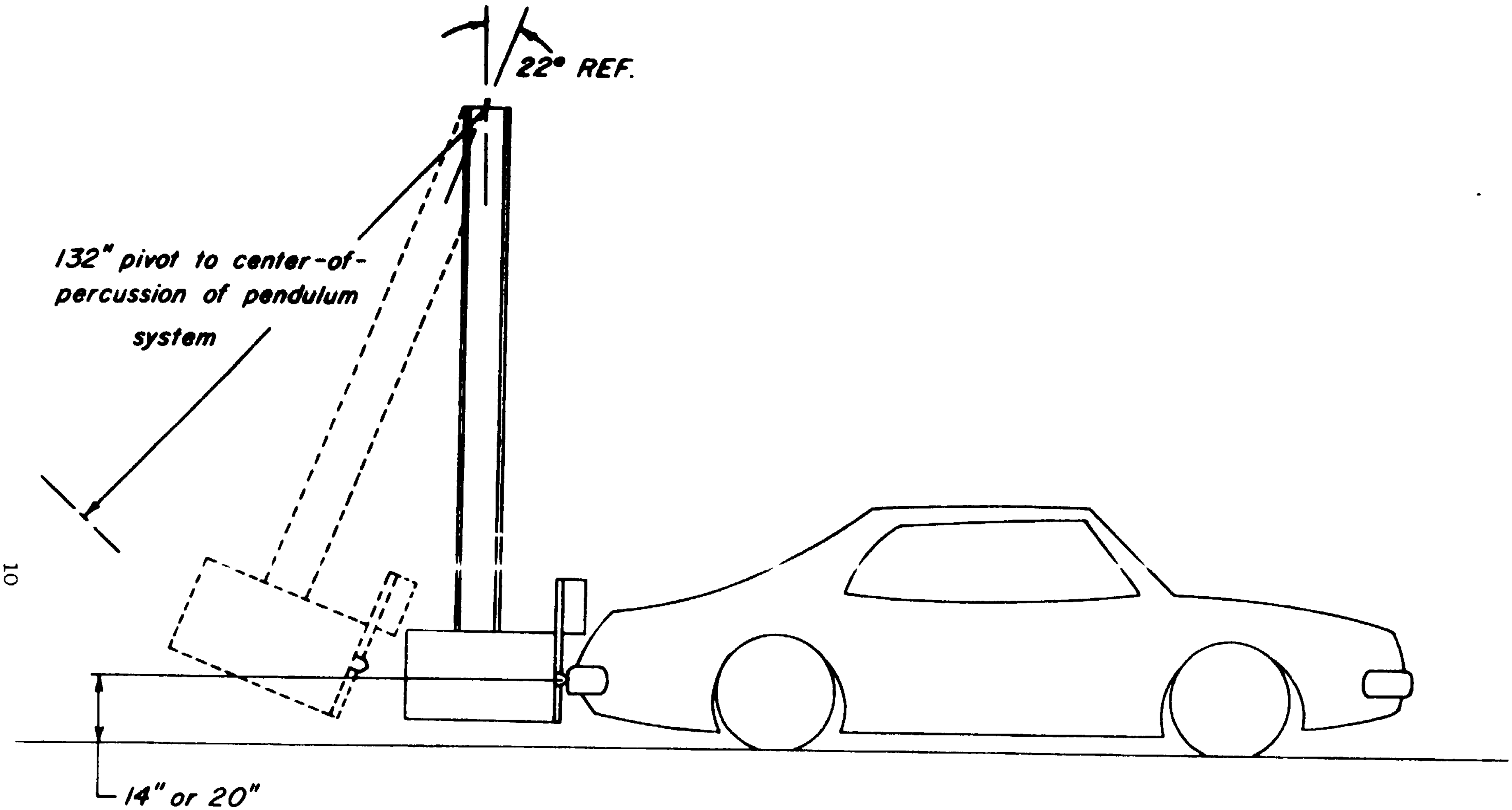

FIGURE 5 - PENDULUM TEST DEVICE

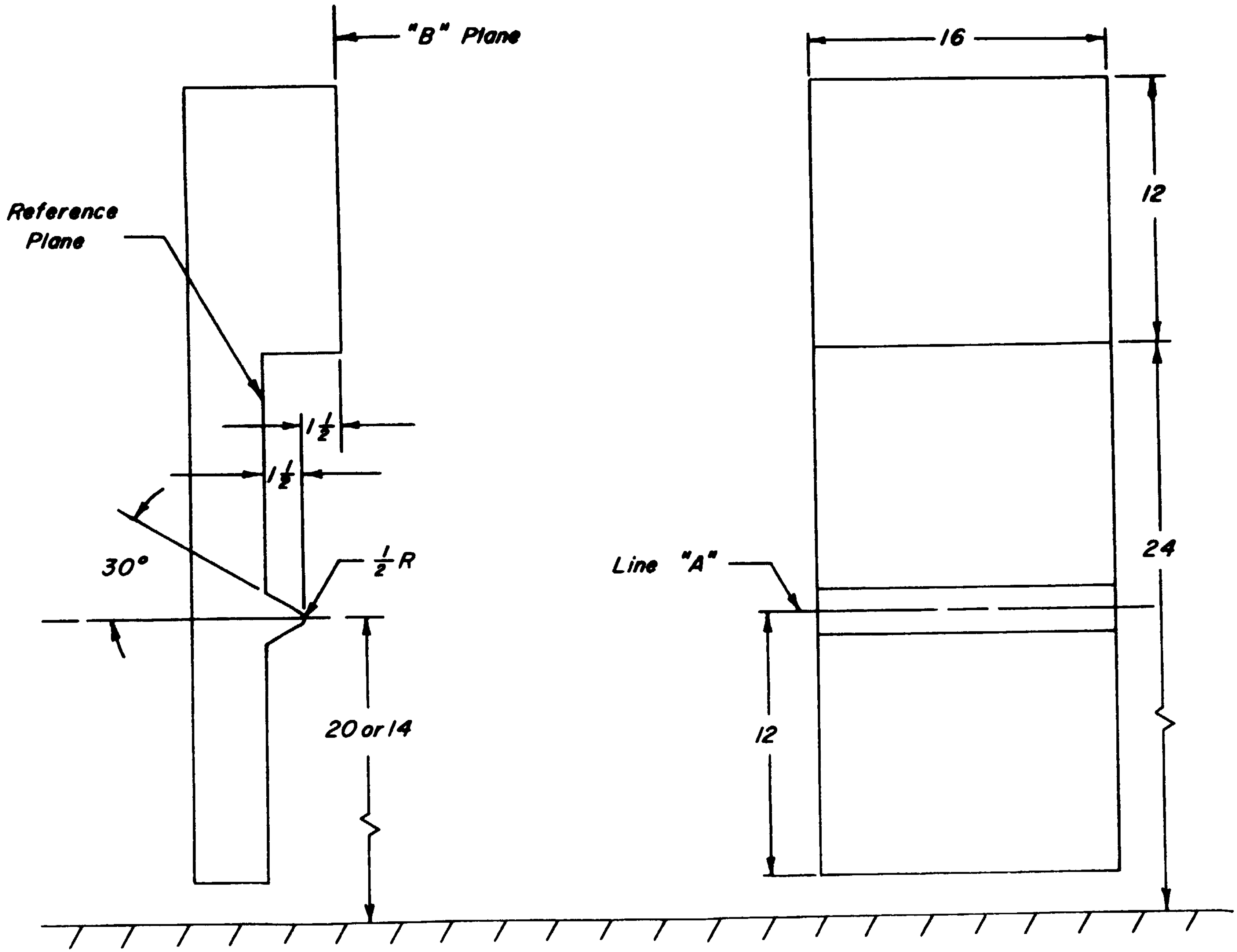

FIGURE 6 - PENDULUM IMPACT FACE

surface and the center-of-percussion of the pendulum shall lie in the same horizontal plane when the pendulum is freely hanging. The overall length of the steel contoured surface shall be equal to the vehicle height measured at the front-most or rearmost wheel centerline minus 6 inches.

3) Method of Impacting the Vehicle

a) Prepare to strike the vehicle with the pendulum contoured surface by swinging the pendulum away from the vehicle to a position that when released to free-fall it will produce a striking velocity of 7 1/3 feet per second. Line A of the pendulum's contoured surface at the instant of impact shall:

1) Impact the vehicle when it intercepts a vertical plane that is tangent to the vehicle surface being impacted, and

2) Be 20 inches above ground level.

b) Impact the front and the rear of the vehicle with the pendulum positioned at four (4) locations across the front and rear in the following sequence - at the 20-inch and 14-inch height along the vehicle center-line and at 20-inch height for one of the vehicle corners and at 14-inch height for the opposite corner (Figure 7). In the event, however, the bumper fails as a result of deformation, cracking,

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* Modification 3 - 36" high substituted

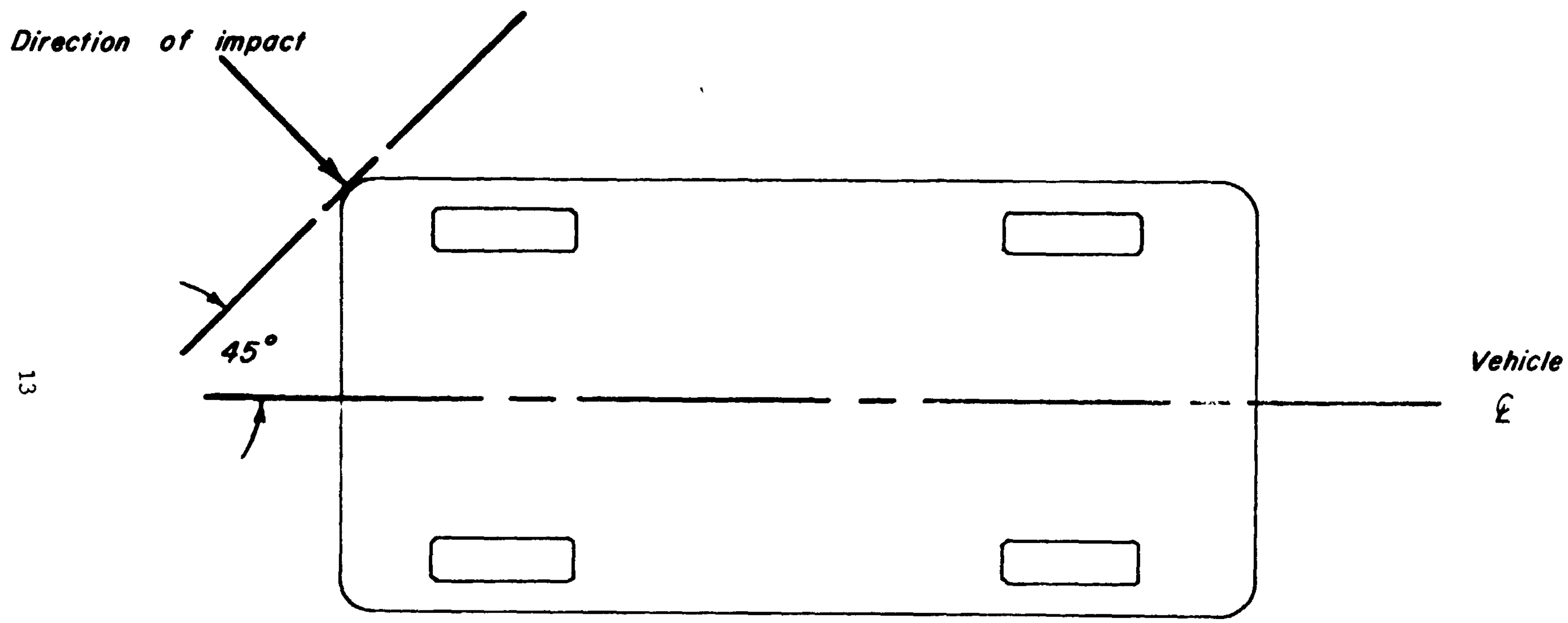

FIGURE 7 – VEHICLE CORNER LOCATION

or failure of the support brackets following the initial impact a the center, the bumper is to be replaced with a new bumper and subjected only to the corner impacts as specified above. In those instances where it can be visually ascertained that the bumper would fail the tests, the following approach is to be followed Center Line-A of the impact face with the bumper's forwardmost surface and impact the bumper once at the center and once at one of the corners. If the center impact causes the bumper system to fail, replace the bumper and impact its corner. At no time during the course of any of these tests shall any vehicle component other than the bumper system be replaced. Finally, if the stated impact speed of 5 mph produces no failure that point(s) of the bumper shall be impacted at higher velocities until failure occurs. Speed of impact shall be increased in one mph increments.

Additional Testing Procedures

1) Car Inspection

   a) Components

   b) Light aim check (SAE J599A)

2) The alignment of the car on the pad was accomplished by simple measurements from centerlines laid out on the pad.

3) The vise was then installed and preloaded to over 1000 lbs.

4) The pendulum was then cranked up so that the c. g. elevation change was 10.0".

5) The piano wire link was installed.

6) Final check.

7) The cameras were turned on.

8) The link was cut and the impact occurred.

9) Light aim recheck (SAE J599A)

2.1.2 Testing

During these three tests the Cadillac was restrainedusing the vise hold-down illustrated in the documentary movie. The car was placed with its longitudinal axis aligned with the plane of pendulum swing so that the pendulum impacted its front center. The vehicle was then placed so that this axis intersected the plane of the pendulum at 45^{o} and displaced such that the left front corner would meet the impact face when the pendulum was at its full-down center position. Using different camera angles it was shown that:

1) The vise could not hold the vehicle rigidly:

a) The vehicle moved forward and aft 4-8" as needed using rear suspension and tire compliance for the needed deflection during front center impacts.

b) The vehicle moved sideways (right and rearward) 4-6 inches statically and as much as 10" dynamically during corner impacts.

c) The car rolled 15-20° during the corner impacts because the impact was above the roll center.

2) A second impact occurred between the impact face and the pendulum. This was due to the much higher frequency of the tire compliance and suspension, when compared to the period of the pendulum. Essentially, the car impacted the pendulum during its slow attempt to rebound.

3) The pendulum did return to the vehicle a third time after rebounding past its center position; and if the vehicle is to be restrained, the catcher must be used.

4) Position of the cameras, which allowed visibility of the contact area, were not the type which would allow data analysis. Pendulum impact speed could not be extrapolated accurately, nor could scaler measurements be made to any accuracy below inches This is partly due to the vehicle corners preceding the vehicle center, lense length, and frame speed.

5) The pendulum rotates 10-20° out of plane during corner impacts, but this does not appear to effect damage.

6) The pendulum also elevates 2-3 inches during impact, but vehicle suspension usually has allowed the steel line "A" to entrap itself by this time. This problem is due to Line "A"'s position ahead of the c. g.

7) The length of the pendulum in the plane of the swing determines the rate of linear rise during impact.

8) Pit lighting would be necessary along with a wider angle lense.

9) During the testing it was also learned that a piano wire release, although functional, is very time-consuming and difficult to adjust when fine elevation changes are needed to obtain correct impact speeds. A release that is mechanical and adjustable is required.

2.2 NON-IMPACT TESTING

2.2.1 Apparatus and Procedures

The physical test system and procedures used in test Section 2.2 were the same as Section 2.1 except for the following changes:

1) A catcher was added to the test system so that the pendulum would not rebound into the vehicle causing a third impact.

