TRAFFIC PATTERNS AT A NARROW BRIDGE

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SYNOPSIS

Permanent structures narrower than the existing pavement are recognized highway hazards. Information has been published to demonstrate the seriousness of the hazard, but little has been done to determine the effectiveness of various types of warning signs and pavement markings used to safeguard such locations.

This paper reports a study at a typical narrow highway bridge location on a two-lane pavement to test the effects of several types of signing installations on driver-approach patterns. Only free-moving passenger cars on a dry pavement with unrestricted visibility were recorded.

Four types of signing installations were considered. These included standard reflector button warning signs with striped panel boards at the bridge; standard size reflectorized background warning signs with enlarged red button clusters at the bridge; and reflectorized background signs with the panels at the bridge, and with the panels and a painted reflectorized center line through the bridge and extending into the approach.

It was found that the type of sign influences the lateral placement pattern at night. The presence of the warning signs forces the driver towards the center of the roadway, the amount independent of type of sign. The use of the center line provides a desirable pattern in the final approach, its presence channelizing the cars onto the bridge more within their own lane. The cluster exerts an equally strong influence, but it is not desirable as it forces the drivers away from the edge of the pavement into the opposing lane. At the entrance to the bridge, the driver usually enters closer to the truss when panels are used than when clusters are used.

For the daytime lateral placement patterns and in all deceleration patterns, the bridge influences driver behavior. The type of sign produces only minor pattern variations which are not significant.

Every day on many of the federal and main state highways, motorists are facing the hazard created by narrow bridges—permanent structures narrower than the existing pavement. The pavement widening programs of many States are increasing the number of these locations, as all too few permanent structures were designed and built to allow for possible expansion. While these locations produce definite driver hazards, comparatively little is actually known regarding the relative efficiencies of the various types of warning installations used to safeguard these danger spots.

This paper presents the results of a study, conducted by the Joint Highway Research Project, Purdue University, for and in cooperation with the State Highway Commission of Indiana, of the effect of various types of prewarning signs and entrance delineators on the speed and lateral placement patterns of passenger cars in the approach to a narrow highway bridge. The location selected as representative of a typical situation was the east approach to the through truss bridge over Big Pine Creek on U. S. No. 52, 1 mile east of Templeton, Benton County, Indiana (Fig. 1). The bridge is 120 ft. long, with a clear width of 19 ft. The approach to the bridge is a concrete pavement which has been widened from 18 ft. by the addition of concrete strips 2 ft.-3 in. wide along each side. The widening extends to within 25 ft. of the bridge ends. The existing blue grass sod shoulders are in good condition because of the ample pavement width. The bridge is in a broad, shallow valley on a long tangent section, and is visible for at least 1500 ft. in each direction.

The driver hazard in a narrow bridge is indicated by the accident experience at the project location for the five year period through 1946. Six major accidents have resulted in the death of one person, injury to six others, and caused an estimated property loss of $14,000. This information is summarized in Table 1. In the official report of the fatal accident, the investigating officer noted that "the attempt to pass (in opposite directions) in the bridge caused an immediate hazard because there is a tendency to crowd the center line. The bridge is the width of the highway, but the structure starts at the road's edge giving just enough room to pass." This is just one example of the toll of narrow bridges. Unfortunately, many similar locations have an even more tragic record.

