HIGHWAY RESEARCH BOARD

Bulletin 185

Tests of Energy-Absorbing Traffic Barriers

National Academy of Sciences—

National Research Council

publication 602

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PRESENTED AT THE
Thirty-Sixth Annual Meeting
January 7-11, 1957

1958
Washington, D. C.

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Contents

Crash Barrier Tests on Multiflora Rose Hedges

RUSSELL R. SKELTON, University of New Hampshire

Multiflora rose hedges offer definite advantages as safety barriers for highways, as shown by a recent investigation conducted for the Bureau of Public Roads. In a study of the effectiveness of a hedge of mature multiflora rose plants, a modern automobile was stopped by the planted mass gradually and without injury to the driver or damage to the vehicle.

The paper briefly covers the results of the summer and winter field tests, which were conducted to determine (a) the stopping distance beyond the crash point as various speeds of contact, (b) the movement and performance of the bushes and the test vehicle during the deceleration period, (c) the magnitude of deceleration, and (d) the resulting damage to the bushes and vehicle.

The 14-year-old multiflora rose hedge used for testing was planted about 3 ft center-to-center in a single row. The hedge was continuous and averaged 10 ft in width and 9 ft in height. A paralleling earth road served as an approach test road.

The uses of the adjoining land and the single row of bushes dictated the character of the approach and speed of each test. Nine crash tests were performed parallel to and on the axis of the hedge. Four tests were run on flat angles with the centerline of the hedge. The speed of the test car at contact for the twelve tests ranged from 22 to 50 mph.

The test car was equipped with an electrically driven recording three-component accelerometer and a spring-wound single-component accelerometer. Three high-speed cameras were used.

The test results indicate that many serious accidents could be prevented in the future if hedges of this variety were planted now in the median strips of divided highways.

● **PLANNED LANDSCAPING**, using shrubs, not only makes a highway more attractive and less monotonous but these same shrubs could save lives. Judicious planting of several varieties of shrubs in median strips would not only reduce headlight glare, but the same shrubs could act as a barrier or buffer between opposing streams of traffic. Also, such plantings could prevent disastrous impacts into bridge abutments or center piers.

Considering the recent trend in highway fatality and injury, every idea, every device, and every plan that offers any possible chance of saving lives should be critically studied. For that reason the Bureau of Public Roads and the University of New Hampshire became interested in the idea that a barrier of shrubs could serve as a living guard rail. As a result, the University initiated in 1954, a proposed program for testing the effectiveness of multiflora rose hedges as crash barriers. Early in 1955, the Bureau approved a sponsored research grant for the above study, and the tests were performed in midsummer and early winter of that year.

The services of the firm of Motor Vehicle Research, Inc., of South Lee, N. H., were retained as a subcontractor to the University for the duration of the project. The director, Andrew J. White, had previously run several crash tests on multiflora rose hedges. The results of his earlier experiences were largely responsible for the Bureau's and University's interest in conducting a larger and more comprehensive testing program to determine the effectiveness of multiflora rose hedges as crash barriers along the margins of highways.

Prior to the running of the field tests, a schedule of eleven tests per season was planned. The tests were to include five angles of approach ranging from 5 deg to 90 deg (head-on), and from 1 to 3 speeds between 30 and 50 mph for each angle of approach. The proposed schedule of tests had to be drastically reduced because the length of hedge destroyed for each run was considerably greater than was initially expected. Nine tests were run in July and three were run in December.

PURPOSE OF THE INVESTIGATION

The general purpose of the investigation was to determine whether hedges of multiflora roses would serve effectively as a highway crash barrier when subjected to the impact of a modern automobile.

Of more immediate and specific interest were (a) the distance required to stop the vehicle after striking the hedge at various speeds and angles of approach, (b) the magnitude of deceleration, (c) the performance characteristics of the hedge and vehicle, (d) the extent and character of damage to the vehicle and hedge, and (e) a comparison of the stopping distance and hedge performance for the summer and winter tests.

CHARACTERISTICS OF ROSA MULTIFLORA (JAPONICA)

This plant was first described by Thunberg, a Swedish botanist, in 1784. The plant is of Asiatic origin and many varieties were found in Japan, Korea, and along the China coast. The plant was first introduced to Europe and American about 1875. (1)

Rosa multiflora (Japonica) is described as "a vigorous, dense shrub with long, arching, moderately thorny canes often exceeding 12 ft in both height and width, and producing enormous quantities of single, white blossoms in late May or early June."(1) "Plantings of Rosa multiflora are adapted to all but the extreme northern and southern states, and when planted at 1-ft intervals in a soil of average fertility will grow into an effective barrier to livestock, within 3 to 6 years." (2)

The multiflora plant, as tested, appeared to have a rather shallow but somewhat massive root system. The root system was confined to an area smaller than the total spread of the canes from one plant. Several of the roots encountered were as large as the largest cane and measured 6 ft in length. The root system seemed to provide very firm anchorage.

The plant does not produce suckers, hence a hedge may be controlled by pruning; however, birds carry the seeds and seedling plants frequently spread rapidly on adjacent land. A hedge of the plants, when planted on 3-ft centers, will form an impenetrable barrier within 8 years. The canes branch and spread laterally, intertwining to form a dense barrier which is shock resistant. It is this springlike characteristic that makes it a potentially ideal plant for use along highways as a living guard fence.

THE TEST SITE

The continuous single row of mature multiflora rose hedge used for the tests was located in the vicinity of Manchester, Conn. The hedge was fourteen years old, and was donated to the University by the owner for test purposes. The average height was 9 ft and the average width was 10 ft. The density of growth varied considerably in different sections, as did the individual cane diameters. The plants were spaced about three feet apart and there were few instances of seedling plants developing within the existing hedge.

A narrow earth road ran parallel with the hedge for its entire length. This road was used for the approach run for all tests. Figure 1 shows one section of the multiflora rose hedge and the adjacent road. The section shown contained 310 ft of usable hedge, which was essentially used for crash testing at various angles of approach. The extreme end was used for one high speed winter test.

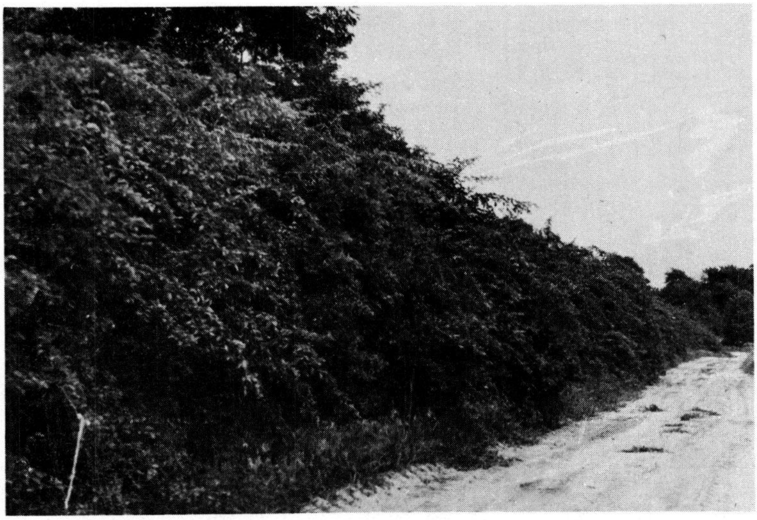

Figure 1. Typical section of multiflora rose hedge.

TEST CAR AND INSTRUMENTATION

The test car, a 1952 Ford, 6-cylinder, 4-door sedan, was loaned to the University by the Bureau for the duration of the 2-season field test period. It was stripped of all nonessential interior equipment that could possibly contribute to the injury of an occupant. The seats were removed and two front bucket-type seats were bolted to the floor. Two sets of 4-in. seat belts and two sets of shoulder harness were fastened securely to the floor of the car. The dash assembly was fitted with a 6-in. covering of polystyrene plastic foam. Figure 2 shows the test car as received, and Figure 3 shows the protective plastic foam being fitted to the interior.

A tachograph mounted on the fire-wall under the hood was coupled to the speedometer adapter gear. This instrument was used to obtain the top speed of the car during the approach run. The test car speedometer was calibrated by attaching a previously calibrated test wheel to the rear bumper and recording simultaneous readings at 10 mph intervals up to 60 mph.

The test car speedometer readings were generally 6 to 10 percent higher than the true speed.

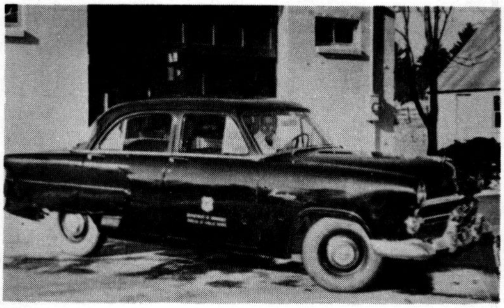

Figure 2. Test car as received.

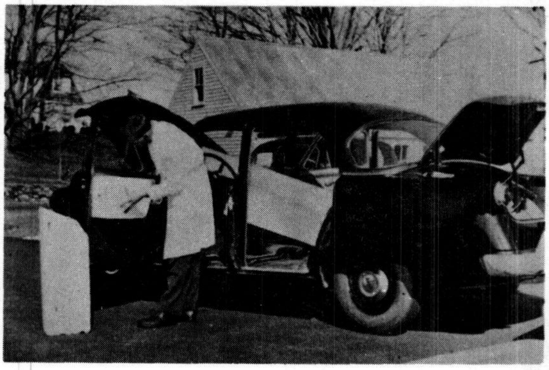

Figure 3. Test car being equipped with plastic foam.

Since one of the principal objectives of the study was to determine the magnitude of deceleration, a motor-driven, constant-speed, 3-component accelerometer was obtained for these tests. This instrument is shown in place with the cover removed in Figure 4. The accelerometer weighed 18 lb and measured 8 in. wide by 8 in. high by 18 in. long.

