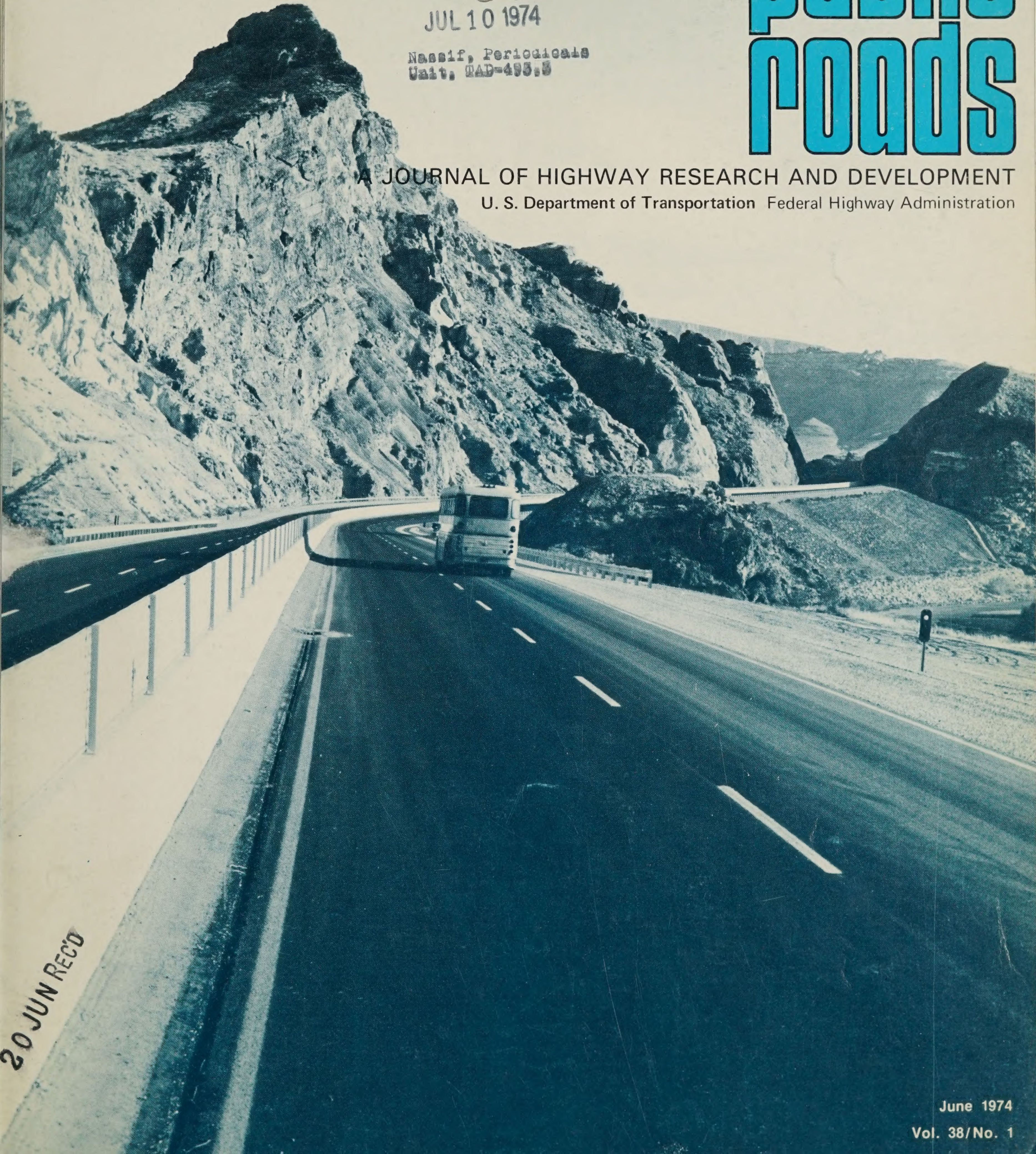
public roads

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT
U. S. Department of Transportation Federal Highway Administration



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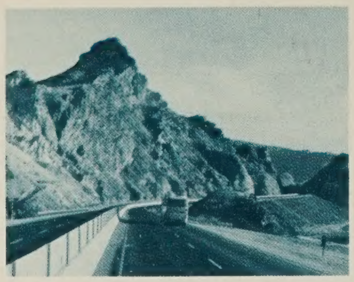

COVER:

Interstate 15 through the Virgin River Canyon in the northwest corner of Arizona. (Photo courtesy of the Arizona Highway Department.)

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NOTICE — The title sheet for vol. 37 is now available. (See page 27.)

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Public Roads, A Journal of Highway Research and Development, is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, at $6.10 per year ($1.55 additional for foreign mailing) or $1.55 per single copy. Subscriptions are available for 1-, 2-, or 3-year periods. Free distribution is limited to public officials actually engaged in planning or constructing highways and to instructors of highway engineering. A limited number of vacancies are available at present.
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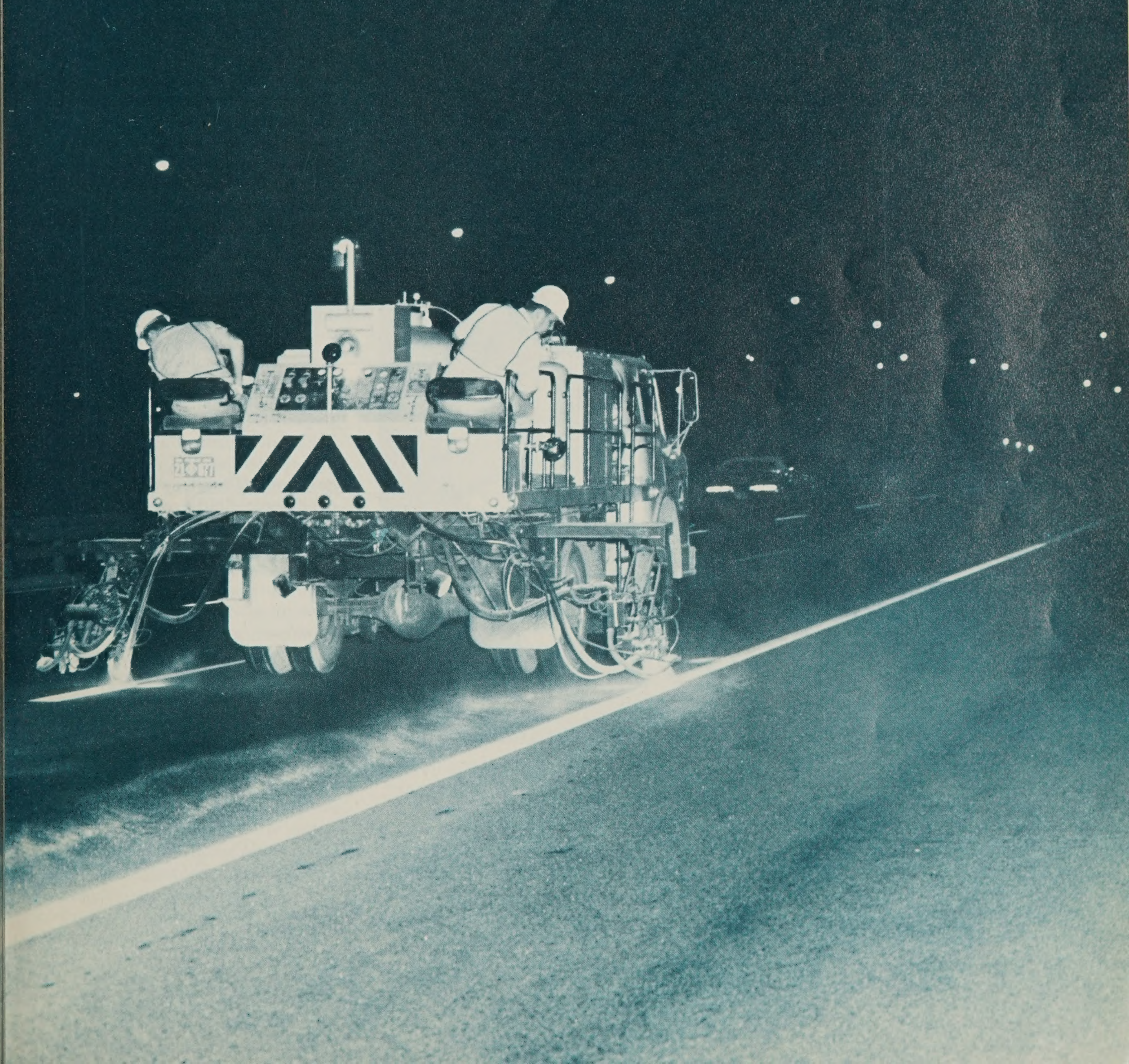
Training for Highway Maintenance Managers

by William N. Records[1]

[1]This article was written by Mr. Records while he was serving as Senior Implementation Manager in the Implementation Division, Office of Development, in Washington, D.C.

"Training for maintenance managers—who needs it?" Twenty-five years ago, most highway department officials would have responded in this manner if asked to comment on special training programs for the field engineers, superintendents, foremen, and crew leaders who are responsible for managing maintenance activities. But much has happened in the last quarter of a century to change attitudes toward this type of training.

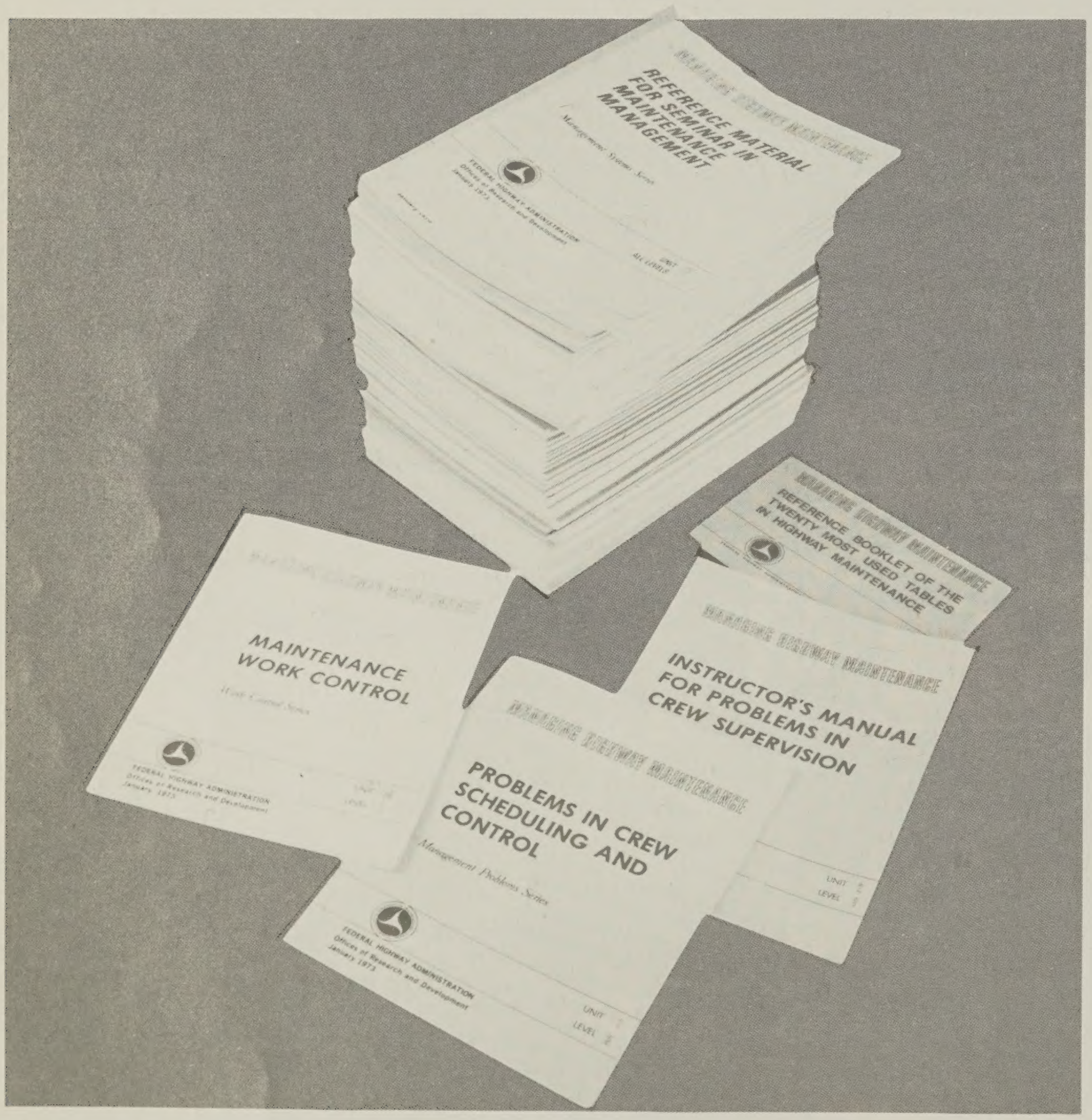
First, there has been a major effort to identify the problems associated with highway maintenance. Federal, State, county, and city agencies conducted a series of in-depth research studies on maintenance operations and management. Data from these studies clearly showed that this was a complex field which encompassed a wide variety of activities. The data also pinpointed a number of major problems, primarily due to management deficiencies.



Pressure for change also came from other directions. Most agencies were faced with the following situations:

- Expanding maintenance workloads due to construction of new facilities.

- Demands for higher levels of service.



- Shortages of qualified personnel.

- Constrictions on maintenance budgets.

- Tightened fiscal and administrative controls.

Problems multiplied and it became obvious that traditional maintenance management procedures were inadequate.

Several State, county, and city agencies became convinced that something could be done to improve the situation. Beginning in 1963, they developed procedures for a systems approach to planning, organizing, directing, and controlling maintenance operations. Field tests of these new procedures demonstrated that in addition to solving many serious problems, they also produced significant benefits. For example, several agencies improved the quality and uniformity of their routine maintenance activities and at the same time reduced their annual costs by millions of dollars.

To date, more than 100 Federal, State, county, and city highway agencies have implemented or have begun to implement the procedures for new maintenance management systems. The implementation process usually involves adaptation of procedures used by other organizations, limited field tests, and agency-wide installation over a period of weeks or months. Field managers are expected to learn how to use the new procedures by reading manuals, attending meetings, and getting pointers from their bosses; rarely do they receive formal training. This approach has not always produced the desired results.

The need for special training first became apparent in 1965, when the Virginia Department of Highways began to implement a maintenance management system. As other States encountered similar experiences, the need became more urgent until, in 1969, the Federal Highway Administration (FHWA) decided to allocate funds for an administrative contract to research and develop a curriculum for training highway maintenance managers. The contractor began work in June 1970.

The work was divided into two phases. Phase I involved: (1) Defining the knowledge, skills, and abilities (KSA's) needed by personnel who are responsible for implementing and maintaining a maintenance management system; (2) conducting a survey of highway, industrial, and military organizations to obtain information on the effectiveness of various training techniques; and (3) testing a representative group of field managers to uncover training needs. The results from all of these activities were used in designing the curriculum and working out administrative aspects for using it in training programs.

Phase II of the contract covered the actual development of the curriculum. The first step was to establish specific training objectives for each course. Once that was accomplished, course material was written and illustrated. As a parallel activity, instructor manuals were developed for courses involving lectures, group discussions, or discussions of management case problems. All materials were then reviewed by a panel of experts from State and county highway organizations.

After the panel approved the training materials, they were field tested in Colorado, Georgia, New York, and Wyoming on groups of typical maintenance managers. Supervisors and engineers from each State scheduled the training and acted as instructors. The tests were observed by contractor personnel who made on-the-spot corrections when problems were encountered. The revised materials were again reviewed and approved by the panel.

The result of this work is a curriculum with 17 training units for each of three levels of field managers. These units are grouped in five broad areas—management problems, management by objectives, work planning, work control, and management systems. The *management problems* area includes training units on crew scheduling and control, supervision, and maintenance management. These units emphasize the difficulties encountered in day-to-day operations.

Training units in the area of *management by objectives* offer solutions to some of the problems by describing a framework for planning and controlling maintenance. Concepts such as standards, work units, and work programs are explained and illustrated. The *work planning* and *work control* groups involve training units on procedures

for scheduling, reporting, and controlling the results of maintenance operations. This includes information on practical ways to apply the basic principles of good management. The final group has only one training unit—a six-session seminar on *maintenance management systems*. Here all of the concepts and procedures covered in the other four groups are summarized and related to show how the systems approach works.

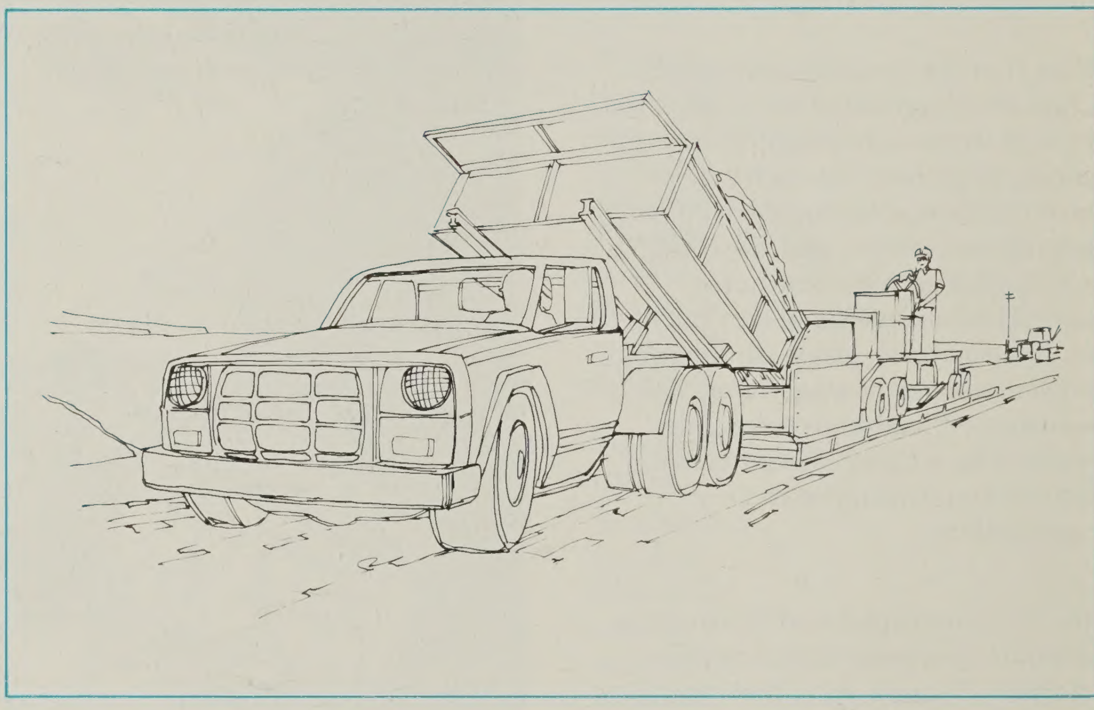
About 80 percent of the training material is in the form of self-instructional workbooks. A typical example of this material can be found on pages 6 through 8.