2) As part of this catcher a release mechanism was added because the piano wire links were too time-consuming to attach and elevation control was not repeatable.

3) Lights were added in the camera pit.

4) This addition in lights added a light turn-on step to the procedures.

2.2.2 Testing

Because of the larger projection of the 1950 Cadillac bumper, it was not directly apparent that most 1969 and 1970 vehicles would fail the proposed impact test geometrically without any dynamic loading. On Monday, June 22, 1970, the following two vehicles were tested according to the proposed test procedure to which they, in all cases, geometrically failed and were not impacted (see Photo Appendix 15-22 and Figure 8 a, b c, d).

Vehicle 1

Pontiac GTO 2-dr. hardtop coupe
Year - 1970
Series - 24237
Identification No. 242370Z131185
California Plate 779-BRZ

Vehicle 2

Ford Galaxie 500 4-dr. sedan
Year - 1969
Serial No. 9J541H181836
DOT Plate 40406

2.3 RESTRAINED IMPACT TESTING - GTO

2.3.1 Apparatus and Procedures

The physical test system and procedures used in test Section 2.3 were the same as Section 2.2 except for the following changes:

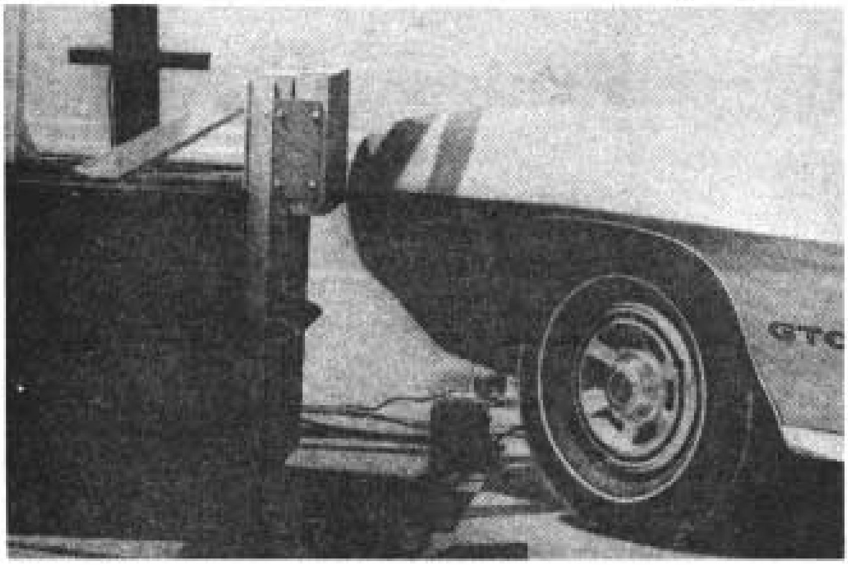

FIGURE 8 a GTO FRONT LEFT CORNER GEOMETRIC FAILURE

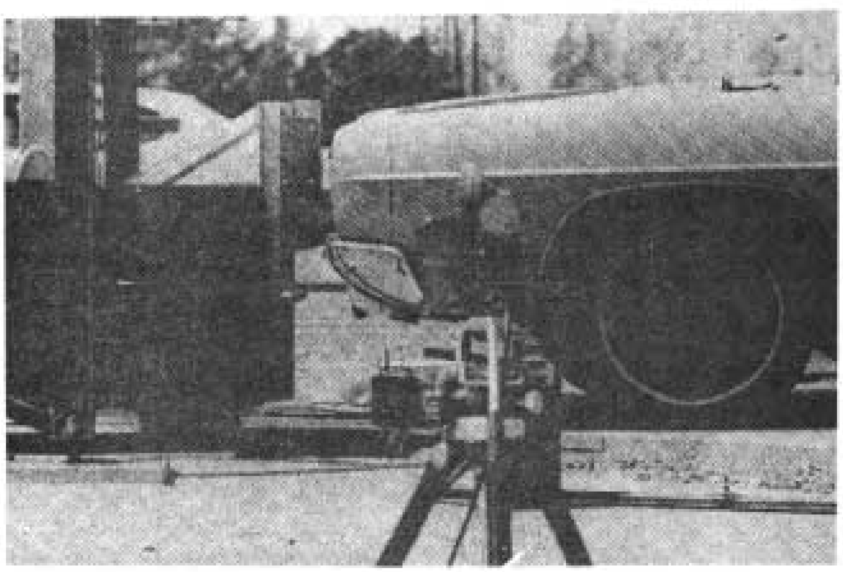

FIGURE 8 b FORD FRONT CENTER GEOMETRIC

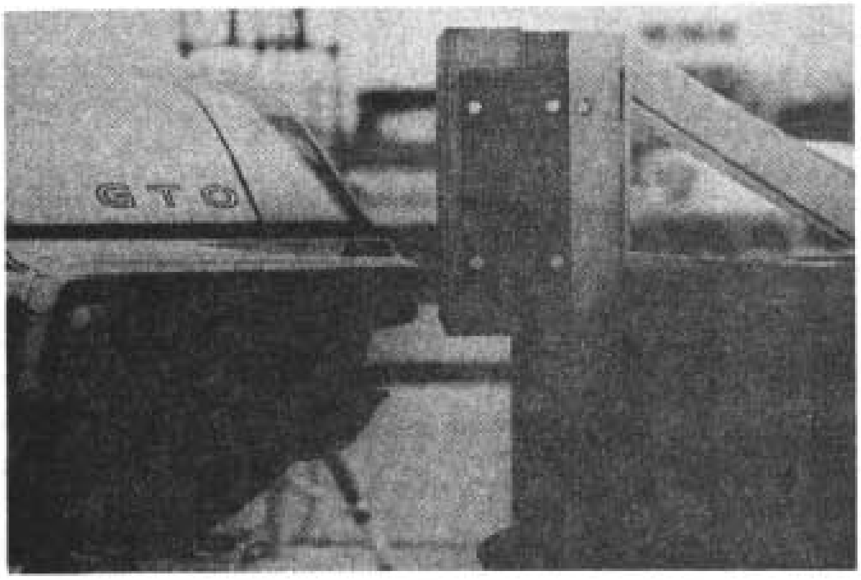

FIGURE 8 c GTO RIGHT REAR CORNER GEOMETRIC FAILURE

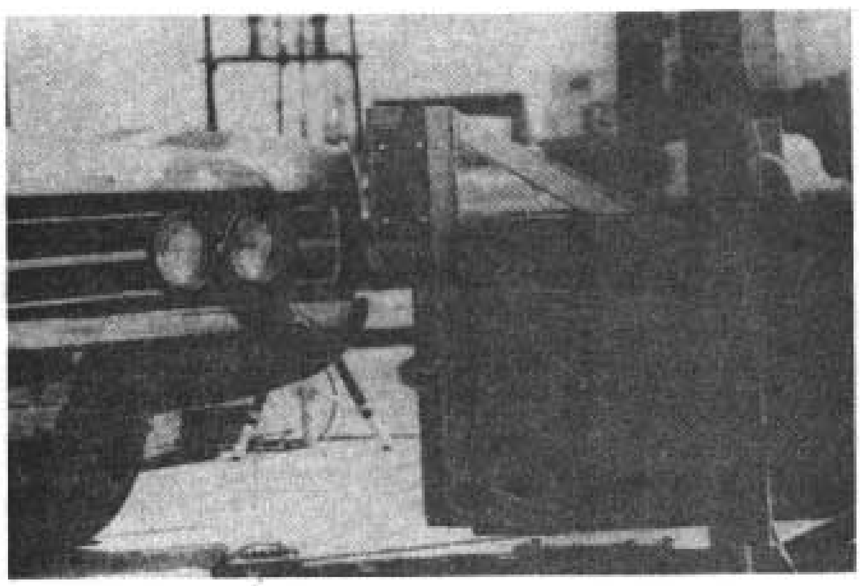

FIGURE 8 d FORD FRONT RIGHT CORNER GEOMETRIC FAILURE

1) Plane "B" was removed.

2) Elevation of the Line "A" is matched to the leadingmost edge of the vehicle surface.

2.3.2 Testing

Test 1

Plane B was removed by direction of the contract manager and the testing proceeded. The GTO was again mounted on the concrete pad. It then became apparent that with Line A at its fourteen-inch elevation and Plane B removed, the reference plane would be the first part of the pendulum face to contact the vehicle and thus would generate geometric failure without dynamic loading. Again, the geometry of the pendulum's impact face was changed by agreement with the contract manager. The new directive was to impact the vehicles so that Line A was at an elevation that would cause it to impact the "leadingmost edge of the bumper system." In the case of the GTO, the leadingmost edge is a forward canting near vertical line. This would cause Line A to be 28-30" above ground. The bumper's leadingmost edge, measured at the left front corner, is 25". Because the pendulum system was designed to go only to 20" above ground the increased elevation was going to be accomplished by putting shims between the pendulum feet and their respective anchors. Eight inches of shims was expected to generate instability in the pendulum fixture. The decision was made to use the corner elevation for the front-end GTO impacts - 25".

The Digitek staff proceeded to make the shims and raise the elevation of Line A. Using the new release and catcher mechanism the GTO was impacted front center - Test 1.

The speed of impact was determined by equation and the c. g. dropped 10. 0" (later found to 4. 4 mph).

The test documentation has been previously sent to NHSB in th form of movies, slides, and sti l photos (photos 23-30)(see figures 11, 12, 13, from Test 4 included).

1) Head Lamp Inspe tion (GTO Test 1)

Prior to any testi g the head lamps were inspected and adjusted in accordan e with the Lighting Inspection Code, SAE J599A. After the "front center" impact, the head lamps were rechecked. Both tl e upper and lower beams on the right side remained undisturbed. The aiming of the upper and lower beam on the left side of the vehicle moved up 1-1/2". (The aiming screen is 25' forward of the head lamps.) The specification allows a ± . " vertical tolerance in the setting. It can then be said that a l four beams remained "in proper adjustment" after impact. It should be noted, however, that had the pretest setting b en closer to the upper vertical tolerance, the impact would have moved the left lamps out of adjustment.

2) Post Test Bumper and Sheetmetal Inspection

Immediately afte the "front center" impact, an attempt was made to ope the hood. Three men pulling and lifting failed to raise the hood more than about one inch. That particular afflictio disappeared by the next morning. The hood opened as easily as it did before the test. There was no latch damage whatsoever which indicated that the bumper (to which the latch trip mechanism is mounted) recovered enough of its original shape to render the latch operable.

The bumper took a permanent set of 3/32" on the left side. The tolerance of the mounting hardware of the left back bar was taken up, allowing this asymmetric compression.

The right front fender remained undisturbed. The left front fender was permanently moved rearward about 3/32" which caused a slight rubbing of the sheetmetal at the door gap (see movie documentary) when the left door was opened. The impact caused the hood to twist slightly to the left. There is some evidence to indicate that the hood may have moved up onto the right fender near the windshield during the impact. The center of the forward edge of the hood rubbed heavily on the bumper causing the hood to lie "in place" but with the front twisted slightly to the left.

By loosening the four bolts holding the main bumper back bars to the frame, a man was able to move the bumper back to its original position. When the bumper loading was removed from the hood, it returned to its original position. By loosening the fender mounting bolts, the fender too could be easily moved into its original position.

With the hood and fenders lined up properly, it was impossible to get the bumper to match the contour set by the fenders and hood. Examination showed the bumper to be bent in at the middle. The sub-frame the rubber was molded to was bent in at the center. The profile of the nose of the bumper was now concave as opposed to its straight or slightly convex original state.

In conclusion, a new bumper was all that was necessary to restore the GTO to the visual condition it was first received. However, since further testing was to be carried out, all parts were replaced.

Cost to repair front bumper was $60.00 labor and $175.90 parts. (Whether all of these parts were needed or would have been replaced without specific request is a matter of question.)

Because of the damaged state of the front left bumper and fender further testing in that area was not attempted.

Test 2 (GTO Rear Corner)

The second test was performed on the right rear corner of the GTO. Static and dynamic documentation of the test setup impact and results have been delivered to NHSB in the form of real time and high-speed movies and black & white still photos (see Photo Appendix 31-37 and Figure 9).

The impact elevation of Line A was 26-3/16". The car was restrained. The impact speed was equated to 10.0" center of gravity drop height (later found to be 4.4 mph).

Vehicle damage was found in the form of a bent right rear bumper and quarter panel damage. The cost to restrore to "like new" condition was $48.00 labor and $95.00 in bumper parts. (The quarter panel was not replaced because it would not effect the strength of the bumper in the next test.) The operational parts of the vehicle were checked and all were found to be functional.

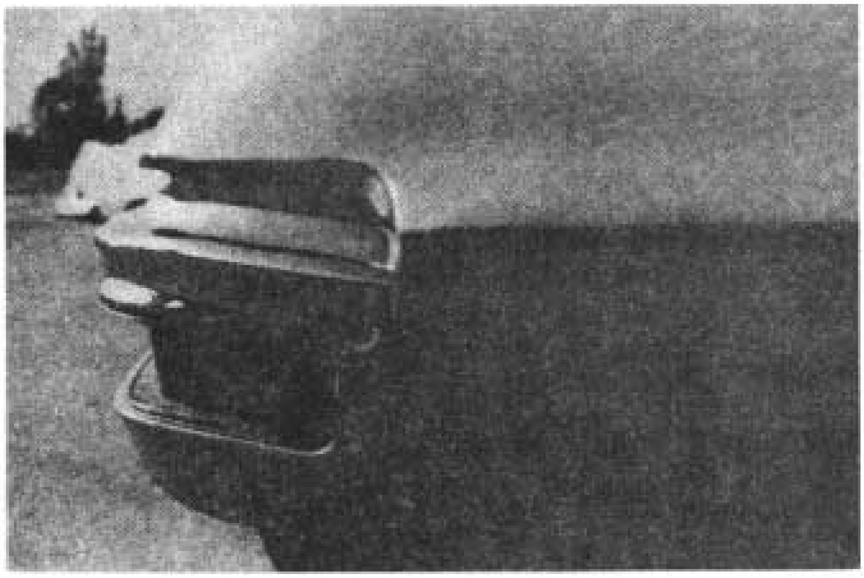

FIGURE 9 RESULTANT DAMAGE TEST 2 (GTO REAR CORNER 4.4 m.p.h.)

