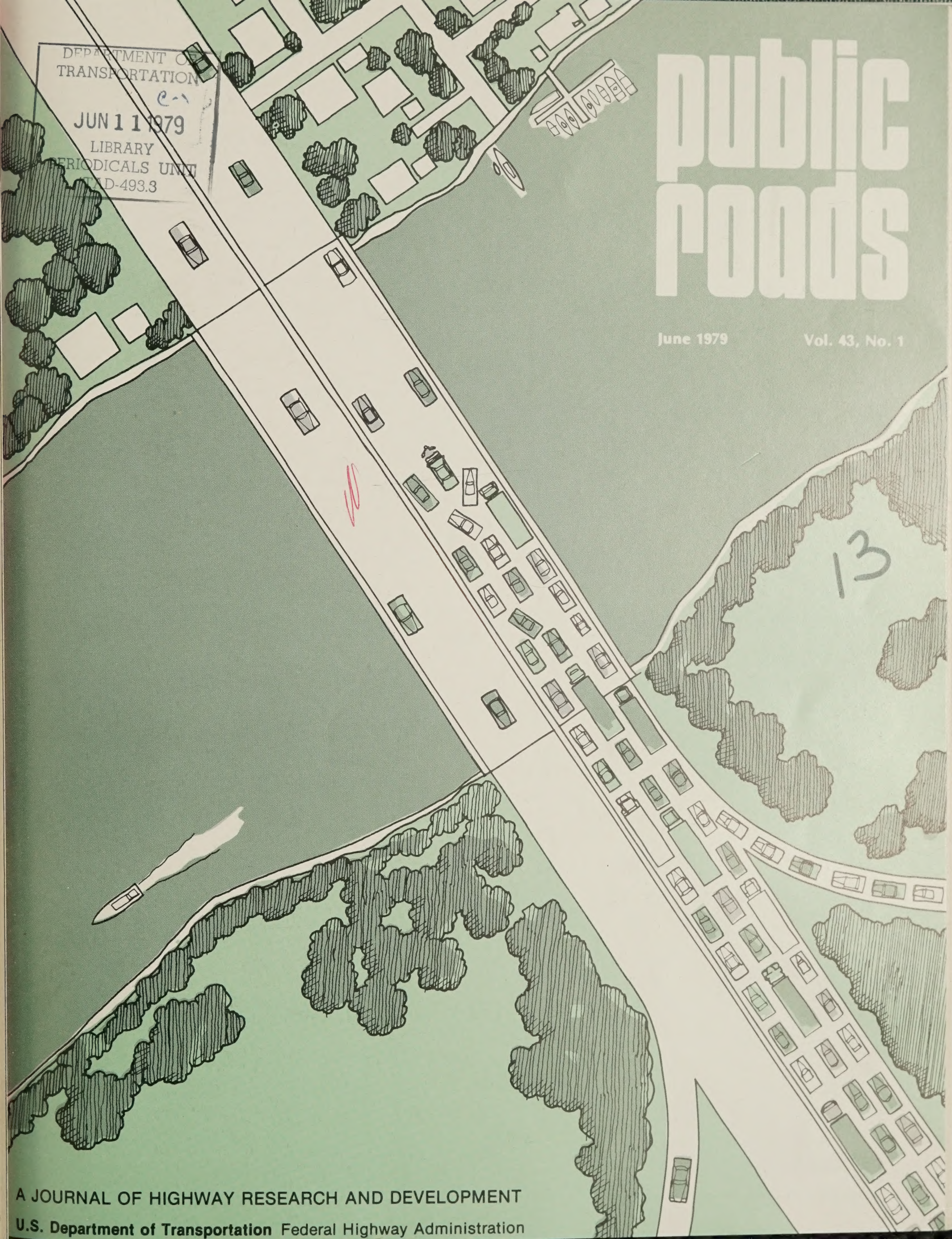

# public roads

June 1979 Vol. 43, No. 1

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT

**U.S. Department of Transportation** Federal Highway Administration

# public roads

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT

June 1979 Vol. 43, No. 1

**COVER:**
Artist's concept of a bottleneck caused by a freeway incident.



## IN THIS ISSUE

### Articles



### Departments



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# Getaway Flow Rates for Freeway Incident and Geometric Bottlenecks

by

Jeffrey A. Lindley and Samuel C. Tignor

## Introduction

When a bottleneck occurs on a freeway, whether due to freeway incident or a geometric restriction, the traffic flow is disrupted. Speeds upstream and volumes downstream of the bottleneck drop as the queue begins to build behind the bottleneck. During and after the time that the queue has been built up, vehicles are being gradually released at the bottleneck location (much the same as vehicles pulling away from a traffic signal), and traffic begins to regain its normal flow. As long as there is a queue behind the bottleneck, a fairly steady volume of vehicles is expected to flow downstream; this steady volume or "getaway" flow rate might be different depending on whether the bottleneck was caused by an incident or freeway geometrics. Results of work on freeway incident management rely on the use of a constant getaway flow rate in the delay computation analyses for low cost freeway incident management systems. *(1)*[1] However, insufficient research is available to give a precise value for getaway flow rate. For bottlenecks resulting from a change in freeway geometrics, the Highway Capacity Manual has generally used 2,000 vehicles per hour as the value for the getaway flow rate. *(2)* This article explains the results of a short study which was undertaken to ascertain the values of the actual observed getaway flow rates from traffic incidents and geometric bottlenecks. The geometric bottleneck analyses was undertaken to add credence to the overall study approach. It also served as a basis of comparison with typically known geometric bottleneck findings.

## Data Base

The first task in this study was to gather data for analysis. It was decided to use previously gathered data from three freeways in Los Angeles, Calif., and additional new data from the Washington, D.C., I–495 Beltway for the incident getaway analysis. For the geometric bottleneck analysis only Beltway data were used. The Los Angeles data have been gathered as part of the Los Angeles Area Freeway Surveillance and Control Project (LAAFSCP) and were collected from loop sensors embedded in the freeway lanes and ramps. *(3, 4)* These sensors are connected over telephone lines to a central computer, which polls each loop 15 times per second in order to build summaries of vehicle counts and occupancy to be used in ramp metering control and incident detection.

Figure 1 shows the freeways that are under LAAFSCP's control. The Harbor Freeway is an eight-lane north-south route that runs from the San Pedro Harbor area to the Los Angeles central business district (CBD) where it becomes the Pasadena Freeway. Average daily traffic (ADT) on this freeway runs

[1] Italic numbers in parentheses identify references on page 7.

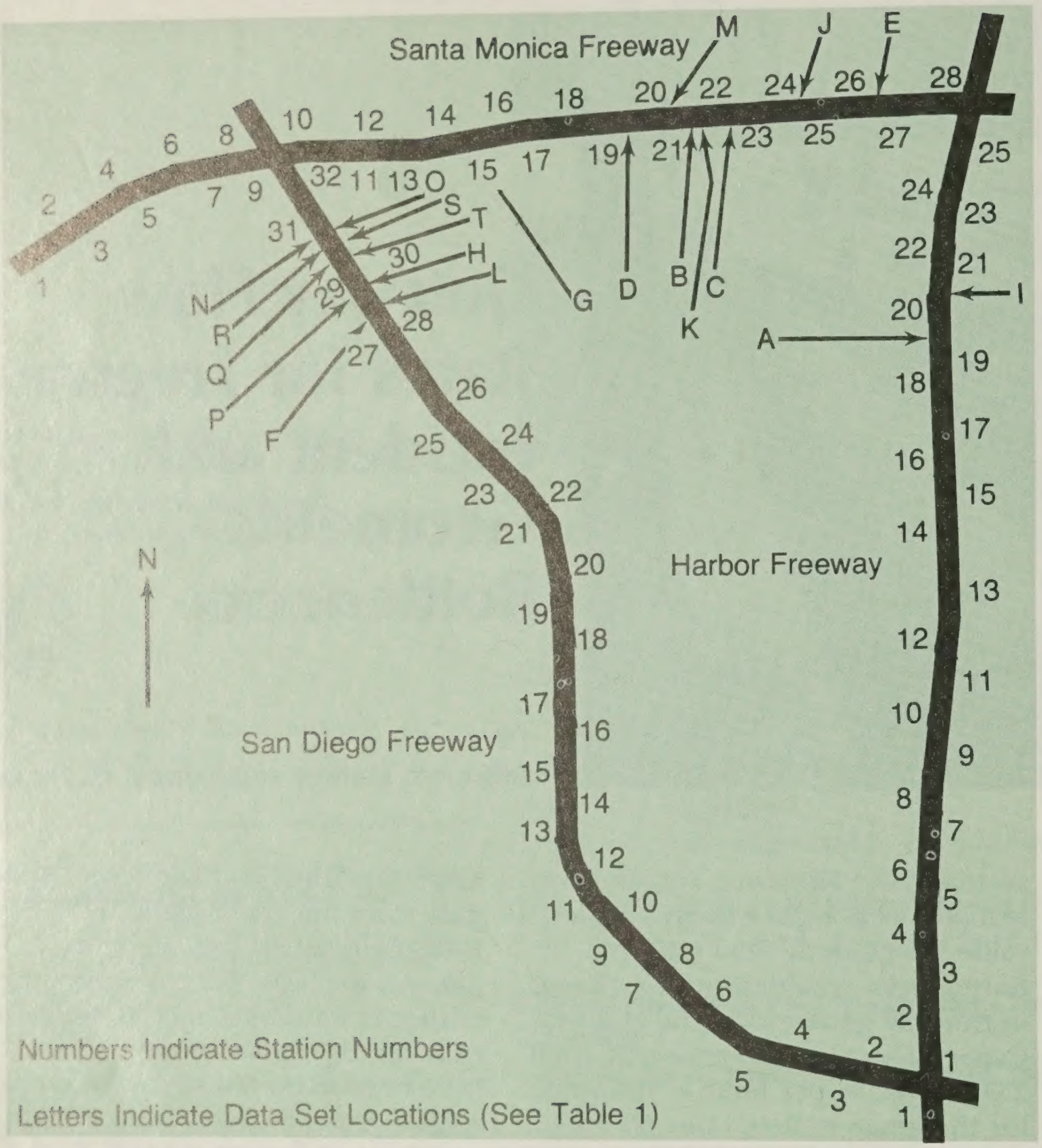



*Figure 1.—Los Angeles data collection site.*

from 110,000 vehicles on the south end to 210,000 on the north end. The Santa Monica Freeway, another eight-lane freeway, runs from the beach area in Santa Monica to the CBD and then feeds into two other freeways. ADT on the Santa Monica Freeway is 124,000 on the west end and 230,000 on the east end. Both the Santa Monica and Harbor Freeways carry heavy directional peak hour flows, with traffic coming into the CBD in the morning and going out in the evening.

The San Diego Freeway is an eight-lane freeway that runs along the western portion of the Los Angeles area. The portion under LAAFSCP control runs from the southern end of the Harbor Freeway to the western end of the Santa Monica Freeway and carries an ADT of from 170,000 to 210,000.

Figure 1 also shows the locations of the sensor stations. The 85 sensor stations are spaced at approximately 800 m intervals with the exception of a 1.57 km section which runs northbound on the San Diego Freeway near the Santa Monica Interchange. The 10 stations on this one section are placed at approximately 180 m intervals.

The LAAFSCP recorded the sensor data (the time of each individual vehicle crossing) in the form of individual data sets on magnetic tapes. Each data set contains its own unique documentation information and data for a specific period of time—usually 3 hours. More than 180 data sets containing incidents were collected by the LAAFSCP and were available data for this study. Typically an incident was a freeway accident, a disabled vehicle, or a cargo spillage onto the freeway.

For this study, 20 LAAFSCP incident data sets were chosen for analysis. The incidents contained in these data sets were varied in number of incident vehicles, location, weather condition, time of day, and traffic condition. Figure 1 shows the freeway locations of these data sets, and the first 20 entries of table 1 list the key characteristics of the data sets. In this study no data sets were used where on- or off-ramps were immediately downstream of the incident location, because past studies have shown that this can erroneously alter the getaway flow rate when the downstream counting station is also downstream of the ramps.

Additional incident data from the Washington, D.C., I-495 Beltway, gathered specifically for the purposes of this study, were taken directly from the field through the use of manual traffic counts. The data were gathered from a one direction, three-lane section to the north of the city that is noted for frequent traffic incidents. For this study two data sets were gathered from the Linden Lane overpass (fig. 2). A listing of some key characteristics of these two data sets also appears in table 1.

Manual traffic data were also collected from three known geometric bottlenecks on the Beltway for the geometric bottleneck analysis. One bottleneck involved a simple lane drop from a one direction, four-lane section to a three-lane section (Linden Lane); another involved a three-lane section on an upgrade coming off a bridge (Cabin John Bridge at George Washington Parkway); the third location was a four-lane section on a grade with an exit at the top of the grade (Bald Eagle Road) (fig. 2). At Bald Eagle Road an off-ramp queue from the exit spills onto the freeway and effectively blocks two lanes during the peak period, causing the bottleneck. Two sets of data were taken at each of these three locations for use in geometric bottleneck getaway analysis. The observation period for the six data sets averaged about 60 minutes.

## Analysis

Having chosen the data to be used in the study, the next task was to analyze the data. An existing FORTRAN program which was developed to analyze the LAAFSCP real-time, sensor data was applied to the Los Angeles data sets used in this study. *(5)* This program was chosen because the user can vary and select the time intervals and geometric locations of interest from the source data stored on magnetic tape. The ndividual data set output contains descriptive information such as data, ocation, weather, number of nvolved vehicles, a listing of all ictive sensors within the station imits specified by the user, and the ictual traffic summaries. These ummaries include computations of otal volume, occupancy, ehicles/lane/hour (v/l/h), density, nd speed for each individual sensor, vhich are also averaged for each tation. The summaries in this study were listed at 1-minute intervals for the duration of the period specified for each data set.

**Table 1.—Incident data set characteristics**

| Data set | Traffic code[1] | Location[2] | Peak | Type of incident[3] | Number of incident vehicles | Lanes At site | Lanes Blocked |
|---|---|---|---|---|---|---|---|
| Los Angeles data: | | | | | | | |
| 74032502 | 1 | A | NO | DISL | 1 | 4 | 1 |
| 74042201 | 1 | B | NO | DISL | 1 | 5 | 1 |
| 74042602 | 1 | C | YES | DISL | 1 | 5 | 1 |
| 74051503 | 1 | D | YES | DISL | 1 | 5 | 1 |
| 74052302 | 3 | E | YES | TCOL | 1 | 3 | 1 |
| 74052804 | 1 | F | NO | TCOL | 2 | 4 | 1 |
| 74053001 | 3 | G | YES | TCOL | 2 | 4 | 1 |
| 74053003 | 1 | H | YES | TCOL | 5 | 4 | 1 |
| 74062402 | 1 | I | NO | SPIL | 1 | 4 | 2 |
| 74062802 | 2 | J | NO | SPIL | 0 | 4 | 2 |
| 74070102 | 2 | K | YES | DISL | 1 | 4 | 1 |
| 74071101 | 3 | L | NO | DISL | 1 | 4 | 1 |
| 75012301 | 2 | M | YES | DISL | 1 | 4 | 1 |
| 75111901 | 2 | N | NO | TCOL | 2 | 4 | 1 |
| 76073001 | 1 | O | NO | TCOL | 4 | 4 | 1 |
| 76080201 | 1 | P | YES | DISL | 2 | 4 | 1 |
| 76091401 | 1 | Q | YES | DISL | 1 | 4 | 1 |
| 76092801 | 1 | R | NO | TCOL | 4 | 4 | 2 |
| 76102901 | 2 | S | NO | TCOL | 4 | 4 | 1 |
| 76122701 | 1 | T | NO | TCOL | 3 | 4 | 2 |
| Washington, D.C., data: | | | | | | | |
| 78082401 | 1 | — | YES | TCOL | 2 | | |
| 78082501 | 1 | — | YES | DISL | 1 | | |

[1]Traffic code: Traffic level:
1 Occupancy > 24 percent
2 Occupancy < 24 percent, lane volume > 1,400 vehicles per hour
3 Occupancy < 24 percent, 700 vehicles per hour < lane volume < 1,400 vehicles per hour

[2]See figure 1.

[3]DISL = disabled vehicle
TCOL = traffic collision
SPIL = spilled cargo

The first analysis performed on the traffic summaries for each Los Angeles data set involved the speed at an upstream station (usually the first station upstream from the incident). Station speed is the average of the speeds of all the active lane sensors at a station. It was found that station speed could generally be broken down, by time period, into four distinct categories. The first category is the pre-incident period when there is normal traffic flow and speeds are generally high and constant. The second category, the incident period, is the time during which the incident happens. During this period, speeds upstream of the incident drop drastically, reach a low point within a few minutes, then slowly rise again. The third category is the steady flow period during which the getaway flow rate should be observed. Speeds during this period are much lower than normal, but are fairly constant because the

