LATERAL VEHICLE PLACEMENT AND STEERING WHEEL REVERSALS ON A SIMULATED BRIDGE OF VARIABLE WIDTH

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Many states are engaged in large-scale programs of highway construction and improvement, which include construction of new bridges as well as widening of older ones. At the present time there are no proven guidelines on the optimum shoulder width for bridges. The research reported here utilized a Greenshields Drivometer and an 8-mm time-lapse movie camera to record steering reversals and lateral placement in the vicinity of a simulated bridge. Eight male and two female subjects were tested for eight shoulder width conditions. Each subject drove the instrumented test vehicle across the simulated 50-ft bridge for a total of 30 runs for each of the eight test conditions. Statistical and graphical analyses of the data showed considerable variation among the individual subjects. However, certain trends were shown for all subjects. Steering reversals, both minor and major, were relatively constant for shoulder widths greater than 4 ft. The distance of vehicle from centerline of roadway also reached a maximum for a 4- to 6-ft shoulder width. The subjects tended to drive closer to the centerline for shoulder widths less than or greater than approximately 4 to 6 ft. These results indicate the need for a minimum shoulder width of 4 to 6 ft if traffic operations are not to be influenced.

•MANY STATES are engaged in a large-scale program of new highway construction and also improving older highways. These programs include construction of new bridges and widening of older ones. There are no available proven guidelines on the optimum shoulder width for these structures. In the past, the design criteria of the various states have specified different widths for long- and short-span bridges. Because of the cost factor, long-span bridges were usually provided with narrower widths than were short-span bridges. AASHO published the following statement (9): "... the clear width on bridges should be as great as feasible, preferably as wide as the approach pavement and shoulders, in order to give drivers a sense of openness. On the other hand, bridges that are long are costly and on them some compromises from the desirable usually is necessary." In addition, Figure IX-8 on page 519 of that publication illustrates full shoulder widths being provided on short structures and no shoulder being provided on long structures.

Another AASHO report (10) recommends that "A full shoulder width should be carried across all structures." This recommendation is therefore a departure from previous practice. This significant decision, if implemented on all structures, would vastly increase the cost, particularly where longer structures are involved.

One of the latest AASHO publications concerning shoulder widths on bridges (13) has been adopted by all states. This report allows less than full shoulder width for low-speed (less than 50 mph) and low-volume (less than 750 ADT) roads. It also allows existing bridges on low-speed, low-volume highways to remain in place without shoulders if the clear roadway width meets certain minimum standards. Other recent publications (11, 12) recommend a constant width of shoulder and roadbed.

If all new bridges are constructed with a full-width shoulder and older structures widened to include a full shoulder, and if this full shoulder is not required from a safety or traffic operations standpoint, an unnecessary financial burden will have been placed on the funding agency. At the present time, little factual information is available concerning any operational benefits to be derived from a full shoulder width.

PREVIOUS RESEARCH

Although a number of studies have been carried out in the general area of roadway shoulders, there is no record of a controlled laboratory study such as this one. However, for comparison purposes the results of some of the reported field studies are presented here.

In 1947, a committee under the sponsorship of the Department of Traffic and Operations of the Highway Research Board was organized to evaluate traffic operations benefits as related to shoulder width (1). The committee reviewed past research projects and reported on a before-and-after study carried out in West Virginia during the period 1947 to 1949. The study revealed that the speed of a moving vehicle is not substantially affected by the width of the shoulder, providing the shoulder is more than 4 ft wide. The study also showed that the lateral position of a free-moving vehicle shows no significant relation to shoulder widths greater than 4 ft.

The first comprehensive analysis of accidents and their relationship to various roadway elements was reported by Raff (2). The study, involving only gravel shoulders, indicated that the most significant factors affecting accident rates are traffic volume, degree of curvature, percentage of cross traffic at intersections, and width of bridge roadways both absolutely and in relation to their approach pavement width. Any extra width in relation to the approach pavement definitely reduces the accident hazard on bridges. The actual width of the bridge pavement also contributed to the safety of the bridge.

