Appraisal of Guardrail Installations by Car Impact and Laboratory Tests

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This paper describes the guardrail tests conducted at the General Motors Proving Ground since the previous paper, "Full-Scale Appraisals of Guardrail Installations by Car Impact Tests," was presented in January 1959 (HRB Proc., 38:353). Approximately 105 tests have been conducted since that time, including tests of improved end sections, chain link fence and cable type barriers, rail mounting and spacing from post, post strength, beam strength, special posts and mounting on superelevated curves.

• THE General Motors Proving Ground at Milford, Mich., has approximately 65 mi of road along which 14 miles of guardrail is used. Most of this rail was of the convex steel-beam type mounted on partially treated wooden posts. Preliminary tests, several years ago, showed that this type of installation was providing practically no protection for cars striking at speeds as low as 35 mph. A paper describing guardrail tests run during 1958 was presented in 1959. (*1*) This paper describes additional guardrail tests run since that time. These tests were conducted to provide information on how to build the best possible guardrail for the proving ground's use.

The technique of full-scale vehicle-to-guardrail impact tests involves driving a car by remote control into a guardrail at a definite angle and speed. Initial work was done at 35 mph because testing at higher speeds is useless until an installation has been proved satisfactory at the lower speeds. Tests were conducted at speeds varying from 30 to 68 mph and at angles from 0 to 33 deg.

Data taken on these tests include standard speed and high-speed motion pictures from various angles, and oscillographic recordings of impact speed and longitudinal and lateral decelerations. A complete still-picture record which includes damage done to the vehicle and guardrail is also obtained before and after impact. An analysis of the most significant findings from these tests will be briefly reviewed.

POSTS

The design of a satisfactory guardrail installation begins from the ground up. The guardrail ribbon supporting posts or structure should have the following parameters:

1. They should yield under impact to prevent the vehicle from being turned too abruptly, thereby generating intolerably high lateral vehicle accelerations.

2. They should not bend at, or above ground level and drag the guardrail ribbon down when they fail under impact.

3. The post should provide longitudinal strength for the installation to help prevent pocketing of the ribbon.

Although a complete investigation of all the various kinds of guardrail supports was not attempted, it became apparent that certain design parameters were more desirable than others. A static pull test was devised to evaluate the ground bearing strength of several sizes and shapes of posts. The load was applied parallel to, and 18 in. above, the ground on the traffic face of the post. The deflection of the post under these loads was measured 18 in. above and parallel to the ground line. When an excavation was necessary for the installation of a post, the replaced soil was tamped thoroughly. All posts had been installed in dry glacial till soil for at least two months before testing.

Figure 1 shows that the 10-in. x 10-in. reinforced concrete post with a 14-in. diameter base was very solidly in the ground as indicated by the steep load vs deflection curve. This undesirable rigidness was verified by an actual test on a guardrail installation using these posts. A 6-in. diameter spirally-wound corrugated steel pipe, concrete filled, mounted in a 14-in. diameter concrete base gave

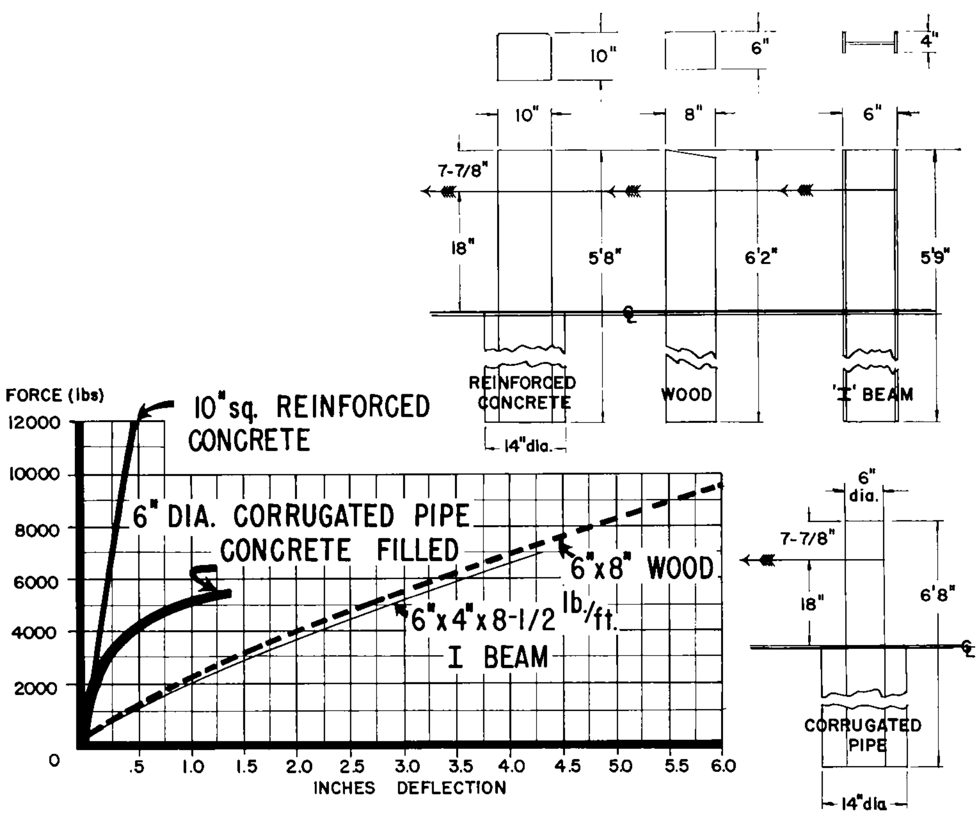


Figure 1. Post soil bearing strength by static pull test; post mounted in dry glacial till for at least 2 months, load applied 18 in. above ground surface.

fair results. However, the post was weak and the base's soil bearing was too strong. The 4-in. x 6-in. x 8½-lb per ft steel I-beam post performed quite satisfactorily in the soil until the post rotated and bent just below the ground line. The 6-in. x 8-in. post, 6 ft 2 in. long, either new wood or precast concrete, has given the most satisfactory soil bearing results to date. This size post produced the long gentle load versus deflection soil bearing curve (Fig. 1).

The proving ground is located in an area where the ground becomes frozen during several months of the winter. With this in mind, a laboratory test was devised to evaluate the breaking strength of the posts under these conditions (Fig. 2). The load

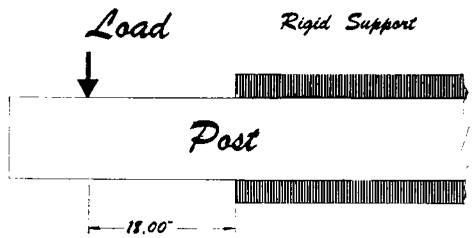


Figure 2. Post breaking fixture.

was applied by a testing machine 18 in. above and parallel to a simulated frozen ground condition. This load was applied to both the traffic face and the side of the post. The 6-in. x 8-in. wood posts gave good to poor results depending upon their age and type of preservation (Fig. 3). The

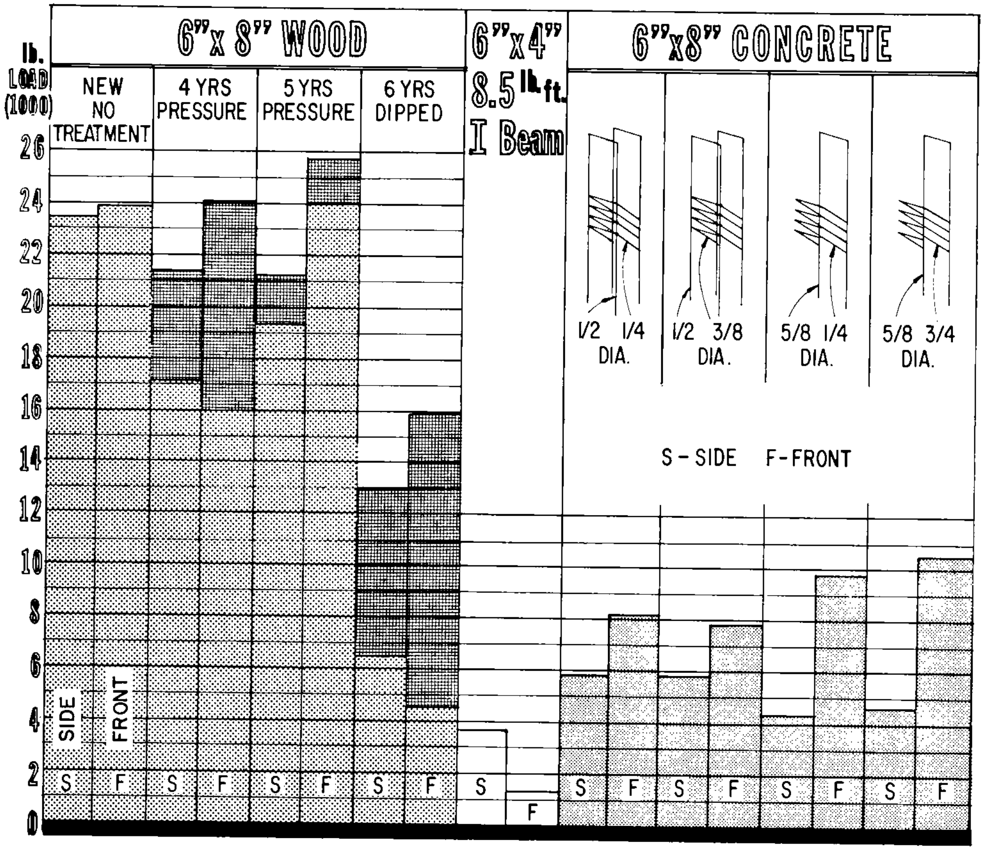


Figure 3. Post breaking strength.

open box areas at the tops of the columns indicate the variation of strength among the posts tested. The 6-in. x 4-in. x $8\frac{1}{2}$-lb per ft I-beam post indicated poor strength during this test. Finding that a 6-in. x 8-in. x 6-ft 2-in. post gives a desirable load vs deflection soil bearing curve, it was attempted to construct a concrete post which would be more durable than the wood post. Figure 3 shows that the strength of the wood post has not been duplicated although many variations of reinforcing rod and stirrup rod location have been tried. Figure 4 shows some of the construction details of this type of post.

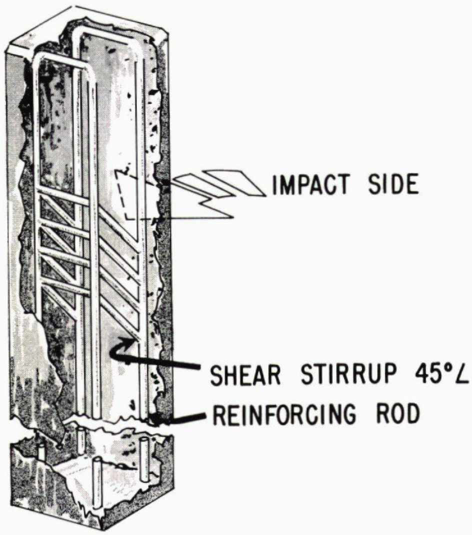


Figure 4. Construction of 6- by 8-in. concrete post.

MOUNTING GUARDRAIL RIBBON

A guardrail installation is improved by mounting the ribbon a minimum of 4 in. away from the post. This helps to keep the vehicle wheels from snagging the posts, thereby generating high decelerations. The vehicle should slide smoothly along the rail. Figure 5 shows the typical impact damage of a

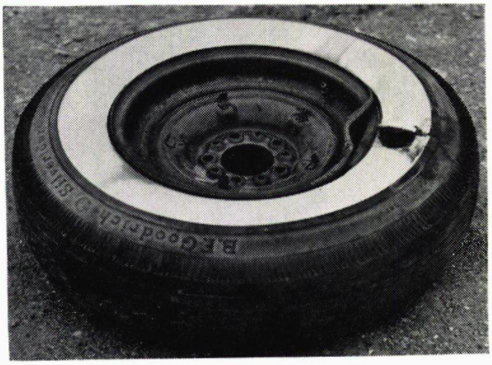


Figure 5. Tire and wheel damage from post contact.

wheel that has snagged a post. This vehicle was traveling at 35 mph contacting the guardrail at a 20-deg included angle.

California has tested guardrail with 8-in. blocking out of the ribbon and a 6-in. channel rub rail to aid in the prevention of post-vehicle snagging. (*2*) This method is not necessary for the specialized proving ground roads with low volume traffic and small angles of departures.

The 4-in. block out of a guardrail ribbon is usable space to lessen the shock of a guardrail impact. Experiments with a spring bracket type of ribbon mounting having a spring rate of 1,000 lb per in. have been conducted. These spring brackets are made of AISI 5160 steel and are 4 in. wide and $\frac{7}{16}$ in. thick. The effective arm of this cantilever spring bracket is 15 in. By combining this spring rate with the load vs deflection soil bearing curve of a 6-in. x 8-in. x 6-ft 2-in. post, desirable results are produced. Figure 6 shows the low rate of load buildup until the bracket contacts the post, and then the increase of load rate until the post finally yields rapidly in the soil. This 4-in. lateral flexibility provided by the spring mount plus the post movement reduce the car damage greatly, and lower the lateral acceleration on accidents of 35 mph and less. In higher speed accidents, this added flexibility seems to do no harm. The deflection afforded by the spring brackets is not affected by ground condition.

The junction of the spring bracket with the post was the only area in which difficulty has been encountered. If the ribbon does not have sufficient

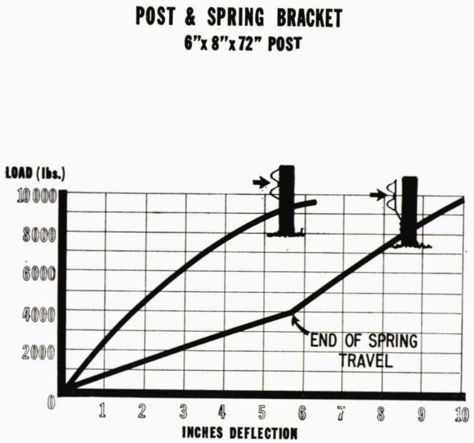


Figure 6. Effect of spring bracket for load 18 in. from ground surface.

longitudinal tension integrity, the brackets (acting as torque arms) burst the post at its lower mounting holes (Fig. 7). This has been improved by using wider spacing of the bolt holes in the bracket and providing end anchors for the ribbon.

The centerline of the guardrail ribbon is mounted 18 in. above the ground. This height seems to work well for both small and large size vehicles. Bumper engagement with the W-type beam ribbon is interesting. The bumper enters the center portion of the ribbon and tends to track in that position as the vehicle slides along.

RIBBON MOUNTING BOLT

The single 5/8-in. diameter bolt connecting the guardrail ribbon to the post or bracket was found to be inadequate. The 1¼-in. diameter head on these bolts was often pulled through the ribbon without breaking the bolt. Laboratory tests indicated that a straight pull of 5,550 lb on the bolt would duplicate this failure. If a drilled hole was used instead of a slotted hole, the bolt would pull through at 13,250 lb load (Fig. 8). A plain steel washer was added as a reinforcement, and the bolt broke at 15,750 lb. Because the plain washer did not have an elongated hole to accommodate the bolt head

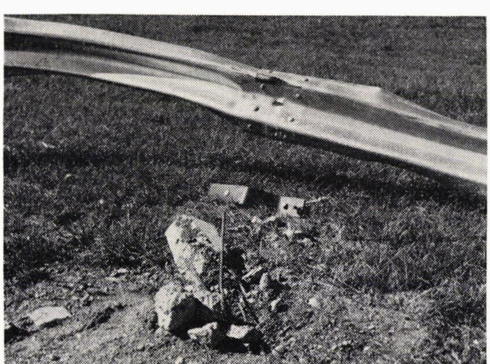


Figure 7. Post failure.