The accelerometer was positioned on the centerline of the car and as near the actual center of gravity of the car as the front seats would permit. Actually the center of the instrument was 13-7/8 in. to the rear of the center of gravity of the loaded car. In the vertical direction the center was very close to the center of gravity of the car.

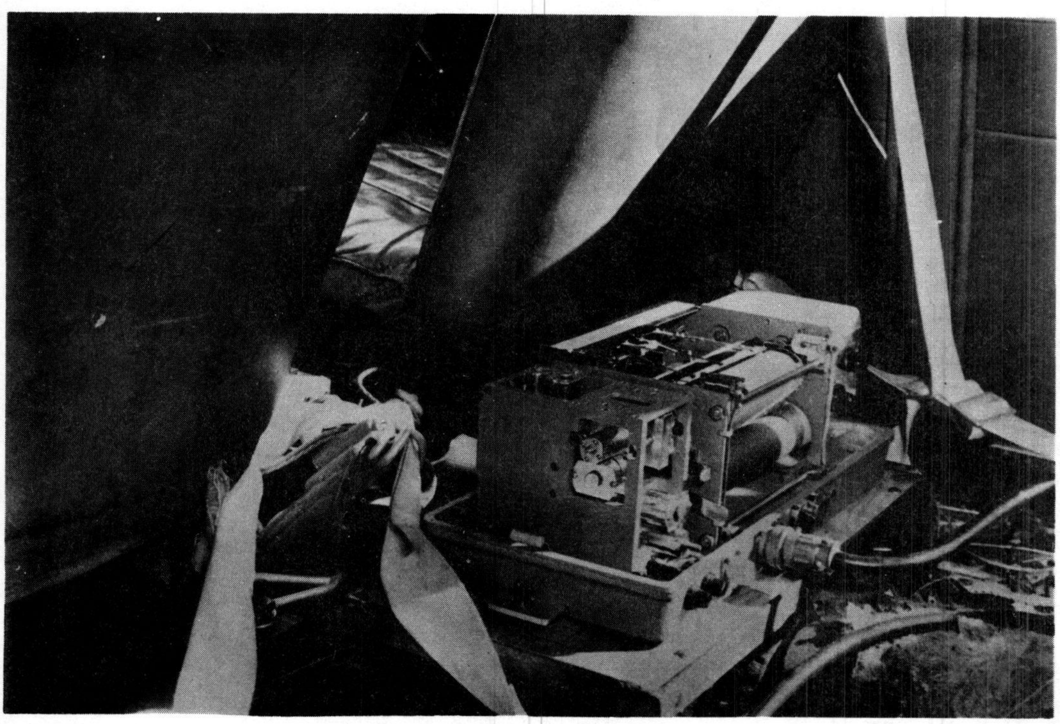

Figure 4. Accelerometer mounted in test car.

The accelerometer was equipped with a 115-volt A.C., 60-cycle, electric motor and inverter. The 6-volt car battery was used as a source of power and heat for the styli and the case. Remote control switches were furnished for the operation and control of the motor and heaters. Wax-coated charts, 7 in. wide, having 2-in. space for each component were used for recording the acceleration and deceleration over the full range of each stylus. The chart speed was 60 in. per minute.

The maximum deceleration in terms of gravity (G) for each direction was estimated and the manufacturer set each stylus to the specified range as follows:

Longitudinal direction: 10 G
Vertical direction: 5 G
Lateral direction: 5 G

The natural frequency was certified to be 15 cycles per second. Orifices were provided for air damping in all three planes. The degree of damping recommended and used on these tests was 80 percent, and the manufacturer calibrated and certified the instrument.

A single component recording, spring-driven, accelerometer was placed in the spare tire well in the rear of the car. This instrument was positioned to record the acceleration in the vertical direction. The range of this instrument was ± 1 G.

The test car hood and front fenders were given a heavy coat of white water-soluble paint before field testing so that the car was more easily followed in the photographs. This covering also served to mark the points of severe contact with the bushes. Distinctive reference marks were placed on the vehicle to aid in the analysis of photographic film.

Photographic instrumentation included one spring-driven 35-mm wide-angle lens camera, set to run at a speed of 48 frames per second (fps), and one power-operated 16-mm camera, set to run at 128 fps. The cameras were positioned perpendicular to the axis of the hedge on an elevated platform at a measured distance from a reference fence. They were adjusted to include the entire crash performance and a portion of the approach run. One additional spring-driven 16-mm camera, operating at 64 fps, was used to obtain the general performance characteristics of the hedge and car.

A reference fence was erected parallel to the axis of the bushes for each test. This fence served as a base line for measurement and a photographic reference for film analysis.

TEST PROCEDURE

Because the hedge consisted of a continuous single row of intertwined bushes, the tests were limited to head-on and small-angle crash tests. Physical limitations in the access road and the small width of the hedge prevented angles of approaches greater than 20 degrees from being made. In a head-on test, the car approached and crashed along the axis of the hedge at an established point. In an angle test, the car approached on a line marking an established angle with the hedge centerline and crashed the fringe of the hedge at a fixed point.

Before running a test, the point of contact, the centerline of the hedge, and dimensions of the hedge were measured in relation to the reference fence. When feasible, a bush count and the number and diameter of individual canes for several typical bushes were made. Representative cuttings were taken for water content determination. All tests were made on sections of the hedge unaffected by previous tests.

In general, the driver declutched the car approximately 20 ft ahead of the marked contact point. This standard procedure eliminated applied power, leaving only the momentum of the car to be considered in the analysis. The loss of speed in this short distance was usually of the order of 8 mph. The roughness and lack of compaction of the approach not only reduced the speed, but introduced considerable pitching of the car in a vertical plane. The latter condition was more pronounced on low-speed tests.

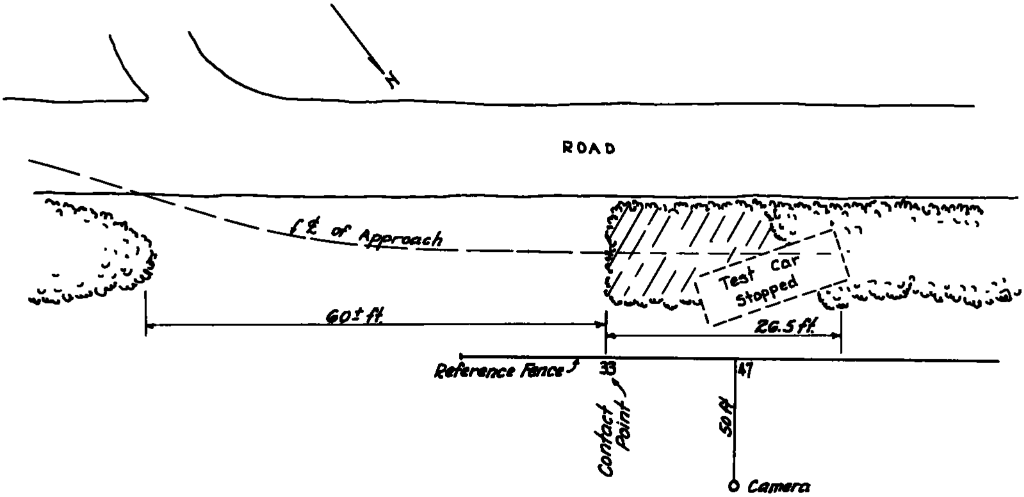

Figure 5. Plan of the site, sketch of head-on test (Test No. 1—30.3 mph contact speed).

The accelerometers were turned on when the test car started the approach run. All cameras were started when the car was about midway of the approach. Immediately after the car had stopped, the distance from the

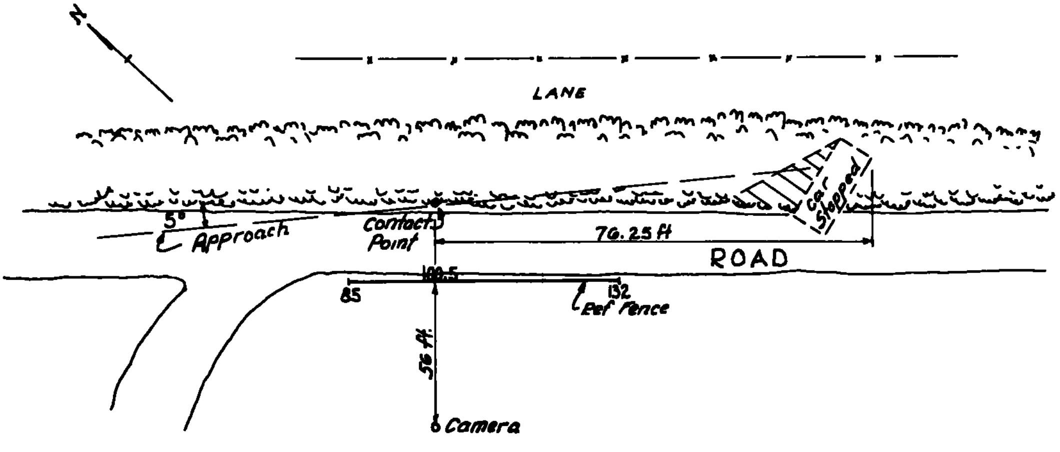

Figure 6. Sketch of angle test, (test No. 4—30.2 mph contact speed).

front bumper to the contact point was measured and recorded as the stopping distance. Offset distances from the reference fence to the tire tracks were made for record. A sketch was prepared showing the area and number of bushes damaged and the final position of the car in relation to the hedge and reference fence. Figure 5 is a sketch of a typical head-on crash and Figure 6 is one of a 5 deg angle test. Also, following each test, the driver's observations and remarks concerning the test were noted. The test car was then removed from the hedge and examined.

