REPORT OF COMMITTEE ON HIGHWAY GUARD

Tests and Studies, 1924-1941

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SYNOPSIS

This report is presented for the purpose of recapitulating the work that has been done in the development of the highway guard through its various stages up to the present time

Tests on highway guard are of two general types (1) development tests or those leading to the development or improvement of a particular type or design, and (2) differentiating tests in which several types or designs are checked against each other and their performance noted. In either case the field test correlated with laboratory control tests represents the desirable method of approach

The generally accepted field test consists of projecting a free running, driverless automobile (car, bus or truck) down an incline and into a short section of guard, at an angle of 20 deg. at various speeds, and noting the reaction of the structure and vehicle to impact.

Data necessary for rational design are now available and should be applied The report also presents the Committee's views on future work which is highly essential if this phase of highway construction is to keep pace with the development of the modern high speed highway.

A summation of the development of the highway guard must be general in nature. No attempt is made at drawing conclusions, other than to cite those of the individual investigators, which may or may not, apply at the present time due to subsequent developments and tests Individual tests play a very important part in formulating conclusions and observation is a deciding factor.

Still pictures and descriptions of reactions may depict a certain point but on final analysis are inadequate. Fortunately a majority of the tests have been recorded in both regular and slow motion pictures. For detailed study a perusal of the various reports together with observation of the motion pictures is recommended.

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SUMMARY OF TESTS

Pennsylvania Field Tests—1924, 1925, 1926, and 1927 (1)[2]

These are the earliest tests of which records are available. The Public Roads Administration, then the Bureau of Public Roads, cooperated in the 1924 tests

These tests started as differentiating tests in order to determine the most suitable type for development The types tested consisted of wire, wire rope (cable) and wood. After a series of elimination tests it was decided to develop the two cable type.

[1] Various angles of impact were used in the early tests, but it is now generally accepted that 20° represents the average angle of impact between vehicle direction and guard under actual service conditions

[2] Numbers in parentheses refer to list of references at end

The tests brought about the following changes:

1. Placing the cable in front rather than through the posts—attaching same with J bolts.
2. Changing the design and strength of fittings.
3. Using 1-in. cable in upper line and ¾-in cable in lower line.
4. Changing the design of the deadman anchorage.
5. Using anchor rods in place of cable.
6. Introducing the use of offset attachments.
7. Increasing the combined strength of the cables from 26,000 lb minimum to 43,000 lb. maximum.

This design in one form or another was adopted as standard in many states.

Period Between 1930 and 1935

The period between 1930 and 1935 saw an intense development in highway guard, induced by the rapid increase in improved highway mileage. During this period we experienced the further evolution of the cable guard and the introduction of steel plate, woven wire mesh, steel beam, wire tape, steel strip and others; also departure from the rigid offset attachment between the rail member and the post through the introduction of the spring or resilient offset. In attempting to evaluate the various designs some highway engineers resorted to overall tensile strength tests in the laboratory, others to field tests, or a combination of both. Practical experience has taught that the field test is the desirable one.

Georgia Field Tests—1933 (2)

These consisted of a series of differentiating tests conducted on the following types of rail:

1. A 4 by 4-in. wooden rail with metal face plate.
2. Steel fabric 14 in. wide.
3. Two strands of steel fabric 4½ in. wide.
4. One strand of steel fabric 4½ in. wide.
5. Two strands of wire tape 2½ in. wide.
6. Two 1-in cables.
7. Four ¾-in steel rods.
8. Two steel strips 2½ in wide.
9. Six different types of steel plate rail.

The conclusions arrived at by the Georgia Highway Department follow.

"The discussion of the results of these tests will be limited to general observations rather than specific comparisons of the various types of rail

"The 6 by 8-in and 7-in diameter pine timber posts 7 ft long and buried not less than 4 ft in the ground had ample strength to carry the rail tested Only four posts were broken and five posts were split in the 40 impacts Two of the broken posts may be considered faulty Timber equivalent in quality to 'structural square edge and sound' grade of the Southern Pine Association should be used

"Posts should not project above the rail any further than is necessary The fenders of cars, and bodies of trucks project over the top of the rail and these projections strike the part of the posts above the rail as the vehicle glides along the face of the rail.