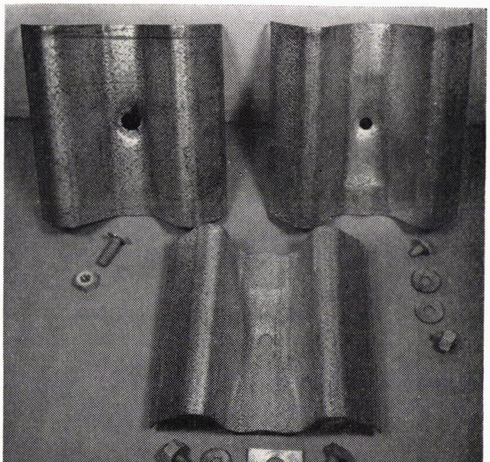


Figure 8. Bolt pull through test

properly, some $1\frac{3}{4}$ x 3 x $\frac{1}{8}$-in. steel plates were made. This type of washer distributed the load more uniformly to the bolt, and a value of 16,275 lb was reached before bolt failure. Ribbon-to-mounting failure has not been experienced since these reinforcing plates have been added to the guardrail installations.

BEAM STRENGTH OF GUARDRAIL RIBBON

Another revealing laboratory test was a simple beam strength test of various guardrail sections with several simulated post spacings (Fig. 9). The load was applied to the traffic face at the center of the test sec-

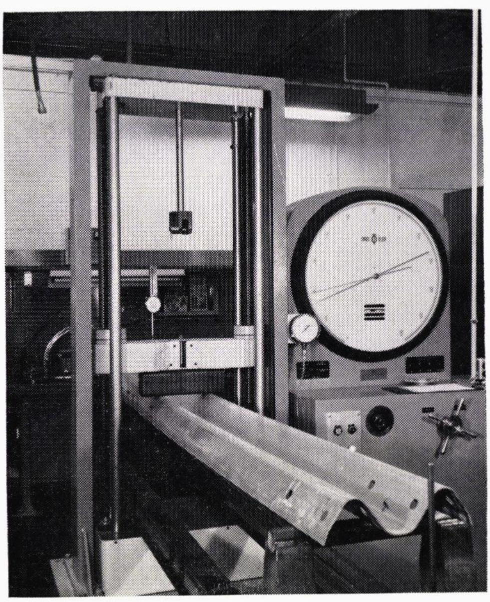


Figure 9. Beam test of guardrail ribbon.

tions with a 4-in. x 4-in. x 13-in. piece of steel. Tests were run on the following samples:

1. Steel convex-type ribbon, 9 gage, 10 ft and 5 ft long.
2. Steel beam-type ribbon, 12 gage, 12 ft 6 in. and 6 ft 3 in. long.
3. Steel beam-type ribbon, 10 gage, 12 ft 6 in. and 6 ft 3 in. long.

Figure 10 shows the results of these tests. These data confirmed the previous conclusion that it was not economically possible to strengthen the existing proving ground convex ribbon satisfactorily by closer post spacings. The gage thickness of the beam-type ribbon

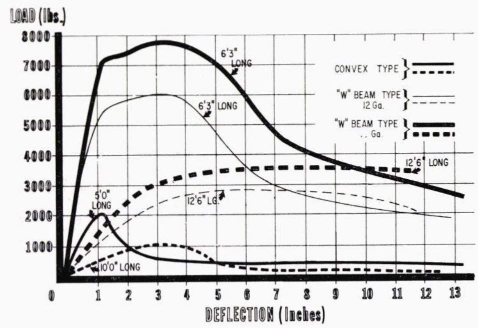


Figure 10. Beam strength of guardrail ribbon.

and the simulated post spacings, all had a pronounced effect.

These beam strength values compare quite favorably with the AASHO specifications for highway guards of $3\frac{1}{2}$-in. maximum deflection at 2,000 lb for a 12-gage, 12-ft 6-in. beam.

One weakness that appeared in the beam-type guardrail ribbon was the ease with which it flattened out and lost its section modulus. This was particularly evident when spring brackets were used with a 6-ft 3-in. post spacing (Fig. 11). To reinforce the section and prevent the ribbon flattening at the non-splice post mounting, a short 12-in. piece of W-beam is now mounted behind the guardrail ribbon (Fig. 12).

GUARDRAIL TENSION

Several full-scale impacts were run with a 4,400-lb vehicle at 35

Figure 11. Flattened and torn guardrail ribbon.

mph and at a 20-deg included angle to evaluate the tensile forces produced in the sections of guardrail ribbon. This was also the beginning of an attempt to solve the problem of the minimum length of a guardrail. Figure 13 shows that the forces are not too high considering the ultimate tensile strength of 80,000 lb for the 12 gage ribbon. The two pronounced families of peaks in the curves are caused by the front of the vehicle hitting the rail first—then being deflected and the rear of the vehicle swinging around and contacting the

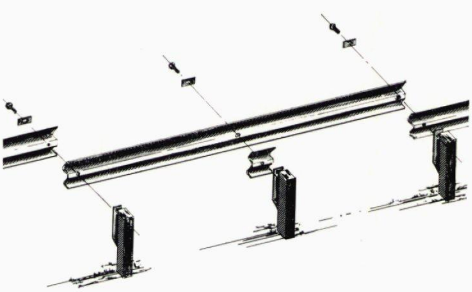


Figure 12. Reinforcement of guardrail installation.

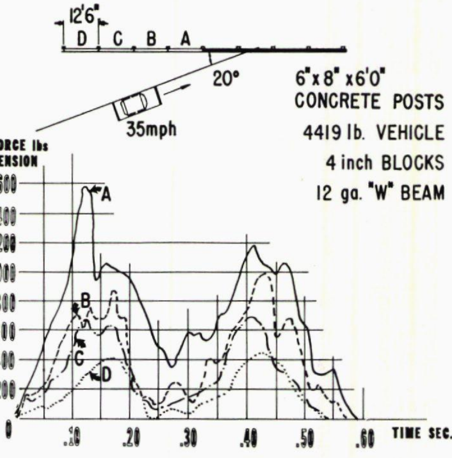


Figure 13. Guardrail ribbon tension.

rail. As yet no guardrail ribbon tension failure has occurred at the proving ground even in higher energy level bus impact tests. The $12\frac{1}{2}$-in. overlap of the ribbon sections at their joints and the eight splice bolts appear to be sufficient. On this basis the 12-gage W-beam galvanized-steel guardrail ribbon does appear to have adequate cross-sectional area to withstand the impact tensile loads applied to it by passenger cars when the proper end treatment is used.

TOTAL GUARDRAIL STRENGTH

From the data derived from the post soil bearing test and the beam strength test, curves were drawn (Fig. 14) to evaluate various configurations in terms of load vs deflection. It was assumed that the load was applied normal to the axis of the guardrail ribbon. In determining the values used to establish these curves, the interdependence of a continuous guardrail installation was disregarded. These curves are based on a 12-ft 6-in. long guardrail installation. If the load was applied at the post location, the load vs deflection curve represented by a heavy solid line would result. If a spring bracket was used on the post, a curve

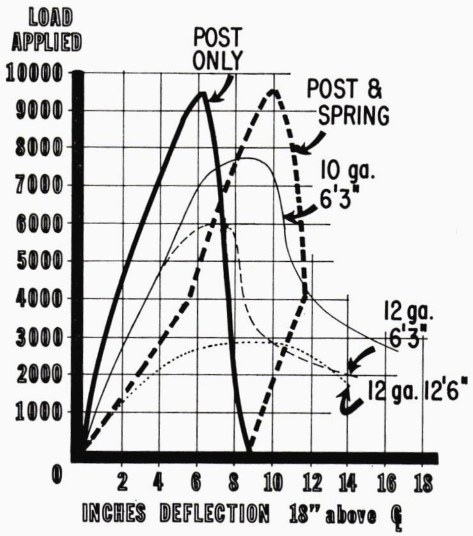


Figure 14. Total strength of guardrail with 6-in. by 8-in. wood posts.

represented by the dashed line would result. If the impact point was midway between the posts, the other curves would result depending upon the post spacing and the thickness of the guardrail ribbon. During an actual impact, the car usually slides along the rail. There is a difference between the load vs deflection curve for the post soil bearing strength and the load vs deflection curve for the ribbon strength. This will result in a lumpy type of lateral reaction to the car impacting the guardrail. This has been verified by oscillograph recordings of the lateral and longitudinal accelerations and decelerations experienced by a vehicle impacting a 12-gage ribbon with a post spacing of 12 ft 6 in. Figure 15 is an oscillographic record of a 39-mph, 20.4-deg impact, and shows the lump experienced in the transverse acceleration curve after impact. The load vs deflection curve for any point along the guardrail should be the same. Therefore, in terms of this graphic analysis of a guardrail's strength, it appears that the posts are either too strong or the ribbon is too weak in bending. The posts should not be weakened because post failures do occur from time to time. It appears that in order to achieve a more balanced guardrail design, the beam-type guardrail must be made stronger in bending, or the post spacing must be reduced accordingly.

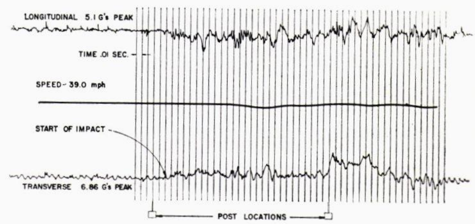


Figure 15. Oscillograph of guardrail impact.

GUARDRAIL END TREATMENT

One phase of the guardrail testing program was to determine the best type of end treatment for guardrail installations. This testing was prompted by reports and pictures of cars striking the ends of guardrail installations on public highways. Tests indicated that the standard terminal section (27½-in. long) was extremely dangerous (Fig. 16). Also tested were installations using an end treatment consisting of a standard 12.5-ft length of guardrail curved to 10- and 50-ft radii (Fig. 17). Both

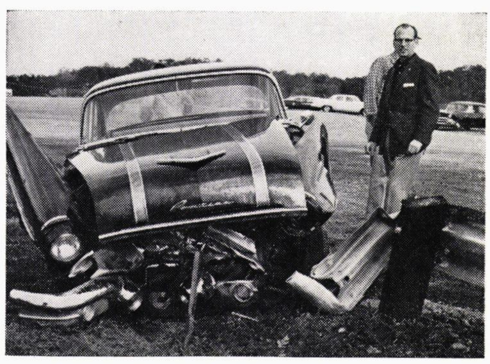


Figure 16. Standard guardrail end impact.

Figure 17. **Impact on guardrail end with 50-ft radius.**

tests produced unsatisfactory high deceleration rates to the vehicle.

The most satisfactory solution found to date is to slope the guardrail into the ground and anchor it in concrete. The length of the sloped-end treatment can vary with speeds driven at these sites. A 37.5-ft length, three 12.5-ft sections of rail, is satisfactory for most locations but not on rural freeways at 65+ mph. Posts are 6 ft 3 in. on centers (Fig. 18). This end treatment has the advantage of using standard materials which all guardrail contractors can supply. Several full-scale tests have been run on this type of installation. Figure 19 is a picture of a vehicle during a 65-mph, 3-deg impact. Vaulting of the vehicle is still a problem; however, the vaulting seems preferable to complete destruction.

Another satisfactory method that may be used when the roadway is going from a cut section into a fill section is to angle the guardrail back from the roadway, anchoring the guardrail end in concrete (Fig. 20).

SHORT SECTIONS

It became apparent that the minimum length of the test installations were critical. It was found that a guardrail installation which would withstand a 35-mph, 20-deg impact, had to be at least 100 ft long; otherwise, it would collapse toward the impact point (Fig. 21). The minimum established length for the 65-mph, 20-deg test was 250 ft. These figures for minimum installation length have been applied to proving ground protective guardrails. As an added insurance, both ends are ramped and anchored into the ground to develop full ribbon tensile strength for the full length of the installation.

A test was run to determine the type and extent of damage sustained when a simulated short-section expressway sign protection-type guardrail was impacted. Figure 22 shows the results of this test—complete failure of the installation. Details of this impact are given in the Appendix, Run No. 601 (Fig. 54).

The guardrail installations resist

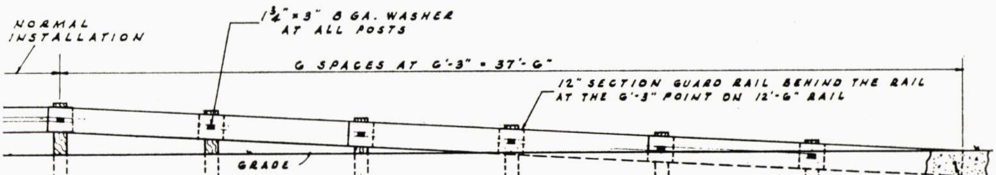


Figure 18. Guardrail sloped end treatment.

Figure 19. Impact on 37-ft sloped end.

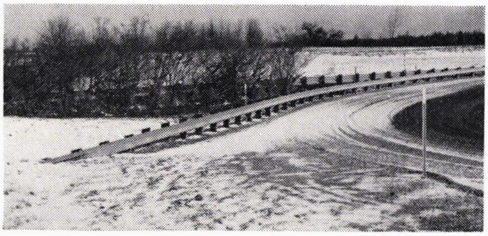


Figure 20. Proving ground standard guardrail end treatment.

impacts initially by the post strength and the beam strength of the ribbon. When the ribbon has been deformed, the primary resistance of the guardrail is obtained from its longitudinal integrity. Without end anchors this cannot be accomplished on short sections.

DRIVER OCCUPIED TESTS

To gather a better understanding of what is happening during a guardrail impact, a series of driver-occupied tests were conducted. The driver was unrestrained. The guardrail used, had 12-gage W-beam ribbon with 6-in. x 8-in. x 6-ft 2-in. concrete posts with spring brackets. The post spacing was 12 ft 6 in. Initially, the included impact angles were low and the speeds were low. The driver was told to build up in speed at each new larger angle until the shock was as high as he wanted to take. Accelerometers were placed on the driver to measure chest and head accelerations and on the vehicle to measure the forces transmitted to him. A data movie camera was located behind the driver to record his motions (Fig. 23). Analysis of the data derived from this experiment was that when the vector resultant of the accelerations measured in the heart region of the driver reached 3.5 g, he then decided not to continue at a higher speed at that angle.

CABLE CHAIN-LINK MEDIAN BARRIER

California's Division of Highways, Materials and Research Department, developed a new concept of median barrier using cable supported 36-in. wide chain-link fence which appeared to have an application on the proving ground. The first test on this barrier involved steering a remotely-controlled 4,200-lb vehicle into the barrier at 65 mph at an angle of 16.7-deg. While the vehicle path was 16.7 deg, the vehicle itself had an attitude angle of approximately 10 deg. This cable chain-link barrier provided an effective means of stopping the vehicle under high angle and high speed, and still maintain reasonably low deceleration values. Many off-the-road departures involve small angle departures of less than 10 deg. To duplicate these high-speed, low-angle impacts, a second test was conducted. The vehicle speed was again 65 mph but the impact angle was reduced to

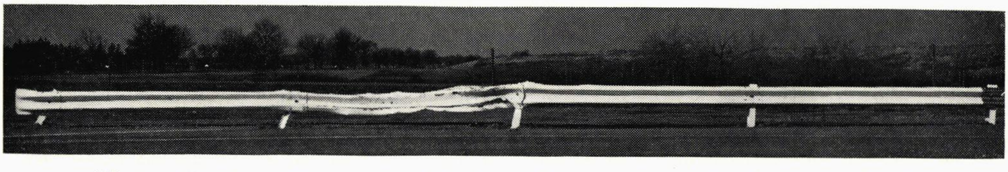


Figure 21. Post movement after impact on short section of guardrail.

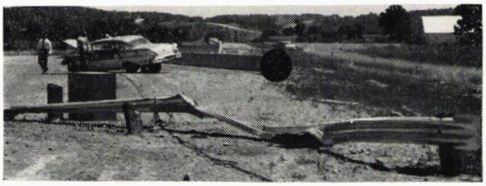


Figure 22. Result of impact on sign protection guardrail.

8.0 deg. The barrier performed as in the previous test until the cable turnbuckles in the middle of the test section were reached. At this point, the chain-link fence stopped sliding along the cables and the vehicle swung around violently. The "dead man" on the leading end of the barrier was jerked loose and thrown nearly 30 ft. The vehicle received a violent longitudinal jerk in excess of 30 g.