As noted, the curriculum had 17 training units for each of three levels of managers. It also includes certification tests, reference data, instructor manuals, and a catalog. These materials are contained in 73 printed pamphlets ranging in size from 12 to 168 pages, as shown on page 2. The catalog includes a brief description of each training unit and information about use of the curriculum in a formal training program. It also has a diagram showing the relationship of the various training units.

The contractor completed work on the curriculum in October 1972. The final draft was reviewed by appropriate FHWA offices and, with minor changes, approved for distribution through the National Highway Institute (NHI). Under the Federal-Aid Act of 1970, the Institute is responsible for making training opportunities available to personnel of the Federal, State, and local highway agencies.

About this time, plans were formulated for an implementation campaign sponsored by the FHWA Offices of Research and Development, Office of Highway Operations, NHI, and nine regional offices. This campaign involved:

- Printing and distributing 2,500 copies of the catalog.
- Printing 300 bound sets of the curriculum for distribution to agencies desiring to see a sample of the training materials.
- Printing 100 unbound sets of the curriculum (printed one side only on coated paper) for distribution to agencies planning to reprint the materials for use in training programs.
- Conducting a series of 1-day workshops to acquaint administrators, training officers, and maintenance managers with the curriculum.



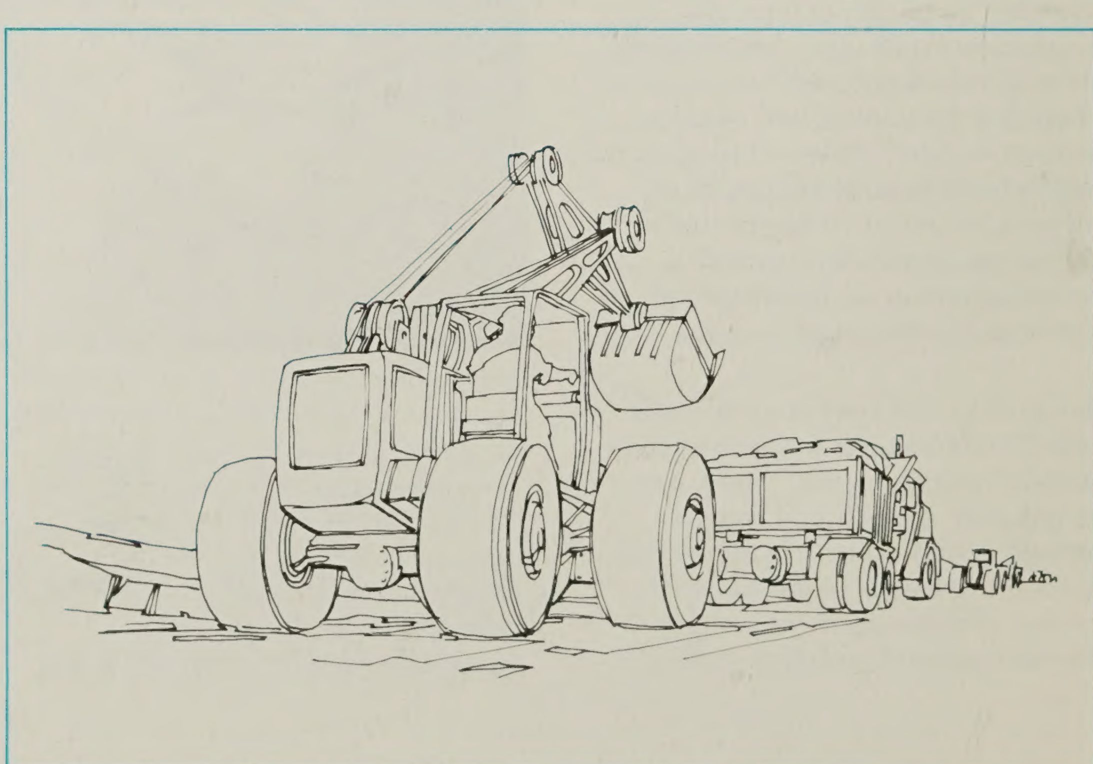


Table 1.—Distribution of materials as of March 1, 1974

Agencies	Catalogs	Bound sample sets	Unbound reproducible sets
FHWA	150	20	2
Other Federal	50	13	3
State	800	54	29
County	850	32	5
City	250	30	5
Tollroad	50	3	1
Other	350	33	3
Total	2,500	185	48

Distribution of the materials as of March 1, 1974, is shown in table 1.

A test version of the 1-day workshop was conducted in Washington, D.C., during January 1973. After revising the format, arrangements were made to conduct sessions in 27 cities in 23 States. There were more than 850 participants including representatives of:

- FHWA offices
- 8 other Federal agencies
- 45 State agencies
- 128 county agencies
- 57 city agencies

The initial campaign has been completed, but implementation efforts are being continued. NHI will make the curriculum available to highway agencies across the Nation and will assist in developing training programs based on the materials. They are already providing this type of assistance to a number of agencies and will continue to do so as long as such a service is needed.

The research, development, and implementation of the FHWA curriculum for training highway maintenance managers has required a great deal of time and money. This investment will begin to pay off only when highway agencies begin to use and benefit from the training. A beginning has been made in 10 States and another 20 agencies are committed to using some part of the available materials. It seems reasonable to expect that more than 5,000 field maintenance managers will be using the curriculum in the next 5 years. If this estimate is correct, the effort will have paid off handsomely.

More information about the curriculum can be obtained by contacting the Director, National Highway Institute, Federal Highway Administration, Washington, D.C. 20590.

Managing Highway Maintenance

An example from Unit 1, Level 2,
Problems in Crew Scheduling and Control

Frame 81

Ted Simpson is in charge of scheduling work for 6 foremen. As a general practice, he prepares a weekly schedule that shows what work is to be done, which foreman will be in charge of the work, and what manpower, equipment, and materials are to be used. It is a good schedule.

It is Monday morning and all 6 crews are doing the scheduled work.
On Monday afternoon:

WEEKLY SCHEDULE FOR AREA TWO

CREW FOREMAN	WORK DAY				
	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
1	Premix Patching	→	→	→	→
2	Paint Guardrail	→	→	Empty Litter Barrels	→
3	Mowing	→	→	→	→
4	Paint Sign Posts	→	→	→	→
5	Clean Ditches	→	→	→	Service Equipment
6	Reshape Shoulders	→	Grade Roads	→	→

A leader of the community calls the office with a complaint about bumpy spots on Route 10. Ted gets the message.
The centerline paint crew arrives in Ted's area and requests two men for traffic control.
Someone calls the office to report a rough railroad crossing. Ted makes a note of what needs to be done.
At the end of the day, one of Ted's foremen says that several litter barrels on Route 17 need to be emptied.

It is Tuesday morning. What will happen?

A. Most of the work originally scheduled for today will be put off until another time. *Go to Frame 82.*

B. The original schedule will be followed and Monday's complaints will be taken care of in next week's schedule. *Go to Frame 83.*

C. Ted will decide which work is most important and adjust the schedule to fit this decision. *Go to Frame 84.*

Frame 82

Scheduled work will be postponed. Some supervisors would delay the schedule until the bumpy spots and rough crossing were repaired. Some would give Monday's complaints top priority, but not Ted. He knows that it doesn't do much good to prepare a schedule and forget it. The scheduled work may be just as important as Monday's complaints.

Pick another answer from Frame 81.

Frame 83

The original schedule will be followed. Yes, it will—almost. If nothing else, Ted will rework the schedule so that the paint crew gets the two men it needs for traffic control.

Monday's complaints will be taken care of in next week's schedule. Maybe, but the bumpy spots and the rough railroad crossing could be bad enough to demand immediate attention. If this is true, part of the schedule will not be followed. This answer is not exactly correct.

Try another from Frame 81.

Frame 84

Ted will decide which work is most important and adjust the schedule. Right. This is the most likely course of action.

The schedule is adjusted: Two men from the mowing crew are loaned to the paint crew, and the patching crew is asked to repair the railroad crossing. Ted decides that the bumpy spots on Route 10 will have to wait until Wednesday. The litter barrels will be emptied on Thursday—as scheduled.

The modified schedule is used on Tuesday. Wednesday morning Ted gets a call from the police. It seems that someone hit a section of guardrail and bent two sign posts—last week. The signs are in good condition, but the sign posts will have to be straightened. The guardrail posts and rail sections have to be replaced.

So the schedule is not as good as it first appeared. What will happen to the schedule for Thursday?

A. Most of the work originally scheduled for Thursday will not get done. *Go to Frame 85.*

B. Ted will again decide which work is most important and adjust the schedule. *Go to Frame 86.*

Frame 85

Most of the work will not get done. Why not? One of the six crews can begin work on the damaged guardrail and sign posts without wrecking most of the schedule. Part of another crew is working for the paint crew, but even this does not prevent most of the scheduled work from being done. Turn to Frame 86.

Frame 86

The schedule will be adjusted again. Right. The guardrail and sign posts probably have a higher priority than some of the work originally scheduled for Thursday. Ted does not want to change the schedule, but something has to give—maybe the ditch cleaning. Maybe not.

Friday is the same story. Other work needs are identified. Some are more serious than the work originally scheduled. Some can be done whenever there is time.

It has been a normal week for Ted Simpson. He becomes confused and frustrated because some of the work he scheduled for this week was postponed.

How do the six foremen feel about the repeated changes in the schedule?

A. There is less interest in the work and morale is low. *Go to Frame 87.*

B. They think Ted doesn't know his job very well. *Go to Frame 88.*

C. They probably are just as confused and frustrated as Ted is. *Go to Frame 89.*

Frame 87

There is no doubt that the foremen are less interested in the work when there are so many changes in the work plans.

They really don't know what to do next. Instead of following a schedule, each foreman has to be directed separately—job by job.

These kinds of constant changes confuse and frustrate everyone involved.

The foremen may also have less respect for Ted. They may feel he doesn't know how to do his job. And if all these things are true, morale is lowered. Why is Ted having so much trouble?

A. Something must be wrong with the procedure used to schedule the work. *Go to Frame 90.*

B. Ted is just not organized. *Go to Frame 91.*

C. Ted is not communicating to the foremen what he wants done. *Go to Frame 92.*

Frame 88

Ted doesn't know his job very well. Some of the foremen might think this way. After all, the foremen aren't able to follow the schedule and Ted is the person who is doing the scheduling. Then again, maybe Ted does know his job, but is not scheduling work in the right way.

Go to the beginning of Frame 87.

Frame 89

The foremen are just as confused and frustrated as Ted is. This is probably true. Not ever knowing what to do next is frustrating. And it's confusing to have a work schedule with a week's work all planned out and then not be able to follow it.

Go to the beginning of Frame 87.

Frame 90

Right. Something is wrong with the procedure used to schedule the work. It looks as though Ted is organizing his work all right. The activities he has planned to do are in his schedule. There's no sign that he has trouble communicating with his foremen.
O.K. So the procedure is wrong.
Can anything be done to improve Ted's procedure for scheduling work?

A. Yes. Most of the maintenance needs discovered this week should have been put in next week's schedule. *Go to Frame 93.*

B. No. The changes in work priorities could not be avoided. *Go to Frame 94.*

C. No. Ted seems to be doing the best he can under the circumstances. *Go to Frame 95.*

D. Yes, Ted should be identifying maintenance needs before they become serious enough to interrupt scheduled work. *Go to Frame 96.*

Frame 91

Ted is not organized? A lack of organization can be a big problem in scheduling work and getting good results. But look at Frame 81 again. Ted's work is organized pretty well. His schedule looks pretty good. He has scheduled and organized all the work he thinks needs to be done.
No, it's not really a lack of organization that's causing Ted's problems.

Try another answer from Frame 87.

Frame 92

Wrong. There is nothing in the problem to show that Ted is not communicating with his foremen.

Try again—Frame 87

Frame 93

Most of the work discovered this week should have been put in next week's schedule. No. At least three jobs were serious enough to be done this week. The bumpy spots on Route 10, the rough railroad crossing, and the damaged guardrail. Ted reworked the schedule because he felt that these things were more important than the scheduled work.

Something can be done to improve the procedure, but postponing high priority work is not one of the things.

Go back to Frame 90.

Frame 94

Wrong. Several of the changes in work priorities could have been avoided. Some supervisors fall into the trap of fighting brushfires instead of looking for and correcting possible future problems. Ted is in this trap. The bumpy spots on Route 10 and the rough railroad crossing should have been corrected before they caused a change in this week's schedule.
The procedure can be improved.

Try another answer from Frame 90.

Frame 95

Ted seems to be doing the best he can. It does seem that way, but the fact is he helps cause his frustrations by having to make more decisions than he should. And these decisions become more complicated every time the schedule changes. This happens whenever work priorities change, and Ted is making these changes. There is a way to avoid some of the circumstances he is creating.

Another answer in Frame 90 is better.

Frame 96

Ted should be identifying maintenance needs before they interrupt scheduled work. He certainly should! Most of the roadway conditions which caused the schedule to be revised could have been put in this week's plan. The bumpy spots on Route 10 and the rough railroad crossing did not become bumpy or rough overnight. The defects probably developed over several days or weeks.

The damaged guardrail should have been put in this week's schedule.

Ted knows that unless something is done he will be spending more and more time fighting brushfires. So his solution is to identify maintenance needs before they become too serious—before they interrupt a schedule.
As Ted improves his scheduling procedures, he increases the chances of making his schedule work.

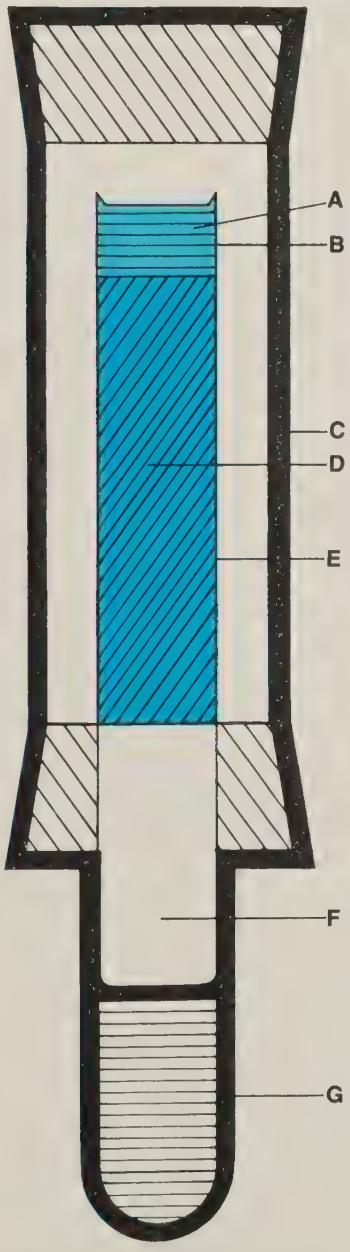
Techniques for Retarding the Penetration of Deicers into Cement Paste and Mortar

by Horace A. Berman and Bernard Chaiken

The article describes the results of a study designed to develop techniques for limiting the penetration of deicing salts into concrete, thereby preventing the corrosion of reinforcing steel in concrete bridge decks which is a result of the presence of chlorides. This presentation is a condensation and update of an Interim Report by the same authors, "Techniques for Retarding the Penetration of Deicers into Cement Paste and Mortar," FHWA-RD-72-46, December 1972, 38 pages. The Interim Report, Stock No. PB 219833, is available from the National Technical Information Service, Sills Building, 5285 Port Royal Road, Springfield, Va. 22151.

Factors affecting the penetration of deicing salts were studied with hydrated cement pastes and mortars as the penetration medium. The salts tested were ammonium fluoride, sodium chromate, calcium chloride, sodium chloride, ammonium chloride, and aluminum chloride.

Figure 1.— *Penetration test chamber.*



A Test solution
B Reservoir
C Glass chamber
D Cement paste or mortar specimen
E Tape insulation
F Humidity conditioning chamber
G Conditioning solution

The most effective retardation technique was impregnation with methyl methacrylate monomer and subsequent polymerization by irradiation. Polymer impregnation (to 30 percent of the dry cement weight) succeeded in decreasing subsequent deep-seated penetration by a factor of 50 and surface penetration by a factor of 5. Impregnation with elemental sulfur was almost as effective. Deep-seated penetration into cement paste decreased in proportion to the quantity of sulfur introduced—by a factor of 100 for 40 percent sulfur to a factor of 5 for 26 percent sulfur—calculated on dried specimen weight. Ammonium fluoride and sodium chromate were relatively nonpenetrating and therefore may be suitable as deicers, although environmental factors might discourage the use of fluoride and possibly the chromate as well. An anion-exchange resin was partially effective in decreasing the available chloride content in cement paste, provided the water-cement ratio could be kept low.

Part of the investigation also included efforts to develop means of reducing dangerous chloride levels already existent in concrete. A back-flushing technique was effective in reversing chloride penetration to a limited extent.

Introduction

The increased use of sodium chloride (rock salt) and calcium chloride in recent years for melting ice and snow on concrete highways and bridge decks has intensified the problem of maintenance. These deicing salts contain chloride ion, which penetrates deeply into the concrete and causes the steel reinforcement to corrode. The products of corrosion occupy more volume than the steel and the resulting expansive stresses can cause disruption in the concrete. The quantity of chloride ion which can initiate corrosion can be as low as 0.2 to 0.3 percent of the cement. Bridge decks in particular are vulnerable because they are exposed on both their upper and lower surfaces. They therefore freeze more readily than the adjacent pavement and are treated with larger quantities of deicer.

Studies under way at the Federal Highway Administration (FHWA) are attempting to solve the bridge deck steel corrosion problem by several means. Some of the experimental chemical techniques tried include:

- Means of preventing the penetration of chlorides into existing concrete.

- Potential deicers that will not significantly penetrate existing concrete.

- Techniques to remove chloride salts which have already penetrated to the depth of the steel.

- Substances which can be added to an original concrete mix to render chloride ion inactive.

Some of the results of this work that offer promise for field application are described in this article. In the first category, prevention of penetration, the most successful technique was the impregnation of cement paste with methyl methacrylate monomer followed by its polymerization in situ by radiation. The penetration of chloride ion into cement paste thus impregnated was decreased to only one-fiftieth the penetration of untreated cement paste. Also promising was the impregnation of cement paste with elemental sulfur. This technique decreased the penetration of chloride ion to at most one-fifth the penetration in untreated cement paste. In heavily impregnated specimens, the penetration was reduced by a factor of 100.

In the second category, nonpenetrating chemicals, two salts were tested and found to be technically promising as possible deicers—ammonium fluoride and sodium chromate. The penetration of these salts was very shallow and the fluoride which did penetrate was largely insoluble in water. Neither salt would therefore be expected to cause corrosion of steel. However, both ammonium fluoride and sodium chromate present serious environmental problems, requiring respective dilution factors of about 40,000 and 2,000 to prevent them from endangering public water supplies or rivers.

In the third category, removal of penetrated salts, a back-flushing technique was promising. Application of this technique would reverse the penetration of chloride already in concrete by creating an upward flow of water. The bottom of a bridge deck would be kept wet at periodic intervals and the top kept as dry as possible. About 40 percent of the chloride contained in the bottom of a laboratory specimen was carried to the top by this upward capillary movement of water.

