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**Federal Highway
Administration**

Public Roads

A Journal of Highway Research and Development

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A Journal of Highway Research and Development

March 1992
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COVER:
Chain of Craters Road
in Hawaii Volcanoes National Park
on the island of Hawaii.

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Federal Highway Administration
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The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department.

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E D I T O R I A L

A time of change is coming for *Public Roads, A Journal of Highway Research and Development.* It is expanding its ability to communicate advances in the transportation industry.

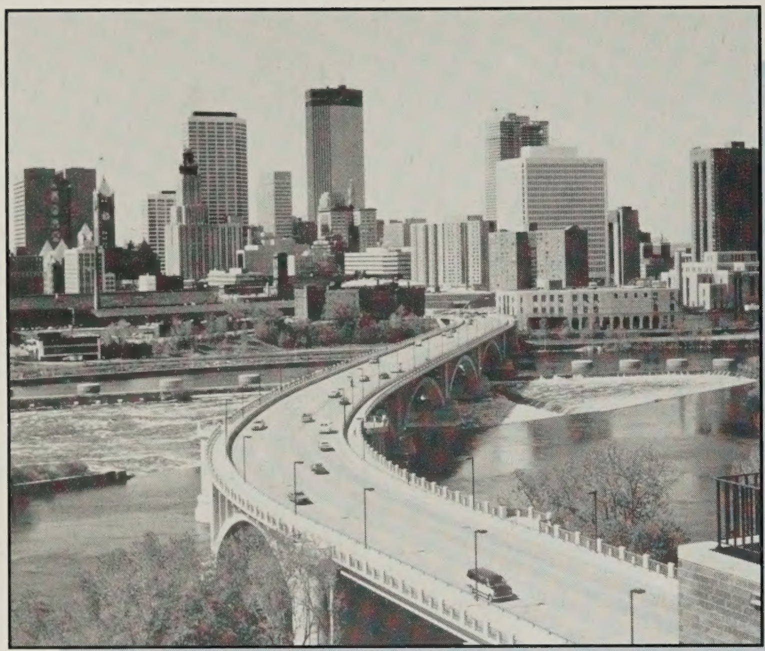
Since 1918, the Federal Highway Administration (FHWA)—and its predecessor, the Bureau of Public Roads—has published *Public Roads* and through the years, the journal has undergone many changes. The Intermodal Surface Transportation Efficiency Act of 1991, signed by the President on December 18, 1991, underscores expansion of research, development, and technology programs. This emphasis on innovation demands that we expand and upgrade the means through which we communicate research results.

In an effort to respond to this change, the *Public Roads* staff have developed a series of initiatives directed toward improvement in the journal. Among these are a niche identification workshop scheduled for March 1992 for FHWA officials and representatives from several transportation organizations to examine the vision for *Public Roads, A Journal of Highway Research and Technology* and how to best serve its readers in the future. The participants in this workshop could form the nucleus of the journal's Publications Board. It is envisioned that the board will have the responsibility to meet on an annual basis to review past issues and determine the future direction of the journal. Its tasks include the development of extensive editorial policies and the establishment of solicitation procedures, which would increase the quantity of articles submitted, the quality of articles through competition and peer review, and the visibility and subscriptions with improved technical content.

A Editorial Board will be formed soon after the March workshop. This Editorial Board is to manage the actual review of articles for technical content. The administrative and editorial arm of the journal will remain at Turner-Fairbank Highway Research Center, McLean, Virginia. The Editorial Board will be made to model the peer review process of the academic/technical journals. Membership in the new Editorial Board will be governed by topic area.

Initially, a call for papers will go out to all available resources at least one year in advance of the published journal. The call would announce the theme issue and/or topics that would be considered for publication. The submitted articles would have to address critical and timely research on that topic/theme. For example, five topics of interest are Innovative Technology Applications, Current Environmental Research, State-of-the-Art Design Concepts, Alternative Materials, and Transportation Statistics.