FILM EVALUATION

All films were developed and reduced to 16-mm positive prints for evaluation by a frame-by-frame method of analysis. A microfilm viewer having a large screen was used for the 48 fps and the 64 fps film analysis. The 128-fps film was analyzed by using a time-study projector. A sufficient number of check tests were made on several films using both pieces of equipment to determine that the results obtained were in satisfactory agreement.

In the frame-by-frame analysis, the film was run until the test car came into view at a point in line with the reference fence. One of the several reference points on the car was selected and noted. The initial frame was recorded as zero and the reading of the footmark on the fence immediately below the reference mark was observed and recorded. The film was then advanced one frame and the process repeated, using the same car

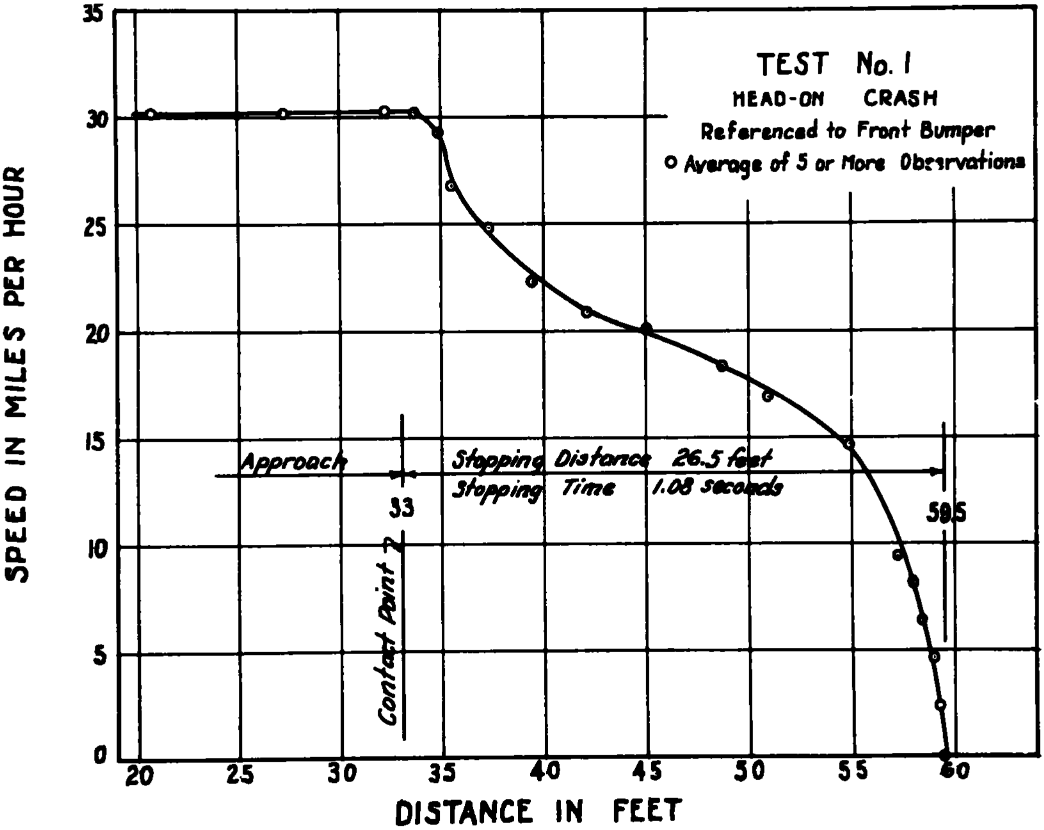

Figure 7. Speed-distance curve for test No. 1.

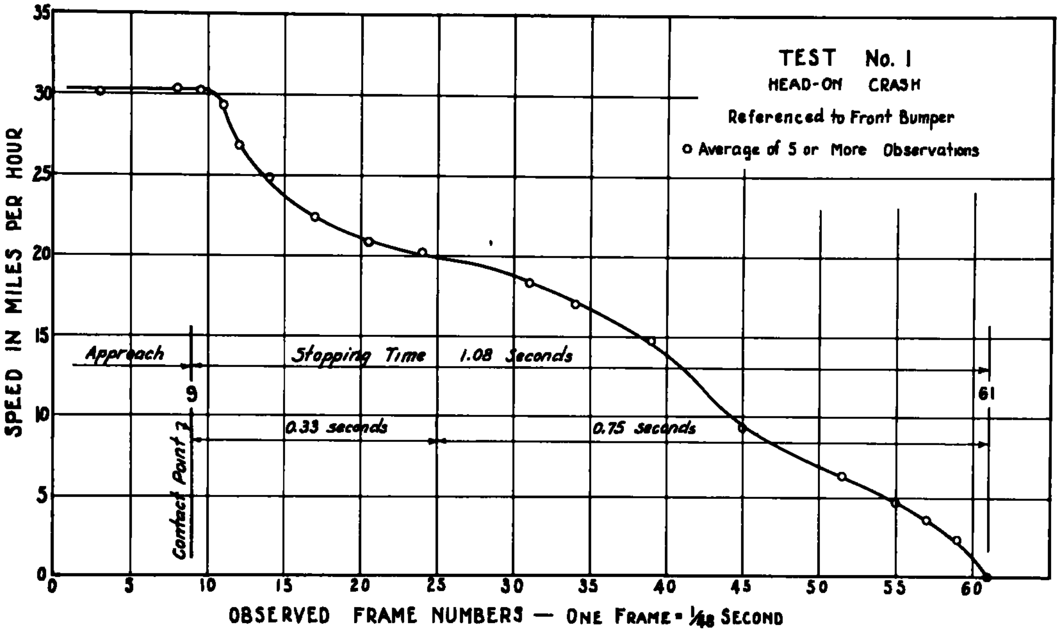

Figure 8. Speed-time curve for test No. 1.

reference point. If the car advanced to a point where the first reference mark was obscured by the bushes, another car reference mark was selected and this frame recorded as zero. The process continued until the test car came to rest.

The actual distance the car traveled in relation to that shown by the film on the reference fence was computed by a simple proportion—knowing the horizontal perpendicular distance from the camera to the reference fence and the distance from the reference fence to the car's tracks. This corrected distance traveled per frame was then converted to miles per hour. Finally all distances and time were equated to the front bumper of the test car and the data were used to plot speed-distance and speed-time curves for each test run.

For example, the speed-distance curve for test No. 1 is shown in Figure 7, and the speed-time curve for the same test is shown in Figure 8. Distances shown in Figure 7 are the actual distances on the traveled path of the test car. In Figure 8 the abscissa is indicated as observed frame numbers, where one frame equals 1/48 second. An average of five observations is plotted as one point. All observations are in reference to the front bumper of the test car.

The test car approached the contact point at 30.3 mph (Figs. 7 and 8) The film evaluation was the primary means used for determining the contact speed. From a study of the two curves, it is apparent that following contact with the bushes, the car speed decreased rather rapidly to about 20 mph in a distance of 12 ft and in a time interval of 0.33 sec. The average deceleration for the period was 22.4 ft per second per second or 0.69G. The car speed then dropped from 20 mph to 0 mph in a time interval of 0.75 sec, which is equivalent to an average deceleration of 19.6 ft per second per second or 0.61G. The over-all stopping time is seen to be 1.08 sec.

The maximum error in reading the distance traveled in one frame was generally observed to be ± 1/10 ft. For the 48-fps film this amounted to ± 3.27 mph. Where the 128-fps film was used for evaluation, an error in distance observation of 1/10 ft produced a possible error in speed of ± 8 mph. However, the maximum deviation from the mean of the computed speeds using the 128-fps film was 6 mph.

In several instances, on the angle tests, the stopping distance was too great to be recorded by the fixed cameras. In other instances the car path curved sharply near the end of the run, which prevented complete evaluation of the car performance from the film record.

The evaluation methods and procedures were the same for the summer and winter tests. During the winter series the temperature was so low that all the cameras were thought to be running slow. Later film evaluation proved the foregoing to be true, consequently the film results were not used. Stopping time for the winter tests were obtained solely from the accelerometer records.

ACCELEROMETER TAPE EVALUATION

The wax-coated accelerometer tapes for each test were photographed and the prints were projected and traced on cross-section paper. The enlarged graph was useful in determining the several peak deceleration values in relation to the time of occurrence and the average deceleration for the duration of the test.

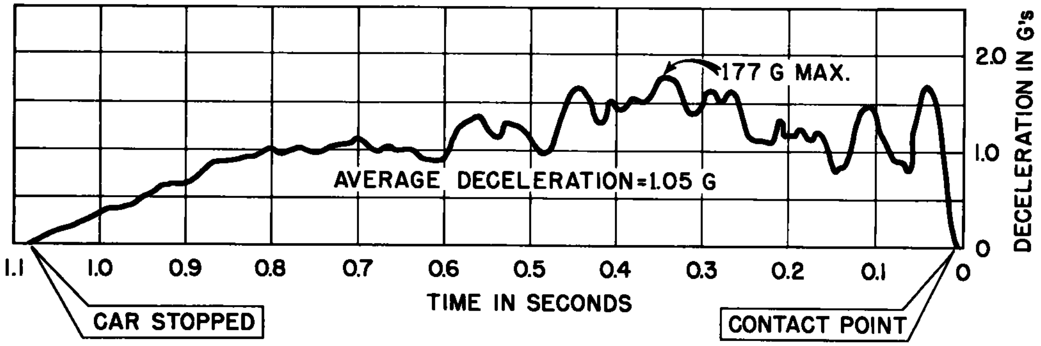

Figure 9. Longitudinal decelerations during test No. 1.

An enlarged graph of the longitudinal section of the chart for test No. 1 is shown in Figure 9. Although this graph is not necessarily typical for all tests, it does indicate the type of data obtained from similar graphs prepared for all succeeding tests. It is seen that the maximum peak was 1.77G. The elapsed time from the crash point for any peak, and the total elapsed stopping time can be read from this graph. In this instance the maximum peak occurred about 0.34 sec from the contact point. The overall stopping time was about 1.08 sec. This stopping time is almost identical with that determined from the film evaluation of the same test, which was the case for all the tests.

