Technical Report Documentation Page

1. REPORT No.

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE

Roadway Barrier Curb Investigation

5. REPORT DATE

December 1953

6. PERFORMING ORGANIZATION

7. AUTHOR(S)

Beaton, J.L. and Harry Peterson

8. PERFORMING ORGANIZATION REPORT No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

State of California
Department of Public Works
Division of Highways
Materials and Research Department

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT & PERIOD COVERED

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Submitted herewith are the pertinent data and results of an investigation aimed at determining the relative efficiency of eleven different designs of barrier type highway curbs.

The primary objective of this investigation was to determine the ability of various types of curbing to serve as a physical barrier to cars striking the curb, and also to determine the potential damage to both car and curb. Several other features were also investigated, such as the effect of different slopes; the effect of shape of curb on the control of a vehicle during and after collision, and the effect of metal compared to concrete curb face.

This study was initiated by Mr. F.W. Panhorst, Assistant State Highway Engineer in charge of bridges. Mr. Panhorst pointed out this need in a letter to Mr. Earl Withycombe, Assistant State Highway Engineer in charge of operations, dated August 18, 1952, in which he stated, "for a number of years -- at least as long as I can remember -- there has been a continual run of arguments regarding the efficiency of various types of curbs. I am not favoring any particular type of curb, but I am interested in trying to determine the one most efficient type and this information can be secured only from tests." Mr. J.W. Vickrey, Assistant State Highway Engineer in charge of planning, concurred with Mr. Panhorst.

The California Highway Commission authorized the expenditure of funds for the work. Mr. Withycombe then directed Mr. F.N. Hveem, Materials and Research Engineer, to proceed with the tests. The program was assigned under the direction of J.L. Beaton, Supervising Highway Engineer and the detailed direction of the test program was handled by Mr. Harry A. Peterson, Jr., Assistant Physical Testing Engineer.

17. KEYWORDS

18. No. OF PAGES:

51

19. DRI WEBSITE LINK

http://www.dot.ca.gov/hq/research/researchreports/1930-1955/53-11.pdf

20. FILE NAME

53-11.pdf

STATE OF CALIFORNIA
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT

CURB TEST

STATE OF CALIFORNIA · DEPARTMENT OF PUBLIC WORKS · DIVISION OF HIGHWAYS

DECEMBER 1953

State of California
Department of Public Works
Division of Highways
Materials and Research Department

ROADWAY BARRIER CURB INVESTIGATION

By

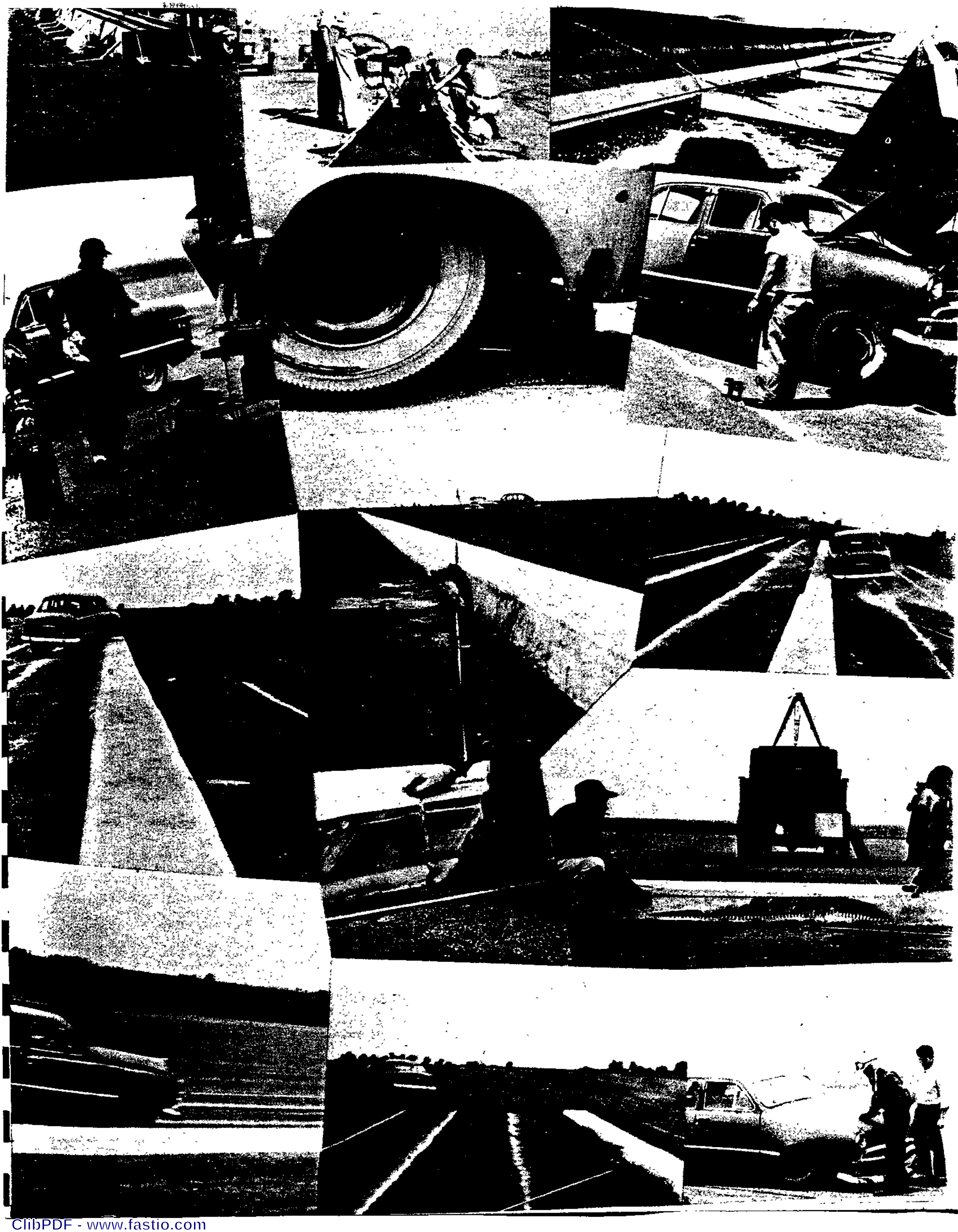
J. L. Beaton, Supervising Highway Engineer

Harry Peterson, Assistant Physical Testing Engineer

F. N. Hveem

Materials and Research Engineer

December 31, 1953



INDEX

Department of Public Works

Division of Highways

Materials and Research Department

Sacramento, California

Submitted herewith are the pertinent data and results of an investigation aimed at determining the relative efficiency of eleven different designs of barrier type highway curbs.

The primary objective of this investigation was to determine the ability of various types of curbing to serve as a physical barrier to cars striking the curb, and also to determine the potential damage to both car and curb. Several other features were also investigated, such as the effect of different slopes, the effect of shape of curb on the control of a vehicle during and after collision, and the effect of metal compared to concrete curb face.

This study was initiated by Mr. F. W. Panhorst, Assistant State Highway Engineer in charge of bridges. Mr. Panhorst pointed out this need in a letter to Mr. Earl Withycombe, Assistant State Highway Engineer in charge of operations, dated August 18, 1952, in which he stated, "for a number of years -- at least as long as I can remember -- there has been a continual run of arguments regarding the efficiency of various types of curbs. I am not favoring any particular type of curb, but I am interested in trying to determine the one most efficient type and this information can be secured only from tests." Mr. J. W. Vickrey, Assistant State Highway Engineer in charge of planning, concurred with Mr. Panhorst.