A third impact was performed on this type of barrier with a vehicle at 35-mph impacting again at approximately an 8-deg angle. This test was conducted to determine whether low speed of the vehicle would indicate any violent snagging of the barrier, and to try to determine the minimum parameters of speed and angle for retention of the vehicle by the barrier. The barrier again retained the vehicle and brought it to a mild stop. For this last test the entire barrier installation was placed 3 in. higher than in the previous tests, which were at California specifications, and it was noted that the vehicle penetrated the upper tension cables up to the passenger compartment. Details of these impacts are given in the Appendix, Run Nos. 591 (Fig. 51), 593 (Fig. 52) and 596 (Fig. 53).

The chain-link barrier may prove to be an excellent installation for medians on high-volume, high-speed roads, but because it makes an accident out of low-angle and low-speed impacts which beam-type barriers deflect quite well, it probably will not be used at the proving ground.

GUARDRAIL INSTALLATION ON TEST TRACK SUPERELEVATED CURVES

The new guardrail installation just completed on the test track superelevated curves is believed unique (Fig. 24). One requirement of the new design was that it could be removed and replaced economically when it became necessary to resurface the track. This requirement was necessary because in the resurfacing operation, the equipment holding the paver and rollers on the steep super-

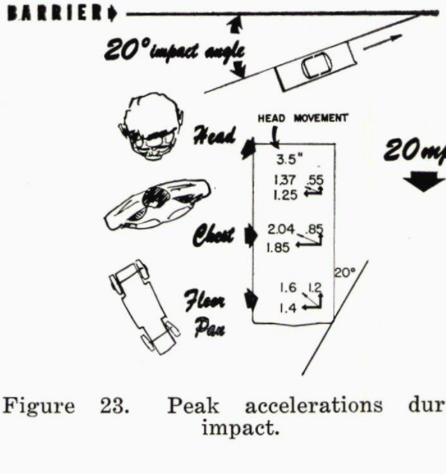


Figure 23. Peak accelerations during impact.

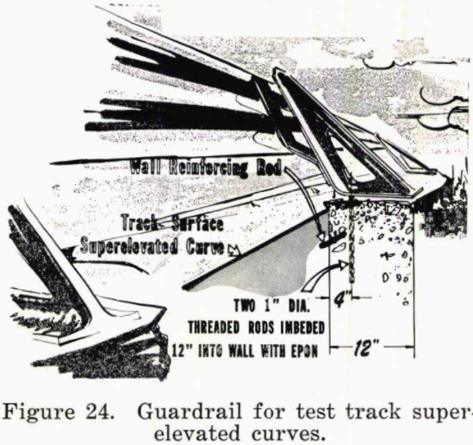


Figure 24. Guardrail for test track superelevated curves.

elevated surface must run along behind the wall. Wooden guardrail posts erected behind the wall were considered for this installation but were ruled out because of the complete removal necessary for the resurfacing operation.

Two types of steel post construction, fabricated steel and cast steel, were investigated. The cast post was chosen because it is less susceptible to rust and it has a much neater appearance. The uniformity of construction is generally higher. Both analytical methods and actual tests were used to determine such requirements as proper guardrail post size and length. The original design parameter was the ultimate strength of the guardrail post. For this, the strength of standard 6- x 8-in. wooden posts was used. After initial tests and one redesign, the strength requirements were met.

The key factor in making this guardrail installation possible was the use of an impact-resistant epoxy resin to cement threaded steel rods into the concrete wall. The epoxy resin was subjected to many tests and was found to be satisfactory. Two holes per post, each 12 in. deep, were drilled in the existing concrete wall, and 1-in. diameter threaded steel rods were set into the holes which had been partially filled with the activated liquid epoxy resin. These threaded rods were then used in fastening the guardrail posts to the concrete wall.

Previous high-speed automobile-guardrail collision tests dictated that the guardrail posts be spaced at 6-ft 3-in. centers using spring steel brackets to fasten the standard deep beam guardrail to the posts. The new sections of guardrail were 12 ft 6 in. long. An extra hole was provided at the midpoint of each section to fasten the guardrail to the spring bracket which is fastened to the post. It was found in testing the installation that the guardrail tended to tear at this midpoint. Short pieces of guardrail, 1 ft long, were used as reinforcing behind the main guardrail at these midpoints to help eliminate this problem. Also included in the design were heavy washers under the head of the post bolt to prevent the head of the bolt from pulling through the guardrail.

All guardrail, posts, brackets, threaded stock, nuts, bolts, and washers were galvanized for this installation. Figure 25 shows a section of the completed installation.

The guardrail installation is anchored at both ends to develop the full strength of the guardrail ribbon. The end anchors are so designed that they will not "spear" a vehicle.

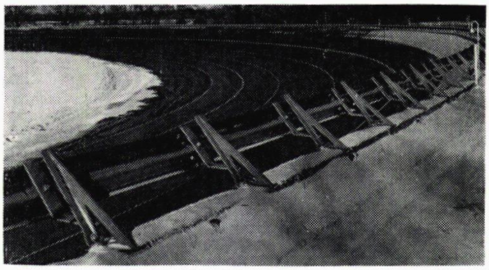


Figure 25. Test track guardrail.

In designing the cast steel posts, extra holes were provided for fastening additional brackets to the posts in the event that double height guardrail is required in the future.

SUMMARY AND CONCLUSIONS

The data reported were observed by use of the best instrumentation and test techniques available at the General Motors Proving Ground to provide a basis for making decisions on guardrail installations on its own road system.

Conditions which influence the design of guardrail installations include speed and volume of traffic, geometry of the road and roadside, soils, and climate. Because of the wide variation on these conditions, each installation must be considered separately.

The following design and specification details provide what are considered optimum installations for the conditions prevailing on the road system at the proving ground. It is not implied that these details can be applied everywhere, and no such interpretation should be placed upon these conclusions. Perhaps the first conclusion should be that they are not applicable universally.

The following guardrail is considered the most suitable and economical for use on these high-speed, low-density roads:

1. Wood posts, 6 in. x 8 in. x 6 ft 2 in., pressure treated, and spaced 6 ft 3 in. apart.
2. Spring brackets with 4-in. travel at 1,000 lb per in.
3. W-beam 12-gage guardrail ribbon.
4. Reinforcing washers on ribbon mounting bolts.
5. Reinforcing pieces under non-splice ribbon mounting to post.
6. Ramped and anchored ends.

This conclusion is based on over 60 actual full-scale impacts at speeds of 30 mph to 68 mph with impacting angles of 0 to 33 deg. Vehicles ranging from small cars to 24,000-lb passenger buses were used. These were supplemented by hundreds of hours of indoor laboratory testing and engineering.

However, it should be remembered that the purpose of a guardrail is to prevent a vehicle from entering an area in which it cannot safely travel. The guardrail should do its job with a minimum of injury to the passengers, damage to the vehicle, damage to the rail itself or creating a serious hazard to other traffic. This means that the ideal guardrail should turn the vehicle from its original path to a path parallel to the guardrail with tolerable decelerations to the passengers. It should not deflect the vehicle back into the road, endangering other traffic. In performing this turning action, it is necessary that the rail deflect because it is impossible to turn a vehicle instantaneously. The amount of deflection largely determines the lateral acceleration peak produced in the vehicle. A rail which will do all these things has not yet been designed and would probably be prohibitively expensive. Therefore, guardrails should be used only as a last resort when all other means of eliminating the roadside hazards have proven completely impractical.

REFERENCES

1. LUNDSTROM, L. C., AND SKEELS, P. C., "Full-Scale Appraisals of Guardrail Installations by Car Impact Tests." *HRB Proc.*, 38: 353-355 (1959).
2. HVEEM, F. N., AND BEATON, J. L., "Full-Scale Testing of Highway Bridge Rails and Median Barriers." SAE Paper 211B, National West Coast Meeting (August 1960).
3. STONEX, K. A., "Roadside Design for Safety." *HRB Proc.*, 39: 120-156 (1960).

APPENDIX

1958 Car - Guardrail Impact Tests 3-10-58

Beam Type Guardrail

Posts - 6" x 4" x 8-1/2 lb. per ft. I Beam 5' 9" long

Speed - 37 mph, Impact Angle 20°

Vehicle - 1956 Pontiac 4 Dr. - Wt. 4163 lbs.
Estimate of Damage: $100.00

Dummy Injury - no dummies used

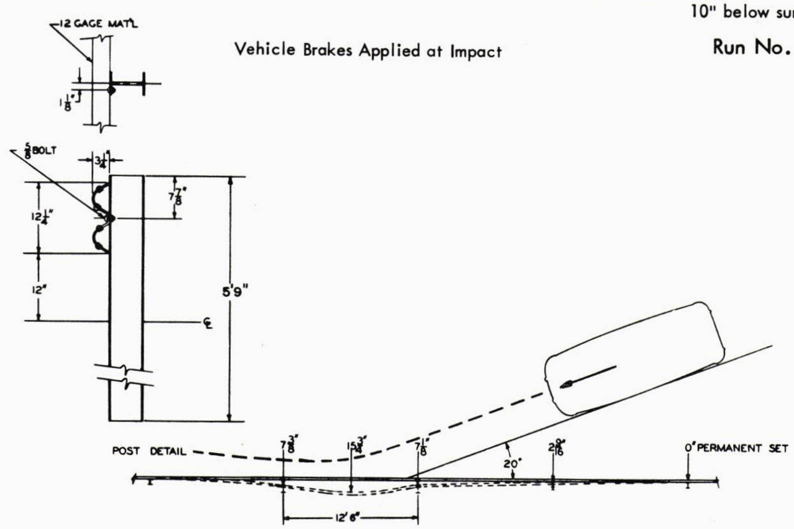
Guardrail Damage - one section of ribbon

Vehicle Deceleration - Longitudinal: 7.5 G
Transverse: 6.0 G

Ground Condition - Glacial Till: 6" frozen layer 10" below surface

Vehicle Brakes Applied at Impact

Run No. 507



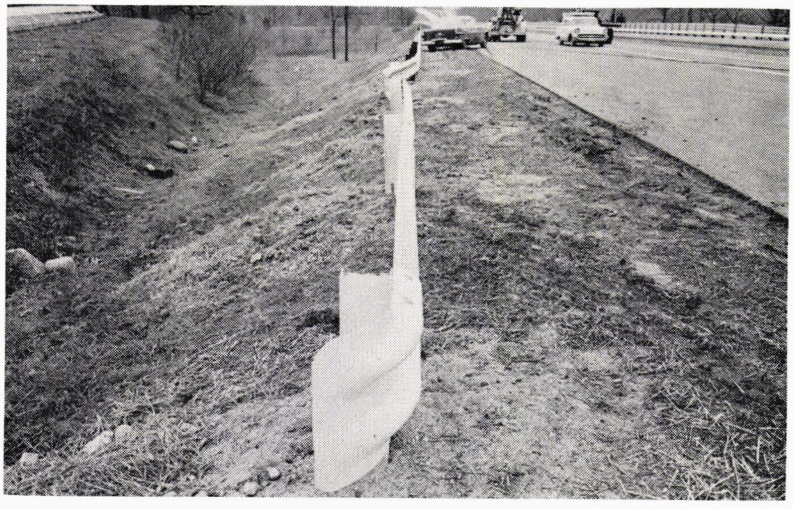


Figure 26.

1958 Car - Guardrail Impact Tests 3-11-58

Beam Type Guardrail

Posts - 6" x 8" wood 6' 2" long

Speed - 37 mph, Impact Angle 20°

Vehicle - 1958 Pontiac 2 Dr. Ht. - Wt. 4029 lbs.
Estimate of Damage: $100.00

Dummy Injury - no dummies used

Guardrail Damage - one section of ribbon

Vehicle Deceleration - Longitudinal: 6.8 G's
Transverse: 5.8 G's

Ground Condition - Glacial Till: 6" frozen layer 10" below surface

Vehicle Brakes Applied at Impact

Run No. 508

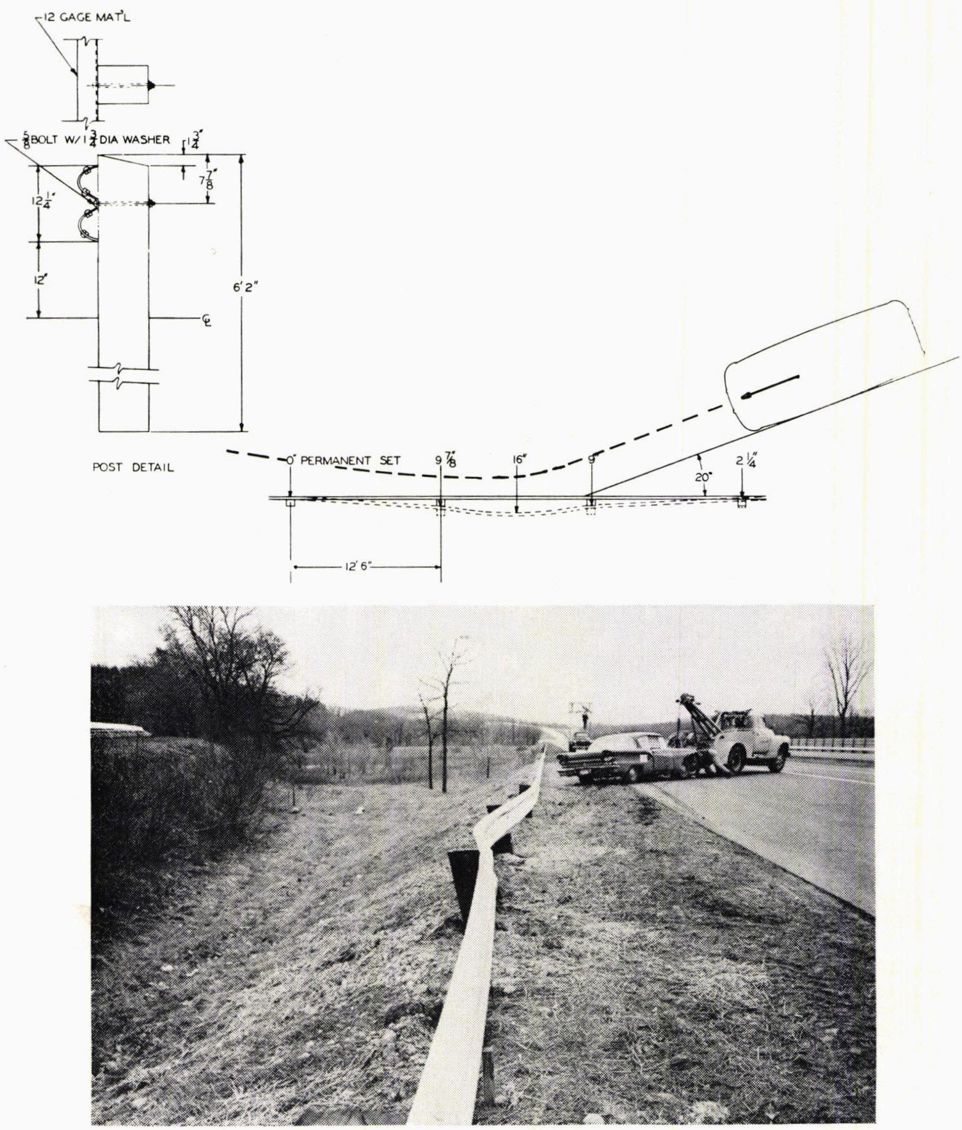


Figure 27.