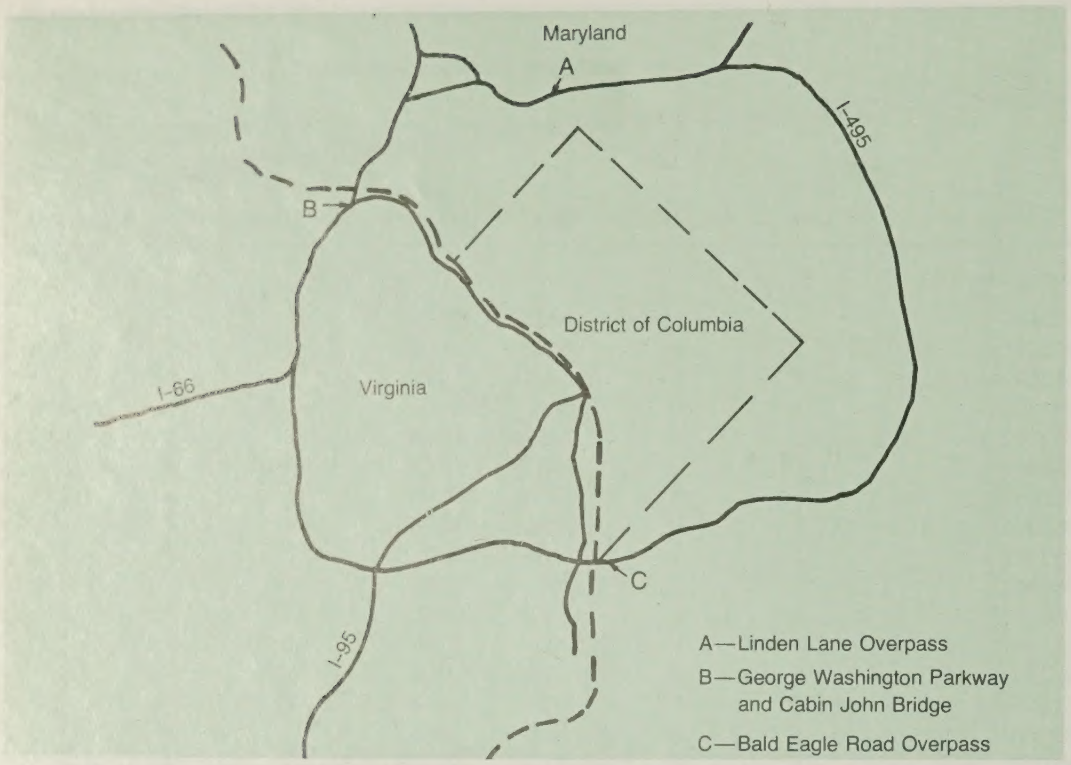
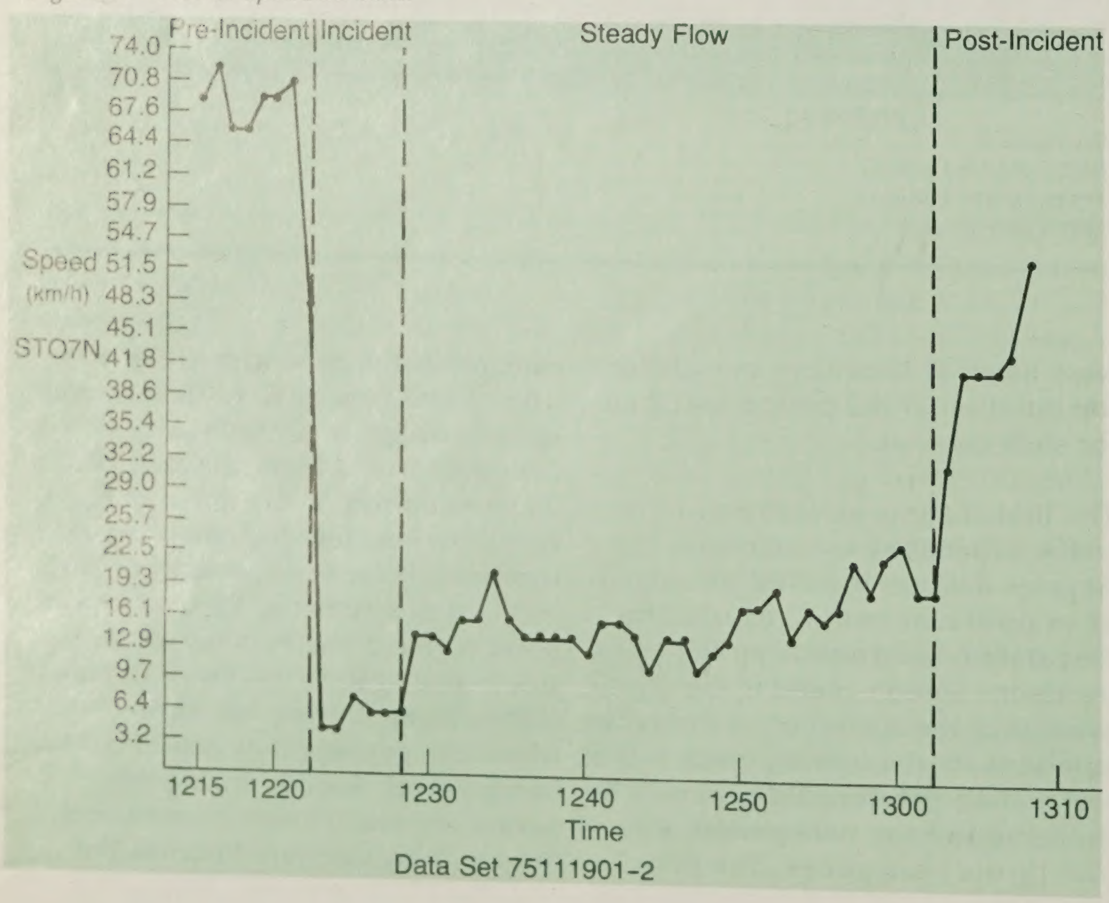



Figure 2.—Washington, D.C., data collection site.

Figure 3.—Plot of upstream data.




traffic is moving from a high density upstream or queue condition to a lower downstream density. During the fourth time category, the post-incident period, the queue has disappeared and speeds rise steadily toward their normal values. The way in which these four time categories relate to upstream speed is depicted in figure 3, using data set 75111901-2 as an example.

The analysis of upstream speed was performed to identify the beginning and end of the steady flow period. The volume at a *downstream* station during the steady flow period was used when analyzing the Los Angeles data. The station generally analyzed was the first one downstream from the incident site, because the getaway flow rate would be most evident close to the incident location. The downstream volumes for each data set were computed for each steady flow period, then converted (because different incidents could have different numbers of active sensors) to hourly, average, single-lane volumes. Hourly lane volumes were obtained for both 5 minute counts and steady flow duration periods. For the LAAFSCP data selected for this study, no geometric bottleneck was immediately downstream of the incident site.

The analysis procedure for the Beltway incident data was much simpler than the Los Angeles data analysis procedure. The data were in the form of downstream volume counts, so the upstream speed analysis was not necessary. Visual observations determined when the incident occurred and the duration of the getaway flow period. For each data set the downstream volumes were totaled for the getaway flow period, then expanded to an hourly, single-lane volume.

Table 2.—Geometric bottleneck analysis results

| Data set | Volume before incident | Duration of steady flow volumes | Getaway volumes | |
|---|---|---|---|---|
| | | | 5 minute expanded | Duration expanded |
| | | *Minutes* | *v/l/h* | *v/l/h* |
| Los Angeles data: | | | | |
| 74032502 | 1,650 | 19 | 1,805 | 1,730 |
| 74042201 | 1,755 | 27 | 1,615 | 1,625 |
| 74042602 | 1,860 | 39 | 1,365 | 1,360 |
| 74051503 | 1,695 | 34 | 1,815 | 1,815 |
| 74052302 | 1,635 | 20 | 1,595 | 1,595 |
| 74052804 | 1,380 | 28 | 1,400 | 1,415 |
| 74053001 | 930 | 31 | 1,935 | 1,930 |
| 74053003 | 1,605 | 40 | 1,480 | 1,480 |
| 74062402 | 1,680 | 9 | 1,465 | 1,500 |
| 74062802 | 1,515 | 28 | 1,450 | 1,460 |
| 74070102 | 1,935 | 36 | 1,765 | 1,765 |
| 74071101 | 1,455 | 53 | 1,140 | 1,145 |
| 75012301 | 1,800 | 54 | 1,580 | 1,590 |
| 75111901 | 1,545 | 34 | 1,160 | 1,185 |
| 76073001 | 1,635 | 20 | 1,430 | 1,430 |
| 76080201 | 1,455 | 59 | 1,540 | 1,540 |
| 76091401 | 1,755 | 20 | 1,575 | 1,575 |
| 76092801 | 1,635 | 30 | 1,300 | 1,300 |
| 76102901 | 1,605 | 22 | 1,530 | 1,540 |
| 76122701 | 1,755 | 43 | 1,335 | 1,345 |
| Average | 1,614 | 32 | 1,514 | 1,516 |
| Standard deviation | 207 | 13 | 204 | 196 |
| Washington, D.C., data: | | | | |
| 78082401 | 2,005 | 30 | — | 1,685 |
| 78082501 | 2,025 | 45 | — | 1,640 |
| Average | 2,015 | 38 | — | 1,665 |
| Standard deviation | 10 | 8 | — | 23 |

The analysis of the geometric bottleneck data was similar to the analysis performed on the Beltway incident data. The downstream volume counts for each data set were totaled, then expanded to hourly, single-lane volumes. In all cases the volume counts were based on at least 40-minute continuous observations.

## Results of Incident Data Analysis

Table 2 lists the pre-incident volumes, duration of the steady flow period, and expanded getaway volumes for each data set. The duration of the steady flow period is the time that it takes for the queue to disappear, *not* the time it takes to clear the incident. Indeed, traffic is usually affected for some time after the incident is cleared, until the initial shock wave passes. The duration of the steady flow period represents the time that it takes for traffic to begin to return to normal.

The average incident getaway flow rate is just over 1,500 v/l/h for the Los Angeles data and around 1,650 v/l/h for the Beltway data (table 2). Thirteen of the twenty-two getaway flow rates fall between 1,350 and 1,650 v/l/h. The average duration of the steady flow period is 30 minutes, and 14 of the 22 durations fall in the 20- to 40-minute range. Table 2 also shows that there is no great difference (less than 5 percent variation) between the 5-minute expanded values and the getaway duration expanded values. This is another indication that the getaway flow rate is very nearly constant.

In two of the data sets (74042201–1 and 76092801–1) complications arose in the form of hazily defined boundaries between the incident and steady flow periods. In these cases the two affected periods were combined. As a result, the getaway flow rate in one of these two data sets falls slightly out of the 1,350 to 1,650 v/l/h range.

Table 3 shows the results of a comparison of the duration expanded getaway flow rates for disabled vehicles and traffic collisions. As one can see, disabled vehicles seem to allow a higher getaway volume than do traffic collisions; however, the difference is only statistically significant at the 0.05 level for traffic collisions involving more than two vehicles. One explanation is that people gawk at a collision more than at a disabled vehicle. This can deflate getaway volumes from traffic collisions and extend steady flow duration time. Also, when there are more than two vehicles involved in the accident, getaway volumes can be further reduced due to additional gawking.

Table 4 shows the results of a comparison of the duration expanded getaway flow rates for incidents occurring during peak periods and nonpeak periods. Incidents during peak periods cause significantly higher getaway flow rates at the 0.05 level than do nonpeak incidents. This is probably due to the continuous upstream supply or demand of vehicles characteristic of peak period flow.

There was not enough weather condition data to draw conclusions about its effect on getaway flow rates. This area needs more research.

## Results of the Geometric Bottleneck Analysis

Table 5 shows the results of the analyses performed on the data taken from the geometric bottlenecks on the I-495 Beltway. The average bottleneck flow rate is approximately 1,800 v/l/h. This average bottleneck getaway flow rate would be much higher (around 2,000 v/l/h) if the Bald Eagle Road data had not been included. The Bald Eagle Road data seems to average lower than the data taken at the other two locations because two lanes are effectively blocked and traffic escapes the bottleneck at a slower rate.

Whether or not one considers the Bald Eagle Road data as good geometric bottleneck flow data, the average getaway flow rate is still higher by at least 300 v/l/h than the incident getaway flow rate. This is mainly because repeat drivers are familiar with the location of the bottleneck; also, there is no gawking effect as there would be in an incident situation. Both these factors would tend to make traffic flow more smoothly and thus increase the getaway flow rate.

**Table 3.—Getaway flow rates comparison**

| Incident type | Number of incidents | Getaway flow rate: Average | Getaway flow rate: Standard deviation |
|---|---|---|---|
| | | *v/l/h* | *v/l/h* |
| Disabled vehicle | 10 | 1,580 | 189 |
| Traffic collision: | | | |
| Two or less vehicles | 5 | 1,562 | 251 |
| More than two vehicles | 5 | 1,420 | 87 |

**Table 4.—Peak versus nonpeak getaway flow rates**

| Time | Number of incidents | Getaway flow rate: Average | Getaway flow rate: Standard deviation |
|---|---|---|---|
| | | *v/l/h* | *v/l/h* |
| Peak | 11 | 1,634 | 152 |
| Nonpeak | 11 | 1,425 | 168 |

## Summary and Conclusions

Analyses on both manual- and computer-detected freeway data in this study have shown that two distinct getaway flow rates do exist—one for freeway incidents, the other for freeway geometric bottlenecks. Although the incident getaway flow rate was found to vary from 1,100 to 1,900 v/l/h, it was generally found that 1,500 v/l/h is a reasonable value to use. The rate is slightly dependent on incident type and number of vehicles involved and is also dependent on whether or not the incident occurs during the peak period. The getaway flow rate values reported herein can be used in delay computational analyses for low cost freeway incident management systems.

**Table 5.—Geometric bottleneck analysis results**

| Location and date | | Duration of observation | Geometric bottleneck getaway flow rates |
|---|---|---|---|
| | | *Minutes* | *v/l/h* |
| Linden Lane | 8-24-78 | 55 | 2,005 |
| Linden Lane | 8-25-78 | 40 | 2,020 |
| George Washington Parkway | 8-29-78 | 70 | 1,960 |
| George Washington Parkway | 8-30-78 | 50 | 1,970 |
| Bald Eagle Road | 8-22-78 | 60 | 1,500 |
| Bald Eagle Road | 9-5-78 | 60 | 1,540 |
| Average | | | 1,830 |
| Standard deviation | | | 222 |

Analyses on manual data taken on the Washington, D.C., I-495 Beltway have shown that the geometric bottleneck getaway flow rate is about 2,000 v/l/h, or approximately the freeway's capacity. This value involves the loss of more than one lane and seems a reasonable value to use for geometric bottlenecks.

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


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# Hazardous Effects of Highway Features and Roadside Objects—Highlights

by C. P. Brinkman and K. Perchonok

## Introduction

A major research study has recently been completed which focuses on the hazards of run-off-the-road accidents. In this study the influences of driver, vehicle, and roadside characteristics were considered. Detailed reports on almost 8,000 single-vehicle accidents were collected especially for this study by specially trained State police officers in Wyoming, South Dakota, Maine, Tennessee, Georgia, and California for year-long periods during 1975 and 1976. Data were derived from noninterstate rural highways where 85 percent of the accidents occur on undivided roads; 99 percent of these accidents occur on two-lane roads. Low-volume roads were well represented with 30 percent of the accidents occurring on roads with an average daily traffic (ADT) of fewer than 400 vehicles per day, and 41 percent occurring on roads with an ADT between 400 and 3,000.

Although this article presents some of the major findings of the study, it is not an exhaustive summary of the final report which is a rich source of additional information.[1] The data collected are available on magnetic tape and have a potential for further analysis because many areas of investigation were left unexplored.

It is important to recognize that although detailed descriptions of each accident site were obtained, the number of times various roadway and roadside features of interest occur on the highways is unknown. For instance, relative exposure to curves and tangents is unknown. Such information would have required a substantial additional effort to inventory the highway system. Much can be discerned from the data without specific exposure information.

## Highway Geometrics

Table 1 shows accident frequencies for horizontal alinement by roadway type. On undivided highways, approximately 44 percent of the accidents occurred on horizontal curves. As curves undoubtedly represent less than 44 percent of the roads in the study, the accident rate was higher on curves than on tangent sections.

The data also show that on undivided roads there were more left curve accidents than right curve accidents. Because it can be assumed that left and right curves experience equal vehicular travel, this implies higher accident rates on left curves. Figure 1 shows the departure locations by horizontal alinement on undivided roads.

There was a pronounced tendency for vehicles to depart the right side of the road. A reasonable explanation is that if a vehicle leaves the travel lane to the left, the

[1] "Hazardous Effects of Highway Features and Roadside Objects, Vol. 1—Literature Review and Methodology, and Vol. 2—Findings," by K. Perchonok et al., Report Nos. FHWA-RD-78-201 and FHWA-RD-78-202, *Federal Highway Administration*, Washington, D.C. September 1978. The two-volume report is available for official use from the Federal Highway Administration, HRS-42, Washington, D.C. 20590, and from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Geometrics Road

adjacent lane often provides room for recovery. Results also show that nearly three-fourths of single vehicle accidents on curves involved departure on the outside of the curve, which means that vehicles tended to not turn enough rather than turn too much.

Other results showed that for right departures, the mean departure angle was 12.9° with 70 percent of the accidents having a departure angle of 15° or less. For left departures, the mean departure angle was 19.9° with more than half of the accidents having a departure angle greater than 15°. Although left departure angles were similar for divided and undivided roads, right side departure angles were larger for divided than undivided roads. Perhaps wider shoulders generally associated with divided roads allow recovery, thereby decreasing the frequency of small angle departure accidents in much the same way as the oncoming traffic lane does for left departures on undivided roads.

The effect of alinement on accident occurrence was also studied by computing accident frequencies for equally spaced intervals after curves; the results are shown in tables 2 and 3.

Table 2 shows a peak accident frequency immediately after horizontal curves followed by decreasing accidents downstream. This phenomenon can be explained by accidents occurring after vehicles leave a curve as a result of problems originating on the curve or in transition from curve to tangent section. A similar effect is noted for vertical curves (table 3).

Table 4 shows that downgrades were overrepresented as accident sites. Because upgrades should have as much vehicular traffic as downgrades, the accident rate for downgrades is 63 percent higher than for upgrades.

Combinations of vertical and horizontal alinements were examined and, not surprisingly, left curves on downgrades were overrepresented as accident sites.

Some associations between alinement and injury were found. Only driver injury was considered to avoid variation due to the number of occupants in the vehicle. Table 4 shows injury rates were lowest for level roads. For vertical curves, injury rates were higher for drivers having accidents traveling down than traveling up the curve. In respect to horizontal alinement, injury rates were higher for accidents on curve rather than tangent sections, particularly on left curves (table 5).

## Road Fill and Ditches

Roadside factors were studied in terms of three basic offroad vehicle behaviors: Rollover, nonroll impacts, and no impact until a later road departure. These behaviors are important in that (1) injury rates were much higher for rollovers than for nonroll impacts, and (2) no impact in the first road departure is a necessary condition for the avoidance of any impact at all.

**Table 1.—Accident frequencies for horizontal alinement by roadway type**

| | Undivided road | | Divided road | |
|---|---|---|---|---|
| Horizontal alinement | Number of accidents | Percent | Number of accidents | Percent |
| Tangent | 3,663 | 56 | 847 | 76 |
| Left curve | 1,751 | 27 | 111 | 10 |
| Right curve | 1,089 | 17 | 151 | 14 |
| Total[1] | 6,503 | 100 | 1,109 | 100 |

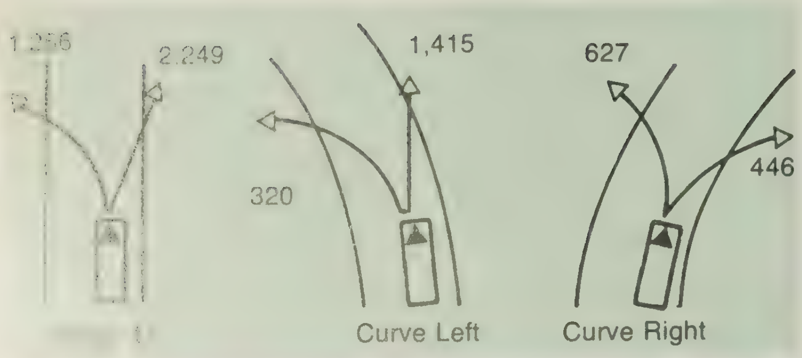
[1] The total number of accidents is not consistent from table to table because of missing data elements for some accidents.

**Table 2.—Accident frequency in relation to distance from previous horizontal curve**

| Distance from curve | Number of accidents | Percent |
|---|---|---|
| *Metres* | | |
| 0-61 | 457 | 34 |
| 61-122 | 416 | 31 |
| 122-183 | 214 | 16 |
| 183-244 | 149 | 11 |
| 244-305 | 112 | 8 |
| Total | 1,348 | 100 |

**Table 3.—Accident frequency in relation to distance from previous vertical curve**

| Distance from curve | Number of accidents | Percent |
|---|---|---|
| *Metres* | | |
| 0-61 | 514 | 32 |
| 61-122 | 348 | 22 |
| 122-183 | 302 | 19 |
| 183-244 | 239 | 15 |
| 244-305 | 193 | 12 |
| Total | 1,596 | 100 |




*[illegible] departure location by horizontal alinement frequencies with [illegible].*

Rollovers were more likely to occur from accidents on roads built on fill than on ditch cut roads. Among nonroll impacts it was found that ditches, embankments, and culverts were overrepresented for ditch cut roads. Increased height of fill and depth of ditch were conducive to rollovers. Rollover rates began to increase when fill exceeded 0.6 m and reached a plateau for fill greater than, or equal to, 1.2 m. Rollover rates jumped [illegible] for ditches 1.2 m to 1.5 m deep, but beyond [illegible] rollovers decreased as nonroll impacts with ditches [illegible].