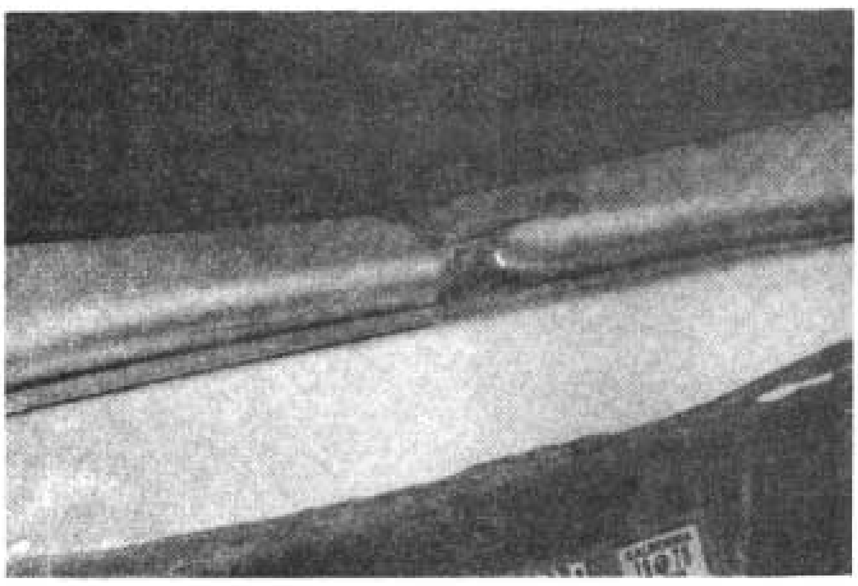

FIGURE 10 RESULTANT DAMAGE TEST 3 (GTO REAR CENTER)

Test 3 (GTO Center Rear)

Although the bumper was damaged by the corner impact, it was felt that further testing would be advantageous because major damage was not sustained. The car was placed on the concrete pad so that the pendulum could hit the bumper-center rear. The car was aligned so that its longitudinal axis was in the plane of the pendulum swing. The vehicle was then restrained. Line A was adjusted to 26" and the pendulum c. g. was raised 10. 0".

The trunk was inoperable. All other items of interest were functional. The static and dynamic documentation of the test setup, impact and results have been delivered to NHSB in the form of real time and high-speed movies and black & white still photos (Photos 38-42) (Figure 10).

With completion of these tests, it became apparent that the restraint system was not generating a rigid enough vehicle restraint to simulate a 5 mph barrier in reverse. The decision was made to test the vehicle unrestrained.

2.4 UNRESTRAINED TESTING - GTO-Ford

2.4.1 Apparatus and Procedures

The equipment and test procedures are the same as Section 2.3 except for.

1) The removal of the vise restraint. This was removed because the use of this technique has caused multiple impacts

whose severity depends on the longitudinal suspension stiffness of the vehicle. For implications of the removal of vise please turn to Section 3.2, Paragraph 3 (P. 25).

2) A device for measuring impact speed was inserted during the pre-test impacts of Section 2.4. The system measured the time the pendulum took to traverse the last ten inches before impact. Using this time in milliseconds and the distance in thousandths, the pendulum speed (average) for the time interval could be calculated. Th system showed that the 10.0" c. g. elevation change, because of friction of the catcher, was 4.4 mph. The pendulum was raised incrementally above its theoretical drop height until the 5 mph speed was obtained.

2.4.2 Testing

General conclusions of this section, Tests 4 - 11 should be accepted with the knowledge that the vehicles left the impact face at two to three miles per hour and that the momentum transferred in this collision is 40 to 60% less than a five mile per hour barrier and thus does not simulate it.

Test 4 (GTO Front Center Impact)

The pendulum speed was measured at 5.06 mph. The car was unrestrained. The elevation of Line A was matched to the leading edge of the GTO's right front corner as done in Test 1-25". The documentation of the test setup, impacts, and results are contained in the high-speed and real time movie, color slides, and black & white still photos (Photos 43-52) (Figures 11, 12 & 13).

FIGURE 11 RESULTANT DAMAGE TEST 4 (GTO FRONT CENTER)

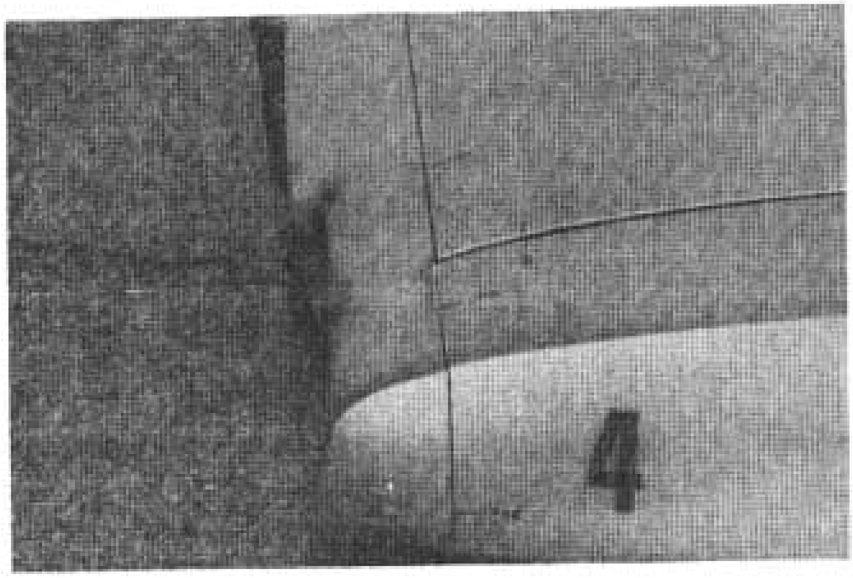

FIGURE 12 RESULTANT DAMAGE TEST 4

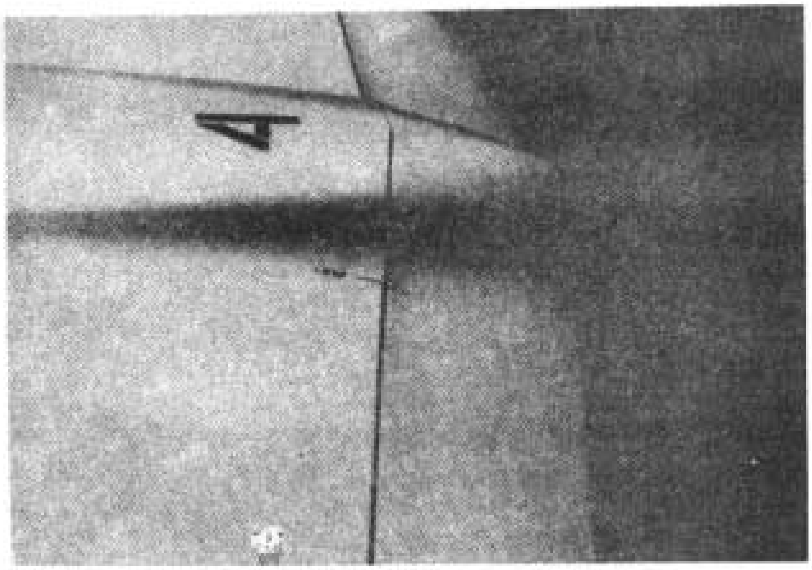

FIGURE 13 RESULTANT DAMAGE TEST 4

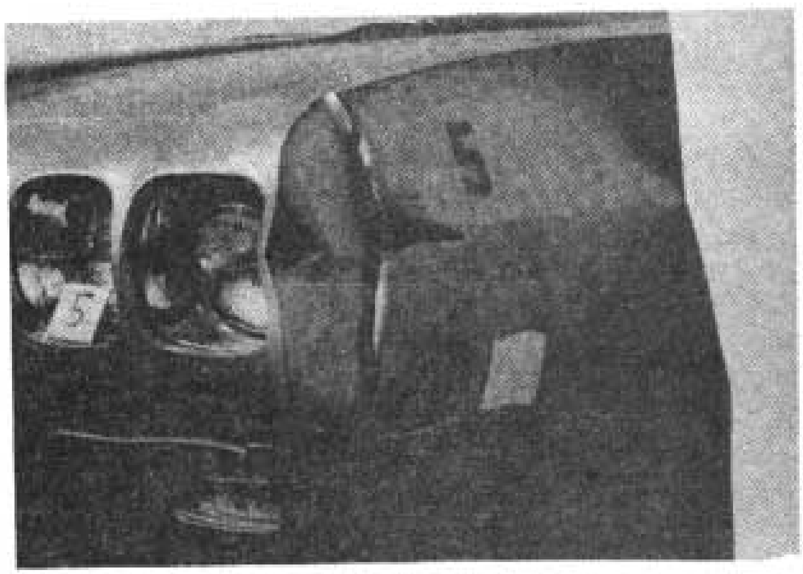

FIGURE 14 RESULTANT DAMAGE TEST 5 (GTO)

The GTO front cent r impac met failure by the following modes:

1) The load concentration generated by Line A was significant enough to embed the entire steel nose in the rubber molding allowing the reference plane to touch the bumper.

2) Failure was also caused by a hood latch mechanism which was inoperable because the bumper impinged on the hood end.

3) Surface failure a so occurred because the left fender moved rearward enough to pinch the left front door.

4) The damage estimate to straighten the bumper and not replace it was $37. 25. The cost to fix the bumper, replacing all parts, would be $235. 00 - $60. 00 in labor and $175. 90 in parts. This is the same as Test 1.

Test 5 (GTO Left Front Corner)

The measured pendulum speed for this impact was 5. 03 mph. The car was in an unrestrained configuration. The elevation of the left front corner leading edge was matched to Line A of the pendulum surface. The documentation of the test setup, impacts, and results are combined in the high-speed and real time movie, color slides, and black & white still photos (Photos 53-61)(Figure 14).

This vehicle failed to pass the proposed standard by several modes:

1) The reference plane touched the car because Line A generated load concentrations significant enough to embed the entire steel nose up to the reference plane.

2) The impact generated severe headlight movement. The headlight after this test pointed down and to the left. The center of the beam normally straight ahead, pointed to a spot 54 inches forward and 9 inches to the left of its position in the car.

3) The hood was not operable.

4) The fender was significantly bent behind the bumper. The entire front bumper was shifted to the right, when facing forward in the vehicle, 1/4 inch (see slides).

5) The left front fender shifted rearward during impact enough to make the left door inoperable.

6) The cost to repair this bumper-fender damage was $286.85.

Test 6 (GTO Rear Center)

The measured speed of this impact was 5.03 mph. The car was unrestrained. The elevation of Line A was matched to the leading edge of the bumper in the rear corner of the GTO. Documentation of this setup is included in the real time and high-speed movie, slides and black & white photos (Photos 62-69) (Figure 15). Failure of this GTO rear center impact was found in three modes:

1) The reference plane did touch the deck lid as shown in the color slides.

2) The trunk was inoperable at the end of testing. This was due to the steel nose slipping through the crack and directly loading the latch mounting.

3) The cost to repair was $168. 00.

<u>Test 7</u> (GTO Left Rear Corner)

The measured pendulum impact speed for this test was 5. 03 mph. The car was unrestrained. The elevation of Line A was matched to the bumper trailing edge measured at the corner of the vehicle. Documentation of the pretest setup, impact, and results are included in the real time and high-speed movie, color slides, and black & white photos (see Photo Appendix 70-77 and Figure 16).

During this test, failure was observed by

1) The touching of the reference plane to the chrome bumper.

2) Severe bumper and Line A intrusion into the fender sheetmetal. The trunk was sprung from previous testing, but it may be assumed that it probably would not have been damaged by this impact.

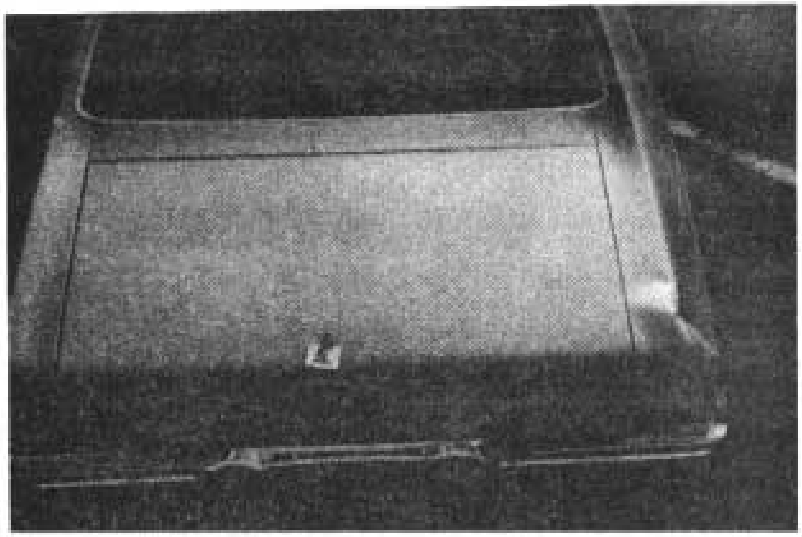

FIGURE 15

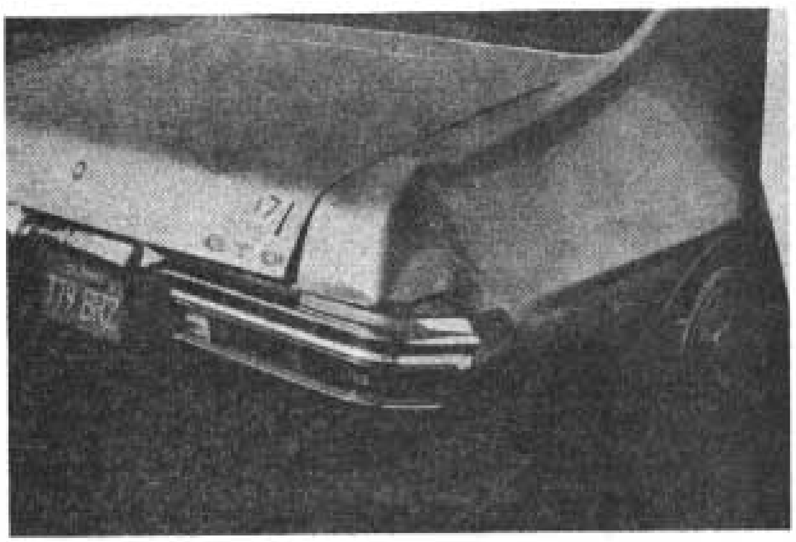

FIGURE 16

RESULTANT DAMAGE FROM TESTS 6 and 7 REAR CENTER & CORNER RESPECTIVELY (BOTH 5.03 m.p.h.)

3) The cost to repair was $175.30.

Test 8 (Ford Left Front Center)

The measured pendulum impact speed was 5.10 mph. The car was unrestrained. The elevation of Line A was matched to the leading edge of the Ford bumper measured at the center. Documentation of this test setup, impact and results is included in the high-speed documentary real time movies and black & white photos (Photo Appendix 78-83 and Figure 17).

Failure may be found in three modes

1) The reference plane touched the hood and the bumper as can be seen in the slides.

2) The bumper yielded in two places. This yielding did not cause any damage to the hood, hood latch or lights. They were all in good working condition.

3) The cost to repair this vehicle was $123.50. Other data run for the Insurance Institute for Highway Safety showed the cost to repair a similar Galaxie for a 5 mph barrier at $180.00 or about a 40% increase.

