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COVER:
Accident rates on highways needing resurfacing are being studied.

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Articles

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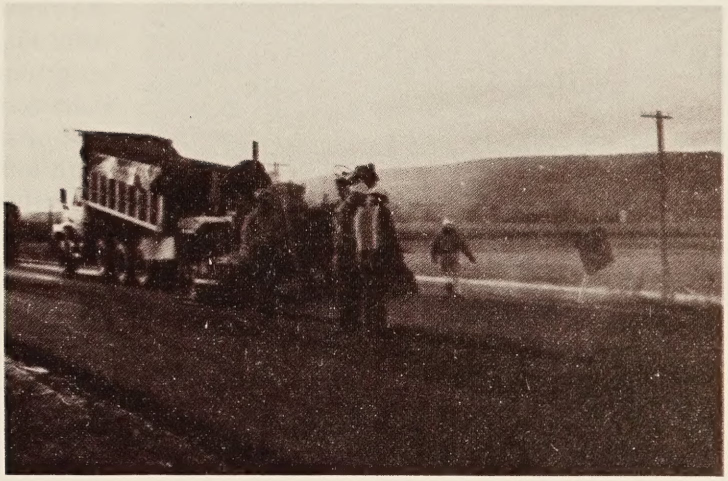
Accident Rates on Two-Lane Rural Highways Before and After Resurfacing

by
Samuel C. Tignor and Jeffrey A. Lindley



Introduction

For years it has been believed that resurfacing highways increases safety. Recently, however, it has been suggested that because of increased operating speeds, resurfacing rural nonfreeways without widening or realining actually increases accident rates. A 1974 study by the Arkansas State Highway and Transportation Department on five highway sections totaling 79 km (49 miles) supports this contention. In the Arkansas study, accident rates increased significantly on four of the five sections that were only resurfaced. (*1*)[1] However, the validity of these conclusions has been questioned, mainly because of the small sample size. Because highway engineers disagree about the safety effects of only resurfacing a highway and not making other improvements, the study discussed in this article was undertaken to determine the effects of resurfacing on accident rates and to quantify these effects if they exist.

[1] Italic numbers in parentheses identify references on page 139.

Data Base

Most of the data in this study was taken from a previous study undertaken to develop relationships between pavement skid number and accidents and to define and evaluate cost-effective alternative skid reduction measures for wet pavements. (*2*) In the skid reduction study, accident data were collected on 428 highway sections in 16 States 1 year before and 1 year after the sections were resurfaced under existing resurfacing programs. Some of these programs included other improvements in addition to resurfacing. The highway sections varied in length and represented rural, urban, two-lane, multilane, controlled access, and uncontrolled access highways and a range of geometric conditions. In the study reported in this article, however, only two-lane, rural, uncontrolled access sections that were resurfaced only were included, yielding a data base of 59 sections with a total length of 657 km (408 miles), representing data from 9 of the 16 States. These data are currently the best available for analyzing accident rates on two-lane rural highways before and after resurfacing.

Data Analysis

The average before and after accident rates for the 59 test sections were 6.128 and 6.264 accidents per million vehicle-kilometres (2.394 and 2.447 accidents per million vehicle-miles) traveled, respectively. These averages are based on total accidents and a composite vehicle-kilometres traveled (vehicle-miles traveled) for the 59 sections. The increase in accidents after resurfacing is 2.2 percent:

$$\frac{(6.264-6.128)\ (100)}{6.128} = 2.2 \text{ percent}$$

However, this computation does not reflect any statistical significance.

Before and after accident rates then were examined for each of the 59 test sections. The data were plotted with the before rates on the y axis and the after rates on the x axis (fig. 1). If, for

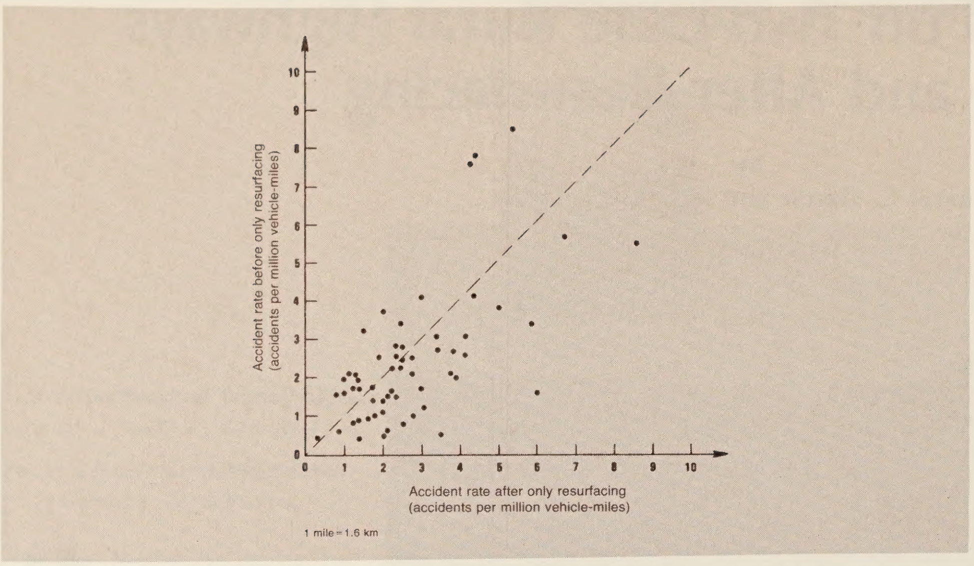


Figure 1.—Comparison of accident rates before and after only resurfacing using the skid reduction study data.

each test section, the accident rate after resurfacing was identical to the rate before resurfacing, the data point would fall on the hypothetical 45-degree dashed diagonal line shown. However, if the after rate was greater than the before rate, the data point would fall below the dashed line, and if the before rate was greater than the after rate, the data point would be above the line. As shown in figure 1, the data are random, with points distributed both above and below the hypothetical 45-degree line.

To determine whether the before and after accident rates were significantly different, a statistical test was performed. The Kolmogorov-Smirnov (K-S) two-sample statistical test[2] was used because *a priori* knowledge of specific population distribution characteristics is not required. The test is performed by statistically examining the cumulative frequency distributions of both the before and after test data (fig. 2). The null hypothesis was that there was no significant difference between the distribution of before and after accident rates. The test was conducted at the 95 percent confidence level. The results showed that no significant difference between before and after accident rates could be found and thus the null hypothesis could not be rejected.

In addition to the K-S test, two additional statistical tests—the sign test and the Wilcoxon matched-pairs signed rank test—were performed on the data at the 95 percent confidence level. The results of both tests were similar: The null hypothesis could not be found to be significantly different at the 95 percent level. It should be noted that no tests beyond the K-S test were necessary to determine statistical significance. These additional tests were performed only to quantify further the K-S test findings.

Supplementary Data

In addition to the analysis described above, data from a study performed by the Alabama State Highway Department were examined. Before and after accident data were collected for various kinds of highway improvements in many Alabama municipalities and counties.[3] One kind of improvement involved resurfacing and increasing the skid resistance of 24 two-lane rural highway sections having a total length of 51 km (32 miles). Average daily traffic volumes on these sections were not significantly different, and the effects of different curvature and terrain were negligible.

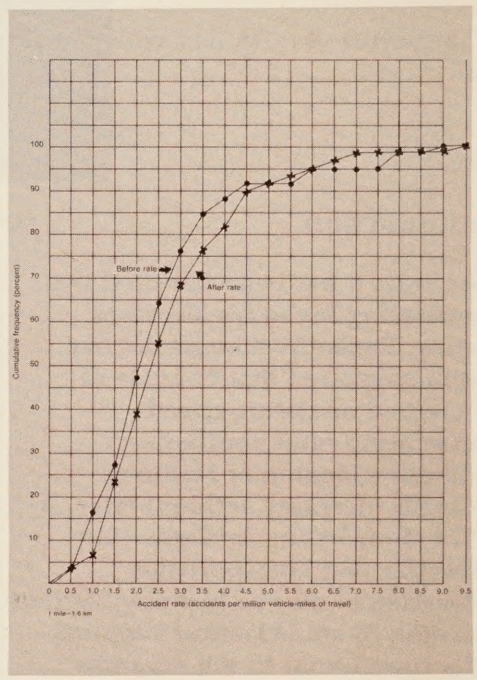


Figure 2.—Cumulative frequency distribution of before and after accident data from the skid reduction study.

[2] A full description of how this test is performed appears in "Non-Parametric Statistics for the Behavioral Sciences" by S. Siegel, 1956.

[3] "Estimating the Safety Benefits for Alternative Highway Geometric and/or Operational Improvements, Vol. II—Research Report," *Alabama State Highway Department*. Report not yet published.

Because the total test mileage in the Alabama study was so small, the data were not considered as broad as the skid reduction study data. However, the Alabama data do exhibit the same random characteristics as the skid reduction study data (fig. 3). The same three statistical tests were applied to the Alabama data. Results of the Alabama data analysis were identical to the results of the skid reduction study data analysis. A computation of before and after average composite accident rates revealed that the average after accident rate was greater than the average before accident rate by 11.85 percent. However, the statistical test results showed that this difference can be expected at the 95 percent confidence level.

Summary and Conclusions

This study examined the effect of only resurfacing on accident rates on rural two-lane, uncontrolled access highways. Analyses were performed using data from two sources and from a total of 83 test sections.

Findings from both data sources yielded similar results; namely, accident rates before and after only resurfacing did not differ at the 95 percent level. Thus the results of the analyses performed in this study clearly indicate that only resurfacing has no significant effect on two-lane rural highway accident rates. The change in accident rates from before resurfacing to after resurfacing is a random occurrence.

As previously mentioned, the data used in this analysis are currently the most extensive and best available for evaluating accident rates on two-lane rural highways before and after only resurfacing. A larger only resurfacing data set is being collected in a Federal Highway Administration study on the safety and operational impact of resurfacing, restoration, and rehabilitation projects. However, the data collection and analysis will not be completed for several years. Thus, at least for now, these data suggest that for safety or safety-cost analyses, the analyst should not estimate an increase or decrease in accidents as a result of only resurfacing two-lane rural highways.

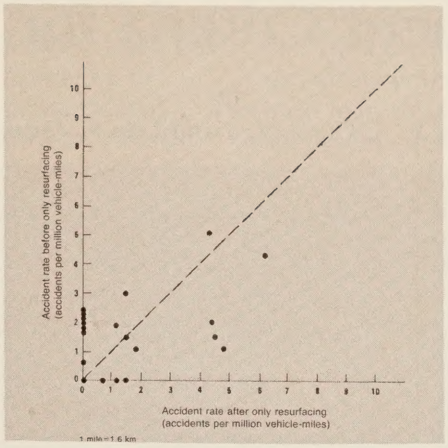


Figure 3.—Comparison of accident rates before and after only resurfacing using the Alabama study data.

REFERENCES[4]

(*1*) "Comparison of Accident Rates Before and After Rehabilitation of Narrow Pavements" *Arkansas State Highway and Transportation Department*, Little Rock, Ark., October 1974.

(*2*) R. R. Blackburn et al., "Effectiveness of Alternative Skid Reduction Measures, Vols. I and II," Report Nos. FHWA-RD-79-22 and -23, *Federal Highway Administration*, Washington, D.C., November 1978. PB Nos. 80 158454 and 80 158462.