1958 Car - Guardrail Impact Tests 3-13-58

Beam Type Guardrail

Posts - 10" x 10" reinforced Concrete 5' 8" long

Speed - 33.5 mph, Impact Angle 20°

Vehicle - 1956 Pontiac 4 Dr. Ht. - Wt. 4033 lbs.
Estimate of Damage: $250.00

Vehicle Brakes Applied at Impact

Dummy Injury - no dummies used

Guardrail Damage - three posts
two sections of ribbon

Vehicle Deceleration - Longitudinal: 8.1 G
Transverse: 5.9 G

Ground Condition - Glacial Till: 6" frozen layer
10" down

Run No. 510

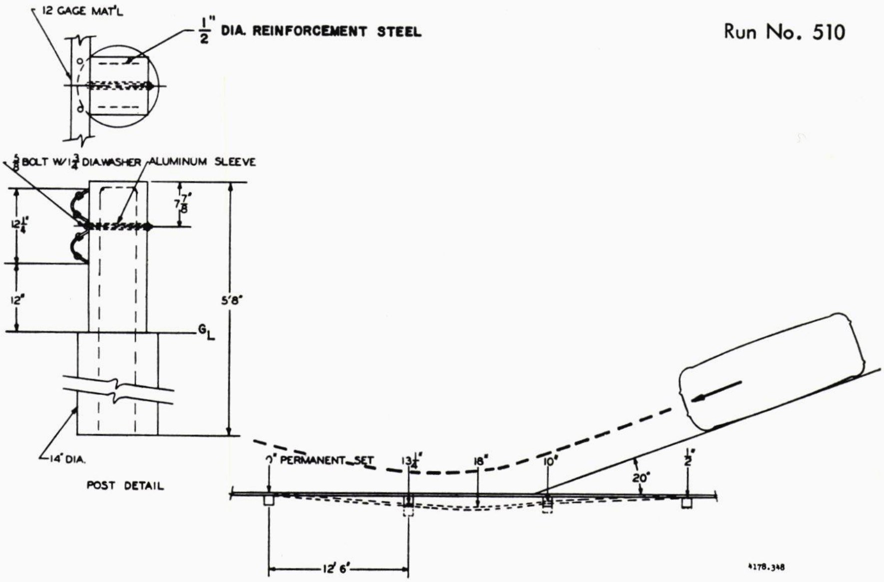


Figure 28.

1958 Car - Guardrail Impact Tests 4-4-58

4 Cable Guardrail

Posts - 6" x 4" x 8-1/2 lb. per ft. I Beam 5' 9" long

Speed - 41 mph, Impact Angle 20°

Vehicle - 1956 Pontiac 4 Dr. Ht. - Wt. 4137 lbs.
Estimate of Damage: $400.00

Vehicle Brakes Applied at Impact

Dummy Injury - moderate contusion to both
dummies on right side of vehicle

Guardrail Damage - 4 posts
4 cables stretched

Deceleration: Transverse (vehicle) 5.8 G's
Transverse (dummy-right front) 4.0

Ground Condition - Glacial Till: Dry

Run No. 511

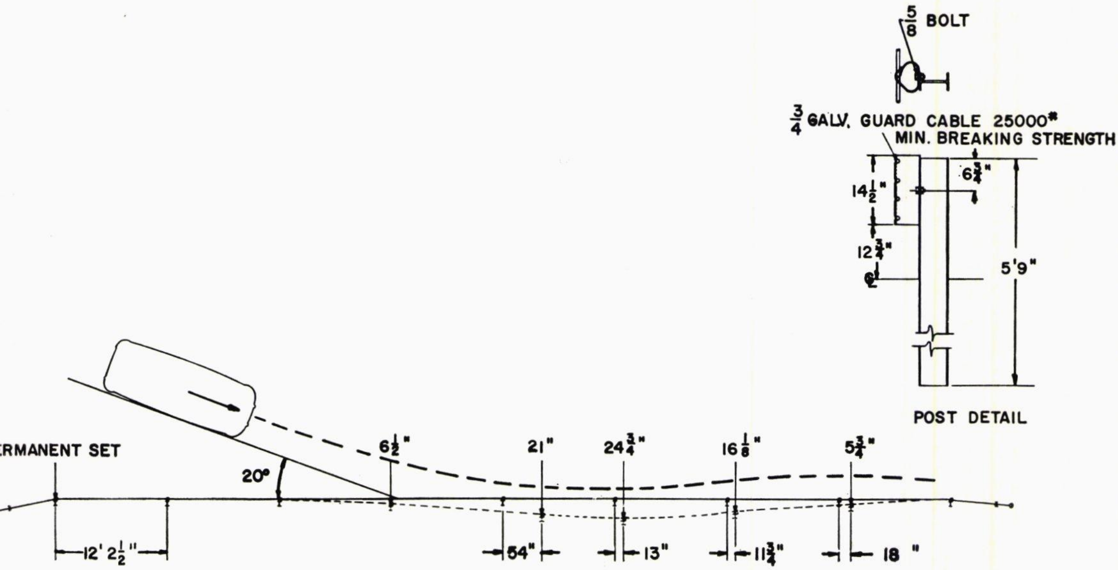


Figure 29.

1958 Car - Guardrail Impact Tests 4-11-58

Beam Type Guardrail

Posts - 6" x 4" x 8-1/2 lb. per ft. I Beam 5' 9" long

Speed - 30 mph, Impact Angle 33°

Vehicle - 1956 Pontiac 4 Dr. Ht. - Wt. 4163 lbs.
Estimate of Damage: $150.00

Dummy Injury - left rear possibly fatal
right rear broken wrist

Guardrail Damage - 3 posts
3 sections of rail

Vehicle Deceleration - none taken

Ground Condition - Glacial Till: Wet

Vehicle Brakes not Applied

Run No. 513

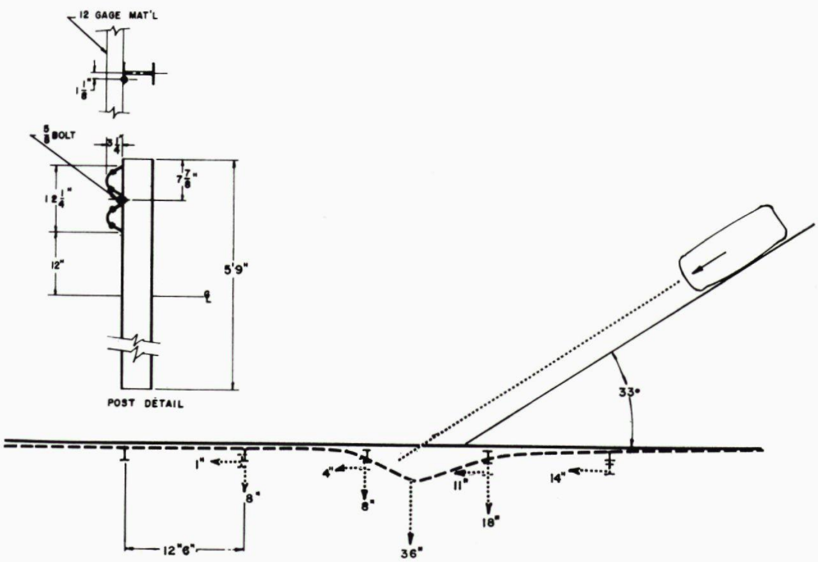


Figure 30.

1958 Car - Guardrail Impact Tests 5-12-58

Beam Type Guardrail

Posts - 6" x 4" x 8-1/2 lb. per ft. I Beam 5' 9" long

Speed - 35 mph, Impact Angle 33°

Vehicle - 1956 Pontiac 4 Dr. Ht. - Wt. 4163 lbs.
Estimate of Damage: $175.00

Dummy Injury - none noted

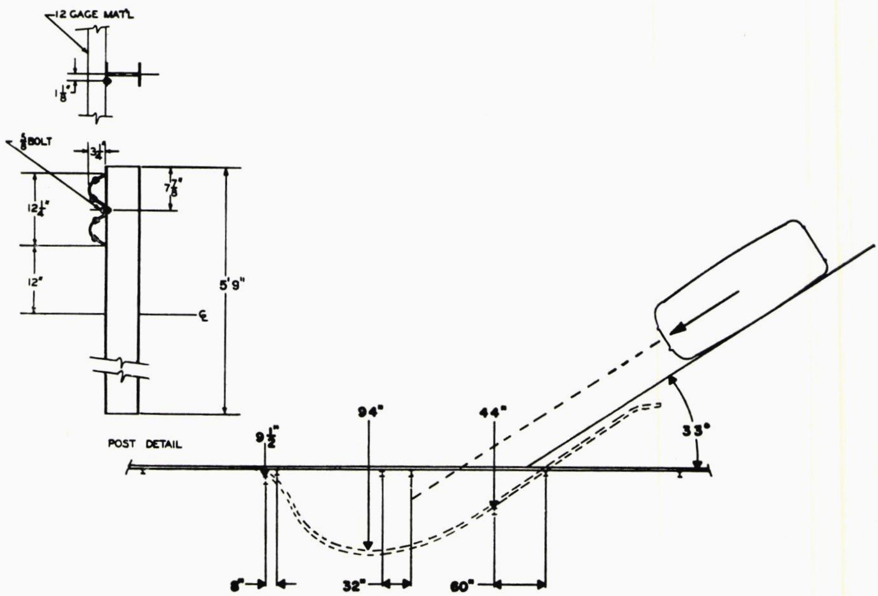
Guardrail Damage - three posts
three sections of rail

Vehicle Deceleration - not taken

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied at Impact

Run No. 515



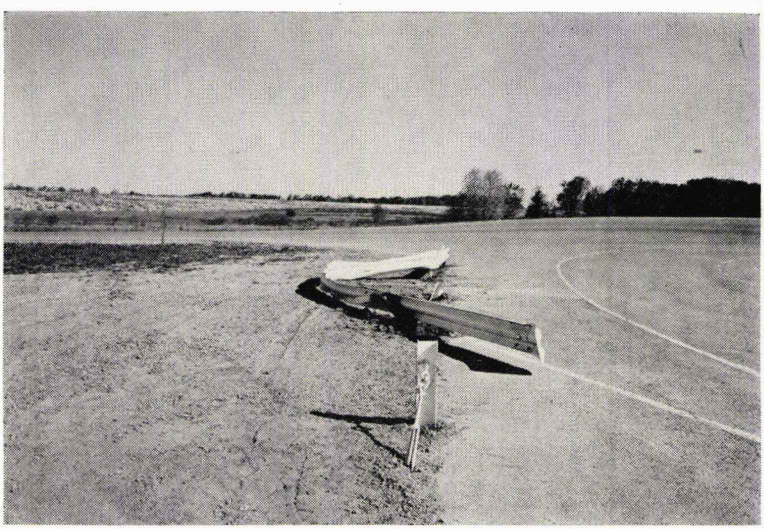


Figure 31.

1958 Car - Guardrail Impact Tests 6-6-58

Beam Type Guardrail - mounted on modified Tuthill spring brackets

Posts - 6" x 8" wood 6' 2" long

Speed - 35 mph, Impact Angle 18.5°

Vehicle - 1956 Pontiac 4 Dr. Ht. - Wt. 4033 lbs.
Estimate of Damage: $75.00

Dummy Injury - none noted

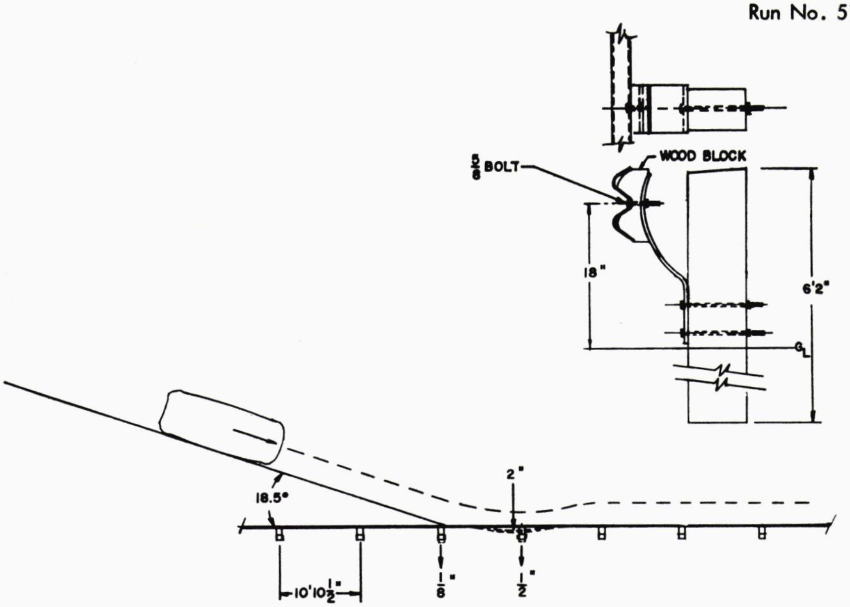
Guardrail Damage - minor

Vehicle Deceleration - not taken

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied at Impact

Run No. 518



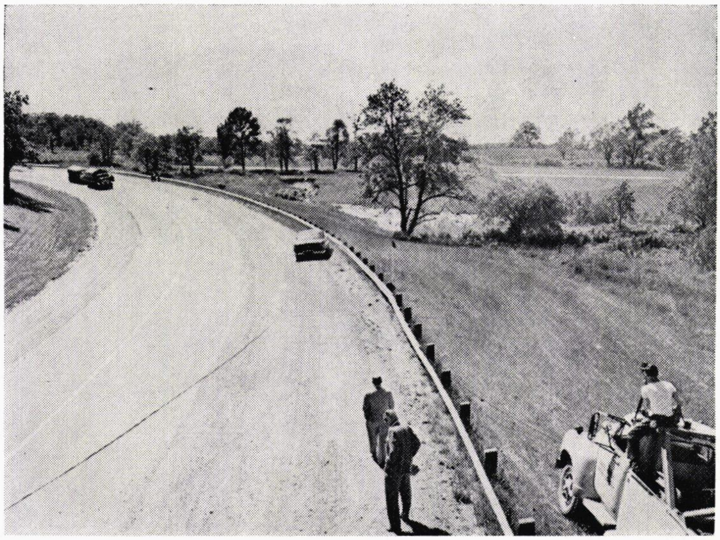


Figure 32.

1958 Car - Guardrail Impact Tests 6-24-58

Standard Tuthill Guardrail

Posts - 6" x 8" wood 6' 2" long

Speed - 35 mph, Impact Angle 18.1°

Vehicle - 1956 Pontiac 4 Dr. Ht. - Wt. 4033 lbs.
Estimate of Damage: $150.00

Dummy Injury - none noted

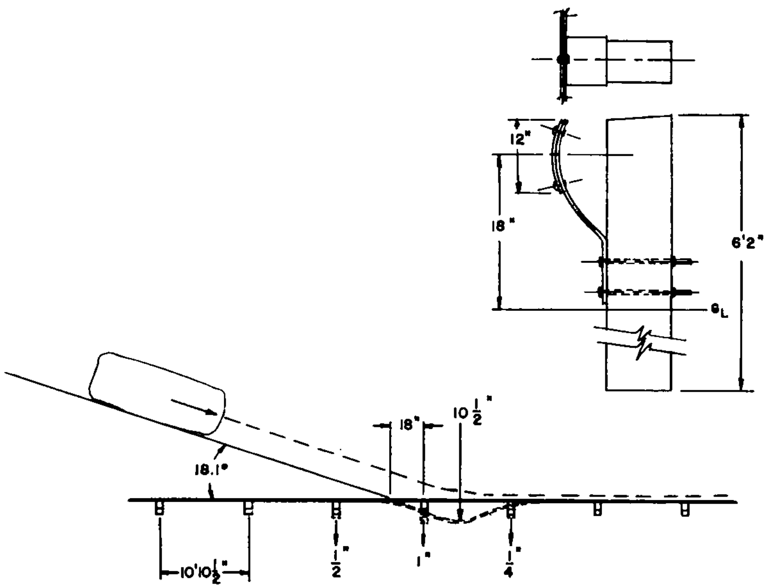
Guardrail Damage - two sections of rail

Vehicle Deceleration - not taken

Ground Condition - Glacial Till: Dry

Run No. 520

Vehicle Brakes Applied at Impact



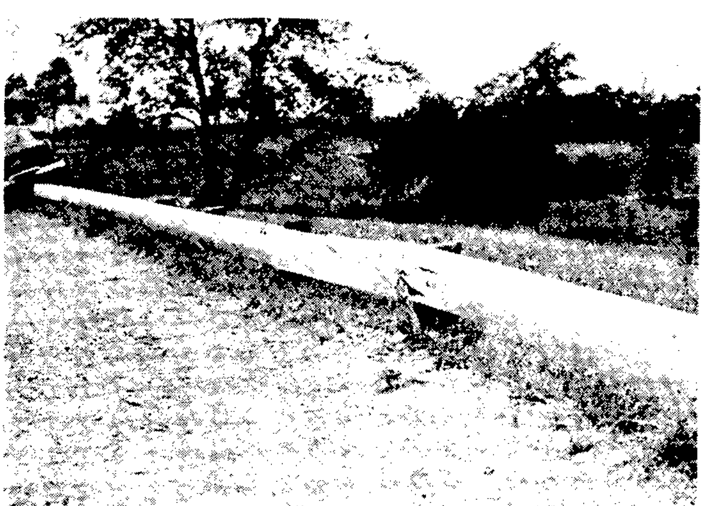


Figure 33.