In the final category, efforts to inactivate chloride ion, marginal success was obtained with the incorporation of an ion-exchange resin into a fresh mortar mix. Although results were not uniform, the resin tended to immobilize chloride ion by rendering it water-insoluble. However, the capacity of the resin to do so was limited by its tendency to draw additional chloride ion from outside the mortar into the upper layers of the specimen while at the same time decreasing its penetration to the deeper layers. This technique could, nevertheless, be developed as a surface treatment in which the resin would be used on an existing deck during a frost-free period, then removed when exhausted and regenerated for another application.

Experimental Methods

Specimens of cement paste or mortar were fabricated to test the ability of a mix or a treatment to resist the penetration of a salt solution or to test a particular salt solution for its degree of penetration into a specimen. The use of cement paste or mortar rather than concrete made it possible to fabricate a large number of small specimens which were still reasonably uniform.

As shown in *figure 1*, the specimens were 1x1x4-inch (25x25x100-mm) prisms fitted at the top end with a reservoir about 0.8 inch (21 mm) deep made of microscope cover glasses cemented to each other and to the specimen with an epoxy resin. Test deicer solutions were placed in the reservoir. The vertical sides of the specimen were covered with electrical tape to prevent leakage of test solution out the sides of the specimen. Each specimen was placed in its own chamber and a preselected constant relative humidity was maintained on the lower surface of the specimen.

The cement paste specimens were made of a type 1 cement (as shown in table 1 of Interim Report FHWA RD-72-46 referred to earlier) mixed with distilled water at water-cement ratios of 0.4 and 0.5. Standard Ottawa sand, ground to 100 to 200 mesh, was used for mortar specimens. The specimens were cured in the moist closet for 14 days (1 day in the molds), then transferred to the chamber for conditioning at constant relative humidity. After 14 days of conditioning, 10 ml of the deicer solution was pipetted into the reservoir. The assembly was allowed to stand without further addition to the reservoir for the duration of the test. The specimen was then taken out of the chamber and any solution remaining in the reservoir removed and measured. Horizontal slices were then cut from the specimen at various depths from the top surface with a dry hacksaw. The slices were ground and analyzed for their content of the deicer under study.

Analytical results in this report are expressed wherever possible in terms of the percentage of the substance analyzed. When the relative degree of penetration of two anions is compared, the results are expressed instead in terms of milliequivalents of the anion per gram of dry cement. This unit is proportional to the number of ions present when the two species of ion have the same electrical charge. To reconcile these units with units employed by other investigators, such as pounds of chloride per cubic yard of concrete or kilograms per cubic meter, the necessary conversion factors are presented as an appendix to Interim Report FHWA RD-72-46.

Exploratory Penetration Studies on Cement Paste

A preliminary series of tests was made to determine the rate and degree of penetration of chloride deicers as a function of porosity, relative humidity, salt concentration, and duration of contact of the salt with the specimen. The tests were designed to study the differences in behavior of different salts and, if possible, to detect salts which could be used as nonpenetrating deicers or as pretreatment agents capable of blocking penetration by chlorides.

Specimens were prepared as described under "Experimental Methods." At 28 days each was exposed to one of several different salt solutions for a period of from 1 week to 6 months. The salts tested were calcium chloride, sodium chloride, aluminum chloride, ammonium chloride, ammonium fluoride, and sodium chromate.

Calcium chloride and sodium chloride are the deicers most often used in practice. Sodium chromate was studied because it has been used as a corrosion inhibitor by many investigators and in some practical installations. Aluminum chloride and ammonium fluoride were studied as possible deicers or as candidates for retarding the penetration of chloride deicers because they are capable of producing insoluble compounds with the calcium hydroxide contained in the cement matrix. Ammonium chloride was studied to assess the effect of still another chloride salt. All compounds were studied with cement paste specimens at water-cement ratios of 0.4 and 0.5.

The various salts were studied at equivalent concentrations; in chemical terms, *equal normalities*. In the case of monovalent ions, such as chloride and fluoride, this means that equal concentrations of the anion were always present in the solution originally placed in the reservoir regardless of the number of chloride or fluoride atoms in one formula weight of the salt. The concentration chosen for most of the tests was 1.18*N* which corresponds in the case of calcium chloride to an 8 percent solution of $CaCl_2 \cdot 2H_2O$ (flake calcium chloride). Calcium chloride was also studied at a concentration of 0.27*N* (2 percent $CaCl_2 \cdot 2H_2O$). Relative humidities of 72 percent and 100 percent were used.

As described in "Experimental Methods," slices were cut from all of the specimens and analyzed for their anion content. In most cases, the slices were analyzed for the total quantity of the anion under test. However, fluoride ion reacts with compounds in cement paste to form insoluble fluorides, which are considered to be unavailable for destructive action on steel. For this reason, the fluoride analyses were broken down into water-soluble and water-insoluble fluoride. For comparison, water-soluble chloride determinations were made on slices taken from selected specimens among those exposed to the various chloride salts.

Results of exploratory penetration studies

Effect of time and porosity. *Figure 2* shows profile curves of chloride ion concentration vs. depth as a function

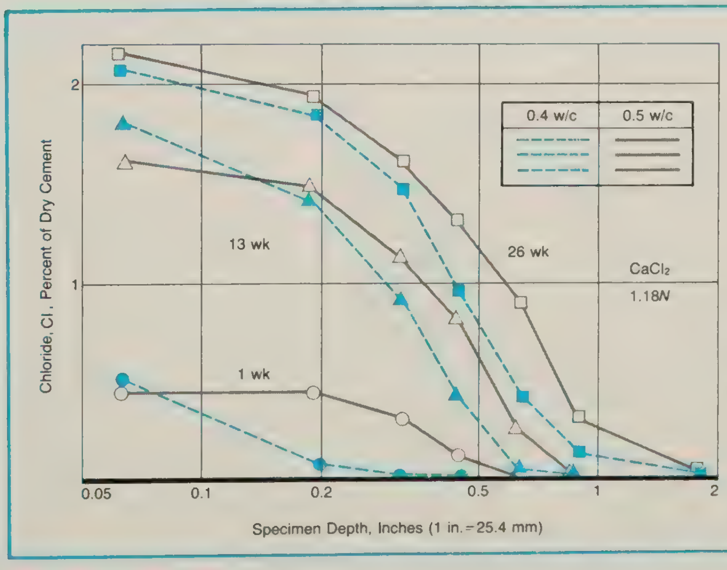


Figure 2. — *Degree of penetration of 1.18N calcium chloride into cement paste vs. depth, time, and water-cement ratio.*

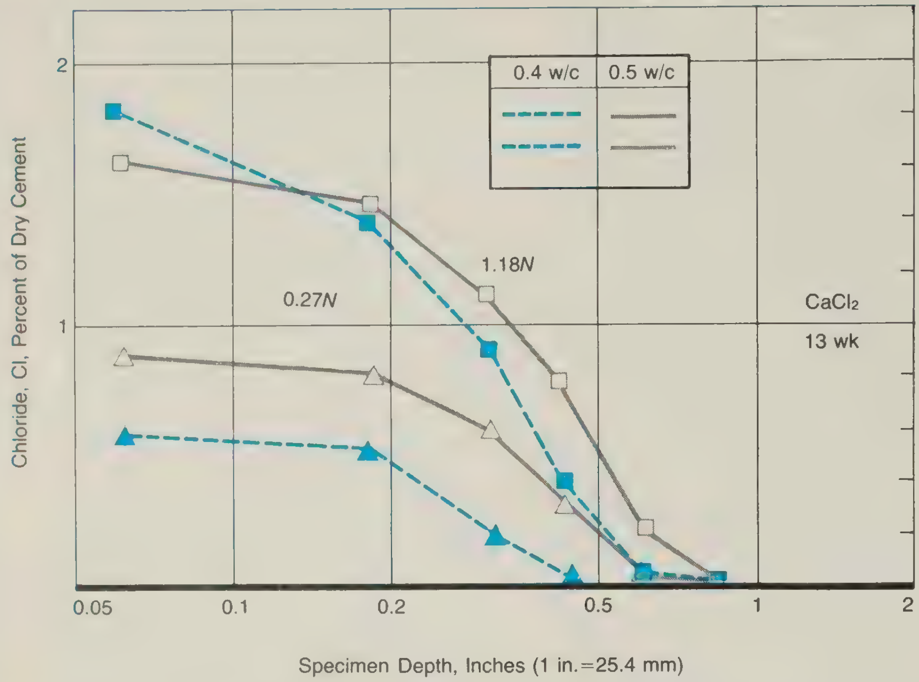


Figure 3.—*Degree of penetration of 1.18N and 0.27N calcium chloride vs. depth at 13 weeks.*

of time and water-cement ratio, for specimens exposed to 1.18*N* calcium chloride solutions. The bottom surface of these specimens was at 72 percent relative humidity.

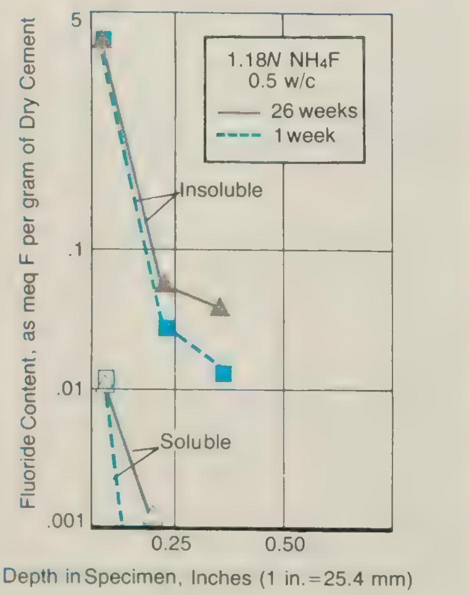


Figure 4.—*Degree of penetration of ammonium fluoride solution shown as water-soluble and water-insoluble fluoride.*

The tendencies observed are essentially those expected. The detectable penetration is deeper, and the chloride content is greater at any depth, the longer the exposure.

Similar trends of increased penetration depth and increased chloride content are observed as a direct function of water-cement ratio. Since porosity is directly related to water-cement ratio, higher porosity favors greater penetration. The increases in chloride content between 13 and 26 weeks were not as great as those between 1 and 13 weeks. This tendency of the rate of penetration to decrease with time is borne out by the results of specimens exposed for intermediate periods.

Other specimens, with the bottom portion exposed to 100 percent relative humidity, showed no consistent difference in penetration rate from those exposed at 72 percent relative humidity.

Effect of salt concentration. *Figure 3* is a similar plot for 13 weeks exposure to the two different concentrations of calcium chloride studied. Values are shown for 0.4 and 0.5 water-cement ratios. As expected, penetration was deeper and the chloride contents greater for the higher concentration.

Behavior of other salts. The behavior of ammonium fluoride is contrasted with that of calcium chloride in *figures 4 and 5*. Most of the fluoride ion that penetrated into the specimens—99 percent of the fluoride— was insoluble in water (*fig. 4*). However, about 80 percent of the calcium chloride that penetrated was soluble in water (not shown in the figure). *Figure 5* illustrates that at a depth of 1/16 inch (1.59 mm) in the specimen the water-soluble chloride ion found in specimens exposed to calcium

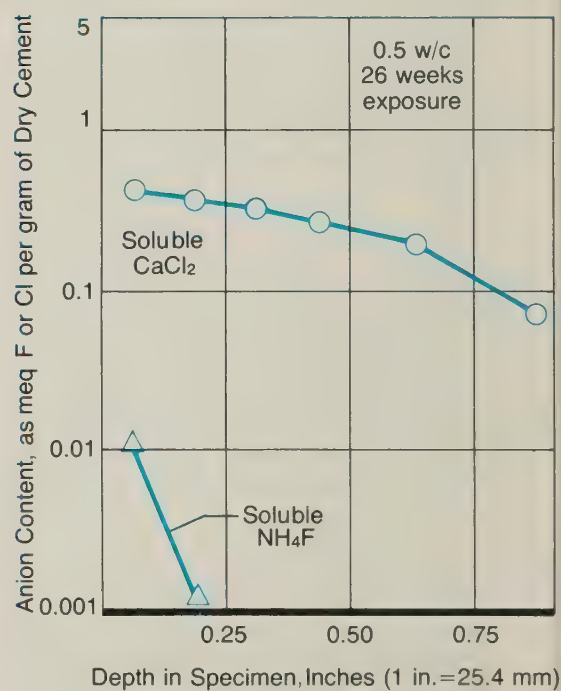


Figure 5.—*Water-soluble fluoride found in pastes exposed to ammonium fluoride solution compared with water-soluble chloride found in pastes exposed to calcium chloride solution.*

chloride was 50 times the concentration of water-soluble fluoride ion found in specimens exposed to ammonium fluoride. The water-soluble fluoride content decreased very rapidly with depth; the water-soluble chloride relatively slowly.

Thus, the penetration of ammonium fluoride was confined almost completely to the top 1/8-inch (3.18-mm) layer of the specimens, and what did penetrate was almost completely insoluble in water. Furthermore, the penetration was almost complete by 1 week of exposure. There was evidence of a rapid and complete reaction between the ammonium fluoride and the calcium compounds contained in the paste to form insoluble calcium fluoride and calcium aluminate fluoride, with release of volatile ammonia and water. Ammonium fluoride can thus be considered relatively nonpenetrating and therefore a potential noncorrosive deicer. These possibilities are discussed further under the heading "Chemical Precipitation Techniques."

The behavior of the other salts tested, compared to the behavior of calcium chloride, is shown in *figure 6*.

Sodium chromate was largely restricted to the top layers and did not penetrate deeply, presumably because of the formation of relatively insoluble calcium chromate and perhaps calcium aluminate chromates. For this reason, sodium chromate, like the fluoride salt, is also a potential noncorrosive deicer, although its nonpenetrating properties are not as great as those of the fluoride.

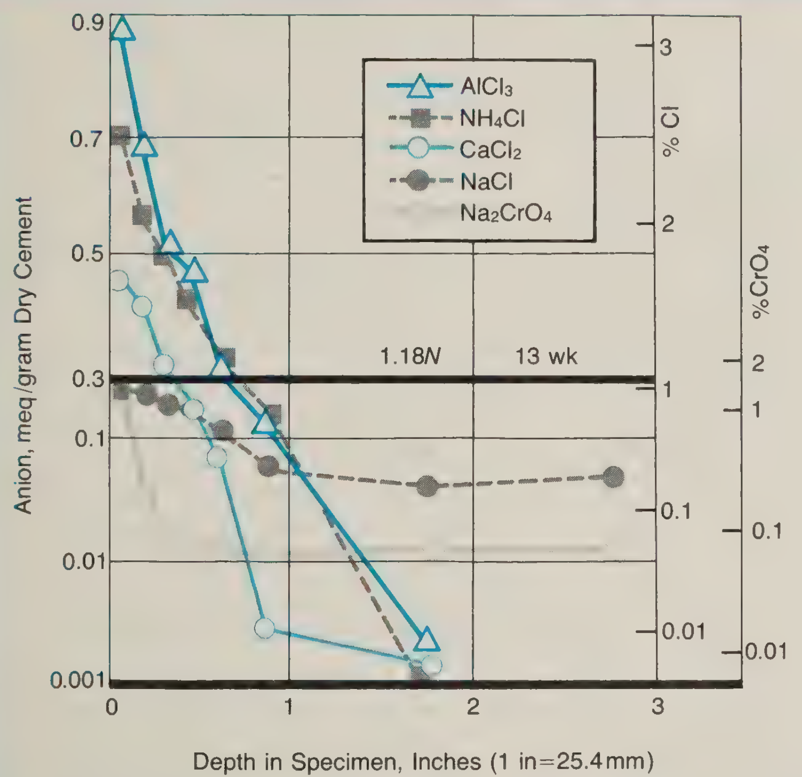


Figure 6.—*Degree of penetration of 1.18N solutions of different salts vs. depth* (*exposure 13 weeks*).

Aluminum chloride was included in the hope that it might precipitate with the calcium hydroxide in the cement capillaries to form calcium aluminate chloride and thus be immobilized in the top layer like ammonium fluoride. Instead, it penetrated considerably more strongly than even calcium chloride. The reaction with calcium hydroxide produced a dense slush of calcium aluminate monochloride in the reservoir on the surface of the specimens. Thus, the calcium hydroxide was pulled out of the specimen and the paste structure opened to further penetration by the aluminum chloride.

Ammonium chloride was also strongly penetrating. The specimens exposed to ammonium chloride and those exposed to calcium chloride developed large hexagonal crystals on the surface, which were identified as calcium hydroxide by optical microscopical examination and X-ray diffraction. This growth is evidence of chemical activity. In the case of ammonium chloride it indicates that calcium silicates or aluminates were being decomposed. Presumably, this decomposition opens the structure to penetration.

As discussed in the preceding paragraphs, ammonium fluoride, aluminum chloride, ammonium chloride, and calcium chloride all show evidence of chemical reaction with cement paste. Sodium chloride showed no evidence of reaction, either visibly or by inference. *Figure 6* reveals a different penetration profile for sodium chloride than for the other chloride salts tested. In all the specimens, its concentration was relatively weaker at the upper part of the specimen, but relatively stronger at greater depths, and it tended to display an almost constant level of chloride content at depths greater than 1 inch (25.4 mm). The use of rock salt—sodium chloride—is now much more widespread than that of calcium chloride, consequently this deepseated penetration is a matter of direct concern in the problem of reinforcing steel corrosion. The unique behavior of sodium chloride may possibly be explained by its lower level of reactivity with the cement paste. The concentration of the more reactive salts drops more rapidly with depth, as they are more tightly bound in the upper layers.

The penetration tests described in this section served as a baseline and preliminary screening test for further experiments described in the sections to follow.

Techniques for Retarding Salt Penetration in Hardened Concrete

Impregnation techniques

The object of impregnation is to deposit a solid material in the capillary pores and large voids of the concrete. This material serves as a barrier to the subsequent penetration of dissolved deicing ions. In this study, several solid materials were investigated as "pore blockers": Methyl methacrylate polymers and other materials such as barium hydroxide octahydrate and sulfur.

Polymer impregnation. Twelve specimens of neat cement paste were prepared at a water-cement ratio of 0.5, as described under "Experimental Methods." After 2 weeks in the moist cabinet, six of the specimens were transported to Brookhaven National Laboratory where they were dried and impregnated with methyl methacrylate monomer. The degree of impregnation is given in table 2 of interim Report FHWA-72-46 referred to earlier. The monomer was polymerized by irradiation.[1] The impregnated and polymerized specimens were returned to this laboratory 5 months later. All 12 specimens (impregnated and controls) were cut square near one end (hereafter called the *top end*) to expose a fresh surface. They were then provided with reservoirs as described, and conditioned in individual chambers 2 weeks with the bottom end exposed to air at approximately 72 percent relative humidity. Calcium chloride solution (1.2*N*) was then added to the reservoir. The specimens were allowed to stand exposed this way for a maximum of 62 days. The results of these tests are shown in *figure 7*. The quantity of chloride ion found in each successive 1/8-inch (3.18-mm) layer of the specimen is expressed as a percentage of the original unhydrated cement.

