Development of Crash Research Techniques At the General Motors Proving Ground

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• VEHICLE DESIGNERS in General Motors have been interested in crash research for more than thirty years. A few tests were conducted in the early 1930's to evaluate the integrity of the body structure at the time of the adoption of the all-steel turret top and to get some information on collision-type tests under controlled conditions that could be correlated with highway accident damage.

Figure 1 shows an early roll-over test conducted by driving the car onto a spiral ramp located at the top of a hill. This test was conducted in 1933 (1). Figure 2 shows a barrier impact test conducted in 1934. In this test, the driver aimed the car at the barrier at a speed low enough so he could get out of it just before the impact. Figure 3 shows a level roll-over test which was conducted by driving the car into a skid on a level sod field.

These tests were made before the development of high-speed cameras or precise, high-response accelerometers; the results were in terms of visual observation made at the time and the damage to the vehicle. Because most tests of this nature look alike to the unaided eye and the gross damage on repeated tests is quite similar, it did not seem to be necessary to conduct them on successive yearly models.

After World War II there began a growing intensification of engineering effort in body design, and changes were evaluated much more carefully than had seemed necessary in the development of prewar designs.

The 1933-type spiral ramp test was deficient in that there was almost no forward speed; in most roll-overs in highway accidents there is an appreciable forward velocity component, and much of the damage may be done as the roof or corners of the top strike the ground at high velocity of slide over the usually rough roadside at nearly the speed of the car before the accident occurred. It became necessary to gain

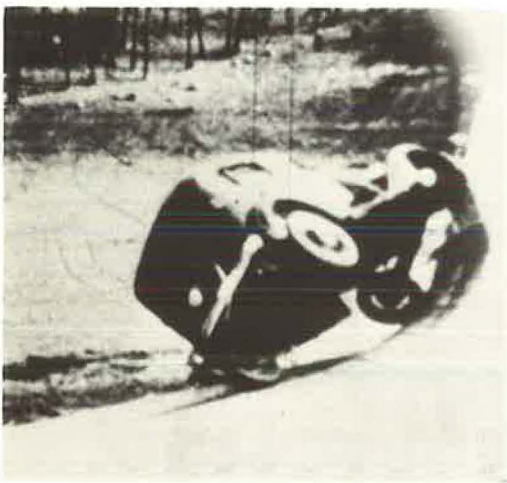

Figure 1. Spiral ramp roll-over test, 1933.

Figure 2. Early barrier impact test, 1934.

Paper sponsored by Committee on Highway Safety Research.

Figure 3. Ground level roll-over test on 1935 turret top body.

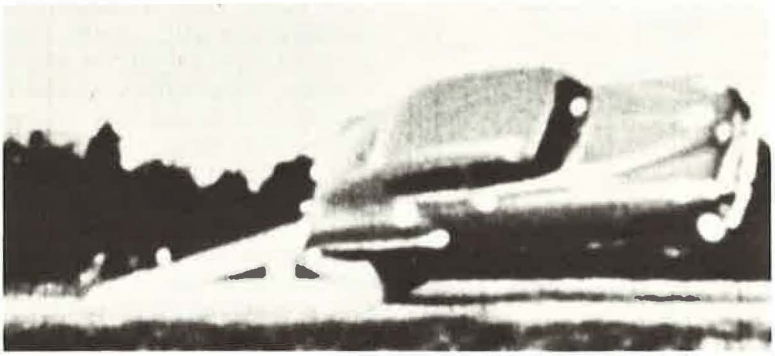

Figure 4. Ramp roll-over of 1948 car.

Figure 5. Ramp roll-over test on 1956 car.

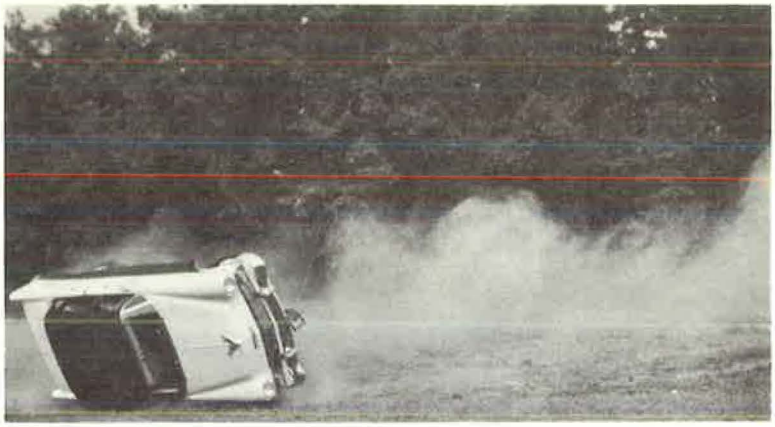

Figure 6. Ground level roll-over on side slope.

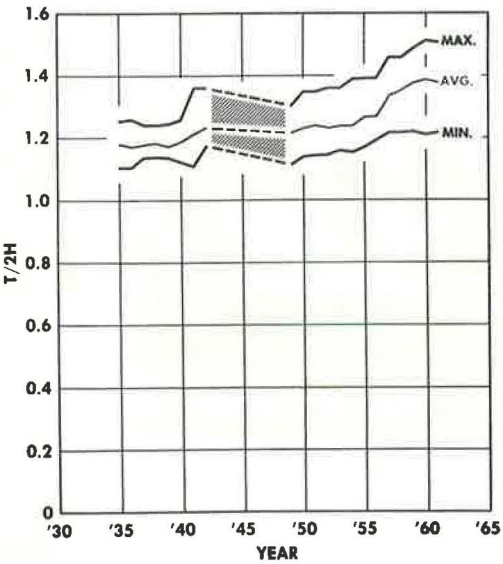

Figure 7. Trend of stability factor from 1935 to 1962.

some experience with a roll-over technique in which the forward velocity was preserved.