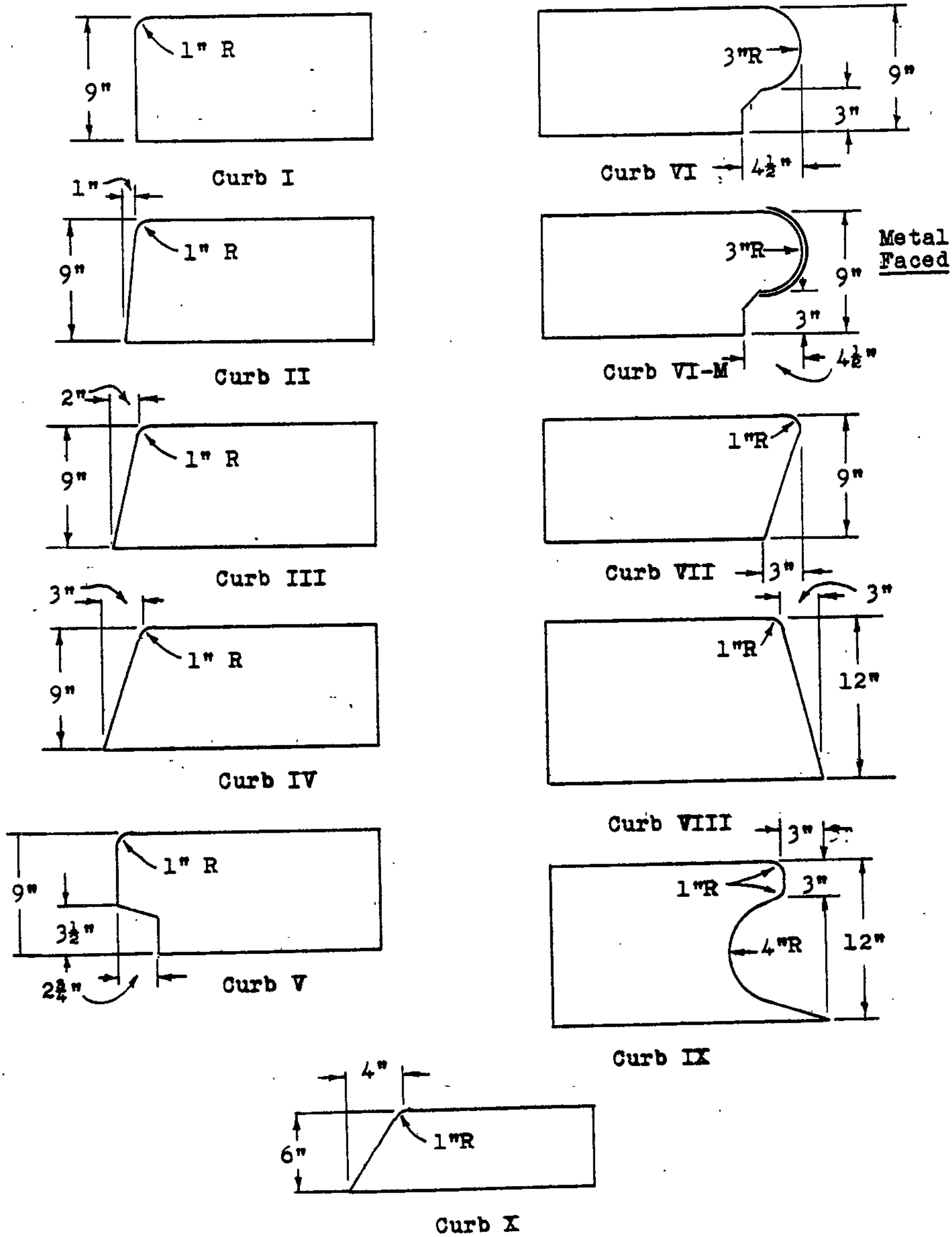
The California Highway Commission authorized the expenditure of funds for the work. Mr. Withycombe then directed Mr. F. N. Hveem, Materials and Research Engineer, to proceed with the tests. The program was assigned under the direction of J. L. Beaton, Supervising Highway Engineer and the detailed direction of the test program was handled by Mr. Harry A. Peterson, Jr., Assistant Physical Testing Engineer.

Motion and still pictures taken during the test for analysis purposes are in the files of the Materials and Research Department. An edited film has been prepared from these test pictures so as to present the general findings of the study. This film is available for showing.

In general the test results show the undercut type of roadway curb to be the most efficient as a barrier; however, conclusive data was not developed on the question of most effective dimensions and type of facing materials.

Plate 1

TEST CURBS



Note: Due to surface and construction variables the 9" and 12" curbs varied as much as plus 1" in height.

DEFINITION OF TERMS

Barrier Curb

A roadway curb intended to provide a barrier to the passage of motor vehicles. (This study is concerned only with physical data concerning the relative performance of several designs of barrier curbs.)

Action of Vehicle on Curbs

Partial Climbing

When the test vehicle wheel tended to ride up on the curb, as indicated visually by seeing the tire lift from the pavement or by the tire print left on the curb, the action was described as partial climbing.

Mounted

If the entire tread surface of a tire was seen to ride on the top surface of the curb, it was described as "mounting" or the curb as being mounted.

Wheel Contact

The wheel contact in feet refers to the marks left on the curb face by the colored tires after contact by test car. The front wheels were colored red and the rear green. The measurements were taken after each test. Rim contact was also measured, however, it was difficult to accurately determine the length of rim contact as differentiated from body contact since they both were measured as a scratch on the curb surface.

Front Wheel Climb

The distance that the tread of the contact tire was raised from the surface of the pavement at the time of contact. Estimates of the height of climb were made by observation of the moving picture data and correlated to field measurements of the tire marks on the curb.

Percent Tire Contact

The percent of the tire circumference that showed contact with the curb.

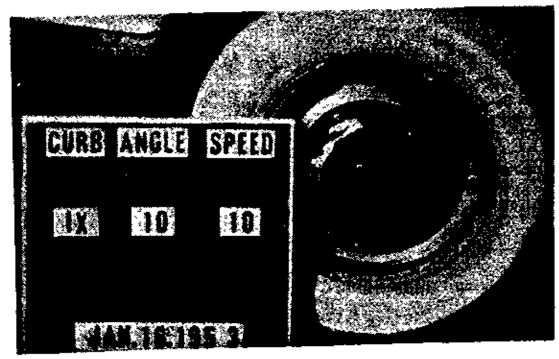
Percent Rim Contact

The percent of the rim circumference that showed contact with the curb.

DAMAGE TO AUTOMOBILE

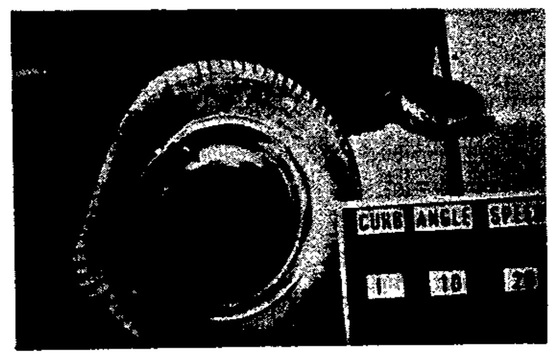
Minor Damage

Illustrates typical minor damage to wheel. Note mark on hub cap.



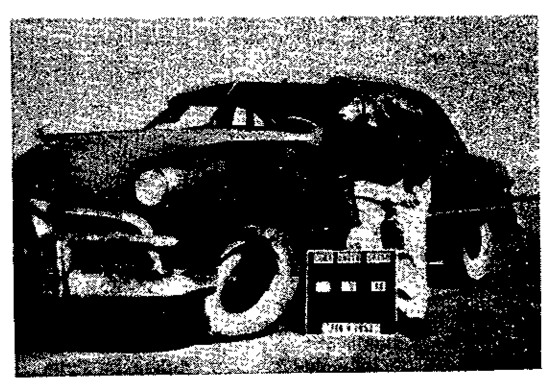
Medium Damage

Illustrates typical medium damage to wheel. Note curled rim.



Major Damage

Illustrates typical major damage to wheel assembly. Note curled rim and angle of wheel.



Effect of Curb on Vehicle

Minor Damage

Any damage to the car that would not alter the control or action of the car upon contact with the curb was considered to be minor damage. Any one or combination of the following types of damage was considered in this category: slight to moderate wheel rim contact, bent hub cap, bumper contacted and slightly marked, and lower portion of fender scraped.

Medium Damage

Any damage that could be corrected by the mechanic without adding new parts was considered to be medium damage. Any one or combination of the following types of damage was considered in this category: moderately bent "A" frame, moderately bent "A" frame pivot bar, slight change in camber, moderately bent tie rods. Included also was the realignment of the front end.

Major Damage

Any damage that required the installation of a new part was considered to be major damage. Any one or combination of the following types of damage was considered in this category: bent wheel, badly bent "A" frame, badly bent "A" frame pivot bar, cut tire, or broken king pin. In the majority of the cases when the term "major damage" is used a complete new lower "A" frame had to be installed due to the severity of the damage. Also in the majority of these cases the wheels were usually bent to such a degree that they could not be used until straightened or replaced.

HISTORY OF THE FIRST CALIFORNIA TEST ON BARRIER CURBS

Questions concerning the efficiency of existing curb designs have been aired many times in the past. Design questions on both shape and height have been discussed pro and con with no conclusive results. Therefore, in August of 1952 the Bridge Department of the California Division of Highways requested that full scale tests be made on various barrier curb designs so as to determine the relative merits of the several types of roadway curbing in general use. The Design and Traffic Departments concurred in this request with the additional recommendation that a few shapes not now in use should be tested and also that the mountable characteristics of the standard 6" high sloped curb should be investigated.

The effectiveness of barrier curbs is of particular importance at this time due to the increased viaduct construction in the metropolitan sections of the State. Obviously a good physical barrier curb design is one that will not allow a vehicle to climb over the curb, yet will provide the maximum safety to the occupants of the vehicle striking the curb as well as to adjacent vehicles on the roadway. Of importance also is the minimizing of damage to the striking vehicle and to the roadway curb.