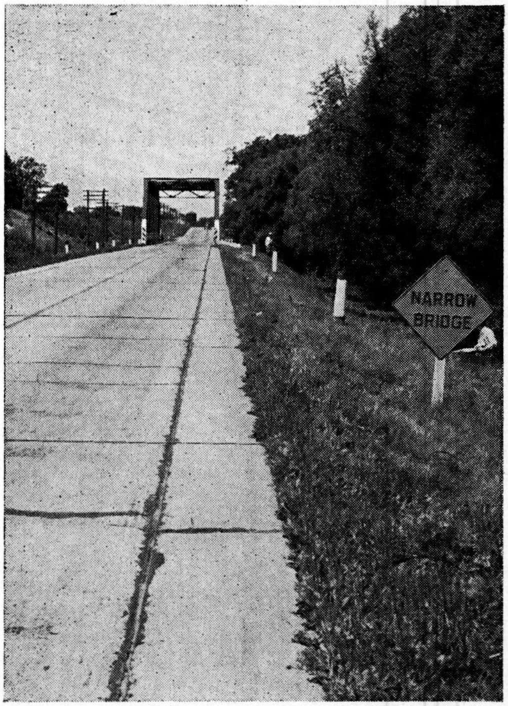

Figure 1. Immediate Approach to Project Bridge

TABLE 1
ACCIDENT RECORD AT PROJECT LOCATION, 1942–1946

Date	Time	Vehicles Involved[a]	Property Damage	Personal Injuries
			$	
11/15/42	7:30 p.m.	Tractor-semitrailer and car	140.00	None
1/30/43	7:45 a.m.	Car and tractor-trailer	50.00	None
9/ 7/44	7:00 a.m.	Tractor-semitrailer	6200.00[b]	One
11/ 5/45	10:30 a.m.	Car with trailer	1000.00	One
1/17/46	12:50 a.m.	Two cars	2700.00	One
4/ 3/46	4:40 a.m.	Car and tractor-trailer	3950.00	One death Three injured

[a] Information taken from the accident files of the Indiana State Police, Indianapolis, Indiana.
[b] Includes $200.00 damage to the bridge.

PRELIMINARY DISCUSSION

The normal patterns of vehicles approaching any hazardous situation are developed from distinguishable driver traits. These measurable factors include the desire on the part of the driver to maintain a straight-line path with a minimum reduction from his natural speed, the practice of aiming rather than steering a vehicle, especially in the higher speed brackets, the instinctive act of shying from any potential danger, and the numerous driver practices dictated by habit. The effectiveness of any series of warning signs and markings at a particular location depends on their ability to focus the attention of the driver, and to control these traits by leading him into a desirable approach pattern.

An average path can be estimated from the published results of several recent investigations on related problems.[1] At a situation similar to the project location, and without reference to type of warning installation, the average driver might be expected to move laterally 5 to 6 ft., from a normal position with his right front wheel 4.0 ft. from the edge of the pavement, to insure ample clearance with the leading members of the truss. This movement, accomplished with a minimum reduction of speed, would bring the left side of the car 3 to 4 ft. into the opposing lane. A slightly larger lateral movement could be expected at night. An effective series of pre-warning signs and entrance delineators would control this wide lateral movement, but still assure the driver sufficient clearance without necessitating an abrupt change in his natural speed.

In any project of this type, certain limitations must be placed on the scope of the investigation. To reduce the number of variables to be considered in the analysis of the patterns, all readings were taken for dry pavement conditions and unobstructed visibility, and only those cars considered to be free moving were recorded. The methods for collecting data involved the study of one car over an extended range. This required a more liberal definition of the term free moving than employed when considering a car at any given instant. A car was recorded as free moving if it was the leading car of a group of cars traveling in the same direction or if it was more than 100 ft. behind a car traveling in the same direction through the zone under study, and, in both instances, if an approaching car was farther than 200 ft. from the end of the particular zone as the car under observation left that zone.

For daylight data a further limitation was applied. In order to reduce the factor of habit to a minimum, only those cars with out-of-state registrations or non-local Indiana registrations were taken. This would tend to produce a sharper contrast in the several patterns noted, as it removed, to a degree, the modifying influence of the pattern of local traffic developed through continual exposure to the same situation.

EQUIPMENT

The equipment used for the study were the Photo-Velaxometer[2] for recording multiple speed readings, and a gunsight-type movie camera for recording multiple lateral placement readings[3]. The Photo-Velaxometer, operating through a series of eight air tubes and switches laid at equal intervals on the pavement, records a photographic image of the time intervals between the crossings of the tubes, and, hence, the average speed of a vehicle through each of the seven sections. These speeds can be taken as representative of the actual speed at the mid-points of the several sections. The camera, operating from an independent circuit, was employed to record the lateral position of the car at the station points marked by the tubes. Using the method described at the 1946 meeting of the Highway Research Board[3], an image of the target boards in place on the pavement at these stations is superimposed on the film strip of a car passing through the zone. The wheels of the car will then appear to cut across the boards, and the lateral distance from the pavement edge can be directly recorded.