The slope of fill and ditches primarily affected the proportion of departures having no impact. For fill, the increase in nonroll impacts appeared as a step function with the increase occurring for slopes steeper than 3:1. The increase in rollover and nonroll impacts occurred in two steps—one increase for slopes steeper than 4:1, and another for slopes steeper than 2:1.

For ditches, the decreasing proportion of rollovers corresponded with the initial increase in nonroll impacts for slopes steeper than 4:1. Reduction in nonimpact departures did not occur until the ditch slope exceeded [illegible].

A separate analysis of ditch depth and injury showed a higher injury rate for deeper ditches, which was associated with a greater frequency of impacts with ditches, culverts, and field approaches. The injury rate was notably higher when the object struck was a deep, rather than shallow, ditch. It was also shown that part of the [illegible] injury rate associated with accidents on roads with deep ditches was due to higher impact speeds.

## [illegible]s Struck

The most frequently struck objects in nonroll impacts were, in order of decreasing frequency, single trees, fences, wooden utility poles, embankments, ditches, guardrails, culverts, and small trees and brush; each constituted at least 5 percent of the total (table 6). For each accident, the most severe impact was designated the primary impact. The nonroll impacts which were most likely to be primary involved wooden utility poles, trees, bridge and overpass entrances, ground contacts, and small trees and brush; those least likely to be primary involved delineators, mailboxes, field approaches, small sign posts, and fences.

As the likelihood of hitting fixed objects decreased, there was a complementary increase in other objects struck, most notably, the ground (mounds or other irregularities in the surface) and ditches. Impacts with the ground are more likely to result in rollover accidents.

## Guardrails

The median estimated angle of impact for guardrails was between 9° and 11°; however, the variation was very large. For example, about 15 percent of the impacts

**Table 4.—Accident frequency and severity by vertical alinement**

| Vertical alinement | Number of accidents | Percent of total accidents | Percent injured | Percent killed |
|---|---|---|---|---|
| Level | 2,001 | 34.6 | 53.6 | 4.7 |
| Upgrade | 943 | 16.3 | 55.6 | 3.9 |
| Downgrade | 1,533 | 26.5 | 58.4 | 5.1 |
| Up on crest | 373 | 6.5 | 59.5 | 6.0 |
| Down on crest | 461 | 8.0 | 62.6 | 5.9 |
| Up on sag | 258 | 4.5 | 57.8 | 6.3 |
| Down on sag | 211 | 3.7 | 61.7 | 6.8 |
| Total known | 5,780 | 100.0 | | |
| Unknown | 2,192 | | | |
| Total | 7,972 | | | |

**Table 5.—Severity of injury by horizontal alinement**

| Alinement | Type of injury | | | | Percent injured | Percent killed |
|---|---|---|---|---|---|---|
| | None | Nonfatal | Fatal | Total | | |
| Tangent | 2,008 | 2,259 | 203 | 4,470 | 55.1 | 4.5 |
| Left curve | 715 | 1,017 | 107 | 1,839 | 61.1 | 5.8 |
| Right curve | 523 | 652 | 64 | 1,239 | 57.8 | 5.2 |
| Total | 3,246 | 3,928 | 374 | 7,548 | 57.0 | 5.0 |

Table 6.—Objects struck in nonroll impacts and driver injury rates for primary nonroll impacts

| Object struck | All impacts: Number of impacts | All impacts: Percent of total | Primary impacts: Number of impacts | Primary impacts: Percent of total | Primary impacts: Percent no injury | Primary impacts: Percent nonfatal injury | Primary impacts: Percent fatal injury |
|---|---|---|---|---|---|---|---|
| Bridge/overpass entrance | 115 | 1.5 | 88 | 2.0 | 33.0 | 52.3 | 14.8 |
| Tree | 874 | 11.6 | 674 | 15.6 | 36.6 | 58.5 | 4.9 |
| Field approach | 220 | 2.9 | 75 | 1.7 | 34.7 | 64.0 | 1.3 |
| Culvert | 436 | 5.8 | 239 | 5.5 | 43.2 | 52.4 | 4.4 |
| Embankment | 773 | 10.3 | 413 | 9.6 | 47.4 | 49.4 | 3.2 |
| Wooden utility pole | 782 | 10.4 | 620 | 14.4 | 52.9 | 46.0 | 1.2 |
| Bridge/overpass side rail | 143 | 1.9 | 87 | 2.0 | 53.7 | 45.1 | 1.2 |
| Rock(s) | 135 | 1.8 | 75 | 1.7 | 55.6 | 44.4 | 0.0 |
| Ditch | 642 | 8.5 | 374 | 8.7 | 58.6 | 41.1 | 0.3 |
| Ground | 224 | 3.0 | 156 | 3.6 | 53.6 | 45.1 | 1.3 |
| Small trees and brush | 386 | 5.1 | 266 | 6.2 | 63.9 | 34.1 | 2.0 |
| Guardrail | 505 | 6.7 | 286 | 6.6 | 69.5 | 28.8 | 1.7 |
| Fence | 835 | 11.1 | 331 | 7.7 | 78.7 | 21.0 | 0.3 |
| Small sign post | 191 | 2.5 | 76 | 1.8 | 80.3 | 18.4 | 1.3 |
| Mailbox | 172 | 2.3 | 32 | 0.7 | 86.7 | 13.3 | 0.0 |
| Other | 1,084 | 14.4 | 721 | 16.7 | — | — | — |
| Total | 7,517 | 100.0 | 4,513 | 100.0 | | | |

exceeded angles of 30°. This suggests that guardrail standards testing could be too limited if conducted only at one angle.

Guardrail impacts were examined for ensuing vehicle behaviors. Results presented in table 7 indicate less than optimal guardrail performance. Forty-six percent of the guardrail strikes resulted in sudden stops, vaulting (becoming airborne), or otherwise traveling through or over the guardrail.

Almost one-third of the vehicles went through or over the guardrails they struck. Another 3 percent vaulted as a result of hitting guardrails. Twelve percent of the vehicles came to a sudden stop after hitting guardrails. Unless the impact speeds were low, this, too, is undesirable due to the danger of high "g" forces. In this regard, of 64 vehicles stopping on impact, 57 had estimated impact speeds. For them, the mean speed was 21 km/h with a standard deviation of 11 km/h. (For the total of 477 estimated guardrail impact speeds for all types of vehicle behaviors, the mean was 53 km/h and the standard deviation was 27 km/h.) This suggests that some of these vehicles stopped partly due to their low speeds rather than because of excessive guardrail stiffness.

The injury rate for guardrail impacts was low relative to rollovers and nonroll impacts with most other objects. Nonetheless, guardrail performance should be improved.

Considering driver injury as a function of vehicle behavior in all guardrail impacts, it can be seen in table 8 that the two most dangerous vehicle behaviors were vaulting and traveling through the guardrail. Note, however, that there were only 13 occurrences of vaulting, thus making inferences risky. The relatively low severity in terms of percent injured and killed associated with vehicles which stopped upon impact was compatible with their lower impact speeds as noted above.

Table 9 gives driver injury for different types of guardrails. It appears that steel post W-beam guardrails were the least effective, in terms of mitigating injury, but this type of guardrail is frequently used on high speed facilities. The data were too sparse to allow adjustments for impact speed. The reason for this increased hazard would be best determined by detailed clinical analysis of the mechanisms behind driver injury in the various guardrail collisions. Future efforts might incorporate such an approach.

## Clear Zones

An attempt was made to estimate the probable effect of roadside clear zones. On the assumption that no impacts (rollover or nonroll impacts) would occur in a hypothetical clear zone, the effect on the percent of vehicles returning to the road without impact in the first departure was estimated. Although no impact in the first departure does not assure that an accident will not still occur either on the roadway or in a subsequent departure, it is a necessary condition for the avoidance of an accident by a vehicle leaving the roadway.

The behavior of all vehicles in a clear zone was simulated by those which had no impact in the zone. Specificaortion of vehicles turning back toward the road, had the zone been clear, was given by the proportion of vehicles turning back among those vehicles with no impact in the zone.

It is important to realize that 17.7 percent of the vehicles in the sample escaped impacts in the first departure without a perfect clear zone. For example, the first row of table 10 shows that had the zone from the edge of the roadway to 0.9 m from the roadway been perfectly clear, [illegible] percent (17.7 + 0.6) of the vehicles would have returned to the road without impact. The percentage of vehicles escaping impacts per unit width of clear zone is nearly constant.

In considering the effectiveness of clear zones, it must be kept in mind that vehicles departing from the roadway tend to travel until they hit something. Also, ostensibly clear zones sometimes have features which can induce rollover accidents.

The likelihood of colliding with wooden utility poles decreased almost linearly with increasing pole offset at an average rate of approximately 2.8 percent for every metre. The speed of impacts with poles decreased with pole offset, but only when pole offset exceeded 7 metres.

Removing objects from the roadside does not create a perfect clear zone. As the likelihood of hitting poles, trees, or small trees and brush decreased there was a complementary increase in other objects struck. Most notable were ground (reflected mostly in rollovers) and ditches.

**Table 7.—Vehicle behavior for guardrail strikes**

| Behavior | Number | Percent of total |
|---|---|---|
| No rollover: | | |
| Vault | 13 | 2.5 |
| Stop | 64 | 12.3 |
| Through or over | 163 | 31.4 |
| Redirect to road | 128 | 24.7 |
| Continue | 135 | 26.0 |
| Other | 2 | 0.4 |
| Rollover and: | | |
| Stop | 2 | 0.4 |
| Continue | 5 | 1.0 |
| Other | 7 | 1.3 |
| Total | 519 | 100.0 |

**Table 8.—Driver injury by vehicle behavior following guardrail impacts**

| Behavior | Type and number of driver injury | | | | | |
|---|---|---|---|---|---|---|
| | None | Nonfatal | Fatal | Total | Percent injured | Percent killed |
| Vault | 2 | 8 | 3 | 13 | 84.6 | 23.1 |
| Stop | 43 | 20 | 1 | 64 | 32.8 | 1.6 |
| Through | 80 | 76 | 4 | 160 | 50.0 | 2.5 |
| Redirect to road | 84 | 42 | 1 | 127 | 33.9 | 0.8 |
| Continue | 83 | 51 | 1 | 135 | 38.5 | 0.7 |
| Stop during rollover | 1 | 1 | 0 | 2 | 50.0 | 0.0 |
| Continue during rollover | 0 | 5 | 0 | 5 | 100.0 | 0.0 |
| Unknown, other | 1 | 8 | 0 | 9 | 88.9 | 0.0 |
| Total | 294 | 211 | 10 | 515 | 40.9 | 1.9 |

**Table 9.—Driver injury by type of guardrail in primary impacts**

| Guardrail type | Type and number of driver injury: None | Nonfatal | Fatal | Total | Percent injured | Percent killed |
|---|---|---|---|---|---|---|
| Blocked W-beam (wood post) | 51 | 19 | 1 | 71 | 28.2 | 1.4 |
| Blocked W-beam (light steel post) | 5 | 2 | 0 | 7 | 28.6 | 0.0 |
| Blocked W-beam (steel post) | 34 | 28 | 2 | 64 | 46.9 | 3.1 |
| Nonblocked W-beam | 22 | 6 | 2 | 30 | 26.7 | 6.7 |
| Box beam | 11 | 3 | 0 | 14 | 21.4 | 0.0 |
| Three-strand cable | 14 | 3 | 0 | 17 | 17.6 | 0.0 |
| Two-strand cable | 12 | 1 | 0 | 13 | 7.7 | 0.0 |
| Wood post | 3 | 1 | 0 | 4 | 25.0 | 0.0 |
| Parapet | 8 | 3 | 0 | 11 | 27.3 | 0.0 |
| Total | 160 | 66 | 5 | 231 | 28.6 | 2.2 |

## Miscellaneous Safety Features

Based on earlier discussions suggesting that many outside departures resulted from insufficient awareness of curves, it was thought that effective delineation would reduce the proportion of outside departures. Results demonstrated edgelines were effective in this way.

Also tested in this way were centerlines, light conditions, and curve warning signs. Results showed fewer outside departures for daytime accidents and for accidents where centerlines were present. No such benefits were found for curve warning signs, but they may have been placed at particularly hazardous locations.

Shoulder width was studied in several ways. It was not found to influence the likelihood of nonimpact departures or rollovers, nor did it have a significant effect on injury rate. Increased shoulder width, however, did result in fewer outside departures on left curves, thereby suggesting that shoulders provide a useful buffer for moderately errant vehicles.

Although the results pertaining to edgelines, centerlines, warning signs, and shoulder widths are suggestive, caution is required, as noted in some instances above, because the results may reflect other factors not controlled in analysis.

**Table 10.—Run-off-the-road vehicles escaping impacts as a consequence of perfect roadside zones**

| Width from edge of roadway | Percent returning to road (Minus 17.7 percent) | Percent getting away per metre width |
|---|---|---|
| *Metres* | | |
| 0.9 | 0.6 | 0.66 |
| 1.8 | 2.1 | 1.2 |
| 2.7 | 3.5 | 1.3 |
| 3.7 | 5.4 | 1.5 |
| 4.6 | 7.0 | 1.5 |
| 6.1 | 9.1 | 1.5 |
| 9.1 | 12.4 | 1.4 |
| 12.2 | 15.3 | 1.3 |
| 18.3 | 21.8 | 1.2 |
| 30.5 | 30.8 | 1.0 |

## Factors Influencing Injury

The single greatest determinant of injury was occupant ejection from the vehicle. The injury rate was high for compound or extended rollovers; it was low for nonroll impacts in which the vehicle went through or over the object struck, or otherwise continued moving after impact. The injury rate was high (table 6) if the object struck in the primary impact was nonyielding (bridge or overpass entrances, field approaches, single trees, culverts) and low for more yielding objects (small trees and brush, guardrails, fences, small sign posts). As shown in figure 2, injury rates increased with increasing impact speed. Finally, in nonroll impacts, injury rates were higher for frontal impacts than for other impacts.

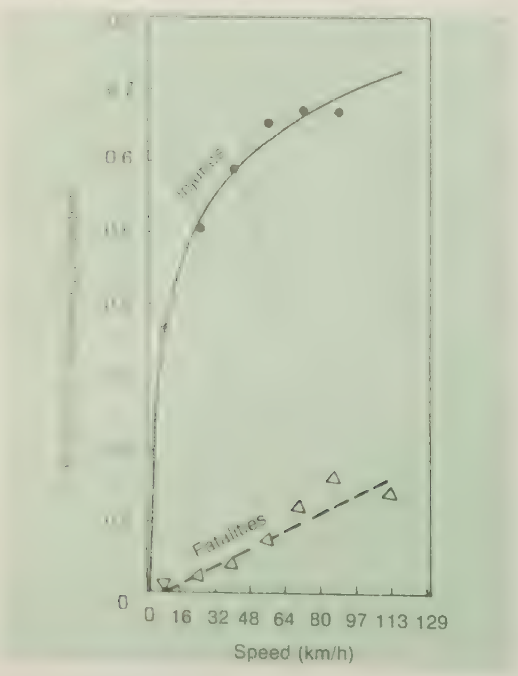
Other factors studied having the greatest effect on injury were (in descending order) intoxication level, pole offset, passenger restraint use, horizontal curve length, predeparture maneuver, departure angle, driver condition, road condition, and distance from the origin of tire marks to the departure point. Of these nine variables, three were wholly driver determined (intoxication level, driver condition, and restraint use), three were behavioral in nature reflecting interactions between the driver and the roadway (maneuver, distance of tire marks, and departure angle), and three were roadway factors (road condition, pole offset, and curve length).

## Roadway Characteristics and Injury

In order to obtain a simple measure of the relative influence of driver, road, behavioral, and off-road factors on injury, the proportion of variables which had a statistically significant relationship to injury was obtained for each group of factors. Of the 8 driver-related variables (including restraint use), 7 had significant effects on injury; of the 11 roadside factors, 5 were significant. Thus, although almost all of the variables largely under driver control were statistically significant, less than half of the variables primarily under the control of the highway engineer were significant.

This should not diminish interest in the design for safety of roads and roadsides. Although the driver-influenced variables were stronger relationships to injury, they are far less susceptible to improvements than are road and roadside factors.

*Figure 2.—Proportion of injury and fatal injury accidents versus impact speed.*




Perhaps the major point here is that every attempt should be made to discern those roadway factors which are of true importance to highway safety, to understand the mechanisms by which they achieve their effects, and only then to implement remedial activity. Some of the factors suggested by this study include the treatment of curves (especially left curves), downslopes and vertical curves, offset instances, and the height of fill and ditches. In almost all instances, consideration of the driver and his or her habitual modes of operation, rather than stipulations of what he or she should do, is an essential requirement in designing for safety.

## Contrary Results

There were a number of findings which appeared to be contrary to the view that improved conditions are, in all respects, safer. Examples include lower injury rates for snow-covered roads, sharper curves, and small border and pole offset. A possible explanation is that all of these conditions are usually associated with low travel speeds.

These results reflect the adaptive capability of the driver who, to one extent or another, takes risks into account. The converse of this is that the better the roadway, the fewer the precautions taken by the driver. Experience with limited access roads implies that this can be a useful trade off; high design standards have led to improved transportation and safety.

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**K. Perchonok** is currently employed at the Institute for Research, State College, Pa., although the work reported in this article was conducted at Calspan Field Services Inc. Mr. Perchonok's principal professional activities have involved the analysis of highway accidents and driver behavior.

# The Application of Visibility Research to Roads and Highways

by Donald A. Gordon and Richard N. Schwab

This article defines visibility and the related measures of legibility and conspicuity and explains how recent research, principally in the programs of the Federal Highway Administration (FHWA), has served to improve visibility on our Nation's roads.

## Introduction

Accident and fatality rates are much greater at night and during periods of adverse weather when the driver's visibility is likely to be reduced. If the driver cannot see a sign, marking, small animal, or pedestrian, he or she cannot react properly. In addition to poor visibility, factors such as intoxication, fatigue, and high speeds contribute to the higher than expected night accident rates.

Critical portions of the highway environment must be clearly visible to the driver not only under favorable daylight conditions, but also under visually degraded conditions due to night, rain, dust, and snow. Research studies have shown a 30 percent reduction in the night accident rate when night visibility is improved by adding fixed illumination. *(1-4)*[1] However, the results of accident studies conducted before and after the addition of fixed illumination have not always been consistent. Occasionally, reverse results have indicated that lighting made the situation worse. Without a knowledge of the visibility factors involved, these changes cannot be explained. Signs and markings used to improve visual guidance fade and change with age and must be renewed based on visibility criteria. Therefore, the highway engineer must be concerned with the measurement of visibility and its adequacy in many different highway situations.

Along with visibility, the related measures of legibility and conspicuity are often specified in highway studies. Legibility refers to the readability of a sign. A sign will, of course, be visible long before it can be read, but it is important to know the distance at which drivers can actually read and interpret the sign. Conspicuity is the attention-getting quality of a sign. Conspicuity is a particularly important characteristic for a railroad grade crossing sign. A railroad warning sign may be visible and legible, but nonetheless be overlooked by the driver. Although the characteristics of legibility and conspicuity are often at issue, visibility is the single most important measure in determining the visual effectiveness of driver guidance information. If a sign or marking cannot be seen, it cannot be read. It would be fruitless to ask if a sign, still not visible, is conspicuous enough to catch the driver's attention.

[1] Italic numbers in parentheses identify references on page 22.

