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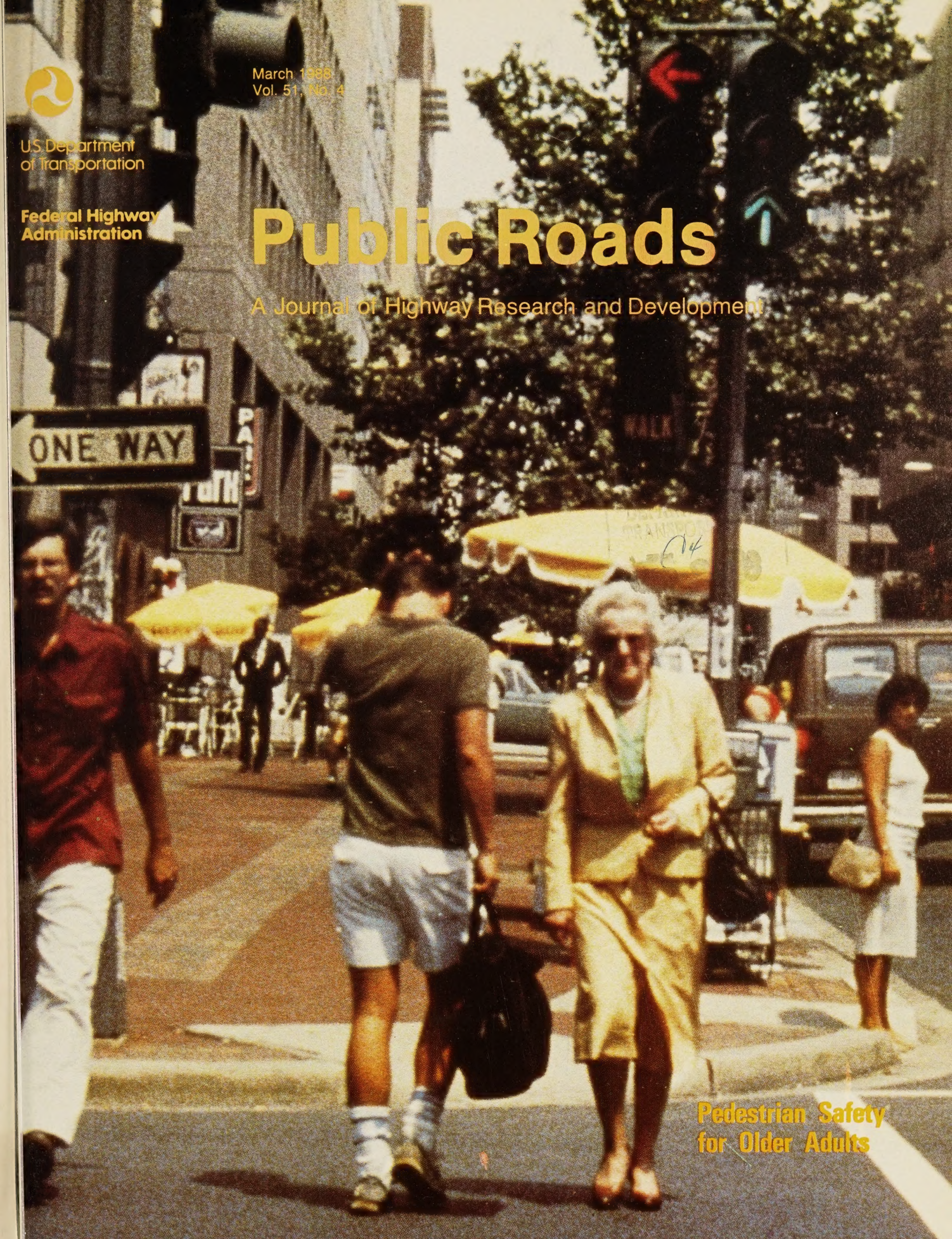

Pedestrian Safety
for Older Adults

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COVER:
Older adult pedestrians have the highest death rate of any age group. Nearly one third of these fatalities occur at intersections. The proper use of traffic control devices at intersections can significantly reduce this number.

U.S. Department of Transportation
Jim Burnley, *Secretary*

U.S. Department of Transportation
Federal Highway Administration
Washington, DC 20590

IN THIS ISSUE

Articles

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David K. Phillips, *Associate Administrator*

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Safety Steps for Pedestrians[1]

by John C. Fegan

A slide-tape show entitled "Safety Steps for Pedestrians" has been developed to meet the unique needs of older adults as pedestrians. The show presents practical guidance on personal safety as well as information on available means of increasing the safety of older persons at the local level.

The population of the United States is getting older. Not only are individuals living longer more active lives, but the overall number of elderly Americans will dramatically increase in the very near future. Older persons are the fastest growing section of the U.S. population. Between 1960 and 1980 for example, the number of persons over 65 increased by 54 percent. In 1986, 1 in 9 persons was over 65. In the year 2000, 1 in 6 will be. If current fertility rates continue, by 2030, 1 in 4 persons in the U.S. will be over 65 years of age. As a group, older adults' health and financial circumstances have improved to such an extent that they continue to participate fully in life for many years after their retirement. Increasingly, older adults are living in suburban areas where, for the first time in history, they outnumber older adults living in the center city.

Mobility is critical for older adults since it allows them to maintain their independence. The value of independence is a vital one for this age group, as they strive to maintain a sense of control over their lives. As with younger persons, the primary mode of travel for the older adult is the personal motor vehicle. The

[1]Mr. Fegan was awarded the 1986 RD&T Outstanding Technical Achievement Award for his slide-tape program "Safety Steps for Pedestrians" on which this article is based.

second most commonly used form of travel is walking. Contrary to popular stereotypes, older adults as a group are physically active, and walking figures prominently both as a means of getting around and also as a way of getting exercise. Older adults are increasingly recognizing the positive aspects of walking. As always, however, there is a negative side to the story.

Adult pedestrians over the age of 55 are three times more likely to die in collisions with motor vehicles than are younger persons. Pedestrian-motor vehicle accidents nearly always result in injuries to the pedestrian, but for older pedestrians these injuries are more likely to be fatal or significantly affect the quality of their lives. Injuries resulting from pedestrian accidents often reduce independence of movement, and severely affect the quality of life after the accident.

To help older adults increase their safety as pedestrians, a slide-tape show has been developed. The show is a result of a joint effort between the Federal Highway Administration and The American Association of Retired Persons (AARP).

The slide-tape show is designed to impart three messages to the older pedestrian:

First, each person must take responsibility for his/her own safety as a pedestrian. Second, engineering techniques to increase pedestrian safety are available. Third, organizing the local community to address pedestrian safety problems is an effective way to improve pedestrian safety for the older person.

Pedestrian Responsibilities

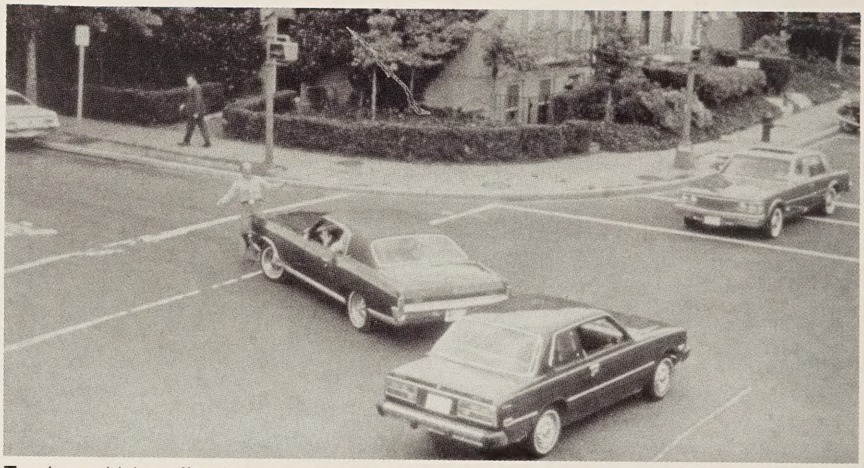
Older adults must become more aware of particular techniques they can use to reduce the possibility of being involved in a pedestrian-motor vehicle accident. Specifically, they should:

- Realize they are responsible for their own safety as pedestrians.
- Watch out for all moving vehicles including turning vehicles and not assume that they are seen by motor vehicle drivers. Catch the eye of drivers turning right on red to make sure the drivers have seen the pedestrian.
- Wear light-colored clothing especially at night.
- Cross streets at intersections rather than at mid-block.

Engineering Techniques

Certain engineering techniques increase pedestrian safety and should be used by older adults.

- Crosswalks are used to regulate the movement of pedestrians when crossing a roadway. Older adults should be cautious in using crosswalks. Pedestrians should not assume that they are safe merely because they are within crosswalk lines. Older adult pedestrians should be especially alert for vehicles turning right on red.
- Pedestrian signals are intended to indicate when pedestrians should cross the street. Pedestrian signals are sometimes troublesome for older adults. Typically the pedestrian begins crossing the street when the WALK signal comes on. As the



Turning vehicles offer the potential for collisions with pedestrians.

Pedestrians should look in both directions when crossing the street.

pedestrian crosses, the DON'T WALK signal may begin flashing. This often confuses older adults, who assume that the traffic signal is about to change. In fact, the flashing DON'T WALK is a clearance interval. It means that pedestrians should continue crossing the street if they have started, but should not start to cross if they have not yet left the curb. Older adults who walk more slowly should always begin crossing at the start of the WALK pedestrian signal message. In certain locations, a longer WALK phase may be needed if slower pedestrians cannot reach the other side of the street in the time allotted. A steady DON'T WALK signal indicates that the pedestrian should wait on the curb for the next WALK indication.

- Roadway signing is used to inform or warn drivers and/or pedestrians of conditions affecting their movement and safety. Pedestrian signs should be obeyed. Older adults must recognize the need to obey such signs.

- Grade-separated crossing structures are installed to separate pedestrians from vehicular traffic. Over- and underpasses can pose problems for the older adult pedestrian. Their use may require more physical effort and increase the person's walking distance. Such structures should only be placed where at-grade street crossing is hazardous.

- Medians are used to regulate traffic flow, but they also reduce the distance pedestrians must cover in street crossings. Medians can be used as a resting place or refuge when crossing a busy street; only half of the street needs to be traversed at a time.

- Extending sidewalks into an intersection reduces the distance a pedestrian crossing the street must travel; this technique also reduces the speed of vehicles at the intersection.

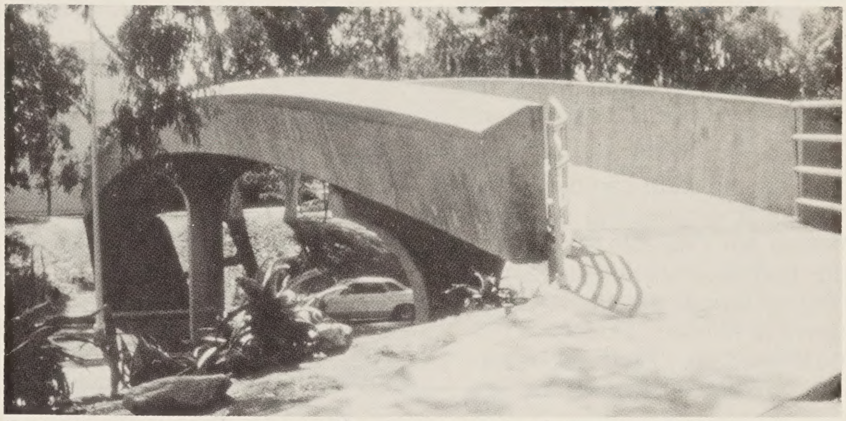
- Traffic-free zones offer areas where pedestrians may walk without interference from motor vehicles. These are particularly effective in shopping areas.

- Physical barriers are used to prevent pedestrians of all ages from crossing the street where it is unsafe. All pedestrians should respect these barriers and cross where it is safer.

- Altered or angle parking channels pedestrians crossing mid-block by directing their lines of sight toward approaching vehicles. This allows the pedestrian to see the driver and vice versa.