The night method for multiple lateral placement is basically the same as that used in the daytime. However, the problem is

[1] Taragin, A.; "Effect of Roadway Width on Traffic Operations," *Proceedings*, Highway Research Board, Vol. 24, p. 292 (1944)

Walker, W. P.; "Influence of Bridge Widths on Transverse Positions of Vehicles," *Proceedings*, Highway Research Board, Vol. 21, p. 361 (1941)

Green, F. H.; "Methods of Recording Lateral Position of Vehicles," *Proceedings*, Highway Research Board, Vol. 26, p. 397 (1946)

[2] Branham, A. K.; "An Automatic Traffic Speed Recorder," *Proceedings*, Highway Research Board, Vol. 21, p. 348 (1941)

[3] Green, F. H.; "Methods of Recording Lateral Position of Vehicles," *Proceedings*, Highway Research Board, Vol. 26, p. 397 (1946)

complicated, as only the image of the head lights of the car appears on the film. Elevated target boards are used to permit direct readings of the lights from the superimposed target image. These readings are not as accurate as the daytime recordings, as an error is introduced when considering the longitudinal location of the car at the moment of recording the lateral position. If the lights are not at the exact height of the target boards, the car would not be over the target point, but at some point ahead or behind the station depending on whether the lights are above or below target height. The error in position increases with this discrepancy and with the distance from the camera lens to the target. The placement at a known location is important when determining an average point of deviation from a straight line path.

As a means of locating the longitudinal position, a series of lights was subsequently developed which would go on at the instant the car crossed the station, and which would then appear as reference markers on the developed film. One marker, consisting of a 6-volt bulb mounted in a small cylindrical housing, was placed at each station, and the entire series was led through the main operating circuit of the Photo-Velaxometer. Thus, their operation becomes an integral part of the functioning of this machine. If the film strip is read on the first frame in which a given light is visible, the car is positioned longitudinally within one frame, or to the same degree of accuracy obtained in daylight records. The size and location of the lights are such as to produce the minimum of flash, and they are not a distraction to influence normal driver behavior.

PROCEDURE

The area of study included the section of roadway from a point 650 ft. before the entrance to the entranceway. To facilitate collecting data and to secure readings at sufficient points to produce accurate patterns, the test section was divided into two zones. Arbitrarily, these were termed the prewarning zone, from 650 to 300 ft. before the entrance, and the approach zone, from 350 ft. before the entrance to the entrance. The overlap was required to join the speed patterns of the zones, and at the same time, provide a double station junction for the lateral placement measurements. A third zone, the midzone, extending from 550 to 300 ft. before the entrance, provided the junction for the first signing situation.

Four sets of warning installations were tested as illustrated by Figure 2. The first signing situation tested the installation in place at the time the study was initiated. This consisted of two standard 24- by 24-in. warning-type signs with reflector buttons, one cautioning "SLOW" located 975 ft. before the entrance, and the second warning

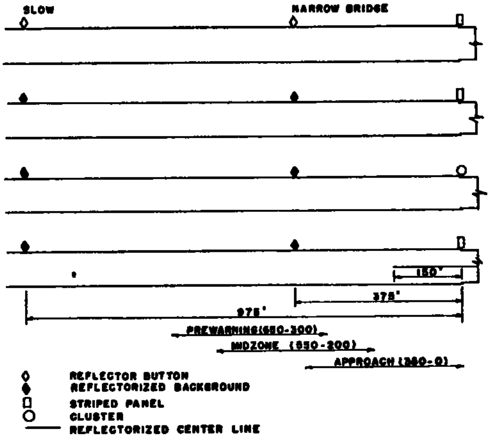

Figure 2. Chart of Warning Installations

"NARROW BRIDGE" located 375 ft. before the entrance, and two 12- by 36-in., 6-in. diagonally striped black and white reflectorized panel delineators mounted in front of the leading members. In addition, and common to all the situations produced, there is a flexible, metallic guard rail extending back 45 ft. from the entrance on the right-hand shoulder, and white, wooded guard posts extending back an equal distance on the left-hand shoulder. A standard black centerline extends to the entrance, with no center stripe on the bridge floor. Both day and night readings for deceleration and lateral placement were recorded for each zone.

The second condition was designed to compare the relative efficiencies of standard reflector button signs with signs of equal size having a reflectorized background (Scotchlite). The new signs, one cautioning "SLOW" and the other warning "NARROW BRIDGE", were mounted directly on the posts in place of the reflector button signs. It was anticipated that the comparison could best be based on the deceleration patterns produced by each set, and, therefore, day and night deceleration readings only were recorded in both zones.