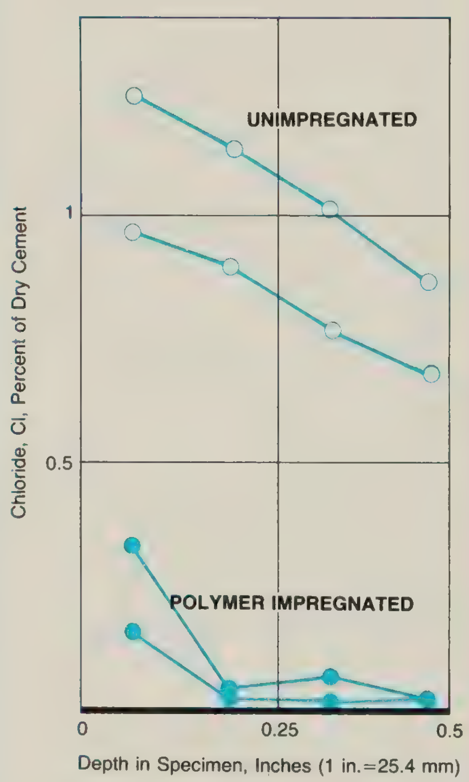


Figure 7.—*Degree of penetration of 1.18N calcium chloride for a 9-week exposure period, into 0.5 w/c specimens of polymer-impregnated cement paste and untreated specimens.*

The top layers of the impregnated specimens contained only 20 percent of the amount of chloride ion found in similar layers of the control specimens. With increasing depth, the chloride content of the controls decreased slowly, whereas the chloride content of the impregnated specimens decreased precipitously beneath the top layer. Thus, the polymer clearly acted effectively to block penetration. For the lower levels, the average ratio of chloride content in control and impregnated specimens was 50 to 1.

The 20 to 1 ratio between the average chloride content of the top 1/8-inch (3.18-mm) and the second 1/8-inch (3.18-mm) layers strongly suggests that the blockage of penetration started well within the top layer of the impregnated specimens.

No significant differences were found in the nonevaporable water contents of the impregnated and unimpregnated specimens. Thus, in spite of the difference in the treatment of these two sets of specimens for the 5-month interval while the impregnated specimens were at Brookhaven or in transit, there was no apparent difference in their degree of hydration or in hydration-related porosity. Partial filling of the pores with polymer is therefore the most likely explanation for the marked reduction in chloride penetration in the polymer-treated specimens.

Impregnation with sulfur. Impregnation with elemental sulfur was almost as effective as polymer impregnation. Fifteen specimens of cement paste were prepared at 0.5 w/c. After 14 days in the moist closet, the specimens were dried in a vacuum oven at 105° C and kept there until ready to be impregnated (1 1/2 to 3 1/2 months). They were then transferred to a chamber immersed in a chemical bath maintained at 120° C. The chamber was evacuated and molten sulfur at 120° C was introduced into the chamber and allowed to stand in contact with the specimen for periods of 1 to 3 hours. Two of the specimens were left untreated. Six of the impregnated specimens and one unimpregnated specimen were allowed to recover gradually about one-third of the water they had lost on drying, by exposure in a desiccator to an atmosphere maintained at 100 percent relative humidity (these are referred to below as *gradually rewetted specimens*). The remaining

[1]Polymerization by thermal techniques is now preferred to radiation polymerization because it is considered more feasible for a practical installation. At the time these tests were conducted, techniques for thermal polymerization had not been developed as completely as those for radiation polymerization. It is our opinion that thermally polymerized specimens would perform almost as well as the radiation polymerized specimens did in retarding the penetration of chloride ion.

water was then restored by immersing the specimens for 24 hours in distilled water. The other seven impregnated specimens and one unimpregnated specimen were kept dry over magnesium perchlorate for 3 to 6 months, then immersed in distilled water for 72 hours (referred to below as *abruptly rewetted specimens*). All the specimens were fitted with reservoirs and conditioned in penetration chambers at 72 precent relative humidity for 3 weeks, then tested for penetration with 1.18*N* sodium chloride solution for 9 weeks.

Figure 8 shows that the impregnated specimens in the gradually rewetted group contained much less chloride ion than the unimpregnated specimen at any given depth. At a depth of almost 1/2 inch (12.7 mm), the ratio was 1:100 for the most heavily impregnated specimen (containing 40 percent sulfur by weight in terms of the dried specimen), and 1:4 for the least heavily impregnated specimen (which contained 26 percent sulfur). The chloride content of the specimens at that depth was inversely related (almost linearly) to the weight of sulfur that the specimens contained. The trend was the same for the specimens in the abruptly rewetted group but the variability of the data was greater.

Chemical precipitation techniques

Candidate deicers. As discussed above, figures 4 and 5 show that ammonium fluoride penetrates cement paste much less deeply than any of the chloride salts and about 99 percent of what does penetrate is rendered insoluble in water by chemical reaction. In contrast to the ammonium fluoride solubility of only 1 percent, about 80 to 90 percent of each of the chloride salts proved to be water-soluble.

Thus, from the standpoint of its low degree of penetration, ammonium fluoride has good potential as a noncorrosive deicer. It should not be able to reach those depths at which it could induce corrosion in steel, and it is very resistant to leaching by water. Melting point curves (*1, 2*)[2] indicate that, down to −16° C, less ammonium fluoride than sodium chloride by weight is required to melt a given quantity of ice. Below that temperature, sodium chloride is more effective, until its eutectic is reached at −21° C. At this point, ammonium fluoride takes over again and is able to lower the freezing point of water to a minimum of −26.5° C. Ammonium fluoride is similarly more effective than calcium chloride, weight for weight, between 0° and −15° C. The fluoride salt is about seven times the cost of sodium chloride, probably not a prohibitive difference when balanced against its promise as a noncorrosive deicer for bridge decks.

[2]Italic numbers in parentheses identify the references on page 18.

However, the use of ammonium fluoride as a deicer is open to environmental objections. The runoff of the solution of ammonium fluoride in melted ice may find its way into the soil, rivers, or public water supplies. U.S. Public Health Service drinking water standards allow an upper limit for fluoride of 1.7 mg/liter or 0.1 mM (*3*). Thus, a 16 percent solution of ammonium fluoride (about one-half the strength of the eutectic composition) would have to be diluted about 40,000 times to meet the maximum permissible limit for drinking water. If runoff could be prevented until the ammonium fluoride had reacted with the cement binder in the concrete, our tests indicate that the fluoride concentration in the runoff might be reduced to about 0.2M, still 2,000 times the drinking water limit. In this case, the ammonia concentration of the water would also be greater than the 2 ppm reported as toxic and the 136 ppm reported as lethal (*4*).

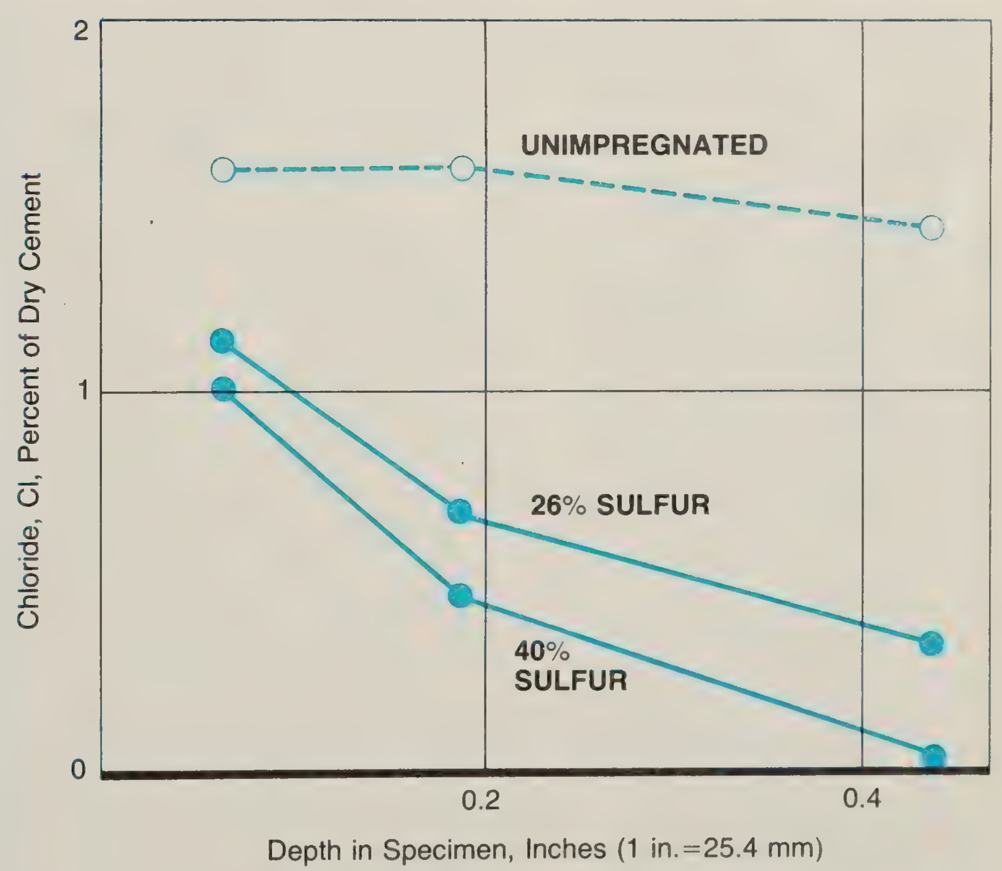


Figure 8.—*Degree of penetration of 1.18N sodium chloride for 9-week exposure period into 0.5 w/c cement paste specimens impregnated with sulfur and rewetted gradually.*

It is clear that if ammonium fluoride is to be considered seriously as a deicer, a practical study is needed of its deicing power and of its effects on the environment when the solution of ammonium fluoride in melted ice runs off the pavement or bridge deck.

Sodium chromate offers the same possibilities as a potential noncorrosive deicer and similar disadvantages. As can be seen in figure 6, its concentration in paste specimens decreases with depth much more rapidly than any chloride salt, although less rapidly than ammonium fluoride.

The cost of sodium chromate is about three times that of sodium chloride. Weight for weight, the ice-melting power of sodium chromate is only one-half to one-third that of calcium chloride, sodium chloride, or ammonium fluoride. On the basis of incompletely defined thresholds of chromate toxicity (3), a dilution factor of more than 2,000 would be required to reach safe concentration levels if a 19 percent solution of sodium chromate were spread on a pavement.

Techniques for Salt Removal

There is an important need for removing chloride from bridge decks which have already been treated with deicing salts. Although damage to the deck may not already have occurred, penetration of chloride in many bridge decks has proceeded to the point where the steel is in potential danger of corrosion with resultant spalling damage to the deck.

A back-flush technique would supply moisture to the undersurface of a bridge deck while the upper surface remained dry (except for rainy periods) through the normal action of wind and sun. Capillary movement of water upward from the wet to dry areas would hopefully carry to the surface the chloride ions which had already penetrated deeply.

A series of tests designed to simulate back-flushing was made in which cement paste specimens 2 inches (50.8 mm) long were prepared at 0.5 solution-cement ratio with 2 percent sodium chloride solution as the original mix solution. When hardened these specimens contained 1 percent sodium chloride by weight of the dry cement. After 14 days of curing at 100 percent relative humidity, the specimens were placed so that a stream of dry air played over the top of the specimen and the bottom was kept immersed in water either continuously or intermittently. After a period of exposure, slices were cut at four locations from bottom to top and analyzed for chloride content.

Figure 9 shows some of the results of these tests. An air stream without water immersion does show some tendency to move chloride upward, evident at 9 weeks but not yet at 1 week. Water flushing alone without air serves only to leach out chloride, moving the salt downward instead. However, combination of air flow across the top surface and water flushing at the bottom produces a definite upward movement of chloride which appears to be most pronounced during the first week, with 23 to 40 percent of the chloride removed from the bottom of the specimen, smaller reductions near the middle, and an increase of 11 to 125 percent in the top 1/4 inch (6.35 mm). Six months of intermittent flushing increased the amount of chloride removed to 45 percent. On an actual bridge deck, the concentration of chloride near the surface could be removed with periodic surface flushing after a period of back-flushing.

Salt-capture Technique for Fresh Concrete

Ion-exchange resin

A series of tests was conducted to determine whether the addition of a special anion-exchange resin to a mortar mix would trap chloride ion entering the specimen and prevent it from reaching the depth at which it can cause corrosion of steel.

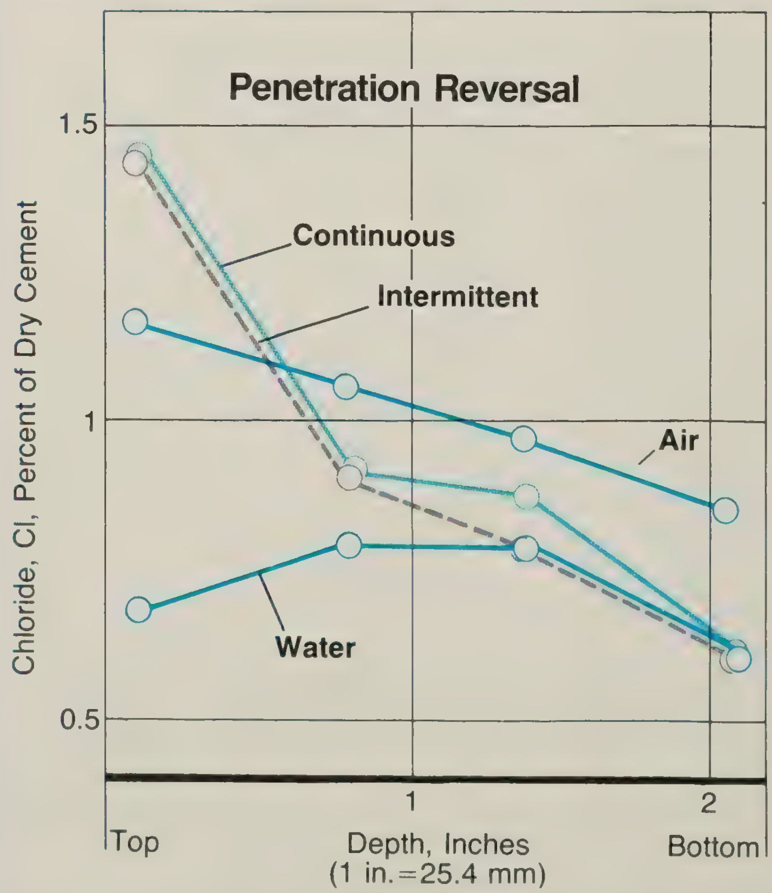
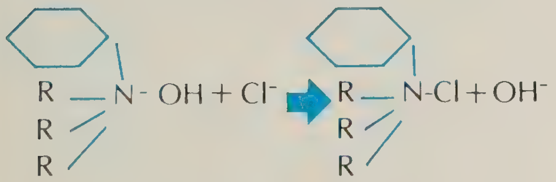


Figure 9.—*Reversal of penetration by undersurface wetting in cement paste specimens originally fabricated to contain 1 percent chloride.*

The principle behind the use of an anion-exchange resin lies in its ability to exchange hydroxyl ion for chloride ion in the hydrated cement matrix. The particular resin selected reacts as follows:



The chloride ion becomes inactivated as a result of its attachment to the resin molecule. In this form, the chloride is insoluble in water, but soluble in nitric acid. In the exchange shown above, the hydroxyl ion (OH^-) originally attached to the resin is donated to the cement paste.

A strongly basic anion-exchange resin was used, designated by the manufacturer as Bio Rad AG1-X8.[3] Its particle size was stated to be finer than 400 mesh. Two batches of the resin were activated by conversion to the hydroxide form by repeated treatment with sodium hydroxide solutions. Batch A was digested 16 times with 1-liter portions of sodium hydroxide, starting with 0.5*N* and ending with 2.5*N*, and the slurry was filtered and washed with water between digestions. Batch B was treated in an ion-exchange column with eight 1-liter portions of 2.5*N* sodium hydroxide and flushed with water between extractions. Analyses of the original chloride-form resin and the two batches of hydroxide-form prepared are given in table 4 of Interim Report FHWA-RD-72-46. They are also compared with the analysis of a resin from another manufacturer commercially available in the hydroxide form and coarser in particle size. The batches prepared in our laboratory turned out to be more thoroughly converted to the hydroxide form than the commercial hydroxide-form resin.

[3]The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear herein solely because they are considered essential to the object of the report.

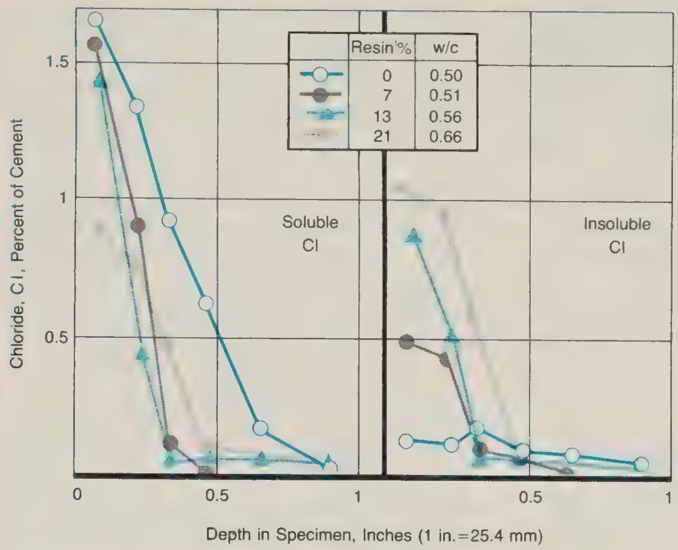


Figure 10.—*Effect of ion-exchange resin on degree of chloride penetration (first series).*

The test specimens were mortar prisms in which the top 1/2 or 1 inch (12.7 or 25.4 mm) contained portland cement and an aggregate consisting of a mixture of varying proportions of the hydroxide-form resin and Ottawa sand (100 to 200 mesh). The aggregate blends were designed to maintain the same volume proportion of cement to total aggregate in all the specimens. The mix proportions are given in table 5 of Interim Report FHWA-RD-72-46. The remainder of the specimen contained Ottawa sand as the only aggregate. The resin-free or bottom section was molded first. Three hours later, before the time of initial set but while the mortar was stiff enough to remain in place, the resin-containing mix was placed in the mold in contact with the resin-free mortar. After the curing and conditioning periods (conditioning at 72 percent relative humidity), the specimens were exposed for 2 months to penetration by calcium chloride solution. They were then sliced in the usual manner. Water-soluble and total chloride content were determined on the slices. The chloride content of these specimens was reported on the basis of the weight of cement in the specimen because this ingredient constituted as closely as possible a constant percentage of the specimen volume.