1958 Car - Guardrail Impact Tests 6-26-58

Beam Type Guardrail

Posts - 6" x 8" wood 6' 2" long

Speed - 60 mph, Impact Angle 24.8°

Vehicle - 1956 Pontiac 4 Dr. - Wt. 4163 lbs.
Estimate of Damage: $200.00

Dummy Injury - none noted

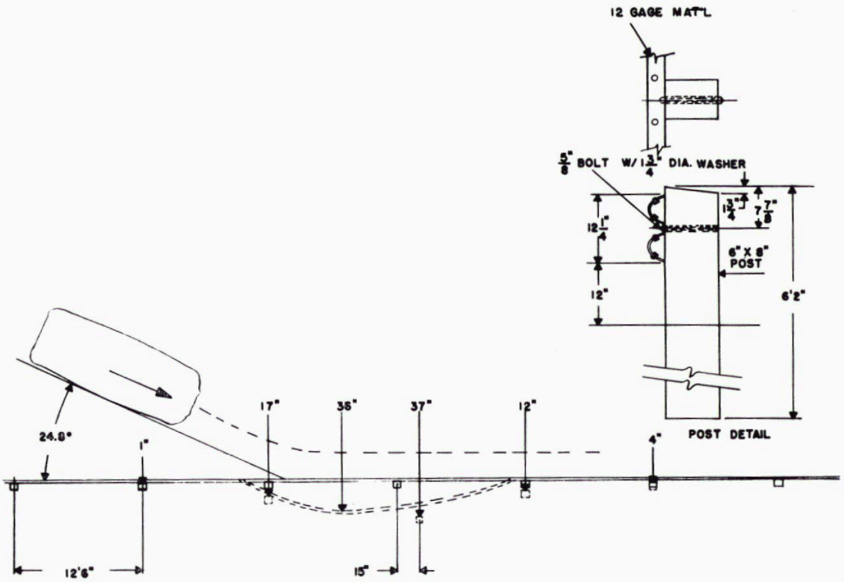
Guardrail Damage - two sections of ribbon

Vehicle Deceleration - not taken

Ground Condition - Glacial Till: Dry

Run No. 521

Vehicle Brakes Applied at Impact



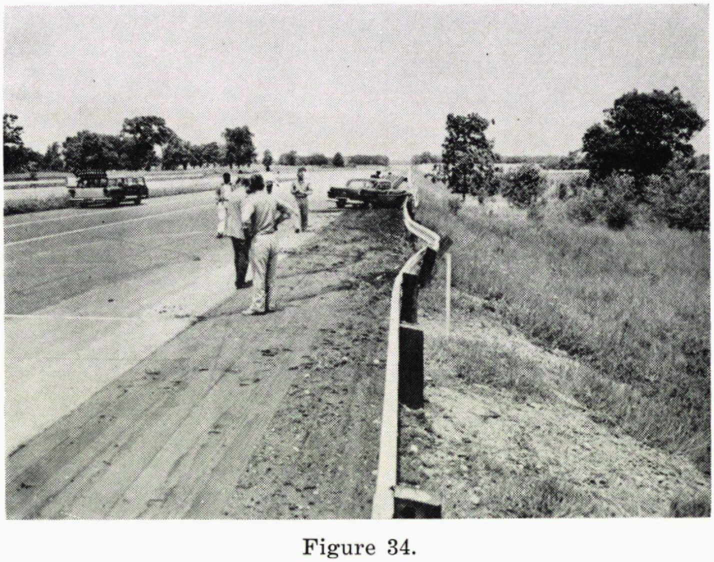


Figure 34.

1958 Car - Guardrail Impact Tests 7-11-58

Beam Type Guardrail

Posts - 6" x 4" x 8-1/2 lb. per ft. x 5' 9" I Beam

Speed - 35 mph, Impact Angle 20°

Vehicle - 1956 Pontiac 4 Dr. Ht. - Wt. 4033 lbs.
Estimate of Damage: $100.00

Vehicle Brakes Applied at Impact

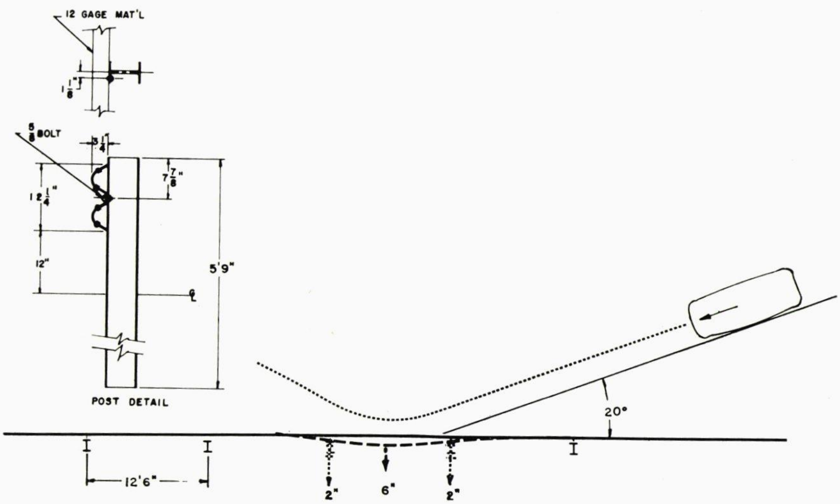
Dummy Injury - none noted

Guardrail Damage - one section of rail

Vehicle Deceleration - not taken

Ground Condition - Glacial Till: Dry

Run No. 522



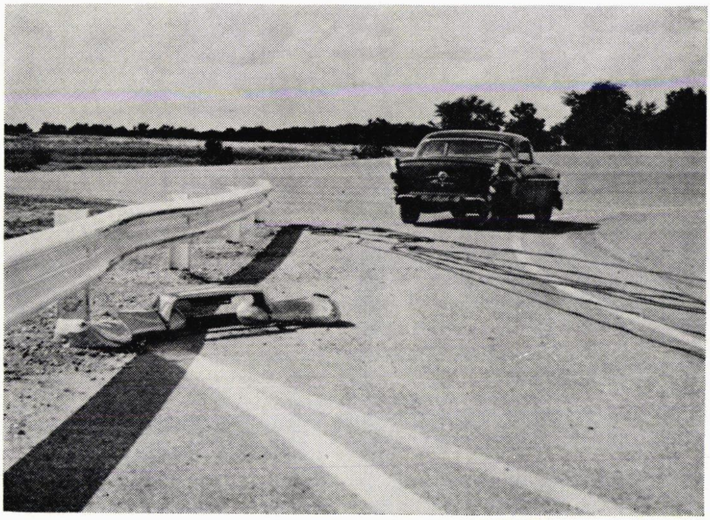


Figure 35.

1958 Car - Guardrail Impact Tests 8-14-58

Deep Beam Guardrail

Posts - 6" x 4" x 8-1/2 lb. per ft. x 5' 9" I Beam

Speed - 35 mph, Impact Angle 33°

Vehicle - 1958 Pontiac 4 Dr. - Wt. 4030 lbs.
Estimate of Damage: $150.00

Dummy Injury - small forehead contusion to right rear dummy

Guardrail Damage - two sections of rail

Vehicle Deceleration - Longitudinal: 5.6G's Peak
Transverse: 3.6 G's Peak

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied at Impact

Run No. 524

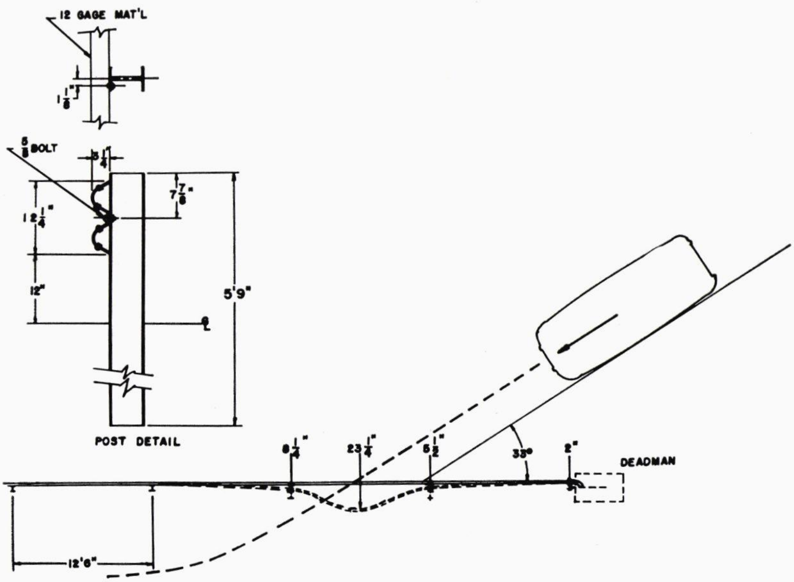


Figure 36.

1958 Car - Guardrail Impact Tests 8-20-58

Beam Type Guardrail

Posts - 6" x 4" x 8-1/2 lb. per ft. I Beam 5' 9" long

Speed - 35 mph, Impact Angle 33°

Vehicle - 1958 Pontiac 4 Dr. Ht. - Wt. 4150 lbs.
Estimate of Damage: $150.00

Dummy Injury - none noted

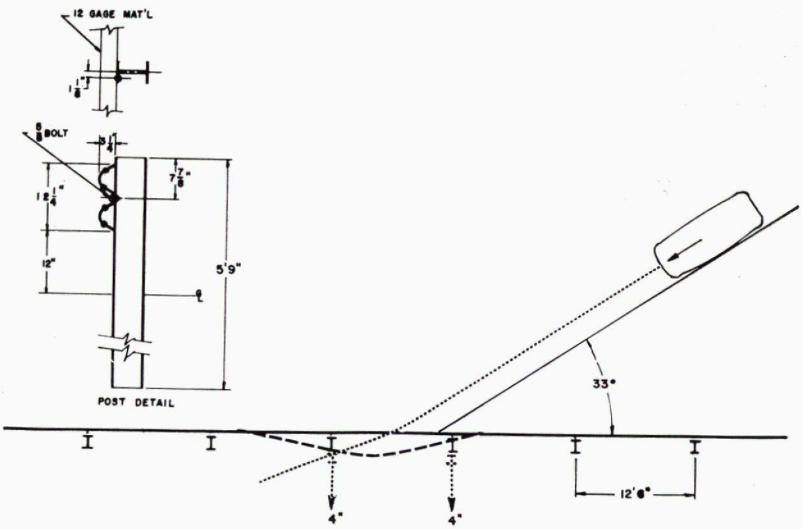
Guardrail Damage - one post
one section of rail

Vehicle Deceleration - not taken

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied after Impact

Run No. 525



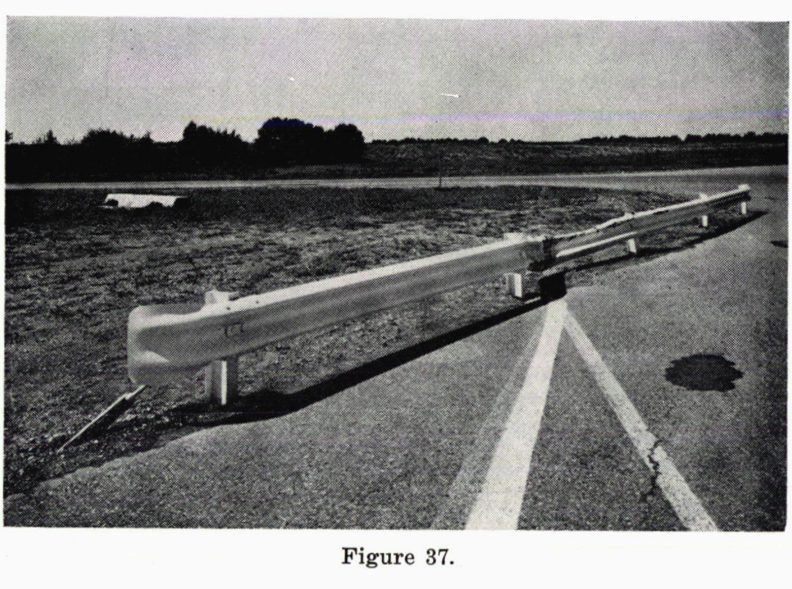


Figure 37.

1958 Car - Guardrail Impact Tests 9-15-58

Beam Type Guardrail

Posts - 6" x 8" Pre Cast Concrete 6' 0" long

Speed - 35 mph, Impact Angle 20°

Vehicle - 1956 Pontiac 4 Dr. - Wt. 4033 lbs.
Estimate of Damage: $150.00

Dummy Injury - none used

Guardrail Damage - minor

Vehicle Deceleration - Longitudinal: 2.0 G's
Transverse: 3.5 G's

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied at Impact

Run No. 526

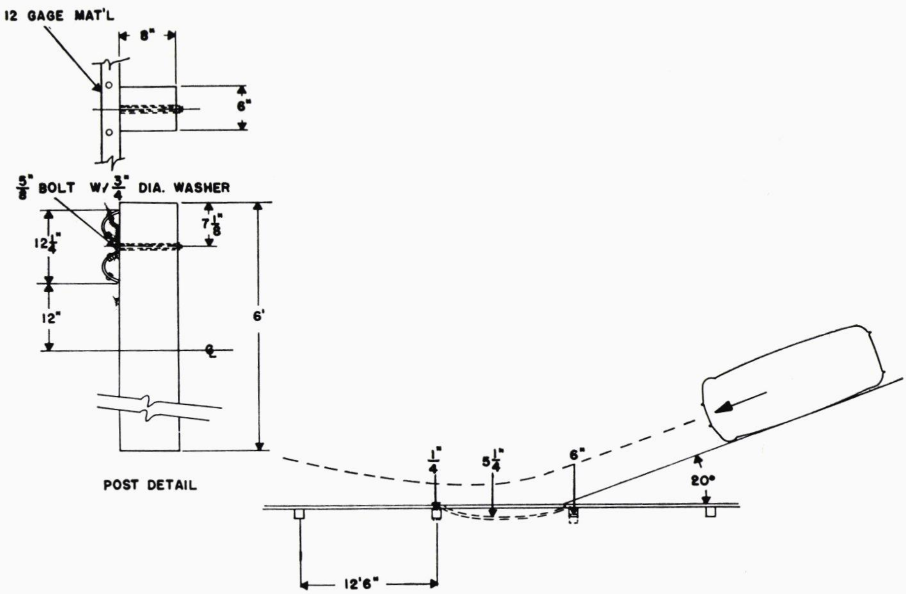


Figure 38.