The third condition tested two types of delineators, the striped panels and enlarged red button clusters. The reflectorized background prewarning signs were left in place and the clusters were substituted directly for the panel boards. The comparison between the two would be shown in the effects produced in the immediate approach. Therefore, both types of data were taken only in the approach zone. Day and night speed records were made, but the lateral placement was only considered at night.

This fourth situation is a continuation of the third. The reflectorized background signs and the panels were left in place and a 6-in. white reflectorized painted centerline was added to extend through the bridge and 150 ft. in each direction (Fig. 3). This line emphasizes the line formed by the longitudinal joint. Again this addition affected only the immediate approach. Because the lateral placement pattern had been secured from the previous situations, it was decided that it would be sufficient to determine an average position at only two points in the approach to show any benefits to be derived from a center line. These points, one at the leading end of the centerline, 150 ft. from the bridge, and one at the end of the widening, 25 ft. from the bridge, would show the magnitude of any change in average position caused by the center line. Because single locations were used, it was possible to use a mechanical method of measuring the lateral position. The machine employed operates through a series of eight air tubes of varying lengths placed four to six inches apart across the roadway at the station point. These tubes are connected through switches to a system of relays and lights. One light is activated for each tube cut by the

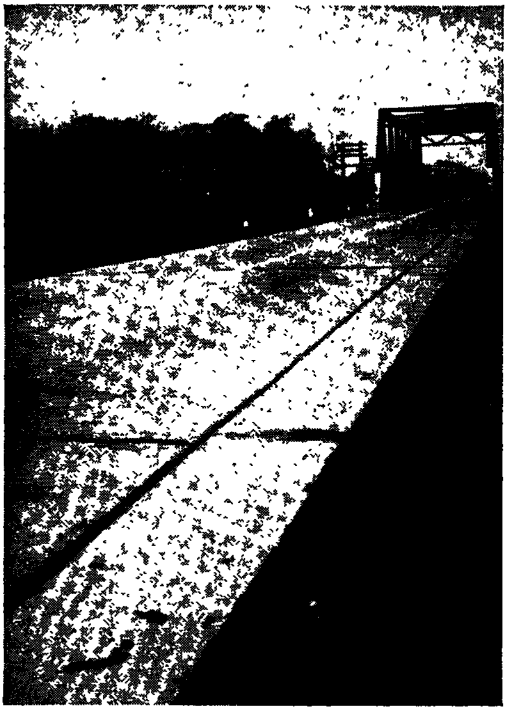

Figure 3. Painted Centerline at Project Bridge

right hand wheels of the car. Both day and night data was recorded.

Approximately 100 cars were recorded for each zone to insure averages within the accuracy desired. The data was recorded simultaneously when possible, but this was not a requirement because there is no need to correlate the two types of data.

visibility of the zone with a minimum exposure to the driver. This reduced the probability of the presence of the operator disturbing the normal patterns.

DISCUSSION OF RESULTS

The results of the decleration study for the several sign installations are presented in

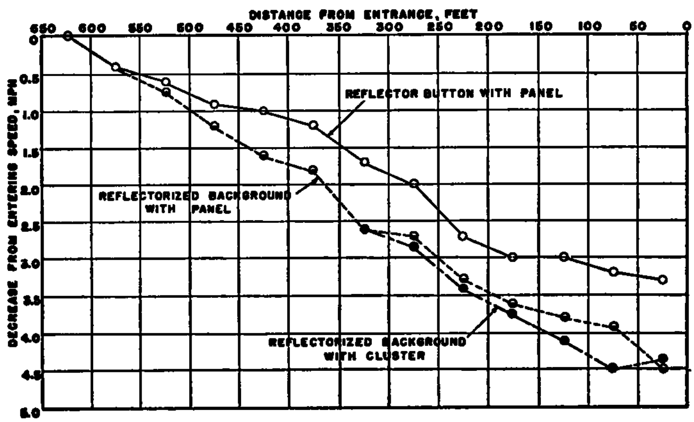

Figure 4. Deceleration from Common Entering Speed at a Narrow Bridge (Day)

