Before I close, I want to add a few words on the subject of code enforcement. I do not believe that it is the function of the public official to act as the code policeman for every industry with which he comes in contact, nor do I believe that he has a right to interfere with the proper operation of any code. By this I mean that it is not the function of the public official to clothe himself with the authority of judge and jury and pass judgment on what shall constitute a code violation. It is my understanding that code authorities have been created for that purpose. I still retain enough “rugged individualism” to believe that any industry operating under code that permits itself to suffer from a known ailment can not mandate my services as a guardian. However, I do contend that it becomes the duty of the public official to recognize the positive action of code authority. Also, I further contend that cooperation should be extended in the form of reasonable delay whenever written notice is given that action of code authority has been requested in a specific instance.

In conclusion let me state that I can think of no matter pertaining to the construction industry that is of more importance than the considerations that we are discussing. They are worthy of the best minds and the best efforts that the personnel of the industry affords. And I know of no better setting for ideas and ideals of the construction industry to emanate from than the campus of Purdue University. Let your discussions be unconfined.

TESTS OF VARIOUS TYPES OF GUARD RAIL

By P. J. Freeman, Consulting Engineer, Pittsburgh Testing Laboratory, Pittsburgh, Pennsylvania

In the early days of horse-drawn vehicles, some thoughtful person placed long poles or rails at dangerous spots along the roadways and thus made the first highway guard rail. The term “guard rail” is used by many engineers to mean any type of barrier which may be erected along the side of a road to prevent a vehicle from leaving the roadway. In a report made in 1931 by a committee of the American Road Builders Association, the term “guard rail” includes earth embankments, boulders, wooden posts, planking, logs, wire cable, woven wire, steel bars, reinforced concrete, and metal plates. The term “highway guard fence” is commonly applied to cable railing, but this term has less general application than guard rail.

Combinations of rails or planks were quite adequate for the protection of early users of automobiles, and no serious attempts were made to improve the construction of such guard
rails until the roads and turnpikes became paved highways and the speed of automobiles had increased considerably.

In sections of the country where the topography was such that the damage to occupants and the vehicles might be very serious on account of leaving the roadway, heavy embankments were built, or in some cases stone or concrete walls were erected. In other cases, heavy wooden posts were placed firmly in the ground at close intervals. The entire thought in the mind of the builder of such guards was to keep the vehicle from leaving the roadway. Little or no thought was given to the amount of damage to the vehicle in case of accident.

In some localities discarded mine cable was used with quite satisfactory results, but such material deteriorated very rapidly from corrosion and specially designed wire rope was developed which could be heavily galvanized. These ropes or cables all passed through the body of the post and this made the work of repairing damaged railings difficult. The posts were also subjected to a splitting action in case of an accident.

It is the purpose of this paper to review the history of the testing of highway guard rail, and also describe briefly the results obtained in a recent series of tests made under the supervision of the writer during the summer of 1933. The actual presentation of this paper must include the use of a large number of slides in addition to the use of moving pictures which cannot be reproduced in a written paper. An attempt will be made to summarize briefly the results of the tests and point out the general trend of development for highway guard rail, as it is equally unfeasible to attempt to give detailed results obtained from the observations made in connection with the tests.

EARLIER TESTS OF GUARD RAILS

Up to the time of the development of these first highway cable guard fences there do not appear to have been any attempts made to determine the comparative efficiency and effectiveness of any of the types of barriers in use. Generally speaking, the guard rails being constructed of wood were built in accordance with the ideas of the individual responsible for their construction, and the need of investigation for the best design was not felt until the construction of guard fence of cables had reached a moderate amount.

The first published report of "Tests of Highway Guard Fence" with which the writer is acquainted is given in a paper by H. S. Mattimore before the Eighth Annual Meeting of the Highway Research Board of the National Research Council. This report on "Guard Fence Research" gives the details of the development of the wire rope highway guard fence and describes a number of tests made by the Pennsylvania Department of Highways. The first series of field tests was
started in 1924 in conjunction with the U. S. Bureau of Public Roads. The Pennsylvania Department of Highways has continued to make these tests at intervals since that time.