After subsequent review and approval of the test program by the various interested departments in the Division of Highways, the Highway Commission alloted funds for the test during November of 1952.

The Franklin Airport, 25 miles south of Sacramento, was chosen as the test location. The Sacramento County officials granted the use of the westerly runway for the test. This was approved by the

Federal Civil Aeronautics Administration. The airport runway supplied enough space to test 500 feet of curb with ample room to accelerate and decelerate the test car to the desired speeds. During December, 1952 construction of the test curbing was completed.

Full scale impact tests are not new, having been run on various guard rail designs by the Missouri Highway Department, and there have been reports of other tests on guard rail installations and curbing. However, no record was discovered of similar tests having been performed on barrier curbs.

The Division of Highways Equipment Department supplied the test car in the form of a 1949 Ford Sedan that had been surveyed for sale. The sedan was converted into a suitable test car by adding bracing very similar to that used by the hard-top racing cars. In addition, a survey speedometer and a camera to record curb contact speeds were added to the vehicle.

A test driver was secured and the running of the actual tests started in January, 1953.

The Materials and Research Department furnished technical personnel and photographic and other general equipment.

An experienced mechanic was assigned by the Equipment Department to appraise and repair the test car damage. The Bridge Department and Photography Laboratory also assigned men and equipment to the project.

The actual testing of the curbs was completed in May, 1953. The film processing, reviewing and editing was completed in August. The results, as given in this report, were founded on analysis of data recorded from observers' reports and photographic records.

TEST UNITS, EQUIPMENT AND PROCEDURE

UNITS

Eleven different designs of roadway curbing were tested, each being represented by a section 100' long. The curbs are identified on Plate I preceding. All of the curbs were constructed of concrete; however, a metal facing was placed on the "round nosed" curb VI after it had been tested as a concrete curb. Three heights of curbing were tested; namely, 6", 9" and 12".

The test curb installation was 500' long and 3' wide with the ten different shapes of curbs formed, five on each side. With one exception, wood forms were used and the concrete was placed directly on the airport bituminous surface pavement. No tie was found to be necessary to hold the curb from sliding.

A metal form was used to construct the round nosed concrete curb. This form was later reinstalled to serve as a metal facing and additional comparative tests were made to determine the difference between concrete and metal as a curb surface.

The approach runway had a bituminous surface somewhat similar in texture to an average plant mix surfacing.

EQUIPMENT

The test automobile was a 1949 Ford 4-door Sedan, Model H8A body type 73A. The wheel base was 114", the tires sizes 6.00 x 16, and the vehicle weight about 3224 lbs. It was well braced around the driver's seat similar to a hard-top racing car, a safety belt

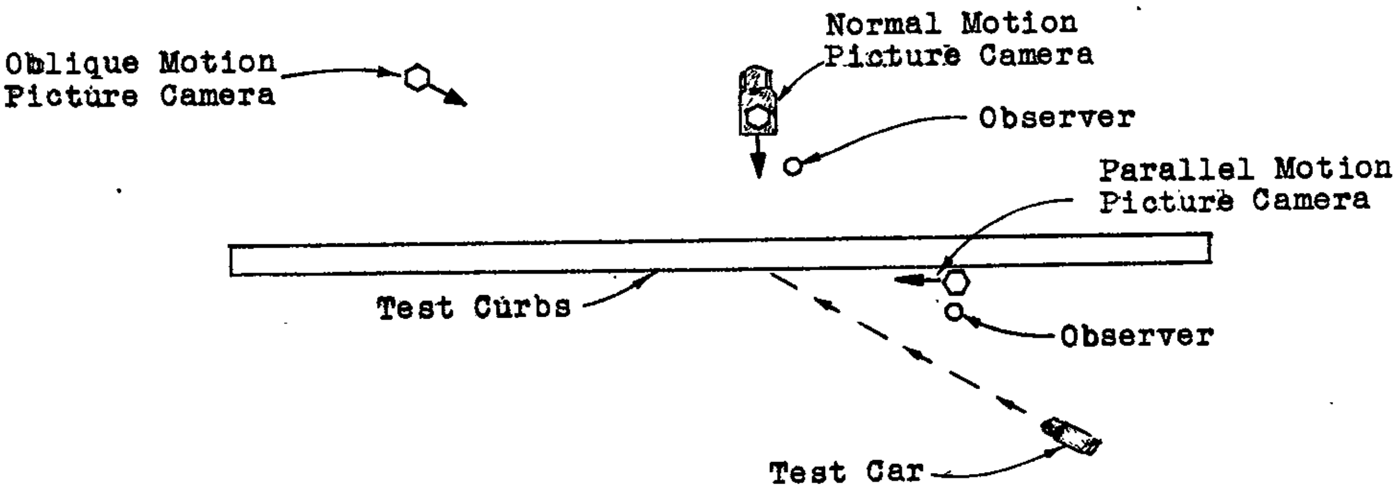
Plate II

PLAN OF TEST SITE

SHOWING POSITION OF

MOTION PICTURE CAMERAS

AND OBSERVERS



installed, and the front seat tied down securely. The engine tied to the frame to keep the clutch from disengaging when the car struck the curb. A 2" structural steel angle was welded across the frame under the driver's seat. This was to protect the undercarriage from damage whenever the car mounted the curb.

A special speedometer was installed in the car and calibrated. A 35 mm. still camera was mounted on the vehicle safety frame. Its purpose was to photograph the speedometer so as to record the contact speed of each collision.. The shutter was triggered by a solenoid, battery and a switch. The switch was attached to the rear bumper of the car and was actuated by a 4" block placed on the pavement.

The outward sides of the tires were painted with cold-water paint, the front tires red and the rear tires green. This paint was readily rubbed off onto the curb showing the tire contact and roughly the height of the climb. The only other change made to the test car was the removal of the back seat. During the test numerous "A" frames, tierods and wheels were replaced. All automotive replacement parts are listed in Table D of the appendix.

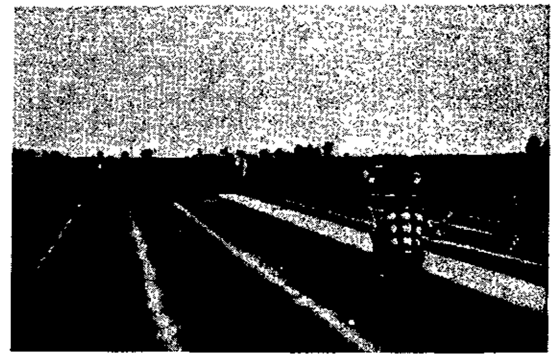
The front coil springs were changed about half way through the test, because the front end started to sag. These new springs were Ford Station wagon coil springs.

The miscellaneous equipment necessary to accomplish the test is listed in Table C of the appendix.

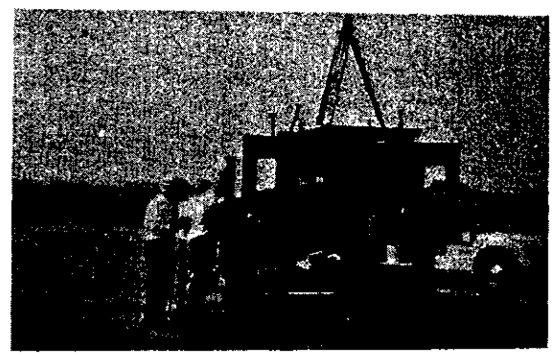
Three motion picture cameras were used to record all test collisions as is discussed under procedure below.

GENERAL TEST PROCEDURE

The alignment of test car to the curb was accomplished by the driver sighting along white tape and checked by observor as shown.



Observations were recorded on a dictating machine and all measurements were listed after each test.



Automobile mechanic checked wheel alignment by use of illustrated frame at conclusion of each test run.

PROCEDURE

Stated in its simplest form the test procedure was to drive a test car into the individual curb sections at various angles and speeds and to record the results. The data included in this report covers a total of 149 such collisions between the car and the test curbs.

The key figure during the entire program was the test driver. The driver worked under the instructions that he was to make his approach at the speed and angle required for the particular test, and that he was to control the car with a normal handhold on the steering wheel and not to force control of the vehicle until after the car had completely contacted the curb. After completion of contact with the curb he could then regain control of his vehicle.

The speed of each collision was controlled by the driver observing a calibrated speedometer. This was checked by a picture taken of the speedometer at the time of contact.

The angle of approach was defined for the driver by laying a white webbed belting 2" wide x 160' long, at the appropriate angle with the curb.