[4]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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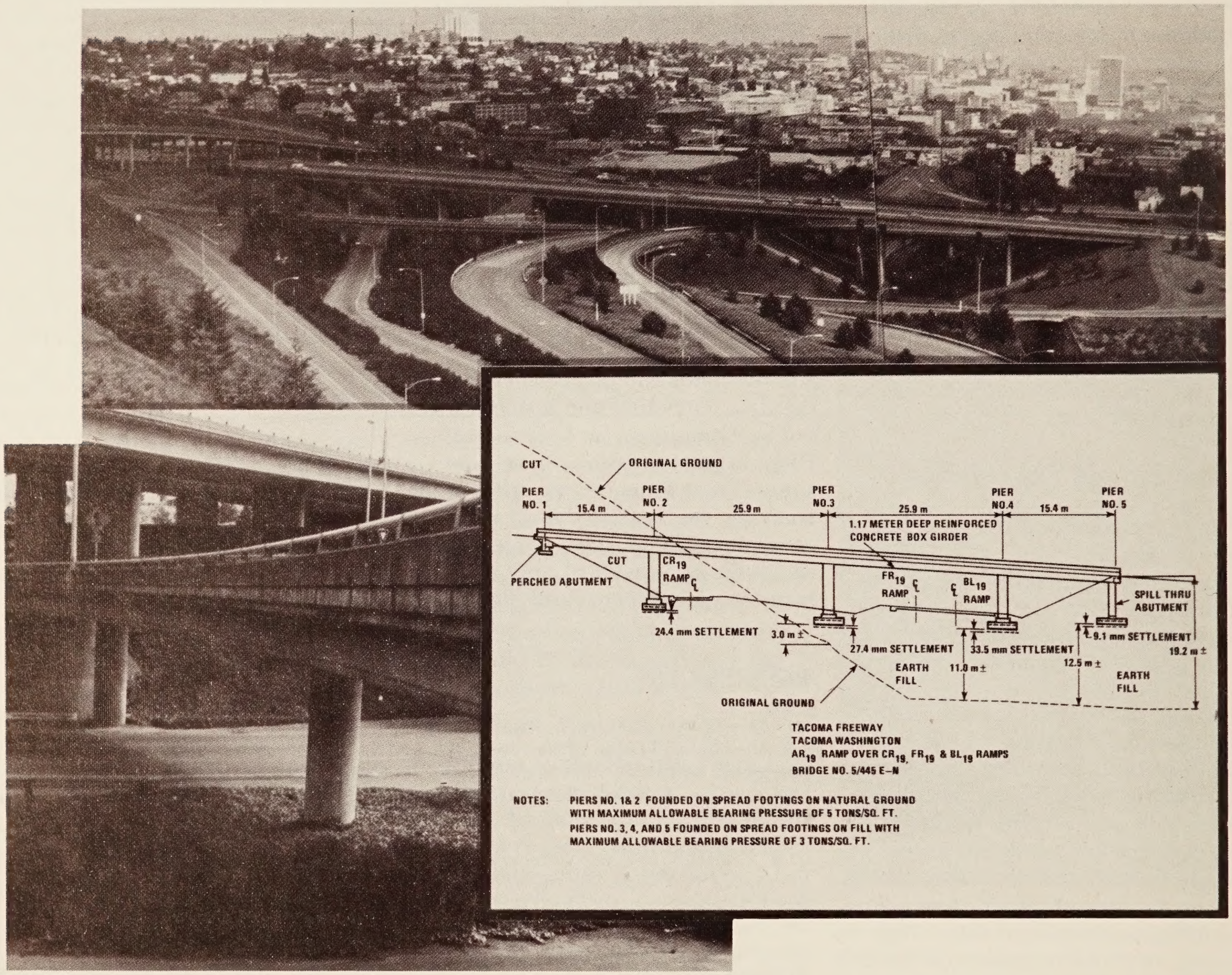
Tolerable Movement Criteria for Highway Bridges

by
Hota V. S. GangaRao and Lyle K. Moulton



Introduction

This is the last of three engineering research articles on the development of tolerable movement criteria for highway bridges. The series was introduced in the June 1980 (vol. 44, No. 1) issue of *Public Roads*. Articles in the September 1980 (vol. 44, No. 2) and December 1980 (vol. 44, No. 3) issues described the significance of the problem, the need to establish tolerable movement criteria for highway bridges, and the results of field and analytical studies on the effects of bridge movements.

Field data on bridge foundation movements were analyzed in terms of structural damage and tolerance to movements.[1] The field data showed that numerous highway bridges experience a range of vertical and horizontal movements. The data also showed that many highway bridges can tolerate significant magnitudes of total and differential vertical settlement without sustaining serious structural damage. Pile foundations did not always eliminate foundation movement and therefore are not necessarily a superior foundation.

[1] "Analysis of Bridge Movements and Their Effects," thesis by J. R. Kula for Master of Science in Civil Engineering, West Virginia University, Morgantown, W. Va., 1979.

Analytical studies also were conducted on the effects of differential vertical movements on a variety of steel and concrete highway bridge systems. The tolerance of superstructure elements to support settlements was investigated in terms of span length, stiffness, rate of settlement, creep and shrinkage, and other system parameters. The results of the analyses were presented in a series of graphs showing the increases in stresses caused by differential support settlement in terms of span lengths and stiffnesses. A set of design equations also was developed to help determine the increase in stresses caused by differential support settlement. For steel bridges, the stress increases caused by a 76 mm (3 in) differential settlement were found to be quite small and perhaps negligible if the stiffness (moment of inertia/span length) was 328 000 mm^3 (20 in^3) or less. For concrete bridges, the effects of differential settlement were complex and time-dependent material properties and the time rate of settlements had to be considered in evaluating the effects of differential settlements.

The results of the field studies (*1*)[2] and analytical studies (*2*)[3] described above have been combined to develop a highway bridge design methodology that embodies a rational set of criteria for tolerable bridge movements. This article summarizes the results of this work as they apply to steel bridges. Tolerable movement criteria for concrete bridges will not be established until complexities associated with the time-dependent behavior of these structures can be resolved.

Development of the Design Procedure

Field and analytical studies have shown that the criteria for tolerable bridge movements must consider both strength and serviceability. The strength criteria must insure that any stress increases in a bridge system caused by the predicted foundation movements do not adversely affect the long term load carrying capacity of the structure. The serviceability criteria, on the other hand, must insure rider comfort and the control of functional distress. The fact that the predicted foundation movements may not immediately jeopardize the load carrying capacity of the bridge does not necessarily insure the long term usefulness and safety of the structure. If the foundation movements significantly reduce the ability of a bridge to serve its intended function, then these movements may be intolerable, even though the load carrying capacity of the bridge is not seriously impaired. For example, movements that could lead to poor riding quality, reduced clearance at overpasses, deck cracking, bearing damage, and other kinds of functional distress requiring costly maintenance must be controlled properly for satisfactory long term bridge performance. This control can be provided by adopting appropriate tolerable movement criteria based on serviceability. The recommended design procedure was developed with these concepts in mind.

Field and analytical studies have shown that, depending upon span length and stiffness, many continuous bridges may experience relatively modest increases in stress because of foundation movements. (*1, 2*)[4] It was initially suggested that one basis for the establishment of strength criteria might be to define overload or overstress limits that would be acceptable for various bridge systems without risking serious damage. There are ample precedents for such criteria in existing American Association of State Highway and Transportation Officials (AASHTO) standards for design and maintenance and in other building codes and design specifications. (*3, 4*) However, these criteria generally involve temporary or transient overloads. For continuous bridges that experience differential settlements, the induced stresses might be permanent, unless remedial jacking operations are undertaken to relieve stress. Overstress would reduce overall safety with respect to the ultimate load carrying capacity of the structure. This could be particularly serious with increased truck loads under conditions of overload design or maximum design loads. In addition, the risk of damage from fatigue would increase. The use of auto stress design was considered but this was abandoned because of the inherent danger of a "collapse mechanism" caused by the combined effects of support settlements and maximum live loads across the bridge. (*5, 6*)

Because of the above considerations, a design procedure was adopted based on working stress design for service loads, reducing the allowable stress by a value equivalent to the stress increase caused by the predicted differential settlements. Thus, the recommended design procedure involves three basic steps:

1. Designing the bridge in accordance with the existing AASHTO working stress procedure assuming zero settlement but using reduced allowable stresses in the top and bottom fibers to adjust for anticipated settlement. (*3*)

[2] Italic numbers in parentheses identify references on page 147.

[3] "Limits of Tolerable Movements for Steel Highway Bridges," thesis by C. A. Haslebacher for Master of Science in Civil Engineering, West Virginia University, Morgantown, W. Va., 1980.

[4] Ibid.

2. Comparing the predicted movements with tolerable movements established by serviceability criteria.

3. Modifying the original design to satisfy minimum strength and serviceability criteria.

Of course step 3 may not be necessary if the comparisons in step 2 show that the original design can tolerate safely the anticipated movements. An alternate procedure for step 1 would be to include the settlement stresses with live and dead load stresses without reducing the allowable stress value. Although the design aids (presented later in this article) to determine the reduced allowable stresses make the recommended procedure somewhat easier, individual designers may wish to use this alternate method.

As noted earlier, for long-span bridges, the increase in stresses caused by moderate differential settlements (for example, settlements up to 76 mm [3 in]) might be very low or even negligible. Under these circumstances, another optional procedure for step 1 might be considered. This procedure would be to design the bridge in accordance with existing AASHTO working stress design criteria assuming zero settlement and then use the design aids to check whether or not the stress increase caused by the predicted settlements is truly negligible. If not, the design should be appropriately adjusted. This procedure might be more directly applicable in the bridge rating process than the recommended procedure for existing bridges subjected to continuing settlements.

Strength Criteria

The primary strength criterion in the recommended design procedure is the requirement that the live load carrying capacity of the bridge not fall below existing AASHTO limits as a result of support settlement. This requirement will not necessitate any change in the AASHTO design procedure for simply supported steel bridges with rectangular deck shapes because no internal stresses will develop in simply supported bridge members as a result of differential settlements. However, for continuous bridges, the superstructure must be designed to accommodate the higher stresses resulting from differential settlements. The recommended design procedure meets this requirement in that the bridge is designed as if it were not going to experience settlement, using reduced allowable stresses to compensate for anticipated differential settlements. The primary advantage of this method over the alternate procedures discussed above is that it provides a uniform design method that is applicable regardless of whether or not any foundation movement is anticipated.