- Bus stops located at the far side of intersections encourage the pedestrian to cross behind the bus, rather than in front of it where he/she may be hidden from the view of vehicles passing the stopped bus.

- Prohibiting right turn on red at busy intersections increases the safety of older adults as they cross these intersections.



Pedestrian overpasses reduce conflicts between pedestrians and vehicles.

Bus stops located at the far side of intersections encourage pedestrians to cross behind the bus where passing vehicles can more easily see them.

Even when pedestrians have the right-of-way, they must still be alert to approaching vehicles.

Organizing Support for Pedestrian Improvements

Techniques older adults can use to organize their communities in developing a pedestrian safety program include:

- Determine the community's specific pedestrian safety problems. Investigations of pedestrian accident statistics can be made. Locations with concentrations of pedestrian accidents can be identified.

- Investigate what has been done with regard to pedestrian safety. Determine what programs and policies have been used, and assess whether they have actually reduced pedestrian accidents.

- Investigate what can be done. Educational, engineering, and legal remedies are available to reduce pedestrian accidents. A guide for setting up a pedestrian safety program is entitled "Model Pedestrian Safety Program Users Guide - Volumes 1 and 2."[2]

- Advocate for new devices and ways of funding them. With assistance from local officials, determine what can be done and find ways to finance these improvements.

- Support educational and law enforcement efforts. Work through local schools and police departments to further educational and regulatory programs to increase pedestrian safety.

- Follow up on results; determine what effects the programs are having.

- Form a pedestrian safety club. Such a club is fun and at the same time serves a valuable public service function.

After the presentation of the slide show, the audience can discuss local pedestrian safety problems with the resource person, and then make realistic plans for addressing these problems. In this way, older adults can participate in improving pedestrian safety in their communities.

The slide-tape show package includes a 13-minute slide-tape show and detailed information on how the tape can be presented to interested groups. The responsibilities of the person presenting the slide-tape show (the program leader) are delineated and described. These duties include doing advance advertising, carrying out administrative/logistic functions, and actually running the show. A local resource person can answer questions and investigate identified problem locations. The slide-tape package also includes sample letters for inviting the resource person, (i.e., someone knowledgeable about local pedestrian safety efforts), sample news releases, and recommendations for discussion topics to be covered after the show has been presented. A suggested introduction to the show and the script for the narration which accompanies the slides is supplied so that the program leader can follow along with the slide show as it progresses.

The slide-tape show package is distributed by the AARP through its 500 U.S. chapters. The package may be obtained on a loan basis by writing to: The American Association of Retired Persons, Program Scheduling Office, 1909 K Street, N.W., Washington, D.C. 20049.

John C. Fegan is a research psychologist in the Safety Design Division Office of Safety and Traffic Operations R&D, FHWA. He has been with FHWA since 1972 and currently is project manager for research on the safety of pedestrians, bicyclists, and moped operators. Mr. Fegan has represented the United States on international committees researching the transportation needs of older adults, and works closely with groups representing the elderly in the United States.

[2]Limited copies of these two volumes are available from the FHWA RD&T Report Center (HNR-11), Federal Highway Administration, 6300 Georgetown Pike, McLean, Virginia 22101-2296.

Effects of Calcium Magnesium Acetate on Reinforced Steel Concrete

by
Brian H. Chollar and Yash Paul Virmani

Introduction

In research aimed at discovering alternative highway deicing chemicals, calcium magnesium acetate (CMA) was identified as a potential alternative deicer to replace salt. (*1*)[1] This research prompted the Federal Highway Administration (FHWA) to initiate a Federally Coordinated project on CMA as an alternative deicer. (*2*) The project included four major tasks: (a) evaluate the effects of CMA on environment; (b) determine the feasibility and development of its economical production; (c) determine its physical and chemical properties and deicing ability; and, (d) evaluate its effects on highway and transportation materials.

Early in the research, the FHWA was interested in learning what effect CMA had on highway metals. Preliminary comparative tests were conducted using steel reinforcements immersed in both CMA and salt (NaCl) solutions. The results concluded that steels exposed to CMA solutions corroded much less than those exposed to salt solutions. (*1*) Besides this, the FHWA also initiated a staff ponding study in 1982 using CMA solutions on reinforced concrete slabs to detect the corrosion susceptibility of CMA under an outdoor environment. More research was conducted in 1984 regarding the effects of CMA on highway metals including ponding studies on small-reinforced concrete slabs. (*3*) This paper examines the results of the 1982 FHWA–CMA staff ponding study and compares these results with those results of the 1984 study.

[1]Italic numbers in parentheses identify references on page 115.

Experimental Procedures

Ponding studies were started in July 1982. The concrete slabs, 2 ft by 5 ft by 6 in containing a single mat of reinforcing steel were fabricated. The details on mix design, properties of concrete, and construction procedures are described elsewhere. (*4*) These slabs were fitted with rubber dams and ponded using 3 percent and 5 percent aqueous solutions of CMA for two slabs and 3 percent aqueous salt solution for the third slab. The slabs were ponded twice a week during July 1982 to March 1983, June to September 1984, March to June 1985, and June to September 1986. During the 4-year period, the slabs were exposed to the outdoor environment at the Turner-Fairbank Highway Research Center facility in McLean, Virginia. Using copper-copper sulfate as a reference electrode, electrical potential measurements were made during the first few months and the last 4 months of the 4-year outdoor-exposure period by an ASTM C876-80 procedure. (*5*)

Results

Laboratory studies and an ASTM standard C876-80 have established that reinforced black steel potentials numerically greater than – 350 mV with respect to a copper-copper sulfate reference electrode indicate that there is a greater than 90 percent probability that corrosion is occurring in areas of the steel at the time of measurement. (*6, 7*)

Figures 1 and 2 show the potentials measured for the embedded black steel rebars of the CMA- and salt-ponded slabs over the 4-year period during the test. For the two slabs ponded with the CMA solutions, electrical potentials of black steel rebar varied between 0 to −60 mV. These potentials are not in the corrosive range. (*5*)

The potentials of the slab ponded with the salt solution numerically increased from −100 mV to −280 mV in the first 3 months, and then to −580 mV in the next 3.5 years, well within the corrosive range. After 4 years under test, the surface condition of the CMA-ponded slabs showed no signs of surface cracking. On the other hand, for the salt-ponded slabs, after 3 years, concrete cracking was noticeable in areas directly over the rebars. After an additional year, the cracks became wider and rust stains appeared in two areas along the cracks.

The University of Oklahoma study used small reinforced concrete slabs, 14 in by 14 in by 4.5 in, containing two rebar mats, one near the top and the other near the bottom of each slab.(*3*) These slabs were ponded indoors with CMA and salt solutions for 15 months. There were four duplicate sets of slabs containing bare steel at the top mat. Set one slabs containing

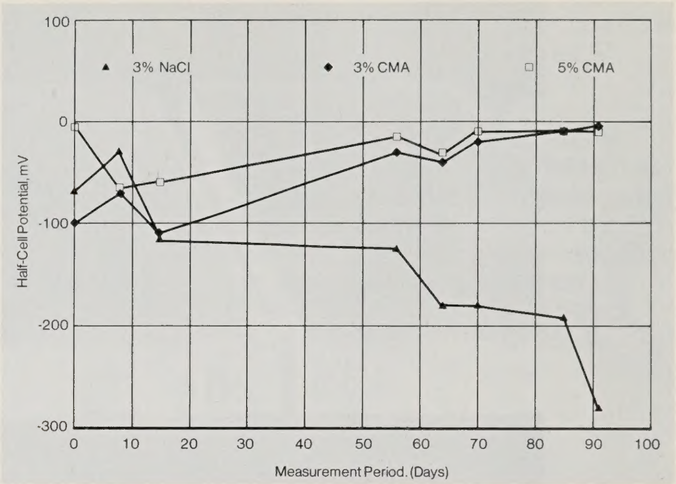


Figure 1.—Potentials of rebars in slabs ponded with salt and calcium magnesium acetate; March to June 1982.

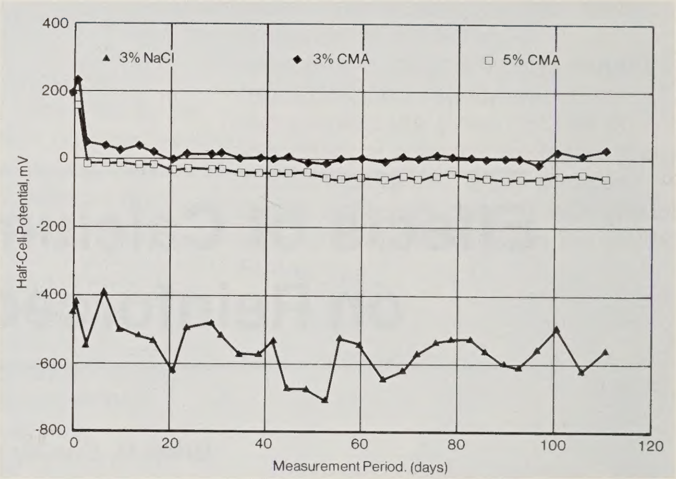


Figure 2.—Potentials of rebars in slabs ponded with salt and calcium magnesium acetate; June to September 1986.

uncontaminated concrete were ponded with CMA solution and had top steel potentials in the range −136 to −208 mV; which are not in the corrosion range. The other three sets of duplicate concrete slabs were either fabricated with admixed chloride and then ponded with CMA solution or just ponded with sodium or calcium chloride solutions. Some of the slabs in this category did show potentials in the corrosion range; which is not surprising since C1 – ions are known to cause corrosion of reinforcing steel.

All research under this study was conducted in the Materials Division laboratories at the Turner-Fairbank Highway Research Center, McLean, Virginia.

Discussion

Our results show that the potential of the black steel rebars in slabs ponded with salt solutions started increasing numerically within the first 3 months of exposure, while that of rebars in slabs ponded with CMA solution did not increase at all during that time period. The CMA solutions did not cause any significant potential shift or corrosion after 4 years on/off ponding in an outdoor environment. This contradicts the Oklahoma results (3) on this subject, where it was concluded that CMA solutions have a potential to corrode uncoated rebars embedded in portland cement concrete to a somewhat similar extent as salt. This conclusion was based on changes in the electrical potentials for the black steel rebars exposed to simulated pore solutions, embedded in mortar cylinders and concrete slabs. The Oklahoma study did not confirm the corrosion of the rebars for CMA or salt-ponded slabs or cylinders by breaking them and observing the rebars.

Future Studies

Since detailed rebar studies were performed indoors and did not simulate outdoor conditions (3), and since our outdoor exposure studies were very limited, a new outdoor exposure study is planned to resolve questions and differences raised with this limited research. This future study should include destructive evaluation of ponded concrete specimens with a detailed examination of the extracted rebars and the analysis of all aggressive ions in the concrete at various depths. It will decide the rate of diffusion of CMA through the concrete and also conclude if the presence of CMA at the rebar surface will cause any corrosion of the rebar in concretes.

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(*5*) "Annual Book of ASTM Standards, Section 4, Volume 04.02, Standard C876-80," *American Society for Testing and Materials*, Philadelphia, PA, 1985.

(*6*) K.C. Clear, "Time to Corrosion of Reinforcing Steel in Concrete Slabs," FHWA–RD–76–70, Washington, DC, *Federal Highway Administration*, April 1987.

(*7*) Donald W. Pfeifer, J. Robert Landgoen, and Alexander Zoob, "Protective Systems for New Prestressed and Substructure Concrete," Report No. FHWA/RD–86/193, Washington, DC, *Federal Highway Administration*, April 1987.

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Yash Paul Virmani is a research chemist in the Structures Division, Office of Engineering and Highway Operations Research and Development, FHWA. Dr. Virmani is the Program Area Manager for the Nationally Coordinated Program, Area D4, "Corrosion Protection." He is the coinventor of conductive polymer concrete, a material that is the basis of several new cathodic protection systems.