The first series of tests, illustrated in *figure 10*, showed that the resin was effective in immobilizing chloride ion when the water-cement ratio was low. Specimens containing respectively 7 and 13 percent wet resin and made at 0.51 and 0.56 w/c, contained much less water-soluble (uncombined) chloride than the resin-free control specimen. The level of water-insoluble chloride (chloride captured by the resin) was much higher than in the resin-free specimen. In fact, the amount of captured chloride was so much greater in the upper layers of the resin-containing mortars that these mortars contained more total chloride than did the resin-free specimen. Thus, the resin attracted larger quantities of chloride into the paste than would otherwise have penetrated, but it also rendered most of this chloride insoluble in water. There is, of course, an upper limit to the amount of chloride in a pavement that could be immobilized in this manner unless some means were found to regenerate the hydroxide form of the resin without again releasing the chloride to do damage. About one-quarter of that upper limit was reached in these tests.

Figure 10 also shows that the resin is not as effective when a higher water-cement ratio is used. In order to obtain a workable mix when attempting to fabricate the specimen with 21 percent resin, it was necessary to use a water-cement ratio of 0.66. The resin in this specimen did not succeed in capturing as much chloride as in the specimens containing only 7 and 13 percent wet resin, but its tendency to attract additional chloride from the reservoir into the paste was unimpaired.

Another series of specimens was made at high water-cement ratios. These specimens were even more permeable than was the control.

Figure 11 shows that a thicker—1-inch (25.4-mm)—layer of resin-containing mortar, or a deeper boundary between resin-containing and resin-free mortar, allows deeper penetration of chloride in the water-soluble form. In this third series of specimens, three of the four specimens containing 5 percent wet resin showed a slower rate of penetration for water-soluble chloride than the resin-free control specimens (R-20 and R-25), but the retardation was not as great as in the first series and the top layer generally contained more water-soluble chloride than in the controls. The one specimen giving completely unfavorable results had a slightly higher water-cement ratio. Of the specimens in the third series, those that contained 11 percent wet resin gave poorer results—one favorable (with w/c = 0.50) and three unfavorable (with w/c = 0.57, 0.57, 0.50).

It is apparent that small percentages of the anion-exchange resin are capable of retarding chloride penetration but the reproducibility of this effect is at this time not completely dependable. Possibly the mixing was not sufficient to make uniform specimens. The fineness and high water absorption of the resin may be responsible for this lack of uniformity.

A relative strength measurement was made on 28 day-old 1-inch (25.4-mm) cubes taken from 3-inch (76.2-mm) specimens made from the resin-free and the 5 percent wet resin mixes. The resin-free cubes had an average compressive strength of 8,280 psi (57.1 MPa), the resin-containing cubes 5,380 psi (37.1 MPa).

The most effective way to use an anion-exchange resin in a concrete mix may be to provide only a thin layer—1/4 to 1/2 inch (6.35 to 12.7 mm)—of resin-containing mortar as the upper surface of a pavement or bridge deck. Nevertheless, the system would be expensive and could be relied on only as long as the resin retained active hydroxyl sites. However, the intermittent use of a resin layer on the surface of an existing deck might be feasible. Such a layer could be removed and regenerated when completely converted to the chloride form.

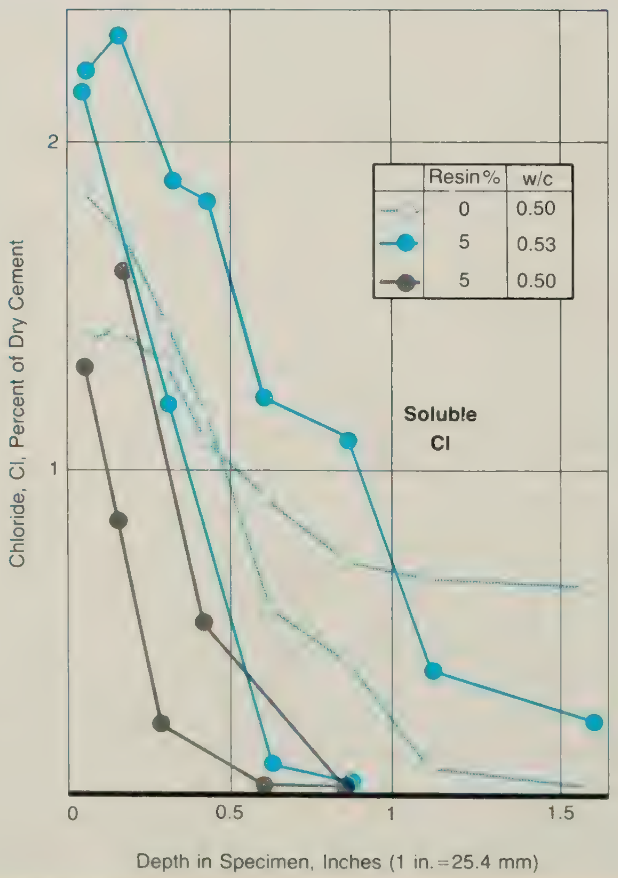


Figure 11.—*Effect of 5 percent ion- exchange resin on degree of chloride penetration (third series)*

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[1]Mr. Steere's biography should have been published in the March 1974 issue of *Public Roads* where a review of his report "Noise Levels Associated with Plant Mix Seals" appears on pages 319 and 320.

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Long Term Observations on Highway Bridges

by Charles F. Galambos

Introduction

Observations and measurements have been made on highway bridges since their inception. Engineers have always been curious to see whether their designs behave in use the way they thought they should and are keen to make full scale tests whenever they have the opportunity to do so. Usually, the behavior of the bridge under live loading is of paramount interest. Aspects such as lateral load distribution, impact factors, location of neutral axis, composite action, and stresses and deflections at various points are determined, often with controlled, simulated design loads. Such tests consist of short term, if not instantaneous, observations that are nevertheless quite valuable.

Some of the tests produce irreversible changes in the tested structure. Of great interest recently has been the testing to failure of several highway bridges in Tennessee (*1*).[1] Yet even these tests were of relatively short duration—lasting only a matter of hours—and still cannot be termed *long term* observations. True long term observations on highway bridges are uncommon but are very useful in helping to determine the life expectancy of bridges. It is the purpose of this article to review available long term measurements on bridges and to outline others for the future.

[1]Italic numbers in parentheses identify the references on page 27.

Long Term Material Behavior

Whenever bridges are manufactured from concrete, prestressed concrete, or another composite material, there is concern over the long term stability of the structure. (More than half of the bridges on the Federal-aid Highway System are nonsteel.) Concrete especially is subject to changes in behavior caused by loading, moisture, and temperature.

The structural application of prestressed concrete in American highway bridges is relatively new; the first such bridge was the Walnut Lane Bridge in Philadelphia, Pa., built in 1951. Since that time, the use of prestressed concrete has steadily increased, being more prevalent in some areas of the country than in others.

With such construction, it is always necessary to estimate at the design stage the long term stress losses in the main load carrying members. These losses can be as much as 20-30 percent of the initial prestressing force and are a function of loading history, the material composition, and the environment in which the bridges are located.

For a long time these stress losses have been known to exist and traditionally are estimated for the prototype structure with the aid of short term laboratory tests using small specimens. In the last few years there has been a growing awareness that such laboratory based estimates often are inaccurate, usually on the conservative side, thereby penalizing the use of prestressed concrete. Field tests on actual structures were, therefore, initiated to better evaluate prestress losses.

These field observations are continuing, notably in the States of California, Illinois, Nebraska, and Pennsylvania. Usually the work is performed by researchers from universities. Measurements consist of internal and external concrete strain measurements, deflection readings at various stages of the bridge construction, smaller concrete cylinder tests, and observations on the weather at the bridge site.

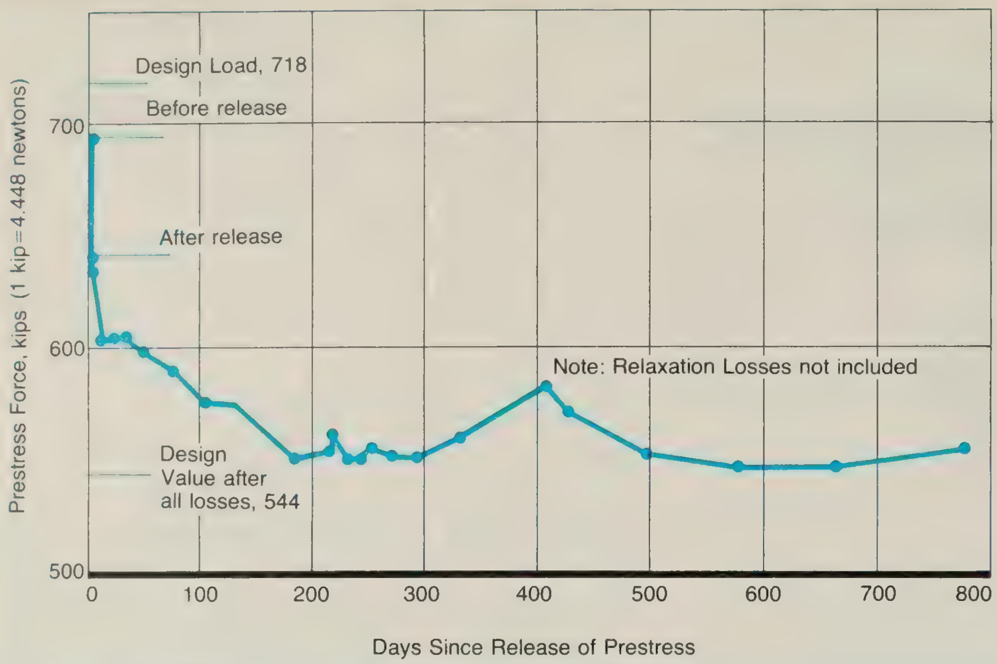


Figure 1.—*Stress loss vs. time behavior of prestressed concrete bridges—Illinois.*

A stress loss versus time curve is shown in *figure 1* based on data from Illinois. Results from other States are generally similar. Note that most of the loss takes place in the first year of the life of the structure. The total stress loss is a function of creep, shrinkage, and relaxation of the prestressing steel. There is a complicated interrelationship between the factors; but it is hoped that the field tests will provide a realistic, though empirical, guide for the more accurate estimation of stress losses.

It should be emphasized that even long term observations are not always the final answer to characterization of structural behavior, but it does seem that intelligently selected long term observations on representative prototype structures make a very good base for specifications.

Long Term Environmental Effects

Highway bridges are placed in a variety of climatic environments and are thus exposed to sun, wind, rain, freezing, and thawing—all of which tend to deteriorate the structures, although very slowly. Therefore, it takes careful long term observations to assess the damage done by the bridge environment.

In one sense, the periodic inspections of bridges to insure structural adequacy and the assessment of what maintenance must be performed constitute a form of long term measurement. But very little of this kind of information has been documented, and it is only in recent years that a more formal bridge inspection program with nationally uniform reporting has been established. Although it is believed that long term observations related to bridge maintenance can be a very fruitful activity, this subject will not be pursued further at this point.

Nor is it planned to say too much about studies of corrosion rates and the adequacy of corrosion protection schemes. Simple atmospheric corrosion of highway bridges is a very troublesome problem, and many corrosion protection schemes are under long term observation in many places with the somewhat unscientific "let's see how it stands up" attitude. Newer corrosion protection schemes especially—such as protective metal coatings (galvanizing), epoxy paints, and the use of the so-called "weathering" steels—are being carefully observed. In some instances these observations are made under the auspices of a cooperative State-Federal research study.

A more organized scientific inquiry into the long term effect of the highway bridge environment on structural performance and serviceability has to do with the subject of stress corrosion. Ordinarily, stress corrosion is not associated with highway bridge environments or materials. However, the catastrophic collapse of the Point Pleasant, W. Va., suspension bridge was linked to a flaw that grew to critical size by some form of stress corrosion mechanism.

Since that collapse, and chiefly because of it, an extensive study of the bridge steels to determine their stress corrosion susceptibility was undertaken, along with a nationwide survey of past, present, and projected future bridge steel usage, and a survey of the corrosiveness of the bridge environment. One phase of a Federal Highway Administration (FHWA) study (*2*) will result in long term observations of stress corrosion specimens at six bridge sites.

Results from the initial phase of the study have been reported (*2*), and generally reinforce the view that for the great majority of highway bridges constructed with the common low strength construction steels, there is no worry of stress corrosion in the usual bridge environment. This is especially true due to the traditionally conservative approach to the design stresses allowed in highway bridges.

Perhaps a closer definition of the highway bridge environment is in order. This would include not only the air and water surrounding bridge members, but also the corrosive environment produced by the extensive use of deicing salts. It was shown in the above-mentioned FHWA study that both atmospheric and water pollution, even in highly polluted areas, were not present in the concentration necessary to cause stress corrosion problems in the lifetime of most bridges. However, the concentration of pollutants in the nooks and crannies of bridges is often unmeasurable. These places, which may be constantly splattered by traffic year after year, are the real victims of the bridge environment.

It is therefore planned to place specimens for long term observation on carefully selected sites on bridges in various parts of the country, and to make periodic observations on the progress of stress corrosion cracking. The specimens would not be a load-bearing part of the bridge but would be stressed to varying degrees. The types of steels used in the specimens would be those showing stress corrosion susceptibility in the more severe laboratory tests. Specimens would be precracked by fatigue loading and, for the steels representing plates and shapes, a double cantilever beam specimen would be used. Appropriate specimens of other configurations are planned for the high strength bolts and the high strength bridge wires and cables. At the selected bridge sites, it is also planned to simultaneously and continuously record the atmospheric concentration of a number of air pollutants.

The deterioration of structural concrete is another type of long term observation linking the environment and bridges that has been and continues to be the subject of much research. Concrete bridge deck deterioration is of particular interest, since it remains the single most troublesome and costly problem associated with highway bridges.

The long term effects of various deicing compounds have been extensively studied, both in the laboratory and in the field. Observations are often of the long term but periodic type, ranging from visual observation of damage to studies under the electron microscope. Extensive literature exists on this subject.

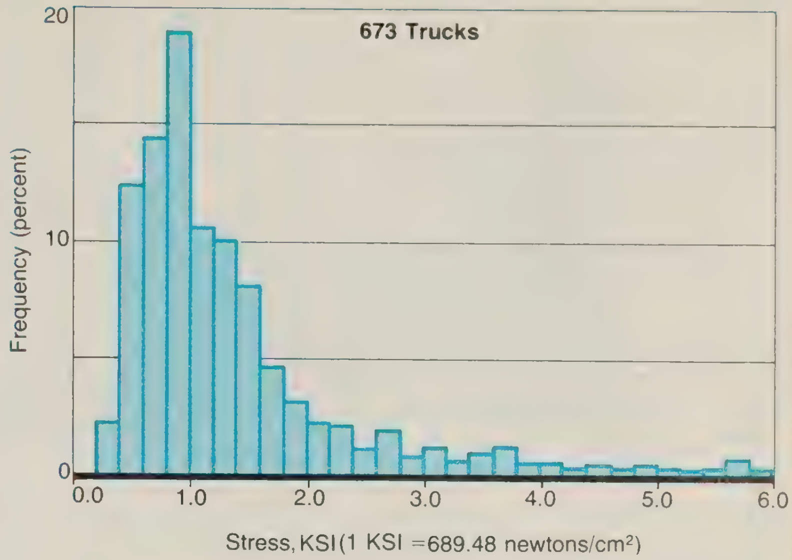


Figure 2. — *Typical bridge live load stress histogram.*

Also related to environmental effects on bridge members are some interesting prestressed concrete and ordinary reinforced concrete beam exposure tests conducted for over 20 years by the Army Corps of Engineers at their severe weathering exposure station located at Treat Island, Maine. The test specimens were installed at meantide elevation, where the alternate conditions of immersion in sea water and exposure to cold air provided an average of about 100 cycles of freezing and thawing each winter. The first specimens were placed on the beach in 1951. Additional specimens were added in 1954, 1958, and 1961. In all, 158 reinforced concrete and 36 prestressed concrete beams were installed.

Test variables were: Type of concrete (air entrained vs. non air entrained), thickness of concrete cover, type of reinforcing steel, degree of stress, and the position of the steel. The long term observations consisted of visual deterioration observations, crack width measurements, stress loss measurements, and concrete soundness pulse velocity measurements.

Several reports on this work have been published (3, 4, 5), and observations are continued every 2 years on those specimens that remain. This study can, therefore, be classified as a true long term behavior test and could become a classic in this field.

Findings of the study conclusively demonstrate the superiority of air entrained concrete in enduring freeze-thaw cycles. They also show that for the end protection of post-tensioned beams, epoxy concrete seems to be superior to portland cement concrete, and that flush anchorages appear to be more effectively protected than external anchorages. As the study continues, one of the most valuable observations will be the state of corrosion of the strands in the prestressed beams.

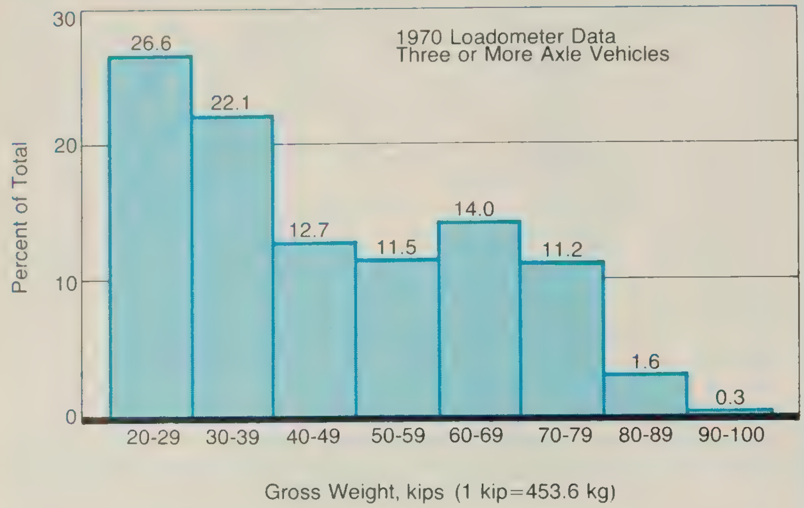


Figure 3. — *Typical truck gross weight distribution.*

Long Term Load Effects

In recent years there has been considerable concern in the highway community over the adequacy of the fatigue provisions of the bridge specifications. Some fatigue distress has been discovered in several bridges located in the very heavily traveled urban corridors of our country, mostly in secondary members subjected to wheel loads, but sometimes also in the main load carrying members (6). In order to properly assess the extent of this problem, various organizations have for a number of years conducted bridge loading history studies. In a sense, such studies are also long term observations, even though the sampling periods for stress measurements on any one structure may last only a week or a few days at a time. Observations on the classification and weights of the truck traffic usually accompany the stress measurements.

Many such studies have been made and are continuing. Results are usually reported as stress histograms and truck gross weight distributions. Typical examples are shown in *figures 2 and 3*. Although usually the truck-produced stress ranges are well below the design live load stresses, there is no doubt that for bridges located on major highways, both the frequency and the magnitude of the load induced stresses are increasing yearly. There is also a noticeable trend toward more frequent use of the five-axle tractor-trailer combination vehicle. This is the vehicle that for many bridges produces the largest stress. *Figure 4* presents a 10-year trend of frequency of occurrence of the five major truck types, illustrating the marked trend toward five-axle trucks. This data is taken from a typical Federal-State-University cooperative bridge loading history study in Maryland (*7*).