To use the recommended design procedure, it is necessary to compute a reduction in allowable stress that will compensate for the stress increase from the predicted differential foundation movements. To facilitate this computation a series of design equations was developed based on the macroflexibility approach. (7) The maximum stresses in the top and bottom fibers of the bridge members caused by support settlement can be calculated simply with these equations. The resulting expressions follow:

Equation 1

$$f_O(+) = \frac{2.5Ecn^3\Delta_O}{L^2} \sum_{i=n-1}^{n+1} \frac{\sin\frac{i\pi}{n} \cdot \sin\frac{2i\pi}{n}}{i^2\left(3\cot^2\frac{i\pi}{2n} + 1\right)}$$

Equation 2

$$f_O(-) = \frac{2.5Ecn^3\Delta_O}{L^2} \sum_{i=n-1}^{n+1} \frac{\sin^2\frac{i\pi}{n}}{i^2\left(3\cot^2\frac{i\pi}{2n} + 1\right)}$$

Equation 3

$$f_\alpha(+) = \frac{10Ecn^3\Delta_\alpha}{L^2} \sum_{i=n-1}^{n+1} \frac{\sin^2\frac{i\pi}{2n} \cdot \sin\frac{i\pi\alpha}{n} \cdot \sin\frac{i\pi(\alpha - 0.5)}{n}}{i^2\left(3\cot^2\frac{i\pi}{2n} + 1\right)}$$

Equation 4

$$f_\alpha(-) = \frac{10Ecn^3\Delta_\alpha}{L^2} \sum_{i=n-1}^{n+1} \frac{\sin^2\frac{i\pi}{2n} \cdot \sin\frac{i\pi\alpha}{n} \cdot \sin\frac{i\pi(\alpha + 1)}{n}}{i^2\left(3\cot^2\frac{i\pi}{2n} + 1\right)}$$

Where,

Δ_O = differential settlement of an abutment with respect to the adjacent pier.

Δ_α = differential settlement of a pier with respect to the adjacent pier or abutment.

$f_O(+)$ = maximum increase in tension in the bottom fiber caused by Δ_O.

$f_O(-)$ = maximum increase in tension in the top fiber caused by Δ_O.

$f_\alpha(+)$ = maximum increase in tension in the bottom fiber caused by Δ_α.

$f_\alpha(-)$ = maximum increase in tension in the top fiber caused by Δ_α.

E = Young's modulus.

n = number of spans.

l = length of each span.

L = nl = total length of bridge.

c, $\bar{c}$ = distance from the neutral axis to the extreme bottom and top fibers, respectively.

α = number of the pier (interior support) with settlement, counted in ascending order from left to right.

Equations 3 and 4 are valid for values of α corresponding to pier locations at or outside the point of symmetry of the bridge. For example, for a four-span continuous bridge, equations 3 and 4 would be valid for $\alpha = 1$ and $\alpha = 2$, that is, for the first interior support and the center support. Values for settlement of the third interior support would, by symmetry, be the same as those for the first interior support. However, such symmetry is not readily apparent from these equations.

Equations 1 through 4 are approximations of Fourier series solutions, and they contain small empirical correction factors to account for the neglect of additional terms. In addition, the location of the maximum positive or negative stress that is incorporated in equations 1 through 4 has been approximated from the deflected shape of the bridge superstructure. However, typical stresses computed with these equations are within 10 percent of those obtained from more exact computations, such as those produced by the ICES STRUDL-II computer package. (*8*)

An apparent limitation of the proposed design equations is that they are only valid for those continuous bridge systems that have equal span lengths and constant moments of inertia. However, this limitation usually does not lead to serious error as long as the individual span lengths of the continuous system are within 20 percent of each other. (*9*) Furthermore, the proposed equations positively lead to an upper bound solution—maximum settlement stresses—when the smallest span length of a continuous system is considered. Of course, the designer can adopt a more accurate analysis based on any of the commercially available "canned" computer codes. Also, it should be noted that the designer can find the bending stresses for dead and live loads using the design equation 1 presented in the December 1980 (vol. 44, No. 3) issue of *Public Roads* (p. 109).

A series of six design aids was developed for the recommended design procedure using equations 1 through 4, which correspond to maximum positive and negative stresses caused by differential settlement of abutments and piers. (*10*) These design aids are presented in figures 1 through 6 and provide solutions for continuous bridges with up to five spans and span lengths up to 76 m (250 ft).

In practice, the designer would use the appropriate design aids to pick off values of $\Delta_O c/f_O(+)$ and $\Delta_O \bar{c}/f_O(-)$ for abutment settlement or values of $\Delta_\alpha c/f_\alpha(+)$ and $\Delta_\alpha \bar{c}/f_\alpha(-)$ for pier settlement. Then the anticipated settlement and estimated values of c and $\bar{c}$ could be used to solve for the corresponding maximum positive and negative settlement stresses. The resulting values then would be subtracted from the AASHTO limit of 0.55 f_y to obtain the allowable stresses for use in the recommended design procedure. (*3*)

Serviceability Criteria

Serviceability criteria are concerned with maintaining rider comfort and controlling functional distress. The kinds of movements influencing serviceability are vertical displacements, including total settlement, differential settlements, longitudinal angular distortion, and transverse angular distortion; horizontal displacements, including translation, differential translation, and tilting; and dynamic displacements. (*2*)[5]

Realistic limits on these movements can be established only if sufficient and relevant field data are available. Because of insufficient field data, however, limits can be

[5] "Limits of Tolerable Movements for Steel Highway Bridges," thesis by C. A. Haslebacher for Master of Science in Civil Engineering, West Virginia University, Morgantown, W. Va., 1980.

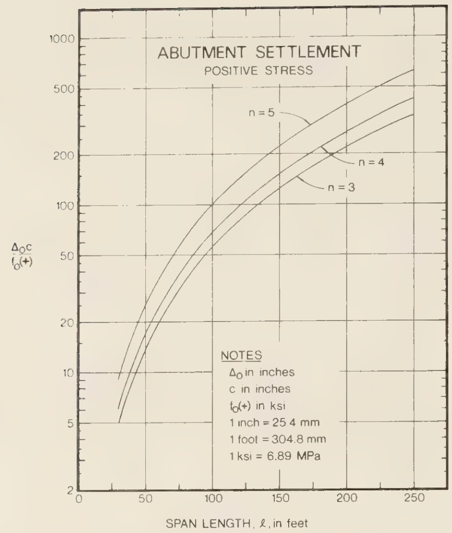


Figure 1.—Design aid for determining the maximum positive stress increase caused by abutment settlement.

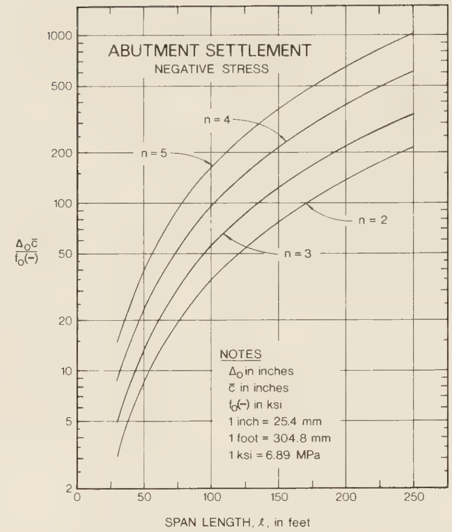


Figure 2.—Design aid for determining the maximum negative stress increase caused by abutment settlement.

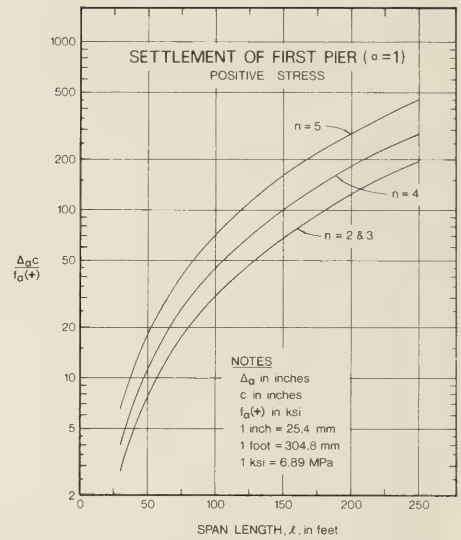


Figure 3.—Design aid for determining the maximum positive stress increase caused by settlement of the first interior support.

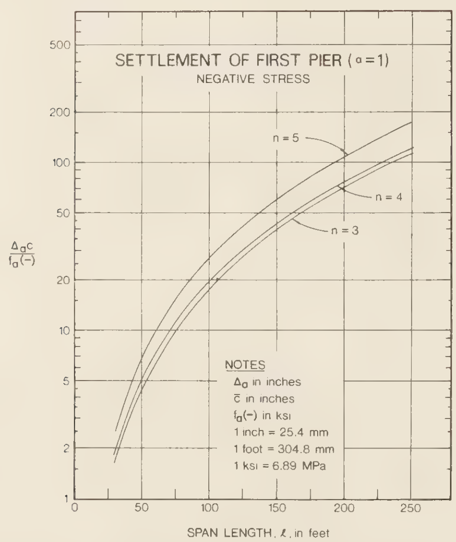


Figure 4.—Design aid for determining the maximum negative stress increase caused by settlement of the first interior support.

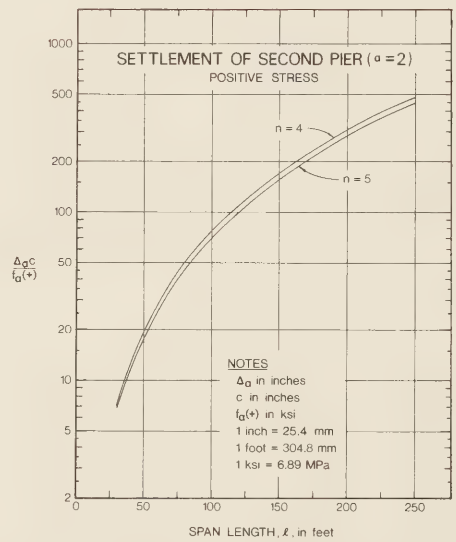


Figure 5.—Design aid for determining the maximum positive stress increase caused by settlement of the second interior support.

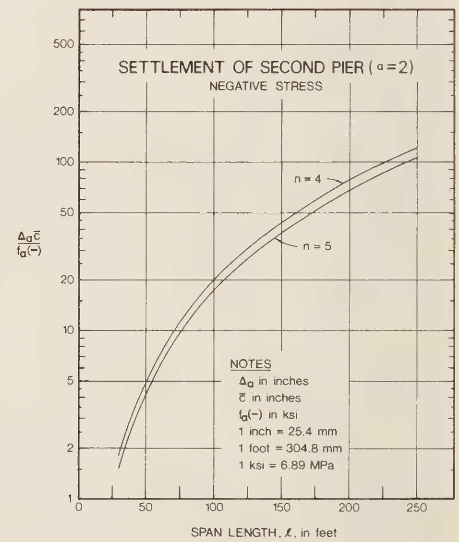


Figure 6.—Design aid for determining the maximum negative stress increase caused by settlement of the second interior support.

established only on some of these movements; criteria for limiting the remaining kinds of movements will be established and implemented after additional field data on these movements and their effects are accumulated. For example, existing field data show that horizontal movements of abutments and piers, either by translation or tilting, must be controlled carefully to avoid structural damage. (*1, 10*)[6] Although setting tolerable limits on these horizontal movements has not been difficult, these movements cannot be predicted reliably at present.

[6] "Analysis of Bridge Movements and Their Effects," thesis by J. R. Kula for Master of Science in Civil Engineering, West Virginia University, Morgantown, W. Va., 1979.

Based on data assembled during this study, tolerable limits have been established on longitudinal angular distortion for simple and continuous bridges, horizontal movement of abutments, differential vertical settlements based on cracking of bridge decks, and bridge vibrations.