Figure 4 shows a roll-over test of a pilot model 1948 car conducted by towing an offset car with a quick-release mechanism so that one pair of wheels could climb a ramp. This technique was relatively effective, and it was used frequently for eight or ten years.

Figure 5 shows a 1956 car. This ramp roll-over test is effective in evaluating the effect of forward velocities during roll-over accidents; however, it is somewhat unrealistic in the sense that the car is lifted 4 or 5 ft off the ground, which is quite unusual in highway accidents. The test results were not as reproducible as desired, and it came to be recognized generally that there was need for a technique that would reproduce the conditions more representative of a typical ground-level roll-over.

Figure 6 shows a ground-level roll-over; the roll-over is accomplished by towing the car up to speed by means of a quickly detachable towing mechanism, then quickly turning the front wheels to the full left-turn position by means of a remotely controlled steering device. On a suitably steep side slope with proper ground conditions, cars can be rolled over with considerable success and reasonably good reproducibility.

The objective of roll-over testing is to establish the sturdiness of the roof and body pillars, to evaluate door lock designs, and in a preliminary fashion, at least, to learn something about the injury-producing potential of interior components. The development of a ground-level roll-over test technique is difficult because the progressive lowering of the over-all height has caused a significant reduction in the height of center of gravity and a corresponding increase in stability.

Figure 7 shows the trend of the stability factor since 1935 of the best, the average, and the poorest car in the fleet at the Proving Ground. This stability factor is the ratio

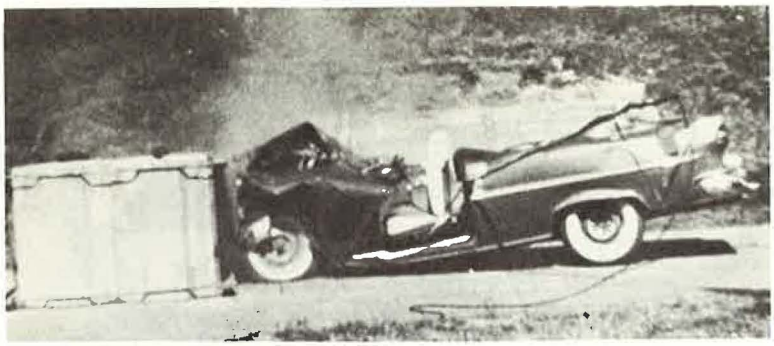

Figure 8. Barrier impact test.

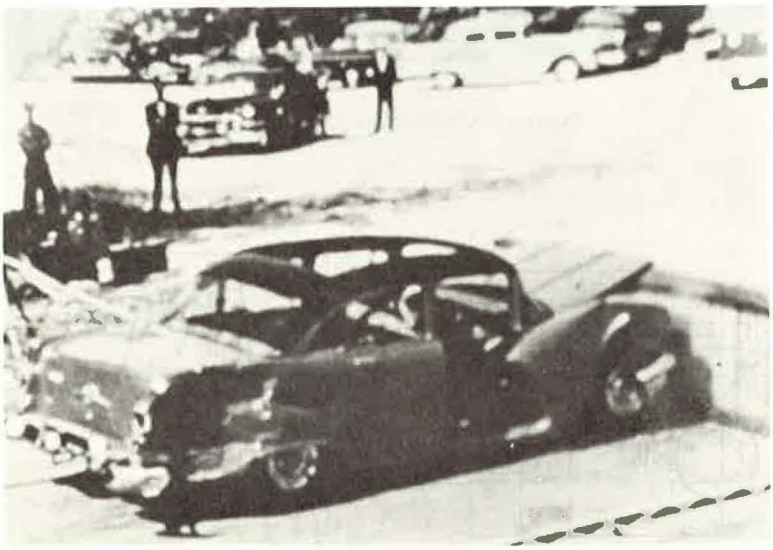

Figure 9. Barrier impact test.

of one-half the tread to the center of gravity height, and it changes most rapidly with the change in center of gravity height (2).

Because the head-on crash or direct impact with a solid obstacle is such an important consideration in highway safety, it is necessary to have a factual background to determine what happens, to gain an understanding of the potential for injury reduction through design, and to arrive at the scale relationships between severity and speed at impact.

Figures 8, 9, and 10 show the results of barrier impact tests. These were run by letting a remotely controlled car coast down a steep grade and collide with a massive concrete barrier. In these tests the impact speeds were approximately 30 mph, and the deceleration rates on the undeformed part of a car frame of the order of 30g. The total and catastrophic nature of these tests leads the investigator to believe that the threshold of serious and probably fatal injury is far below normal highway speeds; it leads to the conclusion that it is impossible to provide secure protection during impacts

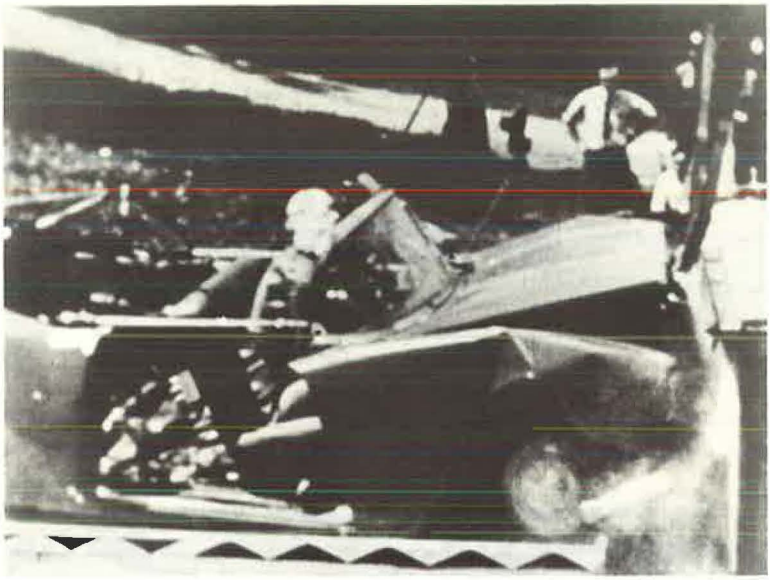

Figure 10. Barrier impact test.