Billion and Stohner (3) studied earth (grass) and gravel (macadam) shoulders. Their study was confined to accidents reported in New York State between October 1947 and July 1955. Only fatal and serious injury accidents and those accidents occurring on highways that used state-owned maintenance equipment were included in the study. The road sections studied were located on two-lane rural highways. The study indicated that medium-width shoulders had lower accident indexes than narrow shoulders under all conditions of horizontal and vertical alignment.

Head (4) studied gravel shoulders on various sections of rural highways. Considering curvature, terrain, sight distance, access and shoulder width, and other variables, he computed the relationship among total accidents, property damage, personal injury accidents, and the various roadway elements. Statistically, he concluded that total accidents and property damage accidents decreased as shoulder width increased in the 3,000 to 5,500 ADT range. No statistical relationship was found between accidents and shoulder width for those sections with an ADT of 5,000 to 7,000 vehicles per day nor between shoulder width and personal injury accidents.

Belmont (5) conducted a study of paved shoulders based on personal injury accidents reported in 1948 for two-lane rural highways on the California Interstate Highway System. The sample was limited to rural roads with a speed limit of 55 mph. Regression equations were computed by using the square root of the number of accidents as a dependent variable. The analysis was based on three groups of shoulder widths: less than 6 ft, 6 ft, and greater than 6 ft. The results showed that 6-ft shoulders were safer than narrower shoulders. They were also safer than wider shoulders for those sections with a traffic volume greater than 5,000 vpd.

In another study that used California accident data for the years 1951 and 1952, Belmont (6) confined his work to an analysis of personal injury accidents. For ungrouped accident data, regression equations were computed by using the square root of the number of accidents as the dependent variable, and, for grouped accident data, the number of accidents was used as the dependent variable. The results indicated a tendency for injury accidents to increase with increased shoulder width except for sections with traffic volumes less than 2,000 vpd for which no relationship was established.

Taragin (7) undertook a study on lateral placement of vehicles as related to shoulder type and width on two-lane highways. He reported that a relationship between vehicle speed and lateral positioning did exist on sections where the shoulders were paved to their full width and that the average positioning of slow-moving vehicles, regardless of type, was closer to the shoulder of the highway than that of fast-moving vehicles.

Jorol (8) observed lateral placement on bituminous-paved two-lane and four-lane rural highways having different shoulder designs in the state of Idaho. He recorded placement data for 7,777 free-moving passenger and commercial vehicles at eight locations during the period 1957 through 1959. The purpose of the study was to evaluate the influence of shoulder design on vehicle placement. Before-and-after data were recorded to measure the effect from other factors. Lateral placement was recorded from visual observations of the vehicle position relative to markings placed on the pavement at 1-ft intervals.

The study showed that the width of the shoulder influenced the lateral placement of vehicles. Both passenger and commercial vehicles traveled closer to the roadway centerline on sections with narrow shoulders than on sections with wide shoulders. In addition, more shoulder encroachment was observed for commercial than for passenger vehicles, and more encroachment was found on the sections with wide shoulders. The narrower the road was, the greater was the tendency for drivers of passenger vehicles to travel in the same wheel tracks.

In summary, the reported studies appear to give some contradictory results when accident rate and shoulder width are compared. For example, gravel shoulders showed a decreasing accident experience with an increase in shoulder width, whereas paved shoulders had an increasing accident experience with an increase in shoulder width. However, the majority of the studies indicated a shoulder width of 4 to 6 ft to be the safest width studied. With regard to lateral placement, the studies generally concluded that narrow shoulders encouraged drivers to drive closer to the pavement centerline.

METHOD

Simulated Bridge

The study utilized a simulated bridge, erected in a large parking lot. The guardrails of the bridge were represented by two 4- by 50-ft lengths of green canvas. Steel pipes, set in concrete bases, held the canvas in place. A broken centerline and solid edge lines were placed on the pavement to indicate two 12-ft traffic lanes. These pavement markings, of 6-in. white reflective tape, extended for 50 ft on both sides of the bridge. The bridge width was randomly varied during the study for a total of eight test conditions as given in Table 1.