## What Is Visibility and How Is It Measured?

Specific factors that have been shown to influence visibility within the highway environment are illustrated in figure 1. *(5)* The signs, markings, and pedestrians are illuminated by the sun or by artificial sources such as the car's headlights. Road markings or words on signs can be seen because of contrast with the background. Many laboratory studies conducted over the past century have indicated that visual performance is mainly dependent upon the following factors:

- Luminance adaptation level to which the eye is previously exposed.
- Size and shape of the object to be seen.
- Time available for seeing.
- Contrast between the object and the background.

Of the variables mentioned above, contrast is the one most conveniently used by the highway engineer to influence visibility.

Contrast is defined as follows:

$$\text{contrast} = \frac{\text{object luminance} - \text{background luminance}}{\text{background luminance}} = \frac{\Delta L}{L_b}$$

where object and background luminances are measured in terms of physical photometric units. If contrast is close to zero, the object will probably not be seen, even if the color of the object differs considerably from the background.

The findings of a typical laboratory study are presented in figure 2. *(6, 7)* The results show that detection of a circular disk is dependent upon target diameter and background luminance. Also, threshold contrast decreases asymptotically as the background luminance increases.

It should be understood that these results were obtained in the laboratory, using highly trained observers and a forced choice psychophysical technique. Subjects were instructed to guess, if necessary, in which of seven positions a faint disk of light appeared. For adequate driving conditions, the motorist requires a sign or marking that has greater visibility than the threshold contrasts found in such studies. How much more contrast is required is an important question which requires further study. A particularly important part of this question is the effect of different contrast levels above threshold on the ability of the driver to adequately perform his task. However, threshold studies are important because the recognition of a sign or marking will follow the same pattern as these detection threshold results. As highway sign letters increase in size or the sign luminance increases, legibility also increases.

*Figure 1.—Factors influencing driver steering control under adverse visibility conditions. (5)*

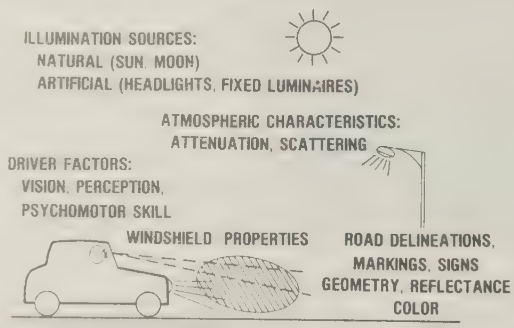
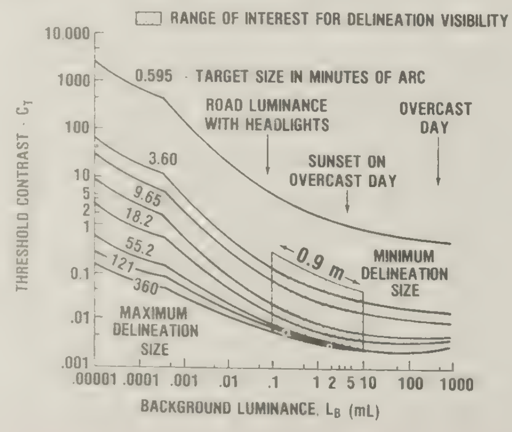



*Figure 2.—Visual contrast threshold characteristics for unlimited viewing times. (6, 7)*




Unfortunately, these laboratory results cannot be directly applied to highway problems. The operational situation has certain built-in complexities that affect the driver's visual sensitivity that must be taken into account. Over the last quarter century, a unified conceptual framework has been developed for dealing with visibility requirements in the operational situation. Blackwell has demonstrated that visual performance potential for a specific visual task may be determined by comparison with a reference task performed under standardized illumination conditions. *(8)* Visual performance potential is dependent upon the intrinsic properties of the task, the background against which the task is seen, and the visual sensitivity of the observer.

The relative visibility *(VI)* of a particular task as a fraction of standard reference visibility is given by the following equation:

$$VI = \frac{\Delta L}{L_b} \times RCS \times DGF \times TAF$$

The first factor, $\frac{\Delta L}{L_b}$, is the measured physical task contrast between the luminance pattern of the object and its immediate surroundings. *RCS*, the Relative Contrast Sensitivity, represents the relative sensitivity of the typical observer in perceiving contrast under conditions approximating those of the task under consideration compared with the same observer's sensitivity at perceiving a standardized laboratory task under specified illumination conditions.

*DGF*, the Disability Glare Factor, accounts for the reduction in visual performance due to veiling luminance (glare) of light sources near the viewed object. The last factor, *TAF*, Transient Adaptation Factor, accounts for the moving fixation of the eye to other parts of the visual field and the manner in which luminance values in these other areas differ from those near the task. For most highway applications, *TAF* can be assumed to have a value of approximately one. However, when there are large discontinuities in the driver's luminous environment, such as at the entrance of a dark tunnel in daytime, *TAF* will become an important consideration.

## Roadway Lighting Studies

Recent research sponsored by the FHWA has been concerned with the relationship between the driver's demand for visibility and visibility supplied by fixed illumination on urban streets. Gallagher et al. developed a method for monitoring vehicle velocity and location as the unsuspecting motorists reacted to a traffic problem. *(9)* A gray "traffic cone" was placed in the middle lane of a lightly trafficked six-lane urban street. The driver avoided the cone by braking or changing lanes.

The responses of over 1,300 drivers were unobtrusively observed under 23 visibility conditions. The basic performance measure was the time to collision from the moment the unalerted driver reacted to the target. (It was assumed that vehicular velocity would not change if the driver did not have to avoid the cone.) The adequacy of visibility conditions could then be assessed in terms of whether or not the driver could have stopped his or her car in time. Results could be generalized to other roadway situations through the application of relative visibility *(VI)* techniques.

The results shown in figure 3 indicate that approximately 95 percent of the maximum level of performance that can be influenced by changes in the illumination are obtained with a *VI* level of 15. It would not be cost effective to provide higher levels of visibility. This result applies only to the detection task studied by Gallagher. *(9)* Other studies are required before general conclusions concerning optimum visibility design levels can be reached.

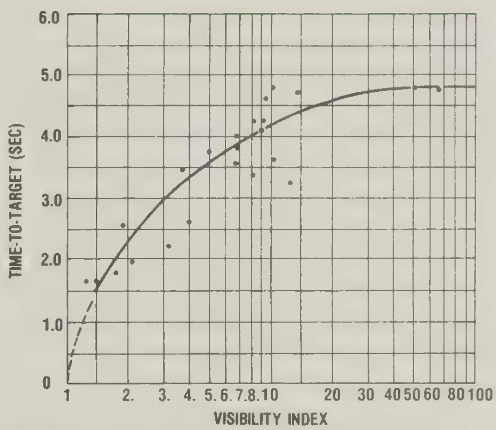



*Figure 3.—Mean driver response to target detection task.*

In a more recent study, Janoff et al. related the probability of dry weather, nighttime accidents to visibility and illumination measures. *(10)* The regression analysis indicates that fewer nighttime, dry weather accidents occur as visibility is increased. Areas of high population density, especially those in the central business district, show high accident rates. Conventional measures of the adequacy of illumination (horizontal illumination and uniform pavement luminance) were found to produce results that were contrary to expectation. For the 84 sites considered in the study, horizontal illumination was positively correlated with accident history; that is, higher illumination levels resulted in increased accident rates. This result leads to the interpretation that illumination level is not an adequate basis for design of lighting systems. It would appear that visibility which relates to the visual effectiveness for the driver is a better basis for lighting design than the previously used conventional illumination criteria.

Results of this accident study were further used in an economic analysis. Janoff et al. showed that a lighting system using High Pressure Sodium sources was more cost beneficial than widely used Mercury Lamp systems. *(10)* However, either type of light source could be applied in an effective manner to give a benefit-cost ratio greater than 1. Higher mounting heights and longer spacings tend to be more cost beneficial except when constrained by visibility requirements. Results also showed that existing Mercury illumination systems can be upgraded to High Pressure Sodium, resulting in reduced energy utilization of 50 percent or more without increasing accident rates. Such changeover programs will pay for themselves within a few years. A computer program and design guide have been developed to assist potential users in conducting analyses of lighting changes at specific locations in terms of visibility. *(11)*

In another FHWA-sponsored study, Rockwell et al. showed that the addition of fixed illumination significantly improved driver performance at isolated rural intersections. *(12)* The intersections studied were typical of secondary routes. Eye fixation measures indicated that the driver detected the intersection sooner when it was illuminated than when it was not illuminated. Vehicular deceleration was smoother. The addition of warning signs and delineator posts had only a marginal effect on driver reactions and new pavement markings showed no effect. In this study, once illumination was introduced, performance did not improve as the quantity of the fixed illumination was increased. It may be concluded that the visibility aspects of the illumination changes were secondary relative to the attention-getting characteristics of the lighting.

## Pavement Marking Systems

Fixed illumination is not economically justified at most rural locations, except perhaps for hazardous intersections and similar configurations. For the rural environment, pavement delineation rather than fixed lighting is the most practical method for enhancing visual guidance at night and during adverse weather.

During the past 3 years, FHWA has sponsored a series of major research efforts to improve visual guidance at night and under adverse weather conditions. A study by Meritt et al. was concerned with the effect of increasing the luminance of yellow traffic markings by the addition of white paint. *(13)* A somewhat whitened yellow paint has better visibility, costs less, and is less toxic than yellow lead-chromate paints now used. However, the yellow marking must not be whitened to where it is indistinguishable from white.

A series of paint samples ranging from 100 percent yellow to 100 percent white (yellow/white pigment weight ratios) was applied to 2.4 m by 102 mm strips of thin sheet metal, simulating delineation stripes. The experimenters used standard highway marking equipment with normal glass bead applications.

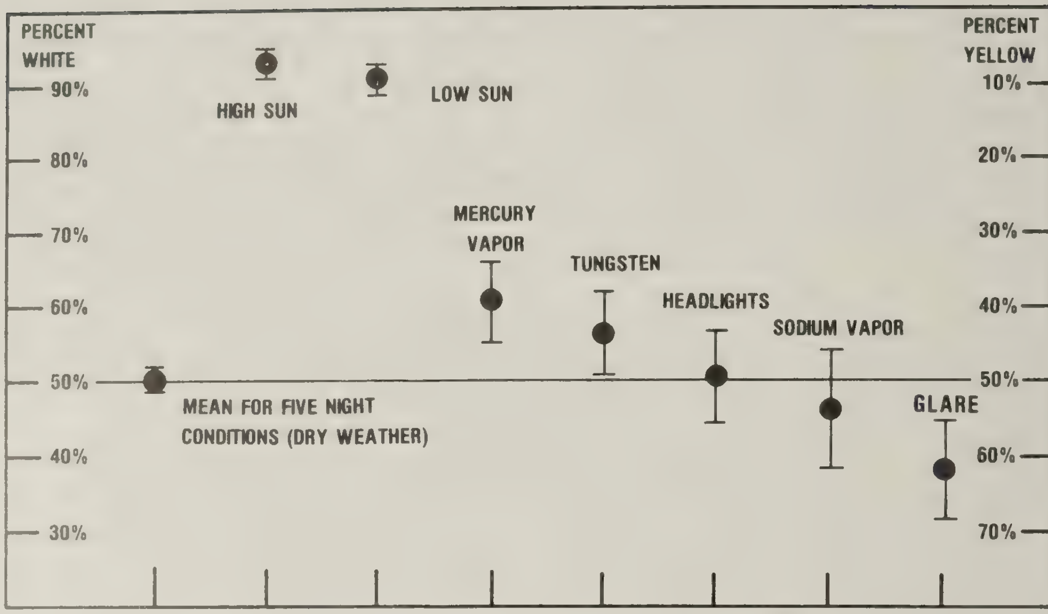



*Figure 4.—Summary data for each of seven dry weather lighting conditions (95 percent confidence limits indicated above and below each mean value).*

Yellow/white color judgments were made by 20 observers from the driver's seat of a parked vehicle at distances of 9 m, 18 m, and 27 m, both with and without a white reference stripe present. The results show the percent of white paint that can be mixed with yellow and still be seen by the driver as yellow under several typical day and night conditions (fig. 4). For example, in daylight under high sun over a 90 percent dilution by white can still be seen as yellow. It appears that in most rural situations yellow paint can be diluted with white paint up to 50 percent white pigment (by weight) without losing yellow color identity. However, in most urban areas where fixed lighting is installed the dilution should be substantially less, particularly as the current trend to increased usage of sodium vapor light sources is accelerated. Limited field experimentation on the use of whitened yellow is currently underway. If found acceptable in operational use, the annual savings in the United States should be over $1 million.

Road markings lose contrast as they age. At what point does visibility become so poor that restriping is required? This problem was examined by Allen et al. in FHWA-supported research. *(5)* A simulator was used that projected computer-generated outlines of the road and markings on a screen in front of a real vehicle passenger compartment. The consequences of decreased marking visibility were measured both by the driver's ability to control his or her vehicle and by subjective rating scales. The rating scales attempted to gage the amount of attention the simulated road required and the driver's estimate of his or her ability to control the car. On a straight road, the driver had to bring the simulated car back under control from the effects of an apparent random crosswind. On a curved road, the control task was to track the road under conditions of reduced visibility.

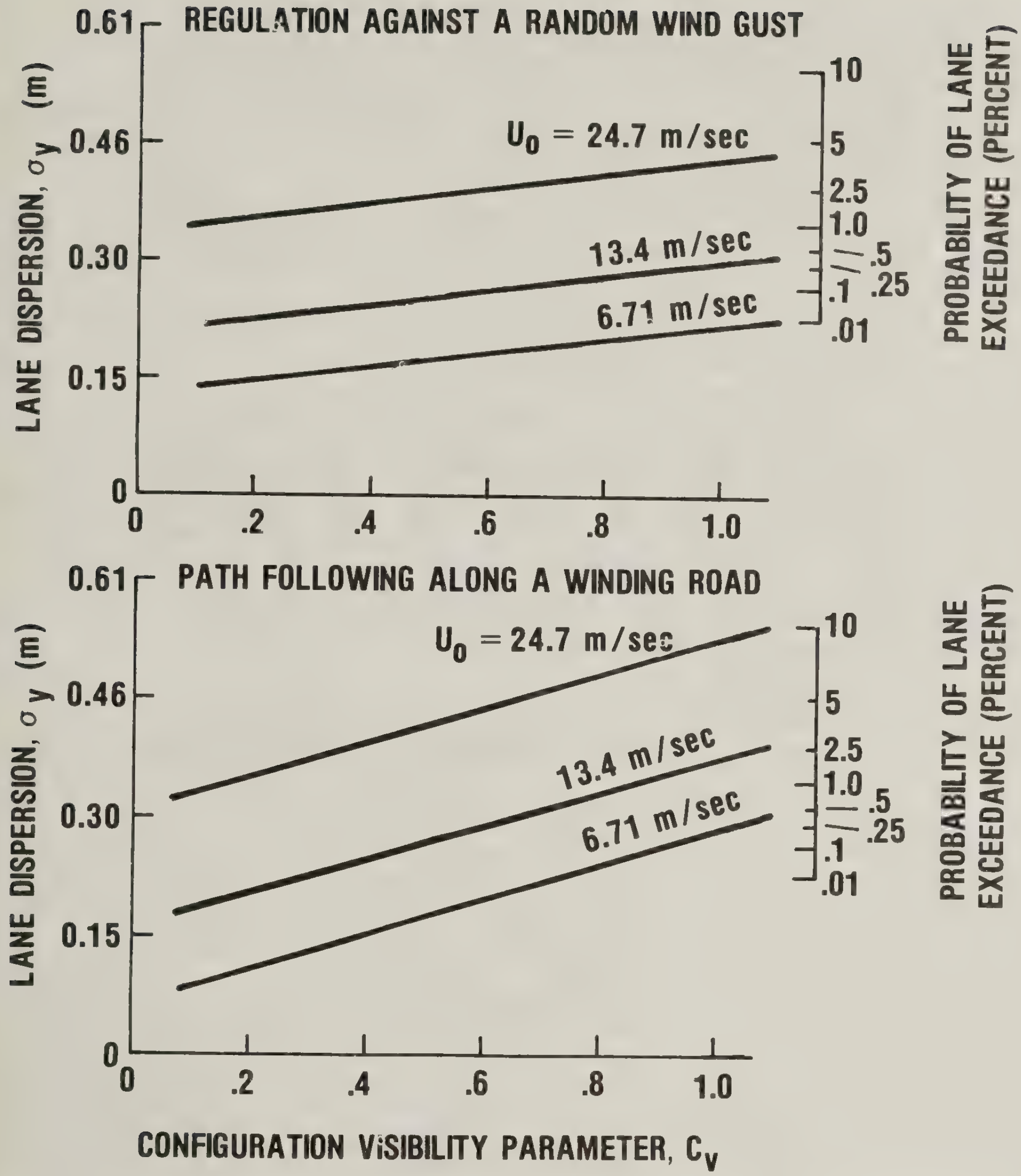



*Figure 5.—Lane dispersions as a function of speed and configuration visibility parameter.*

The driver control results for two studied conditions are shown in figure 5. In this figure, $C_V$ expresses the visibility of the markings as they are affected by atmospheric conditions such as fog. As visibility becomes poorer (indicated by increased $C_V$), vehicular control and lateral path variance ($\sigma$) also become poorer, and the probability of lane border encroachment increases. As might be expected, increased speed (U) also adversely affects vehicular control.

Studies using instrumented vehicles under traffic conditions were undertaken to validate the simulator findings. The results indicate that under normal environmental conditions delineation should be replaced or repainted when contrast falls below a value of 2. In areas with a higher than normal incidence of fog, heavy rain, or other adverse visibility conditions, contrast should be maintained at a higher level than 2 to compensate for atmospheric scattering. An interesting additional finding of this study was that subjective driver reports of discomfort occurred at a visibility level somewhat above the point where vehicular control (lane exceedances) had appreciably deteriorated.

Reflex reflector type pavement markers for use in fog-prone areas have been investigated by Shephard at the Virginia Highway and Transportation Research Council. *(14)* Although in this study emphasis was on nighttime visibility characteristics, consideration was also given to protecting the markers from snowplow damage. Based on the limited observations made, the raised markers were "thought to provide sufficient nighttime roadway delineation for vehicle guidance" during most fog conditions when placed along the edgeline on 6 m centers. *(14)* A field evaluation of the markings is being carried out on a new section of I-77 near Fancy Gap, Va. (fig. 6). Evaluation is also underway on a system of illuminated, pavement edge, insert lights at Afton Mountain, Va., on I-64. The insert lights provide day as well as night guidance.

Additional studies are underway to analyze the effects of delineation on vehicular control and accidents and to develop a cost-effectiveness model to guide engineers in selecting delineation treatments. A series of studies on the use of speed advisory information by drivers during reduced visibility conditions is also underway. These studies deal with the effectiveness of additional driver information rather than the design of the driver's visual environment discussed in this article.

## Sign Visibility Requirements

FHWA has long been concerned with the visibility of signs. Numerous factors are known to affect the visibility of a highway sign and hence the size, spacing, stroke width, and

*—Field evaluation of pavement*

material characteristics required. In addition to being visible, a sign must also be conspicuous and legible. Much of the research effort has been concerned with legibility. Some of the factors that affect the legibility of a sign are letter size, letter-background contrast, sign position (overhead or sidemount), color, alinement, and surrounding luminance. The driver's age, visual abilities, and speed on the road are also of importance, as is the road geometry itself.