Test 9 (Ford Left Front Corner)

The measured pendulum impact speed was 4.97 mph. The car was unrestrained. The elevation of Line A was matched to the leading edge of the bumper as measured at the left front corner. Documentation of the setup, impact and results of this test has been sent to NHSB and

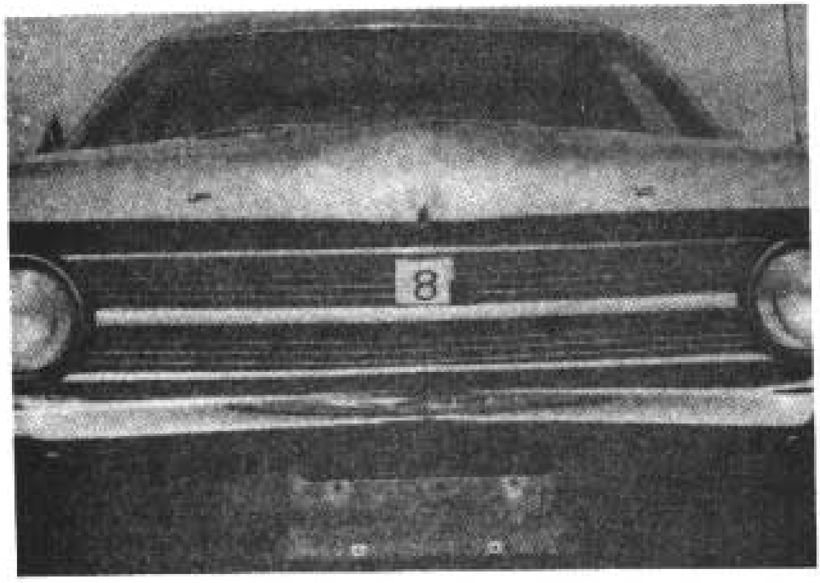

FIGURE 17 RESULTANT DAMAGE FROM TEST 8 (FORD FRONT CENTER)

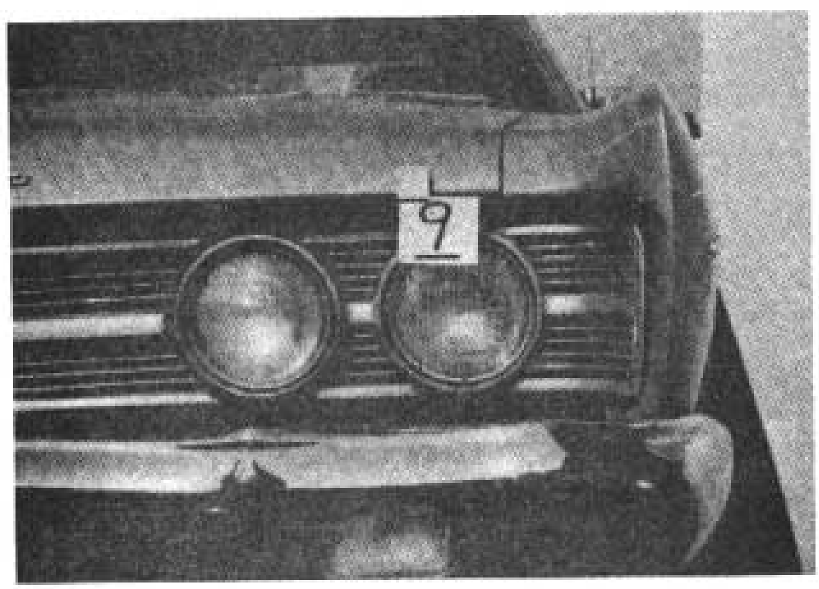

FIGURE 18 RESULTANT DAMAGE FROM TEST 9 (FORD LEFT FRONT CORNER)

includes high-speed and real time documentation movies, slides, and black & white photos (Photos Appendix 84-90 and Figure 18).

Failure in this impact as defined by this modified face was not found.* Contact between the vehicle and the reference plane was not visibly noticeable in either the film or the chalk markings. The dent in the bumper denoted that Line A was entrapped and did not slip out. The bumper was pushed back into the fender and there was fender failure, but reference plane contact was not found. The cost of repair to this vehicle was $96.53.

Test 10 (Ford Rear Center)

The measured pendulum impact speed was 5.03 mph. The car was unrestrained. The elevation of Line A was matched to the trailing edge of the Ford bumper in its center position. Documentation of this test has been forwarded to NHSB in the form of high-speed and real time movies, slides, and black & white photos (Photo Appendix 91-94 and Figure 19). During Test 10, failure was not found.* Line A was entrapped in the bumper. No trunk lid closure problem was experienced. Although there was severe bumper bending and bending of other sheetmetal by the bumper, the reference plane did not contact the automobile. The cost to repair was $149.00.

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* The car did not pass the standard as proposed. It did pass the test as geometrically relaxed for testing in Section 2.4.

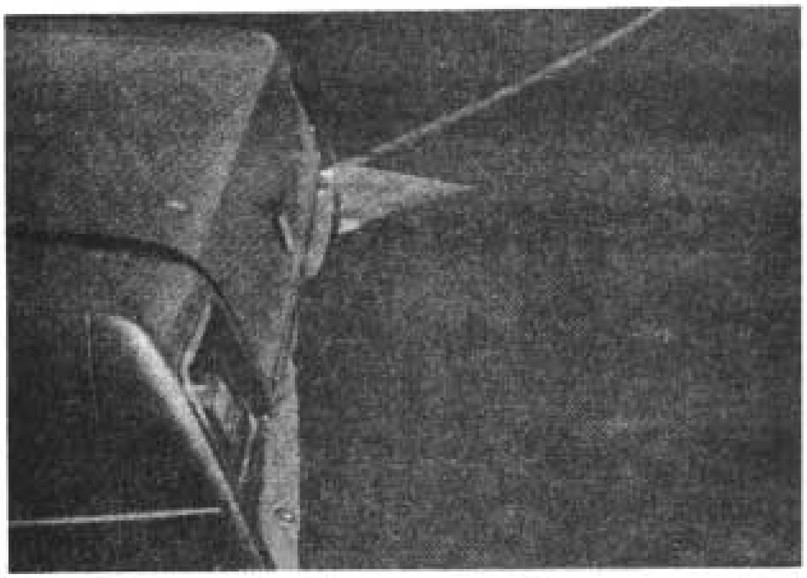


FIGURE 19 RESULTANT DAMAGE TEST 10 (FORD REAR CENTER)

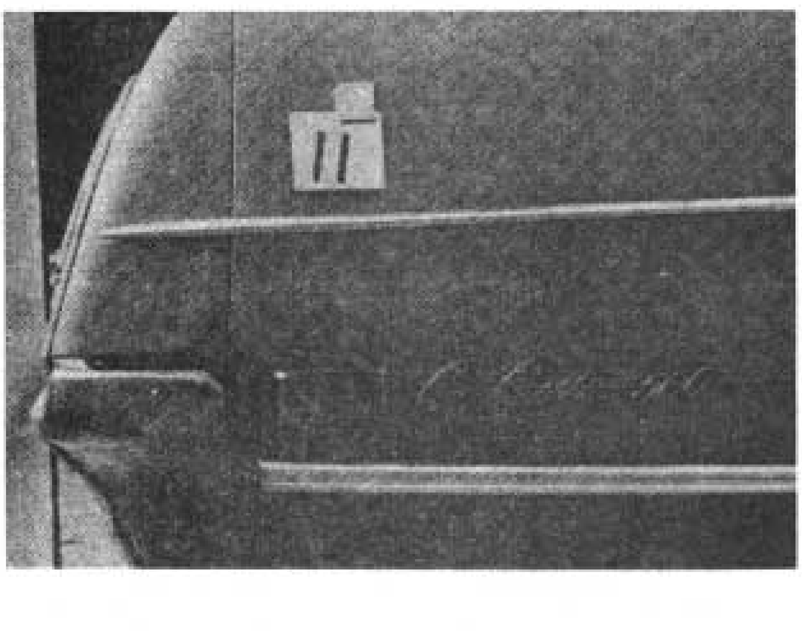


FIGURE 20 RESULTANT DAMAGE TEST 11 (FORD REAR CORNER)

Test 11 (Ford Right Rear Corner)

The pendulum speed was measured at 5.05 mph. The car was unrestrained. Elevation of Line A was matched to the car bumper trailing edge of the right rear corner. Documentation of the vehicle test setup, impact and results has been sent to NHSB in the form of real time and high-speed film, slides, and black & white photos (Photo Appendix 95-100 and Figure 20). The vehicle failed by several modes. Although Line A was entrapped in the middle of the bumper, there was not enough resistance to keep the reference plane from touching the sheetmetal. The quarter panel buckled and the trunk was operable. Cost to repair was $120.70.

3.0 EVALUATION

3.1 SUITABILITY

Is the proposed impact surface and the procedure suited to determine vehicle over/underride propensities?

Although the elevation of Line A is varied some six inches, forcing all car bumpers to be at least that wide, there is no stipulation that the suspension of a vehicle will allow this bumper to move up or down less than three inches. If the nose of one vehicle drops three inches in braking and the rear of the vehicle it will strike rises an equal amount, the bumpers will not match. The bumper width (top to bottom) of any given car should be related to that vehicle's possible attitudes due to suspension deflection. See Section 4, Digitek's recommended bumper standard.

3.2 PRACTICABILITY

Is the application of the pendulum practicable under the specified procedure? Do alternate methods appear to be more practicable? Suggest alternate methods, if required. to retain the test vehicle in one test position. Consideration should be given for a range of vehicle masses (1,000 - 10,000 lbs.).

- <u>Speed Control</u>

The pendulum of the type tested can generate any desired severity between 0-10 mph without major modification. Speeds above 10 mph will generate longer periods of vehicle-pendulum contact and thus larger vertical pendulum displacement. The arc swing of the pendulum will tend to be more geometrically harsh when Line A is applied near the top of the bumper when compared to its application near the bottom. The speed control advantage of the theoretical pendulum is lost if:

1) The catcher (which is not needed) generates too much friction.

2) The face is far enough from the c. g. that it can have significantly higher speeds. (Note A pendulum is valid only on the theoretical assumption that it is a point mass. If this is not the case, then there are variables which tend to not follow theory. The radius length to the front of the pendulum face is longer than to its center; consequently it has higher speed.)

3) The elevation of Line A, following a curved path, artificially moves vertically enough to cause failure.

4) The pendulum moves laterally relative to the plane of the swing and thus changes the corner damage.

- **Alternate Speed Generators**

Other techniques that are repeatable or can be calibrated easily for each test are gravity powered towing devices which could allow the mass and impact face to be mounted on wheels and towed to the struck vehicle. This method would probably cost the same, be more versatile and equally accurate with respect to speed, using pretest calibration techniques. This device could change its weight to 10,000 lbs. more easily than the pendulum. It could also go to a higher speed without introducing an elevation change problem.

- **Change in Simulation Due to Absence of Vehicle Restraint**

It became apparent during testing, that a vehicle could not be held rigid enough to generate a 5 mph barrier simulation in reverse. What is the right simulation using an unrestrained car? Figure 21 shows four impact cases which are equivalent in both passenger perspective and in physical severity. In all four cases, the acceleration time history of all vehicles shown are the same. In the top three cases the occupants optically see a 5 mph impact.

The top line of the drawing shows a vehicle hitting a fixed barrier at 5 mph. Line 2 shows two cars approaching a piece of paper from both sides, each going 5 mph. The two vehicles and their occupants assuming matched front ends will not be able to tell the difference between hitting the barrier of Line 1 or the paper wall of Line 2.

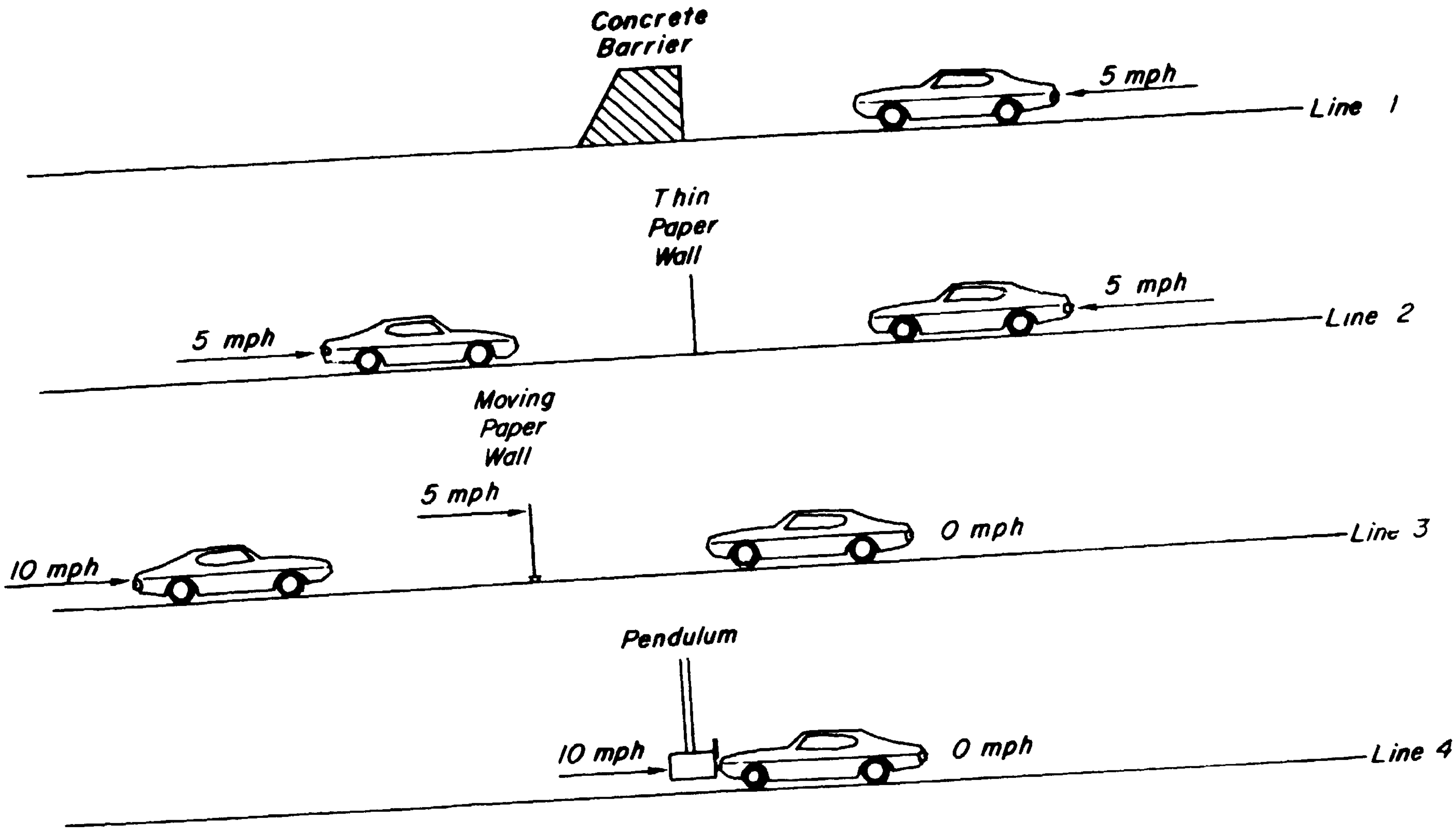


FIGURE 21 - EQUIVALENT IMPACT SEVERITIES

In Line 3, the left car is going 10 mph to the right - the wall of thin paper is moving to the right at a speed of 5 mph. The vehicle on the right is standing still. The paper wall and the 10 mph car both strike the car which is standing still at the same time. As far as the two cars and occupants of Line 3 are concerned the acceleration time history and optical presentation of the collision is the same as that of Cases 1 and 2.