The average deceleration in the longitudinal plane was obtained by measuring the area under the curve with a planimeter and dividing the area by the base line length between the point of contact and the point where the car came to rest. The average deceleration was determined for all tests

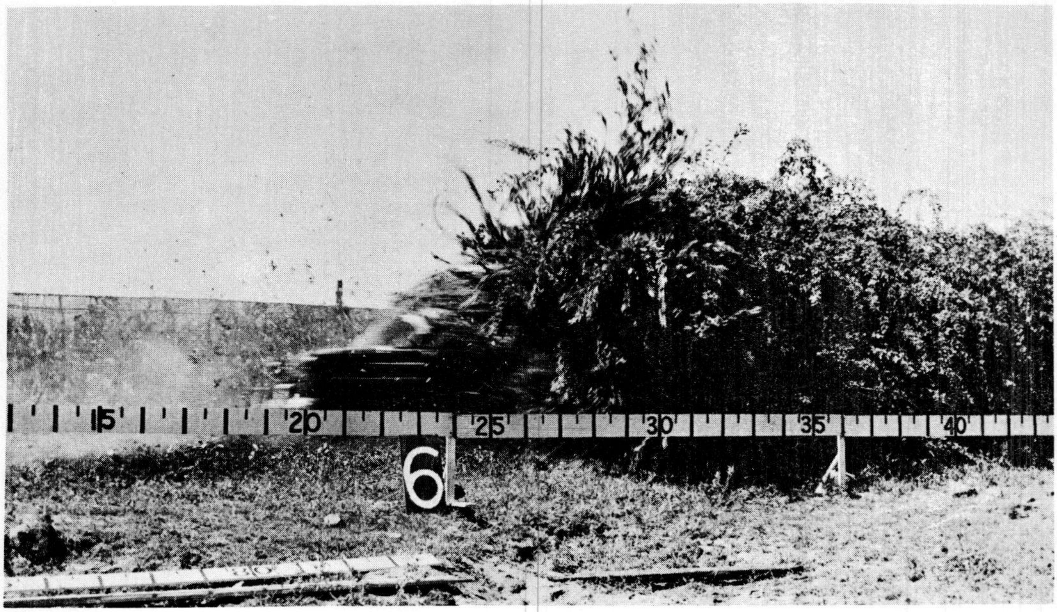

Figure 10. Test car crashing into end of hedge row—test No. 6.

in the longitudinal direction by this method and used as a source of comparison of performance of the car and the bushes. It is indicated to be 1.05G (Fig. 9).

The evaluation of the tape for the single component accelerometer was read directly and the peak results compared to the vertical values obtained from the graph of the three component accelerometer. In general, the single component accelerometer maximum range was inadequate, since the peak vertical acceleration was usually greater than 1G. In instances when the peak vertical acceleration was less than 1G, the values of both instruments were in substantial agreement.

TYPICAL PERFORMANCE CHARACTERISTICS

During the first part of the deceleration period for the head-on tests, the canes of the bushes were sheared off about 3 to 4 ft above ground. Some of the bushes were pulled out and these plus the sheared canes and broken branches were pushed ahead of the car. The results of these actions are shown in Figures 10 and 11 for test No. 6. In this test the contact point was at 12 on the reference fence. The car stopped at 63.8 on the fence.

As the loose mass was accumulated and as the car pushed the entangled mass ahead, the forward bushes were either pushed down or were stripped of their foliage (Fig. 11). In the last one-third of the stopping interval the loose mass was compressed with little forward movement, which resulted in the car being stopped very gradually. A tendency for the car to ride "up" on the bushes and the softness of the ground under the bushes makes it doubtful that the use of brakes would have materially shortened the stop. In two tests where the hedge was wider than 8 ft, and where smaller seedling plants grew outside the axis, the car cut a path along the axis leaving a fringe of bushes on each side. This was the case for test No. 7 (Fig. 12).

Figure 11. Position of test car after test No. 6.

Although the hedge was devoid of leaves in the winter tests, there appeared to be little, if any, significant difference in the stopping performance of the hedge between the summer and winter tests. With the ground frozen, there did appear to be more roots left in the ground.

Two angle tests at 5 deg, one at 10 deg, and one at 20 deg were performed in the summer series. The speed of contact for these tests was planned for a maximum of 30 mph because the hedge was narrow and not too

Figure 12. Path through wide section of hedge—test No. 7.

dense. In all the angle tests the fringe of the bushes did not slow the car appreciably, until the front of the car encountered the central mass on the axis. Since relatively few bushes were on the path of the car, they were either sheared or torn out. There was no massive accumulation of loose bushes to compress, as described previously. Had there been several parallel rows, instead of one, the performance would have been similar to a head-on crash, once the vehicle was turned into the hedge.

The car was stopped within the hedge on both 5-deg tests and on the 10-deg test and passed through the hedge on the 20-deg test. There was no indication that the bushes tended to deflect the car. Actually the retarding effect of the bushes caused the car to swing inward on an arc (Fig. 6).

During the two seasonal tests, there were three different drivers employed. One common observation was of considerable significance; namely, that once the car entered the hedge the driver had no further control of the steering. When the approach of the car was on the line of the axis of the bushes, the car path throughout the test was generally straight. However, toward the end of the stopping period the rear of the car frequently moved laterally as the mass of loose hedge became thoroughly compressed.

TEST RESULTS

A tabular summary of the test data is given in Table 1 for the twelve tests. A study of the data obtained from any one test, or a comparison of the results of similar tests, must be made with caution because there were several factors affecting the results that did not remain constant for each test. Three of the more important factors are (a) the width, height, and compactness or density of the bushes, (b) the pattern of the path the test car followed on the approach, and during the stopping period, and (c) the character and condition of the ground surface on the approach, and within the hedge.

Summer Tests—Nos. 1, 2 and 3 (head-on)

Test No. 1 was made as a pilot run at low speed both to study the performance and to develop procedure. The approach to the axis of the hedge required that the driver execute a reverse curve maneuver of about 9 ft laterally in 60 ft of distance to crash the hedge parallel to the hedge axis. The car tracks indicated that the approach was not parallel to and on the hedge axis; consequently, the rear of the car moved gradually sidewise about 3 ft toward the end of the stopping period. The front remained on the axis. This sidewise movement probably would have been contained had the hedge been wider.

Most of the bushes on the car path were pulled out because the soil was dry and loose. Some bushes were sheared. The measured stopping distance of 26.5 ft and other data are given in Table 1. The entire hood of the car up to the windshield was buried in a compressed mass of tangled rose bushes, but the car was removed under its own power. An area about 20.5 ft in length was swept clean of bushes.

Test No. 2 was a low-speed test intended to duplicate test No. 1. Unfortunately the car hit to the right of the hedge center causing the rear to slide severely to the right. The sliding action which developed, rendered the test unusable for comparative purposes with respect to the accelerations. The stopping distance of 26.0 ft closely approximated that for test No. 1. The final position of car is shown in Figure 13.

TABLE 1

SUMMARY OF CRASH TEST RESULTS

Test no.	Type of test	Contact speed m.p.h.	Stopping		Long. Deceleration			Max. Acceleration	
			Distance, feet	Time, seconds	Ave., "G"	Max., "G"	Time from contact, seconds	Vertical, "G"	Lateral, "G"
1	Head-on	30.3	26.5	1.08	1.05	1.77	0.33	1.25	1.0
2	Head-on	30.5	26.0	1.25	0.5	-	-	0.7	0.25
3	Head-on	21.0	17.0	1.02	-	-	-	-	-
4	5°Angle	30.2	76.2	2.8	-	0.87	1.9	0.5	0.5
5	5°Angle	36.0	117	1.8	0.75	1.40	0.69	1.5	1.25
6	Head-on	35.5	51.8	1.91	0.68	2.72	0.21	1.0	0.5
7	Head-on	47.8	57.2	1.94	0.93	2.24	0.38	1.39	2.12
8	20°Angle	28.4	-	-	-	1.09	0.13	1.33	0.7
9	10°Angle	27.0	56+	1.62	-	1.71	1.00	1.12	0.91
*10	Head-on	35.0	50.1	1.50	-	-	-	-	-
*11	Head-on	22.0	16.3	1.26	0.53	0.82	0.25	0.5	0.5
*12	Head-on	50+	76.5	2.14	0.64	1.74	0.32	1.23	1.27

Note: Decelerations and accelerations were recorded by three-component accelerometer.

*Winter tests.

Test No. 3 was planned to replace test No. 2, using a straight approach over adjacent pasture land. The available distance proved to be insufficient to develop the planned approach speed; however, the rear end did not slide to the right. This test proved that the angle of approach

Figure 13. Final position of car—test No. 2.

coupled with the loose soil was causing the sliding action in previous tests. The accelerometers were not employed on this test accounting for the absence of such data in Table 1.

Summer Tests—Nos. 4 and 5 (angle)

These tests were conducted as 5-deg angle tests for duplicate study. In both tests the stopping distances (Table 1) were large because these distances were measured from the point where the car first touched the fringe of overhanging bushes. The path of the car was straight until the central bush mass was encountered, thereafter the path curved into the central hedge structure.

In both tests, the car was stopped by the hedge and remained within the hedge mass, even though the bushes were thin and less dense than at other locations (see Fig. 6). On test No. 5, the rear of the car swung rather violently in an arc when it struck a large central root mass. It stopped perpendicular to the axis of the hedge 117 ft beyond the contact point. Had the approach speed been higher the tests would have been extremely hazardous, because of the fixed objects located on the far side of the hedge.

Summer Tests—Nos. 6 and 7 (head-on)

Test No. 6 was planned for a contact speed of 50 mph; however, the approach surface was soft and irregular even after preparation, and the approach speed decreased rapidly to 35.5 mph at contact. The hedge was wide and dense. This test demonstrated most effectively the desirable properties of the multiflora rose hedge as a crash barrier.