A record of each test contact was made by two technical observers and three motion picture cameras. The cameras were placed as shown on Plate II. The "parallel" camera was placed in a strategic position to observe the contact of the wheel or wheels with the curb. It was 75' from the contact point and behind the car at the time of contact and was set approximately 3' above the pavement and 1' away from the curb face. A 2" lens was used with a slow motion speed of 64 frames per second.

The purpose of the "normal" camera was to record the side view over-all action of the test car, especially concentrating on the front end. It was placed perpendicular to and 40' from the curb on the opposite side from the contact point at a height of approximately 15' above the pavement surface. This camera was equipped with 1" lens and a frame speed of 64 frames per second was used.

The third camera called the "oblique" camera was used to record the general over-all action of the car. It was placed on the opposite side of the curb from the point of contact and on direct line with the angle of approach. It was 225' from the point of contact and at a height of 5' above the pavement. A 2" lens and a speed of 24 frames per second was used in operating this camera.

Prior to each test run the motion picture cameras recorded a title as to curb, angle, speed and date of test. At this time also the trigger block for the test car speedometer camera was set in proper position on the pavement so that a photograph of the speedometer would record the speed at contact.

Upon completion of the above preliminaries the driver made his approach and, if his speed and angle were correctly adjusted, continued until contact with the curb. After completion of the test the observers inspected the curb and car and ascertained the contact made, damage to the car, type of damage caused by contact, and then immediately recorded all data, comments, and information obtained from visual observation. In addition the driver recorded his reactions and ability to control the car both during and after contact.

The mechanic immediately made a complete check of the car and appraised the damage caused by the particular test collision. The car was then taken to the alignment frame and an accurate check made of the alignment and camber measurements. The car was then immediately repaired either by replacing or repairing the damaged part.

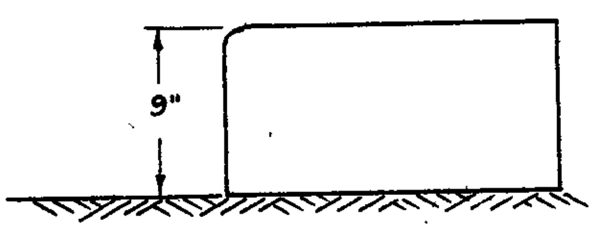
While the car was being repaired, colored slides and measurements were taken of the curb showing the tire contact on the curb. If any damage peculiar to a particular curb was noted, color slides were taken specifically of that damage, otherwise only two photographs were taken, one of the angle of contact and the other at 90° to the curb.

All test observations were immediately recorded by each technical observer and the driver on a voice recording machine. Measurements and sketches pertinent to each test were recorded in a notebook and later correlated to the transcribed observations. A complete listing of the personnel along with their duties is included as Table B in the appendix.

DISCUSSION OF TEST RESULTS

The complete statistical summary of each test run for each curb is listed in Table A of the appendix. The following discussion covers general information and the significant differences between the various curbs that were tested. It will be noted, in reviewing the charts and in the following discussion, that the various ranges of speeds covered within each angle of approach vary for the several curbs. This is due to the fact that each test series was discontinued at the point when the car mounted the curb, or it was obvious that the car would overturn on the next increasing speed, or if increasing damage to the car was of such extent that it was obvious no further comparative value would result.

Curb I



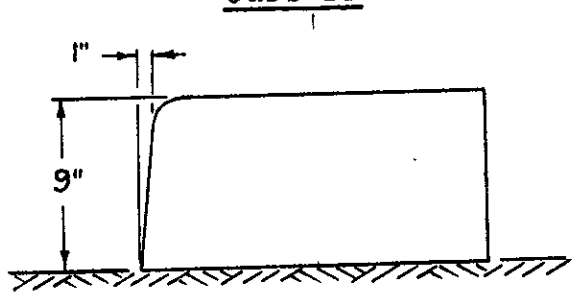
Curb I is a vertical curb. It served reasonably well as a barrier; however, it was not consistent in its effect, and it caused relatively major damage at low speeds.

The most noticeable characteristic of this curb was its contact with the rim of the wheel during practically every test. This resulted in a uniform tendency for the car to climb the curb. It also resulted in a need for rim repair or a new wheel after most of the contacts.

The driver noted that the majority of the collisions caused a sharp jolt or shock to the steering mechanism; however, control of the car was only moderately difficult.

This curb is useful not only for general observation on the effect of height but also for the effect of slope. For this reason it is especially compared with Curbs II, III and IV. It is interesting to note that the effect of the rim in causing climbing fades out as the slope is flattened until in Curb IV the climbing is entirely the result of friction of the tire.

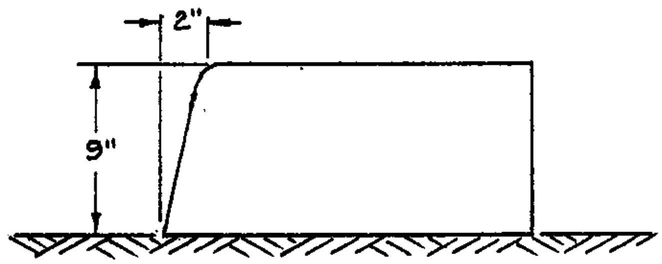
Curb II



This curb is similar to the above Curb I except that its face was sloped back 1" in the height of 9".

In general the effect of this curb was similar to Curb I. The rim damage, driver reaction and mounting characteristics were all about the same. In other words the changing of the slope by 1" had little effect.

Curb III



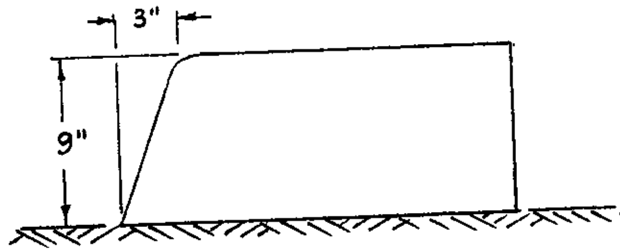
Curb III was a sloped curb similar to the above two but with a 2" batter. It is identified in the Division of Highways Planning Manual as Type F.

A change in the effect of this curb over the first two was very noticeable. While the wheel rim continued to make contact, it no longer bit into the concrete and therefore caused no climbing. In general also the driver indicated that the car shock was less and his after control easier than for either of the first two curbs.

For the 5°, 10° and 15° approaches, this curb was efficient as a barrier. However, it did cause major damage of a general nature at speeds above 20 MPH. As will be noted later, Curb V serves equally as well as a barrier, but major damage does not start until a much higher speed is reached.

The results of the study of the effect of batter is indicated by a comparison of this curb with Curbs I, II, and IV. This comparison shows that this batter of 2" in 9" is the most efficient for a height of 9".

Curb IV



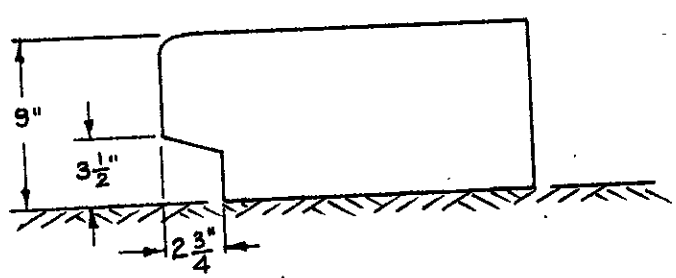
Curb IV was a continuation of the battered curb design, having a slope of 3" in 9".

Trials with this curb showed little or no contact between the curb and the wheel rim, the contact was primarily with the tire. Damage to the car was relatively minor. However, the amount of damage can not be compared to results of other curb tests since the curb was mounted at low speeds and no high speed data was collected.

The driver reported that control of the car after collision was about the same as Curb III.

Curb IV was effective as a barrier only at the low approach angle of 5°.

Curb V



Curb V is a 9" high undercut concrete curb with a vertically faced nose.

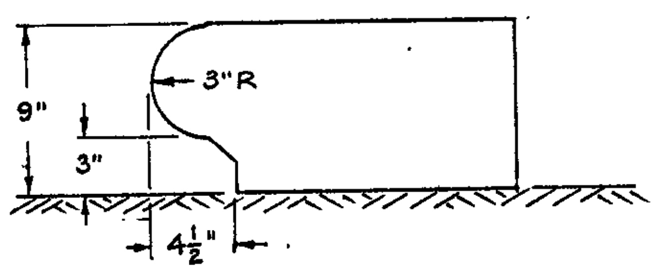
Through the 5°, 10° and 15° angles of approach when compared as barrier to all other test curbs this curb had the best overall performance. At these three angles of approach there was the same tendency as was noted for Curb I for the rim to bite into the top edge of the concrete. Due to the fact, however, that the tire was at the same time trapped in the undercut of the curb, there was little tendency to climb at least not as much as on Curb I. The vehicle did mount once at 25 MPH at the 15° approach. This was attributable to the fact that the rim caught on a hard piece of aggregate. A repeat at this speed and then at 40 MPH resulted in very little climbing.