"Where bolts fastening the rail to the posts are less than 6 in below the top of the posts, provision preferably should be made to strengthen the post against splitting by a small bolt through the post near the top parallel to the rail

"The end braces and bearing blocks on the two end posts used in these tests provided good end anchorage While the end posts moved slightly in some of the tests the movement was not sufficient to materially affect the results.

"Properly designed off-set fittings at the posts lessen the damage to both rail and vehicle They serve as cushions between the vehicle and the posts and the spring action tends to help the vehicle pass the post Rigid off-set fittings or fittings with corners or angles damage both vehicle and rail.

"Off-set fittings at the posts should be protected from a direct blow from the vehicles, and if they carry multiple element rails should prevent the different strands from spreading apart.

"Rails without off-set fittings at the posts are effective in many cases, but the damage to both rail and vehicle, in case the rail is struck, will be greater than if cushioning off-set fittings are provided.

"Where the rail is fastened directly to the posts round posts give best results as they do not form sharp corners in the rail when the vehicle presses it back This statement, of course, does not apply to the wooden rail

"The point of impact is uncertain and the part of the vehicle which will slide against the rail varies widely with the different makes of vehicles These conditions are inherent with the variety of traffic to be expected on the highways To meet these conditions a rail should develop as much strength as possible, regardless of where it is struck and give a smooth sliding surface covering a wide area For these reasons the wide single element rail types have some advantages Where ample provision is made for fastening the separate strands of a multiple element rail so that they will act together these types are improved.

"The edges of all plate types of rail should be rounded Only one tire or body was cut by the edge of a rail plate in the 18 tests of this type, and this occurred on a plate rail with a sheared edge

"Multiple element rails give best results when the elements are fastened together In quite a number of the tests on the two element rails (strip and tape) the wheel of the vehicle was forced between the strands passing over the bottom strand In later tests when the two strands were fastened together by light ties much better results were secured

"A narrow single element rail will not prevent the vehicle from striking the posts. The wheel of the vehicle will generally be forced under the rail and will be guided into the post. This type of rail affords some protection in preventing the vehicle from going over the embankment, but damage may generally be expected

"The steel for guard rail materials should have toughness as well as strength—brittleness being avoided by proper composition of the steel and its heat treatment"

Toncan Field Tests—1933 (3)

These consisted of a series of differentiating tests on various types of guard and a series of development tests on steel plate guard Tests were conducted on the following types of rail:

1. Two different types of steel plate rail.
2. Woven wire mesh.
3. Two cable (¾-in. and 1-in.).
4. Plank and one cable (¾-in.).
5. Wire fabric.

The summary given by the Pittsburgh Testing Laboratory follows:

"Keeping in mind the condition of the vehicles used in these tests, the speeds obtained and the amount of damage done to both the barriers and the vehicles, these tests very clearly indicate that the heavy gauge steel panel type of barrier with adequate end anchorage and intermediate posts which will bend or break not only has the capability and inherent strength to withstand such violent impact but this type of barrier also embodies in its design sufficient resiliency to deflect the moving vehicle and provide more assurance against damage, on the average, than any of the other types tested"

Missouri Field Tests—1934 (4)

These consisted of a series of differentiating tests conducted on the following types of rail:

1. Wire rope, 2-strand—3 types.
2. Wire tape, 2-strand—2 types.
3. Wire tape, 4-strand—1 type.
4. Steel plate—8 types.
5. Steel plate beam—3 types.
6. Woven wire mesh—3 types.
7. Steel plate and wire rope—1 type.
8. Chain link (wire)—1 type.

Conclusions drawn by the Missouri State Highway Department follow:

"Under the conditions of these tests, the single element steel plate rails which were sufficiently strong to withstand the impact force applied were the most satisfactory. These rails prevented the cars from leaving the roadway, deflected them into a path parallel to the rail for a sufficient interval to give the driver some chance to regain control of the car, and decelerated the cars gradually enough that there was small probability of serious injury to the occupants. Furthermore, they did the least damage to the car and seemed to be in more serviceable condition after impact.