Subjects

A total of 10 subjects, eight male and two female, participated in the study. The subjects, all volunteers, were students in an engineering class at West Virginia University. Ages ranged from 20 to 23 years. Nine of the subjects had at least 3 years' driving experience in various states. All subjects had a valid driver's license, and each subject was asked to wear corrective lenses if he or she normally did so while driving.

Data Recording

All subjects drove the same instrumented vehicle throughout the experiment. The vehicle, a 1969 four-door Ford sedan, was equipped with power steering, power brakes, and air conditioning. Driver and vehicle performance data were recorded by a Greenshields Drivometer. The following items were monitored continuously during each test run, and cumulative totals were printed out on paper tape at the command of the experimenter:

1. Macro steering wheel reversals ($8\frac{1}{2}$ deg),
2. Micro steering wheel reversals ($2\frac{1}{2}$ deg),
3. Speed change (2-mph intervals),
4. Accelerator pedal movement ($\frac{1}{8}$ in. up or down from any position),

5. Brake pedal applications,
6. Distance traveled (to $^1/_{100}$ mile),
7. Running time in seconds, and
8. Trip time in seconds.

The speed of the test vehicle, as it approached the bridge, was also recorded by a radar speed meter. The lateral placement of the vehicle along the entire length of the bridge was recorded by a super 8-mm time-lapse movie camera. All filming was done in color at a speed of 6 frames/sec. The camera was equipped with a remote control that allowed the operator to remove himself from the vicinity of the bridge.

Procedure

A single bridge test condition, previously chosen at random, was tested each day. Before a subject was brought to the test site, the time-lapse camera was set up and used to film "calibration tapes" placed at each end and in the center of the bridge. The tapes, made up of alternating black-and-white segments 1 ft long each, were placed perpendicular to the roadway. After several frames of film were exposed, the tapes were removed. The calibration film was later used to define a roadway grid system for the data analysis. The radar speed meter was also set up and tested at this time.

So that the true purpose of the experiment would be concealed, each subject was told that he or she was helping to calibrate a new piece of equipment, the Drivometer. It was felt necessary to take this precaution in order to avoid biasing the data. The subjects were instructed to drive in a normal and comfortable manner over a closed course that included the simulated test bridge. The subject was further instructed not to exceed a speed of 30 mph.

Actual data recording started only after the subject indicated that he had become thoroughly accustomed to both the test vehicle and the course. As the car approached the bridge, the time-lapse camera was remotely switched on and the radar speed meter reading recorded. The camera was switched off after the test car left the bridge. Drivometer readings were printed out as the test car entered and left the bridge. Thirty runs were recorded for each of the 10 subjects, for a given test condition, on a single day.

Data Reduction

After completion of the testing each day, the film was mailed to a commercial photographic laboratory for processing and the Drivometer data were keypunched into computer cards. As each roll of film was returned, it was immediately projected to verify that there had been no equipment failure during the filming. Actual film analysis began after all rolls had been returned.

The film was projected by a stop-motion projector on a 3- by 3-ft white screen from a distance of approximately 15 ft. The film was advanced at normal speed until the black-and-white calibration strips appeared on the screen and then was brought to a halt. The 1-ft interval strips in the picture were then marked on the screen. These marks were next joined by straight lines drawn parallel to the bridge abutment, dividing the bridge into 1-ft parallel strips 50 ft long. The film roll was then advanced until the calibration strips no longer appeared in the picture. While the film roll was advancing, care was taken to see that the position of the calibration strips remained in line with the grid markings drawn on the screen. After this initial preparation, recording of the lateral placement data started. The film was advanced frame by frame, and the position of the centers of the test car's right wheels was recorded for each frame as the vehicle crossed the bridge. This procedure was repeated for each roll of film.