Prediction of the Service Life of Warning Signs

by Faisal I. Awadallah

Introduction

A key decision facing highway maintenance administrators is when to replace retroreflectorized signs installed on streets and highways. This decision is obvious when signs are damaged, vandalized, or stolen; signs are replaced as soon as conditions permit. The real problem is identifying signs which need to be replaced due to loss of retroreflectivity—i.e., when the brightness of a sign as seen at night from approaching vehicles is not sufficient to provide the minimum required visibility distance (the distance required by a driver to recognize the sign and respond safely to its message). Loss of retroreflectivity is usually a slow process, taking many years. Further, the lack of adequate night visibility is rarely apparent from the sign's daytime appearance.

Sign replacement practices vary among States and levels of government within States. Some agencies replace traffic signs based only on driver complaints. Other agencies conduct a nighttime visual inspection, basing replacement on a subjective inspector's evaluation of "too dark."

Still other agencies use a rotation method, replacing enclosed lens signs every 5 to 7 years and encapsulated lens signs every 12 years. In a nationwide survey, however, Olson and Bernstein found that the effective service life of enclosed lens signs was 3 to 10 years. (*1*)[1] In the State of New York, Kenyon et al., found the effective service life of enclosed lens signs to range from 5 to 13 years, with some cases of 15 years and above. (*2*) Therefore, the practice of replacing enclosed lens signs every 5 to 7 years may arbitrarily remove signs with several years of service life remaining, resulting in a waste of money and/or may leave signs standing which do not have sufficient retroreflectivity. If not replaced, these latter signs could lead to an accident for the motorist and a tort liability case for the highway agency.

[1] Italic numbers in parentheses identify references on page 122.

Study Approach

The retroreflectivity service life (RSL) model was developed to predict when a sign has reached the end of its useful life. (*3*) The model is based on providing drivers with the minimum visibility distance required for safe and efficient response to the sign message. As shown in the flowchart (fig. 1), the RSL model comprises three sub-models:

- *Minimum required visibility distance sub-model.* This calculates the minimum distance that the driver needs to recognize a sign, decide on the appropriate action, react, and complete the maneuver (if required). This sub-model is based on previous studies. (*4, 5*)

- *Minimum required retroreflectivity sub-model.* Since measuring the nighttime visibility distance of a large number of signs is not practical, this sub-model uses specific intensity per unit area (SIA)—a physical measurement of a sign's ability to reflect light—as a surrogate measure of the nighttime visibility distance of signs. The relationship between the SIA values and the nighttime visibility distances was developed from a field study.

- *Deterioration sub-model.* This predicts the service life of warning signs based on field data (including SIA measurement) collected for about 500 signs with known dates of installation.

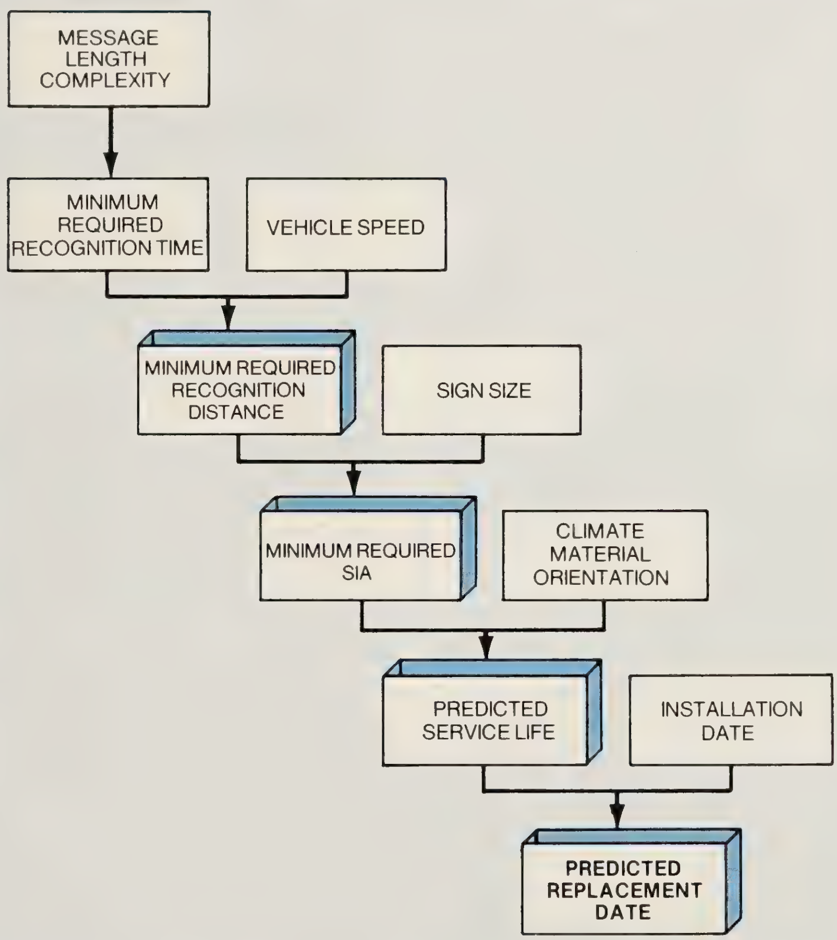

Figure 1.—Logic flow of the retroreflectivity service life model.

Each of these sub-models is further described below.

The Minimum Required Visibility Distance Sub-Model

The minimum required visibility distance of a warning sign is here defined as the distance, before passing a sign, at which the design driver (driving the design vehicle) can just recognize a sign and respond to its message safely and efficiently. This distance is thus a function of sign message length and complexity and driver and highway characteristics.

The methodology for this calculation is based on the decision sight distance model and its subsequent modification for determining nighttime visibility requirements for reflective devices. (*4, 5*) The model assumes that each component of the detection-maneuver process is distinct, separate, and sequential; and that there is no time sharing. These assumptions may be somewhat conservative since overlapping of tasks is likely. Also, each sign is considered to be acting alone in providing the information.

The minimum required visibility distance sub-model has three major components:

- *Standard visibility distance (SVD).* This is the distance for which the sign must be visible to allow the driver to recognize a particular sign, decide on the appropriate action, react and complete the maneuver (if any) before reaching the location where the intended maneuver must be completed.

- *Additional recognition distance (ARD).* At some finite distance upstream, a sign is no longer visible to the approaching driver because (1) it is out of the normal cone of vision, and (2) the driver's angular momentum causes the message to be blurred. If the driver has not recognized the sign by this point, the sign message will not be received. To ensure that the driver has adequate time to recognize the sign, the ARD needed by the driver is computed and added to the standard visibility distance.

- *Distance before maneuver (DBM).* While a sign must be recognized before it drops from the normal cone of vision, the decision, reaction, and maneuver may be performed after the sign drops from the cone of vision, but before reaching the location where the maneuver must be completed. The DBM is the distance between sign location and the location where the maneuver must be completed. DBM varies depending on sign type. For example, a stop sign is located at the place where the maneuver (stopping) is to take place (DBM=0), while a "Right Lane Ends" warning sign is located upstream of where the maneuver should be completed (DBM>0). The DBM is subtracted from the standard visibility distance. Since the driver must be given a sufficient distance to recognize the sign before passing it, the maximum DBM is equal to the sum of the decision, reaction, and maneuver distance.

Equation 1 presents the calculation of the minimum required visibility distance (MRVD). Equation 1 parameters for warning signs are presented in reference (1).

$$MRVD = SVD + ARD - DBM \qquad (1)$$

where:

$$SVD = V_0 * (RT + DT + ST + MT) + \frac{V_0^2 - V_f^2}{2a}$$

Minimum ERD = 0

$$ARD = [\, S + (n-1) * L + 2/3 * L + W/2\,] * \text{Cot}\, x - [\, V_0 * (DT + ST + MT) + \frac{V_0^2 - V_f^2}{2a} - DBM\,]$$

$$\text{Maximum } DBM = V_0 * (DT + ST + MT) + \frac{V_0 - V_f^2}{2a}$$

MRVD = minimum required visibility distance (ft) [m]
SVD = visibility distance required by the driver for a particular sign (ft) [m]
ARD = additional recognition distance required to compensate for the sign being out of the normal cone of vision (ft) [m]
DBM = distance between a sign and the location where the sign's intended maneuver must be completed (ft) [m]
V_0 = initial speed of vehicle or highway speed limit (ft/s) [m/s]
V_f = final speed of vehicle (ft/s) [m/s]
RT = minimum required recognition time (s)
DT = minimum required decision time (s)
ST = minimum required response time (s)
MT = minimum required maneuver time (s)
a = deceleration (ft/s^2)
S = distance from the edge of the traveled way to a sign, offset (ft) [m]
n = number of lanes in the direction facing a sign
L = lane width (ft) [m]
W = sign width (ft) [m]
x = the maximum divergence angle for the human field of vision in degrees

The Minimum Required Retroreflectivity Sub-Model

As mentioned above, SIA values serve as a surrogate measure of a sign's ability to provide needed information to the driver. SIA measures the retroreflectivity of signs and may be expressed in units of candela/foot-candle/square foot. SIA values are measured by retroreflectometers, which simulate the reflection of low beam headlights in a specified geometrical relationship to the sign. Retroreflectometers are simple to operate, and several measurements per sign may be obtained in a few minutes during day or night. The measurements are reproducible within a small, acceptable margin of error.

A nighttime field experiment was performed which measured the visibility distances of 11 subjects for 16 30-inch (762 mm) symbol warning signs with varied SIA values. The test site was a traffic-free, straight, level section of a service road on an abandoned airport with no light sources in the vicinity. The test vehicle was a Chevrolet Chevette with rectangular low beam halogen headlamps. Subjects from a narrow age group (19 to 26) with better than 20/40 visual acuity and normal contrast sensitivity were selected for the experiment.

Each subject was required to drive the test vehicle approaching the sign at about 15 mi/h (24 km/h). The starting point of the experiment was about half a mile from the test sign position. Subjects were asked to say nothing until they could "positively recognize" the test sign, immediately upon which they were to identify the sign. As soon as the subject uttered the sign type, the experimenter activated the distance measuring meter. When the sign was reached, the distance measuring meter was stopped and the distance recorded.

A scatter plot of the data (fig. 2) indicates a definite nonlinear trend. Four alternative models for predicting the SIA value of signs—the linear, power, exponential, and polynomial forms—were explored. The power model was clearly the most accurate and representative of the data. Figure 2 shows the curve fit function of both the 50th percentile (average) and the 90th percentile (the recommended model) superimposed on the data scatter plot. The 90th percentile visibility distance was used in the design, since only young

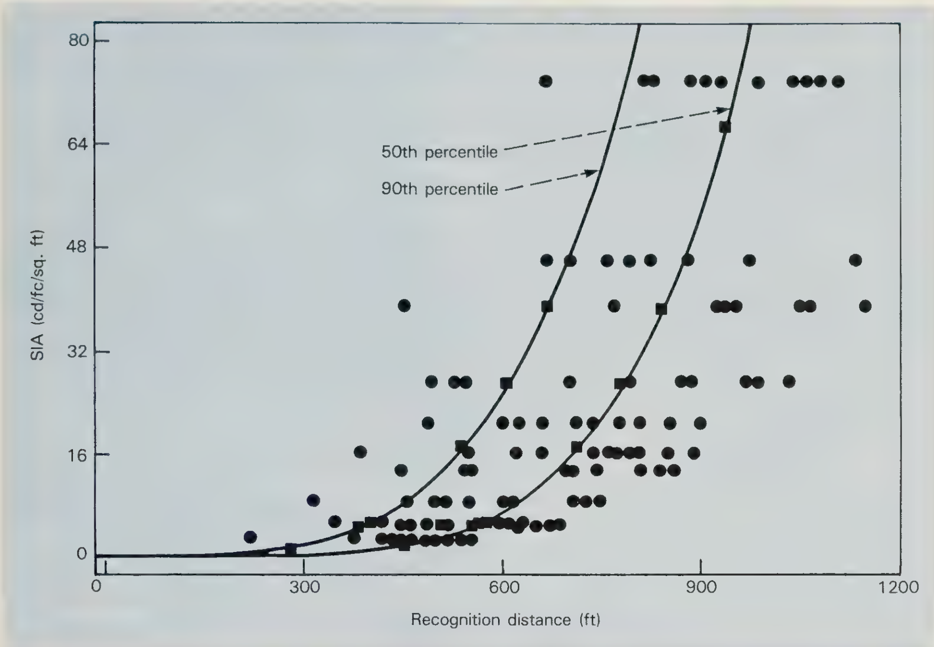

Figure 2.—Recognition distance vs. SIA. Scatter plot, average SIA, and the 90th percentile (recommended) model.

subjects participated in the field experiment. The recommended model, equation 2, for predicting the minimum required SIA value of 30-inch (762 mm) warning signs is:

$$Y_1 = (4.32 * 10^{-10})\, X_1^{3.88} \qquad (2)$$

where:

Y_1 = minimum required SIA value (cd/fc/ft^2)(dc/lx/m^2); the average of at least four measurements representing proportional areas of a sign is recommended;

X_1 = minimum required visibility distance (ft) from equation 1.