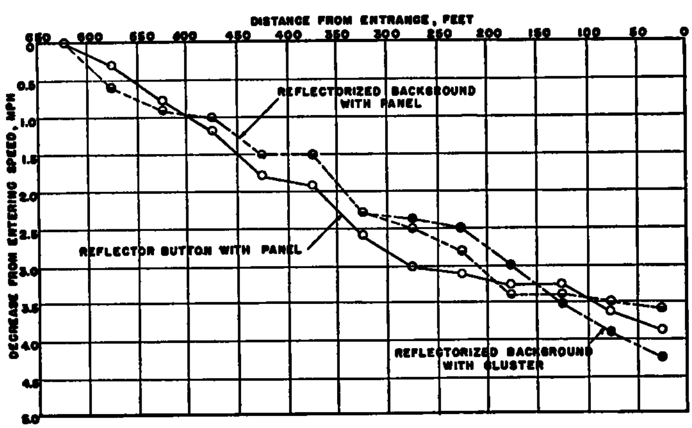

Figure 5. Deceleration from Common Entering Speed at a Narrow Bridge (Night)

In the approach zone the camera was clamped to a vertical member on the bridge, and for the prewarning zone, it was mounted behind a route marker sign temporarily set in place along the shoulder. One operator controlled both the camera and the Photo-Velaxometer from a central point. The control station was placed as far from the road as conditions permitted to give the operator full

Table 2 and Figures 4 and 5. The averages computed and the patterns drawn from these averages are based on records of 1,139 passenger cars or 7,973 actual measurements of individual speeds. Of the totals, 636 cars, 4,452 readings, are for day-light periods, and 503 cars, 3,521 readings, are for night hours. The deviations throughout the entire section from a common entering speed 625 ft. before the bridge are plotted in Figures 4 and 5. These illustrations permit a graphic comparison of the several patterns without reference to the differences in the entering speeds to the various zones for each population tested. It is assumed that the populations follow similar trends within the sections. Figure 4 compares the daylight patterns, and Figure 5, those obtained at night.

The most important conclusion to be drawn from the data presented is based on the shape and degree of deceleration exhibited by the several patterns. All curves show the same general trends with the exception of the daytime pattern for reflector button signs. This discrepancy is not sufficient to alter the conclusion. The general similarity between the patterns would seem to indicate that the type of warning sign had little effect in controlling the basic desire of the driver to maintain a constant speed. Rather, it would seem that the bridge itself performs the function of the warning sign in that the attention of the driver is focused on the entrance and not on the warning message of the particular sign series. This conclusion assumes the driver has unobstructed visibility of the entrance in his approach, as is the condition at the project location. Having a complete view of the situation, the driver can decide on his particular need to reduce his speed, which would mainly depend on the relative spacing of approaching traffic. He is not forced to rely on the prewarning signs to suggest the action.

The overall deceleration is approximately the same for night and day as shown on the graphs. The night reductions vary from 3.6 mi. per hr. for the reflectorized background signs with reflectorized panels to 3.9 mi. per hr. for the reflector button signs and 4.2 mi. per hr. for the reflectorized background with entrance clusters. The daytime patterns are slightly more dispersed, as previously mentioned, varying from 3.3 mi. per hr. for the reflector button signs to 4.4 and 4.5 mi. per hr. for the reflectorized background with cluster and panel respectively. More significant, however, is the overall comparison shown by Table 2 between average entering speeds of the day and night populations for the several zones, and between the average speeds of entry computed to produce a single value. The night speeds generally run 7 to 8 mi. per hr. slower than the corresponding daylight pattern. Only one value, the difference in entering speeds in the prewarning zone for the reflector button signs, is considerably above the average. This comparison would seem to indicate that the populations follow definite trends, that is, as the daylight speeds at a given location periodically move above or below some base assumed as the normal average, the corresponding night population will also vary to maintain a relatively constant difference.

Some importance might be placed on the minor variations between the individual patterns. Considering the night readings, attention should be placed on the continuous deceleration shown by the pattern for the cluster in the final 250 ft. of the approach. This assumes importance when compared with the more level patterns produced by the panel boards. This drop, 1.7 mi. per hr. in 200 ft., would seem to indicate that the clusters augmented the speed control of the bridge itself, the red reflection controlling the final approach speed by evoking a reaction built up through habit. It should be noted that the same effect is partially carried through in the daylight pattern up to the sharp leveling off within the final 50-ft. interval. In this same interval, it is felt that the sharp drop in the pattern for the reflectorized background with panel marks a condition of extreme variability, and that the other situations are more representative of the effect of this type of delineator on the speed behavior.