The highest deceleration, 2.72 G, occurred in this test (Table 1). It is significant to note that 0.21 sec was required to develop this peak value from the instant of impact. The gradual buildup to the peak deceleration is an important advantage demonstrated by this and other tests.

In this particular test the individual bushes were closer than usual, evenly spaced, and the canes were large (Fig. 11). The average diameter was about 3/4 in. and the maximum was 1-3/8 in. The bushes were counted before and after the test and there were 26 bushes destroyed in the test. When the enlarged longitudinal section of the accelerometer record was analyzed, there were 26 distinct peaks averaging 1.25 G over about two-thirds of the stopping distance of 51.8 ft. Field notes indicated that the bushes were sheared off completely in the first half of the stopping distance.

The above observations indicate that each bush offered a distinct and nearly equal resistance in overcoming the kinetic energy of the car, which was finally reduced to zero by the compression of the loose entangled mass. A study of the speed-distance and speed-time curves indicated that the compression of the mass started at about 47 ft or 0.92 sec from the point of contact.

Test No. 7 was similar to test No. 6 except that the contact speed was 47.8 mph. In order that the effect of a discontinuous hedge be studied, 10 ft of hedge were removed for the full width at a point 55 ft ahead of the contact point. This distance was selected on the basis of the stopping distance observed in previous tests and on the characteristics of the hedge, which was wider and more dense than any section previously tested.

The car was declutched about 15 ft ahead of the contact point. It followed a straight path along the axis of the bushes until near the end of the run, where the rear end moved laterally until it came to rest at an angle of about 45 deg with the axis. The final position is shown in Figure 12, the car cutting a path through the bushes. About 3 to 4 ft of partially damaged bushes can be seen on both sides. The mass of bushes above the hood of the car had not yet settled at the time of the picture.

The 10-ft gap which was previously described was partially filled. It was found that the compressed mass was pushed into the opening only 6 ft on the center position and that no intrusion occurred on either edge of the hedge. Since the gap was only partially filled with the compressed mass, it may be concluded that the unsheared canes ahead of the car prevented the mass from being pushed forward, consequently the mattress was pushed upward as it was being compressed. It was generally noted that the front of the car usually rode up on the mass in the last short interval of the deceleration period and that the front end settled slowly after the car stopped.

A study of an enlargement of the accelerometer record indicated a stopping time of 2.03 sec, which was in fair agreement with the 1.94 sec obtained by film analysis. This study also revealed several peak values in longitudinal deceleration, the maximum being 2.24 G at 0.38 sec after contact. The longitudinal deceleration curve for this test was not so erratic as that of test No. 6. It appears from the graph that the last 0.8 sec was consumed in compressing the loose mass of bushes during which time very little shearing action occurred.

As noted in Table 1, this test produced the maximum peak values of vertical and lateral deceleration. The vertical G factor was 1.39 occurring 0.46 sec after contact. There are other vertical peak values spread over the graph which have values of 1.0 to 1.14 G. The above observations are in agreement with the car performance which showed a violent pitching action in the longitudinal plane. On the lateral deceleration record a severe maximum G factor of 2.12 occurred 0.93 sec after contact. A comparison of the enlarged record in each plane indicated a rapid and violent lateral movement or skidding of the rear end of the test car. However, the driver did not report any serious deceleration reaction from the seat or shoulder belts.

Summer Tests—Nos. 8 and 9 (angle)

Test No. 8 was a 20-deg angle test. The contact speed was planned for 30 mph because it was expected that the car would swerve through the thin 8-ft wide hedge. The car passed completely through as predicted and the brakes were applied outside the hedge to prevent serious injury. As a result, little reliable data for evaluation were available.

The car followed a straight line for about 20 ft, after which it veered left on an arc. It was finally stopped 43 ft from the contact point measured along the axis of the hedge. Figure 14 shows the vehicle after it had crashed through and stopped with the help of its brakes.

Test No. 9 was run on a section of the hedge, shown in the foreground of Figure 1. It was made on a 10-deg angle approach and was planned for a speed of 30 mph. The performance of the car was similar to that for previous angle tests. The car was stopped by the hedge, but the impact with

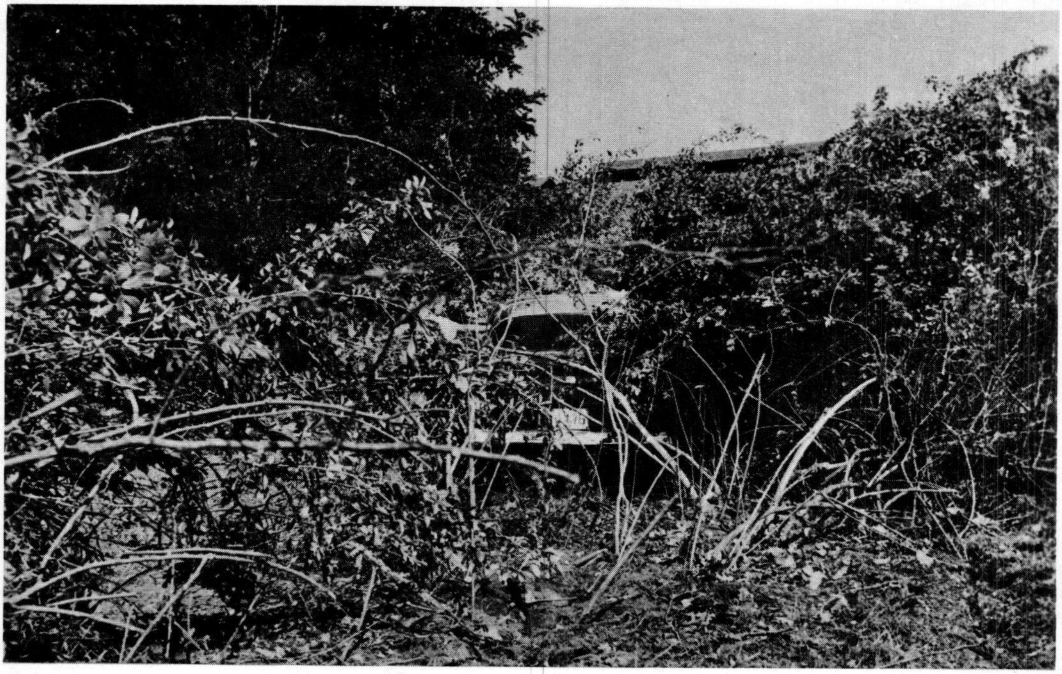

Figure 14. Car stopped after crashing through hedge—test No. 8

the central mass caused the rear of the car to swing violently through an arc of about 80 deg to the axis. Had the hedge at this point been wider and more dense, a more gradual stop would probably have occurred.

Winter Tests—Nos. 10, 11 and 12 (head-on)

Test No. 10 was planned to duplicate the speed obtained in test No. 6. The stopping distances and elapsed time for these tests are quite similar (Table 1). The hedge was similar in width and density although the ground within the hedge on test No. 10 was quite irregular and many rocks were observed to be partly exposed. The approach was on a slight downgrade, and there was a considerable cross slope to the ground. Although the bushes were devoid of leaves, the performance of the hedge was similar in all respects to that described for test No. 6.

Test No. 11 was planned to duplicate the summer test No. 3, which had a contact speed of 21 mph. Because the remaining hedge in this section was located on very rough and rock-strewn ground, it was too dangerous to run any high-speed tests which would have required long stopping distances. The results of test Nos. 3 and 11 were quite similar.

SUMMARY OF FINDINGS

The findings are based upon the results of tests obtained under the conditions described in the report.

1. The effective traveled length within a multiflora rose hedge required to stop a passenger car for a given speed, and without the use of power or brakes, was dependent upon the age of the hedge, the density of the hedge, and the spacing of the bushes.
2. Angular approach and contact with the hedge did not deflect the

car away from the barrier. Once the car was turned into the hedge, the angle-approach crash appeared to require about the same effective length of hedge to stop the car as was required by the head-on crashes.

3. Hedges of multiflora roses were proved to be effective barriers for stopping passenger automobiles, provided the width was sufficient to prevent the vehicle from passing through the hedge. For a vehicle to be stopped within the hedge at speeds not to exceed 50 mph, without the use of brakes or power, the minimum required effective length of hedge on the path of travel was 75 ft.

4. The performance and effectiveness of the hedge in stopping the car were about the same for the winter tests as for the summer tests.

5. The multiflora rose hedge provided a tough, resilient, yielding barrier and permitted the forces of impact to be absorbed so gradually that the maximum deceleration was well within human tolerance.

6. The test vehicle was not damaged except for very minor scratches.

7. It was estimated that 25 percent of the bushes were pulled out. The remaining 75 percent of the plants were not critically damaged and should grow again to almost full effectiveness within three years.

8. During the destructive testing of the multiflora rose hedge barrier, a recurring crash phenomenon developed which indicated that a sizable portion of the energy absorbed by the barrier occurred after a mass of loose sheared bushes had accumulated ahead of the car. The shearing of the bushes ceased when the moving mass bent over the forward bushes.

9. Conclusions drawn from the test driver's observations and reactions are summarized as follows: (a) after the car crashes the barrier and is enmeshed in the hedge, the driver has no steering control of the vehicle, (b) the forces experienced during the stopping period seemed no more severe than an extreme emergency stop.

RECOMMENDATIONS

The following recommendations are suggested for consideration in the event that barriers of the type tested are planted along highways:

1. Bushes should be planted on 4-ft centers in staggered rows, and the spacing of parallel rows should be a maximum of 4 ft.

2. The total width of hedge recommended for stopping vehicles within the hedge, and without brakes or applied power, at speeds not to exceed 50 mph is:

Angle of approach in deg	Width of hedge in ft
5	25
10	30
20	40
30	50
90	80

3. To relieve monotony, it is suggested that long and continuous hedges be broken at short intervals, or that other forms of landscaping be employed frequently.