A validation study of five older subjects (ages 55 to 66) measured the nighttime visibility distance of four 30-inch (762 mm) symbol warning signs on an unilluminated section of public road. This latter study concluded that there was no significant difference between the measured values and those predicted by the minimum required retroreflectivity model (i.e., equation 2).

The Deterioration Sub-Model

The deterioration sub-model predicts the service life of signs, i.e., the inservice period between the month of sign installation and the month at which its SIA value corresponds to the minimum required value. Sign service life is a function of three parameters: The initial SIA value, the minimum required SIA value, and the service period rate. This last is defined as the increase of the service period corresponding to one unit decrease in the SIA value. The initial SIA value is a function of the retroreflective sheeting type and the color of signs, while the service period rate primarily depends on the climate and on the sign's orientation as related to the path of the sun.

The SIA was measured for about 500 yellow and white background inservice signs with known months of installation. Three States with different climate conditions were selected for the data collection—Florida, Virginia, and Wisconsin.

Scatter plots of the data showed a linear trend (fig. 3). Comparison of SIA versus service period regression lines were performed to determine the variables that significantly affect the service life of signs. The regression lines were compared relative to the residual variance, slope, and the y-intercept. Based on this, the SIA value, retroreflective sheeting type, color of signs, and climate of the location of signs were

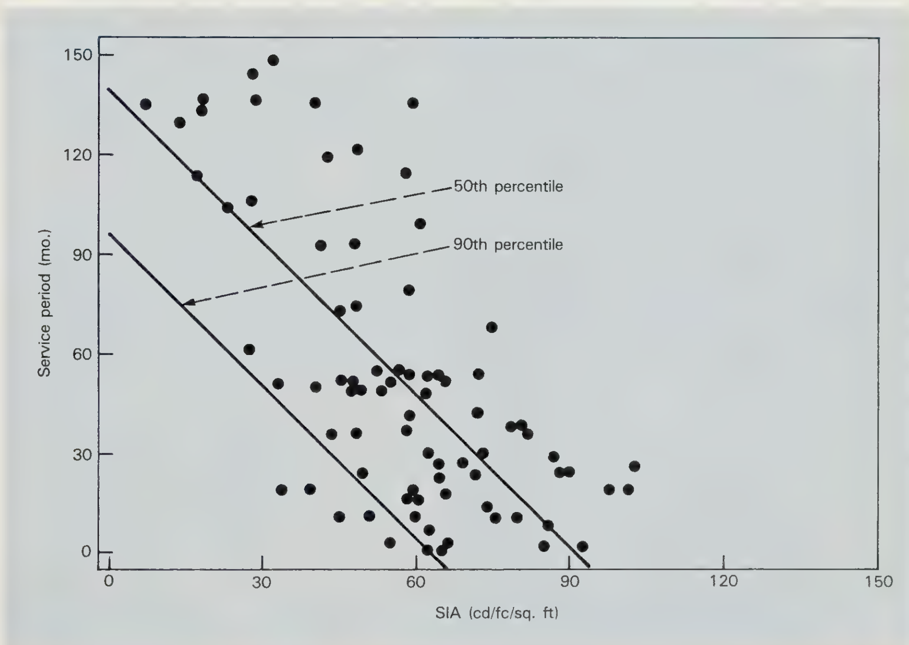

Figure 3.—The Virginia-yellow deterioration model.

determined to be significant in predicting signs' service life.

The deterioration sub-model employed the 90th percentile confidence interval: This means that at the predicted month of replacement, there is only a 10-percent chance that the sign should have been replaced earlier. Figure 3 illustrates the 90th percentile as well as the 50th percentile regression line deterioration model for a mid-Atlantic State (Virginia) superimposed on the data scatter plot. The following is the Virginia-yellow deterioration model for the 90th percentile confidence interval:

$$\text{Service life (months)} = 139.31 - 1.53 * (\text{min. SIA}) - 41.87 * \frac{[1.01 + ((\text{min. SIA}) - 55.90)^2]^{0.5}}{41674} \qquad (3)$$

where:

min. SIA = minimum required SIA value (Y_1) from equation 2.

A validation analysis was conducted, using the data of 20 yellow signs in Virginia which were not used in calibrating the deterioration sub-model. No significant difference was found between the actual service period of the signs and the periods predicted by the deterioration sub-model. A similar model has been developed for Florida, but this model has not been validated. Given the wide variety of retroreflective materials used and the limited amount of data collected, development of a statistically valid model for Wisconsin was not possible.

Results

A microcomputer program has been developed to simplify the use of the retroreflectivity service life model. This program computes the minimum required visibility distance and the minimum required SIA values, and—based on user-supplied inputs—predicts the month of replacement for 30-inch (762 mm) symbol warning signs. To ensure that signs have at least the minimum SIA value required for conspicuity, a lower limit of 18.0 cd/fc/ft^2 (208.6 cd/lx/m^2) was established. This was based on Mace's study of yellow warning signs at low visual complexity sites. (*6*) Thus, the SIA model selected in the program execution sequence is the higher value of 18.0 cd/fc/ft^2 (208.6 cd/lx/m^2) and the value calculated based on the minimum required visibility distance.

Data for each sign are entered using the Sign Management System (SMS). The SMS is an IBM-compatible system which is being developed by the Federal Highway Administration to assist State and local highway organizations involved in the design, maintenance, and research of retroreflective signs. In its present form, the system can be used to develop a sign inventory. Ultimately, the SMS will be able to predict candidate signs for replacement, compare various replacement strategies and their costs, and implement sign retroreflectivity standards.[2]

The SMS input screen is used to create a record containing 26 variables for each sign (fig. 4). Some default values are provided, so not all of the variables are required. Immediately after the last input variable is entered, the program is executed and the results appear on the input screen. The sign record can then be stored for later retrieval and modification. A data base containing sign records can be created, these records sorted and displayed on the screen, and a hard copy report printed (table 1).

Conclusions

While application of the RSL model is now extremely limited—for only 30-inch (762 mm) symbol warning signs located on the right shoulder within a jurisdiction with climates similar to either Virginia or Florida—this study has proven the feasibility of modeling sign retroreflectivity deterioration. The groundwork has been laid for developing additional models to cover other sign types and a wider range of climatic conditions. The Federal Highway Administration has a planned 1988 research effort aimed at developing the sign deterioration models necessary to make the Sign Management System operational. In addition, an ongoing study, "Minimum Visibility Requirements for Traffic Control Devices," is being conducted to determine what minimum inservice retroreflectivity levels are required by the driver for safe and efficient operation.

[2]An update to the status of the Sign Management System is given on page 121.

Location	ID# *14*	Route name/# *Arlington Road*	
Intersect *Elm Street*		Station 0.00	
Orientation *A*	Position *R*	Offset *10*	Height *7*
Characteristics	MUTCD *W13-1*	Install date *3/06/84*	
Sheeting *1*	Backing *S*	Post M	
Size: W: *30* H: *30*	Inspect date *1/01/88*	SIA *20*	Condition *G*
Factors	Visual Complexity *L*	Speed limit *35*	DBM *0*
Direction *W*	Curve *N* No. lanes *2*	Final speed *29*	Flow *2*
Results	Replace date *4/89*	Recognition distance *280*	
	Required SIA *18.0*		
	Press ESC key to exit		

Command <A:> Signinv Rec: 14/14

Figure 4.—The input screen.

Table 1.—Basic Option of the Retroreflectivity Service Life Model

Retroreflectivity Service Life Model: Basic Output

I.D. Code	Route Number	Intersection	Dist.	ASC	MUTCD	Size	Min. SIA	Replace Month
1	Rt. 25	Rt. 1	50.0	A	W13-1	30	20.6	4/93
2	Rt. 1	Duke St.	100.0	A	W1-2	30	18.0	10/87
3	Rt. 1	King St.	85.0	D	W2-1	30	18.0	1/90
4	Rt. 50	Rt. 201	250.0	A	W1-2	30	18.0	4/93
5	Rt. 50	South Ave.	120.0	A	W11-1	30	18.0	4/93
6.	Rt. 50	Randolph Rd.	100.0	D	W6-1	30	27.4	2/93
7	Rt. 17	Elm St.	220.0	A	W2-2	30	18.0	5/90
8	Rt. 17	Maple St.	800.0	D	W1-1	30	18.0	3/88
9	Rt. 17	Main St.	500.0	D	W3-1	30	37.4	1/90
10	Rt. 50	Bridge St.	222.0	A	W4-1	30	18.0	11/92

1 ft = 0.3048 m
1 in = 25.4 mm
1 cd/fc/ft^2 = 11.6 cd/lx/m^2

Sign Management System Update

by
Jeffrey F. Paniati

The Sign Management System (SMS) is being developed by the Federal Highway Administration's Office of Safety and Traffic Operations to provide State and local highway agencies with a predictive tool for use in managing a sign inventory. The SMS framework was outlined in the March 1987 issue of *Public Roads*. (*7*) At that time, the SMS was primarily a research tool available only for use on the DEC PDP-11 minicomputer.

Since then, the SMS has been converted for use on an IBM-compatible microcomputer and several system enhancements have been made. The SMS can now be used to create a sign inventory which will allow the sign's age and condition to be tracked, and a systematic review process to be implemented.

The SMS design goal goes beyond developing a simple inventory system; rather, the aim is to develop computer models—like the retroreflectivity service life model—which predict when a sign is likely to need replacement. The results from ongoing and planned research efforts will be used to upgrade the current SMS into a predictive tool. It is anticipated that the final version of the software will be made available in 1990.

System Requirements

The SMS is designed to run on IBM or IBM-compatible microcomputers with a minimum of 256K RAM (random access memory) and either two 360K floppy disk drives or a hard disk. The software has been written and developed using Ashton-Tates' dBase III Plus. For distribution purposes, the dBase source code has been compiled. This allows the system to run on a microcomputer equipped with MS-DOS or PC-DOS (Version 2.0 or later). *dBase III Plus is NOT required to run this program!*

System Operation

The SMS operates from a series of menus and input screens. The menus are used to move through the system; the input screens allow data to be entered and the inventory created. Help screens are provided to give guidance on data input procedures.

System Components

The SMS is comprised of four main modules, each of which can be accessed through the main menu. The four modules are:

- *Sign inventory.* This module is used to create a new sign inventory data base, add new signs (records) to an existing data base, modify fields within existing records, and delete unwanted records. System default values can be selected for any of the data fields, thus speeding up data entry. Also included is a locate option facilitating searches for records matching user-selected criteria.
- *Sign dictionary.* The sign dictionary contains standard sign characteristics such as color, shape, and size. When the SMS is upgraded to a predictive tool, the dictionary will be used as a standard reference by the models to reduce data entry requirements and minimize the possibility of error. The dictionary can currently be used as a reference source for information commonly found in the Manual on Uniform Traffic Control Devices (MUTCD). A locate option is included to allow the user to search for sign information based on the MUTCD code or sign legend.
- *Parameters module.* This module is not operational at this time. In the future, it will contain the parameters used by the models in calculating the available SIA, required SIA, recognition distance, and estimated date of replacement. It also will allow the parameters to be calibrated for the particular location where the SMS is being used. Work is under way to allow the user to input sign material types and costs as part of this module, enabling estimated sign replacement costs to be calculated by the program. This work should be completed by the time this article is published.
- *Utilities module.* This module allows the user to generate hard-copy reports from an SMS sign inventory data base. The sign inventory reports are based on four user-defined criteria (location, sign type, installation date, retroreflectivity level) which can be used in any combination.