One of the interesting findings of all these studies on truck traffic and bridge stress is that changes in truck weight laws produce marked changes in the truck traffic and, therefore, in the magnitude and frequency of live load stresses.

A problem connected with the long-term, live-load stress measurements has been the cost and sophistication of the measuring instrumentation necessary for producing reliable data. Simpler instrumentation, preferably such that can be left unattended on the bridge for a long time, needs to be developed. One such instrument—the *scratch gage*—is beginning to be used for this purpose. This gage itself is the subject of long term observation, being evaluated over a period of several months on an installation on the Connecticut Turnpike.

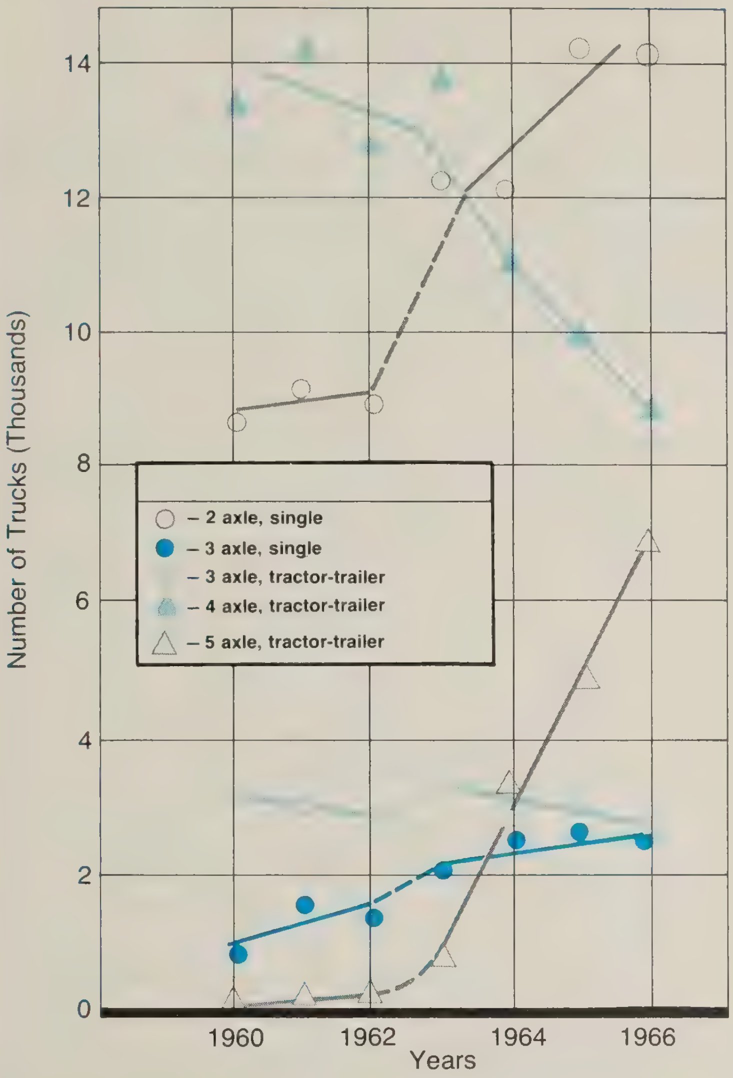
Wind Loadings

A different kind of live loading that is also of great interest to bridge engineers is that produced by wind. Reference here is mostly to the dynamic behavior of bridges, such as the aerodynamic instability of some suspension bridges. The most notable bridge failure in the United States caused by wind was the collapse of the Tacoma Narrows suspension bridge in 1940 (*8*). There have been numerous wind tunnel studies to shed light on this problem, but to determine the exact nature of the wind in the vicinity of real bridges has proven to be very difficult, especially when the wind's variability along the structure and the complicated interaction between structure and wind are taken into consideration.

Fortunately, there have been some recent advances in measurement techniques and instrumentation development that make it possible to begin making long term wind and bridge motion measurements on major highway bridges. One such instrumentation package, developed under contract for the FHWA, is presently installed on the first American cable-stayed bridge, located in Sitka, Alaska. A view of the bridge is shown in *figure 5*.

Anemometers and accelerometers have been placed on several points on the bridge to simultaneously record the direction and magnitude of the wind along with the bridge motion. Of special interest is any movement of the tall towers. The instrumentation can be left unattended, and it is only necessary to periodically collect the data which is in the form of digitized tape. One record showing the wind and tower relationship is shown in *figure 6*. It is planned to make observations on this bridge for 2 years, then move on to other sites.

Figure 4.—*Long term truck type trends.*



Long Term Seismic Observations

Similar to wind induced motion and of great interest to bridge engineers are bridge movements caused by earthquakes. This is especially true on the west coast of our country. Historically, the profession is data poor when it comes to useful recordings of ground and structure movements during earthquakes, especially on bridges. Motions of dams and tall buildings have been of more pressing interest and some types of accelerographs have been in place on these since the 1930's, but the instruments do not always function and are often in the wrong place. Not a single seismic observation was available from the Great Alaska Earthquake of 1963. Even in the recent (1971) San Fernando Earthquake, of the 241 accelerographs in the area, none was on a bridge. It was not until after that quake that the first such instrument was placed on an overpass in the Los Angeles area. In October 1972, an accelerograph was placed on the Sitka Harbor cable-stayed bridge described earlier.

The need exists, therefore, to carry out a program of long term measurements on earthquake bridge motions. A start has been made on several fronts with various cooperative State-Federal research studies, as well as with direct Federal highway funds. Again, suitable instrumentation that is not too expensive, and is above all very durable, had to be developed. One such instrument is shown in *figure 7*.[2]

This accelerograph houses three torsion type accelerometers, which can be oriented as desired. Other items in the instrumentation are a light source, mirrors, and a 70-millimeter film for recording traces from each of the accelerometers along with time signals and a reference line. A motor drive and two 12-volt lead dioxide batteries complete the system.

The instrumentation is triggered by a horizontal movement of 0.02 inch (0.5 mm) or a vertical force of 0.01 g. Recording continues for 7 seconds after the last triggering. The instruments can operate singly or in conjunction with others, where one instrument can be set to trigger all of them. The approximate cost of one unit is $1,600.

[2]The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear herein solely because they are considered essential to the object of the report.

Figure 5.—*Sitka Harbor cable-stayed bridge.*

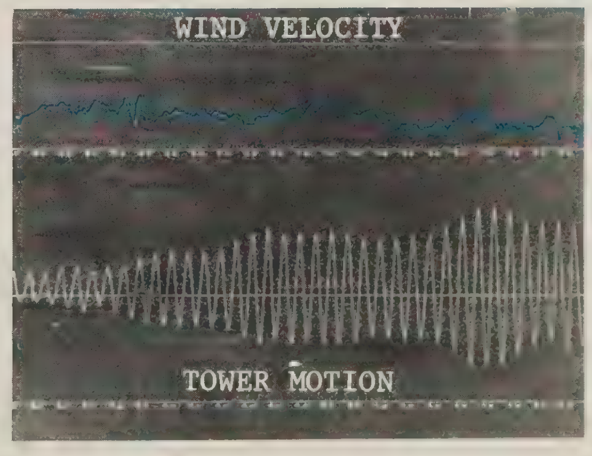


Figure 6.—*Tower motion vs. wind velocity relationship.*

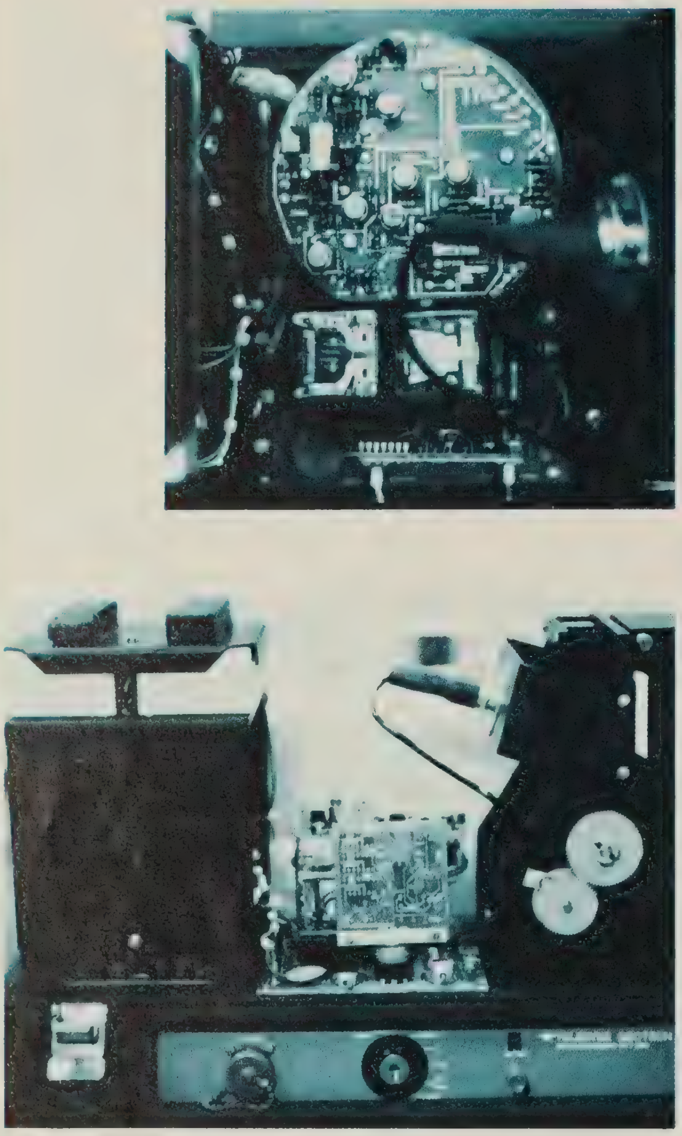


Figure 7.—*Bridge seismic instrumentation.*

It is planned to instrument a few selected bridges thoroughly by placing units on abutments, columns, piers, pier caps, and decks. Maintenance for the instruments must be provided about four times a year, otherwise they can be left unattended. All that is necessary to activate the instrument is an earthquake.

It is also intended that the accelerographs on the bridges be incorporated into the network of approximately 1,000 accelerographs located primarily on the west coast and Alaska that are maintained and monitored by the Seismic Engineering Branch of the U.S. Geological Survey. Following an earthquake, the film records of measured accelerations will be forwarded to the San Francisco office of the Seismic Engineering Branch for processing and inspection. The data will then be distributed to interested parties and a permanent public record will be maintained.

It is hoped that such bridge earthquake records, in conjunction with observations on bridge damage and some laboratory testing, will result in adequate earthquake resistant bridge designs where they are needed. The present emphasis is on a dynamic approach to earthquake designs.

A major problem in this kind of research is the wait for earthquake activity of sufficient magnitude for measurements. California seismologists estimate that on the west coast there will be an earthquake producing recordable motions and forces about once in 5 years.

Summary and Conclusion

Some selected long term observations on highway bridges have been presented. Changes in the structural behavior of bridges subjected to environmental effects and external loads, as well as internal loads, have been described. Included also were field tests to determine stress losses in prestressed concrete bridges, stress corrosion tests on bridge steels placed on selected bridge sites, live-load stress measurements and long term truck traffic observations, concrete deterioration tests, and long term wind and earthquake observations on bridges.

Long term bridge material changes have generally been omitted. Some such items might be observations on structural timber durability in marine environments subjected to biological as well as physical forces, or the long term durability of weathering steels or galvanized steel bridges. The complicated yet important subject of thermally induced long term stresses in highway bridges has also not been discussed because there is not enough experimental field data.

Some long term, potentially useful measurements on highway bridges are now only the subject of feasibility research. These include methods for determining the state of health of a bridge at any time, possibly even through remote sensing. The most promising two such methods are the acoustic emission techniques associated with crack growth measurements in pressure vessels and ships, and the analysis of high frequency vibration behavior of structures as a result of cracking or other deterioration.

ACKNOWLEDGMENTS

The author wishes to thank Richard Gade and James Cooper of the Fairbank Highway Research Station for their help in providing information on and examples of the observations relating to wind and earthquake measurements.

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(*2*) C. S. Carter, M. V. Hyatt, and J. E. Cotton, "Stress Corrosion Suceptibility of Highway Bridge Construction Steels—Phase I," *FHWA,* Office of Research, April 1972.

(*3*) E. C. Roshore, "Tensile Crack Exposure Tests—Results of Tests of Reinforced Concrete Beams, 1955-1963," *U.S. Army Engineers Waterways Experiment Station* Technical Memorandum No. 6-412, Vicksburg, Miss., 1965.

(*4*) E. C. Roshore, "Durability of Prestressed Concrete Beams," *Journal of the Prestressed Concrete Institute,* vol. 10, No. 5, October 1965, pp. 49-59.

(*5*) "Durability and Behavior of Prestressed Concrete Beams—Progress to July 1966," *U.S. Army Engineers Waterways Experiment Station* Technical Report No. 6-570, Vicksburg, Miss., March 1967.

(*6*) D. G. Bowers, "Loading History Span No. 10 Yellow Mill Pond Bridge I-95, Bridgeport, Connecticut," *State of Connecticut Department of Transportation* Research Report No. HPR 175-332, Wethersfield, Conn., May 1972.

(*7*) R. D. Desrosiers, "The Development of a Technique for Determining the Magnitude and Frequency of Truck Loadings on Bridges," *University of Maryland,* Civil Engineering Department, College Park, Md., April 1969.

(*8*) F. Bleich et al., "The Mathematical Theory of Vibration in Suspension Bridges," *Bureau of Public Roads,* Washington, D.C. 1950.

NOTICE

AASHO now AASHTO
HRB now TRB

At the 59th Annual Meeting of the American Association of State Highway Officials in Los Angeles, November 12-15, 1973, members of the Association voted to expand its membership to include all transportation interests and change the name of the Association to the American Association of State Highway and Transportation Officials [AASHTO].

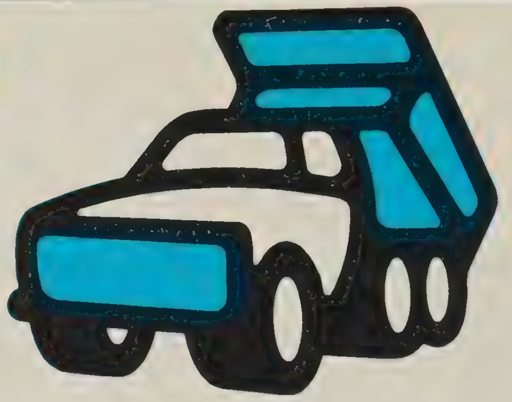
In recognition of its expanding activities in the various transportation modes outside the highway field, the Highway Research Board has been renamed the Transportation Research Board [TRB].

These name changes reflect the nationwide trend in 23 States, in which State highway departments have evolved into or have become part of State departments of transportation.

TITLE SHEET, VOLUME 37

The title sheet for volume 37, June 1972—March 1974, 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 managing editor of the magazine, U.S. Department of Transportation, Federal Highway Administration [HDV-10], Washington, D.C. 20590.

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



The principal tool for implementing research and development is the implementation/user package which provides "how-to-do-it" information to the potential user. The package converts research findings into practical tools. The packaging requirement is accomplished between the identification and promotion stages of implementation.

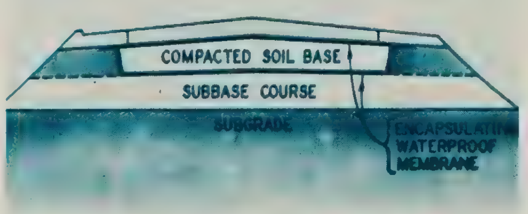
The following items are brief descriptions of selected packages which are actively being developed, or have been recently completed, by State and Federal highway units in cooperation with the Implementation Division, Offices of Research and Development, Federal Highway Administration (FHWA). Completed packages will be available from the Implementation Division unless otherwise indicated. Those placed in the National Technical Information Service (NTIS) will be announced in this department after an NTIS accession number is assigned.

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

Packages Completed

Encapsulated Subgrades by U.S. Army Corps of Engineers

A user package has been prepared by the Corps of Engineers at the Waterways Experiment Station, Vicksburg, Miss. This manual includes construction methods, costs, applications, and specifications for the membrane encapsulated subgrades. This method provides engineers with a rapid and stable road building technique for use in areas where moisture is a problem in stabilizing the pavement structural section and where aggregates are scarce.



FLEXIBLE PAVEMENT SECTION WITH MEMBRANE ENCAPSULATED SOIL BASE COURSE

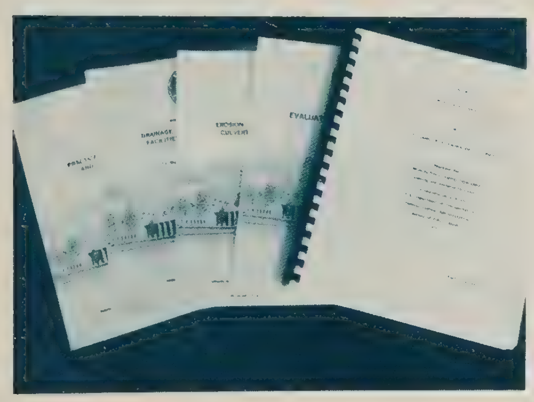
Texas Crash Cushion Trailer by Texas Highway Department and FHWA Region 6, Fort Worth, Tex.

The Texas Crash Cushion, consisting of a number of 55-gallon steel drums, has been adapted to provide highway maintenance vehicles with protection from rear-end collisions by errant vehicles. Wheels and a trailer hitch have been added to the Texas Crash Cushion so that it can be attached to a maintenance vehicle such as a dump truck to provide such needed protection to the truck and maintenance personnel. The implementation package includes a how-to-do-it manual on the process of designing the portable or mobile trailer system to protect slowly moving or stopped maintenance vehicles working on highways. The manual also includes the appropriate procedure for

attaching the protective system to the highway maintenance vehicle.

Culvert Outlet Protection Design: Computer Program Documentation by Wyoming State Highway Department

In response to a widely expressed need to develop a tool useful in the design of measures or devices to reduce scour at culvert outlets, personnel of the hydraulics section of Wyoming State Highway Department have developed a package which consists of the consolidation of the results of research carried out by Colorado State University, the Corps of Engineers, and other investigators. The package includes a computer program and a 253-page documentation (Report No. FHWA-RD-74-501) which will enable the engineer to quickly determine the optimum design of an energy dissipation device or protective measure to be used at the culvert outlet for any given set of hydrological and hydraulic conditions.



Urban Traffic Control/Bus Priority Systems [UTCS/BPS] Brochure by FHWA Traffic Systems and Implementation Divisions

In many cities, highway agencies are currently planning for or installing digital computer controlled traffic signal systems. In order to familiarize these agencies with FHWA technology and research in this area, a multicolor brochure has been prepared which describes the FHWA's Washington, D.C. systems, research activities, and implementation aspects.