An early study by Powers was concerned with the effect of sign conspicuity on the driver's ability to follow a test route. *(15)* Signs with a nonreflective green background, a moderately bright reflectorized green background, and a high-brightness reflectorized background were used to direct the drivers along the route. The resulting luminances provided by these backgrounds varied by a factor of 20:1 and more, depending on the source-sign-observer angle. The test route employed by Powers included 40 km of controlled access roads near the U.S. Pentagon. No systematic differences in route-following errors attributable to the use of the different sign backgrounds were found in this study. Therefore, it was concluded that sign background brightness did not have a major effect on a driver's ability to locate and react to directional signs.

In a more recent study, Olson and Bernstein determined the legibility of various combinations of background and letter luminances. *(16)* A computer model was developed that predicts the legibility distance of a sign for a wide range of highway situations. Reference 16 provides separate functions for several of the more common situations. As the legend luminance and the related contrast increase, legibility also increases up to a point. However, at high luminances, the letters can become glaring and legibility is reduced. Separate threshold legibility functions were developed for signs above and to the right of the road illuminated by low and high beams. Sign placement on vertical and horizontal curves of various degrees was also studied.

This research predicted legibility of signs under various conditions; the problems of driver comfort, conspicuity, and vehicular control were left to future research. Little is known about the amount of legibility required by the typical driver to perform under various traffic and adverse weather conditions. The effects that providing more or less than required legibility levels have on vehicular control and traffic flow also need to be studied.

The legibility of symbolic parking signs has been studied by Gordon and Boyle. *(17)* Some of the signs used in this study are shown in figure 7. Subjects approached the sign until they could recognize the symbol and read the message under the symbol. The distances at which these events took place were recorded. A symbol with a red slash that extended outside the circle (fig. 8) doubled the legibility distance of the symbols shown in figure 7. Symbols were not as legible as equal-sized letters, suggesting that symbol legibility can be considerably increased by an improved symbol design. Because symbols in figure 7 are larger than the word message below, a driver must be close to the signs to read the message. The signs could be improved if larger, uppercase letters were used in the message.

## How Do Visual Conditions Influence the Driving Process?

The end result of the vision process occurs when a driver senses some condition in the highway environment and makes an appropriate response to the situation by steering, braking, or accelerating. To justify visibility improvement costs, improvements need to be related to driver safety, comfort, and improved traffic flow.

The cost of providing highway illumination or other devices to improve visual conditions at night is determined by the type of hardware used (the source type and size) and by the distribution, spacing, and mounting height of the luminaires. Sign cost is related to letter size and the quality of reflective sheeting used. In turn, the hardware used affects the visibility characteristics of the lighting, that is, its uniformity, luminance, glare, and contrast. The resulting visibility may or may not be adequate to the needs of the driver in the particular situation under consideration.

How well the visibility conditions meet the driver's inherent needs should be apparent in changes in his or her behavior—reaction time, braking, accelerator dither, or eye movements. The changes in driver behavior may be reflected in vehicular control measures such as speed, headway, or lateral placement. These, in turn, influence the probability of obtaining a benefit. The benefits of increased visibility should then be shown in increased safety, smoother flow, and driving comfort. However, increased visibility through the addition of fixed illumination or alteration of


*Figure 7.—Signs used in the Gordon and Boyle study. (17)*


*Figure 8.—Symbol with red slash extending outside the circle.*

sign or delineation contrast can produce a benefit only if the increase is actually needed by the driver.

## Some Unanswered Questions

Much remains to be done on the challenging problems of highway visibility. The importance of conspicuity has been recognized and some underlying factors have been studied. The traffic control device must catch the driver's eye—it must be conspicuous. But we are far from the point where a reliable prediction can be made that a sign, marking, or traffic signal will or will not be seen by the driver. We know that the larger the device, the greater its contrast to its surroundings; the nearer its position to the driver's line of sight in an uncluttered environment, the greater the likelihood of its being observed. But an objective research study of conspicuity is needed. It is particularly important that a study be directed to the interaction of conspicuity and legibility of signs. A sign with adequate conspicuity may be glaring and hard to visually resolve when located in some positions, but in other positions it may be adequate in both legibility and conspicuity. Conspicuity may also be an important variable for lighting research. The study by Rockwell appeared to indicate that at the rural intersection, conspicuity may be more important than the actual visibility produced by the lighting system. *(12)*

The interactive effects between methods used to enhance visibility should be studied. Delineation that is adequate for a dry night situation may be inadequate if fixed illumination is added. However, the fixed illumination may be needed for wet nights or to illuminate critical elements in the environment outside the headlamps' beam pattern. Much work needs to be done on the loss in driver control brought on by poor visibility. How are the visual conditions along the highway related to safety, traffic flow, driver comfort, and other measures of "highway effectiveness"? Detection distance must be related to improvements in driver performance to have an impact on the cost-benefit relationship. If that relationship is known, trade offs become clear, and critical decisions can be made as to whether to illuminate a section of highway or improve delineation.

The findings of visibility research must be incorporated into standards for design and maintenance of our highway facilities. After such standards are formulated, there is a [illegible] to develop simple photometric [illegible]ring devices that can be used [illegible] personnel. These devices [illegible] rugged and inexpensive, [illegible]nt to use, and capable of [illegible] an accurate assessment of [illegible] adequacy of lighting, [illegible], and markings.

[illegible]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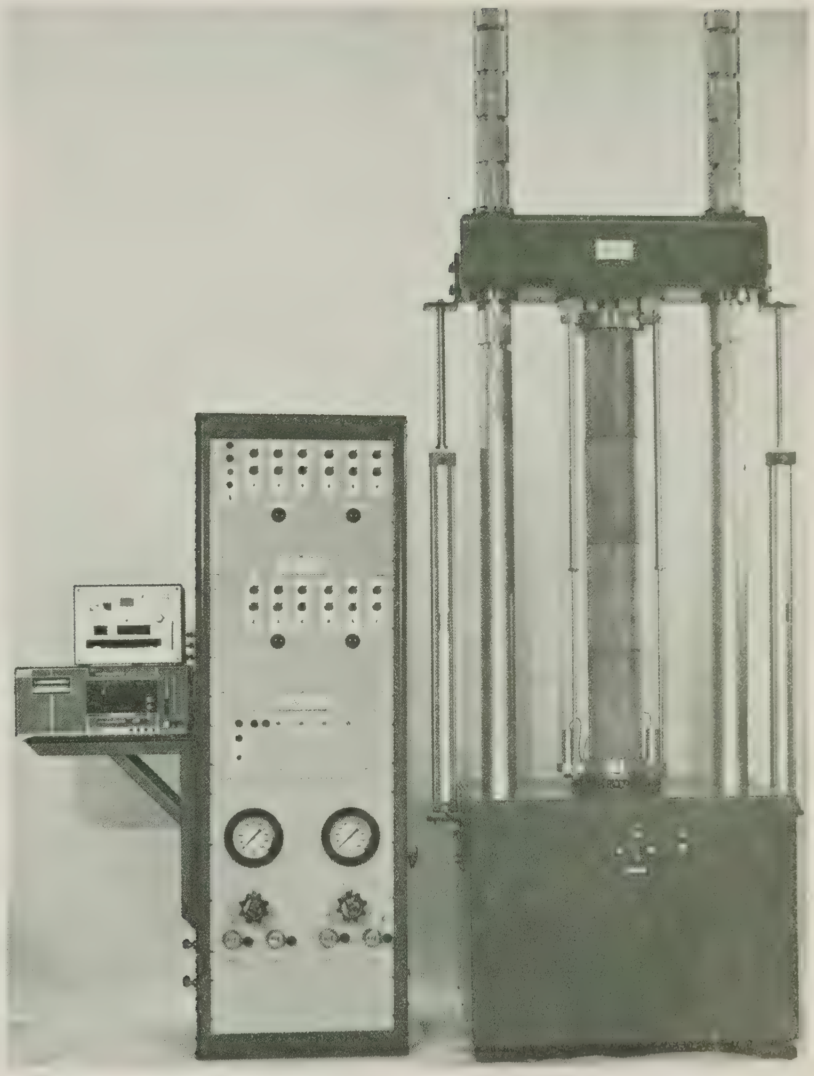
**Richard N. Schwab** is an electrical engineer in the Environmental Design and Control Division, Office of Research, Federal Highway Administration. He has been with FHWA since 1962 and is project manager for FCP Project 1L "Improving Traffic Operations During Adverse Environmental Conditions." His technical background is physiological optics which is the study of optics physiology, and sensory capability of the human visual system. His work at FHWA has involved establishing the effects of adverse environmental conditions such as darkness, fog, snow, dust, and rain on traffic flow and highway safety, and developing methods for overcoming these effects. Prior to joining FHWA, he was a graduate assistant on the staff of the Institute for Research in Vision at Ohio State University.

Concrete - Creep
Jones, Walter R.
Hegarty, James H.

# Automated System for Measuring Creep in Portland Cement Concrete

by

**Walter R. Jones**
**and James H. Hegarty**



## Introduction

Portland cement concrete has become a mainstay of the U.S. highway construction industry since it was first used in a pavement in Bellefontaine, Ohio, in 1893. Its use in structures can be traced even further to similar products used by the Romans.

Over the years, researchers and practitioners have carefully mixed, placed, tested, and methodically measured the characteristics of concrete in order to relate its properties to behavior and performance. One such property of concrete is creep, defined by the American Concrete Institute (ACI) as "time-dependent deformation due to sustained load." *(1)*[1]

## The Problem

Although a vast amount of data has been collected over the last century on the creep of concrete, a critical need still exists for more information. One reason for this continuing need is the uniqueness of each concrete mixture. Another reason is the continuing improvements in chemistry and formulation of admixtures and additives for concrete. Some of the variables which influence the creep properties are the same as those which influence concrete strength, such as, age and curing history (maturity), environmental conditions, and loading schedules.

Recently, the uniqueness of the problem has been expanded because engineers are questioning the effects of the following developments on the properties of concretes:

- Super plasticizers.
- Pozzolanic admixtures.
- New or changed cements, especially those derived from low energy input processes.
- Organic additives, such as latex emulsions and polymer cements.
- Plasticized sulfur.
- Polymer and sulfur impregnations.
- Internally sealed (wax bead) concrete.
- Additions of glass or steel fiber reinforcement.

[1] Italic numbers in parentheses identify references on page 26.

These and other materials and processes are being investigated under the Federal Highway Administration's (FHWA) Federally Coordinated Program of Highway Research and Development Projects 4B, "Eliminate Premature Deterioration of Portland Cement Concrete," and 4G "Substitute and Improved Materials to Effect Materials and Energy Conservation in Highways."[2]

[illegible]eep of these materials must be defined if they are [illegible]ed in structures where the materials will be [illegible] sustained stress. A material exhibiting high creep will change dimensionally under load while a material with low creep will undergo very little dimensional change. The latter is preferred in most cases.

## The Equipment

Research on creep has been handicapped by the lack of easy-to-use, load-sustaining equipment incorporating automated data acquisition. A new system, built for the FHWA staff research on concretes, was designed to [illegible]se the accuracy of data and flexibility in testing a [illegible] materials via automation (fig. 1). Inherently, it [illegible] reduce the need for repeated testing and permit [illegible] materials to be evaluated in a shorter time. This [illegible]m was designed in compliance with the [illegible]quirements of the American Society for Testing and [illegible]erials Designation C-512, Creep of Concrete in [illegible]npression. *(2)*

## [illegible] Description

[illegible]he actual installation includes four loading frames (fig. [illegible]). Each frame has a hydraulic actuator for applying the load and an adjustable upper crosshead supported on two grooved columns. Each frame accommodates up to [illegible] standard 152 mm by 305 mm cylinders, and has provisions for testing different size cylinders and materials, either individually or intermixed, but with a constant applied load.

The loading force, up to approximately 900 kN, is maintained by two regulator controllers (fig. 3) and measured by pressure transducers. These regulators will be used to apply a load to frame Nos. 1 and 2 which can differ from the load applied to frame Nos. 3 and 4. The

[2]These projects are described in the annual "Progress Reports, Year Ending September 30, 1978," which are available from the Federal Highway Administration, Materials Division, HRS-22, Washington, D.C. 20590.

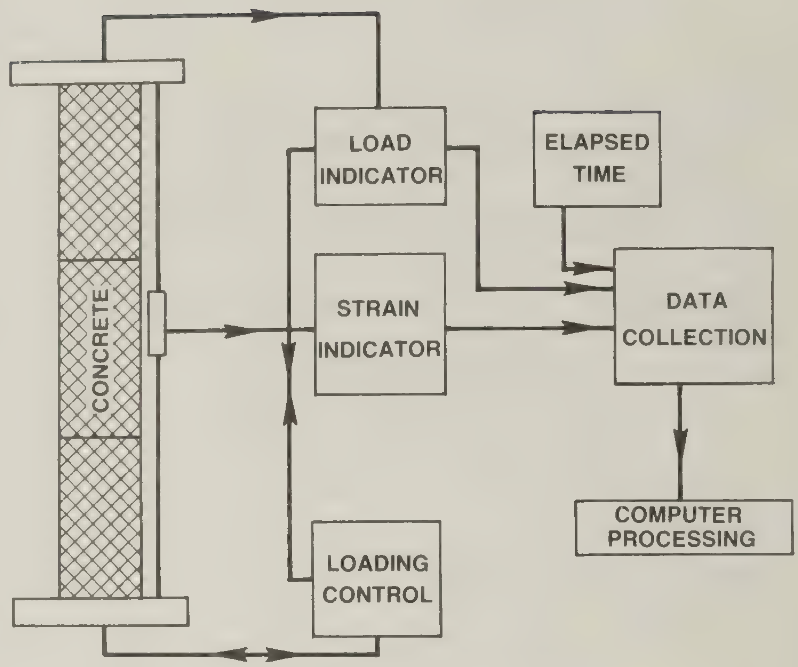



*Figure 1.—Schematic of creep measurement system.*

loading capacity permits the testing of high-strength materials by using standard 152 mm diameter cylinders; ultra-high-strength materials can be tested by using cylinders 102 mm in diameter. These loads can be maintained for several months within ±2 percent of the preset load.

Length change is measured by three linear variable differential transducers (LVDT) mounted symmetrically around each column of specimens. Adjustable rods attached to the top platen of each frame induce the movement in the LVDT cores when length change occurs, and a "U" bend is provided to prevent damage to the rods and LVDT's if a specimen fails. The bottom platen carries the LVDT's in a fixture which has a threaded collar for fine adjustment during the initial setting. The LVDT's have a full travel of 2.5 mm and an output range of 0 to 1 volt. Selector switches for each frame permit calibrating each LVDT separately and then switching to an averaging circuit that produces the voltage to be recorded.

## Design Details

### Loading frame

The base of the loading frame houses the hydraulic actuator. It also supports the two columns (102 mm outside diameter) that hold the crosshead, which is secured by locking rings fitted into machined grooves on the columns. The bottom platen rests on a truncated spherical alinement block, while the top platen is stationary and made to receive a load cell for calibration. Both platens are 203 mm in diameter.

The height of the crosshead can be adjusted by two pneumatic cylinders to eight possible positions. Finer adjustment is made by the insertion of steel spacers fitted with pins for accurate alinement. The pneumatic operating valve has three positions—RAISE, LOWER, and HOLD— and is mounted on the front panel of the housing.

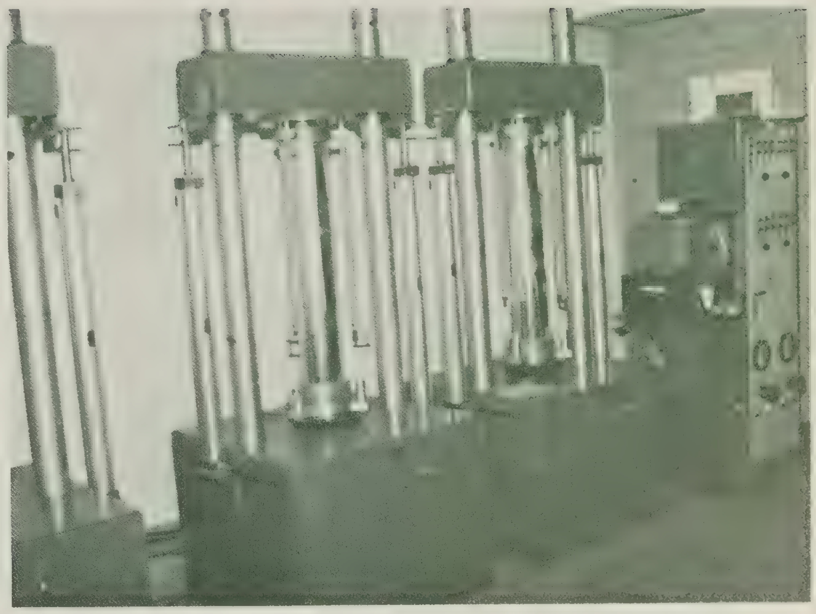
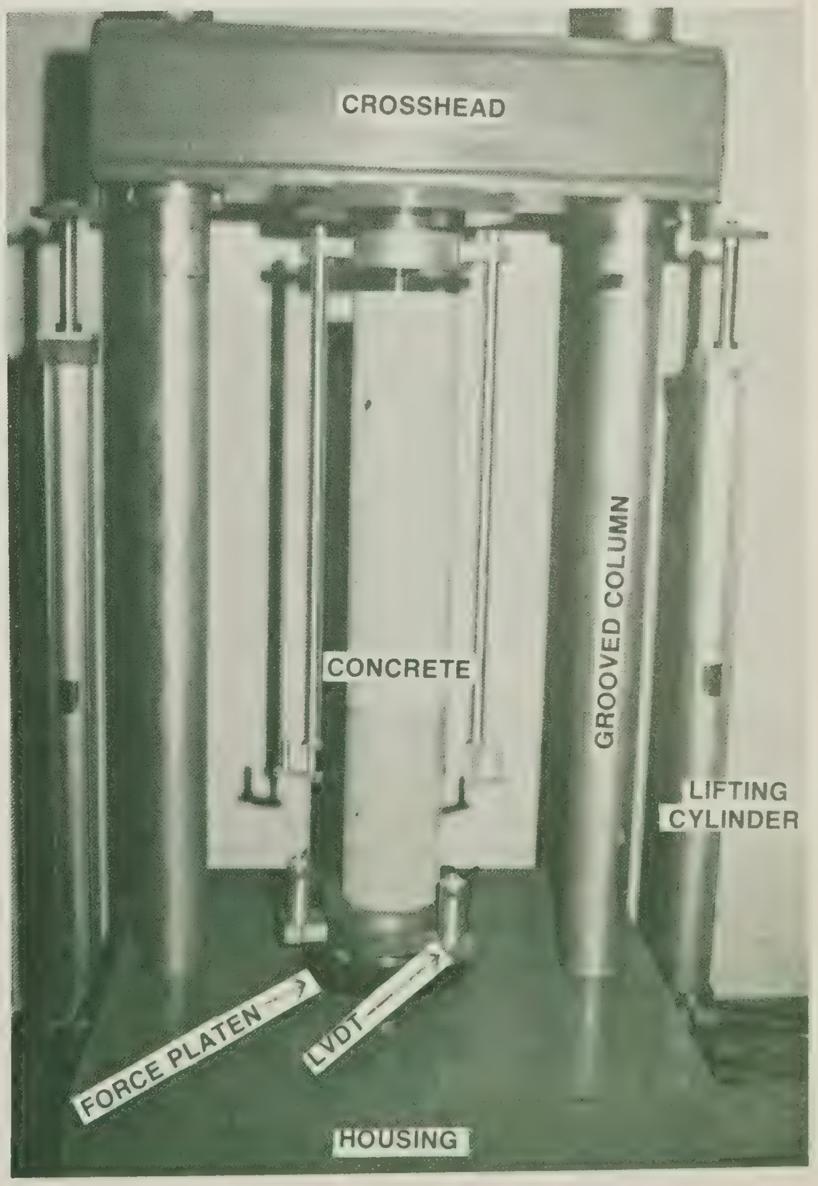


*Figure 2a.—Creep measurement system. 2b—Loading frame.*




### The pressure system

An air driven hydraulic pump pressurizes both regulators and a nitrogen-charged accumulator that eliminates large fluctuations in the system and reduces the pump's running time. The pump operates on the laboratory-compressed air supply (low capacity, 500 kPa). Located between the regulator controllers and the actuators are position valves with four settings—LOAD, UNLOAD, HOLD, and OPERATE. The operating range and sensitivity of the regulators can be varied by changing a sensor and spring assembly. A flow limiter circuit is between the regulators and actuators to prevent damage to the hydraulic system if a cylinder fails.