Longitudinal angular distortion

The field data from this study indicated that structural damage requiring costly maintenance occurred more frequently as the longitudinal angular distortion (differential settlement/span length) increased. To evaluate this phenomenon, the frequency of occurrence of the various ranges of tolerable and intolerable angular distortions was studied for both simply supported and continuous bridges. (*1, 10*) The results of this study showed that for continuous bridges 96 percent of the angular distortions less than 0.004 were considered tolerable. For simply supported bridges, 97.1 percent of the angular distortions less than 0.005 were considered tolerable. The tolerance of both kinds of bridges to angular distortions dropped rapidly for values greater than these. A statistical analysis of the field data showed that there is a 97.9 percent probability that angular distortions less than 0.004 will be tolerable for continuous bridges and a 99.8 percent probability that angular distortions less than 0.005 will be tolerable for simply supported bridges. On this basis, the tolerable limits for longitudinal angular distortion of continuous and simply supported bridges appear to be 0.004 and 0.005, respectively.

Horizontal movement of abutments

Bridges that experienced either horizontal movement alone or horizontal movement in conjunction with differential vertical movement had a high frequency of damaging structural effects, suggesting that horizontal movements are more critical than vertical movements in causing structural damage. (*1, 10*)[7] Although various damaging incidents were reported, the most frequently occurring sequence of events involved the inward horizontal movement of abutments, jamming the stringers or girders against the back wall of the abutments, closing the expansion joints in the deck, and seriously damaging the bearings, abutments, and superstructure.

[7] Ibid.

In terms of horizontal movements alone, movements less than 50 mm (2 in) were reported as tolerable for 83.3 percent of the bridges. (*1*) When accompanied by vertical movements, horizontal movements less than 50 mm (2 in) were reported as tolerable for only 68.2 percent of the bridges. However, horizontal movements of 25 mm (1 in) and less almost always were reported as tolerable.[8] Based on these data, it is recommended that horizontal movements of abutments be limited to 38 mm (1.5 in). However, during bridge design more consideration should be given to the possibility of horizontal movements and their potential effects.

Differential vertical settlement based on deck cracking

Deck cracking as a result of differential settlement is normally restricted to continuous bridges and is a function of the tensile stress developed over the supports (that is, in the negative moment region), the allowable tensile stress in the deck concrete, and the spacing and size of negative reinforcement. The maximum negative stress (tension at the top of the bridge deck) from anticipated vertical differential settlement of abutments or piers can be determined from equations 2 or 4, respectively, or by using an appropriate design aid such as figure 2. The total maximum negative stress is then obtained by adding this value to the negative stress produced at the same point by the design live and dead loads. This total maximum negative stress is limited to the allowable value given by equation 6–30 in section 1.5.39 of the AASHTO specifications. (*3*) In essence, comparing the total maximum negative stress and the limiting stress provided for in the AASHTO specifications constitutes a check on the tolerance of the bridge to the anticipated differential settlement in terms of deck cracking. If the computed total maximum negative stress exceeds the AASHTO limit, then some adjustment may be required in the size and/or spacing of the deck reinforcement.

Bridge vibrations

Traffic-induced bridge vibrations are generated mainly by fluctuations of wheel contact loads as vehicles travel over bridge deck irregularities. These irregularities can be the result of bridge deck deterioration or general roughness

[8] Ibid.

caused by inadequate construction control, or a "ramp" caused by differential vertical movement of abutments or piers. The dynamic effects of both kinds of irregularities were analyzed for continuous steel bridges and compared with the limited field data. (*10*)[9] Comparison of the calculated vibrations with human response data suggested that the dynamic deflections would be within tolerable levels if the ratio of the forced frequencies (ω_f) to natural frequencies (ω_n) is less than 0.5 or greater than 1.5. (*11*) This criterion can be expressed as follows:

$$\frac{\omega_f}{\omega_n} = \frac{2v}{\pi s n^2}\sqrt{\frac{mL^4}{EI}} \begin{matrix} >1.5 \\ <0.5 \end{matrix}$$

Where,
v = velocity of the moving load.
s = truck axle spacing.
n = number of spans.
m = the mass per unit length of bridge section.
L = total span length.
EI = flexural rigidity of the bridge section.

Using this equation, the designer can determine whether or not a proposed bridge has sufficient mass and stiffness to prevent excessive dynamic deflections. Because a substantial increase in deflections leading to uncomfortable levels of human response is observed for ω_f/ω_n ranging from 0.5 to 1.5, the problem parameters should be modified if ω_f/ω_n falls within this critical range.

It is recommended that the criterion embodied in this equation be applied both for the normal bridge deck and for the "ramp" effect produced by differential settlement of abutments or piers. However, in the latter case, a study of traffic on bridges and roads indicated that a maximum of 20 percent increase in forcing frequency from the normal road surface to the "ramp" condition can occur. (*12-14*) Therefore, the forcing frequency for ramp effects, ω_{fr}, should be taken as 1.2 ω_f in applying the criterion of the equation.

Summary

The design procedure presented above considers both strength and serviceability criteria. The procedure involves designing a bridge assuming no settlement will take place, using the AASHTO working stress design procedure with the allowable stresses being reduced to compensate for anticipated settlements. The resulting design is then checked for compliance with serviceability criteria based on limiting longitudinal angular distortion, horizontal movement of abutments, deck cracking, and bridge vibrations. Convenient equations and graphical design aids have been developed to facilitate these operations. The original design of a bridge may need to be modified to satisfy minimum strength and serviceability criteria.

There are several aspects of bridge design, construction, and performance relating to the tolerance to bridge movements that require further research. For example, strength and serviceability criteria for skewed highway bridges experiencing differential movements still need to be established. Preliminary analytical studies revealed that skewed bridges are more susceptible to damage resulting from differential movements than rectangular bridges. However, the work described in this three-part series of articles is a significant beginning to solving complex bridge movement problems. It is hoped that continued work in this area will provide definitive answers to remaining questions.

Acknowledgments

The authors wish to acknowledge the dedication, hard work, and contributions of C. Putcha, Charles Haslebacher, Joseph Kula, and Ran-Jay Chen. The cooperation of Transportation Research Board Committee A2K03 and the many highway agencies that supplied data for the study is also greatly appreciated.

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Driver Considerations in Highway Design

by
Donald A. Gordon

The aim of human factors research in the Federal Highway Administration (FHWA) is to improve the match between the driver and highway. In dealing with the highway, drivers rely heavily on signs, markings, traffic signals, roadway geometry, and perception of the areas adjacent to the road. Concern for the favorable impact of these highway features has been responsible for most of the human factors research on driver-highway compatibility.

Introduction

The study of highway design to achieve driver compatibility has a long history. Psychological studies of letter style and letter dimensioning of highway signs were made as early as the 1930's. (*1, 2*)[1] However, it was considerably later, in 1950, that the human factors involvement with highways was evidenced by the appointment of the first psychologist in the Bureau of Public Roads (BPR). Since then, the role of human factors research in highway design and operation has rapidly expanded.

Early Compatibility Studies

Early compatibility research was concerned with subtle decisions on highway sign color, letter styles, and delineations. In 1933, the visibility of highway sign colors was experimentally investigated. (*3*) Observations were made during the day and at night. The study showed that black letters on a yellow background were more effective than either black on white or white on black combinations. The effectiveness of reflecting buttons in various sizes and spacings also was determined. The results of this research were incorporated into the 1935 Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD). (*4*)

The red and green colors used on traffic signals have been selected to minimize confusion for colorblind drivers. The standard arrangement of the red signal above the green signal

[1] Italic numbers in parentheses identify references on page 153.

(red signal to the left of the green signal on horizontal layouts) offers additional cues to the colorblind driver.

The stop sign color was changed from black on yellow to white on red, the standard now in use, as a result of research that demonstrated that the red sign was more conspicuous. This change was made in the 1955 MUTCD. (*4*)

A study in 1957 supported the selection of green for the background of Interstate signs. The study was documented in the Interstate Manual of the American Association of State Highway Officials (AASHO) and approved by the BPR in 1958. (*4*)

Centerline pavement markings appeared as a traffic control device in an early MUTCD. An FHWA study in 1947 revealed that centerline markings improved vehicle lane positioning and reduced sideways movement and encroachments of traffic on the left lane. (*5*)

The design of highway sign lettering reflects one of the earliest applications of human factors research. In the early 1930's, laboratory studies showed the advantage of sign letters with width-to-height ratios greater than 33 percent, a stroke width 20 percent of average letter width, and a spacing of 50 percent of average letter width. (*6*) Later studies indicated an optimum stroke width for block letters of 15 to 25 percent of letter height. (*7, 8*) Numerous human factors studies have shown that for maximum legibility, white letters on a dark background should have different dimensions than black letters on a white background because of irradiation—the spreading effect of a light source seen against a dark background. Based on information from these studies, a standard block letter alphabet, and later a rounded letter alphabet, and still later a lower case alphabet design were adopted by the National Committee on Signs, Signals, and Markings and the BPR.

A legibility ratio of about 15 m (50 ft) eye-to-sign distance to 25 mm (1 in) letter height was found to hold in daylight for black on white medium letters. (*9*) Eighty percent of the experimental subjects could read signs at this distance. Results also were calculated at night for floodlighted signs and for button reflectorized signs under headlights. In 1942, the letter height required to give motorists sufficient warning time was calculated considering vehicle speed, viewing, and maneuvering times. (*10*) Generally, the 15 m to 25 mm (50 ft to 1 in) rule has been adopted for calculating the distance at which drivers can read highway signs with various letter sizes and designs.

In 1935, the BPR collected data from subjects driving their own vehicles on curves of known radius and superelevation by asking the subjects to report the speed at which they began to feel an outward side pitch. (*11*) It was concluded that driving on curves would be safe when the superelevation was sufficient to counteract centrifugal force for three-quarters of the expected speed, relying on side friction to supply the remaining horizontal resistance up to a maximum side friction factor of 0.16 at 97 km/h (60 mph). The expected speed, or the "assumed design speed," was used to coordinate all alinement and geometric design values.

Recent Compatibility Studies

With the advent of modern highways characterized by high traffic volumes and complex layouts, driver-highway compatibility has assumed critical importance. Many problems not previously considered have received attention, and older solutions have been reexamined.

Driver eye-height standard

The driver eye-height standard in calculating vertical curve design is currently being questioned. The current eye-height standard of 1.14 m (3.75 ft) was adopted in 1965 based on an earlier study of driver eye height and vehicle performance. The standard was based on the following logic:

> The eyes of the average driver in a passenger vehicle are considered to be 3.75 feet above the road surface. In the 1960 model year, the median eye height of drivers in passenger cars was reported as being 47.5 inches with a range of from 44 inches to about 49 inches. Because there are few car models for which the driver's eye height is above 4.0 feet and an appreciable number no higher than 3.75 feet, the latter height is appropriate for measuring both passing and stopping sight distances. (*12*)

Because the eye height of drivers has changed with the prevalence of mini-sized and compact cars and the increased proportion of women drivers, a design eye height of 1.14 m (3.75 ft) may no longer be compatible with present drivers and vehicles. However, developing a design driver eye height is not simple. It must be decided whether the test sample will include, in equal proportions, all cars on the road or mostly newer models. The newer models increasingly will dominate the traffic mix. Also, male and female eye heights differ, as do their annual driving mileages. The percent of drivers to be accommodated by the design height must be prescribed. The 15th percentile will accommodate 85 percent of the drivers; the 5th percentile will accommodate 95 percent of drivers on the road.