To obtain user feedback on system design, the research version of the SMS software and the Users Guide are being made available in a limited distribution. (A full distribution of the SMS system will be made through the McTRANS Center upon completion of the project.) To obtain a copy of the preliminary software, send a FORMATTED 5-1/4" IBM-compatible floppy disk to:

Mr. Jeffrey F. Paniati
Federal Highway Administration
Turner-Fairbank Highway
Research Center
6300 Georgetown Pike, T-210
McLean, VA 22101

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(*1*) P.L. Olson and A. Bernstein, "The Nighttime Legibility of Highway Signs as a Function of Their Luminance Characteristics," *Human Factors,* vol. 21, 1979, pp. 145-160.

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(*3*) F.I. Awadallah, "Durability of Retroreflective Signs," Dissertation, University of Maryland, College Park, MD, 1987.

(*4*) H.W. McGee et al., "Decision Sight Distance for Highway Design and Traffic Control Requirements," Report No. FHWA–RD–78–78, *Federal Highway Administration,* Washington, DC, February 1978.

(*5*) K. Perchonok and L. Pollack, "Luminous Requirements for Traffic Signs," Report No. FHWA/RD–81/158, *Federal Highway Administration,* Washington, DC, December 1981.

(*6*) D.J. Mace et al., "Sign Luminance Requirements for Various Background Complexities," Report No. FHWA/RD–85/056, *Federal Highway Administration,* Washington, DC, September 1985.

(*7*) J.F. Paniati et al., "A Sign Management System to Maintain Sign Visibility at Night," *Public Roads,* vol. 50, No. 4, March 1987, pp. 116–123.

Faisal I. Awadallah conducted this study as a student participating in the FHWA Graduate Research Fellowship Program. He completed his research while obtaining his Ph.D. at the University of Maryland. Mr. Awadallah has held several engineering and teaching positions in the civil engineering field.

Jeffrey F. Paniati is a highway research engineer in the Traffic Safety Research Division, Office of Safety and Traffic Operations R&D, FHWA. Currently, he is working in Nationally Coordinated Program (NCP), Area A1, "Traffic Control for Safety," and NCP, Area A2, "Improved Driver Visibility of the Roadway Environment." Mr. Paniati is a 1985 graduate of the FHWA Highway Engineer Training Program.

Analysis of Concrete Cores from a Cathodically Protected Bridge Deck

by
Yash Paul Virmani and Walter R. Jones

Introduction

It recently was reported that reinforcing bar pull-out strength may be reduced by about 20 percent in those bridge decks subjected to cathodic protection current levels. (*1*)[1] This reduction was ascribed to the accumulation of migrating sodium and potassium ions leading to the softening of the concrete around bars under the influence of applied cathodic protection currents. However, earlier research in the same area found somewhat smaller reduction (10 percent to possibly 20 percent) in ultimate bond strength. (*2*) For that study, specimens were subjected to the equivalent of about 75 years of cathodic operation in the field (i.e., 6920 ampere hours/square foot (74.5 kAh/m^2) of reinforcing steel surface area).

Given these conflicting test results, a limited study was performed on a few concrete cores extracted from a bridge deck under cathodic protection.

Experimental Procedure

Three 4-in (101.6 mm) full-depth concrete core specimens were extracted from the outbound passing lane of the Turkey Run Bridge. This bridge is on the George Washington Memorial Parkway in Northern Virginia and it has been under cathodic protection for 7 years. (*3*)

The cores were examined to determine the condition of concrete around the top rebar mat and if adequate bond strength remains after 7 years of electrical current passage. (*2*)

[1]Italic numbers in parentheses identify references on page 127.

Results

Visual examination

The cores were viewed under a microscope to determine the condition of the concrete around the top and bottom rebars. All cores contained No. 6 steel rebars from both top and bottom reinforcing mats. Figures 1 through 3 show the condition of the extracted cores.

Core No. 1

In this core (fig.1), the rebars were off center and were cut on the core's side. Testing the concrete's paste hardness—done by scratching with a brass rod—showed no apparent difference in that paste hardness near the top rebar as compared to the bottom rebar and other areas of the concrete. There was, however, some slight staining in the paste around the upper surface of the top rebar.

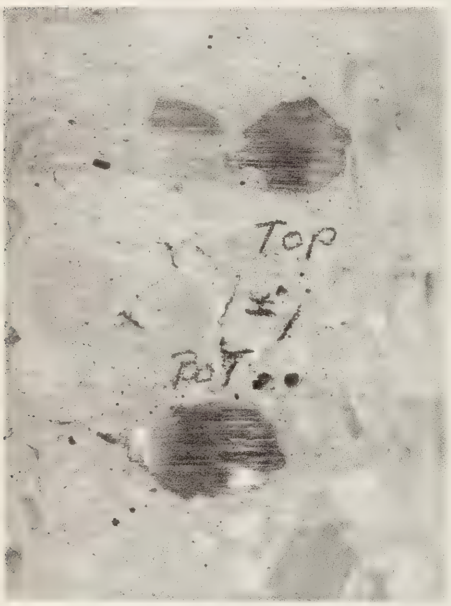
Core No. 2

In this core (fig. 2), the upper and lower rebars were centered in the core. There was no apparent difference in the hardness of paste around the top rebar compared to the rest of the core. A vertical crack in the same plane as the rebars was traceable through most of the core height. The crack is open and visible from the bottom of the core up to the upper rebar. Above the top rebar, the crack is tight and only traceable on one side of the core.

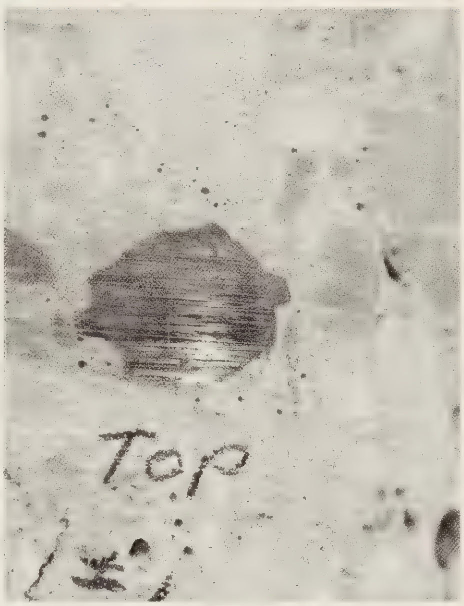
Core No. 3

The extracted core was split open by researchers and the rebars removed; concrete paste hardness was then tested on the imprinted rebar surface (fig. 3). Testing indicated no significant difference between the paste around the rebar imprint surfaces and the rest of the core. The concrete broke through quartz aggregate; this indicates that the bond between the paste and aggregate is good. While concrete residue was strongly adhered to the top rebar, none was found on the bottom rebar. The steel was clean and virtually free of rust stains on both the top and bottom rebars.

Core 1. Top and bottom mat rebar steel.



Core 1. Top-mat steel.



Core 1. Bottom-mat steel.

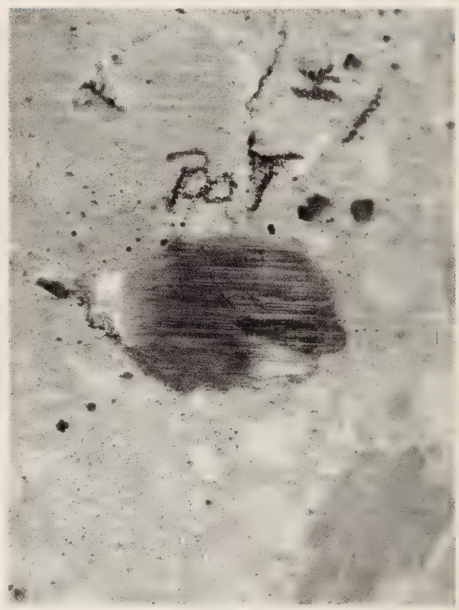


Figure 1.—Concrete Core No. 1 with reinforcement.

Core 2. Overall view. Core 2. Top-mat steel. Core 2. Bottom-mat steel.

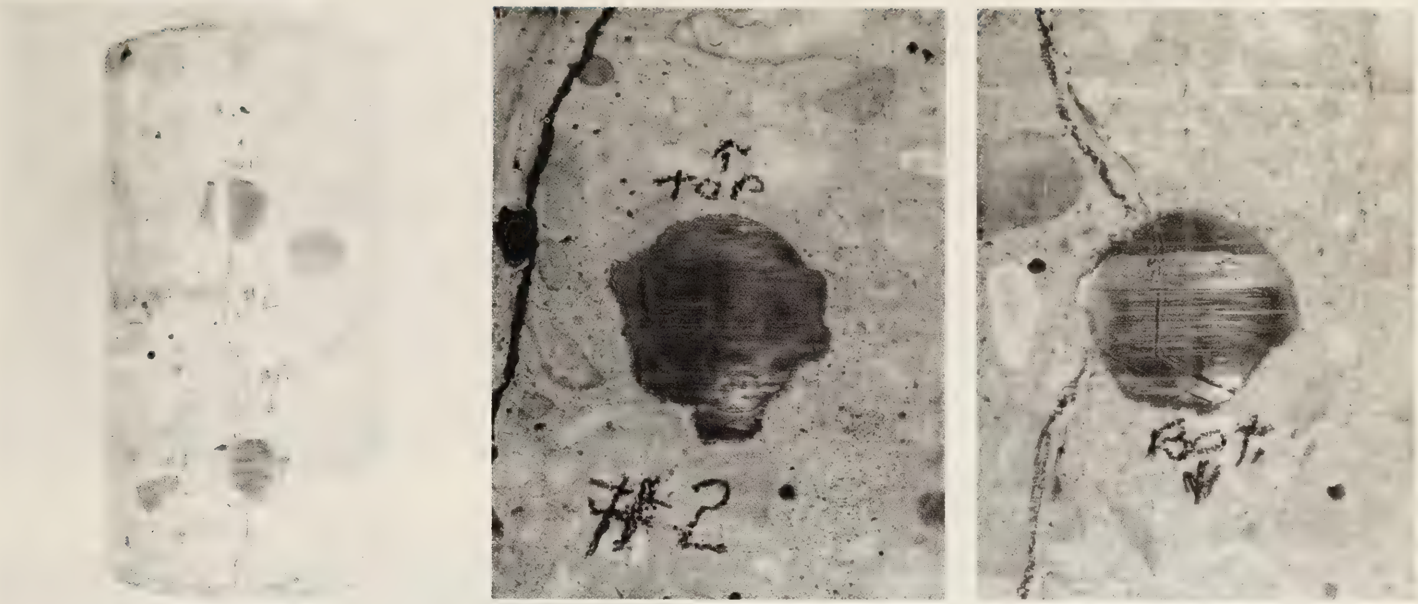


Figure 2.—Concrete Core No. 2 with reinforcement.

Core 3. Split open, top-mat steel rebar. Core 3. Split open, bottom-mat steel rebar.