### The console

The console shown in figure 2 houses the major controls and hydraulic power system for supplying hydraulic pressure to the loading frames. It contains the hydraulic pump, oil sump, accumulator, air regulator, pressure controllers and gages, signal conditioners and their selector switches, two separate power supplies, and auxiliary equipment. All interconnections among the hydraulic components are through flex lines.

### Data acquisition

The data acquisition equipment is shown in figure 2. Hard copy of the data is recorded by a Digitec Data Logger, Model 1267, which has a channel selector for scanning continuously, or at 2-, 10-, 20-, and 60-minute intervals. A magnetic tape record is obtained with a Metrodata 620–B Data Logger that uses a continuous loop, 4-track tape cartridge. A tape transport console is used for retaping to 9-track reels for computer processing. To eliminate possible interference if both units are recording at the same time, an integrated circuit triggers the Metrodata after a scan by the Digitec.

Invar steel strain frames, with LVDT's and unstressed control specimens, provide simultaneous input of the "normal" volume change of the concrete under test.

Computer analyses of the magnetic tape data provide the desired creep versus time information, as well as the load variability data. This confirms that the testing specifications were met.

*Figure 3.—Regulator controllers.*

## Summary

The design and installation of an automated system for measuring creep in portland cement concrete has been completed. More accurate records of creep will now be obtained, permitting a greater variety of materials to be evaluated in a shorter time and, thereby, increasing productivity.

Additional savings of time and labor will be realized through the facility with which tests can be initiated and monitored and the benefits of automating the collection and analysis of data.

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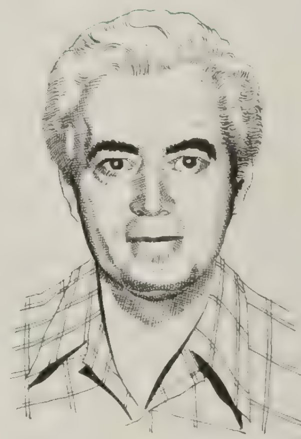


**Walter R. Jones** is a supervisory civil engineering technician in the Materials Division, Office of Research, Federal Highway Administration. Since joining FHWA in 1955, he has done work in the following areas: Conducting tests on cements, aggregates, and concretes; designing innovative equipment; devising new test procedures; and developing exotic construction materials. He also contributed to the development of noncorroding epoxy coated reinforcing steel and internally sealed (wax bead) concrete.



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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 Design and Control Division. The reports are available from the address noted at the end of each description.**

## Determination of Seismically Induced Soil Liquefaction Potential at Proposed Bridge Sites, Volume 1 (Report No. FHWA-RD-77-127) and Volume 2 (Report No. FHWA-RD-77-128)

**by FHWA Structures and Applied Mechanics Division**

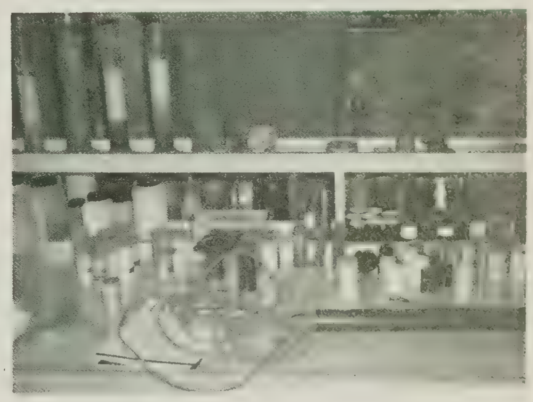
Damage to highways, bridges, and embankments from seismically induced liquefaction of loose, saturated, cohesionless soils, which under ordinary circumstances provide adequate structural support, has demonstrated the need to reduce the damage potential for both new and existing highway structures founded on these types of soils. When seismic ground motions result in soil liquefaction, shear strength is lost through excess pore pressure, and the resultant settlements may increase by at least one order of magnitude over static settlements.

Volume 1, **Theoretical Considerations,** discusses liquefaction phenomena and associated soil parameters. Field investigation and laboratory testing methods are identified for determining the geologic profiles and soil parameters used in the analytical procedures. Methods are proposed for evaluating potential bridge sites to determine design earthquake ground motion. The consequences of soil liquefaction are presented with a summary of observed bridge damage.

Volume 2, **Planning Guide for Evaluation of Liquefaction,** provides guidance to bridge designers faced with the problem of siting a bridge in an area where potentially liquefiable soils exist. The information is useful in reviewing alternative sites to minimize the possibility of liquefaction-induced damage. Computer programs available for analyzing the behavior of the soils at proposed bridge sites are discussed, as well as hand computation methods of site evaluation, assessment, and selection.

The reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 282354 and PB 282355).

## Chemical Grouts for Soils, Volume 1 (Report No. FHWA-RD-77-50) and Volume 2 (Report No. FHWA-RD-77-51)



**by FHWA Structures and Applied Mechanics Division**

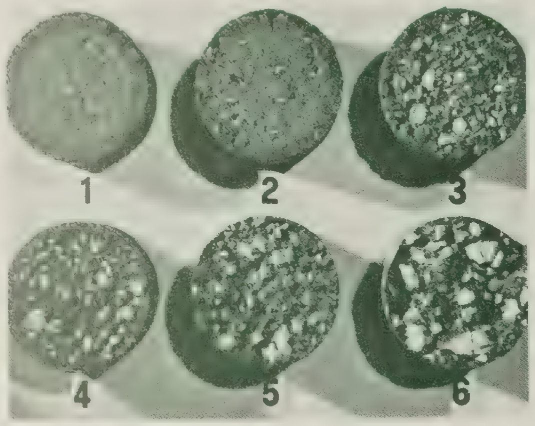
In situ chemical grouting of soils that have a maximum grain size of 1 mm has become a common procedure for the consolidation and/or waterproofing of undisturbed ground in advance of tunnel excavation in urban areas. Research has been undertaken to improve traditional grouts and to devise better performing, cheaper products. The properties and behavior of the various available chemical grouts are discussed in this two-volume report. Additional research approaches are indicated, particularly on certain chemical grouts of plant origin which would be little affected by any future [illegible] prices or decreased availability of petrochemical derivatives which are ingredients of many present-day grouts.

Volume 1. **Available Materials,** presents a thorough review of all known chemical grouts and includes a complete bibliography of more than 800 references. An improved classification of chemical grouts is proposed which is based on the nature of the primary component. All [illegible] in common use may be categorized as either solutions, [illegible] suspensions, emulsions, [illegible] reacting with the ground, or a combination of these systems. Although nearly all grouts are [illegible] of these categories, [illegible] fluid polyesters and the [illegible] polyurethanes, which [illegible] with groundwater, are advantageous in special uses. Eight grout types were studied in detail to determine the possibility of further improvement.

Volume 2. **Engineering Evaluation of Available Materials,** discusses the engineering characteristics of available grouts and defines seven physico-chemical criteria (viscosity, setting time, permeability, intrinsic strength, strength of treated ground, durability, and toxicity) to be used in their evaluation. Standard testing procedures are recommended for each criterion. The report concludes that the quality of any soil grouting operation depends on the suitability of the grout to the ground being treated, and that grouts of different viscosities suitable for a wide range of soils are readily available.

These reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 279685 and PB 279686).

### Mix Design Methods for Base and Surface Courses Using Emulsified Asphalt: A State-of-the-Art Report, Report No. FHWA-RD-78-113




**by FHWA Materials Division**

Emulsified asphalts have been used in highway construction and maintenance since the 1920's. However, the replacement of cutback asphalts with emulsified asphalts has been slow. This is partially attributed to the user agencies' unfamiliarity with asphalt emulsion properties. The use of emulsions in highway work generally has been confined to low volume roads; consequently, emulsions have not received the same engineering attention as hot asphalt mixes or cold cut-back asphalt applications.

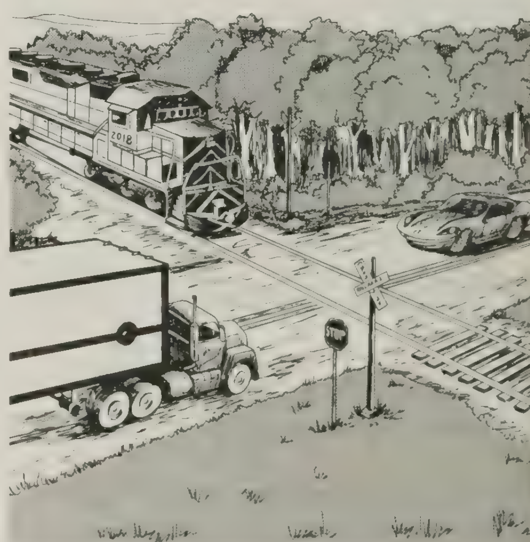
This report presents a comprehensive discussion of the state of the art of mix design methods for emulsified asphalt mixtures used for base and surface courses. A discussion of the findings and recommendations of recent research activities at four universities is also presented. The existing methods are described and analyzed in detail with the intention that a composite mixture design method can be developed for nationwide application.

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

### Safety Features of Stop Signs at Rail-Highway Grade Crossings, Volume I (Report No. FHWA-RD-78-40) and Volume II (Report No. FHWA-RD-78-41)

**by FHWA Traffic Systems Division**

These reports present the results of a study which examined the advantages and disadvantages of using standard highway stop signs with crossbucks at passive rail-highway grade crossings. A literature and crossing inventory study was performed to determine current uses. Accident analysis was performed to compare accidents for crossings with and without stop signs. Field studies were performed to compare driver behavior for crossbuck only crossings to driver behavior for similar crossings having a standard highway stop sign in addition to the crossbuck.

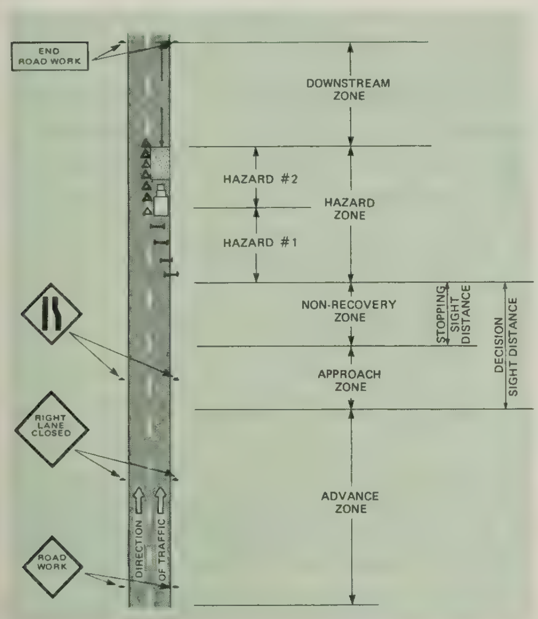


Volume I, **Executive Summary,** gives the results of the study and presents suggested guidelines.

Volume II, **Technical Report,** is the detailed analysis of the study.

A limited number of copies of the reports are available from the Traffic Systems Division, HRS-33, Federal Highway Administration, Washington, D.C. 20590.

### Visibility Requirements of Work Zone Traffic Control Devices, Report No. FHWA-RD-78-143




**by FHWA Traffic Systems Division**

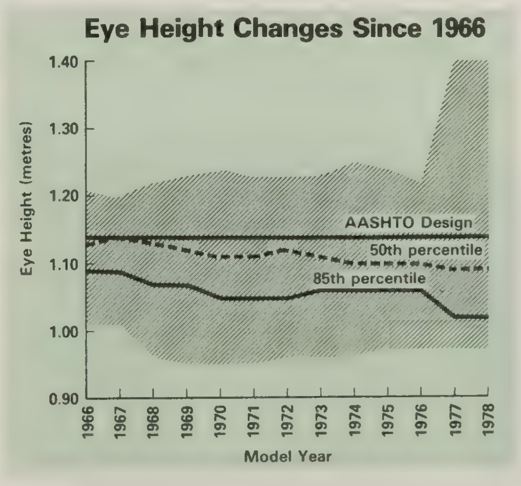
Channelizing devices such as barricades, panels, cones, and drums are important for warning and guiding traffic in work zones. It is essential that they be installed and maintained to be visible to approaching traffic. This report defines the distances at which channelizing devices should be visible to enable motorists to respond in a safe and efficient manner. The visibility distance requirements were established from the principles of driver information needs and, specifically, the concept of decision sight distance. The visibility requirements vary according to traffic speed and environment.

A limited number of copies of the report are available from the Traffic Systems Division, HRS-33, Federal Highway Administration, Washington, D.C. 20590.

### Determination of Motor Vehicle Eye Height for Highway Design, Report No. FHWA-RD-78-66

**by FHWA Environmental Design and Control Division**

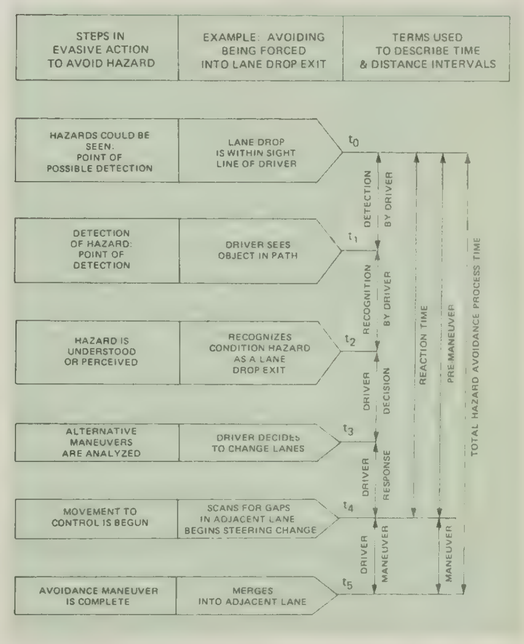
A study was made to determine the current eye height distribution for passenger cars and the eye height and field of vision for trucks. This was accomplished by a comprehensive literature review of eye height studies, a field study of eye height distribution for the most popular makes of passenger cars, a field study on the field of vision of truck drivers, and interviews with representatives from the major American motor vehicle manufacturers.




The study found that there has been a slight decrease in eye height for passenger cars during the last 15 years. The study further revealed that there were no significant differences between the eye height distribution of passenger vehicles as stated in the literature and that used in the pilot study. This report recommends that an eye height of 1.05 m be used for highway design.

A limited number of copies of the report are available from the Environmental Design and Control Division, HRS-41, Federal Highway Administration, Washington, D.C. 20590.

### Decision Sight Distance for Highway Design and Traffic Control Requirements, Report No. FHWA-RD-78-78




**by FHWA Environmental Design and Control Division**

Current guidelines of the American Association of State Highway and Transportation Officials (AASHTO) establish three types of sight distance—stopping, passing, and intersection. These sight distances do not provide for situations with high decision complexity that may be found at urban, suburban, and rural locations such as intersections and freeway interchanges. To accommodate such situations, the concept of decision sight distance (DSD) was developed. DSD is based on the driver's ability to detect a [illegible] or signal in the complex highway environment, recognize its hazard or threat potential, select the appropriate speed and path, and perform the required action safely and efficiently.

This report describes the synthesis, critical evaluation, and field validation of DSD values and concludes that the DSD values are operational and valid. Recommendations made for DSD values differ from the AASHTO sight distance values; this research found that perception-reaction times varied from [illegible] to 10.0 seconds, instead of [illegible] seconds cited in AASHTO [illegible].

A limited number of copies of the report are available from the Environmental Design and Control Division, HRS-41, Federal Highway Administration, Washington, D.C. 20590.

### Urban Intersection Improvements for Pedestrian Safety, Vols. I–V (Report No. FHWA-RD-77-142/146)

**by FHWA Environmental Design and Control Division**

This study was designed to identify problems associated with pedestrian-vehicle interactions at [illegible], develop [illegible] concepts that would [illegible] these problems, and evaluate the effectiveness of pedestrian accident countermeasures. The study also evaluated alternatives to full signalization at pedestrian crossings.

Volume I, **Executive Summary,** reports on the three phases of the study. Phase I, reported in Volume II, **Identification of Safety and Operational Problems,** identified and defined the problems of vehicles and pedestrians at intersections. Phase II was divided into two tasks. Task A, reported in Volume III, **Signal Timing for the Pedestrian,** made recommendations for improving the timing of pedestrian signals to maximize safety and minimize delay. Task B, reported in Volume IV, **Pedestrian Signal Displays and Operation,** evaluated the use of word and symbol messages. Phase III of the study, reported in Volume V, **Evaluation of Alternatives to Full Signalization at Pedestrian Crossings,** evaluated traffic control devices at the intersection of an arterial street and a low-volume residential street where adequate gaps in the traffic stream do not exist to allow pedestrians to cross the arterial street safely.

A limited number of copies of the reports are available from the Environmental Design and Control Division, HRS-41, Federal Highway Administration, Washington, D.C. 20590.

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

**The following are brief descriptions of selected items which 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.**

## Direct Substitution of Sulfur for Asphalt in Paving Materials, Report No. RI-8303

**by U.S. Bureau of Mines and FHWA Implementation Division**

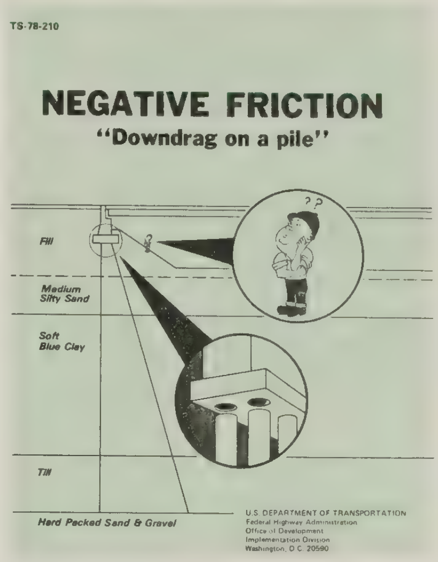

Because of forecasts of sulfur oversupply and asphalt shortages, research is being conducted on potentially large-scale uses of sulfur to extend asphalt binders in pavement construction. Sulfur-extended asphalt (SEA) binders have been developed in which sulfur replaces up to one-third of the asphalt normally present in conventional binders for flexible pavements. Mixing and construction procedures and equipment used with these binders are virtually the same as those used with asphalt binders. This report describes the physical properties of the mix and design methods used for one project on which SEA binders were formulated directly in pugmill. Monitoring for toxic gases during laboratory and commercial mixing and paving operations also is discussed.

The report is available from the U.S. Bureau of Mines, Publication Distribution, 4800 Forbes Avenue, Pittsburgh, Pa. 15213, and the Implementation Division.