At the 20° and 30° angles of approach the car mounted this curb rather easily. This was due to the wheel meeting the curb at such an angle that the undercut no longer had any effect. It is interesting to note that at 5 MPH and 20° angle of approach, that the car was going slow enough so that the contact wheel had time enough to deflect. It was then trapped so firmly under the curb that the motor was stopped before the driver had an opportunity to disengage the clutch. This seems to indicate that at this angle, if a deflector could be provided that would work at the higher speeds, this undercut type of curb would be efficient through a greater range than is now possible. For this reason, and also to eliminate the possible catching of the rim in concrete, it is suggested that a composite curb as indicated on Plate III would be a worthwhile subject for a further test program.

The outstanding feature of this Curb V is the external braking effect which it has on a colliding vehicle. This action appears to be the result of the tire of the front contact wheel entering the undercut of the curb and scraping up against the lip of the undercut as the wheel revolves. This entrance of the tire under the curb may not be caused by the tire bulging under the curb because of elastic deformation, instead it appears that the normal shape of the tire fits under the curb after the original contact has flattened the tire wall. It appears from the evidence that an effective undercut should not be much less than the 3.5" used in this test and also it probably should not be a great deal higher. Some of the retarding action of this curb can also be attributed to the relatively high friction generated by the concrete surface.

The braking action of this curb enabled the driver to keep his car well under control and in close to the curb after collision.

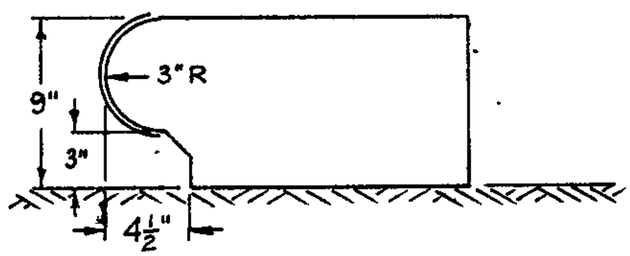
Curb VI



Curb VI is a 9 inch high concrete curb with a 3 inch radius half circle face and a 3 inch high undercut. As constructed Curb VI with its rounded concrete face tended to be one of the poorer curbs insofar as barrier effect is concerned. The test car mounted this curb readily at all the angles from 10° on up. This was due to a combination of the rim and tire holding and climbing onto the concrete surface. There was little deflection of the car due to the fact that the tire and rim tended to climb or hang to the curb. Wheel damage and "A" frame damage occurred in a moderate amount.

As far as a barrier curb is concerned Curb VI with a concrete face cannot be considered as satisfactory because it is too easily mounted.

Curb VI-M



Curb VI-M is the same as the curb above except that the rounded nose was sheathed with sheet metal.

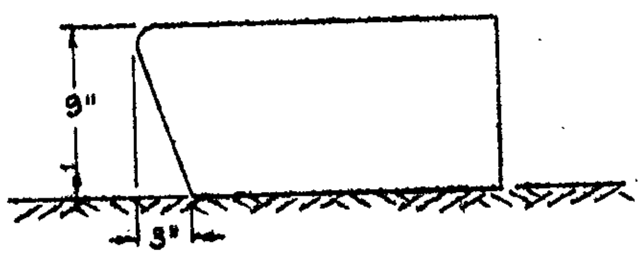
The addition of the metal facing to this curb form completely changed its effect. Whereas it was easily mounted as a concrete curb, after it had been faced with metal, it was not mounted nor even partially climbed at any angle or speed.

This curb was more efficient as a barrier than any other nine inch curb, even more so than Curb V. It has one major drawback, this is the after collision effect on the action of the car.

At high speeds the car was deflected sharply away from the curb at a speed and angle very nearly equal to the approach. This resulted in the car ricochetting from the curb out of control to a position 10' to 15' out from the curb. Tests were stopped at 40 MPH because the wheels on the side opposite from the collision were lifting from the pavement as much as two feet. It appeared that much higher speeds would result in overturn of the vehicle.

The major damage to the car resulting from colliding with this curb was in most cases confined to the "A" frame; however, there was also considerable wheel bending. In this case the tire rim was not folded back as it was for most of the concrete curbs, instead it was bent down and rolled over the tire bead.

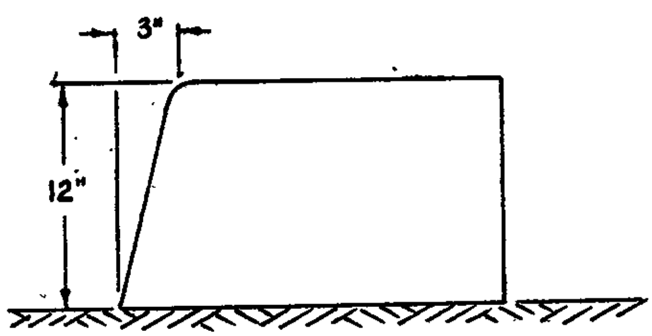
Curb VII



Curb VII is a 9 inch high curb with a 3 inch reversed batter. The edge is a one-half inch radius trowelled edge.

The purpose of this curb was to study the effect of a reverse batter. This was the only curb designed as a barrier curb that was mounted in the 5° range. It was mounted again at 10° at 20 miles per hour, and at 15° at 5 miles per hour. This curb was particularly damaging to the tire rims. The rim in every case bit into the curb easily causing the car to be thrown around quite violently. Severe shock in the majority of the contacts was felt through the steering gear. In one case the steering gear was broken loose from the mounting. The "A" frame damage and wheel damage was high throughout this curb's testing. In general this was not an efficient curb.

Curb VIII

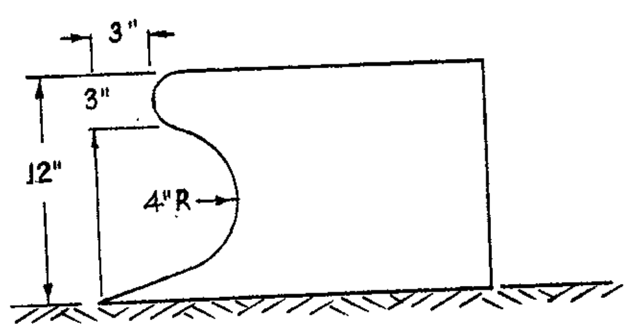


Curb VIII is a 12 inch high curb with a 3 inch batter and a one inch radius trowelled edge. Curb VIII, being 12 inches high, tended to give better results than any other curb as far as rim and wheel damage were concerned. This was due to the fact that the curb was high enough so that the rim did not have the opportunity to catch on the top edge. Partial climbing of the curb was evident in all cases from 10° at 10 miles per hour on through 20°. This partial climbing amounted to only a few inches. This low height of climb was probably due to the fact that the rear end of the car tended to snap in and strike the curb, thus jarring the front wheel down from its climb.

The driver reports contacts as being smooth with only moderate shock to the driver and the car on contact with the curb. Control was maintained easily in all of the collisions, and the driver was able to keep the car within the normal line of travel without much difficulty. Both this and the following 12 inch curb made contact with the body of the car - the fenders were scratched, and in most cases the hub cap was badly bent or flew off. The bumper ticked the top of the curb on all of the runs.

For use as a barrier curb, Curb VIII with a 3 inch batter 12 inches high is good. Its contact with the car body is its major disadvantage. This curb is similar to Curb III, the only difference being the increased height.

<u>Curb IX</u>



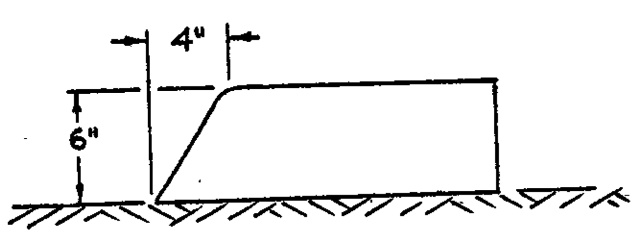
Curb IX is a 12 inch high curb with a modified ogee shape. The 5° and 10° approaches indicated only minor damage throughout their testing. At the higher speeds at the 10° approach angle of 30, 40 and 50 MPH there was major damage. In this case "A" frame bending and wheel damage. The damage during the 15° and 20° tests spread well over the range.

The main factor concerning Curb IX was that the front end tended to "feel light" to the driver, probably due to the lifting effect of the ramp-like toe of this curb. The concrete top lip tends to cause the rim to bite in and curl. Throughout the testing on this curb it was noted that there was body, hub cap and bumper contact on every run. The rim chewed a considerable amount of concrete off the top edge. It was also noticed that this relatively thin edge at the top of the curb tended to chip out when struck a hard blow by the car bumper or wheel.