"There is an indicated difference in the serviceability of these plate rails, relative to each other, but corroborative tests would be necessary before this difference could be evaluated or considered a proven fact."

Texas Field Tests—1934

A series of field tests were conducted by the Texas State Highway Department which have not been reported.

"Preliminary Analysis of Highway Guard Rails"—1936 (5)

A summation and analysis of all available types of guard including their function, design and location was compiled by the Division of Design of the Public Roads Administration. This covered all types from earth mounds to the latest design as of that date.

The conclusions arrived at follow:

"At the present time the great number of guard rails offered for consideration may result in so many different types of guard rails being used in a State that maintenance may become difficult and expensive An adequate reserve of parts for a number of different rails requires a large investment in replacement stocks. Some parts may have to be procured at one source of manufacture which invites high prices and often results in delay

"A great number of different guard rails does not result, necessarily, in real competition. The service to be expected from each guard rail cannot be determined precisely. Under these conditions administrative officials charged with the responsibility of selecting guard rail types on which to receive bids may be unduly influenced by the claims of manufacturers respecting a particular type of rail which may give little if any better service than other types which are not included in the call for bids.

"The details of the various guard rails in the same category often are so nearly alike that little difference may be expected between the behavior of one rail and that of another. This is particularly true of full floating, semi-floating, and non-floating resilient plate rails It is also true to a lesser degree of rails of other categories Open competition may be obtained by limiting guard rail types in any project to one category but permitting the use of all rails meeting the specifications of that category. By this method, however, all the economies and advantages of standardization are lost. A standard rail, on the other hand, would be but little different from any one of the rails meeting the specifications of that category. Competition may be obtained if all manufacturers are permitted, by patent agreements or otherwise, to manufacture the standard rail.

"In general standardization results in lower initial cost. Standardization leads to quantity production which makes it economically advisable for manufacturers to invest in dies, templates, and other cost saving equipment and to routine the supply of material and the fabrication of the rail. This results in the lowest possible cost With the possibility of forecasting orders with some degree of accuracy, production for stock may be undertaken Costs of erection would tend to be lowered as erection crews become familiar with the erection of a standard rail and the purchase of special tools and equipment would be justified.

"Lower maintenance costs also result from standardization. Investment in replacement parts would be required only for the standard rail and stocks could be kept to the minimum because of the large number of sources from which parts could be obtained and the probability that parts would be stocked by manufacturers Maintenance labor cost would tend to be lowered as maintenance crews became familiar with the standard rail and the purchase of special repair tools would be justified

"Standardization would result in a more satisfactory and serviceable rail. The use of dies, made possible by quantity production, results in more accurate work and better fitting. Splices, for example, fit better when both sets of holes are punched in multiple with the same die than when holes are punched individually. At the present time the multiplicity of types of rails makes it necessary for erection and maintenance crews to familiarize themselves with the details of so many rails that they may not learn thoroughly the details of any one rail. Some rails require greater initial tension than others Some rails are affected by temperature changes more than others and more care must be exercised in adjusting to the prevailing temperature. Erection and maintenance crews naturally would become thoroughly familiar with a standard rail resulting in more accurate erection and adjustment

"The service records of a standard rail would be much more complete and cover more rail than any one of a number of different rails Improvements would suggest themselves, be tried, and if found satisfactory applied to all rails On the other hand improvements in one type of rail may or may not improve another type of rail

"While competition between categories often may be obtained by permitting rails of one category to compete with those of other categories, the advantages of standardization would be lost since different type rails may be bid successfully on different sections of highway. In addition a comparison of the services which may be expected from rails of different categories cannot be made readily with our present knowledge and experience so that the rail of lowest cost may not give the greatest service per unit of cost

"The ultimate goal should be a minimum number of standard rails which will give wholly satisfactory service for the conditions of usage and which can be obtained from a number of manufacturers on a real competitive basis."