RESULTS

Initial inspection of Drivometer data showed very few accelerator pedal movements or speed changes in the vicinity of the bridge. This was not surprising inasmuch as the drivers were instructed to maintain a steady, safe, comfortable speed during the test and not to exceed 30 mph. Therefore, the analysis was confined to steering wheel reversals for the Drivometer and lateral placement as recorded by the time-lapse camera.

Steering Reversals

The steering reversal data for minor and major movements while the subject was approaching the simulated bridge are given in Table 2. The values are averages for 30 runs per subject. Due to a malfunction in the Drivometer, data for the 4-ft shoulder width were not included in the analysis.

The data in Table 2 were subjected to an analysis of variance using a standard ANOVA program. The results of the ANOVA are given in Table 3. The ANOVA shows a statistically significant difference for both subjects S and the various shoulder widths W. However, due to the significant interaction between the subjects and various widths, S × W, a test for individual means was not run. Instead the combined data for all subjects were plotted (Fig. 1). A general trend for both minor and major reversals is evident; more steering reversals were recorded for narrow shoulders than for wide shoulders. However, the number of reversals remains relatively constant for widths greater than 4 to 6 ft. Although not included in this report, similar graphs for each individual subject exhibit this same trend.

Lateral Placement

Lateral placement data were recorded for both directions of travel on the simulated bridge. However, due to positioning of the time-lapse camera, results for only one direction of travel were considered to be reliable and are presented here. Lateral placement data for eight of the 10 subjects are given in Table 4. Two subjects were not included in the analysis due to incomplete data. The values shown in Table 4 represent the distance from the center of the left wheel to the pavement centerline. As with the steering reversal data, the lateral placement data were subjected to an analysis of variance, and the results are given in Table 5.

Statistically significant differences are shown among subjects and for the various shoulder widths. A test for individual means is again inappropriate due to the significant interaction between S and W. The data for the eight subjects have been averaged and plotted as shown in Figures 2 and 3. Once again a general trend may be noted in that a shoulder of 4 to 6 ft in width appears to be optimum.

Summary of Results

The results of this study may be briefly summarized as follows:

1. A greater number of minor steering wheel reversals were recorded for narrow shoulders than for wide shoulders.
2. A greater number of major steering wheel reversals were recorded for narrow shoulders than for wide shoulders.
3. For both minor and major reversals, the number of reversals remained relatively constant for shoulder widths greater than 4 to 6 ft.
4. The subjects drove furthest from the marked centerline for a shoulder width of 4 to 6 ft.

DISCUSSION OF RESULTS

This report has concerned itself with steering reversals and lateral placement of vehicles driven by 10 subjects across a simulated bridge with variable shoulder width. Although the 10 subjects exhibited individual driving characteristics, certain general trends were common to all. The combined data for all subjects have been presented in the form of tables and graphs. Inspection of these tables and graphs shows that the number of steering reversals, both minor and major, decreases rapidly as the shoulder width increases from -4 to +6 ft and then increases slightly as the shoulder width increases from +6 to +12 ft. Similarly, the distance of left wheel from pavement centerline increases as shoulder width increases until it reaches an optimum at approximately

Table 1. Bridge test conditions.

Bridge Lane Width (ft)	Shoulder Width (ft)	Total Width (ft)
12	12	48
12	10	44
12	8	40
12	6	36
12	4	32
12	2	28
12	0	24
10[a]	—	20
8[a]	—	16

[a] Width of bridge lanes was less than combined 24-ft width of the two traffic lanes on either approach to bridge. In effect, the bridge acted as a bottleneck in the roadway.

Table 2. Average number of steering reversals.