1958 Car - Guardrail Impact Tests 9-25-58

Beam Type Guardrail (10 gauge)

Posts - 6" x 8" Pre Cast Concrete 6' long

Speed - 39.0 mph, Impact Angle 20.4°

Vehicle - 1957 Pontiac 2 Dr. - Wt. 4058 lbs.
Estimate of Damage: $150.00

Dummy Injury - none used

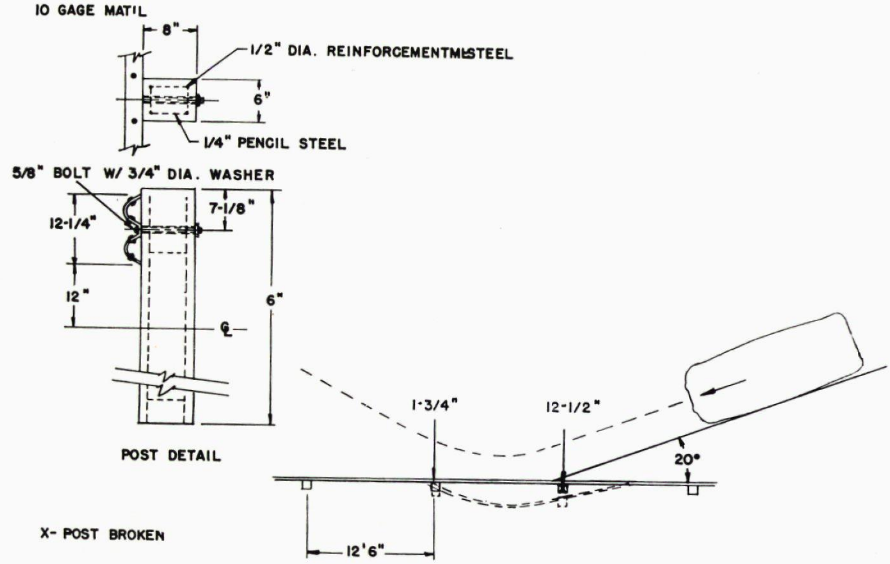
Guardrail Damage - one post
two sections of rail

Vehicle Deceleration - Longitudinal: 5.1 G's
Transverse: 6.8 G's

Ground Condition - Glacial Till: Dry

Brakes Applied at Impact

Run No. 527



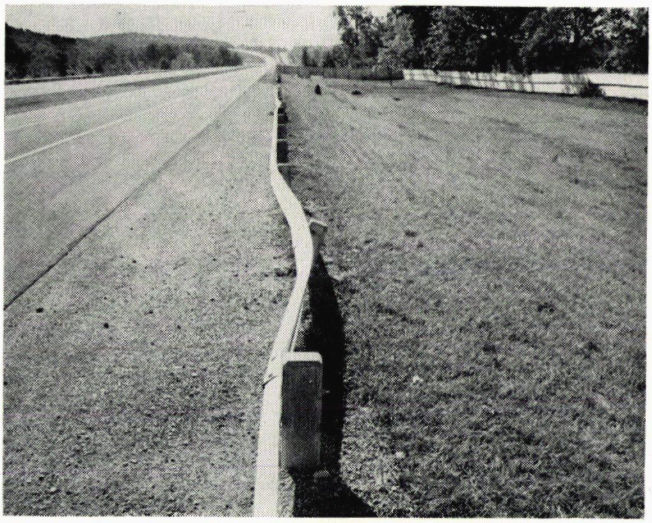


Figure 39.

1958 Car - Guardrail Impact Tests 9-25-58

Beam Type Guard Rail - mounted on spring brackets

Posts - 6" x 8" wood posts 6' 2" long

Speed - 68.4 mph, Impact Angle 18.5°

Vehicle - 1958 Pontiac 4 Dr. Ht. - Wt. 4150 lbs.
Estimate of Damage: $300.00

Dummy Injury - none used

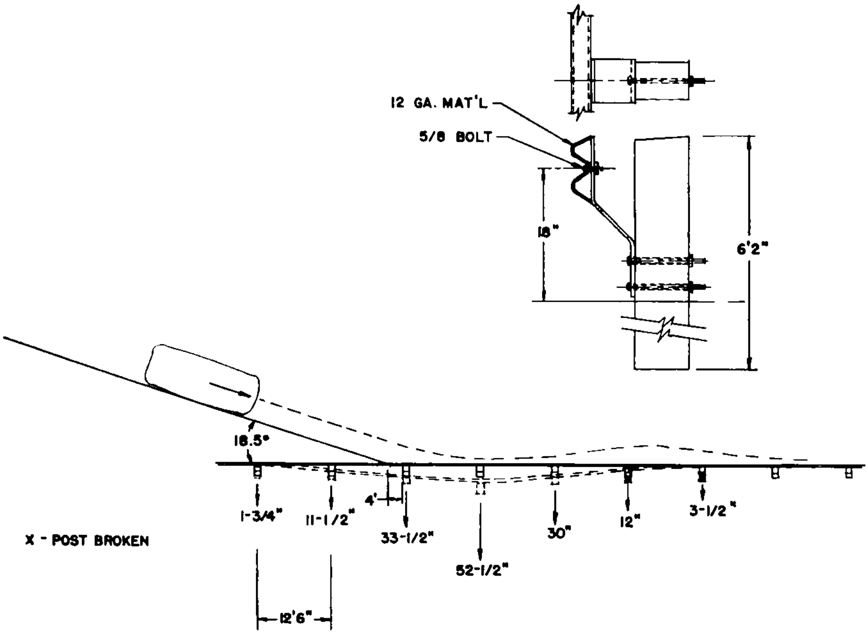
Guardrail Damage - two posts
three sections of rail

Vehicle Deceleration - Longitudinal: 16.4 G's
Transverse: 13.1 G's

Ground Condition - Glacial Till: Dry

Brakes Applied at Impact

Run No. 528



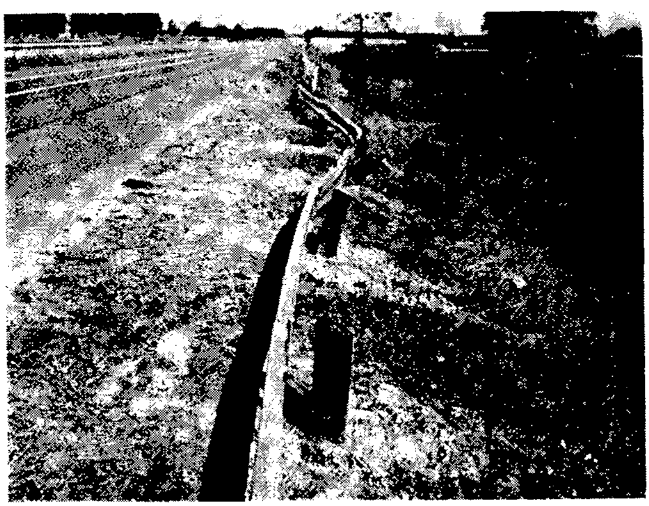


Figure 40.

1958 Car - Guardrail Impact Tests 9-25-58

Beam Type Guardrail (10 guage) - mounted on spring brackets

Posts - 6" x 8" Pre Cast Concrete 6' 0" long

Speed - 64.8 mph, Impact Angle 20.5°

Vehicle - 1958 Pontiac 4 Dr. Ht. - Wt. 4085 lbs.
Estimate of Damage: $450.00

Dummy Injury - none used

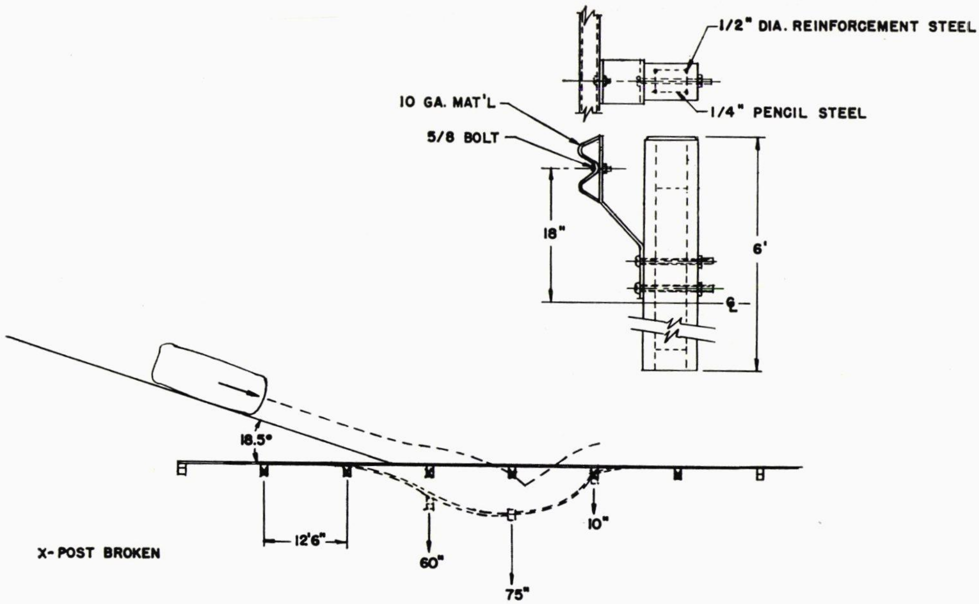
Guardrail Damage - six posts
four sections of rail

Vehicle Deceleration - Longitudinal: 9.3 G's
Transverse: 6.4 G's

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied Prior to Impact

Run No. 529



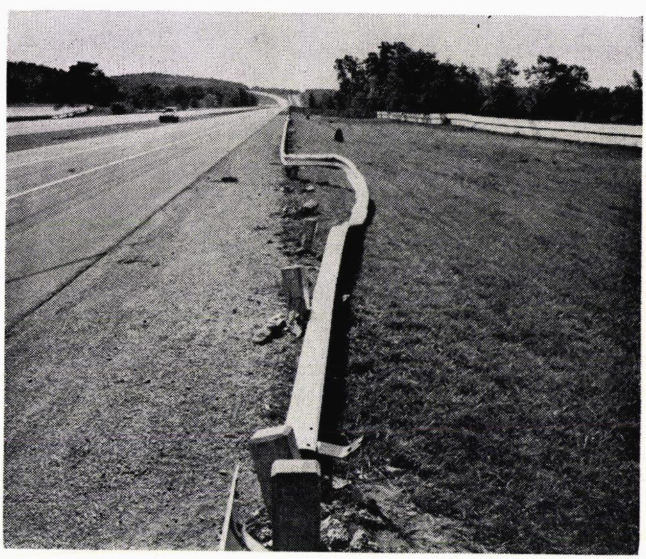


Figure 41.

1958 Car - Guardrail Impact Tests 9-25-58

Beam Type Guardrail - mounted on spring brackets

Posts - 6" x 8" Pre Cast Concrete 6' 0" long

Speed - 66.9 mph, Impact Angle 18.0°

Vehicle - 1958 Pontiac 2 Dr. Ht. - Wt. 4210 lbs.
Estimate of Damage: $300.00

Dummy Injury - none used

Guardrail Damage - four posts
three sections of rail

Vehicle Deceleration - Longitudinal: 12.9 G's
Transverse: 11.5 G's

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied after Impact

Run No. 530

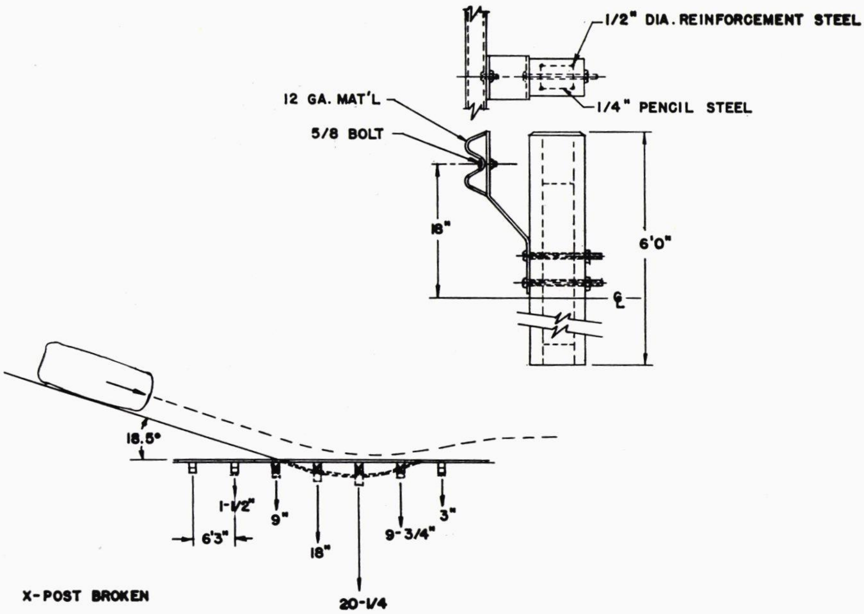


Figure 42.

1958 Car - Guardrail Impact Tests 10-6-58

Standard Tuthill Guardrail

Posts - 6" x 8" Pre Cast Concrete 6' 0" long

Speed - 34.5 mph, Impact Angle 20°

Vehicle - 1957 Pontiac 4 Dr. Ht. - Wt. 4058 lbs.
Estimate of Damage: $150.00

Dummy Injury - none used

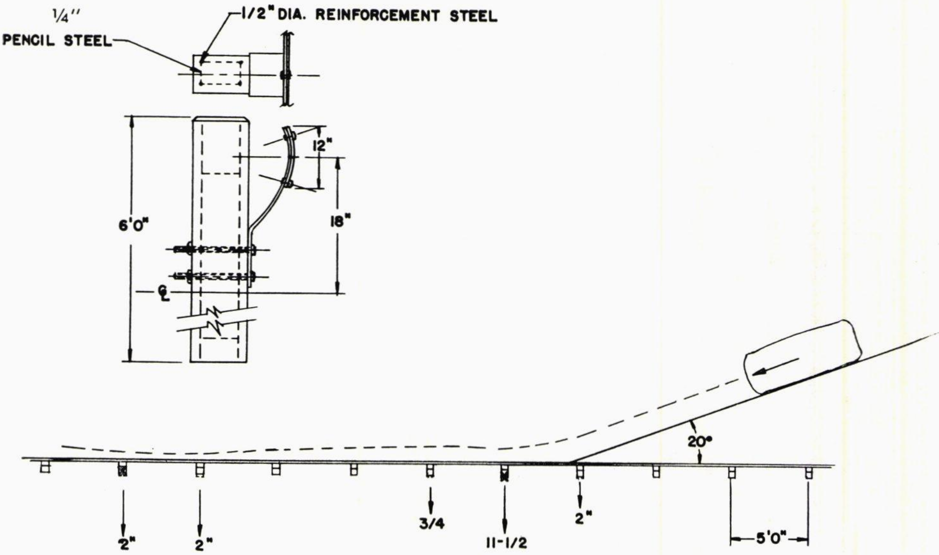
Guardrail Damage - two posts
one section of rail

Vehicle Deceleration - Longitudinal: 7.1 G's
Transverse: 4.0 G's

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied after Impact

Run No. 531



X POST BROKEN

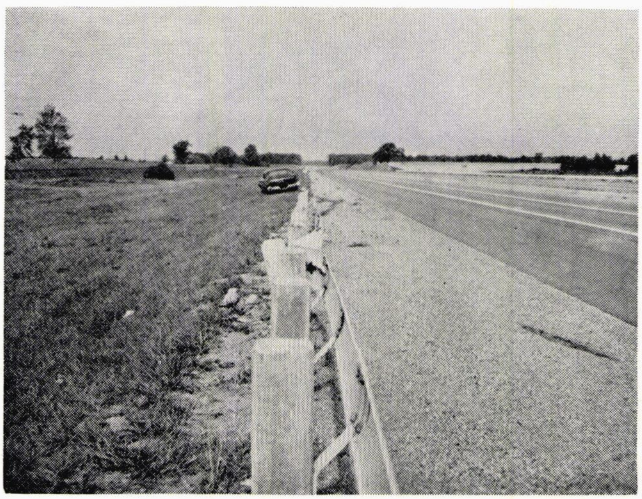


Figure 43.