An inclined wooden runway was constructed on an 8.5 per cent grade with rails to keep the vehicle from leaving the runway. Trucks and automobiles were allowed to coast down this runway and strike the guard fence which was built at the bottom of the runway at different angles. The early tests demonstrated quite effectively that a guard fence must be built along the lines followed by the deacon in building his famous "one-horse shay"; that is, every portion of the cable fence from anchor to anchor must be equal in strength if the design is to be effective.

It was found that the concrete deadmen had to be thoroughly fixed in the ground and the backfill properly placed. It was demonstrated that the most effective way of doing this is to dig a hole for the deadman and cut a notch through the earth for the anchor without disturbing the stability of the ground at that point. This construction is familiar to all engineers who are accustomed to placing reinforced deadmen in the construction of highway guard fence. Early in the program it was recognized that the capability of a highway guard rail to stop a vehicle was governed by the stability of the end anchorages, and they were given first consideration.

It was found that it was necessary to reinforce a concrete block or the anchor bolts would be pulled out, due to the failure of the block. Through additional tests, it was demonstrated that if wire rope is used for the end connection between the posts and the deadmen, it should be one inch in diameter. This end anchorage was also developed to use turnbuckles and heavy bolts in place of wire rope, largely as a matter of ease in construction.

A satisfactory reinforced concrete anchorage having been established, it was then found that the eye-bolts used for holding the cables to a heavy end post failed, because they were welded. These were replaced with drop forged eye-bolts.

It was demonstrated that if the cables passed through the posts, and the cables did not break, the posts were pretty certain to be split, and also the vehicle came in direct contact with the post and was severely damaged. These tests also showed that, in general, the top rope received the greatest impact and the substitution of a one-inch top rope for a three-quarter inch rope greatly increased the value of the guard fence for a small additional cost. A later development consisted in placing the cable on the outside of the post, where it was held in contact with a light hook bolt. This tended to eliminate the splitting of the posts and also greatly facilitated making repairs, but the vehicle was still liable to come in contact with the posts and to be severely damaged.
A metal offset block was placed between the cable and the post and held in place with a hook bolt. Tests of this design demonstrated that fewer posts were torn out or damaged when these offset blocks were used than with the earlier type of guard fence.

It was found that the breaking strength of the cable was increased by the use of thimbles in the loops of the cable and that the clips must be placed in a certain way to provide maximum holding power. The proper way to attach wire rope clips is to have the U-bolt in direct contact with the dead end of the rope, so that all of the clips are facing in the same direction.

This brings the record of testing up to December, 1928, and briefly outlines the results of the tests covered by Mr. Mattimore's paper delivered before the Highway Research Board at that time. Perhaps other highway engineers had made a study of highway guard rail design and conducted some tests, but no record of any general series of tests is available.

RESULTS OF MORE RECENT TESTS

In 1931 a series of tests was made under the direction of Searcy B. Slack, Bridge Engineer of the State Highway Board of Georgia, on some of the newer types of highway guard fence, such as woven wire, flexible steel plates, in addition to the older and wire rope types. These tests indicated the interest which was being shown in the development of a guard rail which would tend to protect the vehicle and the occupants to a greater extent than those types which have been in use.

A more elaborate series of tests was conducted by Mr. Slack in 1933 covering many types and conditions of construction, and a few other tests have been made, but in general the results of such tests are not available for distribution.