The following are completed packages which were announced in previous issues of *Public Roads* and are now available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151.

Title	NTIS Accession Number	Paper Copy Price	Microfiche Price
Rubber-Asphalt Binder for Seal Coat Construction	PB 219012	$3.75	$0.95
Managing Highway Maintenance—Training Guide and Catalog	PB 224407	3.00	1.45
Implementation Package for Slotted CMP Surface Drains	PB 225635	2.75	1.45
Implementation Package for the Use of Liquid Calcium Chloride to Improve Deicing and Snow Removal	PB 224842	3.00	1.45
Project Management System (PMS) Through the Use of the Critical Path Method (CPM)	PB 222009	13.75	0.95

Open Graded Emulsified Asphalt Pavements by FHWA Region 10, Portland, Oreg.

For several years the U.S. Forest Service has successfully used cold mixed, open graded emulsified asphalt mixtures for pavement construction in the Pacific Northwest. These open graded mixes have been low in construction and maintenance cost and have demonstrated good serviceability, durability, stability, and internal drainage qualities. The implementation package includes background construction features, cost and performance data, and guide specifications. The construction procedure outlined in the report is relatively pollution free and offers a significant savings in energy requirements for the total pavements system.

The following completed packages, announced in previous issues of *Public Roads*, are available from the Implementation Division.

User Manual on Finishing of Concrete Structures

Hi-Dri Cell Crash Cushion

Computerized Bridge Rating System

Packages in Preparation

Michigan Noise Model
by FHWA Implementation Division

The State of Michigan has recently completed updating and expanding the original version of the noise prediction computer program which was based upon NCHRP Report 117. The original program was distributed to all of the State highway departments by the Federal Highway Administration in May 1972. This modified version incorporates the methodology contained in the new NCHRP Report 144. The current implementation effort includes conversion of the program from time-share mode to batch mode, program testing and evaluation, modification of user instructions to reflect the program conversion, and nationwide distribution.

Time Lapse Photography
by FHWA Ohio Division
and Region 5, Homewood, Ill.

A users guide is being developed to demonstrate the application of time lapse photography techniques in the field of traffic engineering. The guide will provide information on equipment, photographic procedures, data gathering and analysis techniques, and references for further information. A movie will be produced to accompany the guide, illustrating the principles presented.

Water in Pavements
by FHWA Implementation Division

A state-of-the-practice guide on measures to prevent the premature failure of pavement systems caused by water is being developed. The guide is based on the results of the five regional workshops conducted during the last quarter of 1973. A slide-tape workshop package is also being developed for distribution to the States through the National Highway Institute.

Breakaway Barricades
by Nevada Department of Highways

Urban Traffic Control/Bus Priority Systems [UTCS/BPS] Hardware Specifications
by FHWA Implementation Division

Aerial Drainage Survey Computer Program
by Wyoming State Highway Department

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. 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 Research]—Performing State Highway Department; National Cooperative Highway Research Program [NCHRP]—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety

Title: Development of Procedures for Identifying Hazardous Locations (FCP No. 31A1523)
Objective: Develop and verify procedures for all highway facilities (except freeways) to identify hazardous locations using a method(s) other than accident records.
Performing Organization: Pennsylvania State University, University Park, Pa. 16802
Expected Completion Date: March 1975
Estimated Cost: $115,000 (FHWA Administrative Contract)

Title: Right-Turn-On-Red (FCP No. 31A1544)
Objective: Determine whether permitting the right-turn-on-red maneuver is desirable, prepare guidelines for determining inclusion or exclusion of this movement and how the necessary control is applied.
Performing Organization: Alan M. Voorhees & Associates, McLean, Va. 22101
Expected Completion Date: December 1975
Estimated Cost: $123,000 (FHWA Administrative Contract)

Title: Signs and Markings for Low Volume Rural Roads (FCP No. 31A1553)
Objective: Develop guidelines for traffic control signing and marking requirements for various classes of low volume rural roads.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Expected Completion Date: June 1975
Estimated Cost: $63,000 (FHWA Administrative Contract)

Title: Passing and No Passing Zones—Signs, Markings, Laws, and Warrants (FCP No. 31A1563)
Objective: Development, testing, and evaluation of criteria for establishing passing and no passing zones, restrictive passing zones, traffic control devices, laws, and warrants which can be considered for inclusion in the AASHTO policy and the MUTCD. Involves passing and no passing situations on urban and rural two- and three-lane highways.
Performing Organization: System Development Corporation, Santa Monica, Calif. 90406
Expected Completion Date: December 1975
Estimated Cost: $144,000 (FHWA Administrative Contract)

Title: Traffic Controls for Construction and Maintenance Work Sites (FCP No. 31A2504)
Objective: Develop detailed guidelines to assist governmental jurisdictions and other agencies in implementing uniform control and safety measures at construction and maintenance sites.
Performing Organization: American Public Works Association, Chicago, Ill. 60737
Expected Completion Date: June 1975
Estimated Cost: $86,000 (FHWA Administrative Contract)

FCP Project 1C: Analysis and Remedies of Freeway Traffic Disturbances

Title: Development and Testing of Incident Detection Algorithms (FCP No. 31C3502)
Objective: Develop, test, and evaluate incident detection algorithms using forecasting, time series, and pattern recognition approaches. Study the effects of sensor configuration, geometrics, and weather on the algorithms and their threshold values. Provide algorithm documentation including FORTRAN software.
Performing Organization: Technology Service Corporation, Santa Monica, Calif. 90401
Expected Completion Date: December 1975
Estimated Cost: $245,000 (FHWA Administrative Contract)

ERRATA

In the article "Environmental Research and Highways" in the March 1974 issue of *Public Roads*, vol. 37, No. 8, page 304, col. 3, lines 20-29 should read as follows: The amortized cost of the heat pipe system is likely to be 20 to 40 cents per square foot *($2.15 to $4.30 per square meter)* **per year compared to about 1 cent per square foot** *(10.8 cents per square meter)* **per year for a general snow and ice removal system. There are special locations, however, such as at interchange ramps and bridge decks, where snow and ice removal costs are 10 to 40 cents per square foot** *($1.08 to $4.30 per square meter)* **per year because of the need for assigning a special crew or for other reasons.**

FCP Project 1H: Skid Accident Reduction

Title: Investigation of Tire-Pavement Interaction During Maneuvering. (FCP No. 31H2132)
Objective: Develop an analytic model of the tire-pavement interaction which, when coupled with a vehicle dynamics model, will enable the highway engineer to predict loss of vehicle control. Improve knowledge of interrelation between variables to assist in research to provide higher friction. Macro and micro texture as well as tire variables to be included in the model.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Expected Completion Date: December 1975
Estimated Cost: $207,000 (FHWA Administrative Contract)

Title: Pavement and Geometric Design Criteria for Minimizing Highway Hydroplaning. (FCP No. 31H2212)
Objective: Literature search, analysis of surface flow, surface texture criteria, cross-slope criteria, surface drainage in sag curves. Identify other problems, detail research plan, itemize critical dimensions. Conduct research plan, new drainage concepts, corrective measures for existing highways.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Expected Completion Date: October 1976
Estimated Cost: $231,000 (FHWA Administrative Contract)

Title: Effects of Pavement Grooving on Friction, Braking, and Vehicle Control. (FCP No. 31H2252)
Objective: Determine the effects of pavement grooving on vehicle handling, both beneficial and detrimental. Determine optimal groove configuration and orientation, with special regard to vehicles with various tire treads. Develop simulation programs for use by highway engineers, to serve as tools in design and maintenance of pavements.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Expected Completion Date: June 1975
Estimated Cost: $107,000 (FHWA Administrative Contract)

FCP Project 1J: Improved Geometric Design

Title: Improving the Traffic Operations and Safety of Full Cloverleaf Interchanges. (FCP No. 31J2022)
Objective: Identify elements of full cloverleaf interchanges that have the greatest influence on the safety of the interchange. Develop and evaluate techniques that will improve the operation and safety of the overall interchange.
Performing Organization: Ohio Department of Transportation, Columbus, Ohio 43215
Expected Completion Date: August 1975
Estimated Cost: $99,000 (FHWA Administrative Contract)

FCP Project 1K: Accident Research and Factors for Economic Analysis

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Title: Identification and Programming of Improvements for High Accident Locations. (FCP No. 41K1082)
Objective: Develop procedures to identify potentially high accident locations and a set of procedures for improvement of these locations. These

procedures will apply to both State and local road and street systems.
Performing Organization: University of Maryland, College Park, Md. 20742
Funding Agency: Maryland Department of Transportation
Expected Completion Date: June 1975
Estimated Cost: $41,000 (HP&R)

FCP Project 1T: Advanced Vehicle Protection Systems

Title: Establishment of Interim Standards for Barriers Required to Contain Heavy Vehicles. (FCP No. 31T1022)
Objective: Develop interim design standards and specifications for traffic railing systems required to contain heavy vehicles.
Performing Organization: Ensco, Incorporated, Springfield, Va. 22151
Expected Completion Date: June 1975
Estimated Cost: $134,000 (FHWA Administrative Contract)

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

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FCP Project 2E: Translation of Previous Results in Budget Category II for Operational Use

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Title: Evaluation of a Moving Merge Control System. (FCP No. 32E2514)
Objective: Determine for Green Band Merging Control Systems at substandard ramp locations the level of improvement provided in freeway/ramp merging, the degree of help provided drivers, and the system cost-effectiveness.
Performing Organization: Florida Department of Transportation, Tallahassee, Fla. 32304
Expected Completion Date: June 1975
Estimated Cost: $85,000 (FHWA Administrative Contract)

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

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FCP Project 3E: Reduction of Environmental Hazards to Water Resources Due to the Highway System

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Title: A Study of the Influence of Highway Erosion Sediments and Water-Borne Materials from Roadway Surfaces and Aquatic Biota. (FCP No. 43E2092)
Objective: Determine the influence of erosion sediments and water-borne materials from roadway surfaces on productivity rates of aquatic flora. This study will not identify the constituents of concentrations of highway runoff but is to determine what aquatic biota is affected and to what extent.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95807
Expected Completion Date: June 1975
Estimated Cost: $64,000 (HP&R)

FCP Project 3F: Pollution Reduction and Visual Enhancement

Title: Establishment of Ground Covers for Non-Mowable and Locked-In Areas. (FCP No. 43F1612)
Objective: Select dwarf, well adapted groundcovers with low maintenance, fertility, and moisture requirements which can be reproduced vegetatively.
Performing Organization: Louisiana State University, Baton Rouge, La. 70803
Funding Agency: Louisiana Department of Highways
Expected Completion Date: January 1977
Estimated Cost: $112,000 (HP&R)

Title: Evaluation of New Roadside Ground Cover Materials. (FCP No. 43F1722)
Objective: Determine the utility of 35 species of woody plants for erosion control.
Performing Organization: University of Minnesota, Minneapolis, Minn. 55812
Funding Agency: Minnesota Department of Highways
Expected Completion Date: June 1977
Estimated Cost: $65,000 (HP&R)

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

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FCP Project 5F: Bridge Safety Inspection

Title: Stress Corrosion Susceptibility of Highway Bridge Construction Steel, Phase II-B. (FCP No. 35F2022)
Objective: Stress corrosion tests on double cantilever beam specimens subjected to four corrosive environments. Tests on weldments, prestressing wires, and high strength galvanized bolts. Field studies at six environmentally different bridge sites.
Performing Organization: Boeing Company, Seattle, Wash. 98105
Expected Completion Date: December 1975
Estimated Cost: $78,000 (FHWA Administrative Contract)

Title: Fatigue of Curved Steel Bridge Elements. (FCP No. 35F2052)
Objective: Establish the behavior of curved steel box and I-girders and develop fatigue design for curved steel girder highway bridges in suitable form for inclusion in the AASHTO Bridge Specifications.
Performing Organization: Lehigh University, Bethlehem, Pa. 18015
Expected Completion Date: October 1976
Estimated Cost: $317,000 (FHWA Administrative Contract)

Title: Prestress Losses of Post-Tensioned Members. (FCP No. 45F3692)
Objective: Evaluate the prestress losses in post-tensioned and pre post-tensioned structural members.
Performing Organization: Lehigh University, Bethlehem, Pa. 18015
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: June 1976
Estimated Cost: $85,000 (HP&R)

FCP Project 5H: Protection of the Highway System from Hazards Attributed to Flooding

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Title: Optimal Dimensions for Inlet Gratings. (FCP No. 45H2392)
Objective: Determine the most efficient lengths of Pennsylvania's standard diagonal-bar inlet gratings of 3-ft width on the paved highways and of 4-ft width in the grassed highway drainage channels.
Performing Organization: Lehigh University, Bethlehem, Pa. 18015
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: December 1975
Estimated Cost: $74,000 (HP&R)

FCP Category 6—Development and Implementation of Research

FCP Project 6B: Construction and Maintenance Methods and Equipment

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Title: Maintenance Management in City and County Highway Agencies. (FCP No. 36B6124)
Objective: Develop information on the state of maintenance management, problems faced by managers, and factors deterring the adoption of new management procedures by city and county highway agencies.
Performing Organization: FHWA Region 10, Portland, Oreg. 97204
Expected Completion Date: March 1975
Estimated Cost: $80,000 (FHWA Administrative Contract)

Non-FCP Category 0—Other New Studies

Title: Development of Design Criteria for Cut Slopes in Loess. (FCP No. 40M1422)
Objective: Identify Loessial stratigraphy, correlate stratigraphy with engineering properties, evaluate critical moisture-strength concept and long-term changes in moisture and strength, and evaluate stability analysis techniques to develop criteria for cut slope design.
Performing Organization: Missouri State Highway Commission, Jefferson City, Mo. 65101
Expected Completion Date: July 1978
Estimated Cost: $50,000 (HP&R)

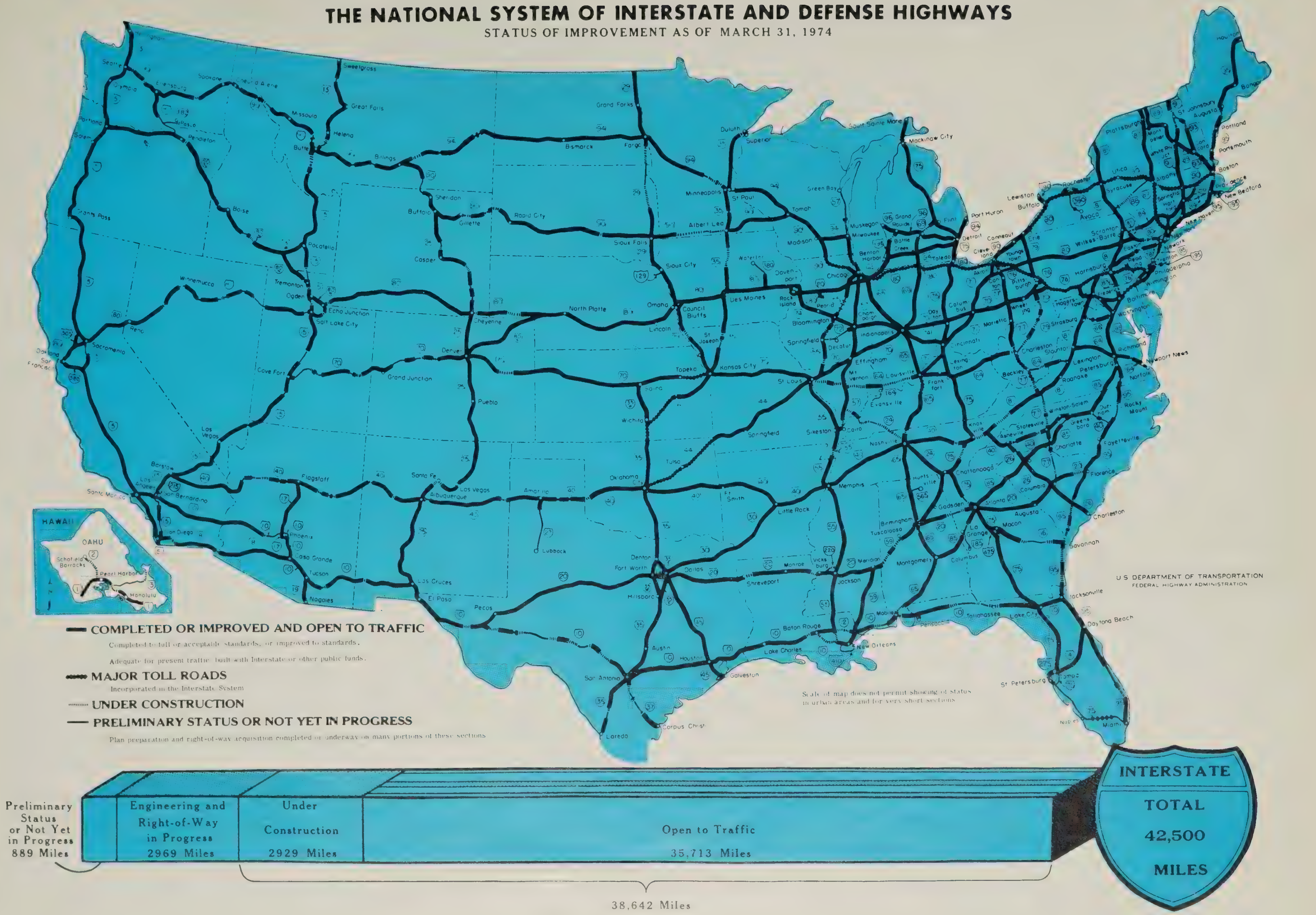
Title: Bituminous Treated Bases. (FCP No. 40M2434)
Objective: Provide the technology for more economical asphalt treated base courses by investigating new construction techniques and more realistic criteria for materials selection and materials design which will provide the desired performance in a given environment.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas Highway Department
Expected Completion Date: August 1975
Estimated Cost: $75,000 (HP&R)

Title: A Program for Improvement of Bituminous Surface Treatments on South Carolina Secondary Highways. (FCP No. 40M2454)
Objective: Review specifications, construction practices, and control techniques for bituminous surface treatments used in South Carolina; compare with those found successful in other areas. Evaluate field performance of standard and trial sections to validate recommended changes.
Performing Organization: Clemson University, Clemson, S.C. 29631
Funding Agency: South Carolina State Highway Department
Expected Completion Date: March 1976
Estimated Cost: $61,000 (HP&R)

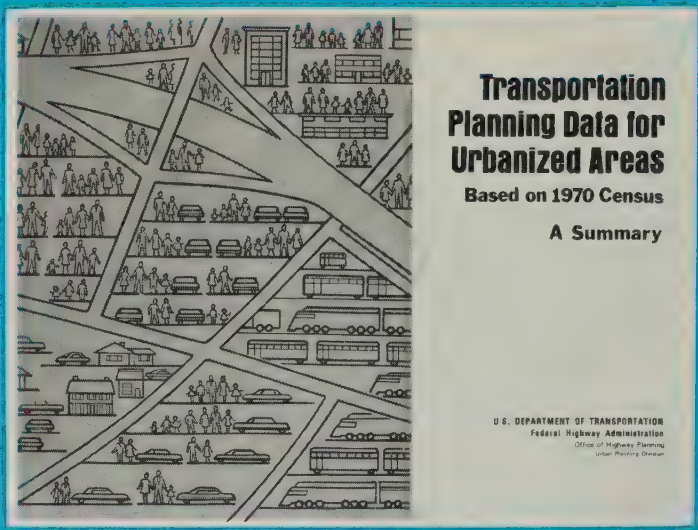
Title: Investigation of Surface Durability and Skid Resistance of Asphalt Pavements. (FCP No. 40M2474)
Objective: Measure the rate of wear of Arkansas aggregates using the British accelerated polishing machine and economically improve the skid resistance of asphalt pavements by blending high quality, polish-resistant coarse aggregates with more readily available polish-susceptible aggregates.
Performing Organization: University of Arkansas, Fayetteville, Ark. 72701
Funding Agency: Arkansas State Highway Department
Expected Completion Date: December 1976
Estimated Cost: $109,000 (HP&R)

THE NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS

STATUS OF IMPROVEMENT AS OF MARCH 31, 1974

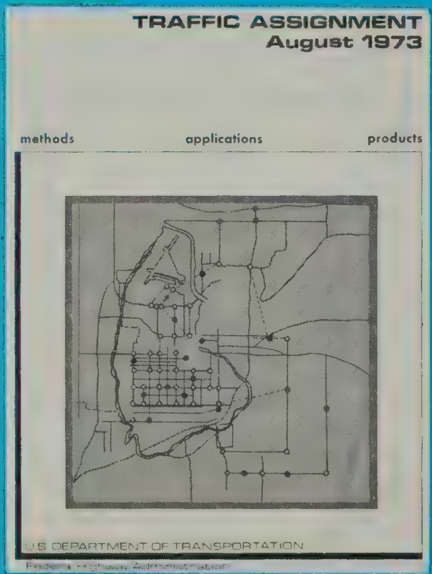


New Publications



Transportation Planning Data for Urbanized Areas, 1973, contains urbanized area data tabulations which are summary data based on the 1970 Census. It presents urbanized area totals of transportation related data for use by transportation planners.