Various eye-height measurement techniques have been used. (*13*) Photographs of drivers in their cars may be preferable to anthropological measurements because the latter do not simulate the ways drivers slump in their seats.

Figure 1.—Sample diagrammatic signs.

The American Association of State Highway and Transportation Officials (AASHTO), formerly the American Association of State Highway Officials, is considering changing the current eye-height standard to 1.07 m (3.50 ft) or slightly less. A distinction may be made between an eye-height design standard for new as opposed to older highways. The high cost of retrofitting vertical highway curves has deterred changing the eye-height standard.

Evaluation of diagrammatic signs

A study in 1970 aroused widespread interest in diagrammatic signs (fig. 1). (*14*) Slides of conventional and diagrammatic freeway signs were shown to volunteer subjects who were asked to indicate the highway lane they should be on to reach a preassigned destination. On four of the six interchanges tested, subjects selected the correct lane more frequently when diagrammatic signs were displayed. Results of this study were widely interpreted as endorsing diagrammatic signs. However, subjects were more confident in their choices when they viewed conventional signs for 18 of the 29 sign situations tested.

To assess more rigorously the effectiveness of diagrammatic signs, a series of sign studies was conducted in the laboratory (*15, 16*) and on the road. (*17–19*) Results showed that diagrammatic signs mainly are applicable in certain highway situations. Diagrammatic signs currently are approved for left exits, splits, exits with route discontinuities, and left exit lane drops.

Yellow highway paint

Yellow highway paint diluted with white has advantages over yellow highway paint currently used in that it can be seen farther, has less toxic lead chromate pigment, and is less expensive. An FHWA study was carried out to determine whether the yellow highway paint now in use could be diluted with white paint and still be identified as yellow under various night illuminations. (*20*) From the driver's seat of a parked car, subjects identified as either yellow or white a series of paint mixtures applied to thin metal strips resembling highway stripes. It was shown that yellow paint now in use can be diluted up to 50 percent and still be identified correctly as yellow under night illuminations. State highway and transportation departments have been encouraged to try the whitened yellow paint. If reactions are favorable, the yellow paint marking standard may be altered.

An FHWA staff study report recommended that yellow road paint usage be reduced. (*21*) The data showed that drivers did not understand the meaning of the yellow markings. It was recommended that yellow delineations be used mainly to indicate caution where a hazardous situation existed. If the yellow marking is used with restraint, its meaning will be conveyed more effectively. The restricted use of yellow markings for hazardous situations is still under consideration.

Changeable message sign displays

Changeable message signs inform the motorist of optimal routes, lanes, and driving speeds in response to existing highway conditions (fig. 2). FHWA research completed in 1978 on human factors requirements for real-time motorist information displays involved extensive human factors laboratory and field tests as well as analyses of operational observations. (*22*) The research findings provide comprehensive rules for developing, designing, and operating both visual and auditory driver displays for freeway corridor traffic management. Recommendations are given for message content, the manner in which messages are to be displayed (format, coding, style, length, load, redundancy, and number of repetitions), and the proper placement of messages relative to the situations they are explaining.

Work continues on improving changeable message signs. Recent research is determining optimal word choice, message length for auditory messages, and preferred format for bulb and disk matrix signs.

Unsolved Driver-Highway Compatibility Problems

Improved driver wayfinding

A lost driver searching for an unfamiliar urban destination may seek assistance from a passer-by or a gasoline station attendant or may consult a map if one is available. Eventually, a more effective method will be developed for urban wayfinding. The interest in citizen band radio systems, the electronic route guidance system, electronic maps, and the call-in system for motorist navigation information indicates the pressing need for urban wayfinding aids. Project 2N in the Federally Coordinated Program of Highway Research and Development is concerned with improving driver-highway wayfinding and consequent conservation of gasoline. The project objectives include improving motorist wayfinding in metropolitan areas of the United States, improving information systems for directing drivers through complex and confusing highway routes, and developing and evaluating advanced communication techniques to improve drivers' wayfinding.

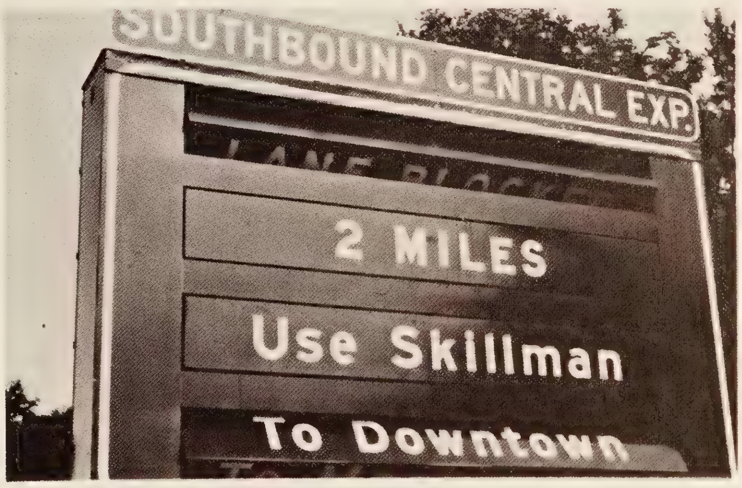

Figure 2.—Changeable message signs, such as this rotating drum sign, allow messages to be changed to reflect highway conditions.

Determining the driver's informational requirements

An important research problem is to determine drivers' informational requirements. If these requirements were known, information possibly could be provided more simply and directly than with the signs, markings, and signals currently used. Informational requirements may be further analyzed into cues for steering, speed control, situational performance, planning, and direction finding.

Informational requirements can be studied by observing drivers as they plan their route and navigate to their destination. The methods used, the questions asked, and particularly the difficulties encountered shed light on the information required to complete the task. Such observations determine information the driver is looking for but does not find. This information should be supplied. Also determined would be information currently on signs but not needed by the driver. This clutter should be removed.

In addition to sign information, the driver could use information on local weather and road conditions. The drivers' performance and comments as they carry out various missions would help indicate whether they would be aided by additional information and generally show what information they need.

Some drivers complain that there are too many signs on highways. Some signs, such as "slippery when wet," do not tell drivers what they are supposed to do about the information displayed. If a driver's performance, comments, or lack of comments show that certain signs are not helpful, removal of the signs should be considered. There also may be too many repetitions of signs conveying useful information.

Signing for extreme conditions and unusual groups

It is now generally accepted that signs should be tested on motorists unfamiliar with an area. Signs also should be tested under adverse dusk backlighting and night conditions and on persons with poor vision, persons of low intelligence, and old persons. Signing is also a problem in urban areas where the driver is overloaded with information from the traffic signal, the driver in the car ahead, street signs, and pedestrians. Signing methods should be modified to meet these special needs.

Drivers' reactions to signing—driver "understanding" studies

The meaning of road signs and markings may be clear to the designers but not necessarily to drivers. Studies have shown that drivers do not understand the meaning of yellow markings and have a poor understanding of the single solid white, single wide white, double broken yellow, and single broken yellow markings. (*21*) Another study showed poor driver understanding of 11 kinds of signs, including crossing signs, the slippery when wet symbol sign, curve versus turn symbol sign, pavement width transition symbol sign, double turn symbol sign, and the climbing lane ahead symbol sign. (*23*) Studies should be conducted routinely to determine whether the meanings of signs and road markings are understood by the driver.

Complex parking signs

Although MUTCD-approved parking signs are effective, difficulties arise when the rules are applied to complicated parking and standing schedules. Two- and three-paneled signs (fig. 3) pose the following interpretation difficulties:

- The driver may have to search two or three panels on the sign to find the information he or she needs. For example, the top panel may provide information on standing, whereas the driver may want to park.
- The driver may have to apply one or more of the following rules: If parking or standing is not prohibited, it is allowed; if the sign explicitly prohibits standing, it implicitly prohibits parking; if the sign prohibits parking alone, it allows standing; and if standing alone is permitted, parking is not.
- In some instances the information is intrinsically confusing. The top panel may cover Monday to Friday, the bottom Monday to Saturday.
- Too much information may be presented on the sign. The regulations involve parking and standing to the left and right of the sign at all times of the day and days of the week.

Studies have shown that only changeable message signs, unacceptable for reasons of cost, proved satisfactory for the display of parking restrictions. (*24, 25*) The problem of designing an acceptable multipaneled parking sign remains unsolved.

Low-cost lane occupancy signs

Research has shown that a single lane occupancy sign that lists the hours that each road lane can be occupied is ineffective and perhaps dangerous (fig. 4). An adequate changeable message lane occupancy sign can be designed, but such signs generally are expensive; it has not been determined whether the information can be presented effectively in the economical shoulder-mounted position.

Figure 3.—Double- and triple-paneled parking signs can be difficult to interpret.

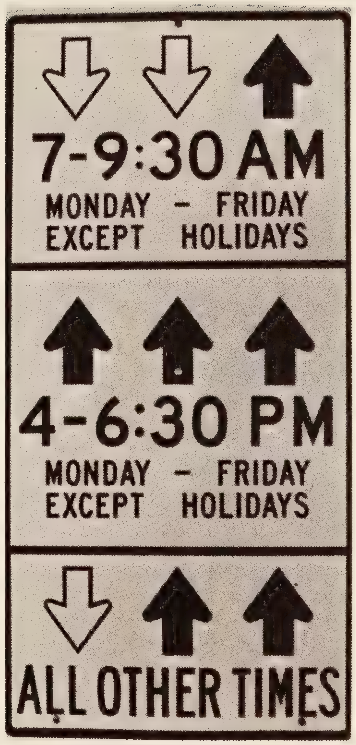

Figure 4.—A single lane occupancy sign is ineffective and perhaps dangerous.

The meaning of symbolic signs

Over 100 kinds of symbol signs are being considered for use on U.S. highways. These signs require less space than signs with words to convey the same message, and they do not require motorists to understand the language. However, it is not certain that the approved designs are as legible as possible or that the meanings are clearly conveyed by the symbols (fig. 5). Many of the new designs have been evaluated (*26*), and other designs are being assessed. New symbol designs should be evaluated systematically before being used on the highway.

Test and evaluation projects

Test and evaluation projects may be developed for comparing alternate signing methods, finding optimum values of signing variables, or simply trying new signing methods. A test is planned of variable aspect signs, which show changeable messages or message motion without mechanical or electronic components. They may be used as railroad warning signs or as changeable message signs. Tests also may be made of alternate sizes, colors, and messages of signs, color coding of route signs, route roadway markings, delineation codes, improved highway maps; in-vehicle displays, and sign message channelization (the separation of messages intended for pedestrians, truck drivers, tourists, and local travelers).

These and similar studies may be undertaken when expert opinion, practice, or operational know-how cannot provide solutions to highway design problems.

Summary

This article has highlighted some historical and recent applications of human factors engineering to highway design. These applications, by improving driver-highway compatibility, contribute to the ease of driving and safety of the highway.

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Figure 5.—Samples of symbol and word signs that have been tested for driver understanding.

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Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Office of Research, Federal Highway Administration, which includes the Structures and Applied Mechanics Division, Materials Division, Traffic Systems Division, and Environmental Division. The reports are available from the address noted at the end of each description.