In studying the results of a series of tests, first consideration should be given to the speed of the vehicle at the time it strikes the guard rail. The kinetic energy of a moving vehicle varies directly with the square of the speed so that for example, in order to stop a vehicle traveling at a speed of 30 miles per hour, the energy absorbed by the guard rail will be 2.25 times that which would be necessary to stop the same vehicle if it were traveling at 20 miles per hour. From this, it will be seen that in order to compare the effectiveness of guard rails, it is necessary to have vehicles of approximately the same weight and moving at approximately the same speed when they strike the guard rail. Some of the earlier tests were made at speeds as low as 10 miles per hour, and very few exceeded 20 miles per hour.

With the removal of speed limits in many states, it has become necessary for highway guard rail designers to give more attention to developing a structure which will tend to deflect the vehicle back on to the roadway rather than to stop.
it. By doing this, it is not necessary to absorb all of the kinetic energy of the moving vehicle and, therefore, a guard of this type may be more effective in protecting a vehicle moving at a high speed and cause less actual damage to the vehicle than would result from contact with a different type of guard by the vehicle moving at a considerably lower speed.

The tests conducted under the supervision of the writer during the summer of 1933 covered several general types of guard rail as indicated later.

For these tests, a field was selected about four miles south of Canton, Ohio, and a runway erected on a convenient hill.

This runway consisted of heavy planking with guides for the wheels, as shown in Figure 1. The total length of the runway was 335 feet with an average slope of 13.18 per cent. The runway was sufficient to give the vehicle a speed of about 30 miles per hour, running without power and from a standing position at top of the runway.

The field selected was of firm clay soil sufficiently uniform in quality to provide full support for all of the posts. Calcium chloride was mixed at the foot of the runway and served very effectively in allaying the dust without making the ground slippery. Dust elimination was necessary in order to aid in taking photographs.
Each guard rail was erected at the foot of the runway at an angle of $20^\circ$ with the center line of the runway. It was not possible to use the same holes for all types of guard rails, but the holes were located in such a manner that they did not interfere with the proper setting of the posts. Each post was set at the depth called for in the specifications for that guard rail and the earth properly tamped.

Guard rails requiring concrete deadmen were installed by sinking the hole for the concrete block and then cutting a channel for the anchor road without disturbing the remainder of the earth.

![Fig. 2. Apparatus used in determining speed of vehicles just prior to impact.](image)

The speed of the vehicle was determined by a timing apparatus shown in Figure 2, consisting of a metal drum carrying sensitized paper on which impressions were made by an electrically-operated tuning fork vibrating 100 times per second and a solenoid wired to two switches in the runway. The distance between these two switches was made less than the wheelbase of the shortest vehicle used, and the second switch was placed so that it would be acted upon when the right front wheel of the vehicle was about two feet from the guard rail. When the front wheel touched the first switch, a record was made by the solenoid and when the same wheel reached the second switch near the guard rail, a second record
was made. The number of dots made by the electrically-driven tuning fork between these two records indicated the actual time, from which the speed was computed.

The metal drum was turned by hand as it was only necessary to have a speed sufficient to separate the dots made by the tuning fork sufficiently to count them. By this device, it was possible to read the time correctly to a hundredth of a second, and estimate to a fraction of a hundredth second for the last vibration. Duplicate records were also made by another solenoid attached to two switches contacted by the other front wheel.

Each vehicle was weighed prior to the test and if necessary additional weight added to bring the gross weight of the truck to 10,000 pounds, which was used for all of the truck tests. In general, sedans were used for the automobile tests and their weights varied with the manufacturer of sedan used.

The longitudinal movement of each post was determined by measuring from a fixed bench mark to a point on each post before and after each test. Readings from a fixed base line set by a transit were also taken to these points on the post to determine the lateral deflection.

During the process of erection and finally before each test was made, every installation was inspected to make certain that all requirements of the specifications, issued by the manufacturer or by the highway department using such rail, had been followed by the erector.