If the above analogy is true, then Line 4 shows that if the pendulum is going to simulate a 5 mph barrier, then it should be traveling 10 mph. This is correct except for two considerations that must be taken into account:

1) The analogy assumes perfect geometric match of the pendulum face and the bumper, and

2) That the crush properties of the pendulum face and the impacted vehicle are the same.

Since both of these assumptions are not true, and the pendulum applies load through a rather stiff face with high load concentrations, a speed less than 10 mph is necessary to maintain the premise of simulating a 5 mph barrier which simulates a 10 mph car-to-car impact.

The experimenter does not wish to imply that the testing done so far shows a meaningful relationship between the proposed pendulum face and a desirable speed reduction from 10 mph. The 5 mph pendulum test is not a substantiated simulation, it is only the arbitrary level with which these tests were run.

3.3 REBOUND

Is the pendulum rebound a problem? Suggest methods to eliminate the rebound problem.

The best method to eliminate rebound is to release the car from its constraints and let it roll. Although catching a 4,000 lb. pendulum was accomplished, the friction in the catching system nullified the effect of using a pendulum to guarantee speed.

3.4 COSTS

Furnish cost to fabricate impact test device and cost to conduct complete test on one vehicle.

The pendulum can be designed, built, and pretested for $1000.00 in parts, 145 hours of technician fabrication time, and 145 hours of engineering time divided between design, fabrication and check-out. Electrical instrumentation used to calibrate the speed is not included nor is any general managerial direct labor. Depending on the amount of high-speed photo documentation, still documentation, and SAE headlight alignment checks, the 20 impacts for each vehicle, requested in the test procedure, could take as long as four days per vehicle or as short as two days. Assuming only one headlight alignment check is made on the test vehicle headlights after the front ten impacts, and high-speed film is used only to back up the touch chalk identification system for cases of the reference plane contact, the 20 impacts could be performed in two days.

This testing would include an engineer (16 hours) and 3 technicians (48 hours). The car would take 8 hours (tech. time) to acquire and set up for testing and 4 hours for disposal. The reporting format has not been decided upon but would probably take 16 hours engineering time, 16 hours secretarial time, and 8 hours staff time if no failure occurred and non-failure damage was not verbally documented in the report. Movie film editing and labeling would take 30 hours labor at $4.00.

ODC FOR TESTING WOULD INCLUDE:

Movie film and work prints	$ 200.00
B&W 35mm 8x10 prints, 5 per impact - 2 setup, 3 results (one set)	$ 150.00
Printing	$ 100.00
(vehicle repair not included)	

Cost		Cost/hr.	Hr.	
$ 140	Prg. Mgr.	at 10.00	14	10 + 2 + 2
1329	Eng.	at 7.50	177	145 + 16 + 16
1080	Tech.	at 5.25	205	145 + 48 + 8 + 4
56	Sec.	at 3.50	16	16
152	Sta.	at 4.00	38	30 + 8
2657				
2920	110% Overhead			
5577				
1450	ODC* 1000 + 200 + 150 + 100			
7027				
1604	G&A - 20%			
8631				
963	10% Profit			
9594	Cost to Build Pendulum and Conduct and Report One Test			

4

8?

* Other Direct Costs besides labor

COST TO FABRICATE PENDULUM ON FLAT SURFACE

(No concrete tie-down pad or catcher necessary)

Cost				
$ 200	Prog. Mgr.	at	10.00	20 hours
1087	Engineer	at	7.50	145 hours
752	Technician	at	5.25	145 hours
2039				
2240	110% Overhead			
4279				
1000	ODC			
5279				
1056	G&A 20%			
6335				
636	Profit 10%			
7071				

Cost to Test One Car

10,593	Cost to build and test
7,071	Cost to build only
3,522	Cost to test one car

This does not include the cost of returning the car to its original condition.

3.5 PROBLEM AREAS

Estimate the cost of damage to the vehicle by the first strike and when all strikes are completed. Report real and anticipated problems that may arise in conducting these compliance tests on both domestic and foreign vehicles.

The damage by impact follows from bids generated after all pendulum strikes have been completed. Damage which could be generated by both center and corner impacts, like hood alignment and deck lid alignment were attached to both. The cost of removing dinges and re-chroming the bumper was added to both. The joint bids are considerably less than some of the individual repair costs.

Valid cost sheets were not made for Tests 1, 2, and 3. Because the cars were returned to like new condition, all parts were replaced not straightened.

Test 1	estimated same as	Test 4
Test 2	estimated same as	Test 7
Test 3	estimated same as	Test 6

These similar cost estimates do not indicate

1) that the 5 mph restrained and 5 mph unrestrained testing produce the same results. Photos included in the report such as Figures 9 and 16 show that damage was different, though projected repair costs were similar.

2) that 5 mph restrained vehicle tests and 5 mph barrier tests are equivalent. Testing done to date does not support this equivalence.

	Labor (hrs.)	Parts	Misc.	Sublet
<u>Test 4 GTO Front Center</u> (vehicle failed)				
Align bumper	2.0			
Paint damage, as nec.	2.0		5.00	

Total Labor Costs	$ 32.00
Paint	5.00
Tax	.25
TOTAL	$ 37.25

(If bumper parts are replaced because of surface blemish, add $175.00)

	Labor (hrs.)	Parts	Misc.	Sublet
<u>Test 5 - GTO Left Front Corner</u> (vehicle failed)				
Remove & replace front face bar	2.9	145.00		
Str. back bars	1.5			
Str. left front fender	4.5			
Remove & replace left O/S, H/L	.2	3.90		
Align & str. lower valance	1.0			
Paint damage, as nec.	5.0			

Total Labor Costs	$ 120.00
Parts	148.00
Paint	10.00
Tax	7.95
TOTAL	$ 286.85

	Labor (hrs)	Parts	Misc.	Sublet
Test 6 - GTO Rear Center (v hicle failed)				
Remove & replace rear face bar, str. & plate	1.5			65.00
Str. bumper back bars	1.0			
Str. back body panel	3.0			
Str. deck lid & align	3.0			
Paint damage, as nec.	3.5		7.00	

Total Labor Cost	$ 96.00
Paint	7.00
Sublet	65.00
TOTAL	$168.00

	Labor (hrs)	Parts	Misc.	Sublet
Test 7 - GTO Right Rear Corner (vehicle failed)				
Remove & replace rear bumper, str. & plate	1.5			65.00
Str. bumper back bars	1.0			
Str. right rear quarter panel	7.5			
Paint damage, as nec.	3.0		6.00	

Total Labor Cost	$ 104.00
Paint	6.00
Sublet	65.00
Tax	.30
TOTAL	$ 175.30

	Labor (hrs.)	Parts	Misc.	Sublet
Test 8 - Ford Front Center (Vehicle Failed)				
Remove & replace front bumper, str & plate	1.4			42.00
Str. bumper back bars	1.0			
Str. hood & align	3.0			
Str. front gravel & align	1.0			
Paint damage, as nec.	3.0		6.00	

Total Labor Cost	$ 75.20
Sublet	42.00
Paint	6.00
Tax	.30
TOTAL	$ 123.50

	Labor (hrs.)	Parts	Misc.	Sublet
Test 9 - Ford Left Front Corner (vehicle passed)				
Remove & replace, str. & plate front bumper	1.4			42.00
Str. bumper back bars	.5			
Remove & replace left front fender ext.	1.5	9.60		
Paint damage, as nec.	1.5		5.00	

Total Labor Cost	$ 39.20
Parts	9.60
Paint	5.00
Sublet	42.00
Tax	.73
TOTAL	$ 96.53

	Labor (hrs)	Parts	Misc.	Sublet
Test 10 - Ford Center Rear (failure not found)				
Remove & replace rear bumper, str.&plate	1.7			40.00
Str. bumper back bars	1 5			
Str. back body panel	2.5			
Str. back crossmember	1.0			
Remove & replace back body panel mldg	.3	21.90		
Align deck lid	1.0			
Paint damage, as nec.	2.0		5.00	

Total Labor Costs	$ 80.00
Parts	21.90
Paint	5.00
Sublet	40.00
Tax	3.10
TOTAL	$ 149.00

	Labor (hrs)	Parts	Misc.	Sublet
Test 11 - Ford Right Rear Corner (vehicle failed)				
Remove & Replace rear bumper, str &plate	1 7			40.0[illegible]
Str. bumper back bars	1 0			
Str. right rear quarter panel upper	1 0			
Str. right rear quarter panel lower	2.0			
Remove & replace right quarter ext. mldg.	5	3 10		
Paint damage, as nec.	3.0		5.00	

Total Labor Costs	$ 73.60
Parts	3.10
Paint	5.00
Sublet	40 00
TOTAL	$ 121 70

COMBINED DAMAGE, TESTS 4 - 7

1970 GTO

	Labor (hrs.)	Parts	Misc.	Sublet
Remove & replace front face bar	2.9	145.00		
Str. back bars	1.0			
Str. left front fender	4.5			
Remove & replace left O/S head light	.2	3.90		
Remove & replace rear face bar, str & plate	1.5			65.00
Str. bumper back bars	1.0			
Str. back body panel	3.0			
Str. deck lid & align	2.0			
Str. right rear quarter panel	7.5			
Paint damage, as necessary	6.0		12.00	

Total Labor Costs	$ 236.80
Parts	148.90
Paint	12.00
Sublet	65.00
Tax	8.65
TOTAL	$ 471.35

COMBINED DAMAGE, TESTS 8 - 11

1970 FORD

	Labor (hrs.)	Parts	Misc.	Sublet
Remove & replace front bumper, str & plate	1.4			42.00
Str. bumper back bars	1.0			
Str. hood & align	3.0			
Str. front gravel pan & align	1.0			
Remove & replace left front fender, ext.	1.5	9.60		
Remove & replace rear bumper, str. & plate	1.7			40 00
Str. bumper back bars	1 5			
Str. back body panel	2.5			
Remove & replace back body panel mldg.	.3	21.90		
Align deck lid	1.0			
Str. right rear quarter panel	3.0			
Remove & replace rt. rear qtr ext. mldg.	.5	3.10		
Paint damage, as necessary	6.5		13.00	

Total Labor Costs	$ 199.20
Parts	34.60
Paint	13.00
Sublet	82.00
Tax	2.38
TOTAL	$ 331.18

The problems involved with using the pendulum to test compliance of bumpers are very small. Weight and speed can easily be controlled to within test tolerance. Chalk and high-speed film will easily show a great majority of the failures without further inspection of function parts. There is one minor drawback to the test technique and that is a bumper like the GTO, which if it had been strong enough not to pinch the hood and left door during the front center impact, it would have failed anyway because Line A embedded itself 1.5 inches into the soft rubber, allowing the reference plane to touch the bumper,

The most important problem with the technique is not found in its ability to control the phenomena which the compliance test was designed to do - "Be sure a car is safe to drive after low speed impacts." The problem lies in the real world of dollars spent for lives saved. The automotive manufacturer in an effort to meet this bumper standard will have to generate a completely new front and rear impact system; the cost of which will be passed on to the constituents of the NHSB (the consumers). This represents a large cost for which the consumer is getting very little in return. The compliance test certainly does little to rule out good bumper design, and in many respects, it encourages it. But, additional interdepartmental activities between NHSB and the consumer protection agencies of the Government might be able to get the American motorist a considerably better bumper package for the same amount of dollars.

This interdepartmental activity may be extremely difficult and time-consuming, but the final output may well add credibility and integrity to both groups by bringing the American public both safety and value.

4.0 RECOMMENDATIONS FOR TEST IMPROVEMENT AND THEIR RATIONALE

INTRODUCTION

The final report of the pendulum impact testing, thus far, has evaluated the mechanical effectiveness of the proposed standard. This section takes a slightly broader look at the overall problem of the low speed impact phenomena on the U. S. motoring public. This section tries to bring to light the assertion that the proposed standard has a more far-reaching meaning than the functional safety of the vehicle after a low speed impact. These meanings are certainly inter-disciplinary in the areas of safety and consumer interest. Although interdepartmental activity is slow and time consuming, the tremendously advantageous overlap in the area of vehicle front-end design seems to demand this interdepartmental action. The following section should help to quantify this overlap and give recommendations as to how the goals of both groups might be met. The output from this interaction might, at no extra cost to the consumer and taxpayer, produce a far more meaningful standard.

The reader is again cautioned that these opinions and recommendations for expanded interdepartmental activity in the development of the bumper compliance standard are those of the author and not necessarily those of the National Highway Safety Bureau

This section contains information and recommendations for an expanded bumper evaluation program. The information and recommendations are presented in the following format

- The Visualization of Three Undesirable Real World Bumper Phenomena - (Section 4.2)

- Performance Goals Toward Which We Feel the Standard Should Lead - (Section 4.3)

- A Discussion of the Parameters that Could be Used in the Generation of a Standard - (Section 4.4)

- A Recommended Test Procedure that the Staff Feels Will be Meaningful in the Attempt to Control the Observed Undesirable Bumper Phenomena - (Section 4.5)

4.2 THE VISUALIZATION OF THREE UNDESIRABLE REAL WORLD BUMPER PHENOMENA

One commonly used problem approach is to define the undesirable real world phenomena that the standard is to control. These phenomena in the past have been lumped together and called low speed impact safety; for discussion we have divided them into three parts:

- Low Speed Impact - (4.2.1)

- Bumper Elevation Control for Impact Safety - (4.2.2), and

- Vehicle Pushing and Towing Considerations - (4.2.3)

4.2.1 Low Speed Impact

The low speed impact has currently been given the most attention by insurance companies and consumer interest groups because of the considerable and unnecessary cost to the public. This natural phenomenon most commonly expresses itself in three different modes.

The most severe is the relatively square rear-end or freeway-collision which is most commonly found to be in the 0-10 mph range, the parking lot collision in which a moving car hits a parked car at speeds of 0-5 mph, and the concentrated or pole impact where a car strikes a stiff small diameter column at speeds of 0-5 mph.

4.2.2 Bumper Elevation Control for Impact Safety

The second phenomena, not so highly publicized, is the elevation control of bumpers. Attempts to limit passenger compartment intrusion are severely limited by the fact that the impinging member of the vehicle front structure to which the door beam or side structure must be designed to exclude is randomly distributed geometrically in both position and shape. Could this standard define an elevation for the forward-most and stiffest element of all vehicle (not just truck) front ends and an anti-penetration quantity, the side structure designer could be considerably more effective in protecting occupants.

4.2.3 Vehicle Pushing and Towing Considerations

The third natural phenomenon which will take on meaning as soon as controls are placed on low speed impact damage will be the normal add-on cost of fixing the damage caused by the towing of a vehicle by a tow truck. This damage occurs because the mud guard under the bumper must carry a load which it is not designed to do, and the bumper is liable to spring enough in the middle suspension to cause grill fracture during towing. Along with these phenomena go the inability for one vehicle to push another without incurring damage and the inability to attach trailer hitches to non-decorative, non-deformable structures

Although the original standarc did not intend to go into the above areas, it should be clear that it will have a great deal to do with them, and their consideration at this point will prove valuable in the future.

4.3 PERFORMANCE GOALS TOWARD WHICH WE FEEL THE STANDARD SHOULD LEAD

The reason for writing a standard is the hope that it accomplishes a goal. This section lays out some goals as they relate to the above experienced undesirable bumper phenomena.