Effect of Changes in Legal Load Limits on Pavement Costs, Volume 1 (Report No. FHWA-RD-79-73) and Volume 2 (Report No. FHWA-RD-79-74)

by FHWA Structures and Applied Mechanics Division

These reports describe program NULOAD, the computerized evaluation methodology for determining the effects of changes in legal vehicle size, weight, and configuration on highway pavement performance and for relating these effects to pavement maintenance and rehabilitation life cycle costs. Program verification and improvement were provided through computer runs of NULOAD using representative data collected from State highway and transportation departments. Costs can be estimated at the local level for subsequent aggregation at the State and national levels by functional highway type to provide the necessary information for legislative decisions on legal vehicle size, weight, and configuration changes. Existing design data are used; additional field studies are required only when such data are inadequate.

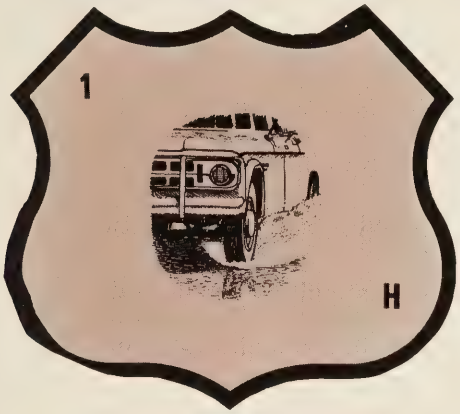
Volume 1, **Development of Evaluation Procedures,** describes how program NULOAD can assess the effects of legal vehicle limit changes on the life cycle costs of flexible, rigid, and composite highway pavements. Up to 50 representative pavement sections can be grouped by highway system (such as Interstate) to reflect the effects of changed traffic loadings on the different classifications of highway. The program can consider a maximum of ten different truck types with various axle and tire configurations and loads. Triple trailer units also can be considered in the procedure.

Volume 2, **Users Manual for Program NULOAD,** describes all necessary program input parameters and provides a detailed user guide, illustrative examples of sample program inputs and outputs, and an outline of the research approach taken. Included are discussions of the pavement performance and remaining life prediction model selection; the study and development of load equivalency factors; a load distribution shifting procedure that generates new load distributions; economic modeling; and an outline of the flow of the evaluation methodology. Results from a parametric study of input variables in program NULOAD are presented with a summary of findings, conclusions, and ways to implement the procedure.

The reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 80 150600 and PB 80 150618).

Pavement and Geometric Design Criteria for Minimizing Hydroplaning, A Technical Summary (Report No. FHWA-RD-79-30) and Final Report (Report No. FHWA-RD-79-31)

by FHWA Structures and Applied Mechanics Division



Hydroplaning may occur on highways when a layer of water separates the tires of a moving vehicle from the road surface causing a loss of vehicle directional control. Partial hydroplaning results when any significant amount of surface water is present.

Hydroplaning does not occur often because of the infrequency of rainfall intense enough to cause a critical water depth to accumulate on the pavement surface. However, the consequences of hydroplaning are extremely hazardous. These reports describe the development of pavement surface and geometric design criteria for minimizing the possibility of hydroplaning of highway vehicles. Variables such as vehicle speed, pavement surface texture and cross slope, water depth, tire inflation pressure and tread depth, and two modes of tire slip were investigated in full-scale field tests.

Pavement surface water depth and vehicle speed are considered the most critical elements leading to hydroplaning on highways. Rainfall records in Alabama, Illinois, and Texas were used to develop a methodology for calculating a design rainfall intensity. For a given rainfall intensity, surface water depth can be computed for any pavement slope, runoff length, and texture using equations developed to incorporate these variables.

Vehicle traction tests under controlled conditions were performed on a variety of wet pavement surfaces including 17 different transverse and longitudinal textures formed in portland cement concrete, grooved portland cement concrete, and open-graded asphalt friction courses. For given environmental conditions and pavement geometry, the accumulated water depth becomes a function of the drainage capacity of the pavement surface. An open-graded asphalt friction course is currently considered to be the best texture for minimizing the potential for hydroplaning.

By using the equations, curves, and examples provided in the reports, highway pavement surface and geometric designs can be formulated that prevent hydroplaning except in extremely intense rainfalls or for vehicles with substandard tire tread depth.

The reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 80 190457 and PB 80 146194).

Effects of Highway Operation Practices and Facilities on Elk, Mule Deer, and Pronghorn Antelope, Report No. FHWA-RD-79-143

by FHWA Environmental Division

This report documents a 3-year study of the effects of highways on the movements and behavior of elk, mule deer, and pronghorn antelope near Laramie, Wyo. Movements were monitored by radio telemetry, photography, and direct observation. The impact of snow fencing on vegetation and the behavior of big game were evaluated. Methods for detecting the presence of big game on highway rights-of-way and methods to activate warning signs were assessed. The effectiveness of deer fencing to reduce collisions between big game animals and motor vehicles is described and should be of interest to those responsible for managing big game populations.

The report is only available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 107898).

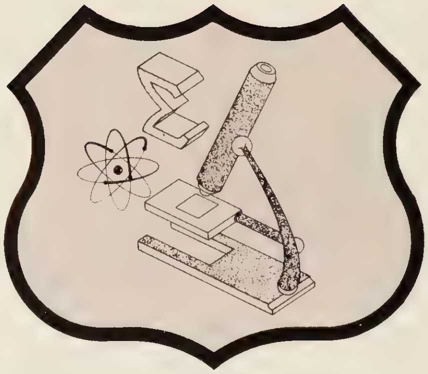
Stream Channel Degradation and Aggradation: Causes and Consequences to Highways, Report No. FHWA/RD-80/038

by FHWA Environmental Division

Gradation changes are long term stream bed lowering (degradation) or filling (aggradation) processes that affect the integrity of highway stream crossings. Degradation can cause the loss of crossing structural foundation, increase the severity of obstruction and contraction scour, and increase channel bank erosion. Aggradation can decrease flood conveyance and promote channel bank erosion.

This interim report describes gradation problems at highway stream crossings in the United States. Gradation problems are regionalized from a case history data base to show major causes and general associations. In addition, the report provides guidelines for recognizing the potential for a significant gradation change and analyzes methods for determining the extent of the gradation change and the effects it may have at a stream crossing. The final report, which is not yet available, will cover specific techniques for estimating gradation changes and measures for mitigating their consequences.

The report is only available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 135832).



Epoxy Thermoplastic Pavement Marking Material: Specification and Testing, Report No. FHWA/RD-80/069

by FHWA Materials Division

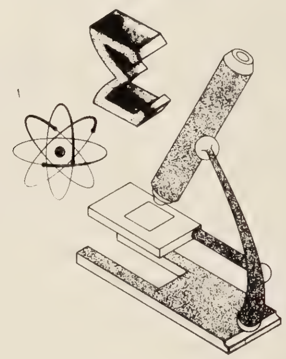
This report presents the results of an extensive laboratory program to establish a specification for an epoxy thermoplastic (ETP) striping material that was developed for the Federal Highway Administration. Laboratory test procedures were developed to evaluate the significant properties of the ETP material and its components. Properties studied included viscosity, reflectance, thermal stability, softening point, epoxy equivalent weight, and infrared spectrum. The effects on selected ETP properties of variations in ETP component ratios and epoxy resin properties also were studied. Upper and lower limits for the ETP physical properties were statistically determined. An interim composition performance specification based on commercially manufactured epoxy resins and pigments was then established for this material. Analytical procedures for determining titanium dioxide, lead chromate, glass bead, and organic contents also were incorporated into the specification.

The report is available from the Materials Division, HRS-23, Federal Highway Administration, Washington, D.C. 20590.

Evaluation of Super-Water Reducers for Highway Applications, Report No. FHWA/RD-80/132

by FHWA Materials Division

Super-water reducers were characterized and evaluated as potential candidates for production of low water-to-cement ratio, high strength concretes for highway construction applications. Admixtures were composed of either naphthalene or melamine sulfonated formaldehyde condensates. A mini-slump procedure was used to assess dosage requirements and workability with time of cement pastes. Required dosage was found to be a function of tricalcium aluminate content, alkali content, and fineness of the cement.



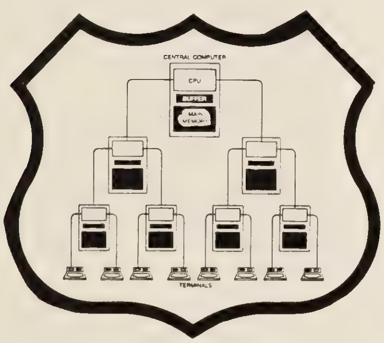
Concretes exhibited high rates of slump loss when super-water reducers were used. Slump loss was found to be a function of cement and admixture composition, dosage of admixture, time of addition of admixture, concrete paste contents, and temperature. Based on results of this testing, the use of these admixtures in central mix paving operations is not recommended.

Incorporation of super-water reducers into conventional concretes was found to alter the entrained air system. Use of higher initial plastic air contents of 7 to 8 percent is recommended. These products appear most promising in producing dense, high cement content concrete using mobile concrete mixer/transporters.

The report is available from the Materials Division, HRS-22, Federal Highway Administration, Washington, D.C. 20590.

A Study of the Feasibility of Distributed Multi-Level Traffic Control Systems, Report No. FHWA/RD-80/022

by FHWA Traffic Systems Division



This report examines the feasibility of distributed multi-level traffic control systems through utility-cost analysis. Tutorial and reference material and examples of cost comparisons are provided to aid in determining the choice of control configuration for a specific traffic control system installation.

The results of this analysis identify certain conditions under which distributed traffic control is likely to be cost effective. The control requirements include clusters of signals scattered throughout an urban area without a highly concentrated central business district, and a signal system with few existing computer or interconnect facilities.

The report also provides recommendations for further research in hardware and software that could enhance the benefits of distributed traffic control.

Limited copies of the report are available from the Traffic Systems Division, HRS-32, Federal Highway Administration, Washington, D.C. 20590.

Implementation/User Items "how-to-do-it"

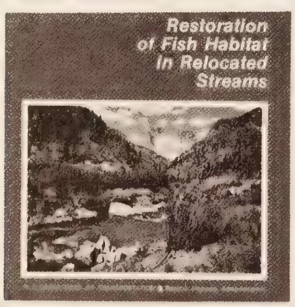
The following are brief descriptions of selected items that have been recently completed by State and Federal highway units in cooperation with the Implementation Division, Office of Development, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies.

U.S. Department of Transportation
Federal Highway Administration
Office of Development
Implementation Division (HDV-20)
Washington, D.C. 20590

Items available from the Implementation Division can be obtained by including a self-addressed mailing label with the request.

Restoration of Fish Habitat in Relocated Streams, Implementation Package 79-3

by FHWA Implementation Division



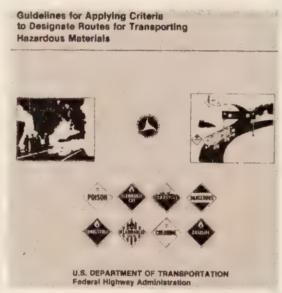
Occasionally, in constructing a highway, it may be necessary to encroach on a natural stream or even to relocate the channel. This interference can increase erosion and sedimentation, harm aquatic life, and destroy natural esthetics. This manual provides guidelines for the design and construction of channels that will be relocated and describes measures that will promote rapid recovery of new channels by natural processes. Through good design and implementation of these measures, a relocated stream can recover its esthetics and its value as a fishery.