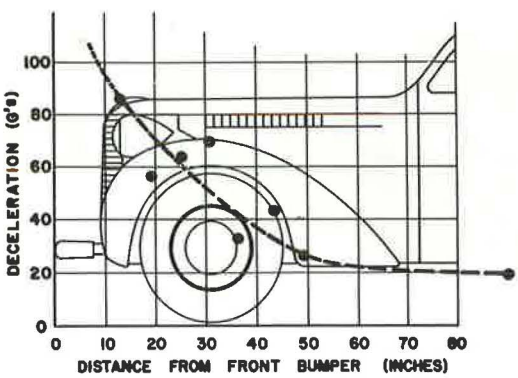

Figure 11. Deceleration during impact with fixed object as function of distance back of front bumper.

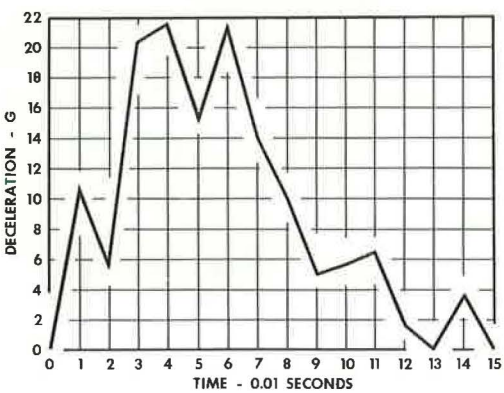

Figure 12. Typical deceleration-time curve, barrier impact test.

of this nature by any amount of design modification, or by the use of any restraining devices that the average customer would be willing to use.

There is extensive literature on tests of this nature, including car head-on and side impact accidents contributed by Mathewson and Severy and others (1, 3). Of considerable interest is a typical result from their work (Fig. 11). This shows the deceleration during impact with a fixed object as a function of the distance back of the point of impact. The deceleration falls from a value of well over 100g at the point of impact to a nearly stabilized value of 20g at points more than 60 in. back of the point of impact. This reduction in deceleration of more than 80g illustrates the energy-absorbing capability of the front-end chassis and sheet metal; this is a most effective device, and it is probably much more satisfactory than any practical hydraulic shock absorber installation would be.

Figure 13. Remotely controlled tree impact at 35 mph.

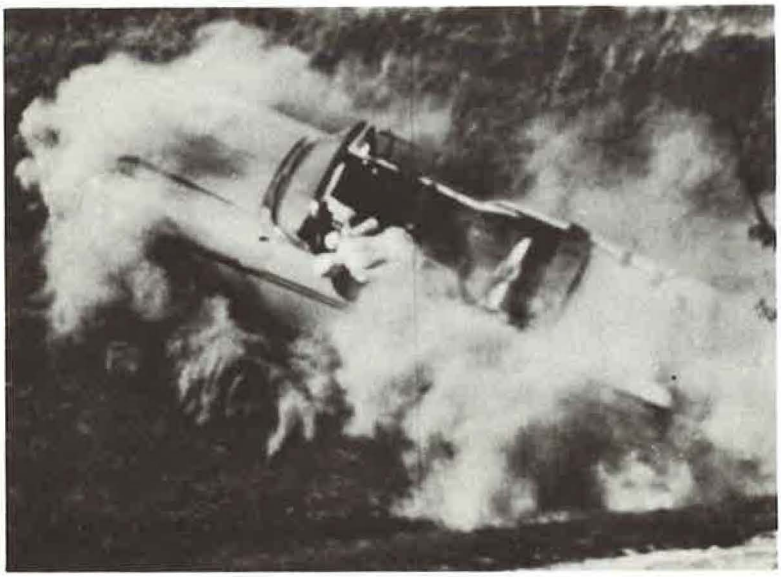

Figure 14. Impact test, ditch with 2:1 back slope.

This absorption characteristic is shown in another way in terms of a deceleration-time curve as in Figure 12. This shows a rather slow rate of rise of deceleration. In fact, nearly one-third of the time of the impact has passed before the deceleration reaches the peak. This is a characteristic of the direct impact tests that is found many times.

Figure 13 shows another type of impact characteristic of the single-car, non-collision accident. This car was driven by remote control at 35 mph against a tree of medium size. The severity of the impact at such a low speed is demonstrated graphically, and the energy-absorbing deformation of the front-end chassis and sheet metal is again demonstrated.

Figure 15. Proving Ground crash test against 2:1 bank.

Figure 16. Car passing through ditch, bumper strikes ground.

There are other types of roadside crashes of extreme severity of operation where some background is required to evaluate the potential of design improvement.

Figures 14 and 15 are two views of the same test where a remotely controlled car was driven off the road at 35 mph into a 2:1 back slope (4). It is evident that the injury threshold in these conditions can be raised materially by the use of simple restraining devices such as seat belts. On the other hand, much more interesting is the fundamental treatment of these situations, which is to eliminate the hazardous characteristics of the roadside. This has been discussed at an earlier meeting of the Highway Research Board (2) but Figures 16 and 17 follow the last two as a simple transition from a very dangerous roadside (Figs. 14 and 15) through one of moderate severity (Fig. 16) to one so gentle that the car can be driven through it easily at 60 mph (Fig. 17). Present Proving Ground standards are to design for a computed severity of no more than 0.5g at design speed and to remove obstacles out to 100 ft on all roads where operating speed is expected to be equal to rural highway speeds.