4.3.1 Low Cost = Elastic Impacts

The basic and primary goal of the low speed impact protection standard is to stop the cost of minor bumps while driving a car. As demonstrated in the relaxed geometry Ford tests, if the car passes the test performance criterion and it still must be taken to a body shop, and it still costs $100. to fix, the standard doesn't perform as intended.

The words, "stop the cost" mean to develop a standard that allows passage only of vehicles that have elastic collisions. This means that the only repair needed is to wash the car if the accident has left residue from the impacted object. The speed of impact is a debatable point (its magnitude can be adjusted), but to meet the intent of the standard, the impact should occur like a tire going over a bumper in the road, the same appearance before as after.

As proved by the Ford impacts, any minor chrome damage which requires the removal of the bumper for minor "dinge removal" and rechroming is just slightly ($20.00) less than total replacement cost for a more severely damaged bumper which would cost $120.00. (Chromed metal bumpers without major rubber or plastic inlays will probably never pass regardless of how slow the impact speed.) The outer surface of the bumper should be elastic and capable of taking abrasion between cars without permanent deformation or surface defacement. If the impact is violent enough to demand more than the skin surface deformation, the support structure should yield elastically. The Endura GTO bumper may have the correct skin properties but the bumper support system cannot transmit and carry the loads to the vehicle elastically, thus the moved fenders and pinched doors generate failure by exhibiting permanent deformation. The word elastic could be clearly defined by the following example: If the bumper is hit four times and it permanently deforms 1/8" each time but does not cause mechanical failure until the fourth hit, the plastic deformation of the first hit is not elastic and thus constitutes a failure.

4.3.2 Good Geometry = Higher Severity Tolerance

The second major responsibility of the standard should be to encourage the manufacturer to, on his own, extrapolate the performance of the bumper system to higher speeds. It is not so much the fact that the standard might deter future changes, but that by the use of proper kinds of dimensional leverage and wording, the standard can be designed to allow the manufacturer as easy next step to extrapolate higher speed performance without having to refight the war with the body stylist. If the standard, under pretext of matching existing road vehicles, would give good geometry, the bumper designer could design vehicles to withstand even higher impact levels. This will be demonstrated later by the use of a pretest condition of a space block. This block will be the major input to the performance of an "elastic system", the proposed major requirement of the standard for bumper passage.

4.3.3 Elevation Control = Side Impact Safety

A goal which might prove to be the most valuable, with respect to occupant protection during front-to-side collisions, is the standardization of bumper height and a way of controlling corner penetration for side impacts If the door beam designer can insure himself of low stiff bumper structure, he can more easily support the door beam using the frame and door sill. If he knows the penetration properties of the bumper corner, he can design for a given load concentration and thus more easily control passenger compartment intrusion. And, finally, the recession of all parts of the striking vehicle relative to bumper surfaces will give these areas less penetration by geometric considerations.

4.3.4 Bumper Design = Safe Convenience

The goal of the bumper standard should ensure that the bumper-car configuration can be

1) Pushed by another vehicle for a short distance without permanent damage;

2) Towed by a conventional tow truck or at least a standardized towing technique without permanent deformation to the vehicle; and

3) A means for connection of a rear bumper hitch which has a rated load capacity and standardized mounting points and techniques.

Admittedly, these are rather energetic goals, but if Detroit is going to modify to meet the basic standard, they should get as many inputs into the system on the first retooling. Detroit will appreciate the standard's extra effort not to cause secondary retooling.

4.4 A DISCUSSION OF THE PARAMETERS THAT COULD BE USED IN THE GENERATION OF A STANDARD

This section deals with the parameters involved with the determination of meaning and effectiveness of the proposed standard. They have divided into two groups. The first group deals with geometric considerations, while the latter group deals with severity considerations. The section will not try to put absolute values on any bumper dimension, but will attempt to organize the areas of interest.

4.4.1 Geometric Parameter Considerations

The geometrical considerations in the design of bumpers have been purely aesthetic. The following section deals only with functional parameters such as the directional performance, the bandwidth of elevational performance and the effects of the space gap or projectional performance.

- In what directions should a bumper system be responsible to the standard? (Responsibility to the standard being elastic deformation only.)

With the reservation that all directions will not be subjected to the same severity, the recommendation as shown in Figure 22 allows impacts up to 135° right and left of center. The recommendation is that the bumper be able to successfully comply with the standard, elastic deformation only, in all five cases in Figure 22. (The severity of each impact will be dealt with later.)

- What shape should the impact surface have?

Because we are dealing with a problem of interaction between vehicles, protection of a vehicle's bumper surfaces at the expense of the other vehicle is unreasonable. For this reason there may be some justification for some design specification as to what the designer is allowed to hit with, which, in fact, is the only way he can be told what he is going to get hit by. In reality, two types of testing are needed, the first kind being some sort of control on bumper design to limit its ability to produce damage on the vehicle it is striking and a different testing program to show its performance in taking impacts without seeing permanent deformation itself. It follows that the standard is then responsible in defining the mutual ground rules between cars. These ground rules would include a standardized impact elevation, or datum, and limitation on load concentration or minimum bearing surface. This could include a minimum bandwidth of vertical bumper surface above and below the datum line and a minimum radius of corner curvature.

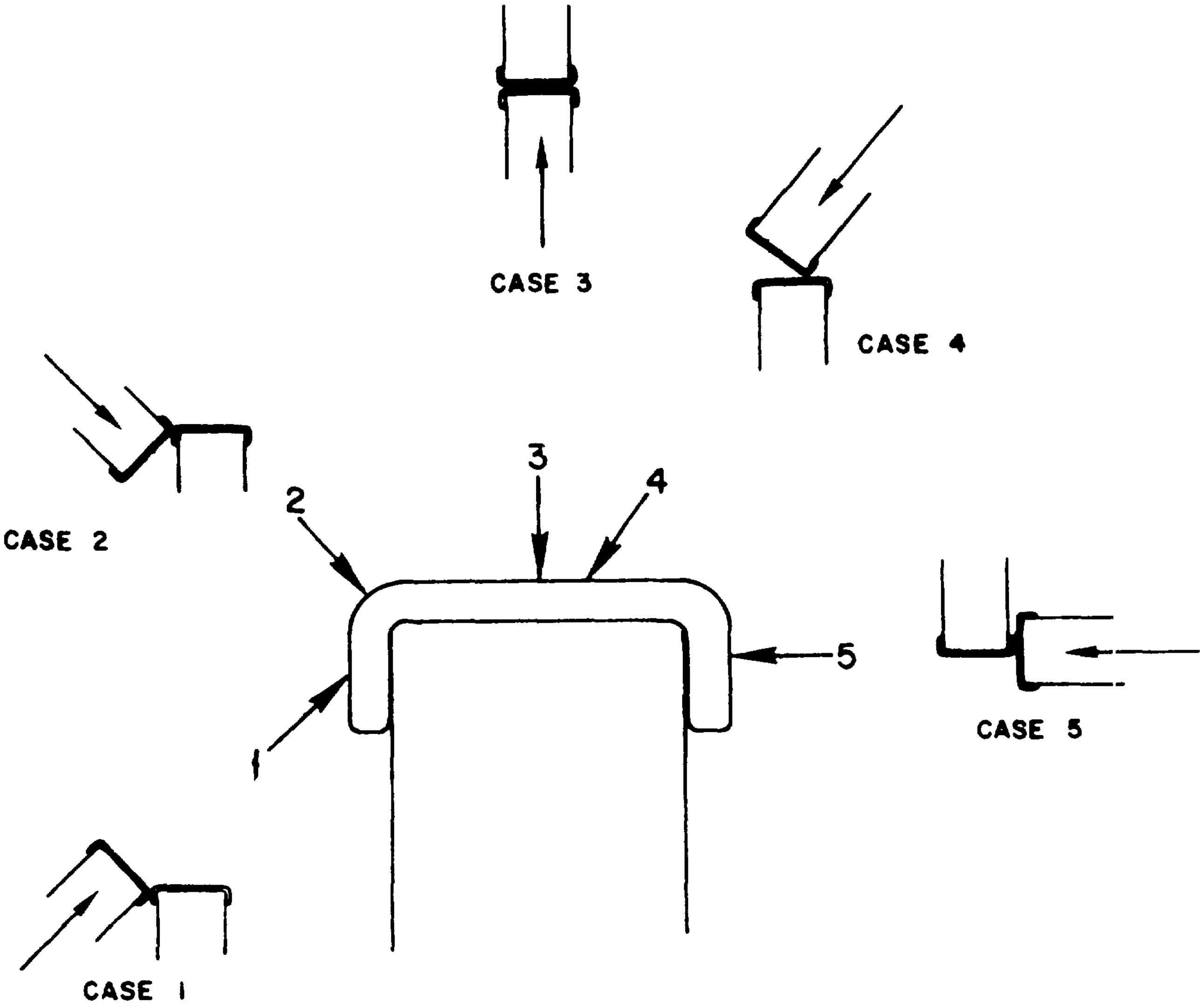


Figure 22 —

Recommended Directions of Impact

Figure 23 shows the dimensions of interest. The first dimension that requires a value is d_1. d_1 is the uniform datum elevation for all bumpers and truck underride guards. The impact surface should have an elevation bandwidth large enough to overlap the standard elevation d_1 by a dimension "X" inches regardless of the vehicle loading or dynamic pitching effects. This means that any vehicle if operated on the public road, regardless of loading or pitch configuration, will at all times show a flat vertical surface of width "X" equally distributed above and below the d_1 standard datum elevation. Dimension "X" is called the minimum overlap, and with the control of vehicle corner radius, defines the crit cal bearing area for any particula impact.

Dimension d_1 should be as low as possible. The reasoning is that of side impact protection. The lower the door beam, the more stiffly it can be designed and supported from frame and door sill elements. The lower limitation of datum level is controlled by the amount of vehicle pitch upward in the rear. Remember that the bumper statically must extend below the elevation datum by the amount of rear end pitch upward. If this dimension is large, the vehicle in its heavily loaded state may see very low ground clearance.

Once d_1 is determined, a dimension of minimum overlap "X" must be determined. Minimum overlap should be large enough that if contact between the two vertical surfaces occurs, over or underride will be improbable, and the load concentrations will not generate permanent deformation.

For example, let's assume the dimension of minimum overlap was two inches, then, a vehicle with an infinitely stiff ride could have a bumper with a flat vertical surface of two inches in height with a centerline elevation of d_1. A car with suspension will have a bumper which

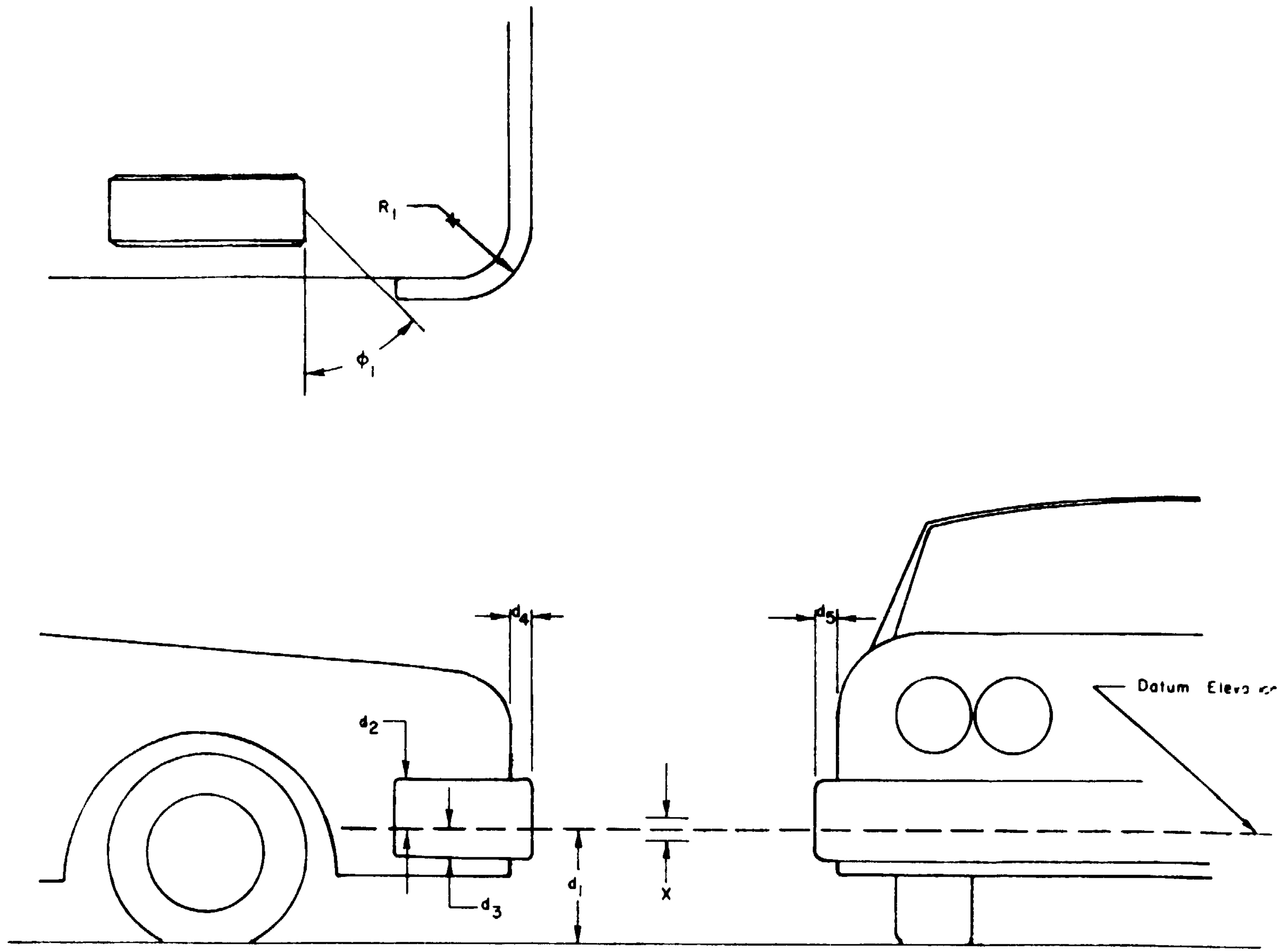


FIGURE 23

DEFINITION OF CRITICAL DIMENSIONS

reflects the possible attitudes of the car allowed by the suspension. The front bumper will have a dimension d_2 (Figure 23) which reflects the worst vehicle pitch and load configuration Dimension d_2 will be one-half the minimum overlap plus the amount of vehicle dive measured at the bumper position. Dimension d_3 will be (for front ends) one-half the critical overlap plus the worst vehicle loading for front bumper rise. Following similar procedures the vertical dimensions above and below the datum for the rear bumper can be constructed. Dimensions d_2 and d_3 are not parts of the standard but are inputs to the bumper designer for each car that he will design Figure 24 shows the effect of the critical overlap of dimension d_1 and its effect on maintaining a common impact area between a vehicle with severe nose dive and one with rear end lift.

Another parameter which should be decided by agreement is the distance ahead of the front wheel and the distance behind the rear wheel that the bumper should protect (angle theta) (Figure 23).

Other geometric bumper inputs are discussed under projection below and in sections on severity, i. e., corner radius R_1 and bumper projection d_4 and d_5.