In general the action was good with the exceptions as noted. The driver reported contact causing sharp deflection from curb due to the ramp, and also that the contact and control was moderately difficult.

Between the two 12" high curbs there is little to choose, except that the damage to the curb itself was less for Curb VIII than for this Curb IX.

Curb X



Curb X is the Division of Highways standard Type B with a smooth face. This curb is 6 inches high with a 4 inch batter.

Curb X, or the semi-barrier curb as it is classified in Division of Highways Standards, was contacted only one time during this test. The 5° approach speed was 5 miles per hour. The front control wheel drove easily up on the curb causing no damage to the car, control was easy.

It is considered that any barrier effect this curb may have would be entirely psychological. From a comparison of the effect of the slope of this curb with that of Curb IV (3" in 9"), it appears that this slope (4" in 6") is about as steep as a curb should be built so as to provide an easily mounted ramp.

SUMMARY AND CONCLUSIONS

It should be emphasized that the basic data collected during this study covers only an investigation of the behavior of eleven specific designs of curbing. This test program was not formulated with the intent of developing a new curb design; therefore the conclusions drawn are limited to the eleven types. As noted below, it does appear that a composite of the two curbs giving the best results in this study would result in an excellent curb. However, this is a presumption that should be tested.

Nine inch high test curbs V (vertical with 3.5" undercut), VI-M (metal faced 6 inch diameter semicircular nose), and the two 12 inch high curbs VIII and IX proved to be the most efficient as physical barriers; however, each has its limitations and also its good points.

At angles of collision of 5°, 10° and 15°, Curb V proved to be overall the most effective type. This curb not only prevented climbing at these angles of approach but also acted as an external brake on the forward motion of the car. This latter action also caused the post collision travel of the car to be close in and parallel to the curb. Mounting of this curb was relatively easy at the 20° and higher angles of approach.

Curb VI-M, the metal faced round nosed undercut curb, was more efficient than Curb V when considered only as a barrier. It has two drawbacks. The first is that there is little or no retardent to the motion of the colliding vehicle, and second there is a "tripping" action of the vehicle at the higher speeds. The lack of retarding action of this curb resulted in the test car ricochetting off the curb at an angle and speed very nearly equal to the approach angle and speed of the test. The vehicle did not mount nor even partially climb Curb VI-M at any time during the test; however, any further increases probably would result in overturn of the car.

The two twelve inch high test curbs also proved to be effective barriers; however, neither had the braking effect of Curb V nor was any more effective as a barrier than VI-M. There was an indication from the modified ogee shaped Curb IX that a rail located at hub center height may be most effective as a barrier. However, such a rail probably should be armored so as to withstand the collisions and resist the biting action of the rim. The major drawback of the 12" height is that it will contact the body of a modern car on each collision, thus causing an additional type of damage to the car.

The effect of height was reasonably demonstrated during this test. It is, of course, obvious that any obstruction placed below the center of mass of a vehicle will, upon collision, cause an overturning moment. The force of gravity and friction of tires resists this moment. The tests seemed to indicate that for the modern car the center of gravity is in such a position and the construction of the car is such that within the usual operating speed ranges it is difficult to cause overturn on collision with a nine or ten inch high curb. There is more of a tendency to overturn when the front colliding wheel folds under on contact. The action of the 12" high ogee Curb IX compared with Curb VI-M indicates that a contact point at the hub cap would be the most effective to prevent the wheel from folding under the car and would act as a barrier for the majority of collisions.

The effect of changing the slope of the face of a nine inch high solid curb was clearly indicated by Curbs I, II, III, IV and VII.

Curbs VIII (12" high) and X (6" high) were also sloped types and aided in the observations concerning slope; however, the heights of these last two curbs so dominated the action that it is difficult to draw specific conclusions as to their slope effect. It does appear that the slope of Curb X (4" in 6") is as steep as will allow a vehicle to mount with no damage.

The first four of the nine inch high sloped curbs were sloped from their base at various angles from vertical to three inches back from vertical. Curb VII was sloped forward 3" from the vertical. Of this group Curb III (sloped back 2" in 9") proved to be the most effective. This is the Division of Highways standard Type F. Its performance very nearly matched the undercut vertical Curb V except that partial climb occurred at lower speeds and angles of approach and there was little braking action evident during contact. The forward sloped curb proved to be the least efficient as a barrier.

It may be that a curb constructed as shown on Plate III as a composite of the upper half of Curb VI-M and the lower half of Curb V, would be more efficient as a barrier than any of the curbs included in this test. However, no tests have been made on such a design.

The results of this investigation indicate that further tests should be carried out to determine the most effective design for a barrier curb. Such a program could be limited to the undercut type of curb and could concentrate on dimensional and material changes such as indicated on Plate III. Instead of the 100 feet of test section used in this study, a 25 foot section would be sufficient.

The expense of continuing this study to definitely settle the remaining unanswered questions would not be very great.

Acknowledgments

The excellent objectiveness of the field data is directly attributable to the leadership of Mr. Peterson during the conduct of this test. An equal amount of credit must go to Mr. E. W. Kessinger, the professional test driver who drove the test car throughout the entire investigation.

Mr. Stewart Mitchell, Bridge Engineer in charge of Design, contributed a wealth of background and experience throughout the test and was represented during the investigation by an observer, Mr. R. W. Douglas.

Mr. Merritt Nickerson, Division of Highways photographer, assigned photographers from his staff from time to time as needed.

Mr. Earl Sorenson, Equipment Engineer of the Division of Highways, assigned Mr. A. R. Hatton, Automobile Mechanic, who contributed his mechanical skill and knowledge throughout the program. The execution of the entire field test went smoothly and with little waste of man power due largely to the expertness and rapidity with which Mr. Hatton kept the test car in operation throughout the complete program.

Various men were assigned from the Materials and Research Laboratory to perform certain specific tasks. The results of the investigation are a tribute to the enthusiasm of this complete crew.

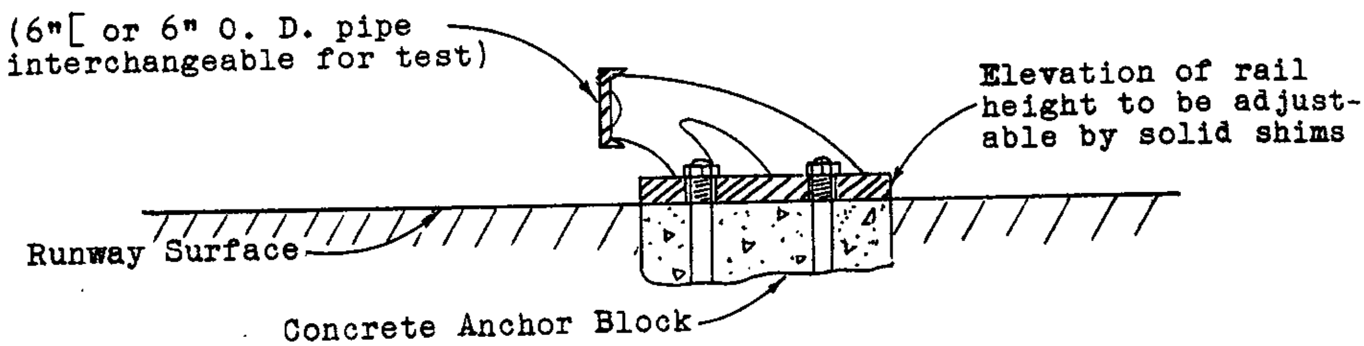
Mr. E. T. Telford, Traffic Engineer, and Mr. J. C. Young, Design Engineer for the Division of Highways, each reviewed the work in the field and made valuable suggestions both before and during the test program.

A special note of appreciation is due to Mr. Charles W. Deterding, to the Sacramento County Board of Supervisors and to the Federal Civil Aeronautics Commission who made it possible to use one of the runways on the Franklin Airport.