4. A future testing program should be planned and multiflora roses, as well as other suitable varieties of plants, should be planted in a 50-ft level or depressed median strip on a level section of highway, in order that more satisfactory crash studies can be made under actual highway conditions.

5. Experimental plantings of the type tested above should also be made so that the related problems of snow removal, drainage, accumulation of litter, monotony and highway-user reaction may be studied and compared to the advantages of life-saving possibilities of barrier hedges.

ACKNOWLEDGMENT

The author wishes to acknowledge the splendid cooperation received from the personnel of the Bureau of Public Roads and the Connecticut State Highway Department, and from the State Police of the Connecticut Motor Vehicle Department.

Special mention is due Dr. James A. Farnham of South Windsor, Connecticut, for the donation of the hedge and use of his land.

Carl C. Saal of the Bureau of Public Roads deserves the personal thanks of the author for his assistance during the field tests, for his careful review of the project report, and for his help in preparing this report for publication.

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An Energy-Absorbing Barrier for Highways

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In recent years the unprecedented increase in traffic volume and speed compounded the problem of death on the highways. One of the most severe contributors is the head-on collision caused by an out-of-control automobile crossing the centerline of a highway.

An energy-absorbing barrier system to eliminate this hazard has been developed. The barrier consists of a series of corrugated concrete slabs extending above a road surface about 2 ft and arranged in a row in the center of the median strip of a highway.

An automobile or truck, out-of-control and commencing to cross into the lane of the oncoming traffic, will break off a number of these concrete barriers and stop, instead of causing a head-on collision.

Evaluation of this concept of automotive protection was made by both laboratory techniques (static) and field experiments (dynamic). The laboratory tests provided the basis for the appropriate selection of configuration and materials which provided the highest barrier performance. The field tests permitted evaluation of the dynamic performance of a row of these barriers.

In these experiments, a car was driven through a series of the barriers at 17 and 31 mph. Deceleration rates were determined by micromotion analyses of high-speed motion pictures used for instrumentation. A 16-mm film has been produced covering these experiments.

The feasibility of the concept of providing a collapsible barrier to govern the deceleration of out-of-control vehicles to prevent injury to the vehicle occupants has been demonstrated by these experiments.

● THE EVER EXPANDING volume and the continuing trend toward increase in speed of automobiles and trucks on the highways threaten an increasing death rate from highway collisions. These collisions are killing more people on highways in peace times than were killed by enemies in times of war. Deaths by automobile accidents have reached a point where they are considered to be a national epidemic.

Billions of dollars in research are being spent to develop more positive means for securing protection from enemies and still other billions to develop better methods for protecting soldiers in times of war, and yet an astounding apathy pervails toward the biggest killer—the highway accident, generally a collision of one kind or another. Of the more frequently occurring accident types, the two most deadly kinds of collisions are (a) the head-on collision of two vehicles traveling in opposite directions, and (b) the collision of a vehicle with a fixed object.

For sometime it has been evident to highway engineers that the placing of the high speed lanes adjacent to each other, separated only by a painted line, is extremely hazardous. Two vehicles approaching each other at a speed of 55 mph have a closing speed of 110 mph (161 ft per sec).

Considering that two vehicles moving in adjacent highway lanes separated only by a 1-ft double line (total width) will pass with a clearance of from 3 to 6 ft in normal driving, momentary inattentiveness or loss of control of either vehicle can easily result in a head-on collision. Even at ordinary speeds, a sideswipe frequently leads to complete loss of control of one or both vehicles; the ensuing secondary impacts often result in fatalities or serious injuries. Driving under these conditions requires a motorist to function with the penalty of sudden death for one moment of inattentiveness. Man's inability to handle this task is documented by our annual death and injury toll in motor vehicle accidents.

Divided highways and freeways have contributed considerably towards the elimination of this hazard. However, this improvement is to some extent offset by the freeways tending to give drivers a feeling of safety at speeds of 70 or 80 mph. Out-of-control vehicles are crossing over the median strips of divided highways, resulting in head-on collisions at these higher speeds. Therefore, the divided highway has not completely solved the problem. In some places heavy steel barriers have been placed in the median strip to prevent an out-of-control vehicle from crossing into the lanes of opposing traffic. Although this guardrail is adequate for preventing a car from crossing the median strip, a vehicle striking one of these barriers may be deflected back onto the roadway and possibly across the lanes of high speed traffic. A very serious collision can occur as a result of this unexpected rebound of the out-of-control vehicle.

This problem then resolves itself into one of preventing a vehicle from crossing over the center line of the highway or being deflected back across lanes of traffic on its own side.

One possible solution to this problem would be to place an energy-absorbing barrier where the vehicle would pass after leaving the regular course of travel and before it could engage in a destructive collision. This barrier would absorb the kinetic energy of the vehicle, bring it to a safe stop, and thus eliminate serious danger to the occupants of the vehicle and to those in other vehicles in the immediate vicinity.

A great deal of work has been done by highway engineers and by others in developing safety barriers for highways. Most of these barriers have been designed with the thought of keeping the vehicle on the roadway with an insurmountable or impenetrable barrier. Very few have been developed with the thought of safely absorbing the kinetic energy of the vehicle while bringing it to a stop. It is the purpose of this paper to describe an energy-absorbing solution and only those references relating to such a procedure will be discussed.

One of the earliest approaches to the principle of absorbing the kinetic energy of an automobile by a highway barrier was the "Danish Safety Wall" (1). This barrier has been built on a mountain road in Denmark and has performed very successfully. Its principal application is limited to mountain or curved roadways with the attending disadvantage that the concrete rail must be cast to fit the curvature of the roadway. The high cost of custom manufacture has restricted its application.

The California Division of Highways has conducted considerable research on the design of curbs and bridge railings. A recent report (2) deals with the full scale testing of highway curbs by automobile impact. The basic object of this study was to develop a curb that was insurmountable. Among the curbs tested were several undercut curbs designed to have an action similar to that of the Danish Safety Wall. Another report (3) by the California Division of Highways on full scale tests of highway guardrails covers the use of the above undercut curb in conjunction with bridge guardrails.

The Department of Civil Engineering of the Johns Hopkins University has conducted extensive tests using scale models to determine the effect of impact of a vehicle against both a cable and a beam type guardrail (4). This report deals directly with the measurement of the energy loss of a vehicle as the result of a collision with a guardrail composed of steel cable, brackets and posts. Calculations were made to determine the amount of energy absorbed by:

1. Friction between the cable and the vehicle.
2. Yielding of the barrier posts in the ground.
3. Yielding of the barrier cable.
4. Deflecting the mass of the vehicle from the approach angle to the exit angle.
5. Sliding friction between the tires and the roadway surface as a result of the deflection described.

Their findings suggest that the bulk of the energy was lost through friction between the cable and the vehicle. Also, the amount of loss was found to be dependent upon the contact pressure and the contact time. The relative position of contact with respect to the position of the guardrail posts was therefore an important factor. Actually, in order to prevent collision between the vehicle and a guardrail post, the points of contact had to be selected between the posts. The article suggests that in order to prevent post collisions a new type of post bracket will have to be developed. The above study comes the closest to approaching the problem of designing a safety barrier on an energy-absorbing basis. However, this aspect of the design comes as a by-product of a rail designed to keep a vehicle from running off a roadway.

To the authors' knowledge the only example of an energy-absorbing barrier being placed in a median strip is contained in a report by White (5), describing tests of driving an automobile into a shrub planting (Rosa Multiflora Japonica) at 30 mph without damage to either the automobile or driver. Here is a barrier that serves the purpose of absorbing the kinetic energy of a moving vehicle, bringing it to a stop without injuring the occupants or damaging the vehicle. This would seem to be an ideal solution to the problem under consideration. However, as a barrier for highways and freeways carrying large volumes of traffic, it has the following disadvantages:

1. Approximately 3 years are required for an adequate growth.
2. This plant life would be continually subjected to exhaust gas damage.
3. Fire damage (cigarettes) would require 3 years to replace growth.
4. Watering is required (at least in some areas).
5. Considerable space is necessary.
6. Frequent pruning is required if space is restricted.

The two basic requirements of a highway safety barrier are that it will: (a) permit an out-of-control vehicle to remove itself from the roadway proper, and (b) absorb the kinetic energy of the vehicle and thereby bring it to a complete stop without injury to the occupants.

Rosa Multiflora Japonica plantings—in areas where they can be grown economically and in sufficient density—meet both of the above basic requirements. In large areas in the United States such a solution is beyond attainment. Moreover, there are additional desirable requirements some of which dictate the use of some other material. Among these requirements are that the material:

1. Be permanently reliable regardless of the weather conditions.
2. Be adaptable to the specific degree of energy absorption required for a given road situation.
3. Ensures a reasonably uniform deceleration.
4. Absorbs a considerable amount of energy for a small unit price.
5. Holds to a minimum the tendency to deflect the vehicle.
6. Be free from added hazards, such as sharp protrusions or cutting surfaces.
7. Allows high speed impact without throwing fragments into the oncoming traffic.
8. Be inexpensive to build.
9. Be easily replaced if damaged.
10. Presents an attractive appearance.
11. Does not collect paper or rubbish.

Requirement (a) "Permit an out-of-control vehicle to remove itself from the roadway proper," can be met by the proper placement of the barrier. Requirement (b) "Absorb the kinetic energy of the vehicle and thereby bring it to a complete stop without injury to the occupants," is to be satisfied by the characteristics of the barrier. A large amount of kinetic energy is associated with a motor vehicle traveling at high speed; thus, a somewhat unique solution is required to absorb such a large amount of energy in the manner prescribed.