Figure 17. 60-mph test, driving through flat-bottom ditch.

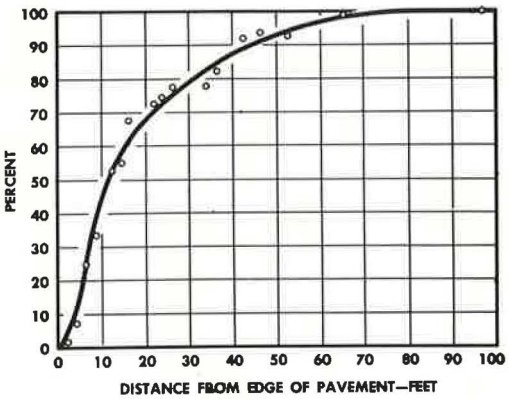

Figure 18. Percentile distribution of 56 Proving Ground "accidents" as function of distance from edge of road.

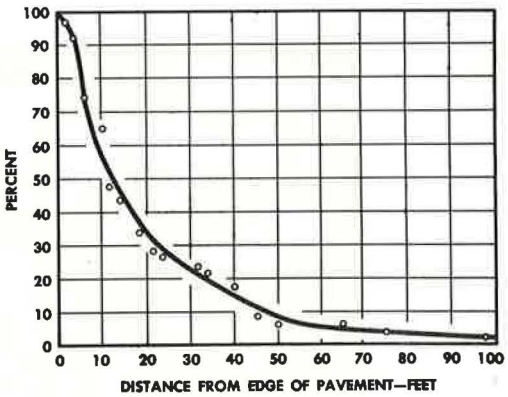

Figure 19. "Hazard" curve, Proving Ground "accidents."

Consideration of the elimination of roadside obstacles invites the question of what is an effective and practical width of the traversable area. Because the Proving Ground roadsides have been modernized, there have been 56 cases where the car left the road; in none of these cases was an obstacle struck and none resulted in injury to the driver; Figure 18 is a percentile distribution of the distances from the edge of the pavement to the point of maximum deviation; in most cases the vehicle was stopped, but in several the driver merely turned back onto the road and continued on his way. Figure 19 shows the same data reversed in the form of a "hazard" curve. The maximum distance or deviation exceeded 50 ft in only 10 percent of the cases and 25 ft in only 25 percent of the cases. There is little general relationship with speed; however, the most extreme points are associated with rural highway speed levels. Taken at face value, these data suggest that provision of traversable roadsides 50 ft wide would eliminate 90 percent of the non-collision serious accidents.

Figure 20 is a hazard curve showing the distribution as a function of distance of impacted obstacles in 82 fatal accidents reported in the Cornell Automotive Crash Injury Research study (5).

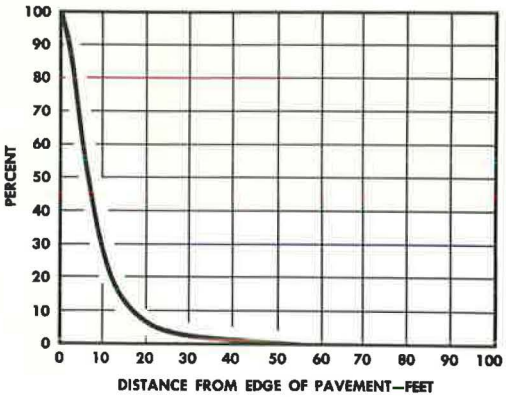

Figure 20. Distribution of impacted roadside obstacles vs distance from edge of pavement (from 82 "accidents" in Cornell study).

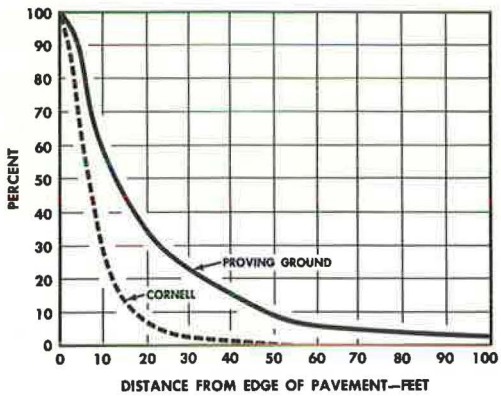

Figure 21. Comparison of Proving Ground and Cornell "hazard" curves.

Figure 22. 35-mph guardrail test showing remote control.

Figure 21 is a comparison of these two hazard curves. This shows that the cars in the Cornell group struck obstacles, with injurious and fatal results, at distances considerably less than the maximum deviations of the Proving Ground drivers.

The Proving Ground hazard curve should be considered as a first approximation to the deviations drivers will make on a traversable roadside, and it may be regarded as a first approximate guide to the determination of an effective and practical width of traversable area.

Another type of highway crash which occurs too frequently is the collision with a guardrail. This situation also required some background evaluation. Although it is easily possible to raise the threshold of injury in certain types of guardrail collisions by the use of packaging devices such as seat belts and crash helmets, other types are

Figure 23. 35-mph guardrail test remote control.

Figure 24. 65-mph guardrail test.

closely similar to collision with a tree, and no effective vehicle design treatment exists. It was found that here, too, there was tremendous room for improvement in guardrail design and installation and that inexpensive modifications would eliminate the most serious guardrail deficiencies. This work has also been discussed, but the highlights are relevant to this paper (6, 7).