	Shoulder Width (ft)							
Subject	12	10	8	6	2	0	-2	-4
Minor Reversals								
1	3.26	3.47	2.20	3.90	3.30	3.60	4.00	1.60
2	1.50	1.13	0.60	0.93	1.23	1.43	1.63	1.20
3	1.63	1.90	1.90	2.00	2.23	2.30	3.90	3.83
4	1.37	1.53	0.67	1.30	2.10	1.21	2.53	1.60
5	1.83	2.50	1.43	2.18	2.20	1.99	3.37	3.93
6	2.70	1.87	2.17	2.00	2.37	2.13	2.93	1.95
7	2.43	2.70	1.90	2.23	1.97	2.50	4.27	6.47
8	1.50	2.17	0.90	1.93	2.33	1.61	—	2.97
9	1.57	1.83	1.27	1.93	1.87	1.07	1.27	2.93
10	—	2.40	1.45	2.83	2.93	—	3.63	1.83
Mean	1.97	2.15	1.45	2.02	2.25	1.98	3.10	2.83
Major Reversals								
1	0.57	0.74	0.33	0.33	0.44	0.38	1.20	0.30
2	0.60	0.57	0.40	0.13	0.44	0.59	1.17	0.26
3	0.57	0.57	0.54	0.47	0.40	0.84	1.90	2.10
4	0.25	0.37	0.25	0.40	0.30	0.38	1.13	0.50
5	0.54	0.40	0.50	0.70	0.30	0.40	1.20	1.44
6	0.60	0.74	0.57	0.64	0.50	0.70	1.10	0.54
7	0.44	0.44	0.27	0.40	0.30	0.73	1.10	2.30
8	0.23	0.30	0.17	0.60	0.63	0.17	—	0.63
9	0.60	0.63	0.53	0.70	0.47	0.83	1.00	0.87
10	—	0.40	0.40	0.70	—	0.73	0.87	0.37
Mean	0.49	0.52	0.40	0.51	0.42	0.58	1.20	0.90

Table 3. Analysis of variance for steering wheel reversals.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio[a]
Minor Reversals				
Subject S	7	38.61	5.52	11.19
Shoulder width W	8	178.00	22.25	45.13
S × W	56	137.86	2.46	4.99
Experimental error	2,088	1,029.27	0.493	
Major Reversals				
Subject S	7	836.78	119.54	65.82
Shoulder width W	8	702.89	87.86	48.38
S × W	56	866.43	15.47	8.56
Experimental error	2,088	3,792.47	1.816	

[a] $p < 0.05$.

Figure 1. Steering wheel reversals for all subjects.

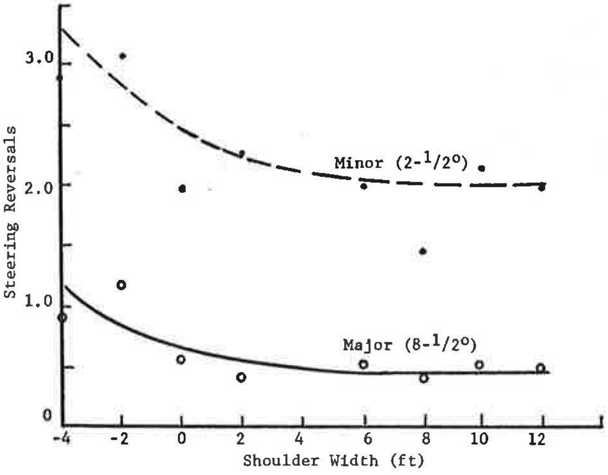


Table 4. Average lateral placement in ft.

	Shoulder Width (ft)								
Subject	12	10	8	6	4	2	0	-2	-4
1	1.87	2.60	2.27	3.47	3.00	2.13	3.00	1.80	-1.13
2	1.73	2.47	2.80	2.47	2.87	3.00	3.07	2.00	-0.80
3	3.00	2.20	2.80	3.13	2.93	2.93	3.80	3.00	0.00
4	1.33	2.07	2.40	1.87	2.33	2.47	2.33	2.00	-2.26
5	1.93	2.40	2.20	3.40	2.07	2.47	2.53	2.07	0.067
6	1.93	2.87	2.20	2.87	3.67	3.00	3.20	1.93	-0.933
7	2.73	2.06	2.73	3.06	2.67	2.73	2.93	2.13	0.067
8	2.00	3.07	2.33	3.73	2.93	3.13	3.67	3.00	-0.20
Mean	2.07	2.47	2.12	3.00	2.81	2.73	3.07	2.24	-0.65

Table 5. Analysis of variance for lateral placement.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio[a]
Subject S	7	101.97	14.57	62.53
Shoulder width W	8	1,237.45	154.68	663.86
S × W	56	144.18	2.57	11.03
Experimental error	1,008	235.87	0.233	

[a] $\underline{P} < 0.05$.