"Report of Problem Committee on Guard Rail," American Road Builders' Association—1938 (6)

By this time, with the constantly increasing numbers of types and designs, the matter of standardization became one which could no longer be overlooked. This is evident in the conclusions of the foregoing analysis and mirrors the thought of the highway field. The Problem Committee on Guard Rail of the A. R. B. A, composed of producers and users of highway guard, made an effort with this objective in mind.

While the resulting report cannot be regarded as an ideal in standardization, the fact remains the committee was successful in standardizing a number of essential features in several designs, which represents a start in the right direction.

"Design Loads for Guardrails," by Joseph Barnett—1939 (7)

This paper presents a rational approach to the design problem, augmented by a background of empirical data on the weight, type and speed of motor vehicles common to the highways of the United States, thereby eliminating the element of guess as to the types of vehicles and the proportion of these types of vehicles, all of which data are highly important in guard design.

His conclusions follow:

"Based on the data shown herein it is recommended that guardrail to resist motor vehicle traffic be constructed with the center about 19 in above ground to resist the following weights and speeds of vehicles approaching the guardrail at an angle of 16 deg (see Table 1)

"A guardrail designed for passenger vehicles in accordance with Table 1 will resist 90 per cent of all passenger vehicles at the indicated speeds and practically all passenger vehicles at 95 per cent of the indicated speeds. It will resist very few busses Allowing for a reduction of 20 per cent in the speed it will resist only 50 per cent of single unit trucks and very few semi-trailers and full trailers

"A guardrail designed for busses in accordance with the above will resist two-thirds of all busses at the indicated speeds and 90 per cent of all busses at 91 per cent of the indicated speeds It will resist all passenger vehicles. Allowing for a reduction of 20 per cent in the speed it will resist practically all single unit trucks, about 80 per cent of semi-trailers and 50 per cent of full trailers.

TABLE 1
(From Design Loads for Guard Rails—Barnett)

Type of vehicle	Weight in pounds	Speed of vehicle — Design speed of road: 60 and 70 m p h	30, 40 and 50 m p h
Passenger vehicles	4,000	50	40
Busses	20,000	50	40
Trucks	14,000	40	32

"A guardrail designed for trucks in accordance with the above will resist 90 per cent of all single unit trucks at the indicated speeds and practically all single unit trucks at 80 per cent of the indicated speeds It will resist only 28 per cent of semi-trailers and 20 per cent of full trailers It will resist all passenger vehicles. Allowing for the greater speed of bus travel it will resist only about 25 per cent of all busses"

"Discussion on Design Loads for Guardrails," by A. E. Brickman—1939 (11)

In this discussion various reactions, as noted in the tests on cable guard, are cited. These include cable tension, end post and anchor stresses, etc., from which was prepared "a mathematical functional analysis of the guard in a cycle of impact."

Oregon Field Tests—1940 (8)

These represented development tests on the wood beam rail and on account of its recent development and importance at the present time, it will be dealt with somewhat at length.

Quoting from the report of Bishop and DeFrance: "When the search for the best type of guard rail began, metal, concrete, and timber construction were considered. The plentiful supply of structural timber available locally gave this material special advantages and the study soon focused on the most effective timber design, particularly the method of attaching a horizontal rail to posts with a type of connection that would have the necessary strength without undesirable rigidity."

The tests were conducted as follows, again quoting, "In the tests made in the Salem yard, a truck weighing 8,850 lb. was driven against the section of guardrail at angles of incidence ranging from 15 to 45 deg. and at speeds of 5 to 20 miles per hour. The following is a summary of results:

1. At small angles of incidence, elastic rebound was sufficient to deflect the truck into a position roughly parallel with the fence. As the angle of incidence increased, the horizontal timber rail failed under impact.
2. Brackets and the timber beam both deflected noticeably under load but returned to their original position for all loads that did not cause failure of the rail.
3. Vertical posts were displaced by collision and showed but little elastic recovery, even under the low speed impacts, and smaller angles of incidence.
4. The steel brackets showed marked deflection in all cases although in the lighter impacts they were not forced against the posts. For the higher speeds and larger angles of incidence, the vertical posts were definitely indented or marked by the deflecting brackets, indicating that the full spring effect had been used.
5. The ¾-in. bolts that fastened brackets to posts appeared adequate in tension; however, a noticeable crushing of the timber was observed under washers on the rear face, indicating need for a plate washer large enough to insure better bearing.