Figure 22 shows a remote-control technique in making a test of guardrail installation at 35 mph.

Figure 23, run at 35 mph and at a 33° angle of impact, shows a failure which is typical of the standard installations. The bolt in the last post pulled through the guardrail, allowing it to lose tension and fail completely.

Figure 24 was taken during a test at 65 mph on a design which had shown satisfactory results at 35 mph. Here too, the end pulled loose and the guardrail failed, resulting in a very serious accident.

Figure 25. Successful 65-mph guardrail test.

Figure 26. Standard guardrail end impact.

Figure 25 shows a successful test at 65 mph; this installation redirected the car with only a slight reduction in speed.

Figure 26 shows the result of a direct impact against the end of the guardrail. In some cases, if the collision occurs at one side or the other of the engine block, the car is impaled on the guardrail. In accidents of this type at normal highway speeds, it seems impossible to provide secure protection for the occupants by any means within the control of the vehicle designer. However, Figure 27 shows a satisfactory solution to the problem. Here the end of the guardrail is buried in the back slope and anchored in the concrete block, thus preserving tension from the very beginning of the guardrail and eliminating the hazardous end.

In automotive engineering development work, the interests are generally in one component at a time or, at the most, in a very few components, and the total destruction during barrier impact tests at speeds even as low as 30 mph is generally out of keeping with the objectives of such a development test. It would be extravagant of both time and material to attempt the evaluation of several seat belt anchorages by barrier impact tests.

Figure 27. Guardrail buried in back slope and anchored in concrete block.

Figure 28. Proving Ground snubber test technique.

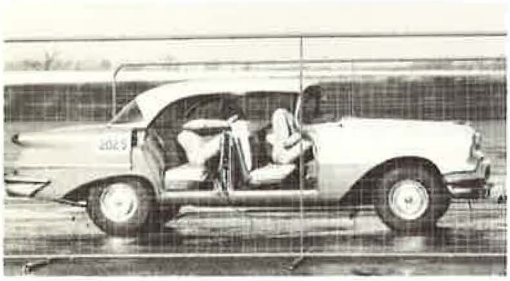

Figure 29. Snubber test conducted at 5g.

Figure 30. Snubber test conducted at 10g.

Figure 28 shows a practical tool for such development work. This is a heavy-duty hydraulic snubber developed in 1955. Relatively precise control is provided from 3g to 35g by regulating the air pressure behind the relief valve and by choosing the test speeds carefully. The engine and transmission are removed from the test vehicle to reduce the total energy. A heavy cable is attached to the car at the center of gravity

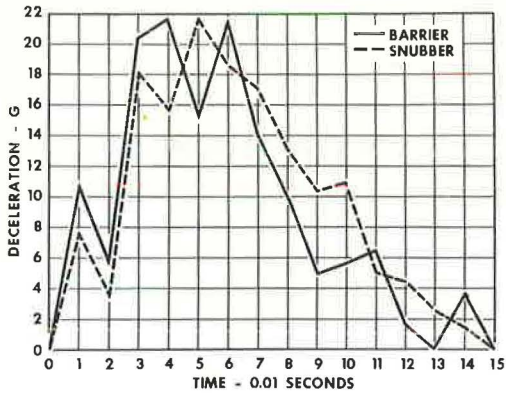

Figure 31. Barrier and snubber comparison.

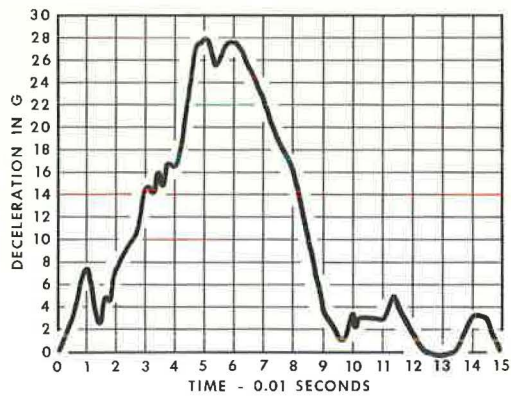

Figure 32. Car-to-car deceleration (Severy data).

Figure 33. Snubber test using current platform.

height and threaded through a yoke at the back of the snubber. A steel slug on the end of the cable bottoms on the yoke as the car is towed at test speed, and the car is stopped at a predetermined rate.

Figure 29 shows a typical test where the car is stopped at 5g, and Figure 30 shows a comparable test at 10g. With this device it is very easy to make repeated tests, or a series of tests, at intervals of only a few minutes and without damage to the test vehicle chassis. This device gives a deceleration-time curve very closely similar to that measured during barrier impact tests (Fig. 31). For comparison, a typical deceleration-time curve from Severy's work is shown (Fig. 32).

For a great deal of component testing, such as seat belt anchorages and seat anchorage, only the floor of the car body needs to be involved. Figure 33 shows a simplification of the snubber technique where a test bed and a platform are substituted for the test car; this makes it possible to make comparative tests of a number of design proposals in quick succession.