This color-illustrated manual will be useful to highway designers, hydraulics engineers, forestry personnel, and others interested in natural stream maintenance.

The manual may be purchased for $4.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00167-5).

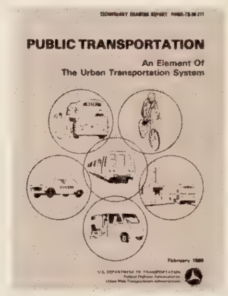
Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials, Implementation Package 80-15

by FHWA Implementation Division



This report describes techniques that may be used to evaluate alternative highway routes for hazardous material movements. Interstate highways, urban arterials, and rural highways are evaluated according to the risks that hazardous material movements on these roadways pose to nearby populations and property. Detailed routing procedures are applied to a hypothetical case study. The hypothetical example includes personal and property risk calculations and illustrates the techniques for analyzing urban arterials and rural highways.

The report may be purchased for $4 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00198-5).



Public Transportation—An Element of the Urban Transportation System, Report No. FHWA-TS-80-211

by FHWA Implementation Division

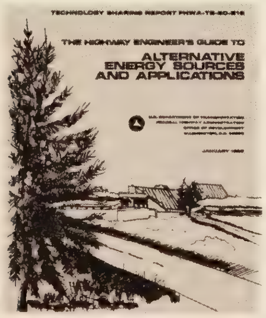
This report is a comprehensive introduction to the history, financing, planning, and operations of public transportation facilities and services. Transportation legislation and regulation, needs of the elderly and handicapped, transit marketing, and the decisionmaking process are described. The report is intended for personnel with responsibilities in transportation project development, design, and operation. It provides practical and timely information on the role of public transportation and its relationship to high energy prices, supply shortages, and national concerns on air pollution, redevelopment of the center city, and urban mobility for all segments of society.

The report may be purchased for $7.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00173-0).

The Highway Engineer's Guide to Alternative Energy Sources and Applications, Report No. FHWA-TS-80-212

by FHWA Implementation Division

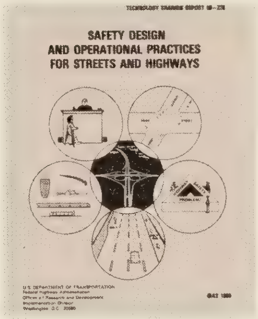
Highway engineers responsible for administering, selecting, or designing highway buildings, equipment, or other highway facilities must consider alternative energy sources to combat growing energy supply problems and costs. This manual provides guidelines for quickly determining whether or not an alternative energy source is cost effective. A selected bibliography of published information is included, as are actual case studies of highway agencies that have used alternative energy sources successfully and a list of people with experience in applying alternative energy sources.



The manual may be purchased for $5 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00176-4).

Safety Design and Operational Practices for Streets and Highways, Report No. FHWA-TS-80-228

by FHWA Implementation Division

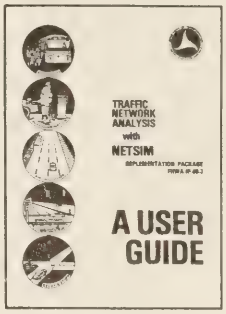


This report is intended to provide local, State, and Federal highway agency personnel with practical, state-of-the-art information for the application of traffic safety in the design and operation of streets and highways. Emphasis is on effectively integrating safety as a principal criterion in planning, designing, and operating streets and highways, identifying hazardous conditions or situations, and selecting and applying appropriate countermeasures to eliminate or neutralize any hazard.

The report may be purchased for $7 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00180-2).

Traffic Network Analysis With NETSIM, A User Guide, Implementation Package 80-3

by FHWA Implementation Division



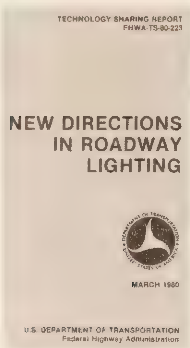
NETSIM, a microscopic traffic simulation model for traffic and transit operations analysis, accurately determines transportation performance, fuel and pollution impacts of operational designs, and transportation systems management measures and strategies. Information available from NETSIM includes stops, delay, average speed, fuel consumption, emissions, and bus statistics. Typical applications of NETSIM include evaluations of alternative methods of control, bus lanes and bus headways, changes in geometrics, and changes in traffic regulations.

This user guide is intended as a working tool for transportation engineers using the NETSIM program. The guide will assist in collecting and preparing input data for the NETSIM program, interpreting error messages, and analyzing the output.

Limited copies of the guide are available from the Implementation Division.

New Directions in Roadway Lighting, Report No. FHWA-TS-80-223

by FHWA Implementation Division



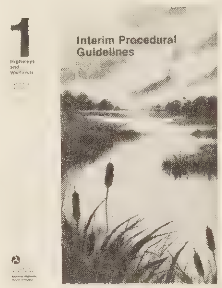
This report, intended primarily for State, county, and city engineers, describes a new public roadway lighting design process currently being adopted and incorporated into the 1982 *American Standard Practice for Roadway Lighting.* Concepts that will influence future roadway lighting designs are presented in the report.

A 15-minute slide-tape presentation supplements the concepts described in the report.

The report may be purchased for $2.25 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-000-00159-8). The slide-tape presentation is available from FHWA regional offices (see inside back cover) and the National Highway Institute, HHI-4, Washington, D.C. 20590.

Highways and Wetlands: Volume 1, Interim Procedural Guidelines; Volume 2, Impact Assessment, Mitigation, and Enhancement Measures; and Volume 3, Annotated Bibliography, Implementation Package 80-11

by FHWA Implementation Division



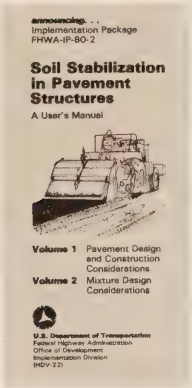
This three-volume series of reports outlines the Federal Highway Administration's commitment to protect, preserve, and enhance the Nation's wetlands during planning, construction, and operation of highway facilities and projects. This commitment reflects the goals and objectives of various Federal and State statutes, Executive Orders, and Internal Orders of the U.S. Department of Transportation.

The series is a compilation of procedural guidelines to implement the national policy. The guidelines focus on key decisions affecting wetlands in each phase of project development, including planning, maintenance, and operation; possible impacts associated with each decision; and alternatives for mitigating adverse impacts and enhancing positive impacts and methods for selecting these alternatives.

Limited copies of the reports are available from the Implementation Division.

Soil Stabilization in Pavement Structures, A User's Manual, Volumes 1 and 2, Implementation Package 80-2

by FHWA Implementation Division



The shortage and attendant rising cost of conventional aggregates, as well as rising production costs of materials for various pavements, have been major concerns in recent years. Therefore, more economical substitute materials, such as stabilized soils and marginal aggregate that can be upgraded through stabilization, must be developed.

This two-volume user's manual provides guidance for pavement design, construction, and materials engineers responsible for soil stabilization operations associated with transportation systems.

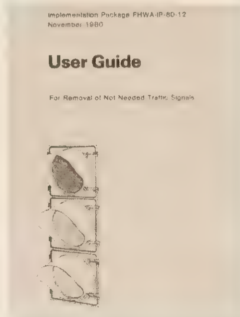
Volume 1, **Pavement Design and Construction Considerations,** contains a method for selecting the kind of stabilizer, pavement thickness design methods, and construction information. Quality control, guide specifications, and cost and energy considerations are discussed in the appendixes.

Volume 2, **Mixture Design Considerations,** discusses methods for determining the kind and amount of stabilizers suitable for a particular soil, methods of estimating stabilizer content, test methods, and mixture design criteria.

The manuals may be purchased for \$6 (Vol. 1 [Stock No. 050-001-00160-8]) and \$5 (Vol. 2 [Stock No. 050-001-00161-6]) from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

User Guide for Removal of Not Needed Traffic Signals, Implementation Package 80-12

by FHWA Implementation Division



This report discusses criteria for determining whether an existing urban traffic signal should be removed. The criteria apply only to regular red, yellow, and green color operation signals that alternately assign right-of-way and not to flashing signals or beacons. The report also presents the procedural guidelines that may be used to remove a signal.

The report may be purchased for \$3.75 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00193-4).

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. Space limitation precludes publishing a complete list. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R)—Performing State Highway or Transportation Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1V: Roadside Safety Hardware for Nonfreeway Facilities

Title: Bridge Deck Design for Railing Impacts. (FCP No. 41V3292)
Objective: Improve the reinforcement of and strengthen concrete slabs in bridge rail attachments. Develop more effective bridge rail-to-concrete deck connection details.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1982
Estimated Cost: $100,000 (HP&R)

FCP Project 1X: Highway Safety Program Effectiveness Evaluation

Title: Testing of Improved Evaluation Techniques Using a Representative Set of Accident Countermeasures. (FCP No. 31X2022)
Objective: Perfect and test dynamic programing, integer programing, and incremental benefit/loss analysis with improved solution algorithm as cost effectiveness analysis techniques using data obtained in five States.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: September 1982
Estimated Cost: $293,000 (FHWA Administrative Contract)

FCP Project 1Y: Traffic Management in Construction and Maintenance Zones

Title: Handling Traffic in Work Zones. (FCP No. 41Y1722)
Objective: Develop traffic control and management procedures for selected work zone problems such as night maintenance. Evaluate portable changeable message signs. Collect capacity data for urban freeway maintenance operations. Develop methods to establish work schedules and measures of handling traffic to minimize congestion.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1982
Estimated Cost: $150,000 (HP&R)

FCP Category 2—Reduce Congestion and Improve Energy Efficiency

FCP Project 2P: Improved Utilization of Available Freeway Lanes

Title: Developing a Freeway Data Collection System. (FCP No. 42P4054)
Objective: Define data needs for Texas freeways. Design a data collection system and software package. Demonstrate system on one or two freeways in Texas.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1983
Estimated Cost: $220,000 (HP&R)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4G: Substitute and Improved Materials to Reduce Effects of Energy Problems on Highways

Title: Field Evaluation of Sulfur-Extended Asphalt Paving Materials. (FCP No. 44G1464)
Objective: Evaluate the performance and durability of Pennsylvania Department of Transportation ID-2 wearing course with sulfur-extended asphalt binders.
Performing Organization: Pennsylvania Department of Transportation, Harrisburg, Pa. 17120
Expected Completion Date: July 1985
Estimated Cost: $112,000 (HP&R)

Title: Sulfur-Extended Asphalt Pavement. (FCP No. 44G1484)
Objective: Gather information on the design, placement, and performance of a single sulfur-extended asphalt pavement. Compare its properties and performance with a conventional asphaltic control pavement.
Performing Organization: New York State Department of Transportation, Albany, N.Y. 12232
Expected Completion Date: March 1984
Estimated Cost: $112,000 (HP&R)

Title: Sulfur-Extended Asphalt in Connecticut. (FCP No. 44G1494)
Objective: Place large-scale sulfur-extended asphalt pavements. Evaluate emissions during construction and determine long term performance of the pavement compared with an asphaltic concrete control pavement.
Performing Organization: Connecticut Department of Transportation, Wethersfield, Conn. 06109
Expected Completion Date: September 1987
Estimated Cost: $78,000 (HP&R)