As the series of tests was rather limited in scope, definite conclusions should not be made too sweeping, however, an analysis of observed results, in connection with the service record of the various field installations, warrants the following general statements.

1. Because of its greater visibility and strength, the 6 by 10 in horizontal rail member consisting of two plies of 3 by 10 in plank is the preferable rail construction
2. Use of the spring-steel-bracket mounting is warranted because of its distinct shock-cushioning advantage The action of the brackets in deflecting the path of the vehicle into approximate parallelism with the fence line is a distinct advantage and safety measure Also, this type of mounting transmits and distributes impact stresses to a number of posts.
3. The attachment of the spring brackets to the vertical posts at a point close to the ground tends to reduce bending moment in the posts
4. The marked displacement of the vertical posts (which appeared roughly proportionate to impact) emphasizes the need for extreme care in setting them in the ground For some time an asphaltic gravel mixture has been used in Oregon for backfilling around guardrail posts and results indicate that such a precaution is warranted

Note: These tests led to a special specification for the spring steel post brackets The brackets are cantilever in shape and action.

"Report on Erection and Maintenance of Highway Guard," American Road Builders' Association—1940 (9)

The types covered are contained in Bulletin No. 53 of the American Road Builders' Association (reviewed previously), which is supplemented by A. R. B. A. Bulletin No. 73

"Highway Guards—Their Development, Design and Use," by G. A. Rahn—1941 (10)

This paper points out that the development of the highway guard has been brought about by test procedure and through observation of the finished structure under field conditions. A classification of types according to strength is suggested. It also points to the necessity of continuing the improvement of the guard in order to keep pace with the increasing speed and density of traffic. In conclusion the statement is made:

"In analyzing the events and practices leading up to the present guard it is gratifying to be able to report that this phase has kept its place at the side of various other developments leading up to the modern highway. It is gratifying in two ways, one from the standpoint of improvement in design, the other is, that 'Safety consciousness' has become definitely established as a basic principle in the design formula of the highway engineer"

SUMMATION

Standardization of a universally accepted type of guard naturally would be the ideal, but with the multitude of minds engaged in this problem it is extremely doubtful if this ideal will ever be achieved. This is apparent from many angles, for apart from individual opinion as to serviceability of type or design, economics, speed and density of traffic play a very important part in dictating design.

As now conducted the usual exceptions can be taken to any series of field tests on account of the variables introduced. It is, therefore, the opinion of this committee that a standard field performance test should be developed and used to qualify the contemplated design, in which the variables would be reduced to a minimum and these results tied in with suitable laboratory control tests.

This test might consist essentially of projecting a free running driverless vehicle of given design, at a given angle, into the guard at a given point or points, at speeds which the structure is expected to withstand, and noting the deflection of the impacting vehicle. The vehicle should be deflected parallel to the guard or at such a light angle to on-coming traffic, so as to insure recovery of control.

From this point it may be possible to determine, through the use of instruments, the component forces, "shock" values, deceleration, height of center of gravity, elastic values of the rail, post spacing, post resistance, effect of temperature stress, length of guard section and other data highly essential in guard design.

While the types and designs of highway guard now in use may be serving their purpose, the fact remains that, what was satisfactory ten years ago is not satisfactory today. Conversely, what is satisfactory now will be obsolete ten years hence. The evolution of the motor car and the highway will continue and if the highway guard phase of this development can be put on a rational, coordinated basis, it will serve as a ready means of solving the various problems in this field as they arise.

REFERENCES

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  c *Motion Pictures* (regular speed) of some of the 1925, 1926 and 1927 tests, in the Library of the Pennsylvania Department of Highways.

2. *Georgia Field Tests 1933.*
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