TABLE 2
COMPARISONS OF ENTERING SPEEDS BY ZONES

Type of Sign	Zone	Entering Speed		
		Day	Night	Difference
		mph.	*mph.*	*mph.*
1. Reflector button (with panel)	Approach	54.2	46.9	7.3
	Pre-warning	55.4	45.2	10.2
	Midzone	55.0		
Average at 625 ft.[a]		55.6	47.3	8.3
2. Reflectorized background (with panel)	Approach	52 3	45.6	6.7
	Pre-warning	52.7	45.5	7.2
Average at 625 ft.[a]		53.8	46.7	7.1
3. Reflectorized background (with cluster)	Approach	56.2	47.4	8.8

[a] This average is computed by converting all entering speeds to an entering speed 625 ft. before the entrance.

Some significance might be placed in the steeper curve slopes exhibited by all the curves between the 400 and 300 ft. markers. The steepest slopes are noted for the reflectorized background patterns, 0.8 mi. per hr. in both cases compared with 0.5 mi. per hr. in daylight and 0.7 mi. per hr. at night for the reflector button signs. As the "NARROW BRIDGE" signs are located at the 375 ft. point, it is possible that they take partial control of the deceleration pattern through this section, the reflectorized background type to a more marked degree because of its greater visibility. However, in line with the general conclusion, it is argued that the presence of light averages are developed from 953 readings, and the night patterns from 1,638 readings.

The study of these patterns leads to several important conclusions. First, it should be noted that the type of warning installation has little effect in controlling the lateral movement during the daylight hours. As was noted from a consideration of the deceleration patterns, the presence of the bridge apparently dictates the driver reaction. The lack of variation in the averages is definitely shown by the relative positions of the points checked for the center line with the pattern for the reflector button signs with no center line

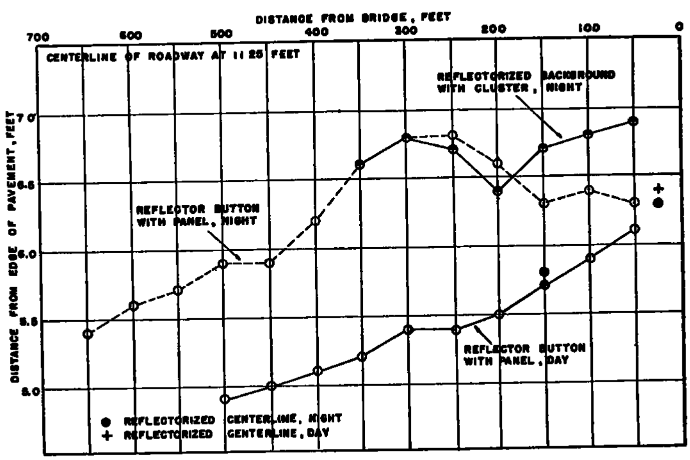

Figure 6. Average Path of Right Front Wheel in Approach to a Narrow Bridge

the bridge is exerting the main control. The factor of visibility might also cause the variation in the daytime patterns in the prewarning zone.

If the primary purpose of the signing installations is to control the tendency for a driver to hold to a constant speed throughout the approach, the type of sign used, considering only the standard size of sign, would seem to have limited effect.

The results of the lateral placement portion of the study are shown in Figure 6. These curves, which plot the average path of the outside edge of the right front wheel with respect to the right hand edge of the pavement, are taken from records of 754 cars, or a total of 2,591 single measurements. The day-marking. Despite the widely different signing installations, the average values differ so slightly that the amount is insignificant. The extent of the lateral movement is 1.4 ft. in 500 ft., and is accomplished to allow the driver an average clearance of 4.5 ft. between the outside of his front wheel and the bridge ends. Assuming the width, outside to outside of wheels, of the average car is 5.4 ft., the average path would take the car outside of its own lane in the final 100 ft. of the approach.

Another important conclusion is that the type of sign at the bridge end has a marked control over the lateral movement at night, but the type of prewarning signs exhibit little beneficial control. The general agreement shown by averages noted between 450 and

200 ft. before the entrance for the reflector button and the reflectorized background type sign would show that the presence of a sign at 375 ft., rather than the type of sign, forces the driver to move toward the middle of the pavement through this area. This phase of the curve is not too desirable as it brings the left side of the car up to and into the opposing lane of traffic. The delineation at the bridge would seem to take up the control near the 200 ft. station and guide the driver through the final stages of his approach.