## Negative Friction "Downdrag on a Pile" (Report No. FHWA-TS-78-210) and Two Videotapes

**by FHWA Implementation Division**

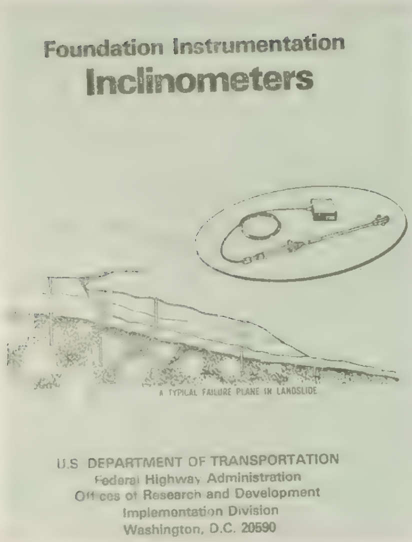
The settlement of soil surrounding pile foundations causes negative friction to develop between soil and pile. If not considered in the design, the resulting downdrag force can cause excessive pile settlement or other serious pile distress which can result in unsatisfactory structure performance (that is, settlement of bridge abutments and piers). Procedures for estimating the magnitude of pile downdrag and methods of reducing the problem have been developed.




The videotape presentations summarize both the research and the results of a symposium conducted in conjunction with the research. The philosophy of the prediction technique is described, and the mechanics of negative friction and the method of analysis and correction are discussed.

The reference manual consists of a series of graphics and narratives of points made in the videotapes and includes an appendix of the design manual on negative skin friction analysis.

The manual is available from the Implementation Division. The videotapes are available from FHWA regional offices (see page 30) and the National Highway Institute.




### Foundation Instrumentation, Inclinometer Reference Manual (Report No. FHWA-TS-77-219) and Videotape

**by FHWA Implementation Division**

The inclinometer is an instrument for monitoring the lateral deformation of embankments and structures during construction. This instrument also is a useful device for analyzing and understanding landslide movements.

The reference manual and videotape acquaint highway engineers with the application of the inclinometer to situations where lateral deformations must be controlled such as slope and embankment constructions and sheet piling. The development of the instrument and its installation are described; interpretation of the field data is provided.

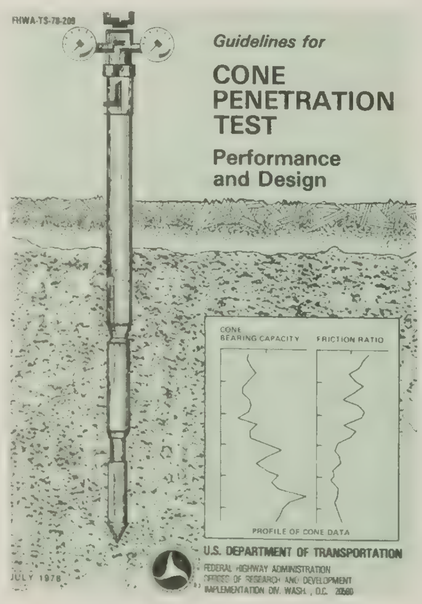
The text and videotape are excellent training material for personnel unfamiliar with the inclinometer concept. Engineers experienced with inclinometers will find it valuable as a reference text.

The manual is available from the Implementation Division. The videotape is available from FHWA regional offices (see page 30) and the National Highway Institute.

### Guidelines for Cone Penetration Test, Performance and Design (Report No. FHWA-TS-77-209) and Three Videotapes

**by FHWA Implementation Division**

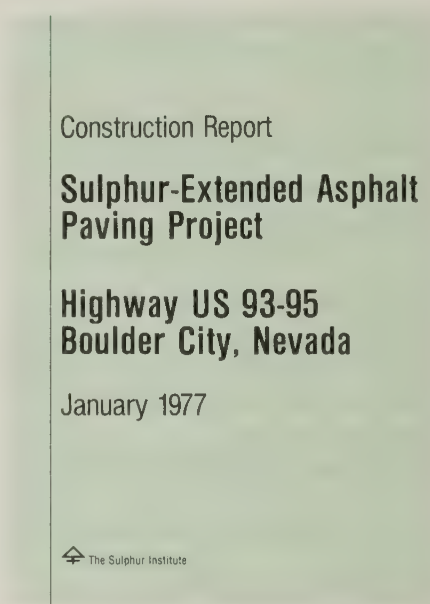
The Dutch Cone Penetrometer is a device which can be an effective tool in a soils exploration program. It can be used to determine in situ soil shear strength and pile design parameters. This device has been used in Europe for several years to obtain subsurface information but has only recently been introduced in the United States. The results are used by designers to more accurately design foundation support needed for roadways and bridges. The reference manual and videotapes describe the instrumentation and field methods for using the Dutch Cone.




The manual is available from the Implementation Division. The videotapes are available from FHWA regional offices (see page 30) and the National Highway Institute.

### Sulphur-Extended Asphalt Paving Project, Boulder City, Nevada

**by The Sulphur Institute and FHWA Implementation Division**

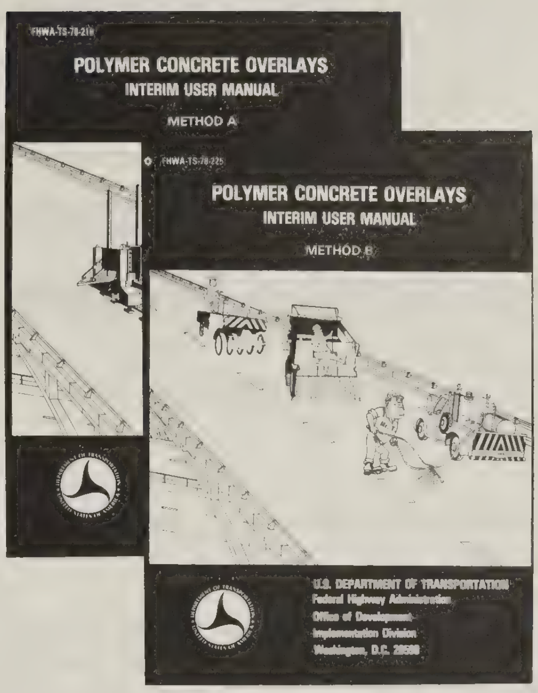



In January 1977, the Nevada Highway Department constructed highway test sections in which conventional asphalt binders were replaced by sulphur-extended asphalt (SEA) binders. In the test sections, SEA binders were used in a base course, a surface course, and a full-depth section. The sulphur/asphalt binder rates were about 26/74 by weight.

Previous trials with SEA in Texas, Canada, and Europe have used high-shear mixing equipment to blend sulphur and asphalt prior to mixing the binder with the aggregate. The trial in Nevada demonstrated a simplified SEA technology, where the sulphur and asphalt were not premixed but were added directly to the aggregate in the pugmill, which was used as the primary mixing device.

Preparation and placement of the SEA pavement sections were accomplished without problems. Quality control carried out during the construction indicated that the characteristics of the paving material were satisfactory. The test sections have been subject to heavy traffic; performance has been excellent. Laboratory and previous road tests indicate that SEA may outperform conventional asphalt. In addition, SEA may have economic advantages. Sulphur is less expensive than asphalt in many areas, and this situation is expected to become more prevalent.

The report is available from The Sulphur Institute, 1725 K Street, NW., Washington, D.C. 20006, and the Implementation Division.




**Polymer Concrete Overlays, Interim User Manual, Method A (Report No. FHWA–TS–78–218) and Method B (Report No. FHWA–TS–78–225)**

**by FHWA Implementation Division**

Two methods for placing polymer concrete (PC) for overlays on bridge decks have been developed—one by Brookhaven National Laboratory (BNL) and one by Oregon State Highway Division (OSHD). These manuals provide sufficient information for the formulation and placement of PC overlays.

Method A describes the OSHD technique, which can be applied similar to a latex-modified or low-slump concrete overlay system used for deck rehabilitation. The monomer and aggregate are mixed together, and the mix is placed with a paving machine.

Method B describes the BNL technique, which is similar in placement to a multiple bituminous surface treatment. The overlay consists of an application of a medium viscosity organic liquid to the bridge deck, followed by an application of aggregate. The aggregate is compacted into the monomer, and the layer polymerizes or hardens to form a thin layer of PC. The process is repeated until four layers are placed. Test results and limited field experience have shown the overlay to be impermeable to water and chloride penetration. The technique also shows potential as a means of restoring the skid resistance of a polished deck.

Field trials indicate that both overlay methods are suitable for experimental use by highway agency maintenance forces.

The manuals are available from the Implementation Division.

# International Symposium on Traffic Control Systems

The International Symposium on Traffic Control Systems will be held August 6–9, 1979, at the University of California, Berkeley, Calif. This symposium is sponsored by the Federal Highway Administration, Institute of Transportation Engineers, Institute of Transportation Studies of the University of California, National Electrical Manufacturers Association, Organization for Economic Cooperation and Development, Texas Transportation Institute, and Transportation Research Board.

The symposium will focus on the latest developments in the field of traffic control systems and will provide a forum for interaction between researchers and users from all over the world. The morning plenary sessions are designed to provide the opportunity for persons representing all branches of traffic control technology to meet in joint sessions and obtain an overview. In the afternoons, the technical presentations will break into four concurrent sessions to permit symposium participants to hear presentations and discussion in more narrow fields of technical interest.

There is no registration fee for the symposium. The following is a tentative program for the symposium.

**Monday a.m., Aug. 6, 1979**

Registration

**Monday p.m., Aug. 6, 1979**

Moderator:
William L. Garrison
University of California

Keynote Speakers:
John J. Fearnsides
Deputy Under Secretary
U.S. Department of Transportation

Wilhelm Leutzbach
Institute for Traffic Systems
Karlsruhe, Federal Republic of Germany

**Tuesday a.m., Aug. 7, 1979**

**Plenary Session #1**
Moderator:
William W. Wolman
Federal Highway Administration

Resource Papers:
"Concepts and Strategies for Urban Street Control Systems," by Phil Tarnoff, AMV & Associates, Inc.
"Traffic Control Systems Hardware," by Art Cimento, Sperry Systems Management
"Static Displays," by Robert Dewar, University of Calgary, Canada
"Measures of Effectiveness," by Jack Kay, JHK and Associates

**Tuesday p.m., Aug. 7, 1979**

**Technical Session #1**—Concepts and Strategies—Urban Street Control Systems

Topics: Control policies to maximize capacity in an urban road network, intersection capacity and signal timing calculation methods, traffic responsive control, computer control algorithms, and bus preemption at traffic lights.

Speakers will be representatives from Australia, England, France, Japan, and the United States.

**Technical Session #2**—Traffic Control Systems Hardware

Topics: Distributed route guidance systems, coordinated adaptive traffic control systems, surveillance and control systems, cableless systems, and online vehicle classification.

Speakers will be representatives from Australia, the Netherlands, and the United States.

**Technical Session #3**—Static Displays

Topics: Metric signs, guide signs, low-volume intersection control, and driver informational requirements.

Speakers will be representatives from France, the Netherlands, and the United States.

**Technical Session #4**—Measures of Effectiveness

Topics: Measures of effectiveness for urban traffic management, quality of flow and capacity of urban arterials, surveillance and control system measures of effectiveness, and environmental protection aspects of freeway traffic control systems.

Speakers will be representatives from Belgium, Germany, and the United States.

**Evening Session**—Special Program on the Automobile and Traffic Control—A Look to the Future
Speakers will be representatives from U.S. and foreign automobile manufacturers.

**Wednesday a.m., Aug. 8, 1979**

**Plenary Session #2**
Moderator:
David Witheford
Transportation Research Board

Resource Papers:
"Special Control Topics," by Doug Robertson, Federal Highway Administration
"Driver Information and Motorist Aid Hardware," by Frank Mammano, Federal Highway Administration
"Warning Displays," by Slade Hulbert, Consultant
"Traffic Simulation Models," by Ed Lieberman, KLD & Associates, Inc.

**Wednesday p.m., Aug. 8, 1979**

**Technical Session #5**—Special Control Topics

Topics: Residential neighborhood traffic control, traffic control devices in work zones, planning and scheduling of work zone traffic control, and establishment of safe passing zones.

Speakers will be representatives from the United States.

**Technical Session #6**—Driver Information and Motorist Aid Hardware

Topics: In-vehicle information systems, changeable traffic signs, highway advisory radio, and citizen band radio for motorist aid.

Speakers will be representatives from Germany, Japan, and the United States.

**Technical Session #7**—Warning Displays

Topics: Fog warning signs, advanced warning signs at railroad grade crossings, regulatory school flashers, and speed control signs in rural school zones and small communities.

Speakers will be representatives from the United States.

**Technical Session #8**—Traffic Simulation Models

Topics: Iterative simulation and assignment model, microscopic model for rural road networks, assessment of integrated traffic control systems through simulation, and simulation model for signalized intersections.

Speakers will be representatives from England, Germany, Norway, and Sweden.

**Thursday a.m., Aug. 9, 1979**

**Plenary Session #3**
Moderator:
Charles Pinnell
Texas Transportation Institute

Resource Papers:
"Freeway/Corridor Systems," by Don Capelle, AMV & Associates, Inc.
"Advanced Systems Hardware," by Robert Fenton, Ohio State University
"Dynamic Displays," by Conrad Dudek, Texas Transportation Institute
"Strategy Optimization and Analytical Models," by Dennis Robertson, Road Research Laboratory, England

**Thursday p.m., Aug. 9, 1979**

**Technical Session #9**—Freeway/Corridor Systems

Topics: Evaluation of freeway traffic control systems, control of freeway speeds, freeway ramp control during congested conditions, and automatic incident detection.

Speakers will be representatives from France, Germany, and the Netherlands.

**Technical Session #10**—Advanced Systems Hardware

Topics: Wide area detection system, hardware aspects of driver's guidance and information system, automatic vehicle identification, and automatic vehicle monitoring.

Final speaker arrangements not finalized.

**Technical Session #11**—Dynamic Displays

Topics: Rural motorist information and diversion system, real time traffic condition information, strategy and application of traffic guidance and information systems, and changeable message signs.

Final speaker arrangements not finalized. Speakers will be representatives from Germany, Italy, and the United States.

**Technical Session #12**—Strategy Optimization and Analytic Models

Topics: Design and evaluation of traffic control schemes, scope and limitations of analytical models, dynamic traffic assignment model, and analysis of route choice and traffic control in central urban areas.

Speakers will be representatives from England and Japan.

For information on lodging for the symposium or for a final program, contact William Garrison, Director, Institute of Transportation Studies, University of California, 109 McLaughlin Hall, Berkeley, Calif. 94720, (415) 642-3585.

# Instructions to Authors

[illegible] icles proposed for publication [illegible] Roads magazine are [illegible] suitability by the [illegible] editors. Authors will be [illegible] acceptance or rejection as [illegible] ssible.

[illegible] issues of the magazine should [illegible] ved for type of articles, [illegible] illustrations, tables, [illegible] eferences, and footnotes. *Public* [illegible] *ads* [illegible] ollows the U.S. Government [illegible] rinting Office Style Manual.

## [illegible] mission of Manuscripts

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[illegible] thors outside the Federal [illegible] overnment, or in State, city, or [illegible] vernment agencies, should [illegible] wo copies of the manuscript [illegible] appropriate Federal Highway [illegible] nistration regional offices (see page 30).

## [illegible] anuscript Treatment

Manuscripts should be typewritten, double spaced, with at least 1-inch margins on 8½ by 11-inch paper. Excluding art, 1 magazine page requires about 3 pages of manuscript. End each page with a completed paragraph. Type main headings flush left in initial caps. Subheadings should be flush left, and the first letter only capitalized. The article title and the name of each author should be typed on a separate page. If the article has been presented at a meeting, that should be indicated in a footnote at the bottom of the title page. Each page of the text should be numbered in the upper right margin. Because the Federal Government does not endorse products of manufacturers, avoid trademarks and brand names in articles unless their use is directly required by the objectives of the article.

## Biography

A brief biography should be supplied. This should include the author's present position and responsibilities and previous positions relevant to the subject matter of the article. Biographies are limited to approximately 100 words. Biographies are accompanied by sketches of the authors drawn from photographs. Send a photograph of each author to the editor when the author is notified that the article has been accepted for publication.

## Abstract

An abstract should be supplied with technical articles. For a *development paper,* the abstract should tell: (1) What has been accomplished, (2) its outstanding features, and (3) its applications, if known. The abstract of a *research paper* should focus on: (1) What has been accomplished, (2) its most important facts and implications, and (3) logical steps open to study.

## Tables

Nonessential technical tables should not be included in the article. Each table should be typed on a separate page. It should be identified by an Arabic number and a caption. Note the location of the table in the text in the margin, but avoid putting it on the first page. Details of data already presented in tables or charts should not be repeated in the text.

## Illustrations

Illustrations *referenced in the text* are called figures, and numbers and captions should be assigned to each. Organize the text so that illustrations can be scattered throughout the article. Avoid referencing several illustrations in one page, to prevent problems in the layout. Black and white glossy photographs of good quality are preferred; however, color photographs and art are acceptable. Send original artwork to the editor when the author is notified that the article has been accepted for publication. Send legible copies with the manuscript. All captions (numbered and unnumbered) should be typed underlined on a separate page.

## Metrication

**Under present law and FHWA regulation, *Public Roads* is required to express measurements in metric (SI) units in the text and in tables and illustrations. English units will not be used.**

## References

Number references consecutively in the body of the text, enclosed in parentheses and underlined. Copyrighted material referenced and quoted will require copyright releases. Unpublished material referenced in the text will be described in a footnote. Type citations on a separate page under the heading REFERENCES. Number citations in the same manner as in the text and list in the same sequence.

## Galley Proofs

Galley proofs will be sent to authors for their inspection.

For further information, contact the editor: (703) 557-4304.