1958 Car - Guardrail Impact Tests 10-17-58

Beam Type Guardrail

Posts - 6" x 8" wood 6' 2" long

Speed - 39.0 mph, Impact Angle 0°

Vehicle - 1956 Pontiac 4 Dr. Ht. - Wt. 4033 lbs.
Estimate of Damage: Total Loss

Dummy Injury - none used

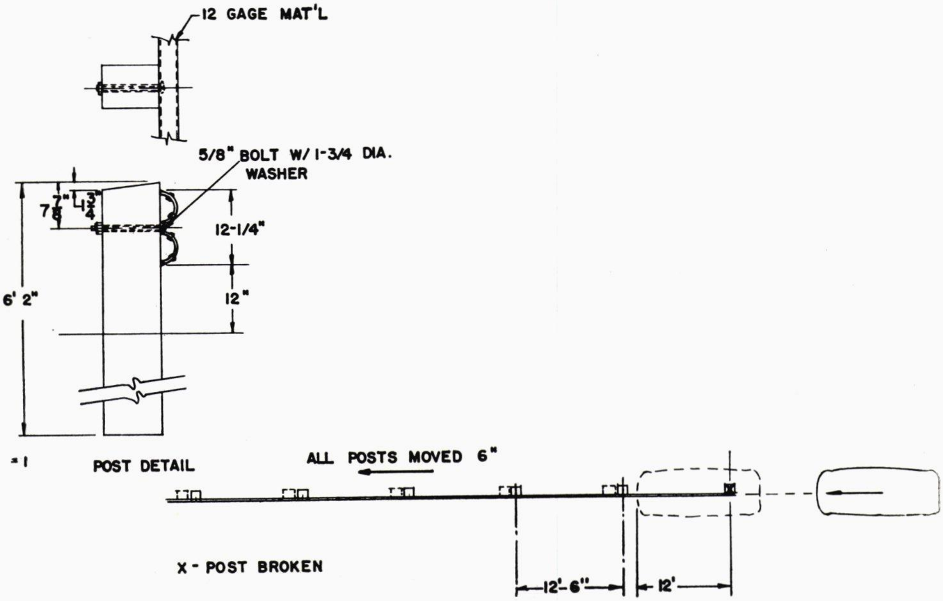
Guardrail Damage - one post
one section of rail

Vehicle Deceleration - Longitudinal: 18.0 G's
Transverse: 5.2 G's

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied after Impact

Run No. 535



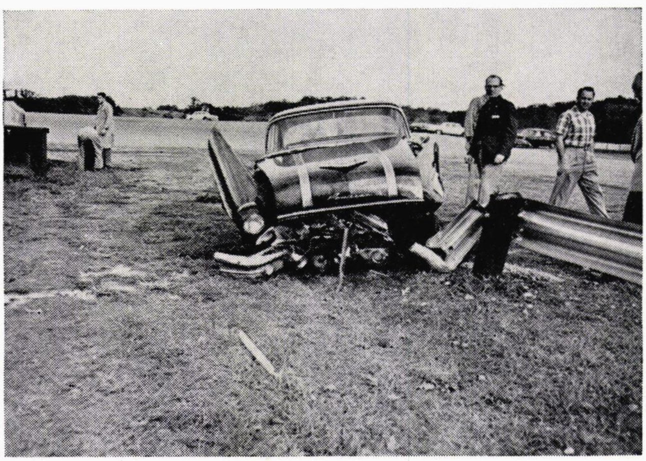


Figure 44.

1958 Car - Guardrail Impact Tests 10-31-58

Special Curved End Section Beam Type Guardrail

Posts - 6" x 8" wood 6' 2" long

Speed - 41.0 mph, Impact Angle 0°

Vehicle - 1957 Pontiac 4 Dr. Ht. - Wt. 4058 lbs.
Estimate of Damage: $300.00

Dummy Injury - none used

Guardrail Damage - two sections of rail

Vehicle Deceleration - Longitudinal: 10.0 G's
Transverse: 6.8 G's

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied after Impact

Run No. 536

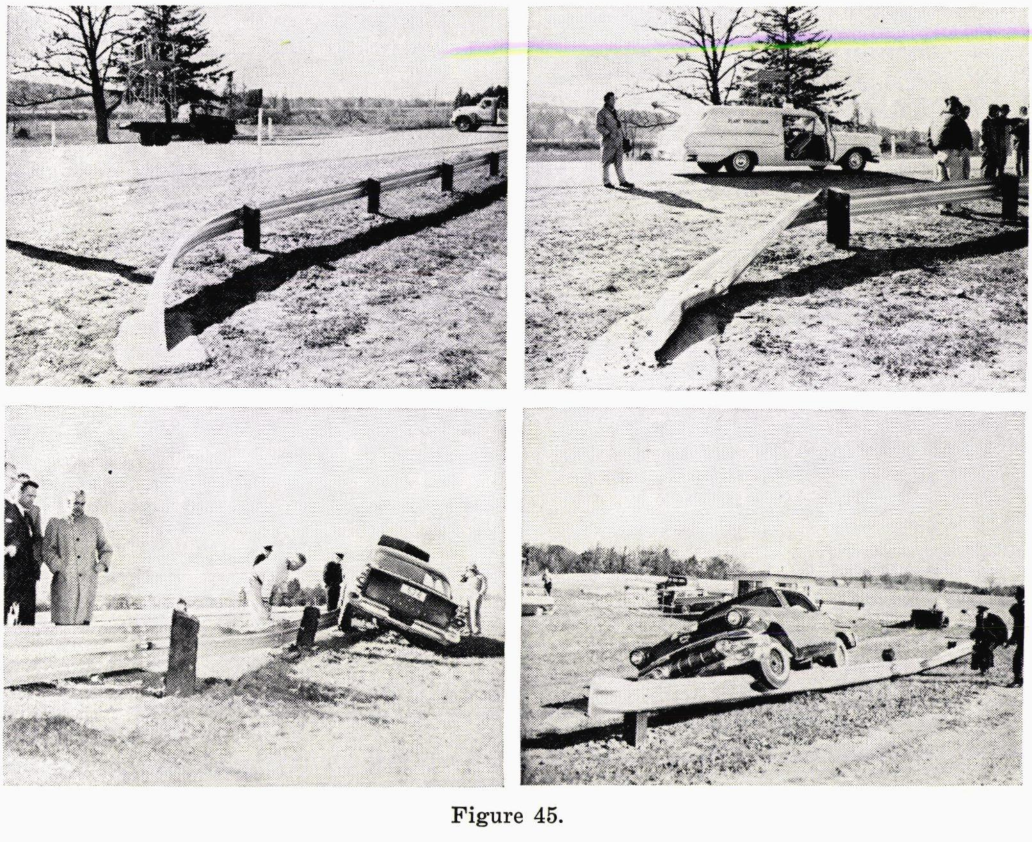


Figure 45.

1958 Car - Guardrail Impact Tests 11-10-58

Tuthill Guardrail - mounted directly on post

Posts - 6" x 8" Pre Cast Concrete 6' 0" long

Speed - 32.4 mph, Impact Angle 20°

Vehicle - 1957 Buick 4 Dr. Ht. - Wt. 4317 lbs.
Estimate of Damage: $200.00

Dummy Injury - none used

Guardrail Damage - two posts
three sections of rail

Vehicle Deceleration - Longitudinal: 16.5 G's
Transverse: 11.7 G's

Ground Condition - Glacial Till: Dry

Vehicle Brakes Not Applied

Run No. 538

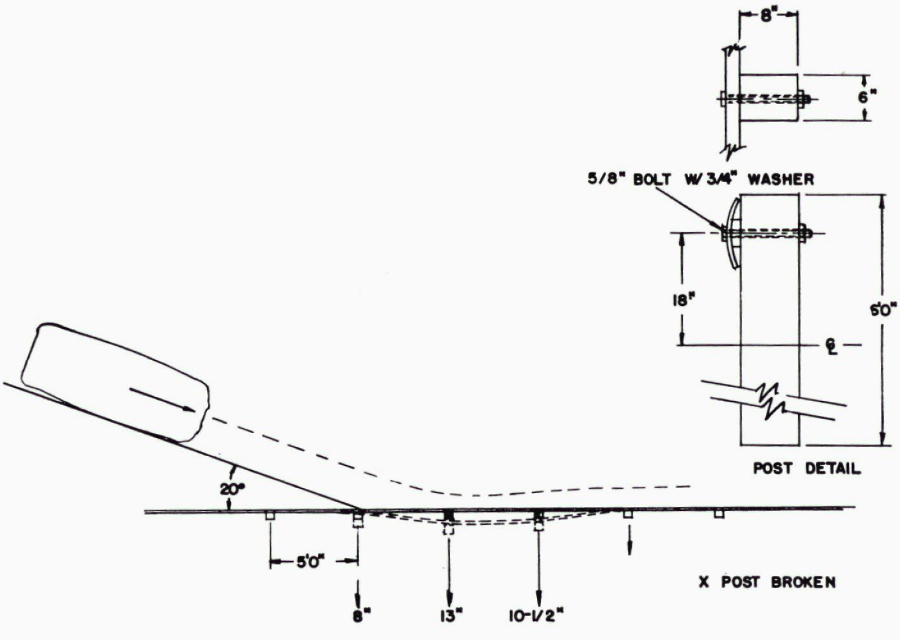


Figure 46.

1958 Car - Guardrail Impact Tests 11-20-58

Beam Type Guardrail

Posts - 6" x 8" Pre Cast Concrete 6' 0" long

Speed - 27 mph, Impact Angle 15°

Vehicle - 51 Passenger Bus - Wt. 23,590 lbs.

Dummy Injury - none used

Guardrail Damage - three sections of rail

Vehicle Deceleration - instrumentation failure

Ground Condition - Glacial Till: Dry

Vehicle Brakes Not Applied

Run No. 539

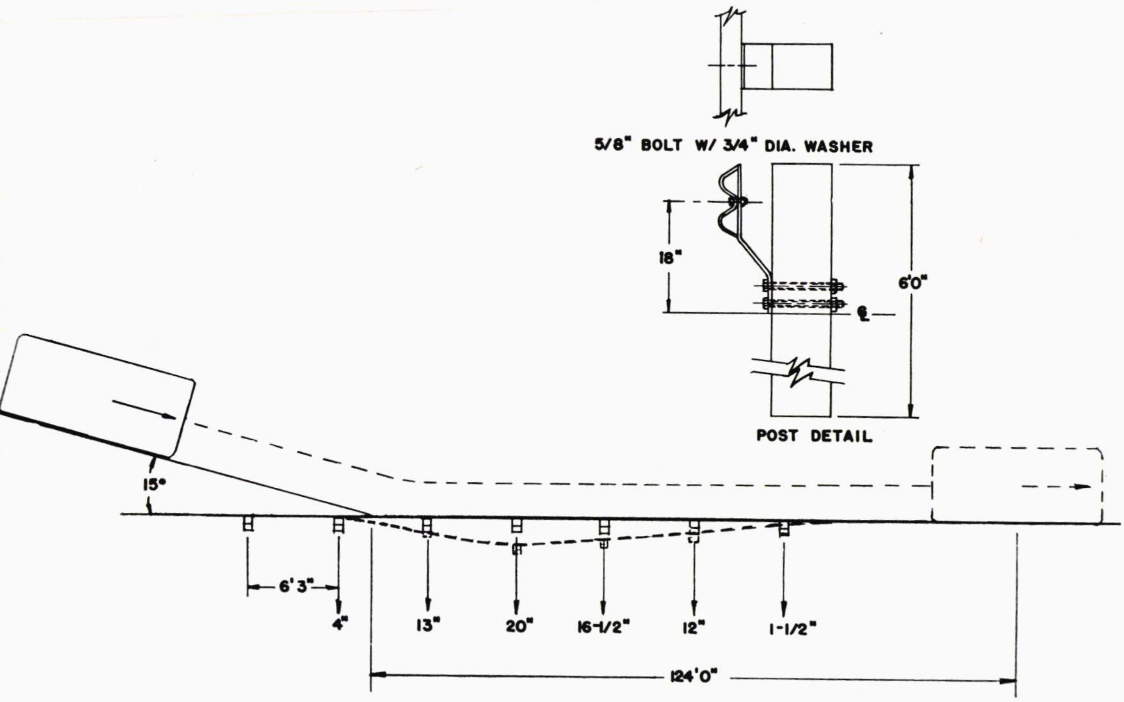


Figure 47.

1958 Car - Guardrail Impact Tests 11-25-58

Beam Type Guardrail

Posts - 6" x 8" Pre Cast Concrete 6' 0" long

Speed - 40.0 mph, Impact Angle 15°

Vehicle - 51 Passenger Bus - Wt. 23,590 lbs.

Dummy Injury - none used

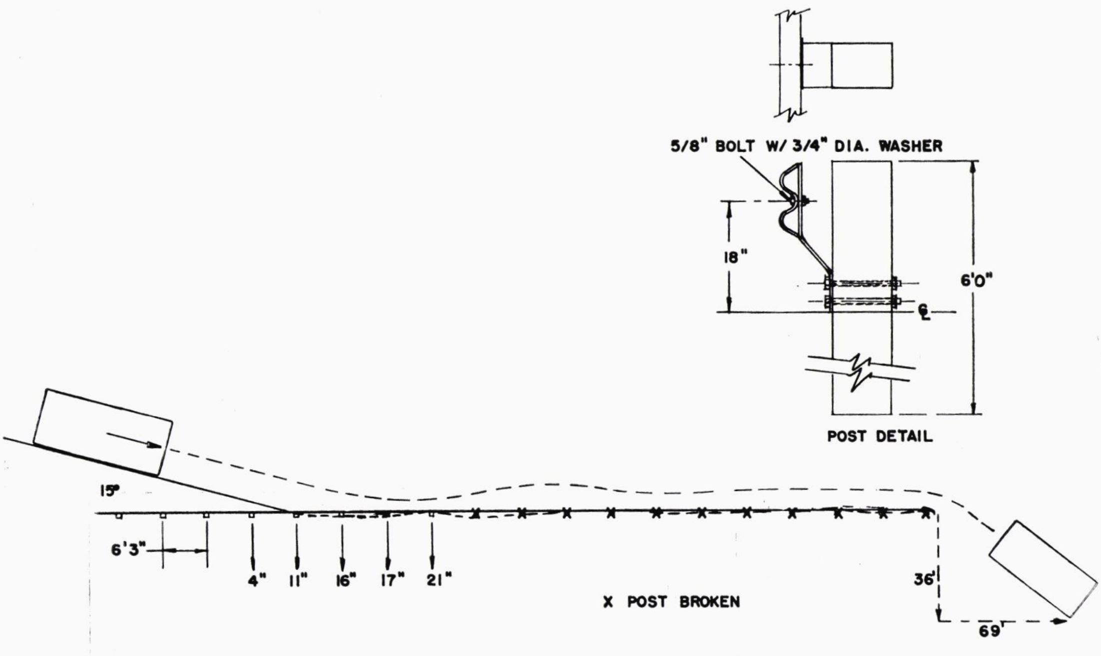
Guardrail Damage - eleven posts
six section of rail

Vehicle Deceleration - Longitudinal: 8.8 G's
Transverse: 5.0 G's

Ground Condition - Glacial Till: Dry

Vehicle Brakes Applied After Impact

Run No. 540



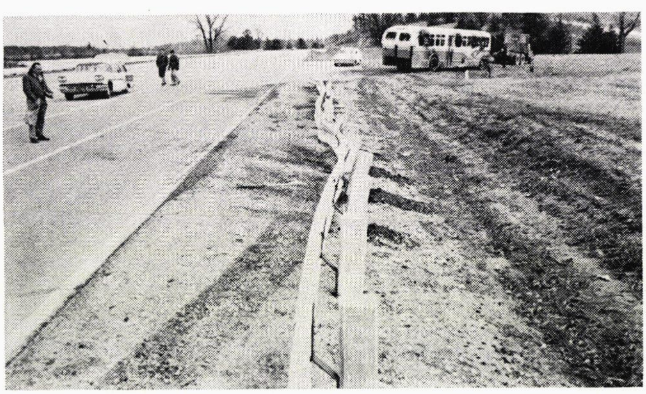


Figure 48.