In this stage the more important and desirable control is indicated by the presence of the reflectorized painted center line. The average values for the points checked, 5.8 ft. at 150 ft. and 6.3 ft. at 25 ft. before the bridge, approximate daylight conditions, and their position relative to the other patterns, show that the line maintained the control throughout its length. They would also show that the center line overcomes the effect of the prewarning sign as it channelizes the traffic and brings the average path more into the right hand lane. Driver habit insures the evident success of the center line. At the entrance way itself the panel boards become important as it can be noted that the value for the center line and panel agrees closely with that for the panel alone. In both instances the clearance is approximately 4.7 ft., a value not significantly different from the daylight value.

The reflectorized panels are not as startling as the enlarged type clusters as evidenced by the approach patterns for each. Habit combined with the instinctive act of ducking or shying from a potential danger leads the driver farther into the opposing lane when clusters are used. It should be brought out that the clusters do have a control on both the deceleration and the lateral movement. While this control does have a definite usage in certain instances, it would not seem to be justified at this type location.

In all instances it can be noted that the clearance, and the lateral movement required to obtain this clearance, is less than anticipated.

If the primary purpose of signs and markings is to control the extent of lateral movement, and to keep a driver within his own lane over as wide a range as possible, it is apparent that the use of a reflectorized type center line is desirable.

SUMMARY OF RESULTS

From the study of the effect of four types of signing conditions, i.e., standard reflector button warning signs with striped panels at the bridge, reflectorized background warning signs with striped panels, button clusters, and a center line and the panels at the bridge, on the deceleration and lateral placement patterns of cars in the approach to a typical narrow bridge, the following conclusions may be drawn:

1. At the location studied the signing installations appeared to influence the lateral movement at night, but the bridge rather than the signs or markings, influences the daytime pattern.
2. At night the presence of the warning sign at 375 ft. tends to cause the driver to move towards the center of the roadway. The type of sign seems to exhibit little effect on the amount of movement. This movement is undesirable because the average path brings the left side of the vehicle into the opposing late of traffic.
3. At night the signing-in-place on the bridge controls the pattern in the final approach.
4. The presence of the center line provides a desirable control. The values at the stations checked and their location with respect to the several other patterns would indicate that the center line channelized traffic and led the driver through the final approach more within the correct lane.
5. The use of the cluster keeps the driver beyond the center line, and, therefore, its control is not desirable in this situation.
6. At the entrance the effect of the panel on the driver is less startling than that of the cluster. When the former is used, the average driver tends to drive closer to the bridge ends.
7. For daylight patterns the difference noted between average values with and without a center line is not enough to show that the bridge is not the dominant controlling influence.
8. For both the day and night deceleration patterns the bridge itself, rather than the signing installations, appears to control the driver behavior. The changes in speed and the shapes of curves showing the decrease from a common entering speed exhibit little variation due to type of sign.

9. The minor variations within the curves may be traced to the signing.

10. All the curves exhibit a sharper deceleration at the warning sign at 375 ft. the greater reductions being noted for the reflectorized background type.

11. The use of the cluster at the bridge produces a slightly greater reduction in speed in the final approach, while the panel boards tend to level off the speeds.

12. The day and night patterns are similar in shape and degree of speed reduction. The night patterns hold averages 7 to 8 mi. per hr. less than the same daytime pattern.

This study has covered only one typical location and only a few of the many types of signing installations used at narrow bridge locations. Of the types tested, however, it is evident that the use of a center line through the bridge and extending into the approach can be effective in controlling the driver behavior.

ACKNOWLEDGMENTS

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DISCUSSION

W. A. Sutherland, *Secretary, The Automobile Association, Wellington, C.I., New Zealand*—You may be interested to hear of our experience in dealing with three narrow bridges on a main highway leading out of Wellington, The Capital city of New Zealand. One in particular had a very bad record of accidents. In an attempt to reduce the accidents we erected larger signs than usual (our standard signs are 2 ft. by 2 ft.) with variation in the color scheme from a yellow background with black lettering to a black background with silver lettering. We varied also the wording as a means of attracting greater attention.

Unfortunately this did not reduce the accidents to any degree and finally we painted the approach rails to the bridge yellow as a contrast with the white super-structure of the bridge. The result has been a substantial reduction in the accident rate, and we now use this variation in the color of the approach rails on all our narrow bridges—the effect being that the darker approach rails convey a narrowing down effect to the motorist whose first reaction is to reduce his speed. If you are carrying out further research into this question, I commend you to experiment with this method if you have not already done so.