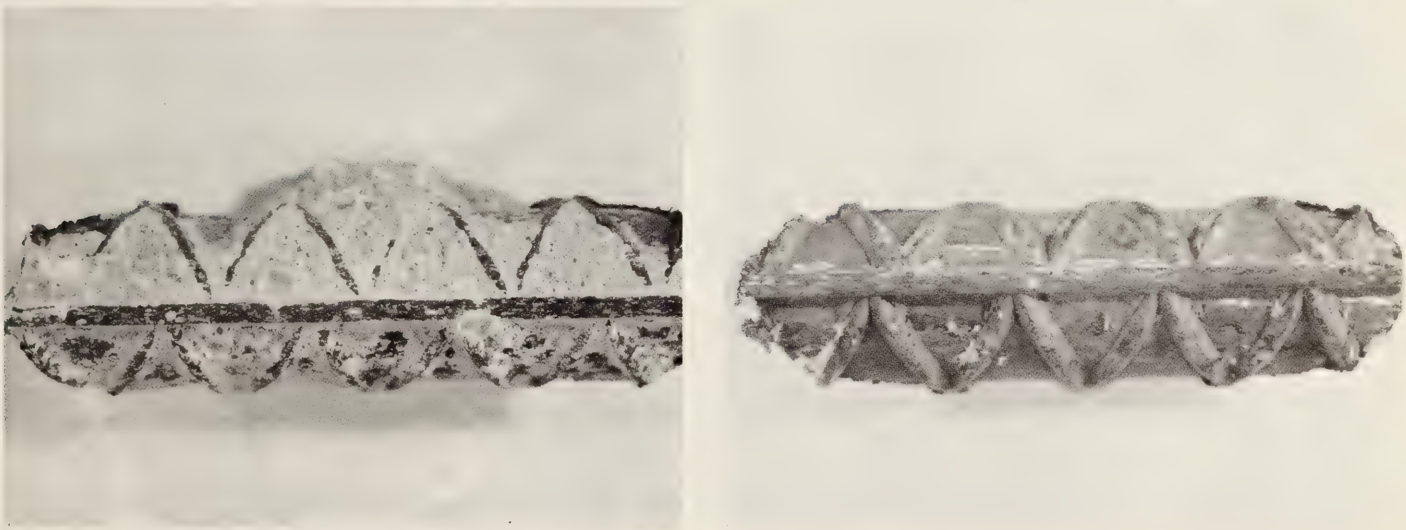


Figure 3.—Top and bottom mat steel rebar in Concrete Core No. 3.

Chemical Analysis

Concrete paste samples were collected at various depths above and below the top and bottom rebars of Core No. 3. The samples were pulverized and analyzed for the concentration of sodium and potassium ions using the atomic absorption technique. The concentration of both sodium and potassium ions around the rebar and at various distances away from the rebar had no regular pattern. Since only one core was examined, no definite conclusion could be drawn regarding the migration of these ions with current.

Pull-Out Rebar Strength

Because of limitations in the core used (e.g., the fact that the 4-in (101.6 mm) core is not a standard bond testing size as specified by ASTM C 234, and the extreme difficulty in ascertaining and loading the exact position of the embedded rebar in the extracted core) an ad hoc procedure was followed in estimating the pull-out strength of the embedded rebars. The top and bottom rebars in Core No. 2 were internally threaded and a 3-ft

(0.9 m) long threaded bar was fitted into the core rebar to pull each out in turn. (Core No. 2 was used for this test since it was the only core with rebars going through its center.) To prevent the core from splitting open, it was first encased in an epoxy-mortar mixture (fig. 4). The top rebar could not be pulled out since the threads broke at both ends of the top rebar. It initially yielded at a bond stress of 1,170 psi (8.1 MPa); the threaded rod failed at 1,322 psi (9.1 MPa). Failure to properly pull out the top rebar, a punch-out test was then tried on the bottom rebar: When the rebar broke free, however, the entire reinforced core split apart. The punch-out value under compression for the bottom rebar was 1,464 psi (10.1 MPa) bond stress. These bond stresses are higher than the 500-psi (3.4 MPa) value frequently cited as the bond's minimum requirement. Figure 5 shows the split-open concrete core after rebar extraction and the condition of bottom and top mat rebars.

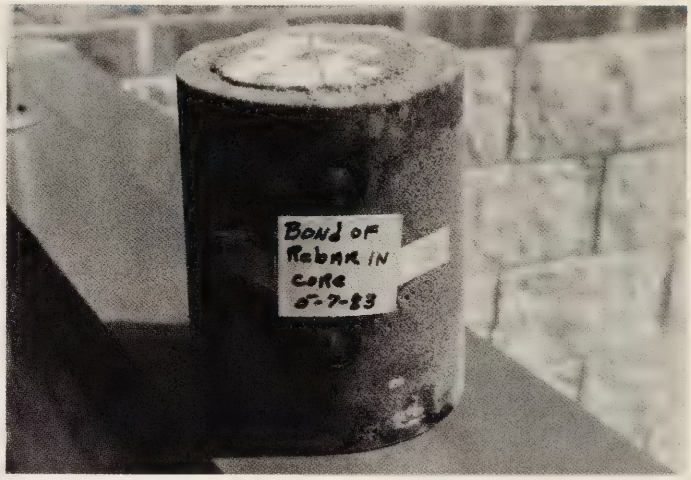
The surface condition of the extracted rebar steel on both Cores No. 2 and 3, were the same; the bottom bars were free of paste, while the upper rebars had adherent paste which was hard and tightly affixed. Test results are summarized in table 1.

Table 1.— Test results on extracted cores.

Core No.	Rebar	Pull-out Strength psi	Bar Condition
1	Top	—	—
	Bottom	—	—
2	Top	1170 a 1322 b	Rust free; cement paste adhered
	Bottom	1464 c	Rust free; no cement paste adhered
3	Top	—	Rust free; some cement paste adhered
	Bottom	—	Rust free; no cement paste adhered

1 psi = 6.9 kPa
a – Initial yield point
b – Loading System failed at this loading
c – Punch-out valve under compression

Encased concrete core in epoxy mortar.



Set-up for pulling out rebar.

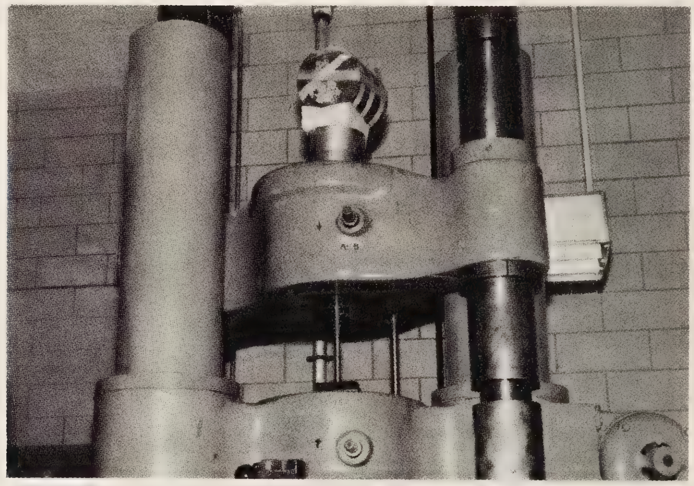


Figure 4.—Core No. 2 encased in epoxy mortar with pull-out equipment.

Conclusion

Limited physical and chemical testing of core specimens indicated no apparent deterioration of the paste around the upper rebar after the deck was under cathodic protection for 7 years. Further pull-out strength of the top rebar (single specimen) was significantly higher than the minimum often required. Similarly, scratch-hardness tests did not reveal any differences between paste around the top rebar and the rest of the concrete surface.

Concrete core after rebar is pulled out.

Embedded rebars in fractured core.

Figure 5.—Core No. 2 after pull-out test.

These results—although admittedly based on a very limited number of tests—contradict those obtained by a detailed research study in which a significant reduction in pull-out strength and softening of concrete around rebar was found after only 3.5 years of applied realistic cathodic protection current levels.

Recommendation

The conflicting results of the limited test data, strongly indicate the need for another control research study to ascertain the condition of concrete around rebars and pull-out strengths for the designed life of active cathodic protection systems under realistic field conditions. Since the completion of the limited test, such a study has been initiated by the Strategic Highway Research Program in the area of bridge component protection. (*4*)

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(*1*) C. Lock and C. Dehghanian, Report No. FHWA/OK–83/06, "Related Studies to Cathodic Protection of Reinforced Structures," *Oklahoma Department of Transportation,* January 1984.

(*2*) John B. Vrable, National Cooperative Highway Research Program Report No. 180, "Cathodic Protection for Reinforced Concrete Bridge Decks, Laboratory Phase," *Transportation Research Board,* Washington, DC, 1977.

(*3*) Donald R. Jackson, Report No. FHWA–DP–34–2, "Cathodic Protection for Reinforced Concrete Bridge Decks," *Federal Highway Administration,* October 1982.

(*4*) Strategic Highway Research Program Research Plans, Final Report, *Transportation Research Board,* Washington, DC, May 1986.

Yash Paul Virmani is a research chemist in the Structures Division in FHWA's Office of Engineering and Highway Operations Research and Development. Dr. Virmani is the program manager for the Nationally Coordinated Program, Area D4, "Corrosion Protection." He is the coinventor of conductive polymer concrete, a material that is the basis of several cathodic protection systems.

Walter R. Jones is an engineering technician in the Structures Division in the Office of Engineering and Highway Operations Research and Development in the Federal Highway Administration. He has over 22 years of experience in FHWA in conducting laboratory studies of concrete and corrosion in concrete.

Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Offices of Research, Development, and Technology (RD&T). The Office of Engineering and Highway Operations Research and Development (R&D) includes the Structures Division, Pavements Division, and Materials Division. The Office of Safety and Traffic Operations R&D includes the Traffic Systems Division, Safety Design Division, and Traffic Safety Research Division. All reports are available from the National Technical Information Service (NTIS). In some cases limited copies of reports are available from the RD&T Report Center.

When ordering from the NTIS, include the PB number (or the report number) and the report title. Address requests to:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Requests for items available from the RD&T Report Center should be addressed to:

Federal Highway Administration
RD&T Report Center, HRD-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
Telephone: (703) 285-2144

Investigation of Asphalt Additives, Report No. FHWA/RD-87/001

by Pavements Division

This report describes research which (1) identified through laboratory testing, the most promising types of additives or admixtures for reducing rutting and cracking in hot-mixed asphalt pavements; (2) developed guidelines showing how the additives can be incorporated into actual pavements; and (3) developed procedures for evaluating additives. Additives selected for evaluation included latex, black copolymer rubber, ethylene vinylacetate, polyethylene, and carbon black. All additives demonstrated the ability to substantially alter the temperature susceptibility of asphalt concrete mixtures.

Limited copies of the report are available from the RD&T Report Center.

An Evaluation of Stop Signs Used with Flashing Traffic Signals, Report No. FHWA/RD-87/066

by Traffic Safety Research Division

A study was conducted by the Development Assistance Corporation sponsored by the FHWA in cooperation with the Bureau of Transportation Engineering, City of Orlando, Florida, to evaluate the use of STOP signs at intersections when traffic signals are in a flashing mode for a good part of the day or night. The signs were blanked when the signals were operating in colors, i.e., red, yellow, green. The objectives of the project included determining the safety benefits of the use of blank-out STOP sign installation and resultant cost-effectiveness ratios. The data exhibit great variability between intersections and periods and do not enable a favorable conclusion on the effectiveness of the blank-out signs.

The report may be purchased from NTIS, PB No. 87 188058/AS, Price code: A04.

Feasibility Study of Combining HVOSM and BARRIER VII, Report No. FHWA/RD–87/084

by Safety Design Division

This report discusses the results of a feasibility study dealing with the development of a new simulation program by combining the two existing simulation programs HVOSM and BARRIER VII. The first of these programs has a sophisticated vehicle model including vehicle handling and maneuvering and one of its versions, HVOSM–RD2, even has the reported capability of crash simulation. The barrier model in HVOSM–RD2 is very crude. The second program, BARRIER VII, has a good barrier model but its vehicle model is unrealistically simple. The idea, therefore, arose about the feasibility of combining the good features of both programs to make one improved crash simulation program.