There are simplifications of other component test programs. One such example is shown in Figure 34. Here a series of steering wheel designs can be screened in the

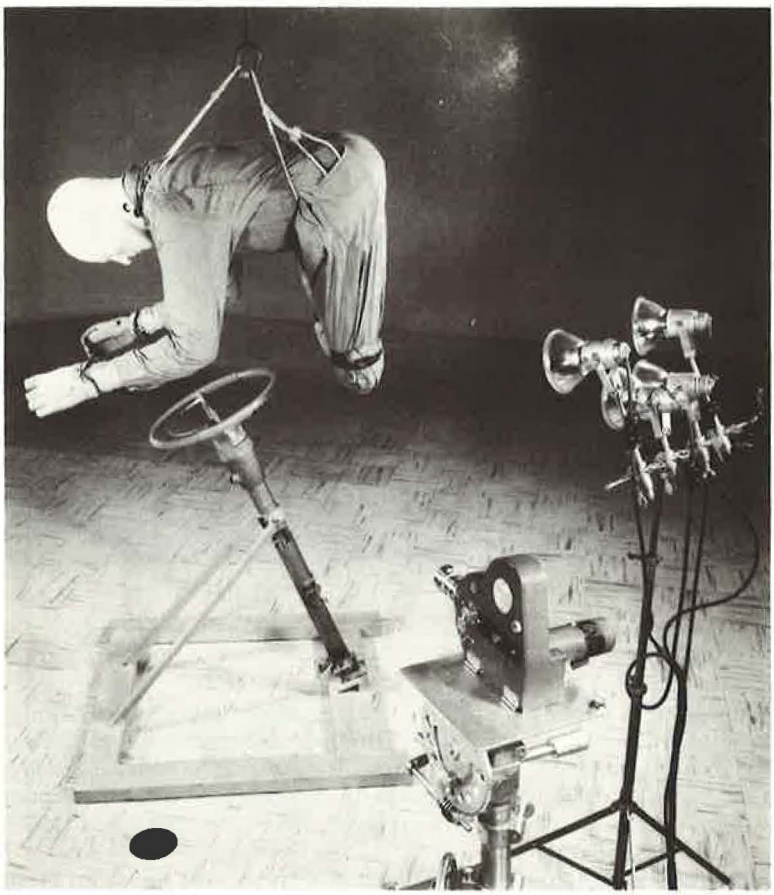

Figure 34. Steering wheel drop test.

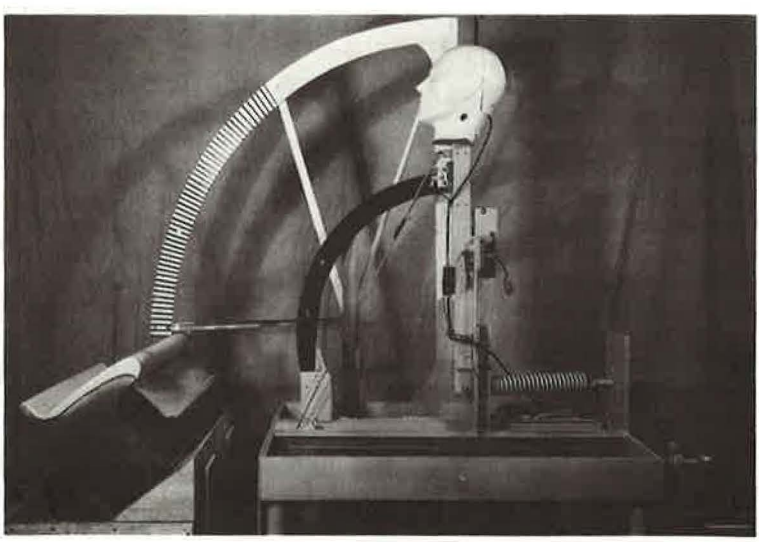

Figure 35. Head knocker test.

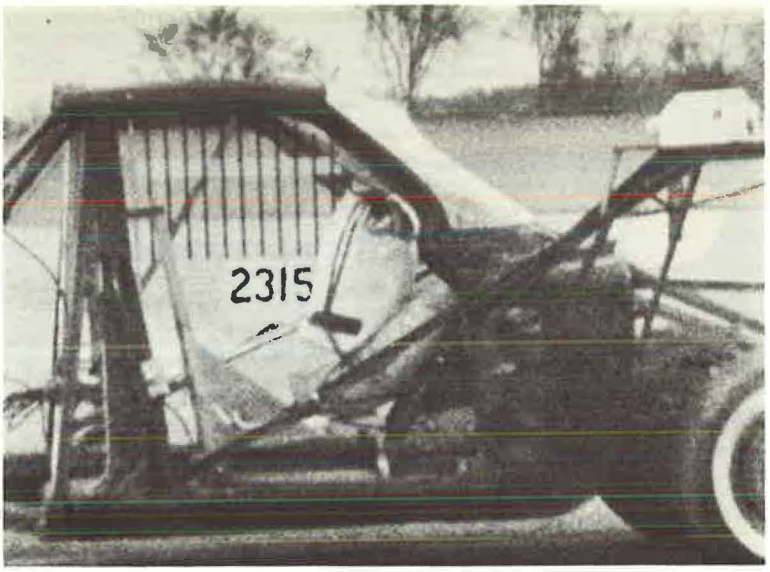

Figure 36. Windshield test.

laboratory by dropping a dummy on them. For more definitive evaluation, the best designs can be tested further when mounted in a car and subjected to the snubber test.

Figure 35 shows a relatively simple laboratory apparatus which may be used to evaluate various types of instrument panel pads or seat-back construction or other components which might be struck by the driver's or passenger's head during an accident.

For evaluation of windshield design, windshield frame and seat can be mounted on the snubber platform (Fig. 36).

The snubber technique has the inherent disadvantages of conducting tests with high transients outdoors. During cold winter weather, sunlight is lacking or weak; sunlight is essential because high-speed photography is the most valuable, single measuring device for this technique. Control is limited by the short stroke available, changes in viscosity of the hydraulic oil with temperature, and the difficulty of reaching exact towing speeds in the short available towing distance.