- What will the bumper projection mean to the standard?

Bumper projection is the dimensions d_4 and d_5 in Figure 23. It is the distance available for elastic deformation. It is the distance between the plane of the initial bumper surface and the non-plastic parts of the car. All parts of the car which lay in this region must be of the elastic range. (Zero cost to impact at respective levels, no visual damage, and no resultant mechanical failures. Repeated impact will generate identical results.) The determination of d_4 will in reality

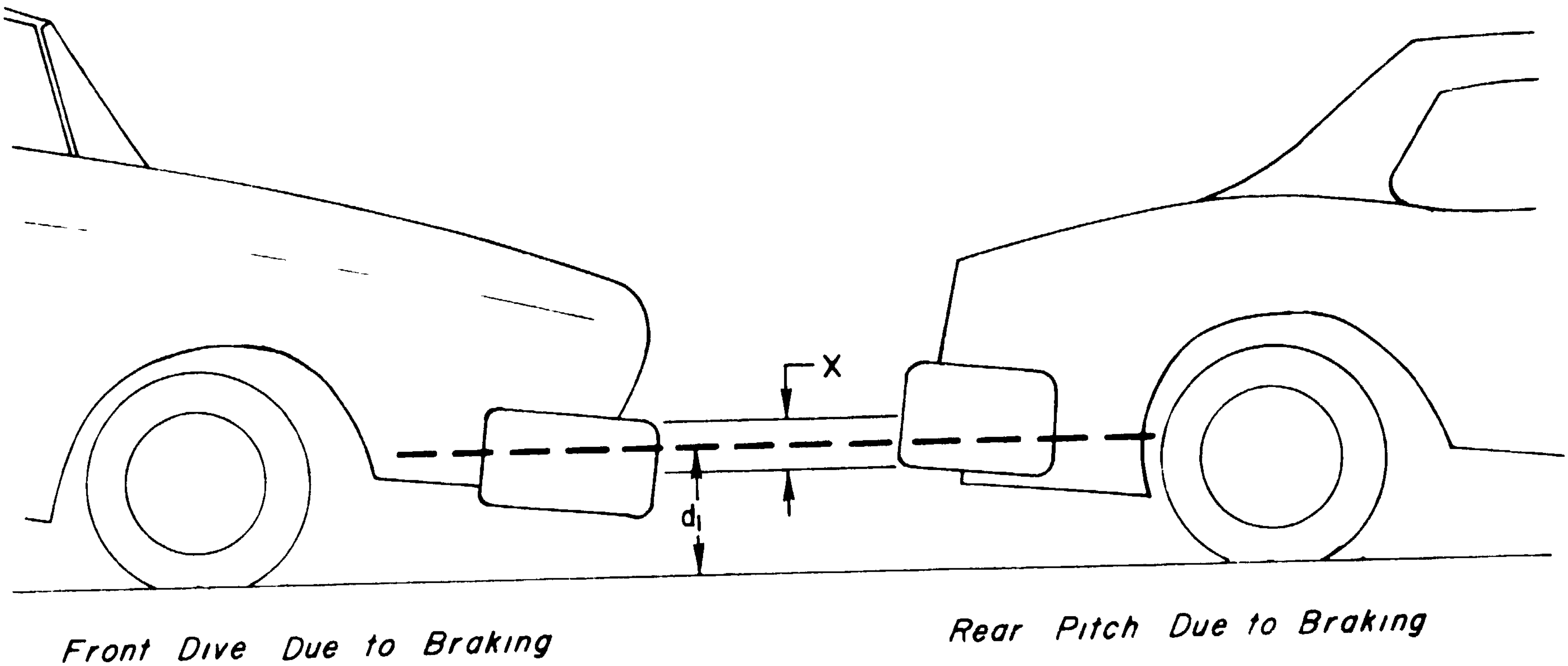


FIGURE 24

DEMONSTRATION OF CRITICAL OVERLAP

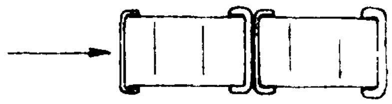
determine the rate at which the auto industry or the Federal Government can increase the speed of elastic collisions. As stated before, this is a design specification and as such is not acceptable. How this is brought to bear on the testing technique will be explained in the section on test procedures. What should be understood is that dimensions d_1, d_4, and d_5 are not arbitrary inputs, and like d_1 will have the most significant overtones as to the effectiveness and performance of present and future standards.

4.4.2 <u>What Impact Severity Has Meaning?</u>

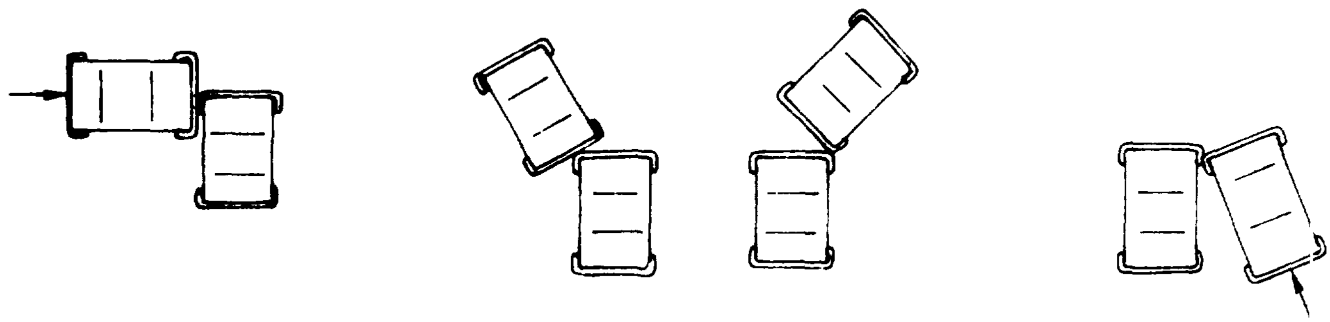
The testing done by Digitek on a Ford shows that the damage costs for a 5 mph barrier and a 5 mph pendulum unrestrained impact are similar.* The energy involved and the momentum transferred are not the same. The damage should have been considerably less for the pendulum impact. The reason may be because of the load concentration of the pendulum testing system. This leads us to believe that the speed of impact and the load concentration at the point of impact have had meaningful effects that cannot be extrapolated from one single type of impact testing. For this reason three separate types of impacts are recommended to insure the elastic properties of the bumper system. These three types of impacts are depicted in Figure 25.

1) The first of the three is the 0-10 mph square car-to-car impact. This is the one most seen in stop-and-go or freeway driving, and has been simulated by a 5 mph barrier crash. This impact can be

* This does not mean to contend the experiments were equivalent, only the costs to repair were similar

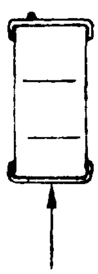


Freeway Impact (Square) 0-10 mph



FRONT TO SIDE   CORNER TO FLAT   CORNER TO CORNER   CORNER TO SIDE

Non-Square Parking Lot Collisions (0-7 mph)
Involving Major Radii (14" - 20") or Equiv.



Small Diameter Pole Impact (0-4 mph)

FIGURE 25

THREE TYPES OF VEHICLE IMPACT

simulated by a pendulum impact close to, but slightly less than, 10 mph. The characteristics of the pendulum bumper will seem stiff when compared with the dynamics of the entire vehicle mass and the way in which it is suspended. The amount the test speed should be less than 10 mph is related to the relative stiffness of the pendulum mounted bumper.

2) The second major type of impact will test for the parking lot accident impact (Figure 25). In this impact one car is standing still while the other impacts it. The speed of interest of the striking vehicle lies between 0-7 mph. Once R_1 or its equivalent is established, a reasonable test speed can be arrived at. The smaller the radius, the higher the load concentration and the lower the probable impact speed that will not leave permanent deformation in the struck vehicle. Although deciding on a radius is like determining a design specification, because of the future connotation of the door beam design problem, it is recommended that a study pick a minimum design radius or its equivalent and it be included in the original first bumper standard (first guess, between 10-20" radius).

3) The third type of impact is that of the concentrated load (Figure 25). This impact is the bumper impacting a small diameter pole in the range of 3-4 miles per hour. In this test, the pendulum would be fixed with a small diameter vertical pipe face and the weakest point of the bumper would be determined and impacted. This test controls the "dinge proof" quality of the bumper.

4.5 RECOMMENDED TEST PROCEDURE

The recommended test procedure that the staff feels will be meaningful in the attempt to control the observed accident phenomena and to fulfill the goals laid out in Section 2 can be divided into three parts

1) Pretest Development - (Section 4. 5. 1)

2) The Testing - (Section 4.5.2), and

3) The Evaluation of Performance - (Section 4.5.3)

4.5.1 Pretest Development

The pretest program involves three activities. The first is weighing the vehicle and adjusting the weight of the pendulum accordingly. The second is an evaluation of the effects of loading and braking on the dynamic elevation of the front and rear bumper and the procedures for making the vehicle maintain this attitude statically while being tested And, thirdly, the procedures and test techniques used to demonstrate that the bumper system has either a minimum geometrically determined load distributing bumper surface or its equivalent

- The Weight Considerations

Of the three pretest procedures, the determination of a test weight is by far the simplest. The car should be weighed. This weight (curb weight) should be used as a base weight of all testing or each set of tests described in both the next section and Section 4.4. 2. This test weight can be brought up to commuter or travel weight, two passengers

The testing techniques used to insure minimum corner radius and/or bumper projection can be defined as the use of pretest templates that check the intended projection measurements and corner radii. The templates described in Figure 26 side-step the problem which will arise in performance testing of corner structure penetration controls. This testing would involve generating a standard door structure and running the equivalent corner design into it to demonstrate its properties to be equal to or better than the radius called out by the standard. The above requirement looks like design specification, but is the only way the designer can be told what he is protecting against. This rather subtle addition to the bumper standard has significant meaning and deserves further study.

4.5.2 The Testing

This section deals with the additions to the bumper standard which the Digitek staff feels would help extend the standards capability to meet the goals laid out in Section 4.2.2 and Section S.1 of the notice of proposed bumper standard. This section generates the general recommendations for number and type of tests on each car, the pendulum surface for each type of test, the pendulum speed for each test, as well as recommendations for the evaluation of secondary problems like tow truck generated damage, vehicle-vehicle pushing damage, and bumper hitch performance criterion.

- The first type of testing the bumper will be subjected to will be the simulation of the 10 mph square freeway impact front to rear (Figure 25). This will be equivalent to the original 5 mph barrier. The car will be impacted four times, twice in the front and twice in the rear. The difference of the two impacts at each end will be vehicle attitude,

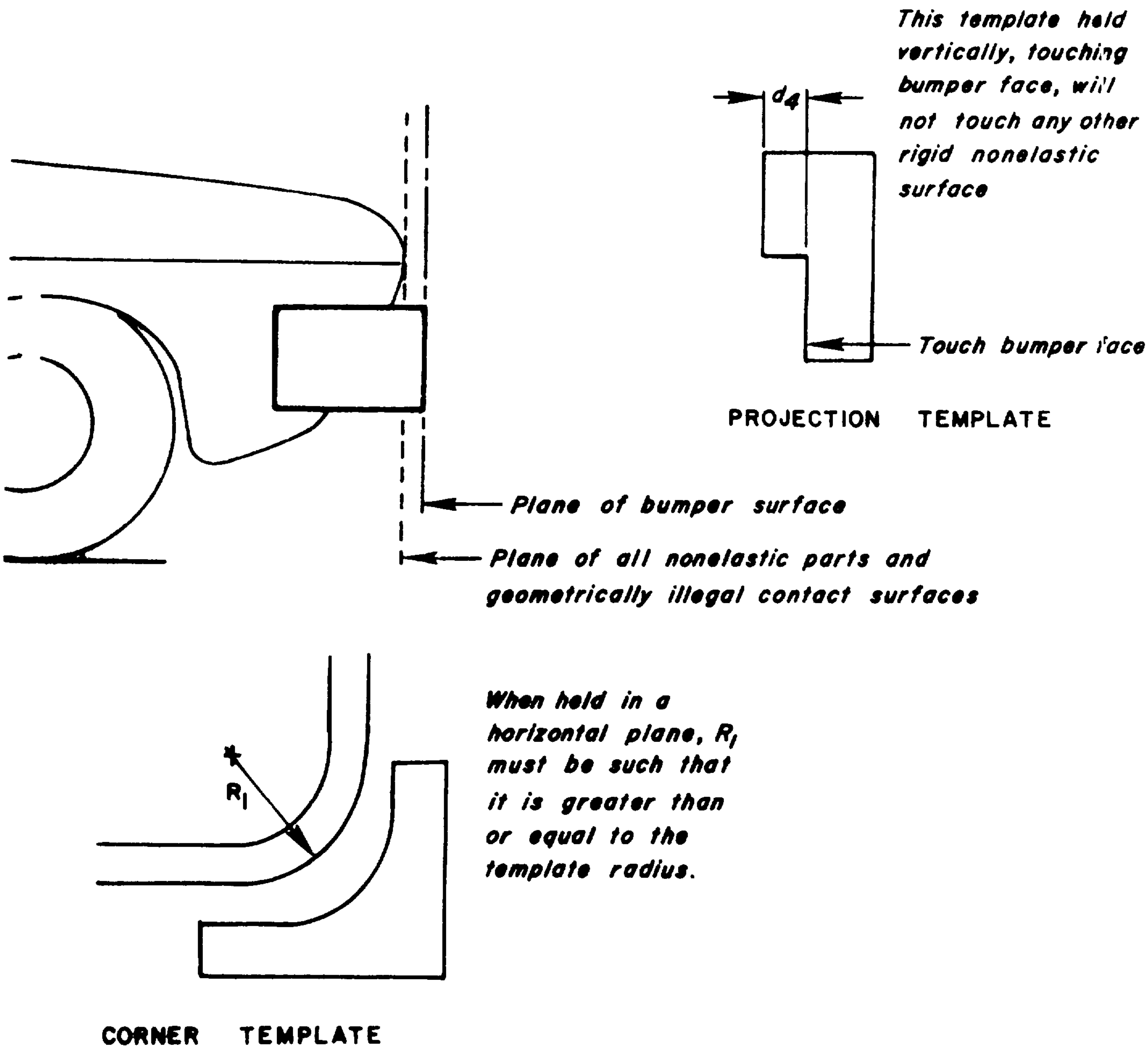


FIGURE 26 — TEMPLATES

i.e., full-up and full-down. The pendulum face will be a flat bar with a height of "X" and fixed elevation d_1 at its centerline (see Figure 23). This bar will be 80 inches long and will appear as in Figure 27. The performance criterion will be no cost to repair. This means the entire impact must produce only elastic deformations. Any noticeable dinge in the skin surface that cannot be removed to optical satisfaction will constitute a cost to repair and thus a failure.