FCP Project 4J: Coating Systems for Controlling Corrosion of Highway Structural Steel

Title: Evaluation of Alternate Coating Systems for Structural Steel Protection. (FCP No. 44J1064)
Objective: Conduct laboratory and field tests to compare and evaluate lead- and chromate-free bridge coatings. Investigate the degree of surface preparation required, the application techniques and restrictions, and the degree of protection afforded.
Performing Organization: Georgia Department of Transportation, Atlanta, Ga. 30334
Expected Completion Date: January 1988
Estimated Cost: $56,000 (HP&R)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5A: Improved Protection Against Natural Hazards of Earthquake and Wind

Title: Data Processing Software for Bridge Structures Research. (FCP No. 35A1041)
Objective: Review computer programs being used by Federal Highway Administration bridge researchers. Modify, enhance, or discard each program. Provide revised documentation.
Performing Organization: Automated Management Systems, Lanham, Md. 20801
Expected Completion Date: August 1982
Estimated Cost: $135,000 (FHWA Administrative Contract)

FCP Project 5D: Structural Rehabilitation of Pavement Systems

Title: Lateral Placement of Truck Traffic in Highway Lanes. (FCP No. 45D1413)
Objective: Determine by field measurements a representative frequency distribution of lateral truck wheel placement. Develop a practical technique for estimating.
Performing Organization: University of Texas, Austin, Tex. 78701
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1982
Estimated Cost: $110,000 (HP&R)

Title: Improved Methods to Eliminate Reflective Cracking. (FCP No. 35D2572)
Objective: Make literature search of past research concerning reflective cracking and select most appropriate theoretical model for analysis and test. Develop and use a small prototype laboratory testing device for evaluating effectiveness of methods to prevent reflective cracking under simulated field conditions.
Performing Organization: Resource International, Worthington, Ohio 43085
Expected Completion Date: September 1982
Estimated Cost: $135,000 (FHWA Administrative Contract)

Title: Rational Method for Analyses of Portland Cement Concrete Pavements. (FCP No. 45D2734)
Objective: Simulate with elastic theory (CHEVRON) road rater deflections on portland cement concrete pavements. Develop a procedure for evaluating their condition using the road rater. Incorporate this into an overlay design procedure and confirm the procedure through empirical correlation with field measurements.
Performing Organization: Kentucky Department of Transportation, Frankfort, Ky. 40601
Expected Completion Date: December 1983
Estimated Cost: $168,000 (HP&R)

FCP Project 5E: Premium Pavements for "Zero Maintenance"

Title: Strain Energy Principles Applied to Asphaltic Concrete Pavement Performance. (FCP No. 45E1152)
Objective: Determine the effects of shear using the structures of the AASHO road test. Develop shear repetitions criteria. Determine the fatigue effects of unequal axle weights within groups.
Performing Organization: Kentucky Department of Transportation, Frankfort, Ky. 40601
Expected Completion Date: June 1984
Estimated Cost: $92,000 (HP&R)

FCP Project 5K: New Bridge Design Concepts

Title: Thermal, Live Load, Creep, and Shrinkage Deformations and Stresses in the Denny Creek Bridge. (FCP No. 45K3082)
Objective: Evaluate stress distribution during construction, stresses from thermal gradients, and shear lag in the top and bottom flanges.
Performing Organization: University of Washington, Seattle, Wash. 98105
Funding Agency: Washington State Highway Commission
Expected Completion Date: June 1982
Estimated Cost: $85,000 (HP&R)

Title: Response of the Linn Cove Viaduct to Construction, Thermal, and Other Loadings. (FCP No. 35K3094)
Objective: Develop a plan for instrumenting the Linn Cove viaduct to measure and evaluate temperature differentials, thermal and torsional strains, and prestress losses during and after casting and erection of the bridge segments.
Performing Organization: Teng and Associates, Inc., Chicago, Ill. 60604
Expected Completion Date: September 1982
Estimated Cost: $62,000 (FHWA Administrative Contract)

FCP Project 5L: Safe Life Design for Bridges

Title: Innovative Methods of Upgrading Structurally and Geometrically Deficient Through Truss Bridges. (FCP No. 35L3031)
Objective: Develop innovative methods to economically and rapidly upgrade the roadway width, vertical clearance, and load-carrying capacity of geometrically inadequate and structurally unsound through truss bridges. Prepare drawings and specifications for four to eight rehabilitation schemes and cost-effective analysis of each method.
Performing Organization: Sheladia Associates, Inc., Riverdale, Md. 20840
Expected Completion Date: October 1981
Estimated Cost: $94,000 (FHWA Administrative Contract)

Title: Strength and Anchor Bolt Groups. (FCP No. 45L3082)
Objective: Conduct full-scale tests to determine the effect of grouping anchor bolts while under static and low level cyclic loading of axial tension and lateral shear forces. Determine the spacing between bolts in a group and edge cover and the effect of containment devices design.
Performing Organization: University of Texas, Austin, Tex. k78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1983
Estimated Cost: $120,000 (HP&R)

FCP Category 0—Other New Studies

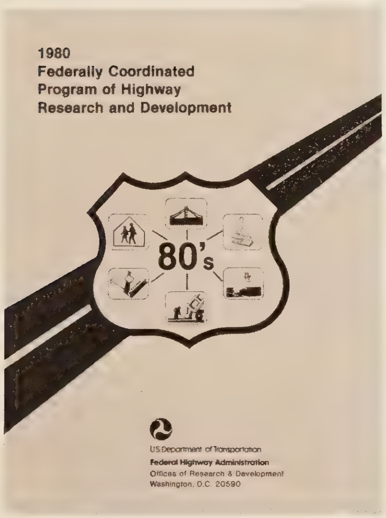
Title: Analytical Photogrammetry in Application to Transportation Survey. (FCP No. 40M1742)
Objective: Improve the accuracy and reliability of aerial analytical photogrammetric systems that use both "guard-centered" and "data log" photo imagery procedures. Include an application report and demonstrations.
Performing Organization: Ohio State University, Columbus, Ohio 43210
Funding Agency: Ohio Department of Transportation
Expected Completion Date: September 1983
Estimated Cost: $92,000 (HP&R)

Title: Geophysical Centerline Surveys for Permafrost and Ground Ice. (FCP No. 40M1754)
Objective: Introduce magnetic induction method into roadway foundation investigation programs to provide more information that can be used to develop a national drilling program. Extend information on subsurface permafrost and ground ice conditions away from boreholes.
Performing Organization: University of Alaska, Fairbanks, Alaska 99701
Funding Agency: Alaska Department of Highways
Expected Completion Date: June 1982
Estimated Cost: $76,000 (HP&R)

Title: Field Evaluation Site for Ground Ice Detection. (FCP No. 40M1764)
Objective: Reduce the number of boreholes required for preconstruction investigation of a highway or public facility while simultaneously providing geophysical evidence for subsurface permafrost and ground ice conditions between boreholes.
Performing Organization: University of Alaska, Fairbanks, Alaska 99701
Funding Agency: Alaska Department of Highways
Expected Completion Date: July 1982
Estimated Cost: $82,000 (HP&R)

New Publications

The Offices of Research and Development (R&D), Federal Highway Administration (FHWA), have released their fiscal year **1980 Annual Report on the Federally Coordinated Program (FCP) of Highway Research and Development.**



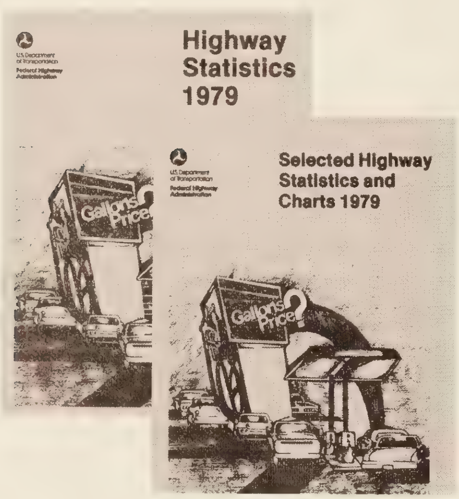
The report briefly describes the goals of the FCP, FCP accomplishments in highway R&D during FY 1980, and the organization and facilities of the Offices of R&D. Specific accomplishments in safety research, traffic operations research, environmental research, materials research, structural research, and highway maintenance are cited. The report is prefaced by a message from Federal Highway Administrator John S. Hassell, Jr.

While supplies last, individual copies of the report are available free of charge to highway-related agencies and universities. Requests should be sent on agency or institution letterhead to the Federal Highway Administration, Engineering Services Division, HDV-14, Washington, D.C. 20590. Copies of the report are on sale for $2.25 by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00202-7).

Flagging Handbook presents guidelines for traffic control during construction, maintenance, and utility operations on all roads and streets open to public travel. The guidelines will assist the flagger and others responsible for traffic control in the understanding and performance of their duties. The guidelines can help reduce the number of and potential for traffic accidents that occur in work zones. Also included are suggestions for obtaining a more favorable public acceptance of traffic control operations in work zones. The handbook is consistent with the 1978 edition of the Manual on Uniform Traffic Control Devices (MUTCD).

The handbook may be purchased for $2 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Handbooks may be purchased in bulk rate for $60 per 100 copies.

Highway Statistics 1979, a 160-page book, the 35th in the annual series, presents statistical and analytical tables of general interest on motor fuel, motor vehicles, driver licensing, highway-user taxation, State and local highway financing, road and street mileage, Federal-aid for highways, and highway usage and performance. Also reported are 1978 highway finance data for municipalities, counties, townships, and other units of local government. A short one-time addition to this issue is a summary of the Nationwide Personal Transportation Study. A listing of the data is given in the table of contents and a brief discussion is given in the text accompanying each section.



The publication may be purchased for $6 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00201-9). It is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Report No. FHWA-HP-HS-79). Microfiche is $3.50 and paper copy is $6.

The Highway Statistics series has been published annually beginning in 1945 but most of the earlier editions, except 1969 and 1975-1978, are now out of print. Much of the earlier data is summarized in **Highway Statistics, Summary to 1975.** These documents also may be purchased from GPO and NTIS.

Selected Highway Statistics and Charts 1979 is a 28-page compilation of statistical highlights and charts prepared as a convenient summary supplement to various tables published in **Highway Statistics 1979** and prior years. Historical trends, as well as 1980 estimates, are included. Copies may be obtained from the Office of Public Affairs or the Highway Statistics Division, HHP-41, Federal Highway Administration, Washington, D.C. 20590.

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Harold R. Bosch Receives Award

Mr. Harold R. Bosch was the recipient of the 1979 award in the annual outstanding paper competition held among the employees of the Federal Highway Administration Offices of Research and Development. This award covers the documentation of any technical accomplishment, which may be a publication, technical paper, report, or package; an innovative engineering concept; an instrumentation system; test procedure; new specification; mathematical model; or unique computer program. Each eligible candidate is judged on excellence, creativity, and contribution to the highway community, general public, and FHWA.

Mr. Bosch, a structural research engineer in the Bridge Structures Group, Structures and Applied Mechanics Division, Office of Research, received the award for his research paper "Aerodynamic Investigations of the Luling, Louisiana Cable-Stayed Bridge."

Mr. Bosch (right) is shown receiving a plaque for his accomplishment from Dr. Gerald D. Love (left), Associate Administrator for Research and Development.

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