The volume of development testing in this general area made it essential to devise a facility that would be more conveniently located indoors so that programs could be carried on independent of weather and lighting conditions. The installation of an impact machine (shown in layout in Fig. 37) has just been finished. This is a scaled-up version of an accelerator available commercially that was developed originally for shock testing military components. This is a high-capacity, air-powered accelerating device which can be controlled very precisely within a range up to 50g; test components up to the size and weight of a complete automobile can be mounted on the bed in any orientation. Fixed lighting and camera installations are available for the most effective use.

The following are the general capabilities of the facility:

1. Lighting of 10,000 foot-candles which will permit photography up to 3,000 frames per second.
2. Air pressure up to 3,000 psi to supply operating power.
3. Operating force up to 200,000 lb.
4. Performance capacity exceeding 50g at 1,500 lb load or 20g at 5,000 lb load.
5. Stroke adjustable up to 5 ft.
6. Pulse duration 6 to 75 msec.
7. Pulse wave form variable by choice of metering pin.

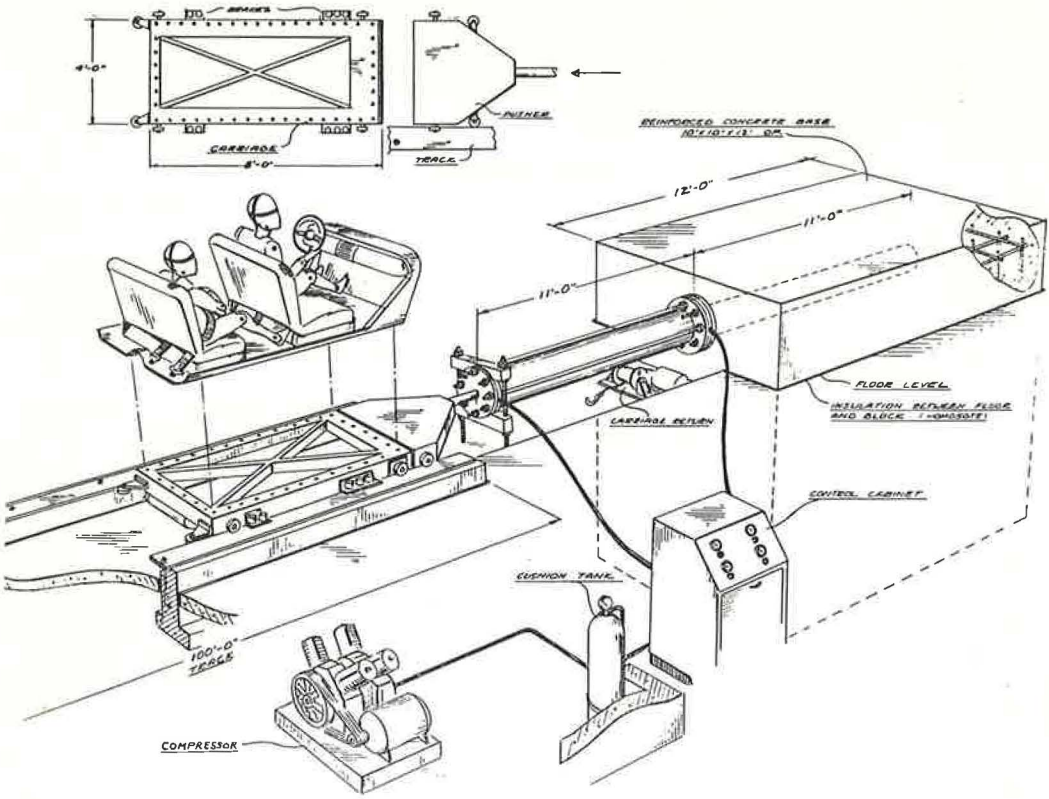

Figure 37. Impact machine layout.

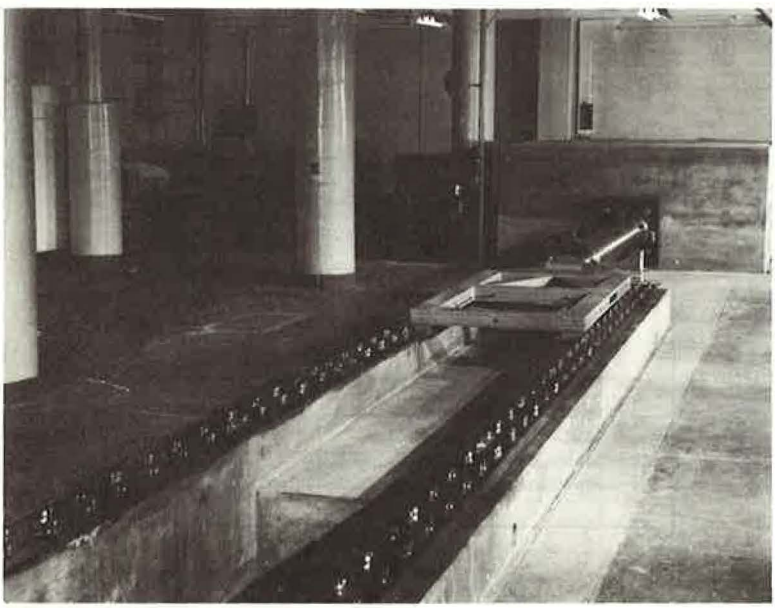

Figure 38. Impact machine.

Figure 38 shows the device. Unfortunately, there has not been time to accumulate data through the use of this facility. Typical test results will be discussed in a later paper, and a more complete description of operating principles and controls will be reserved until then. It will probably surpass any previous techniques in precision of control and the efficient use of test time.