The primary purpose of the investigation was the development of a panel type of guard rail using heavy gauge flat steel plates having rolled edges. Figure 3 shows the effect of impact from a coach weighing 4,450 pounds and traveling at a speed of 30 miles per hour at time of impact. One light steel post was demolished, but the damage to the rail and vehicle was slight. It will be observed that the auto coasted for a distance of about 200 feet after contact with the guard rail, where it was stopped by an auxiliary barrier.

A considerable number of tests were made with this type of rail, using all wooden posts with knee brace end construction and also using end anchorages attached to wooden posts with intermediate light steel posts.

Tests were also made on plain plate guard rail of both light and heavy gauge and the results obtained for the heavy gauge steel were about the same as shown in Figure 3.

A test of highway guard fence using two cables is shown in Figure 4. The vehicle was a sedan weighing 4,000 pounds which was traveling at a speed of 30.7 miles per hour when it reached the barrier. From contact with the post, the front wheel was demolished although the vehicle did not pass through the guard fence.

The results of one of the tests made on a guard fence constructed of heavy planking and one wire rope are shown in
Fig. 3. A panel-type guard rail deflects car with but slight damage.

Fig. 4. A 4,000-pound sedan after impact at 30.7 miles per hour.
Figure 5. It will be observed that the truck having a gross weight of 10,000 pounds traveling at a speed of 30 miles per hour passed completely through the guard fence.

CONCLUSIONS

In studying the results of such a series of tests, it should be borne in mind that the damage to the vehicle is, no doubt, much greater than would be the case if new automobiles and trucks were used, but the effect of the vehicle on the guard fence is probably about the same for a new vehicle. It is impossible to adequately depict the results of the test by a written description, a compilation of data, or by photographs. It requires a combination of sight and sound to properly bring out the terrific forces exerted by a vehicle moving at a speed of 30 miles per hour and indicate the resistance which a highway guard must exert to withstand such impact.

No attempt is made in this paper to give details or photographs showing the results of tests on the several types of guard rails, but the purpose is to indicate the methods used and show some typical examples of the results obtained.

There are many other types of guard fence being developed which are, no doubt, very satisfactory and this paper should not be construed as covering anything more than the work which was done.
From the results of these tests it seems quite probable that if similar tests could be conducted with a driver in the vehicle or a device to turn the wheels away from the guard at the moment of impact, which would be the natural condition if the accident were caused by skidding, highway guards made of heavy steel plates would act in an unusually successful manner.

From personal observation covering a period of years, it is the belief of the writer that the necessity for keeping the vehicle away from contact with the posts is very obvious, and it seems equally obvious that the most satisfactory results will be obtained from highway guard rail in which end anchorages are used, having sufficient rigidity to utilize the full strength of the guard rail throughout its entire length, rather than depend on the resistance of heavy posts.

The subject of guard rail design is attracting the attention of highway engineers and many improvements may be expected during the next few years. Some of the modern types of guard rail provide a reasonable degree of protection for the traveling public and there are other types which are now wholly inadequate due to the increase in speed of motor vehicle traffic.

STABILIZATION OF GRAVEL ROADS BY USE OF CALCIUM CHLORIDE

By Walter O. Dow, County Engineer, Grand Traverse County, Traverse City, Michigan

Grand Traverse County is located in the northwestern corner of Michigan, in the center of the summer resort region. Because of this fact, our roads, in summer, carry from two to three times the normal traffic. The type of people involved in this summer traffic expect and demand a smooth, dustless road surface.

It has taxed our resources to the limit to maintain such a standard on gravel roads under summer traffic conditions. The county now maintains approximately 350 miles of this type. Because of the sandy nature of the material which is locally available, these have been covered usually with loose gravel, and have required blading several times a week during the summer months in order to give even reasonable service to the traveling public. Such frequent maintenance has been expensive; yet replacement by a hard surface type has been out of the question because of the large investment of funds necessary. We have been eager, therefore, to find a type of surface which could be built at reasonable cost and which would remain smooth and dustless with low maintenance costs.

When the new stabilized gravel type of surface was called