As used in the normal operation of stopping an automobile, brakes convert kinetic energy into heat at the braking surfaces. However, in an out-of-control type of emergency the assumption is that brakes cannot be used or that they are ineffective and that the vehicle must be stopped by a supplementary decelerator. This decelerator should absorb the energy of the vehicle at a reasonably uniform rate over a sufficiently long period of time to minimize the possibility of injury to the occupants and function without causing excessive damage to the vehicle. It is to be understood that, in the context of this paper, a "sufficiently long period of time" is at most only a few seconds.

In searching for a material that can absorb large amounts of energy, it occurred to the senior author that in the action of forming sheets of metal by the stretch operation, large amounts of energy are required. Also, it is recalled that when a heavy object is dropped on a piece of timber, breaking it under the impact of the fall, much of the kinetic energy of the dropped object is utilized in breaking the timber.

An approach to the problem may be the utilization of the energy-absorbing potentialities of the stretching of metals and breaking of materials. The breaking of wood presents the possibility of sharp slivers and spikes which may lead to serious secondary damage. Stretching and breaking steel presents the danger of sharp knife-like cutting edges that might be as dangerous as broken wood. Breaking concrete presents the danger of throwing broken pieces into the path of oncoming vehicles, thus causing secondary accidents. However, if concrete can be reinforced with steel in such a way as to prevent the pieces flying away from the impact, then it may be the logical material to use. If the reinforcement could be distributed throughout the concrete to tie it together after breaking, it might eliminate the fragmentation problem. This suggests the use of expanded metal lath as a possible solution.

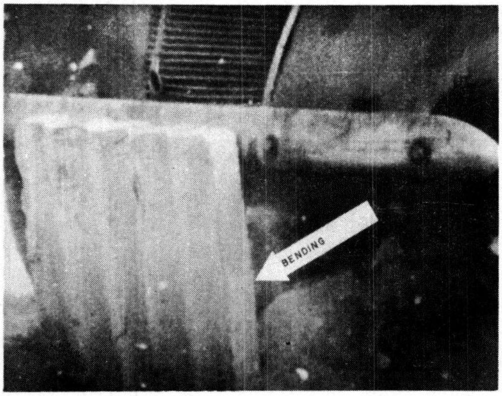

Figure 1.

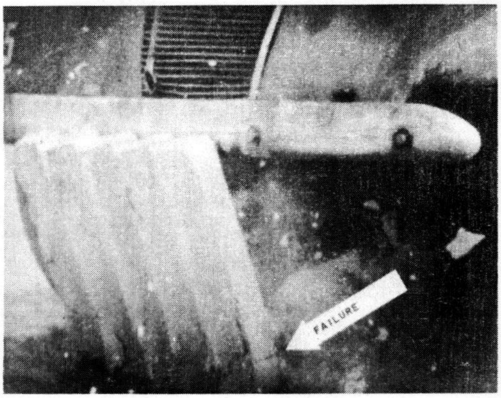

Figure 2.

It is therefore proposed that thin slabs of concrete reinforced with expanded metal lath be used as the element of the barrier. One end of the slab would be anchored in the ground; the other end would extend about two ft above the ground to form the barrier. A row or rows of these barriers some distance apart would then be placed down the center of the median strip of a highway. A vehicle going over the roadway curb and into this median strip, running into this row of barrier slabs and breaking them off consecutively, would be brought to a stop in the middle of the median strip. With a continuous row of barrier elements, the weight and speed of the vehicle becomes less important. It could break as many barriers as are required to absorb the energy it possesses. The total energy absorbed by a barrier element will be the sum of the energy absorbed by elastic bending, breaking, and accelerating of concrete particles.

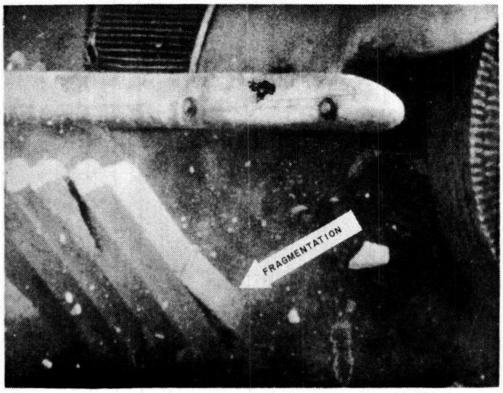

Figure 3.

If barriers are designed to provide a deceleration rate of -0.6G for a small vehicle, it is also desirable for them to decelerate a truck at approximately the same rate. In most instances this cannot be done with a single row of barriers but a double row could be set up to stop trucks. Consequently, any degree of energy absorption can be designed into the safety barrier.

From the observation of many tests of reinforced concrete beams, it is recognized that failure in concrete tends to occur abruptly and that the energy absorbed is therefore small. However, the breaking characteristics vary with the shape of the element. The selection of shape should, therefore, be one that prolongs the breaking period and breaks as much material as possible. Shaping the concrete beam into a corrugated configuration would tend to reduce its elastic deflection but would prolong the breaking process (Fig. 4). If the slab contains sufficient steel, the initial failure will be in the concrete. The crest of the corrugations will fail first, being the farthest from the neutral axis. The concrete will fail by crushing or shear, pieces breaking off on the outer surface at the area of maximum moment. Then the remaining concrete, being exposed by this breaking away, will be subjected to excessive stress and will also break away. This will continue until the slab has completely broken.

As the concrete breaks away and the neutral axis shifts, the steel also becomes stressed to the yield point at the crest of the opposite surface of the slab and yields, stretches, and then breaks. The steel, next in order, stretches and breaks. The shape of expanded metal lath is such that, after the concrete breaks away from it in the area of failure, the lath will straighten out, by plastic bending and stretching of the elements, thereby absorbing additional energy. Thus, breaking of both the concrete and the steel is progressive and is extended over a prolonged period of time.

In a curve in which the breaking force is plotted as the ordinate and the deflection of the slab as the abscissa, the energy absorbed will be equal to the area under the curve (Figure 4). To absorb a maximum amount of energy it is desirable to present a high resisting force, and then to sustain that force through as long a deflection distance as possible. This corrugated configuration of the slab with its feature of progressive failure prolongs this resistance and absorbs a maximum amount of kinetic energy.

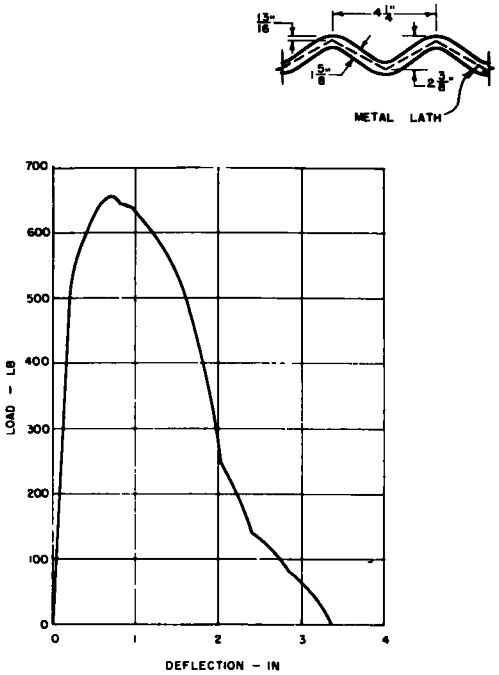

Figure 4.

For economy, it is desirable to have the barrier as light as possible. This can be accomplished by keeping the dimensions of the barrier small. By keeping the thickness of the barrier to a minimum and developing the necessary section modulus by the depth of the corrugations, the proper balance of economy and energy absorbing capacity should be obtainable.

After conducting suitable static tests (Fig. 5 and 6) there followed the impact tests consisting of two runs of an 1937 Ford sedan into a row of barriers. Figure 7 shows the car and barriers at the end of Run No. 2. The barriers, 55 in number, were set on end at 2 ft intervals in a trench 22 in. wide and 10 in. deep. Each barrier was held in place by an 8-in. slab of concrete against the back side and a 3-in. slab against the front side. A plan view of the field setup is shown in Figure 8.

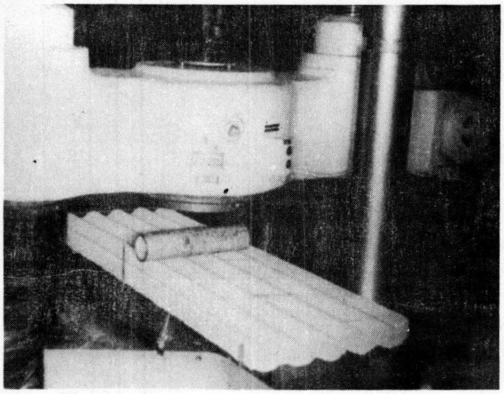

Figure 5.

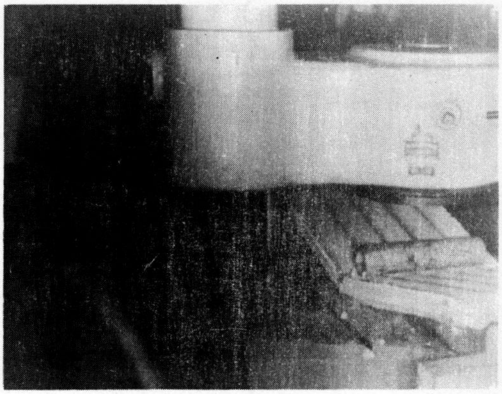

Figure 6.

As protection for the driver, the test car was equipped with a seat belt, shoulder harness and an expanded metal screen over the windshield as shown in Figure 9. The automobile was weighed after all alterations had been made. The total weight including the driver was 3,085 lb.