1958 Car - Guardrail Impact Tests 12-26-58

4 Cable Guardrail

Posts - 6" x 4" x 8-1/2 lb. per ft. I Beam 5' 9" long

Speed - 61.5 mph, Impact Angle 20°

Vehicle - 1958 4 Dr. Oldsmobile - Wt.
Estimate of Damage: $700.00

Vehicle Brakes Applied just after Impact

Dummy Injury - none used

Guardrail Damage - 3 cables broken
4 posts

Vehicle Deceleration - Longitudinal: 7.0 G's
Transverse: 6.0 G's

Ground Condition - frozen 18" deep

Run 542

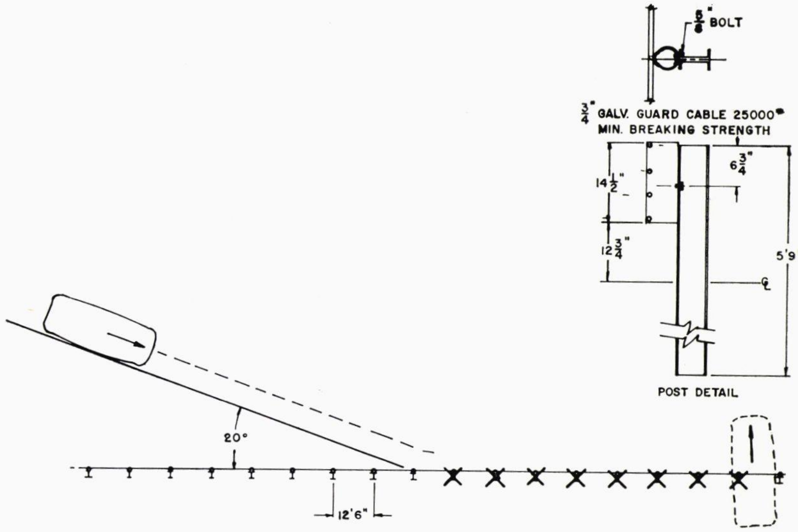


Figure 49.

1959 Car - Guardrail Impact Tests 3-4-59

Sloped End Section Beam Type Guardrail

Posts - 6" x 8" Wood 6' 2" long

Speed - 50 mph, Impact Angle 0°

Vehicle - 1958 Oldsmobile 2 Dr. Ht. - Wt. 4528 Lbs.
Estimate of Damage: $300.00

Dummy Injury - none used

Guardrail Damage - six posts

Vehicle Deceleration - instrument failure

Ground Condition - Glacial Till - 18" frozen layer 1" below surface

Vehicle Brakes Applied after Impact

Run No. 543

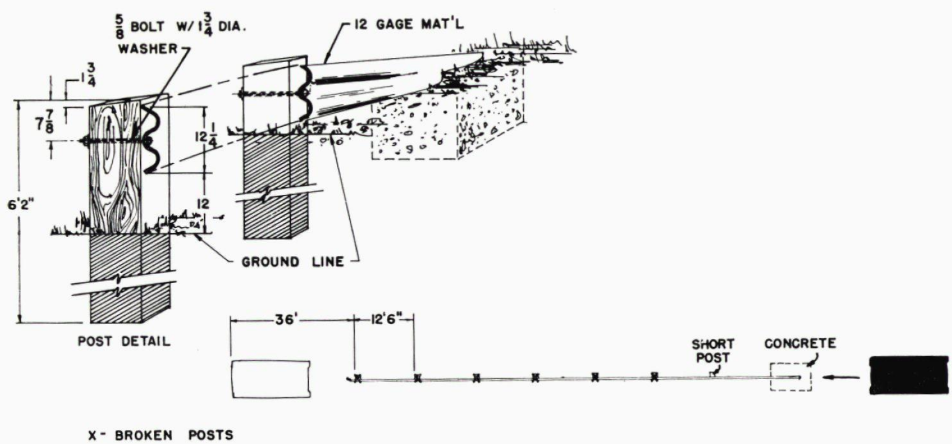


Figure 50.

1960 Car - Guardrail Impact Tests 5-24-60

Chain Link Cable Type Guardrail

Posts - 2-1/4 in. H Section 4.1 lb/ft

Speed - 65 mph, Impact Angle 16.7°

Vehicle - 1960 Pontiac 2 Dr. Ht. - Wt. 4190 lbs
Estimate of Damage: $500.00

Dummy Injury
Right Front - Minor Cuts
Left Rear - Scalp Laceration

Guardrail Damage - 14 Posts
100 ft. Fence
1 Concrete Deadman

Vehicle Deceleration	Peak g	Average g
Longitudinal	4.5	1.6
Transverse	5.0	1.6

Ground Condition - Glacial Till: Dry

Vehicle Brakes Not Applied

Run No. 591

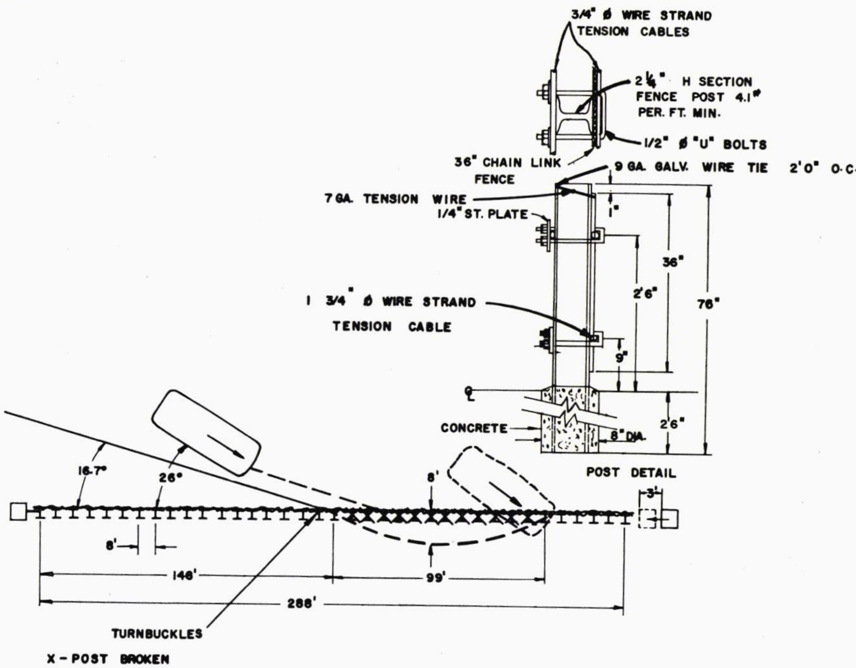


Figure 51.

1960 Car - Guardrail Impact Test 6-3-60

Chain Link Cable Type Guardrail

Posts - 2-1/4 in. H Section 4.1 lb/ft

Speed - 65 mph, Impact Angle 8.0°

Vehicle - 1957 Cadillac 4 Dr. Ht. - Wt. 4922 lbs.
Estimate of Damage - Total Loss

Dummy Injury - No Dummies Used

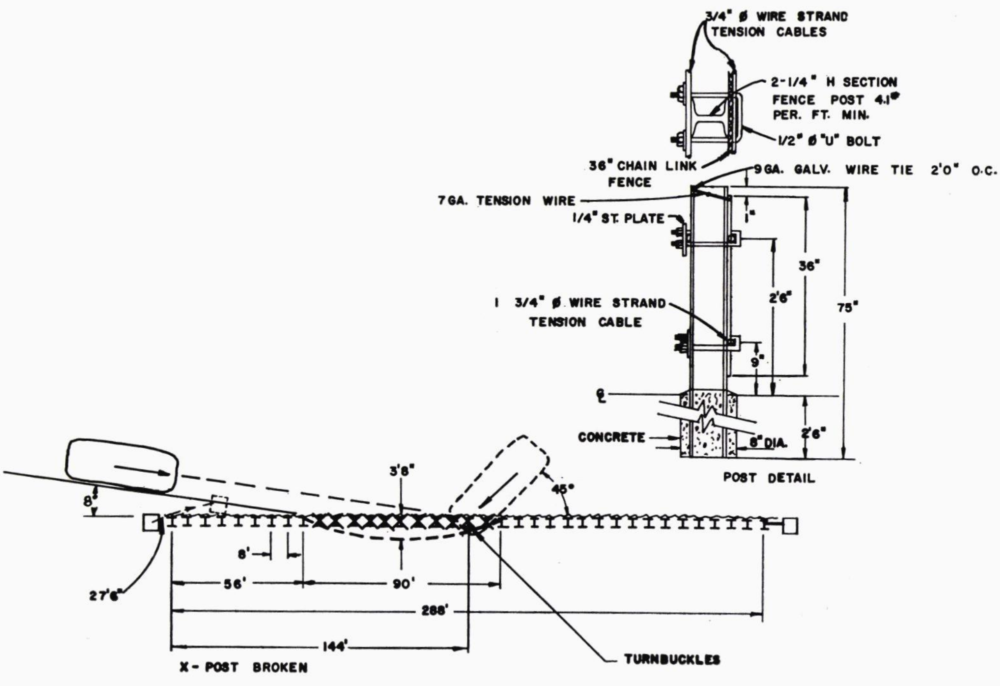
Guardrail Damage - 13 Posts
90' of Fence
1 Deadman

Vehicle Deceleration	Peak g	Average g
Longitudinal	34	1.5
Transverse	4.5	2

Ground Condition - Glacial Till: Dry

Vehicle Brakes Not Applied

Run No. 593



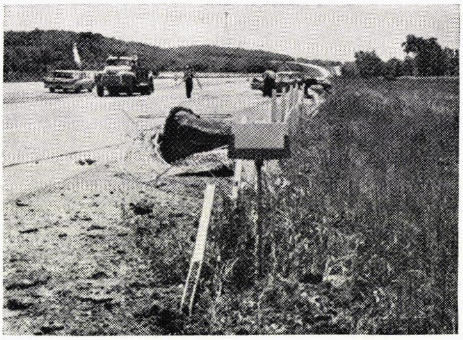


Figure 52.

1960 Car - Guardrail Impact Tests 6-23-60

Chain Link Cable Type Guardrail

Posts - 2-1/4 in. H Section 4.1 lb/ft

Speed - 35 mph, Impact Angle 8.5°

Vehicle - 1960 Pontiac 2 Dr. Ht. - Wt. 3870 lbs
Estimate of Damage: $500.00

Dummy Injury - None Used

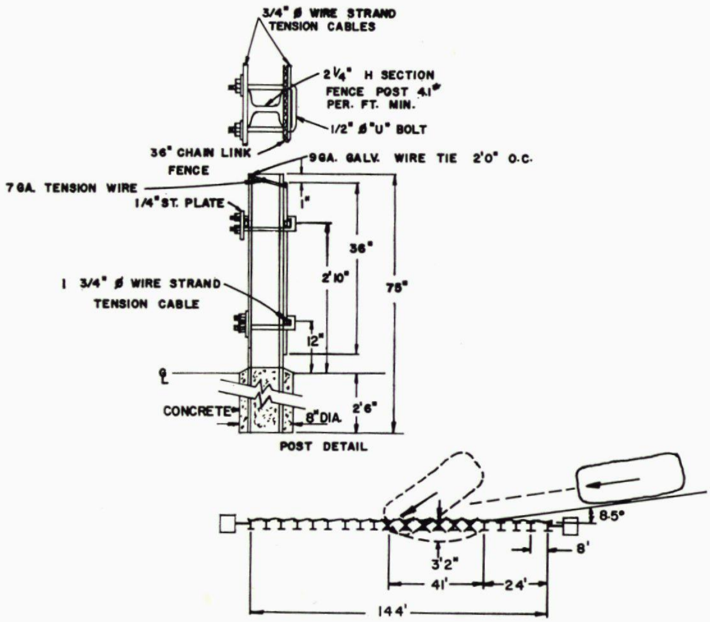
Guardrail Damage - 6 Posts
41 ft. Fence

Vehicle Deceleration	Peak g	Average g
Longitudinal	3.8	1.0
Transverse	2.6	.6

Ground Condition - Glacial Till: Dry

Vehicle Brakes Not Applied

Run No. 596



X - POST BROKEN

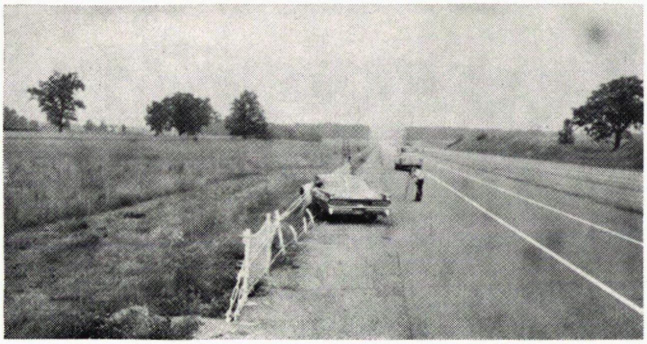


Figure 53.

1960 Car - Guardrail Impact Tests - 7-20-60

Beam Type Guardrail

Posts - 8" x 8" and 6" x 8" Wood 6' 2" Long

Speed - 65 mph, Impact Angle 25°

Vehicle - 1958 Chevrolet 4Dr. - Wt. 3963 lbs
Estimate of Damage: Total Loss

Vehicle Brakes Applied After Impact

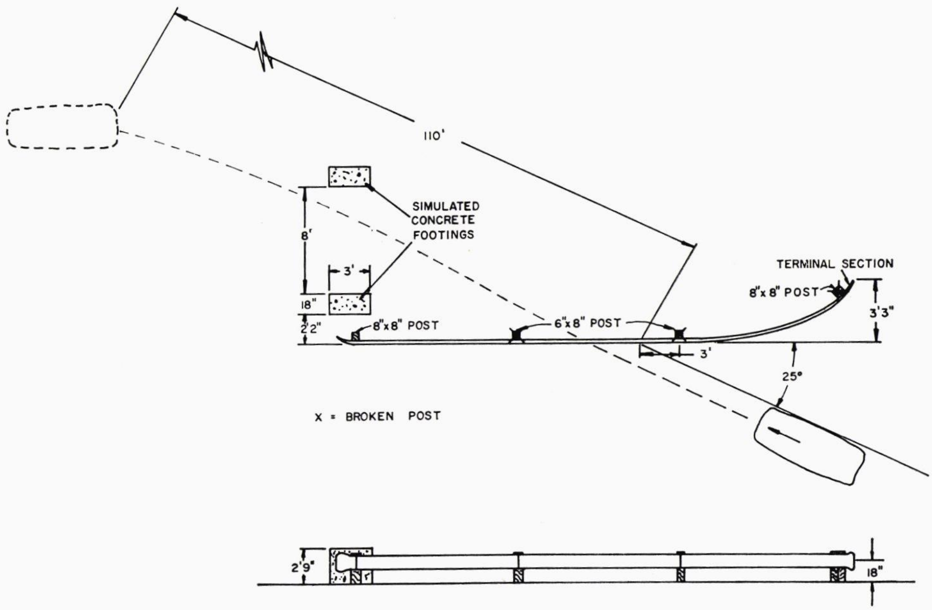
Dummy Injury - None Used

Guardrail Damage - 2 posts
3 sections of rail

Vehicle Deceleration - Longitudinal: 10.1 G
Transverse: 8.0 G

Ground Condition - Glacial Till: Dry

Run No. 601



NOTE:
3 SECTIONS 12'6" LONG
DEEP BEAM GUARD RAIL

SCALE - 1" = 6'

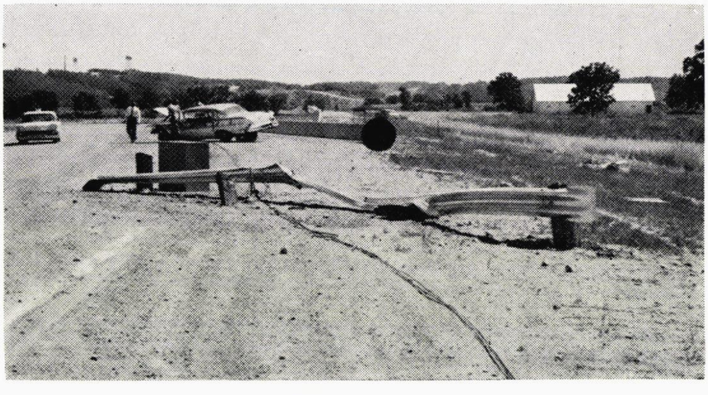


Figure 54.