Figure 2. Percentage of vehicles with various lateral placements.

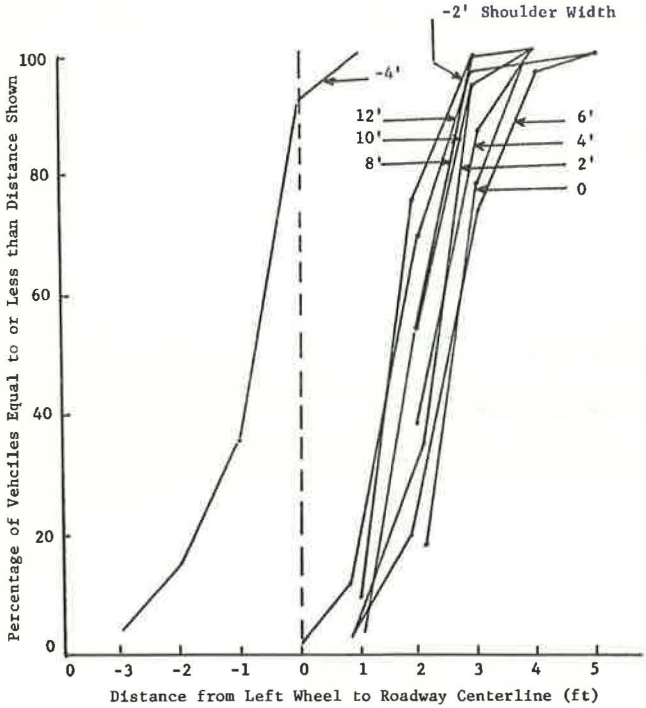
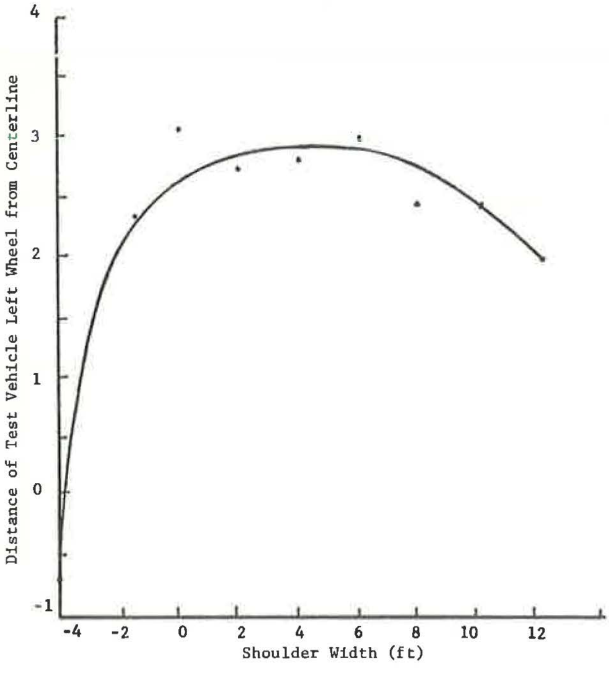


Figure 3. Lateral placement in relation to shoulder width.



+4 to +6 ft and then begins to decrease again. Based on these findings, it would appear that a minimum shoulder width of 4 to 6 ft would be required in order not to influence traffic operations. However, it should be noted that the results for this simulated bridge study have not as yet been verified by an actual field test.

ACKNOWLEDGMENTS

This paper is based on an interim report submitted to the West Virginia Department of Highways as part of the Bridge Shoulder Width Study. The opinions, findings, and conclusions are those of the authors and not necessarily those of the West Virginia Department of Highways or the U.S. Department of Transportation.

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