This study concludes that it is theoretically feasible to combine HVOSM and BARRIER VII to obtain a new program with improved vehicle and barrier simulation features. However, many practical problems are associated with such a development, and the effort required to accomplish this task may far outweigh the benefits. The study further concludes that the new simulation program, if developed, will at best be able to simulate the gross barrier behavior. Two finite element simulation programs, CRUNCH and GUARD, already exist to study the barrier and vehicle behavior in great detail. Therefore, it is not cost-effective to develop a new program.

The above conclusions are supported by a thorough comparison of HVOSM and BARRIER VII programs with regard to program description, mathematical model, computer program structure, and input/output requirements. The results of the study are reported in detail in this report.

This report may be purchased from NTIS, PB No. 87 191730/AS, Price code: A04

Improved Joint Systems for Concrete Pavements, Report No. FHWA/RD–86/040, FHWA/RD–86/041, FHWA/RD–86/042, and FHWA/RD–86/043

by Pavements Division

These reports present the results of research conducted under one study. The objectives of the contract were to develop improved joint systems and load transfer devices for jointed concrete pavements, and to evaluate load transfer restoration techniques and undersealing practices. Each report gives the methods used in conducting the research, a summary, and/or recommendations based on these findings.

The first report contains results of a study conducted to develop improvements to concrete pavement joints. Improvements in design identified to produce better joint performance include use of tied-concrete shoulders, widened lanes, and use of fewer non-uniformly spaced dowel bars. No new load transfer devices were developed as part of this study. The second report presents details of a computer program, denoted as JSLAB, for analysis of jointed concrete pavements. The third report presents results of an investigation conducted to obtain data to develop placement tolerances for dowels at concrete pavement joints. The results of this investigation were inconclusive. The fourth report gives results of a study conducted to evaluate the performance of "retrofit" load transfer devices installed at a test site on I–75 in Georgia. Retrofitted dowels were the only devices with satisfactory performance. A summary of practices for undersealing of concrete pavements is presented.

These reports may be purchased from the NTIS, Report No. FHWA/RD–86/040, "Improved Rigid Pavement Joints," PB No. 86 205747/AS, Price code: A08; Report No. FHWA/RD–86/041, "Analysis of Jointed Concrete Pavements," PB No. 86 203924/AS, Price code: A04; Report No. FHWA/RD–86/042, "Dowel Placement Tolerances," PB No. 86 203932/AS, Price code: A03; Report No. FHWA/RD–86/043, "Evaluation of Load Transfer Restoration Techniques and Undersealing Practices," PB No. 86 203957/AS, Price code: A05.

Weigh-in-Motion and Response Study of Four Inservice Bridges, Final Report, Report No. FHWA/RD–86/045

by Structures Division

This report presents the results of a 30-month investigation during which an FHWA weigh-in-motion (WIM) system was redesigned and used to acquire and process simultaneous truck weight plus bridge response data from 19,402 trucks crossing four inservice bridges in Pennsylvania. The new system is designated the WIM+RESPONSE system. The WIM+RESPONSE system is capable of acquiring and processing data to provide information on simultaneous bridge loading and response including gross vehicle weight and stress range distributions, strain rates, maximum stresses, load distribution, and dynamic effects.

Limited copies of the report are available from the RD&T Report Center.

Protective Systems for New Prestressed and Substructure Concrete, Final Report, Report No. FHWA/RD–86/193

by Structures Division

A 3-year research study on 11 corrosion protection systems was undertaken in two laboratory studies A total of 124 small reinforced concrete slabs were subjected to a 48-week, cyclic wet and dry salt water exposure in one part of the study. Another part of the study dealt with cyclic salt water exposure on 19 full-size sections of reinforced concrete columns and beams, precast, prestressed piles and stay-in-place bridge deck panels. Design considerations are suggested for the different corrosion protection materials to provide for greater corrosion protection for new cast-in-place reinforced concrete and precast, prestressed concrete bridge members.

Limited copies of the report are available from the RD&T Report Center.

Safer Timber Utility Poles, Summary Report, Report No. FHWA/RD–86/154

by Safety Design Division

Two methods of modifying timber utility poles to radically increase the safety of passengers in impacting vehicles have been developed. The first is a slipbase installed on the pole at the groundline and an upper hinge mechanism located about 20 ft above ground. Development of this breakaway hardware is complete. Its performance has been proven by the results of full-scale vehicle compliance tests. This breakaway system is ready for selective implementation. The second is a breakaway attachment for down guy wires. The breakaway guy wire hardware has been successfully crash tested and developed, and is

ready for implementation. A device called the CAM, which prevents vehicles from directly impacting a utility pole, has been subjected to a single feasibility test. It exhibited good potential. However, the CAM requires further development and appropriate compliance testing before implementation can be considered. A new method of evaluating compliance tests for breakaway timber utility poles has been described. The "safety philosophy" which forms the basis for the new method may be generally applicable to roadside safety improvements.

Limited copies of the report are available from the RD&T Report Center.

Environmental Evaluation of Calcium Magnesium Acetate (CMA), Report No. FHWA/RD-84/094

by Pavements Division

To promote the safe, effective operation of our transportation system year round, many highway departments have adopted a bare pavement policy in areas affected by snow and ice. As a result, the use of sodium chloride (NaCl) as a deicing chemical has increased dramatically since the mid 1950's. Currently, between eight and ten million tons of NaCl are used annually in the United States for highway snow and ice control.

NaCl may have adverse effects on vehicles, pavements, structures, vegetation, wildlife, and water supplies; therefore, research was undertaken to develop alternative deicing chemicals. As a result, calcium magnesium acetate (CMA) has been identified as a potential alternative to NaCl. CMA is effective in melting ice and snow, is easily stored, can be dispersed with existing equipment, is noncorrosive, and appears to be environmentally acceptable. However, CMA is at least 10 times more costly than NaCl.

The purpose of this study was to conduct a literature and limited laboratory evaluation of the potential interactions of CMA with the environment and to identify potential beneficial/detrimental impacts. It addresses impacts of CMA on surface water, groundwater, and air quality, as well as aquatic and terrestrial ecology.

The report may be purchased from the NTIS, PB No. 86 228541/AS, Price code: A05.

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

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Implementation, Offices of Research, Development and Technology (RD&T), Federal Highway Administration. Some items by others are included when the items are of special interest to highway agencies. All reports are available from the National Technical Information Service (NTIS).

When ordering from the National Technical Information Service, use PB number and/or the report number with the report title, and address requests to:

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Requests for items available from the RD&T Report Center should be addressed to:

Federal Highway Administration
RD&T Report Center, HNR-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
Telephone: (703) 285-2144

Accessibility for Elderly and Handicapped Pedestrians – A Manual for Cities, Report No. FHWA–IP–87–8

by Office of Implementation

This users manual provides guidance for implementing the accessibility provisions for elderly and handicapped pedestrians in the city environment. It draws upon the state of the practice of eight cities and uses nationally accepted standards.

The report describes a method for planning and programming accessible pedestrian routes in cities. It provides explanations of the details needed to execute an accessible pedestrian route.

The report may be purchased from NTIS, PB No. 88 113170/AS, Price code: A10.

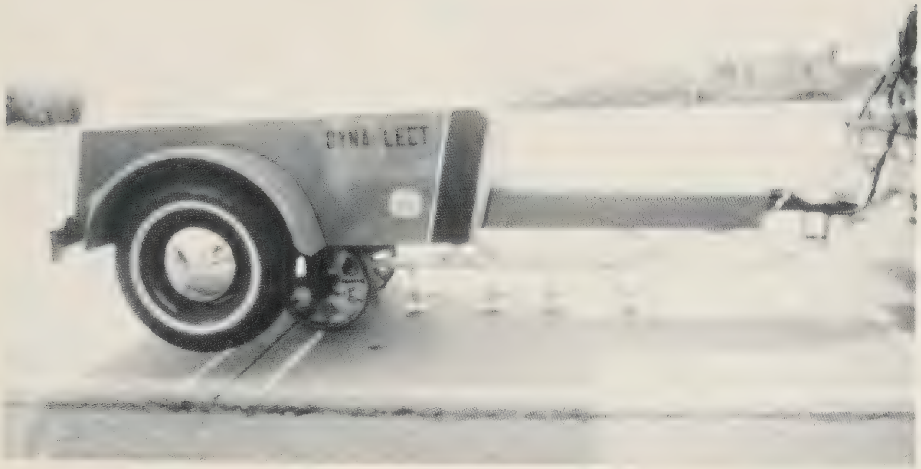
Value Engineering Study of Guardrail and Impact Attenuator Repair, Report No. FHWA–TS–87–226

by Office of Implementation

This report summarizes the findings, results, and recommendations from a series of three Value Engineering meetings relating to the repair and maintenance of guardrail and impact attenuators. The study was conducted cooperatively by the Florida, North Carolina, and Virginia Departments of Transportation.

If implemented, the recommendations detailed in the report can be expected to reduce (a) the unit cost of attenuator maintenance, (b) the cost of guardrail maintenance, (c) the number of impacts and the resultant costs of repair and replacement, and (d) speed the repair/replacement process, thus, reducing labor costs per incident.

Limited copies of the report are available from the RD&T Report Center. Copies also may be purchased from NTIS, PB No. 88 119987/AS, Price code: A04.



Evaluation of Pavement Deflection Measuring Equipment, Report No. FHWA-TS-87-208

by Office of Implementation

This report documents the research performed for the Federal Highway Administration on evaluation of pavement deflection equipment. Devices included in side-by-side field tests were the Benkelman Beam, C.E.B.T.P. Curviameter, Dynaflect, Dynatest Falling Weight Deflectometer (FWD), Kuab FWD, Phonix FWD, and the Road Rater. The report includes descriptions and comparisons of the devices through information obtained from a literature search, field tests, and user survey conducted for this study.

The side-by-side test program was performed over a broad range of pavement structures, including thick and thin flexible and rigid pavements, and composite pavements. The measured deflections were compared statistically, and interpretations of the deflection basis were made.

The report concludes that, based on the interpretation of field data, all devices gave comparable results on the tested pavements, except the Curviameter which gives invalid results on rigid and composite pavements. In addition, the Benkelman Beam and Curviameter exhibited much larger variability in comparison with the other devices.

The report may be purchased from NTIS, PB No. 88 117114/AS, Price code: A08.

Traffic Forecasting for Pavement Design, Report No. FHWA-TS-86-225

by Office of Implementation

Vehicular loading is an important input parameter in the pavement design process. However, accurately forecasting traffic loading over the design life of a pavement is a very difficult task. Many past forecasts have not been representative of actual traffic conditions because of overloaded trucks avoiding weighing scales and insufficient traffic sampling programs. In addition, most forecasting procedures have not reflected increases in legal load limits, significant increases in the volume of heavy trucks, or the shift to larger trucks that have occurred in recent years. All of these factors have contributed to insufficient forecasts which can result in significant differences between actual and anticipated pavement performance.

A multi-State study concerning traffic forecasting for pavement design has recently been completed. Representatives from four States (Florida, Kentucky, Oregon, and Washington) met on three occasions to discuss the subject. Some specific topics of these discussions included data input needs, equipment and methods used to collect data, algorithms and models used to make predictions, and levels of sophistication for forecasting procedures.

Each participating State representative contributed to the preparation of a summary report. This report addresses many important aspects of traffic forecasting and discusses available options for each step of the process. Those individuals that develop and use traffic forecasts for pavement design purposes should find the information in this document to be interesting and useful.

The report may be purchased from NTIS, PB No. 88 115506/AS, Price code: A08.

New Research in Progress

The following new research studies reported by FHWA's Office of Research, Development, and Technology are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description and contact the following: Staff and administrative contract research—*Public Roads* magazine; Highway Planning and Research (HP&R)—performing State highway or transportation department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, DC 20418.