- The next type of collision to be simulated will be that of the non-square parking lot impact as seen in Figure 25. This can be described as the corner of one vehicle striking another somewhere on the bumper surface. In preparation for this impact, the bumper will be inspected for the weakest point of support structure. This point must lie at the datum elevation when the car is in some real attitude in which it might be hit or it could impact another car. The car will then be set in this attitude so that the pendulum impact face seen in Figure 28 will impact the predetermined spot on the bumper at 4-7 mph, depending on the radius R_1 (Figure 28), and will have similar geometrical properties to the standard vehicle corner radius R_1 (Figure 23). This radius will be determined by further study and investigation. If more than one area looks as if it is a weak point, the bumper may be impacted as many times as necessary to convince the tester that the impact will not generate any damage. Because of the no-damage requirement high-speed documentation will not be necessary and repeated testing will not be very expensive. In performing this kind of test care must be taken to ensure that the decided impact trajectory (vehicle attitude) must have a reasonable real world probability of happening.

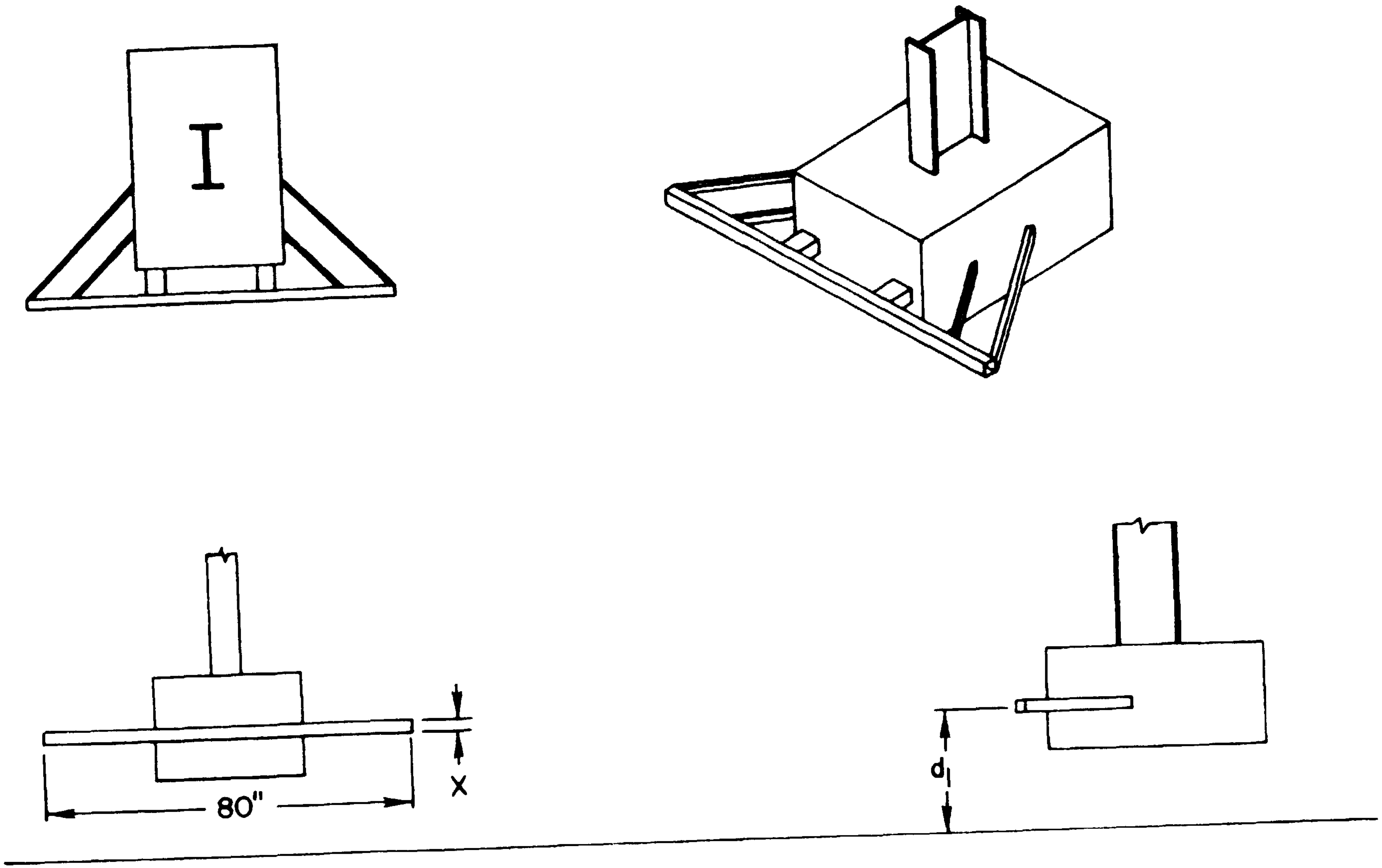


FIGURE 27

FREEWAY IMPACTER

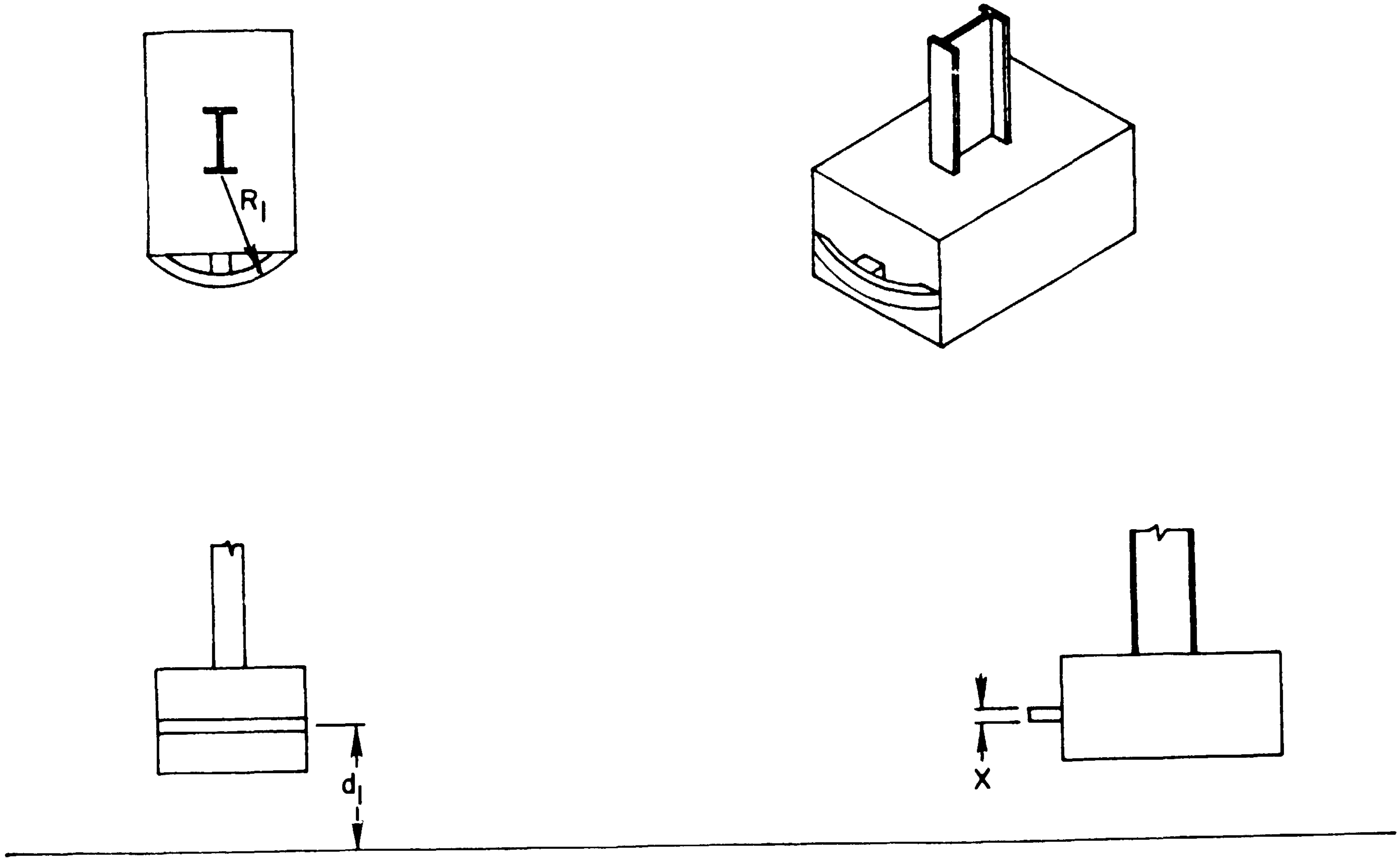


FIGURE 28

PARKING LOT IMPACTER

- The third type of testing will evaluate the bumper surface damage resistance to impact with small diameter poles (Figure 25). During this test, as in the previous series, the experimenter will look for the weak point of the bumper design and test only those areas. Again, he is not limited by documentation because the performance criterion is no cost to repair, no non-elastic deformation. The pendulum face will look like Figure 29 and its speed of impact will be 3-5 mph depending on the radius R_2, the designed stiffness of the bumper cushion and the dimensions d_4 and d_5.

All the test devices and impact faces, assume the use of a template during pretest to insure the dimensions of d_4, d_5, and R_1. The use of the template would demonstrate the effect of both the reference plane and Plane B of the present proposed test.

- The Vehicle-Vehicle Pushing, Tow Truck Compatibility and Bumper Hitch Accommodation

This section is included only as a reminder. The bumper system demanded by the proposed standard is not directly concerned with these non-impact phenomena, but is certainly, at least with respect to its cost consciousness, closely akin. The needed effort to write considerations like these into the first retooling seems worth the time and effort. At this time a study in this area could prove to be helpful.

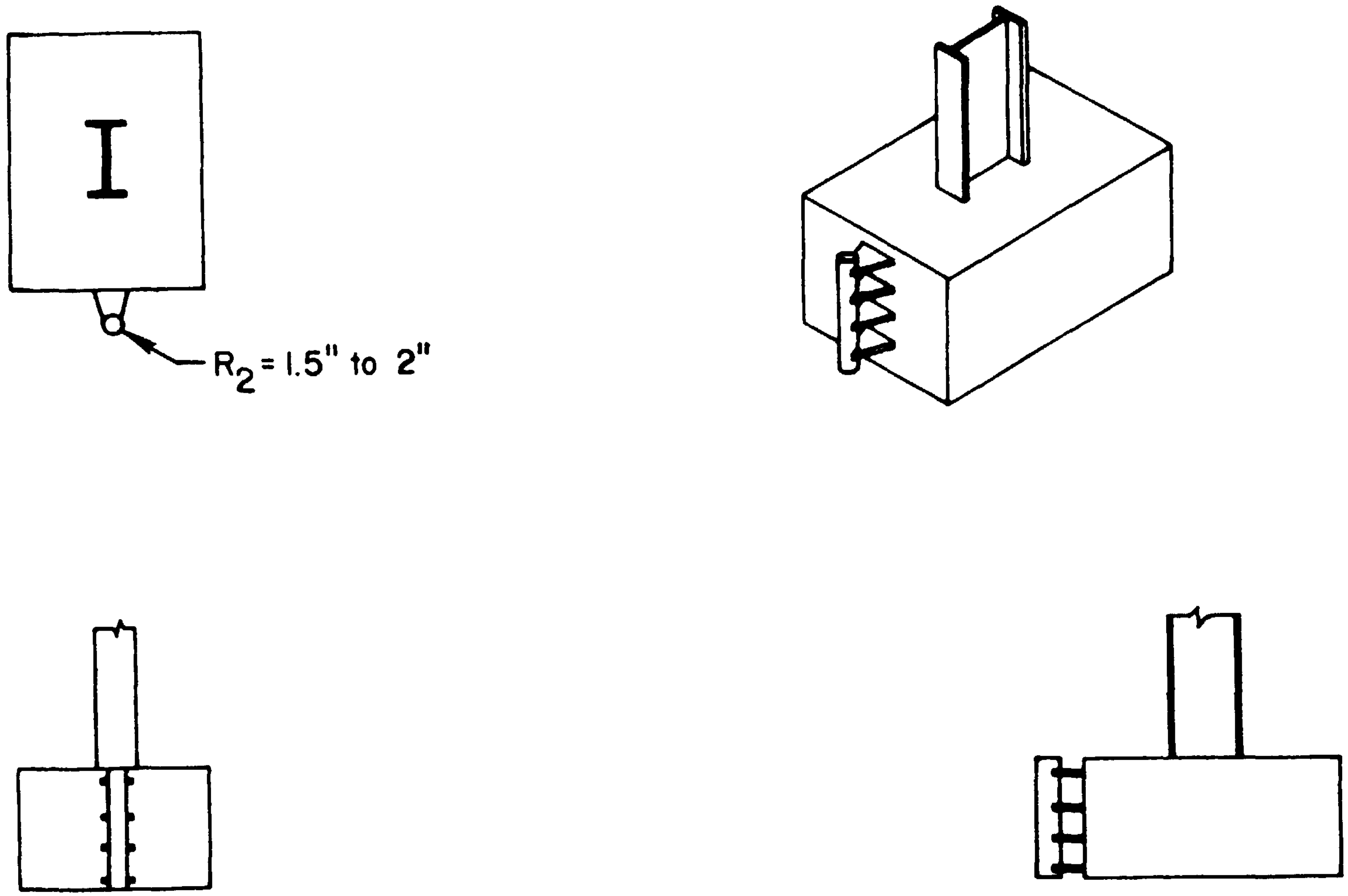


FIGURE 29

POLE IMPACTER

4.5.3 Performance Criteria

The basic performance criteria of the proposed standard is to ensure that a vehicle which has been involved in a minor accident and is self-mobile is also safe to drive with respect to visibility and mechanical systems. The section which precedes, (4.0) contends that to accomplish these initial goals Detroit will have to completely retool. If this is true, then in the retooling process which is extremely expensive, several sets of goals may be actualized at the same time for the same cost to the consumer. The additional goals have to do with three areas:

1) Injury reduction of side impact collisions,

2) Vehicle cost control for low-speed impacts, and

3) Convenience and safety factors under non-impact conditions.

The performance criteria needed to accomplish the first goal are

1) Standardization of bumper height.

2) Establishing projection minimums so that the projection elements can perform without being fouled by their surrounding sheetmetal (see Page 52).

3) Standardizing the radius of vehicle corners, thus controlling minimum bearing area, getting the lowest probability of door penetration, and highest probability of deflection.

These elements may sound like design specifications, and in some cases they are, but as previously stated, "If you are going to tell a designer what his door beam is going to be hit by, he must agree to limit the geometry his vehicle can hit with."

The second consideration has to do with the cost of low speed impacts. Test performance criterion should include thoughts like, "no damage testing" and "limited to elastic deformation during impact." It would be the intent of a recommended test program to test only at levels that a bumper system would be expected to withstand elastically. It would be better to call out in the test procedure a reduced pendulum speed of 8 or 9 mph and demand "no damage at that level" than to test at 10 mph and allow visible deformation that could be mechanically tolerated because it made no parts inoperable.

Another reason for no-damage testing is that it allows multi-hitting and non-permanent recording of dynamic deformation during impact which is time-consuming and expensive.

The third set of performance criterion, which deals with vehicle-to-vehicle pushing, tow-truck towing, and bumper hitch attachment points, has not been developed. This paragraph is only included so that it can be given consideration.

In closing, it is clear that Section 4 goes beyond the absolute scope of the proposed rule making. It is also clear from an economic viewpoint that a great deal more than just low speed safety can be gained for the same number of dollars if some additional effort is done in the area and the findings of these efforts are included in the proposed rule making.