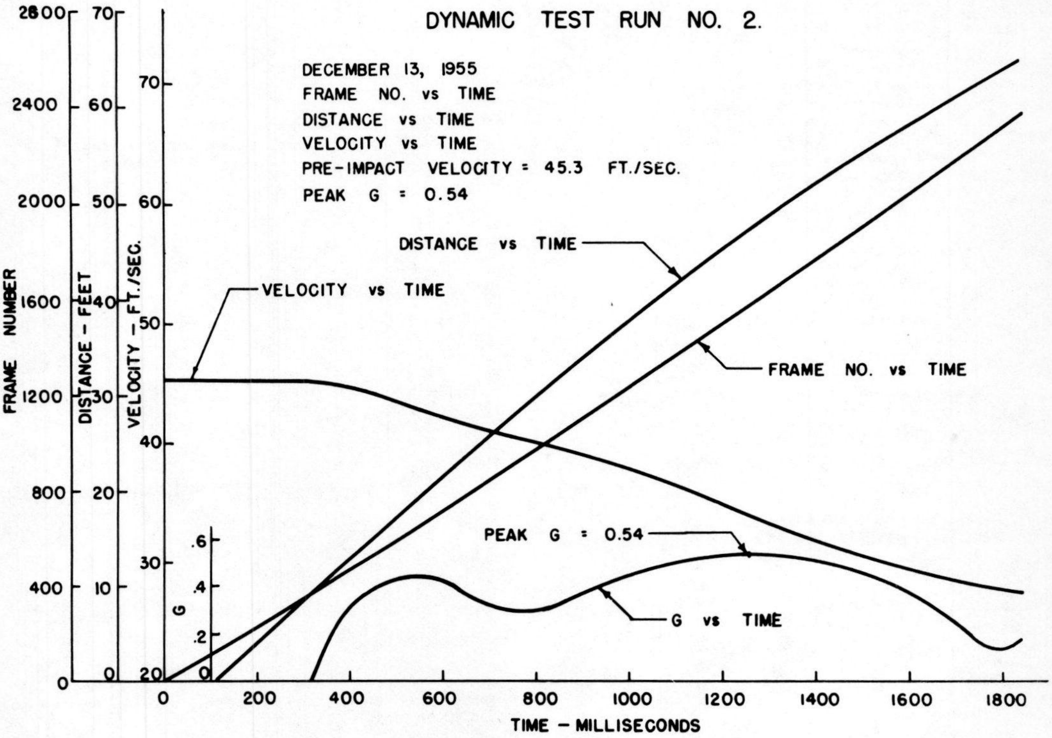

Table 7.

In the initial run the automobile struck the first barrier at 17 mph. It broke 23 barriers before coming to rest one foot from the 24th barrier. Figures 10 and 11 show car and barriers at the end of the run. The distance traveled in stopping was 52 ft.

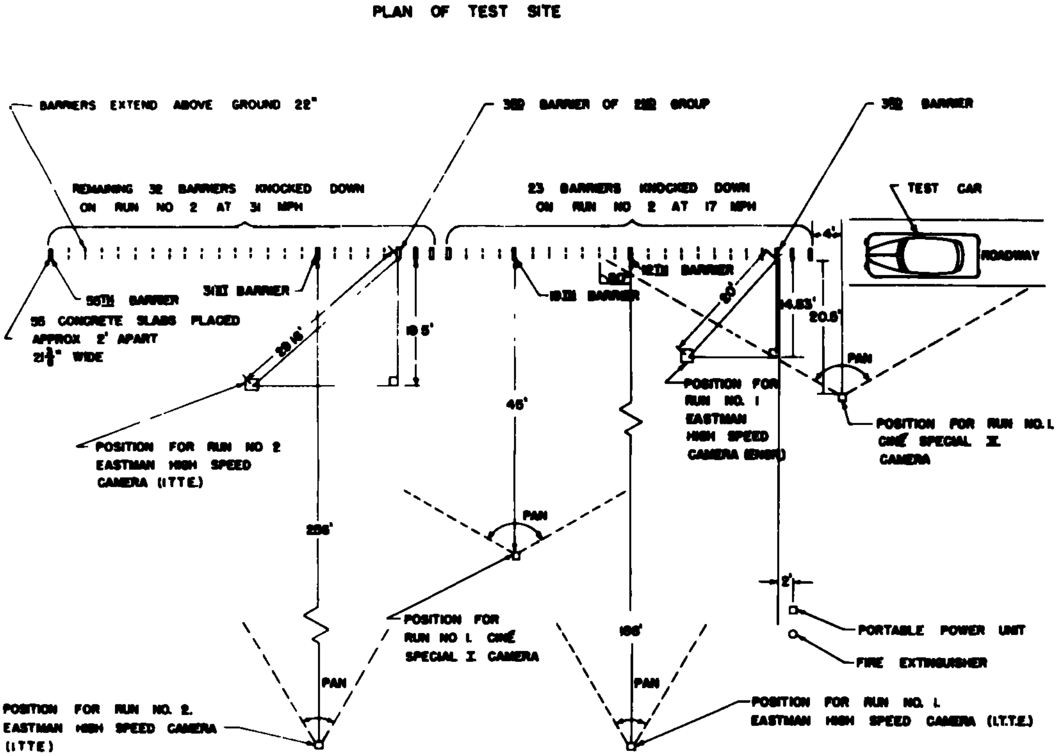
PLAN OF TEST SITE

Figure 8.

The broken barriers were removed to clear the approach to the remaining barriers. In the second run the automobile struck the first barrier at 31 mph and mowed down the remaining 32 barriers. It was traveling at approximately 8 mph at the end of the run. The brakes were then applied to stop the automobile. The distance traveled through the barrier was 72.5 ft.


Figure 9.


Figure 10.

By micromotion analysis of the high-speed motion pictures it was determined, after making allowance for ground friction and wind resistance, that the energy absorbed per barrier in run No. 1 was 1,000 ft lb, and in run No. 2 was 2,500 ft lb. The average energy absorbed per barrier in the static tests was 1,258 in. lb or 105 ft lb. Comparing this value with the values obtained in the impact tests, it becomes evident that additional tests are required before any reliable relationship can be established between the capacity of a barrier for static and dynamic energy absorption. The absence of satisfactory correlation between static and dynamic experimental test results is commonly encountered in impact studies.

These experiments have shown that it is possible to develop a barrier of sufficiently low resistance to stop a light vehicle at as low a rate of deceleration as is practical. The opposite limit of performance now remains to be determined. This limit would be the maximum rate of deceleration possible without injury to vehicle occupants. By selecting the amount of steel and concrete in the barrier as well as the depth of the corrugation, a barrier can be designed with performance at some optimum value between these two limits.

After examining the extent of scatter of pieces of concrete during the high speed run (Fig. 3), it is apparent that better control of these pieces is necessary. It is suggested, therefore, that the barrier elements be reinforced with two layers of metal lath—one at each face rather than the single centrally located lath. Placing the reinforcing mesh at the extreme surface will give a maximum effective depth for the element and therefore maximum strength for a given amount of material. There should be no difficulty in casting the elements in this manner, since the paste and fines will readily flow into and around the mesh when vibrated. In previous castings uniformity of construction could not be maintained because it was difficult to place and hold the metal lath in the exact center of the element. If the metal lath is placed against the surfaces of the forms and the concrete poured between them, they can be accurately held in this position in all barrier elements, and uniformity will result. It is also suggested that the depth of corrugation be increased to provide a wide range of energy absorption.

Figure 11.

The problem of replacing broken barrier slabs will require additional study and experimentation. A suggested method would be to coat the lower end of the slab with some form of mastic. Thus, when the base concrete was poured it would be prevented from bonding to the lower end of the barrier slab, and the latter could be removed easily after the upper end had been broken off. A new barrier slab could then be set into the cavity formed in the original base pour. Thus, the base pour would have to be made only once and the slab elements could be easily and quickly replaced.

Testing the energy-absorbing capacity of barriers could be accomplished [1] by a method used in reference (4). A large-negative still camera

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[1] High-speed cameras and micromotion analysis are preferable.

would be set on a firm support and focused on the barrier to be tested. The automobile to be used to break the barrier would be marked with a target made of a reflective tape. The test should be run in poor light or at night, the only light source being a strobe light set to flash at a known high rate and at short duration. The camera lens should be open from a minimum of 4 flashes before the automobile strikes the barrier until 4 flashes after breaking the barrier. Micromotion analysis could be made as follows: the time interval between the strobe flashes and the distance between the target images before impact and after impact, measured in thousandths of inches on the negative when used with appropriate conversion factors, constants and formulas provide the basis for computing the energy absorbed, the velocity change and the average deceleration.

Barriers could be more economically tested in this manner since only one to three barriers are required. Thus, an optimum barrier could be developed relative to the specifications of concrete, reinforcement, and configuration with the expenditure of a minimum number of barriers.

Tests should also be made driving an automobile into the barrier at an approach angle, since the barrier will usually be encountered in this manner. Characteristics of rebound could be determined in this manner and any necessary modifications made in the design to improve its effectiveness.

CONCLUSION

These experiments have demonstrated the feasibility of decelerating an out-of-control motor vehicle at a rate sufficiently low to be non-injury producing by means of collapsing a series of reinforced concrete slabs. Further study is suggested to improve the performance of the unit barrier in order to:

1. Provide better control over the dispersal of concrete fragments during collapse. Barrier elements with two layers of metal lath, one at each face would improve this condition.
2. Increase the depth of corrugation to provide a wider range of energy absorption.
3. Increase the mass of the barrier. A more massive barrier will tend to offset the decrease in barrier performance for vehicles striking at higher velocities.
4. Devise an inexpensive and expeditious method for replacing barrier units following an accident. A suggested method consists of coating the portion of the barrier unit to be embedded in concrete with an anti-bonding agent so that the broken base can be extracted and replaced by a new element.

The maximum rate of deceleration developed in these test-runs was approximately one-half G. Since this is the normal stopping rate of automobiles using brakes, the experiments have established that this type of barrier can be designed to provide very low resistance to collapse. It remains now to develop and evaluate a barrier having optimum performance by giving appropriate consideration to the findings and recommendations provided by this study.

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