NCP Category A—Highway Safety

NCP Program A.2: Improved Driver Visibility of Roadway Environment

Title: A Mobile System for Measuring Retroreflectivity of Traffic Signs. (NCP No. 5A2A1110)
Objective: Develop a practical system concept for measuring the retroreflective properties of inservice traffic signs in daylight from a moving vehicle. Demonstrate the feasibility of the system concept by devising and testing a proof-of-concept model.
Performing Organization: Ektron Applied Imaging, Bedford, MA 01730
Expected Completion Date: March 1989
Estimated Cost: $150,000 (NCHRP)

NCP Program A.5: Design

Title: Traffic Barriers on Curves, Curbs, and Slopes. (NCP No. 3A5B1012)
Objective: Improve the effectiveness of guardrails. Guidelines will be offered for the placement of existing guardrail types on downslopes. Develop guardrail hardware designs that offer improved performance on downslopes and curves. Examine effects of curbs on the performance of guardrails. Make recommendations for the design and placement of traffic railings on curves and nontangent locations.
Performing Organization: ENSCO, Inc., Springfield, VA 22151
Expected Completion Date: December 1991
Estimated Cost: $632,000 (FHWA Administrative Contract)

Title: Work Zone Control for Highway and Bridge Construction. (NCP No. 5A5D1016)
Objective: Develop improved end treatments for temporary traffic barriers, traffic control plans, and user guidelines for restricted work–zone situations.

Performing Organization: Texas A&M University, College Station, TX 77843
Expected Completion Date: October 1990.
Estimated Cost: $500,000 (NCHRP)

NCP Category C—Pavements

NCP Program C.2: Evaluation of Flexible Pavements

Title: Study of AC Stripping Problems and Corrective Treatments. (NCP No. 3C2A3082)
Objective: This is a follow–up study of two previous FHWA research studies entitled, "Introduction of Lime into Asphalt Concrete Mixtures," and "Evaluation of Procedures Used to Predict Moisture Damage in Asphalt Mixtures." The first study involved the experimental construction of 15 test sections in four States while the second study was conducted in the laboratory with moisture susceptible materials provided by State Highway Agencies. The objective of this contract is to use the preliminary conclusions reached in the earlier studies and combined with both laboratory testing and field sampling and condition surveys to produce definitive results.
Performing Organization: Austin Research Engineers, Inc., Austin, TX 78746.
Expected Completion Date: March 1990
Estimated Cost: $347,000 (FHWA Administrative Contract)

NCP Program C.3: Field and Laboratory Testing

Title: Calibration of Profilographs (NCP No. 3C3A1182)
Objective: Calibration procedures for different types of profilographs. Provide calibration factors, curves, and data on repeatability for each system. Develop kinematic models of different systems, and conduct simulation runs.
Performing Organization: Penn State University, University Park, PA 16802
Expected Completion Date: November 1988
Estimated Cost: $110,000 (FHWA Administrative Contract)

NCP Program C.4: Management Strategies

Title: Impact of Truck Characteristics on Pavements—Truck Load Equivalency Factors. (NCP No. 3C4A2012)
Objective: Determine the degree of pavement damage caused by various types of heavy vehicles. Develop guidelines to estimate the damage caused by current and anticipated vehicle types based on pavement response. Test heavy vehicles of various axle configurations for the measured responses with instrumented pavements.
Performing Organization: ARE, Inc., Austin, TX 78746
Expected Completion Date: September 1989
Estimated Cost: $410,000 (FHWA Administrative Contract)

NCP Category D—Structures

NCP Program D.1: Design

Title: Fatigue Behavior of Welded and Mechanical Splices in Reinforcing Steel. (NCP No. 5D1B1032)
Objective: Evaluate the fatigue behavior of, and develop practical fatigue guidelines for welded and mechanical splices for reinforcing steel in bridges. Review current practice and literature, conduct laboratory tests, and develop design guidelines.
Performing Organization: Wiss, Janney, Elstner & Assoc., Chicago, IL 60062
Expected Completion Date: April 1990
Estimated Cost: $300,000 (NCHRP)

Title: Enhancement of Culvert Analysis and Design Model. (NCP No. 3D1D1012)
Objective: Enhance the advanced computerized method for "Culvert Analysis and Design" (CANDE) by adding routines for designing culverts having stress-relieving slotted bolt holes. Make program code corrections to CANDE to assure convergence and consistent computation of moments. Develop a unified CANDE users manual. Develop a study format for States to apply CANDE to develop charts and tables for fill heights. Develop easier to use and automatic application routines that reduce time and effort required to execute solutions.
Performing Organization: Syro Steel Company, Centerville, UT 84014
Expected Completion Date: September 1988
Estimated Cost: $62,000 (FHWA Administrative Contract)

NCP Program D.2: Management

Title: Develop Post Processor for Program "BRUFEM" to Obtain Bridge Rating on Non-Posttensioned Concrete Bridges. (NCP No. 4D2B2032)
Objective: Program "BRUFEM" is a finite element program for bridge rating of posttensioned concrete bridges. Expand the post processor for inclusion of non-posttensioned bridges (AASHTO and Bulb Tee), reinforced concrete tee beams (simple and continuous), and simple and continuous reinforced concrete flat slabs.
Performing Organization: University of Florida, Gainesville, FL 32611
Funding Agency: Florida Department of Transportation
Expected Completion Date: August 1991
Estimated Cost: $328,000 (HP&R)

Title: Simple Load Capacity Tests for Bridges to Determine Safe Load Posting Levels. (NCP No. 4D2B1102)
Objective: Develop a simple instrumentation system and field test procedure to evaluate the load capacity of existing bridges. Test eleven State bridges to validate the system and technique. Train PennDOT staff in using the system.
Performing Organization: University of Colorado, Boulder, CO 80309
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: December 1989
Estimated Cost: $206,000 (HP&R)

Title: Automation of Bridge Inspection Process. (NCP No. 4D2B2044)
Objective: Review techniques currently used by the State for bridge inspection. Review current state-of-the-art techniques for field data acquisition and recommend tools and equipment to improve the State's procedures.
Performing Organization: University of Central Florida, Orlando, FL 32816
Funding Agency: Florida Department of Transportation
Expected Completion Date: September 1989
Estimated Cost: $111,000 (HP&R)

NCP Program D.3: Hydraulics

Title: Measuring Performance of Bridges During Floods. (NCP No. 3D3C1102)
Objective: Conduct a field study to measure scour performance and stability of bridges, and bridge approaches, observe scour countermeasures, and quantify resulting flood damages. Evaluate causative failure mechanisms. Develop, calibrate, and verify procedures for estimating magnitude of local scour, bridge construction scour, and general scour and degradation, and develop improved design methods for scour resistant piers and abutments and countermeasures for bridges and highway structures.
Performing Organization: U.S. Geological Survey, Reston, VA 22092
Expected Completion Date: July 1990
Estimated Cost: $205,000 (FHWA Administrative Contract)

Title: Formulation of New Hydrologic Methodologies. (NCP No. 4D3A2912)
Objective: Assemble data base of rainfall, runoff, and other hydrologic information relevant to highway-related drainage. Study rainfall inputs and drainage design options, and develop procedures for selection of appropriate storm data design

techniques for use on relatively small drainage basins.
Performing Organization: Universty of Florida, Gainesville, FL 32611
Funding Agency: Florida Department of Transportation
Expected Completion Date: September 1990
Estimated Cost: $158,000 (HP&R)

Title: Calibration of Hydrologic Models for Maryland. (NCP No. 4D3A2932)
Objective: Compile a data base, calibrate the unit hydrograph and the inputs to it, and calibrate the channel routing method to improve the accuracy of the hydrograph model for use in Maryland.
Performing Organization: University of Maryland, College Park, MD 20742
Funding Agency: Maryland State Highway Administration
Expected Completion Date: March 1989
Estimated Cost: $99,000 (HP&R)

NCP Program D.4: Corrosion Protection

Title: Evaluation and Condition Assessment of Deck Protective Systems. (NCP No. 3D4C0282)
Objective: Identify the most cost-effective system to stop or reduce the deterioration of concrete caused by the corrosion of the reinforcing steel. Various techniques will be compared on selected bridge decks.
Performing Organization: Norton Corrosion Engineering, Bothell, WA 98011
Expected Completion Date: September 1990
Estimated Cost: $325,000 (FHWA Administrative Contract)

Title: Premature Failures of Latex-Modified Concrete Bridge Overlays in Ohio. (NCP No. 4D4C0302)
Objective: Evaluate the premature cracking, spalling, and delamination of latex-modified concrete overlays on various bridge decks in Ohio. In addition, the study will identify the causes of these problems, and develop guidelines and recommendations for longer overlay life with reduced maintenance.
Performing Organization: CTL Engineering, Inc., Columbus, OH 43204
Funding Agency: Ohio Department of Transportation
Expected Completion Date: October 1988
Estimated Cost: $93,000 (HP&R)

NCP Program D.9: Technology Transfer for Structures

Title: Inspection of Marine Timber Piling. (NCP No. 3D9B0083)

developed nondestructive testing technique for determining the in-place residual strength of marine timber piling. Incorporate up-to-date results of pile testing relating nondestructive data with pile strengths. Develop comprehensive users manual.
Performing Organization: University of Maryland, College Park, MD 20742
Expected Completion Date: June 1988
Estimated Cost: $82,000 (FHWA Administrative Contract)

Title: Detecting Cable Flaws in Prestressed Concrete by Magnetic Field Disturbance. (NCP No. 3D9B0053)
Objective: Evaluate the field performance of the magnetic field disturbance system by using it to inspect inservice prestressed concrete beams with known or presumed flaws. One or more States will be allowed to use the system so it will gain credibility.
Performing Organization: University of Wisconsin, Madison, WI 53707
Expected Completion Date: June 1988
Estimated Cost: $63,000 (FHWA Administrative Contract)

NCP Category E—Materials and Operations

NCP Program E.2: Cement and Concrete

Title: Durability Testing of High-Strength Concrete Containing High-Range Water-Reducing Admixtures. (NCP No. 3E2B3002)
Objective: Investigate the significance of various concrete properties, such as air void characteristics, on the durability of high strength concretes (compressive strengths greater than 4,000 psi) containing high-range water-reducing admixtures. Compare and assess the variance of durability factors calculated from various methods of testing concretes for freeze-thaw durability.
Performing Organization: Utah State University, Logan, UT 84321
Expected Completion Date: March 1990
Estimated Cost: $250,000 (NCHRP)

NCP Program E.8: Construction Control and Management

Title: Evaluation of New Nuclear Density Gauges on Asphalt Concrete. (NCP No. 3E8A3012)
Objective: Evaluate, in the laboratory and the field, roller-mounted nuclear density gauges, and establish the capability of commercially available static nuclear gauges for monitoring the density of thin (1- to 2-in thick) asphalt concrete layers.
Performing Organization: Analysis Group, Inc., Washington, DC 20006
Expected Completion Date: March 1989
Estimated Cost: $175,000 (FHWA Administrative Contract)

NCP Program E.9: Technology Transfer for Materials and Operations

Title: Expert Witness on Earthwork and Foundation Claims. (NCP No. 3E9C2164)
Objective: Modify the existing course materials by updating and expansion, and conduct up to 30 presentations over a 28-month period. Each course will be presented by two instructors, i.e., a geotechnical engineer, and an attorney familiar with expert witness testimony.
Performing Organization: Hill International, Inc., Willingboro, NJ 08046
Expected Completion Date: October 1990
Estimated Cost: $208,000 (FHWA Administrative Contract)

NCP Category H—R&D Management and Coordination

NCP Program H.3: General Support Service

Title: Use of Electronic Media for Technology Transfer. (NCP No. 3H3C0106)
Objective: Evaluate and adapt existing electronic media for technology transfer to reach emerging audiences at a reduced cost. Among the systems to be considered are computer-generated graphics, microcomputers with laser disc interfacing, and microcomputer/display systems. These devices will be used in conjunction with "expert systems" for training Highway personnel.
Performing Organization: STATCOM, Inc., Herndon, VA 22071
Expected Completion Date: September 1989
Estimated Cost: $225,000 (FHWA Administrative Contract)

ERRATA

On page 66 of the December 1987 issue of *Public Roads* magazine, under Highway Planning and Research Program Pooled-Fund Study, three additional States are among the 24 highway agencies now participating in this study: Colorado, Virginia, and Wisconsin.

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