This publication is available for 40 cents a copy from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

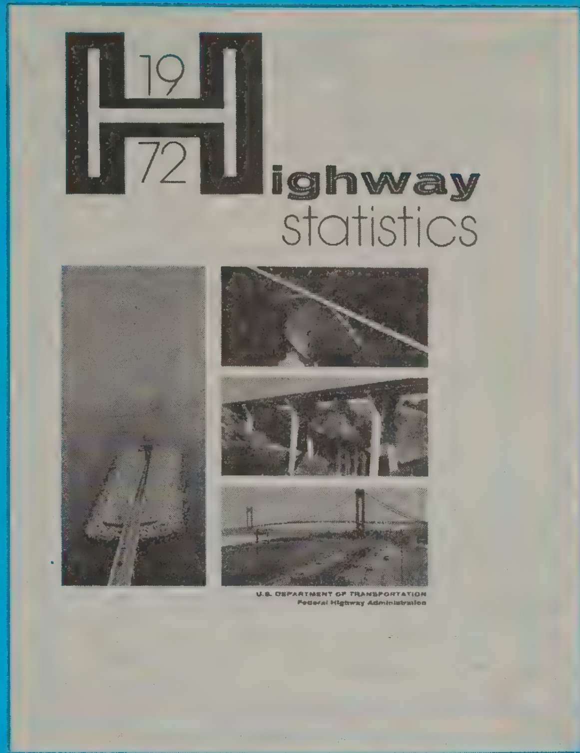


Traffic Assignment—Methods, Applications, Products, August 1973, provides methods for estimating loads on a transportation network, including selection of zones and network, selection of network impedance values, application of trip loading-adjustment process, application of the procedures to other than traditional network planning, and evaluation of the assignment process products. The manual should be useful to at least three groups of individuals: (1) Those just beginning their transportation planning careers, (2) professional transportation planning personnel who wish to evaluate current techniques, and (3) Federal, State, and local government administrators who must be able to evaluate traffic assignment results.

This document is available for $2.45 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Highway Statistics, 1972 ($3.20 a copy), a 216-page bulletin, is the 28th in the annual series presenting statistical and analytical tables of general interest on motor fuel, motor vehicles, driver licensing, highway-user taxation, State and local highway financing, road and street mileage, and Federal aid for highways.

The **Highway Statistics** series has been published annually beginning in 1945 but most of the earlier editions, except 1967, 1968, 1969, 1970, and 1971, are now out of print. However, much of the information presented in earlier editions is summarized in Highway Statistics, Summary to 1965 ($1.25 a copy). These documents may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.



Preferential Treatment for High Occupancy Vehicles, April 1974, describes many of the projects already in operation to provide buses and carpools with priority use of urban highway facilities. The projects in the 28-page illustrated booklet involve exclusive freeway lane use, priority access to freeways, preferential treatment on city streets, and complementary facilities.

This publication may be obtained from the U.S. Department of Transportation, Federal Highway Administration, Office of Highway Planning (HHP-26), Washington, D.C. 20590.

Highway Research and Development Reports Available from National Technical Information Service

The following highway research and development reports are for sale by the National Technical Information Service, Sills Building, 5285 Port Royal Road, Springfield, Va. 22151.

Other highway research and development reports available from the National Technical Information Service will be announced in future issues.

STRUCTURES

Stock No.	
PB 225426	Material and Strength Characteristics of Concrete Mixtures by Acoustic Spectra Analysis.
PB 225468	Welded Plate Girders—Final Report for Research Project 58-4
PB 225539	Performance Study of the Bituminous Concrete Section of the John F. Kennedy Expressway (I-95)
PB 225554	Investigation of Base Courses of Flexible Pavements
PB 225600	Pavement Evaluation III
PB 225604	Continuously Reinforced Concrete Pavements in Mississippi.
PB 225654	Experimental Strain Analysis of Continuous Skew Slab Bridge Decks.
PB 225661	Investigation of the Use of Plate Analysis in the Design of Slab Bridges.
PB 225704	Static, Fatigue, and Impact Strength of Electro-slag Weldments.
PB 225733	Torsional Stresses in Prestressed Concrete Bridge Beams.
PB 225769	An Instrument System for Measuring Pavement Deflections Produced by Moving Traffic Loads
PB 225777	Live Load Distribution on Simple Span Steel I-Beam Composite Highway Bridges at Ultimate Load.
PB 226097	Fatigue and Stress Analysis Concepts for Modifying the Rigid Pavement Design System.
PB 226550	Traffic Evaluation for Secondary and Local Pavement Design.
PB 226594	Implementation of a Complex Design System.
PB 226667	An Investigation of Skid Resistance in Missouri.
PB 226718	An Investigation of the Effectiveness of Existing Bridge Design Methodology in Providing Adequate Structural Resistance to Seismic Disturbances.
PB 226762	Tensile Properties of Subbases for Use in Rigid Pavement Design.
PB 226793	Analysis and Design of Skew Box Girder Bridges.
PB 226801	Camber and Deflection Behavior of Prestressed Concrete Beams, Phase II.
PB 226842	Model Studies of Curved Box Girder Bridges.
PB 227389	The Resonant Vibration Responses of Two Horizontally Curved Steel Girder Bridges.
PB 227515	Bridge Resonant Excitation With Portable Vibration Generators.
PB 227551	Horizontally Curved Highway Bridges—2nd Annual Report.
PB 227552	Horizontally Curved Highway Bridges—1st Annual Report.
PB 227557	The Catskill-Cairo Experimental Rigid Pavement: A Five-Year Progress Report.
PB 227621	Deflection Study of Flexible Pavement Overlays.
PB 227674	The Rehabilitated AASHO Test Road. Part I—Materials and Construction.
PB 227746	Transverse Joint Construction Methods Related to Performance.
PB 227784	Bearing Capacity Prediction by Wave Equation Analysis—State of the Art.
PB 227841	Analysis and Full-Scale Lateral Load Tests "Pile Group Foundations."
PB 227931	The Compaction of Soil and Rock Materials for Highway Purposes.
PB 228104	Bond of Untensioned Prestress Strand.
PB 228159	Verification of Fracture Mechanics Concepts to Predict Cracking of Flexible Pavements
PB 228191	Creep and Shrinkage of Concrete Based on Major Variables Encountered in the State of Texas.
PB 228205	Use of Precast-Prestressed Concrete for Bridge Decks.
PB 228213	Development of an Improved Contraction Joint for Portland Cement Concrete Pavements.

MATERIALS

Stock No.

PB 225699 Detection and Definition of Subsurface Void Spaces by Ground-Based Microwave Radiometers.

PB 225842 Proceedings of Workshop on Expansive Clays and Shales in Highway Design and Construction (Complete Set).

PB 225843 Volume 1.

PB 225844 Volume 2.

PB 226032 A Road Stripe Reflectometer for Use During Daylight Hours.

PB 226053 Time-To-Corrosion of Reinforcing Steel in Concrete Slabs. Volume 2—Electrical Potential Data.

PB 226158 Pavement Slipperiness—Final Report.

PB 226413 Testing for Debonding of Asphalt from Aggregates.

PB 226593 Summary of Proceedings of Workshop on Expansive Clays and Shales on Highway Design and Construction.

PB 227447 Utilization of the Electron Probe Microanalyzer in Highway Materials Analysis, Feasibility Study—Final Report.

PB 227464 A Study of Active Clays as Related to Highway Design.

PB 227465 Appendix.

PB 227479 Design of Open-Graded Asphalt Friction Courses.

PB 227677 Road Marking Materials. Interim Report No. 2.

PB 227965 Subaudible Rock Noise (SARN) as a Measure of Slope Stability.

PB 228158 Service Behavior of Asphalt Concrete—A Ten-Year Study.

TRAFFIC

Stock No.

PB 226077 Diagrammatic Guide Signs for Use on Controlled Access Highways
Volume I—Recommendations for Diagrammatic Guide Signs

PB 226078 Volume III—Traffic Engineering Evaluation of Diagrammatic Guide Signs.
Part 1—Technical Overview of the I-495 (Capital Beltway)/I-70S Field Study.

PB 226079 Part 2—The I-495 (Capital Beltway)/I-70S Field Study.

PB 226080 Part 3—Synthesis and Conclusions.

PB 226081 Appendixes A, B, & C to Part 2.

PB 226134 Analytical Models of Multilane Traffic Flow—Study II (Complete Set).

PB 226135 Volume I—Fundamental, Statistical and Car-Following Characteristics of Multilane Freeway Traffic.

PB 226136 Volume II—Lane Changing, Continuum, and Statistical Multilane Freeway Models.

PB 226137 Volume III—Freeway Gaps Prediction and Stability, On-Ramp Flow Estimation, and Multilane Freeway Digital Simulation.

PB 226258 Methodology of Traffic Flow Efficiency—Final Report.

PB 226259 Methodology of Traffic Flow Efficiency—Non-Technical Summary Report.

PB 226888 Investigation of Lane Occupancy as a Control Variable for a Safety Warning System for Urban Freeways.

PB 226893 Truck Paths on Short Radius Turns.

ENVIRONMENT

Stock No.

PB 225546 Economies of Roadside Beautification and Recreational Development—Final Report.

IMPLEMENTATION

Stock No.

PB 225635 Implementation Package for Slotted CMP Surface Drains.

PB 226585 Quality Assurance for Portland Cement Concrete.

PB 226597 Biased and Random Sampling.

PB 226884 Development of Louvered Signs to Reduce Wind Load.

PLANNING

Stock No.

PB 226121 Airport Access Survey Manual.

PB 226752 A Computer Simulation Model for Evaluating Priority Operations on Freeways.

Instructions to Authors

All articles proposed for publication in *Public Roads* magazine are reviewed for suitability by the technical editors. Authors will be notified of acceptance or rejection as soon as possible.

Recent issues of the magazine should be reviewed for type of articles, style, illustrations, tables, references, and footnotes.

Submission of Manuscripts

Three copies of the manuscript should be submitted to the Managing Editor.

Managing Editor (HDV-10)
Public Roads Magazine
U.S. Department of Transportation
Federal Highway Administration
Washington, D.C. 20590

However, authors outside of government employ, or in other government agencies (State, city, local), should submit manuscript copies through appropriate Federal Highway Administration regional offices (address inside front cover).

Manuscript Format

Manuscripts should be typewritten, double spaced, with at least 1-inch margins on 8 by 10 1/2 inch paper. Paragraphs should be indented and each page should end with a completed paragraph. Main headings should be centered, typed in initial caps, and underlined. Subheadings should be flush left and the first letter only capitalized. Metric equivalents should be included in parentheses after any English unit measure. 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 bottom of title page. Each page of the text should be numbered in the upper right margin.

Biography

A brief biographical sketch of each author 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.

Abstract

An abstract should be supplied with technical articles. In the *development report* it 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 next 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. Position of the table in the text should be noted in the margin. The article should be planned so that a table will not be located on the first (title) page. (Approximately three manuscript pages should be allowed for one magazine page, excluding art.) 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. The text should be organized so that illustrations can be scattered throughout the article. The referencing of several illustrations in one page should be avoided, as this presents problems in the layout. Black and white photographs of good quality are preferred; however, color photographs and art are acceptable. Original art work should be sent to the editor when the author is notified that his article has been accepted for publication. Legible copies should be sent with the manuscript. All captions (numbered and unnumbered) should be typed underlined on a separate page.

References

References should be numbered consecutively in the body of the text, enclosed in parentheses, and underlined. When copyrighted material is referenced and quoted, copyright releases should be obtained. Unpublished material referenced in the text will be described in a footnote. Material cited should be typed on a separate page under the heading REFERENCES. References should be numbered in the same manner as in the text and listed in the same sequence.

Galley Proofs

Galley proofs will be sent to authors for their approval.

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Publications of the Federal Highway Administration

The following publications are sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

Aggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and a new Graphical Evaluation Chart (1962), 25 cents.

Analysis and Modeling of Relationship between Accidents and Geometrics and Traffic Characteristics of the Interstate System (1969), $1.

Bridge Inspector's Training Manual (1970), $2.50; (1971), $2.50.

Capacity Analysis Techniques for Design of Signalized Intersections (1967), 45 cents.

Corrugated Metal Pipe (1970), 35 cents.

Economics and Social Effects of Highways (1972), $1.25.

Evaluation of Potential Effects of U.S. Freight Transportation Advances on Highway Requirements (Research Phases 1 and 2), $2.75.

Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems (1971), 45 cents.

Federal-Aid Highway Map (42x65 inches) (1970), $1.50.

Federal Laws, Regulations, and Other Material Relating to Highways (1970), $2.50; (1972), $2.50.

Freeways to Urban Development (1966), 15 cents.

A Guide to Parking Systems Analysis, $2.60.

Handbook of Highway Safety Design and Operating Practices (1968), 40 cents; (1973), $2.
- Supplement No. 1 (Nov. 1968), 35 cents.
- Supplement No. 2 (Nov. 1969), 40 cents.

Highway and Urban Mass Transportation (Fall 1972), 65 cents; (Winter 1972), 65 cents; (Spring/Summer 1973), 90 cents.

Highway Joint Development and Multiple Use (1970), $1.50.

Highway Research & Development Studies Using Federal-Aid Research and Planning Funds (1970), $2.50.

Highway Statistics (published annually since 1945): 1968, $1.75; 1970, $1.75. 1971, $2.85; 1972, $3.20. (Other years out of print.)

Highway Transportation (Nov. 1970), 65 cents; (Spring 1971), 60 cents; (Fall 1971), 45 cents; (Spring 1972), 55 cents.

Highway Transportation Research and Development Studies (1972), $4.20.

Hydraulic Engineering Circulars:
- No. 5—Hydraulic Charts for the Selection of Highway Culverts (1965), 55 cents.
- No. 9—Debris Control Structures (1971), 50 cents.
- No. 10—Capacity Charts for the Hydraulic Design of Highway Culverts (1965), $1.
- No. 11—Use of Riprap for Bank Protection (1967), 50 cents.
- No. 12—Drainage of Highway Pavements (1969), $1.

Hydraulic Design Series:
- No. 1—Hydraulics of Bridge Waterways, 2d ed. (1970), $1.25.
- No. 3—Design Charts for Open-Channel Flow (1961), $1.50.
- No. 4—Design of Roadside Drainage Channels (1965), 65 cents.

Hydraulic Flow Resistance Factors for Corrugated Metal Conduits (1970), 55 cents.

Interstate System Accident Research Study (1970), $1.

Joint Development Opportunities Outside the Highway Right-of-Way (1971), 20 cents.

Labor Compliance Manual for Direct Federal and Federal-Aid Construction, 3d ed. (1970), $3.75.

Manual of Instructions for Construction of Roads and Bridges on Federal Highway Projects (1970), $3.25 (for use with specifications—FP-69).

Manual on Uniform Traffic Control Devices for Streets and Highways (1971), $3.50.

Maximum Safe Speed for Motor Vehicles (1969), $1.

Modal Split—Documentation of Nine Methods for Estimating Transit Usage (1970), $1.25.

Motor Carrier Safety Regulations (1971), 65 cents; (1972), 95 cents.

National Highway Needs Report, H. Comm. Print 91st Cong., 70 cents.

The National System of Interstate and Defense Highways (1971), 15 cents.

The New Look in Traffic Signs and Markings (1972), 35 cents.

Program Documentation Urban Transportation Planning (March 1972), $6.25.

Quality Assurance in Highway Construction. (Reprinted from PUBLIC ROADS, A Journal of Highway Research, vol. 35, Nos. 6-11, 1969), 50 cents.

R&D Highway and Safety Transportation System Studies (1970), $2.50; (1971), $2.75.

Reinforced Concrete Bridge Members—Ultimate Design (1969), 45 cents.

Reinforced Concrete Pipe Culverts—Criteria for Structural Design and Installation (1963), 30 cents.

Safety Rest Area Development (1970), $1.

Selecting Digital Computer Signal Systems, $1.05.

Specifications for Aerial Surveys and Mapping by Photogrammetrical Methods for Highways (1968), $2.

Standard Land Use Coding Manual (1965), 50 cents.

Standard Plans for Highway Bridges:
- Vol. I—Concrete Superstructures (1968), $1.25.
- Vol. II—Structural Steel Superstructures (1968), $1.
- Vol. III—Timber Bridges (1969), 75 cents.
- Vol. IV—Typical Continuous Bridges (1969), $1.50.
- Vol. IV A—Typical Continuous Bridges Load Factor Design (1973), $1.40.
- Vol. V—Typical Pedestrian Bridges (1962), $1.75.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (1969), $3.50.

Standard Traffic Control Signs Chart (as defined in the Manual on Uniform Traffic Control Devices)
- 22x34—20 cents, $15 per 100
- 11x17—10 cents, $5 per 100

Transportation Planning Data for Urbanized Areas based on 1960 census (1970), $9.25.

Typical Plans for Retaining Walls (1969), 75 cents.

Urban Mass Transportation Travel Surveys (1972), $1.50.

Urban Origin-Destination Surveys, $3.20.

Urban Planning General Information (March 1972), $2.75.

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Long-term Observations on Highway Bridges

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