# 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 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 1A: Traffic Engineering Improvements for Safety

Title: Criteria for Removing Traffic Signals. (FCP No. 31A1854)
**Objective:** Obtain information from 30 political entities who have removed traffic signals. Develop criteria to justify traffic signal removal. Propose a procedure for removing traffic signals. Test both the criteria and procedure.
**Performing Organization:** JHK and Associates, Alexandria, Va. 22304
**Expected Completion Date:** March 1980
**Estimated Cost:** $82,000 (FHWA Administrative Contract)

### FCP Project 1T: Advanced Vehicle Protection Systems

Title: Assessment of Vehicle Bumper-Guardrail Interaction—Phase II. (FCP No. 31T4072)
**Objective:** Implement a detailed full-scale validation testing plan for program "Guard" limited to testing railing type protective roadside systems, their transitions, and end designs.
**Performing Organization:** Texas A&M Research Foundation, College Station, Tex. 77843
**Expected Completion Date:** March 1980
**Estimated Cost:** $77,000 (FHWA Administrative Contract)

## FCP Category 2—Reduction of Traffic Congestion, and Improved Operational Efficiency

### FCP Project 2L: Detection and Communications for Traffic Systems

Title: Analysis of Feasibility and Design Configuration for In-Vehicle Route Guidance. (FCP No. 32L3043)
**Objective:** Examine the feasibility of developing a route guidance system, and produce a recommendation for a preferred system together with preliminary design drawings.
**Performing Organization:** Sperry Rand Corporation, Great Neck, N.Y. 11020
**Expected Completion Date:** December 1979
**Estimated Cost:** $248,000 (FHWA Administrative Contract)

### FCP Project 2M: Arterial Flow and Control

Title: Development of an Arterial Analysis Package. (FCP No. 32M2012)
**Objective:** Assemble a series of currently existing computer programs into a single package that will be able to analyze the operation of arterial facilities and determine optimal control measures. Develop graphical capabilities and perform both simulation and field tests.
**Performing Organization:** University of Florida, Gainesville, Fla. 32611
**Expected Completion Date:** December 1979
**Estimated Cost:** $173,000 (FHWA Administrative Contract)

### FCP Project 2N: Improved Traffic Signing and Motorist Information Systems

Title: Call-In Systems for Motorist Navigation Information. (FCP No. 32N1023)
**Objective:** Determine the feasibility of a computer-controlled voice response system for motorist navigation information.
**Performing Organization:** I/O Computer Services, Cambridge, Mass. 02138
**Expected Completion Date:** March 1980
**Estimated Cost:** $202,000 (FHWA Administrative Contract)

## FCP Category 3—Environmental Considerations in Highway Design, Location, Construction, and Operation

### FCP Project 3F: Pollution Reduction and Environmental Enhancement

Title: A Probabilistic Approach for the Near-Roadway Impact of Nitrogen Dioxide. (FCP No. 33F3512)
**Objective:** Develop an approach and algorithm for estimating the probability that a given highway facility will violate a given 1-hour national ambient air quality standard for nitrogen dioxide.
**Performing Organization:** University of Virginia, Charlottesville, Va. 22901
**Expected Completion Date:** July 1980
**Estimated Cost:** $100,000 (FHWA Administrative Contract)

## FCP Category 4—Improved Materials Utilization and Durability

### FCP Project 4B: Eliminate Premature Deterioration of Portland Cement Concrete

**Title: Bridge Deck Patching. (FCP No. 44B2352)**
**Objective:** Investigate bridge deck patching materials and methods for the purpose of establishing standards and specifications. Perform both laboratory tests and field evaluations. Address the need to match material type and method with weather conditions and time constraints.
**Performing Organization:** New Jersey Department of Transportation, Trenton, N.J. 08625
**Expected Completion Date:** August 1980
**Estimated Cost:** $69,000 (HP&R)

### FCP Project 4C: Use of Waste as Material for Highways

**Title: Fly Ash Experimental Projects. (FCP No. 44C2222)**
**Objective:** Determine the optimum use of fly ash in stabilized subgrades and as a cement replacer in portland cement concrete pavements and in structural concrete.
**Performing Organization:** Texas Transportation Institute, College Station, Tex. 77843
**Funding Agency:** Texas State Department of Highways and Public Transportation
**Expected Completion Date:** August 1981
**Estimated Cost:** $190,000 (HP&R)

**Title: Design and Characterization of Recycled Pavement Mixtures. (FCP No. 44C4193)**
**Objective:** Develop mixture design procedures for recycled asphalt, granular, and concrete pavement materials. Determine engineering properties of laboratory prepared and field core recycled materials.
**Performing Organization:** University of Texas, Austin, Tex. 78701
**Funding Agency:** Texas State Department of Highways and Public Transportation
**Expected Completion Date:** August 1981
**Estimated Cost:** $160,000 (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: Deflection Criteria for Wind Induced Vibrations in Cantilever Highway Sign Structures. (FCP No. 45A1092)**
**Objective:** Establish design criteria for cantilever highway sign structures which exceed 12.2 m. Conduct analytical, model, field, and wind tunnel studies.
**Performing Organization:** North Carolina State University, Raleigh, N.C. 27650
**Funding Agency:** North Carolina Department of Transportation
**Expected Completion Date:** May 1980
**Estimated Cost:** $63,000 (HP&R)

### FCP Project 5B: Tunneling Technology for Future Highways

**Title: Groundwater Control in Tunneling. (FCP No. 35B1112)**
**Objective:** Develop state-of-the-art reports on groundwater systems for use during construction of cut-and-cover, soft ground, and hard rock tunnels in urban areas; control systems to prevent intrusion of groundwater into completed tunnels; and remedial measures to control and prevent leakage into existing tunnels. Recommend guidelines for selection of control systems. Develop concepts for improving control technology and recommend research.
**Performing Organization:** Goldberg, Zoino, Dunniclif, Newton Upper Falls, Mass. 02164
**Expected Completion Date:** May 1980
**Estimated Cost:** $184,000 (FHWA Administrative Contract)

**Title: Slurry Walls as an Integral Part of Underground Transportation Structures. (FCP No. 35B1342)**
**Objective:** Determine advantages of using slurry walls as a permanent part of underground transportation structures. Identify site conditions suitable for slurry walls, establish design concepts, and assess physical dimensions and limitations which will offset mobilization cost of equipment and instruments for slurry wall construction.
**Performing Organization:** Chi Associates, Inc., Arlington, Va. 22209
**Expected Completion Date:** December 1979
**Estimated Cost:** $105,000 (FHWA Administrative Contract)

### FCP Project 5C: New Methodology for Flexible Pavement Design

**Title: Soil Support Values for Michigan Highway Soils. (FCP No. 45C2423)**
**Objective:** Establish relationships between the material characteristics of cohesive soils and the soil support value scale using the repeated load triaxial tests under different conditions and establish a limiting stress and/or strain criteria that could be used in different design methods.
**Performing Organization:** Michigan State University, Lansing, Mich. 48904
**Funding Agency:** Michigan Department of State Highways and Transportation
**Expected Completion Date:** August 1980
**Estimated Cost:** $67,000 (HP&R)

### FCP Project 5D: Structural Rehabilitation of Pavement Systems

**Title: Evaluation of Rigid Pavement Overlay Design Procedures. (FCP No. 35D2232)**
**Objective:** Evaluate currently available rigid pavement overlay design methods and submit findings to a panel to establish "standard" method of overlay design based on analysis of submitted findings. Design a simplified procedure by which other designs can be judged against the "standard" method.

**Performing Organization:** Resource International, Worthington, Ohio 43085
**Expected Completion Date:** February 1980
**Estimated Cost:** $99,000 (FHWA Administrative Contract)

**Title: Pavement Rehabilitation by Means Other Than Overlay—Second Phase. (FCP No. 35D2522)**
**Objective:** Further develop and evaluate design techniques and construction procedures for the restoration of the quality of deteriorated rigid pavements without resorting to overlays.
**Performing Organization:** Delon Hampton and Associates, Silver Spring, Md. 20910
**Expected Completion Date:** October 1981
**Estimated Cost:** $250,000 (FHWA Administrative Contract)

**Title: Laboratory Evaluation of Asphaltic Concrete Reflection Crack Retarders. (FCP No. 45D3312)**
**Objective:** Develop a laboratory procedure for evaluating the effectiveness of fabrics for retarding the development of reflective cracks in asphaltic concrete overlays.
**Performing Organization:** California Department of Transportation, Sacramento, Calif. 95805
**Expected Completion Date:** July 1981
**Estimated Cost:** $99,000 (HP&R)

**Title: Evaluation of Condition of Longitudinal Steel in CRC Pavements in Illinois. (FCP No. 45E2122)**
**Objective:** Determine the extent of steel corrosion at the transverse cracks and corresponding effect on serviceability of CRC pavements in Illinois. Study the relationship between crack width and corrosion condition of longitudinal steel at transverse cracks.
**Performing Organization:** Illinois Department of Transportation, Springfield, Ill. 62764
**Expected Completion Date:** January 1981
**Estimated Cost:** $92,000 (HP&R)

### FCP Project 5K: New Bridge Design Concepts

**Title: Application of Transverse Prestressing for Bridge Decks. (FCP No. 35K3012)**
**Objective:** Develop and evaluate concepts for using transverse prestressing for bridge decks.
**Performing Organization:** Byrd, Tallamy, MacDonald, Falls Church, Va. 22042
**Expected Completion Date:** December 1979
**Estimated Cost:** $75,000 (FHWA Administrative Contract)

### FCP Project 5L: Safe Life Design for Bridges

**Title: Relation of Toughness Test Values to Fatigue Cracking in Bridges. (FCP No. 45L1012)**
**Objective:** Determine the relative effectiveness of several tests in determining the susceptibility of A-36 bridge steel to fatigue cracking, and correlate crack growth test data with field observations of crack growth rates in a full-scale bridge.
**Performing Organization:** University of Missouri, Columbia, Mo. 65201
**Funding Agency:** Missouri State Highway Department
**Expected Completion Date:** December 1979
**Estimated Cost:** $65,000 (HP&R)

**Title: Guidelines for Investigation and Rehabilitation of Localized Failures in Bridge Structures. (FCP No. 35L4031)**
**Objective:** Document postmortem investigations and failure analysis of past failures in Europe and the United States showing conclusions and retrofitting techniques, and recommend preventive measures in a format suitable for use in a design guide handbook.
**Performing Organization:** Lehigh University, Bethlehem, Pa. 18015
**Expected Completion Date:** December 1979
**Estimated Cost:** $53,000 (FHWA Administrative Contract)

## FCP Category 9—Research and Development Management and Coordination

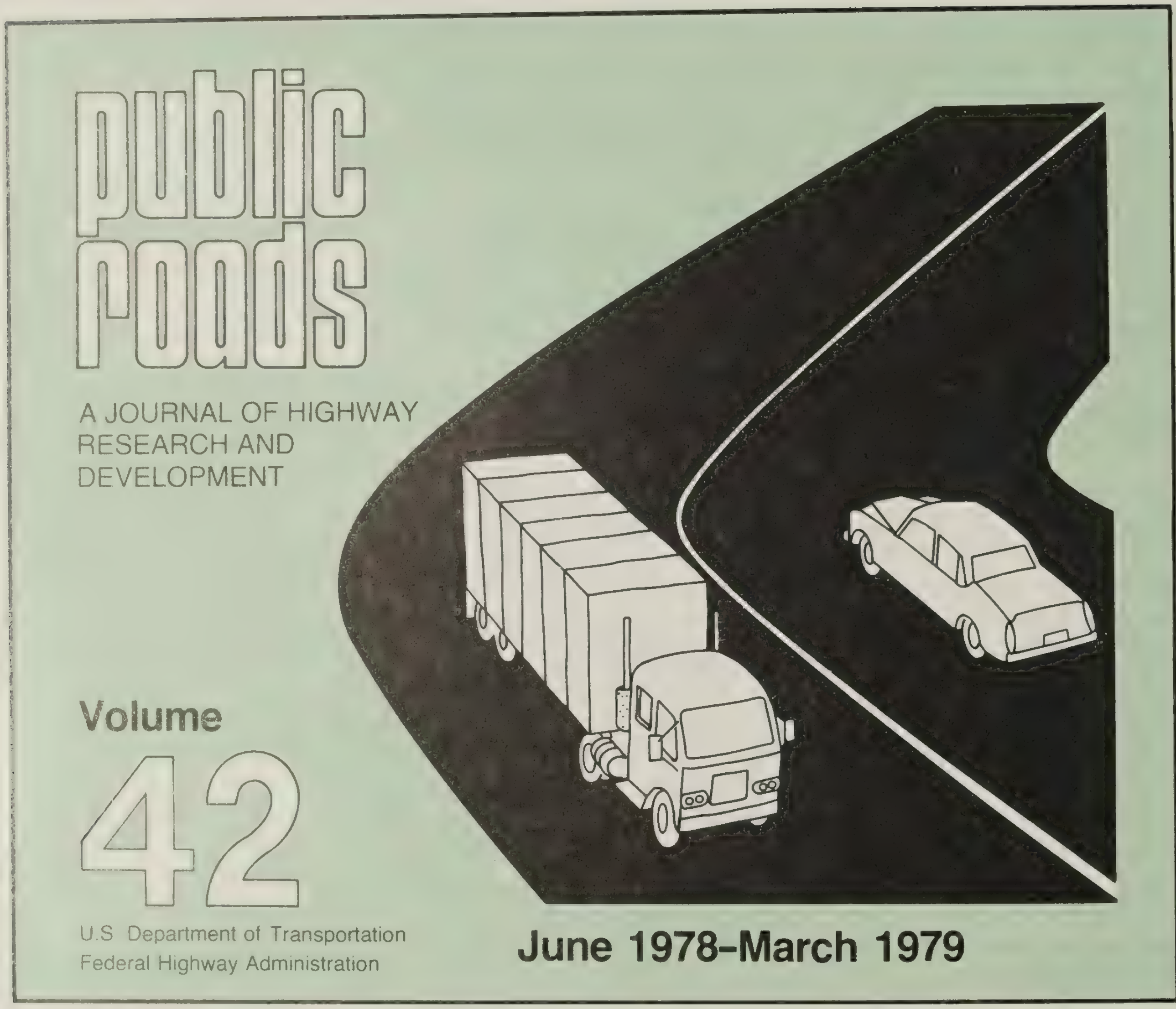
### FCP Project 9B: New Concepts Development and Systems Characterization

**Title: Noncontact Road Profiling System. (FCP No. 39B2014)**
**Objective:** Design and assemble an expandable noncontact road roughness profiling system at highway speeds, based on the acoustic probe profiling system being furnished by FHWA.
**Performing Organization:** Ensco, Springfield, Va. 22151
**Expected Completion Date:** December 1979
**Estimated Cost:** $81,000 (FHWA Administrative Contract)

## FCP Category 0—Other New Studies

**Title: Moisture Effects on Asphalt Texture. (FCP No. 40M3512)**
**Objective:** Develop terminology descriptive of adverse moisture effects on asphalt mixtures. Survey the nature and extent of the moisture damage problem in Texas. Collate basic research findings aimed at adverse moisture effects in pavements. Evaluate techniques for early detection of mixtures susceptible to moisture problems. Apply existing tests, modified tests, and developed tests in field trials.
**Performing Organization:** University of Texas, Austin, Tex. 78701
**Funding Agency:** Texas State Department of Highways and Public Transportation
**Expected Completion Date:** August 1981
**Estimated Cost:** $131,000 (HP&R)

# TITLE SHEET, VOLUME 42




The title sheet for volume 42, June 1978–March 1979, of Public Roads, A Journal of Highway Research and Development, is now available. This sheet contains a chronological list of article titles and an alphabetical list of authors' names. Copies of this title sheet can be obtained by sending a request to the editor of the magazine, U.S. Department of Transportation, Federal Highway Administration, HDV-14, Washington, D.C. 20590.

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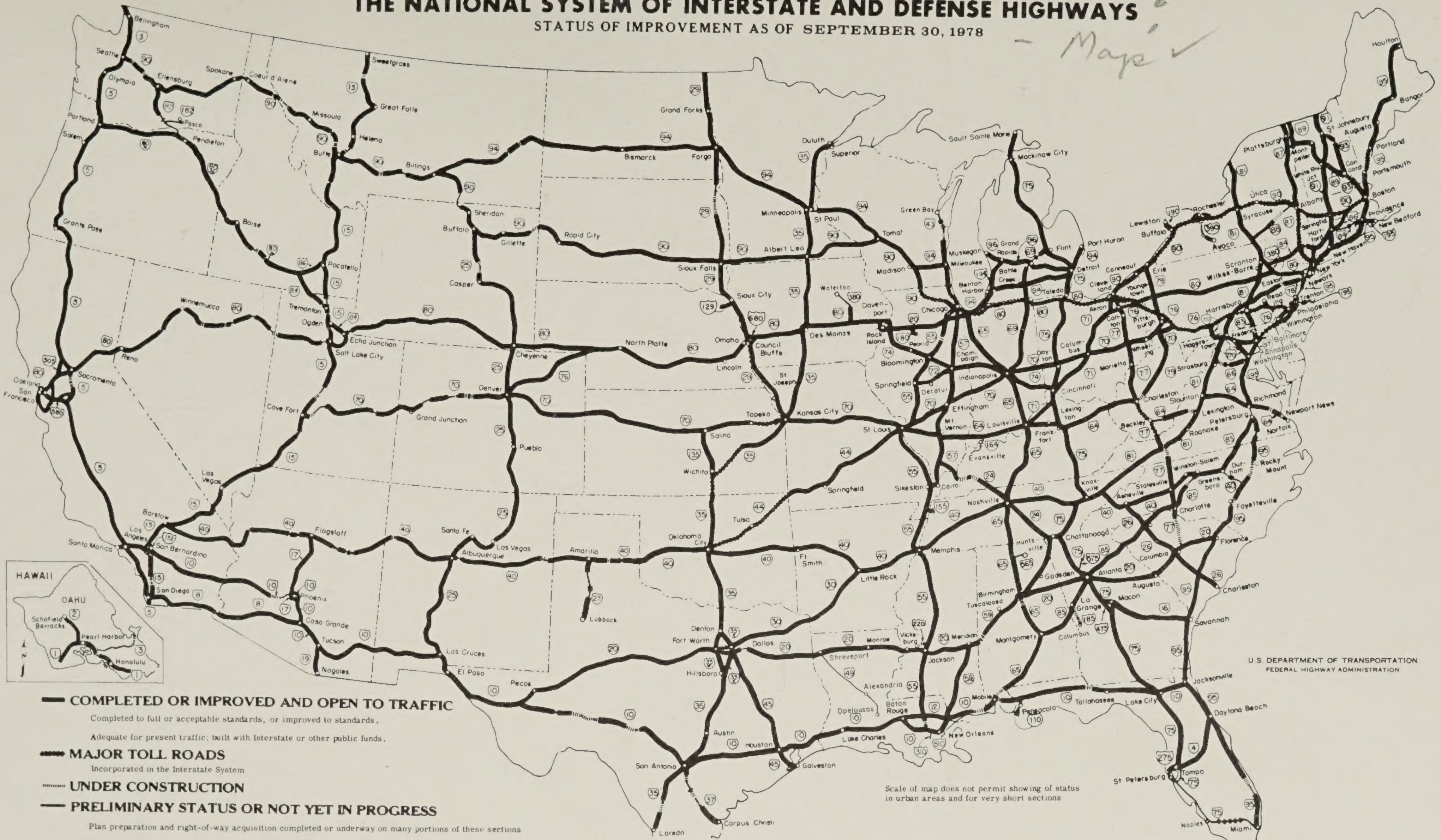
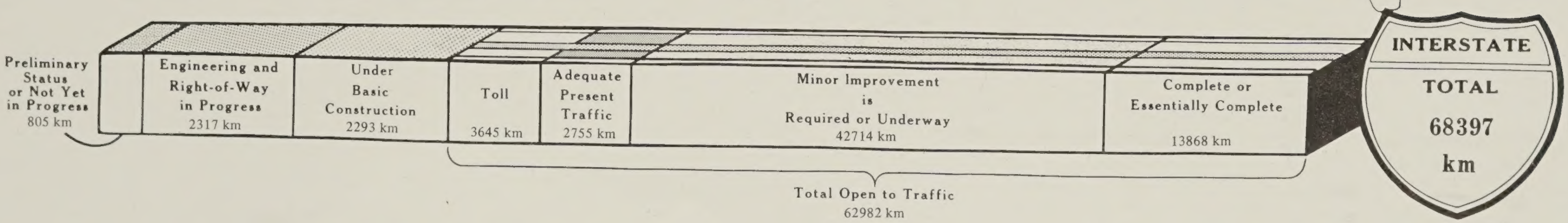



- COMPLETED OR IMPROVED AND OPEN TO TRAFFIC
  - Completed to full or acceptable standards, or improved to standards.
  - Adequate for present traffic; built with Interstate or other public funds.
- MAJOR TOLL ROADS
  - Incorporated in the Interstate System
- UNDER CONSTRUCTION
- PRELIMINARY STATUS OR NOT YET IN PROGRESS
  - Plan preparation and right-of-way acquisition completed or underway on many portions of these sections



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