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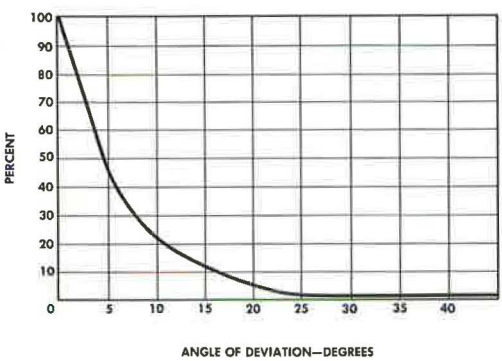

Figure 39. Percentile distribution of angle of vehicle encroachments.

Appendix

Since the preparation of this paper, data have been received from John Hutchinson, of the University of Illinois, from his study of median encroachment. The data include 91 cases observed primarily on Route 66, which is a divided highway with a 40-ft median.

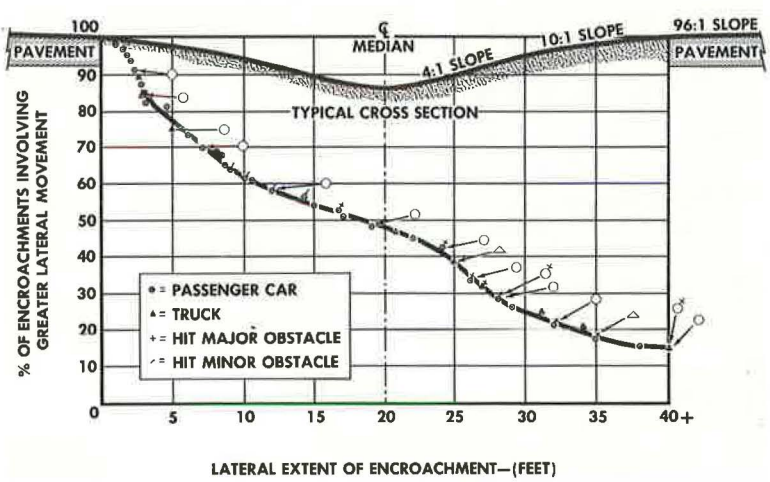

Figure 40. Distribution of median encroachments (Hutchinson).

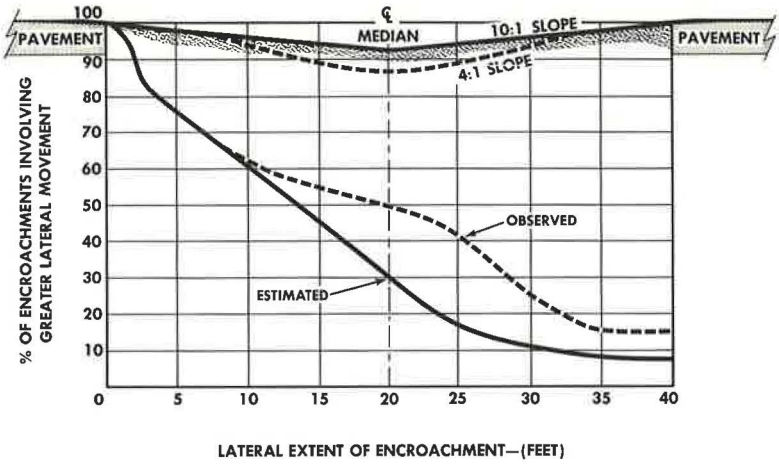

Figure 41. Distribution of median encroachments (Hutchinson).

Angles of departure, the lateral distance of encroachment and the length of travel in the median, among other things, were observed.

Figure 39 is a percentile distribution of the angle of departure. The 80th percentile is at approximately 10^0 and the 90th percentile at approximately 17^0; in other words, more than 80 percent of the vehicles left the pavement at an angle of less than 10^0.

Figure 40 is the distribution of lateral encroachment into the median. The passenger car data are designated by circles, truck data by triangles, multiple points by circles and arrows, and collisions with major obstacles by small crosses. The 80th percentile is at approximately 33 ft and the 90th percentile is more than 40 ft; that is, 80 percent of the vehicles entered the median at distances less than 33 ft but more than 10 percent of them crossed the median onto the opposing traffic lane.

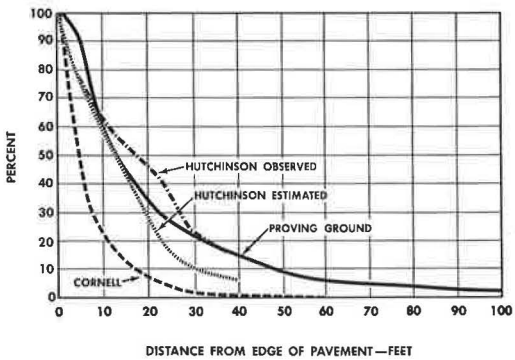

Figure 42. Comparison of Proving Ground, Hutchinson, and Cornell "hazard" curves.

Hutchinson believes that the collision with obstacles in the median has influenced the encroachment distribution somewhat; in Figure 41, his estimated curve of what encroachment might have been without obstacles is shown in comparison with the observed data.

Figure 42 is a comparison of the Cornell, Proving Ground, and Hutchinson curves. There is a close agreement between the Proving Ground distribution and the Hutchinson observed data. Both are influenced by factors of possible significance. There were almost no restrictions on the freedom of movement of the Proving Ground drivers and they may have made wider excursions than were required to stop safely, or regain control. No doubt, drivers from the Hutchinson sample were unimpeded in many locations even though several collisions with obstacles were noted. The behavior of a driver leaving the pavement and going into the median may be different from that of a driver leaving the road on the right shoulder.

These fragmentary data, however, suggest that an obstacle-free roadside of 33 ft would provide safety for at least 80 percent of the drivers leaving the road on either side, and that safety would be assured for more than 90 percent of them on a roadside free of obstacles on both sides for 50 ft.