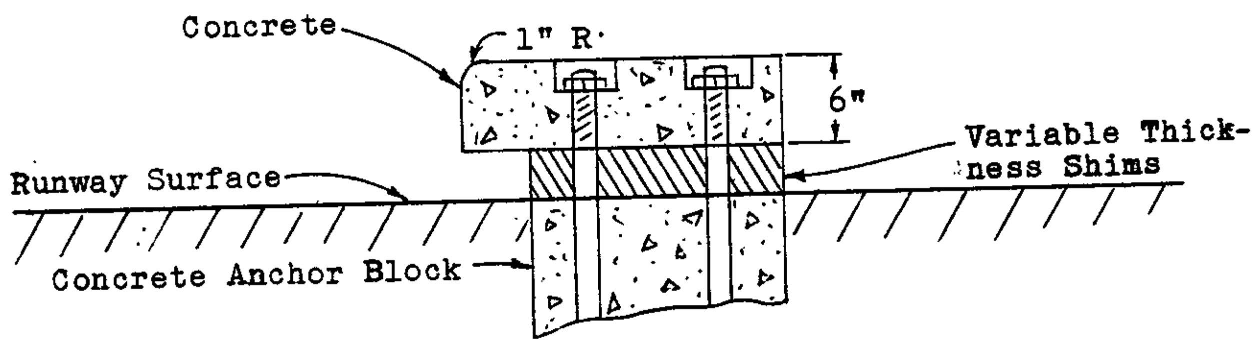
Plate III

PROPOSED NEW TEST CURBS

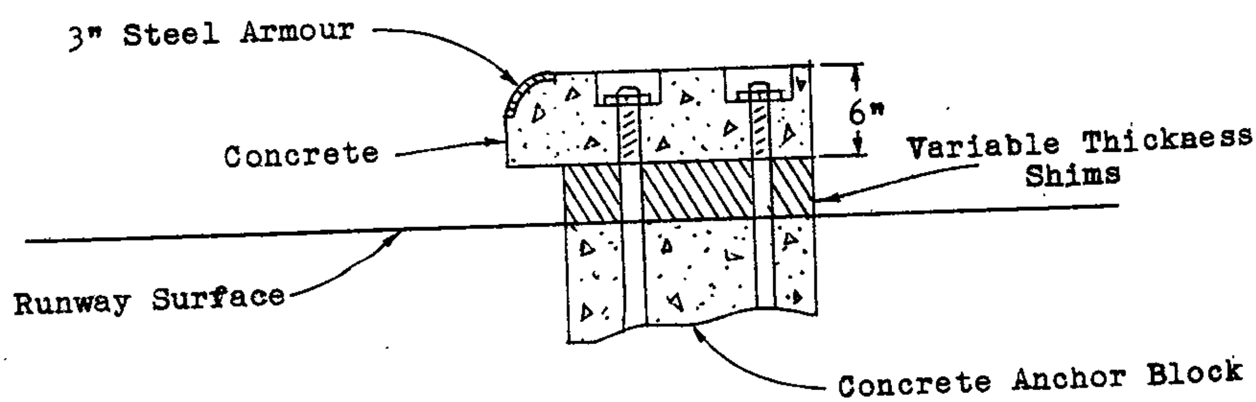
Steel Faced Curbs



Concrete Faced Curbs



Composite Faced Curb



APPENDIX

Table A	Physical Test Data
Table B	Personnel and Duties
Table C	Equipment and Use
Table D	Replacement Parts

TABLE A

Curb I

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	DAMAGE TO CAR			WHEEL CONTACT ON CURB (LF)				CURB CONTACT ON WHEEL (%)				Ft.Wh. Partial Climb (Inch.)
				Minor	Medium	Major	Front		Rear		Front		Rear		
							Tire	Rim	Tire	Rim	Tire	Rim	Tire	Rim	
5	5						6.1								0
	10						7.4								0
	15						10.4				100	50			0
	20			x			6.5				100	60			0
	25				x		8.9	5.0			100	90	80		0
	30				x		8.4	4.5			100	80	90		0
10	5						5.2	1+							0
	10						7.9	1+							0
	15	x			x		6.2	2.0			100	50			2
	20	x			x		6.9	3.8			100	50			5
	25	x			x		7.5	5.7			100	85	80		2
	30	x				x	8.8	7.0			100	100	80	40	1
15	5						7.9	1.7			100	20			0
	10				x		7.9	1.7			100	50			0
	15	x				x	7.1	3.0			100	50			2
	20		F & R			x	3.3	3.3	1.8		60	50	30		9
20	5	x		x			7.9	1.5			100	50			7
	10	x		x			5.0	2.0			75	40			4
	15					x	7.5				75	40			0
30	5		F		x		0.5				40	30			9
	10		F & R		x		0.7		0.7		25	10	25		9

Curb II

Angle (Deg)	Speed (MPH)	Partial Climb	Damage to Car: Mount	Damage to Car: Minor	Damage to Car: Medium	Damage to Car: Major	Wheel Contact on Curb (LF): Front Tire	Wheel Contact on Curb (LF): Front Rim	Wheel Contact on Curb (LF): Rear Tire	Wheel Contact on Curb (LF): Rear Rim	Curb Contact on Wheel (%): Front Tire	Curb Contact on Wheel (%): Front Rim	Curb Contact on Wheel (%): Rear Tire	Curb Contact on Wheel (%): Rear Rim	Ft. Wh. Partial Climb (Inch.)
5	5						5.5								0
	10						9.6								0
	15			x			11.6				100	30			0
	20			x			6.5	3.0			100	30			0
10	5	x					4.7	1+			50	15			1/2
	10						7.2	1.0			100	25			0
	15	x		x			6.0	3.0			100	75			1
	20	x			x		7.2	5.0			100	100			2
	25	x				x	6.0	3.0	5.0		100	100	80	75	2
15	5						8.0				100	8			0
	10						8.2	2.0			100	25			0
	15	x			x		6.4	4.3			95	50			2
	20		F & R		x		3.7	2.0	1.0		50	40	25		9
20	5			x			7.7	2.0			100	25			0
	10	x		x			9.0	1.0			100	25			1/2
	15		F & R		x		2.0	0.5	1.7	0.5	50	25	10	4	9

Curb III

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	DAMAGE TO CAR: Minor	Medium	Major	WHEEL CONTACT ON CURB (LF): Front Tire	Front Rim	Rear Tire	Rear Rim	CURB CONTACT ON WHEEL (%): Front Tire	Front Rim	Rear Tire	Rear Rim	Ft. Wh. Partial Climb (Inch.)
5	5						7.3				100				0
	10						8.6				100				0
	15			x			6.8				100				0
	20			x			7.3				100	50			0
	25			x			10.4				100	60	80		0
	30				x		10.4				100	60	95		0
	45				x		10.0				100	80	100	60	0
10	5			x			6.5	0.5			95	15			0
	10			x			8.8	1.2			100	30			0
	15			x			6.0	1+			85	50			0
	20	x			x		5.9	1+			95	80			1
	25	x				x	11.2	6.0			100	75	80		1/2
	30	x				x	9.4	3.0			100	75	80	25	1
	40	x				x	7.0	3.0	4.0		100	90	100	50	1
15	5			x			4.8	0.5			50	15			0
	10					x	14.1	1+			100	75			0
	15			x			7.8	1+			60	40			0
	20	x				x	6.6	3.0			90	60			1
	25	x				x	6.6	1+			60	50	60	40	0
	30	x				x	1.8	1+	4.2		50	40	60	50	1
	40	x				x	5.0	1+	5.0		100	60	90	80	1
20	5		F	x			1.8				25	15			9
	10		F	x			2.2	1.0			30	15			9

Curb IV

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	Damage to Car: Minor	Damage to Car: Medium	Damage to Car: Major	Wheel Contact on Curb (LF) Front: Tire	Wheel Contact on Curb (LF) Front: Rim	Wheel Contact on Curb (LF) Rear: Tire	Wheel Contact on Curb (LF) Rear: Rim	Curb Contact on Wheel (%) Front: Tire	Curb Contact on Wheel (%) Front: Rim	Curb Contact on Wheel (%) Rear: Tire	Curb Contact on Wheel (%) Rear: Rim	Ft. Wh. Partial Climb (Inch.)
5	5						7.2				100				0
	10	x					9.0				100				1
	15						16.6				100				0
	20	x		x			14.0				100	50	1		1
	25	x		x			11.2				100	50	80		1
	30	x		x			11.6				100	75	100		2
	40						13.5				100	75	100		0
10	5	x					5.8				50				1
	10	x		x			7.7	1.2			100	30			5
	10R	x		x			7.0	0.5			100	15			5
	15		F & R				5.6	1+			50	9	33		9
	15R	x					9.5	0.7			100	15			4
15	5		F				2.2				50				9
	5R		F				3.0				60				9
	10	x		x			5.6	1.7			90	35			4
	10R	x		x			5.5	1.7			90	35			5
	15	x			x		5.5	2.7			90	60			3
	25		F & R				4.0	2.0			60	20	40	1	9
20	5		F				1.6				20		30		9
	10		F				1.8		5.0		20		100		9

Curb V

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	DAMAGE TO CAR			WHEEL CONTACT ON CURB (LF)				CURB CONTACT ON WHEEL (%)				Ft.Wh. Partial Climb (Inch.)
				Minor	Medium	Major	Front Tire	Front Rim	Rear Tire	Rear Rim	Front Tire	Front Rim	Rear Tire	Rear Rim	
5	5						6.8				100				0
	10						7.9	0.7			100	15			0
	15						14.4	1.2			100	30			0
	15R						11.7				100				0
	20			x			13.3	2+			100	50			0
	25			x			9.7	2+			100	50	50		0
	30			x			8.4	2+			100	60	100		0
	45					x	9.8				100	100	100	60	0
10	5			x			6.0	0.9			95	20			0
	10			x			7.4	1.6			10	50			0
	20				x		6.4	3.5			100	80	4		0
	25				x		8.2	5.0			100	60	50		0
	30	x				x	8.0	5.0			60	60	80	60	1/2
	40	x				x	11.1	5.0			90	80	90	80	1
15	5			x			9.4	1.7			100	25			0
	10			x			16.0	2.0			100	30			0
	10R	x		x			8.7	2.0			100	50			1/2
	15	x			x		13.6	2.0+			100	70			1
	20	x				x	7.0	4.0+			100	80			2
	25		F & R			x	3.4	0.5			60	30	20	6	9
	25R	x				x	10.3	2.0+			90	75	60	30	1
	40	x				x	8.0	4.0+			100	80	90	75	1
20	5			x			9.5	3.0+			100	1			0
	10		F		x		1.7	1.4			35	15			9
	10R		F			x	17.6	1.5			100	60			9
30	5		F & R		x		0.7	0.2	3.0		5	2	30		9

Curb VI

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	DAMAGE TO CAR			WHEEL CONTACT ON CURB (LF)				CURB CONTACT ON WHEEL (%)				Ft.Wh. Partial Climb (Inch.)
							Front		Rear		Front		Rear		
				Minor	Medium	Major	Tire	Rim	Tire	Rim	Tire	Rim	Tire	Rim	
5	5						7.6				100				0
	10			x			9.1	0.9							0
	15			x			14.4	2.0+			100	70			0
	20	x		x			6.6	2.0±			100	50			2
	25	x		x			8.4	3.0±			100	90			1/2
	30	x			x		9.0	4.0±	6.6		100	100	90	30	2
10	5						6.0	0.7			100	15			0
	10	x		x			7.8	2.1			100	50			1
	15	x		x			6.9	3.0			100	50			3
	20		F		x		3.5	2.0+	15.5		80	25	100	25	9
	25		F & R		x		3.0	0.5±	3.0	0.5±	60	15	15	15	9
15	5	x		x			10.1	1.6			100	60			2
	10	x			x		12.2	2.7			100	40			6
	15		F		x		3.0	1.4			50	25	100	10	9
20	5		F	x			1.8	0.8			25	10	100	10	9
	10		F	x			1.8	0.8			25	15	100	15	9

Curb VI-M

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	DAMAGE TO CAR			WHEEL CONTACT ON CURB (LF)				CURB CONTACT ON WHEEL (%)				Ft.Wh. Partial Climb (Inch.)
							Front		Rear		Front		Rear		
				Minor	Medium	Major	Tire	Rim	Tire	Rim	Tire	Rim	Tire	Rim	
5	45					x	10.6				100	50	100	50	0
10	15						11.4				100				0
	20			x			12.0	2.0+			100	20			0
	30					x	10.9	3.0±			100	50			0
	40					x	10.0	2.0±			100	100	100	50	0
15	30					x	12.0	2.0±	10+		100	50	80		0
	40					x	9.0	2.0±	4±	2±	100	50	90	40	1*
20	20					x	11.5	2.0±	4±		100	30	30		1/2*
	30					x	10.0	2.0±	6±	2±	60	40	80	40	2*

*Wheel raise - due to immediate collapse of wheel (car did not climb).

Curb VII

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	DAMAGE TO CAR			WHEEL CONTACT ON CURB (LF)				CURB CONTACT ON WHEEL (%)				Ft.Wh. Partia Climb (Inch.
							Front		Rear		Front		Rear		
				Minor	Medium	Major	Tire	Rim	Tire	Rim	Tire	Rim	Tire	Rim	
5	5			x			8.8	1.0			100	50			0
	10			x			9.7	2.7			100	50			0
	30		F			x	7.2	4.0			100	60	90	25	9
10	5			x			6.8	1.5			100	60			0
	10			x			9.4	3.5			100	90			0
	20		F			x	7.5	3.0			75	50			9
15	5		F		x		1.7	0.7			30	5			9
	10		F		x		2.2	1.2			50	15			9

Curb VIII

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	DAMAGE TO CAR			WHEEL CONTACT ON CURB (LF)				CURB CONTACT ON WHEEL (%)				Ft.Wh. Partial Climb (Inch.)
							Front		Rear		Front		Rear		
				Minor	Medium	Major	Tire	Rim	Tire	Rim	Tire	Rim	Tire	Rim	
5	5			x			7.5				100				0
	10			x			11.0				100				0
	15				x		8.3	1+			100	25			0
	20			x			7.8	1±			100	30			0
	25				x		10.3	1±			100	50			0
	30			x			10.6	1±	1±		100	50	100		0
10	5						8.2				100				0
	10						7.4	1.0			100	15			0
	40				x		8.3	1±	2±	1±	90	80	100	75	0
15	5						5.9				90				0
	10	x					8.8	1.0			100	25			1
	15	x		x			5.7	1+			100	50			2
	20	x				x	6.1	1±			100	60			2
	30	x				x	6.0	1±	4.0	1±	80	60	75	50	5
20	30	x				x	6.6	1±	3.0	1±	90	60	60	50	5

Curb IX

Angle (Deg)	Speed (MPH)	Partial Climb	Mount	DAMAGE TO CAR: Minor	Medium	Major	WHEEL CONTACT ON CURB (LF): Front Tire	Front Rim	Rear Tire	Rear Rim	CURB CONTACT ON WHEEL (%): Front Tire	Front Rim	Rear Tire	Rear Rim	Ft.Wh. Partial Climb (Inch.)
5	5			x			7.8				100				0
	10			x			12.5	1.2			100	25			0
	15			x			5.6	1±			100	50			0
	20			x			6.6	1±			100	50			0
	25			x			6.3	1±			100	50			0
	30			x			10.6	2±			100	75			0
10	5			x			5.3				90				0
	10			x			8.3	1+			100	25			0
	15			x			5.8	4.0			100	75			0
	15R			x			9.1	1.9			100	50	5		0
	20			x			8.1	3.5			100	50			0
	25				x		6.1	2.7			95	60			0
	30					x	7.5	6.0			100	90	5		0
	40					x	9.8	1+	3+	1+	60	50	95	60	0
	50					x	14.6	2±	4±	2±	80	75	100	90	0
15	5			x			9.2	2±			100	50			0
	10	x		x			9.6	3.0			100	60			1/2
	15	x			x		6.6	4.5			90	80			1
	20	x				x	9.6	5.0			60	50			2
	30	x				x	10.9	6+	2±		50	30	30		1
20	5			x			6.6	1.3			80	30			0
	30	x				x	10.5	3±	2±		50	40	30		2

TABLE B
PERSONNEL AND DUTIES

2 observers	Observed action of car upon contact with curb, recorded notes and co-ordinated test procedure and routine.
1 driver	Drove test car as directed and recorded action and controlability of car.
3 camera men	Operated 16 millimeter black and white motion picture cameras, took color slides of color contact prints left by painted tires, damage to car, and other items of statistical interest.
2 routine assistants	Title cameras before each run, cleaned curb, stood by with fire extinguishers during test runs, laid out approach angle and generally assisted in running the tests. Assisted the mechanic in repairs.
1 mechanic	Appraised damage to car after each run, made alignment and camber adjustments and repaired any damage to car.

TABLE C
EQUIPMENT AND USE

1 test car	1949 Ford Sedan, Model H8A, Body Type 73A, wheelbase 114 inches, tire size 6.00x16, total weight 3224 lbs. used for all test collisions.
1 mechanics wagon	This vehicle was used to carry all the operating equipment, served as a mobile office for recording the data and as a camera mount for one of the motion picture cameras.
1 1/2-ton pick-up	This vehicle served as a garage for the mechanic. All of the necessary tools, parts and maintenance equipment was stored in this vehicle during the test.
1 Audiograph Recorder	All notes and comments on the testing were recorded immediately on the Audiograph.
1 tennis court marker	At 5, 10 and 15 feet from the face of the curb, lines were drawn parallel to the curb using lime in the marker.
1 two-inch wide cotton web tape	This served as a marker for the angle of approach. The length of this tape was 160'.

Among the miscellaneous items necessary were fire extinguishers, tape, cloth tape, and various other tools and supplies.

TABLE D
REPLACEMENT PARTS

The following replacement parts were used during the test program:

12 "A" frames

10 wheels

1 king pin kit

1 set of tie rods

1 set Ford Station Wagon front coil springs

2 tires

Each day the mechanic stocked the following items:

6 to 8 complete lower "A" frame assemblies

10 to 12 wheels and tires assembled

2 tie rod assemblies

2 king pin kits