We look forward to the challenge that is before us: to define *Public Roads* mission and to expand our vehicle for communicating achievements in technology and innovation. If you have any comments, please direct them to: Anne N. Barsanti, Editor, *Public Roads,* Federal Highway Administration, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, Virginia 22101.



Intermodal Surface Transportation Efficiency Act of 1991

by Charles L. Miller

Introduction

For many years, U.S. highway research and technology (R&T) programs were funded at very modest and relatively constant levels. In fact, program funding was actually decreasing because of inflation factors. Over the years, some agencies have had to reduce the size of their R&T programs, including making reductions in staff.

Support for our Nation's highway R&T programs took a turn for the better with the enactment of the Surface Transportation Assistance Act of 1987. This Act provided for the Strategic Highway Research Program (SHRP). The SHRP provided an influx of funds to carry out research and development (R&D) work on highway problems that could not otherwise be fully addressed because of insufficient resources in the highway community.

On December 18, 1991, President Bush signed into law the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. This 6-year authorization Act will significantly shape the future of the Nation's highway program for the remainder of this century. Like the 1987 Act, the 1991 ISTEA reflects the growing support of Congress and the President for highway research and technology.

The ISTEA provides the impetus for an intermodal perspective and performance-based criteria that place strong emphases on efficiency, contributions to productivity, and environmental responsibility. More specifically, the ISTEA of 1991 will affect the Federal Highway Administration's R&T programs through:

- Greater program visibility and resources.
- Strong support for intelligent vehicle-highway systems.
- Collaborative research.
- Emphasis on commercial motor vehicle safety.
- International outreach.
- Expanded education and training programs.

This article summarizes key R&T efforts established or continued by the ISTEA in the above areas.

Program Visibility and Development

The Act provides for the establishment of a National Council on Surface Transportation Research. This council will make a complete investigation of current surface transportation R&T developments both in the United States and internationally. It will identify gaps and duplication in these efforts and will determine R&D areas that could increase efficiency, productivity, safety, and durability in the Nation's surface transportation systems. The council will be composed of seven members appointed by Congress and the President. These members will report their findings to Congress by September 30, 1993. The council will be dissolved by March 30, 1994.

The Act also establishes an independent surface transportation Research Advisory Committee that will provide ongoing advice and recommendations to the Secretary of Transportation on surface transportation R&D. The committee will be composed of 20 to 30 members appointed by the Secretary and will include representatives from universities, corporations, associations, consumers, State Government agencies, and Federal agencies other than Transportation.

The Act requires the Secretary to develop an integrated National Surface Transportation Research and Development Plan. This plan will provide appropriate funding levels and a schedule with milestones, preliminary cost estimates, work plans, personnel requirements, and estimated costs and goals for the next 3 years for each R&D area. The plan will also include a 10-year projection of long-term research and development.

Also within the program visibility and development area, the Act provides a minimum of $108 million to implement the products of the completed SHRP and to continue the Long-Term Pavement Performance Program.

Intelligent Vehicle-Highway Systems

The Act established an IVHS Program, authorizing approximately $660 million over the 6-year authorization period. The IVHS Program will include research, development, and operational tests of innovations and technologies that will enhance the mobility, efficiency, and safety of the Nation's surface transportation system. The Act also establishes goals to use IVHS to:

- Help improve air quality.
- Develop and promote an IVHS industry.
- Reduce the societal, economic, and environmental costs of traffic congestion.
- Enhance industrial and economic competitiveness and productivity.
- Develop a technology base and establish the capability to perform demonstration experiments at national laboratories.
- Transfer the technology to the private sector.

The Act directs the Department of Transportation (DOT) and other involved Federal departments and agencies to promote maximum involvement by the private sector, universities, and State and local governments.

The Department is also directed to develop and implement standards and protocols that will ensure compatibility in implementing IVHS technologies. It also requires evaluation guidelines for IVHS operational tests and the establishment of an information clearinghouse.

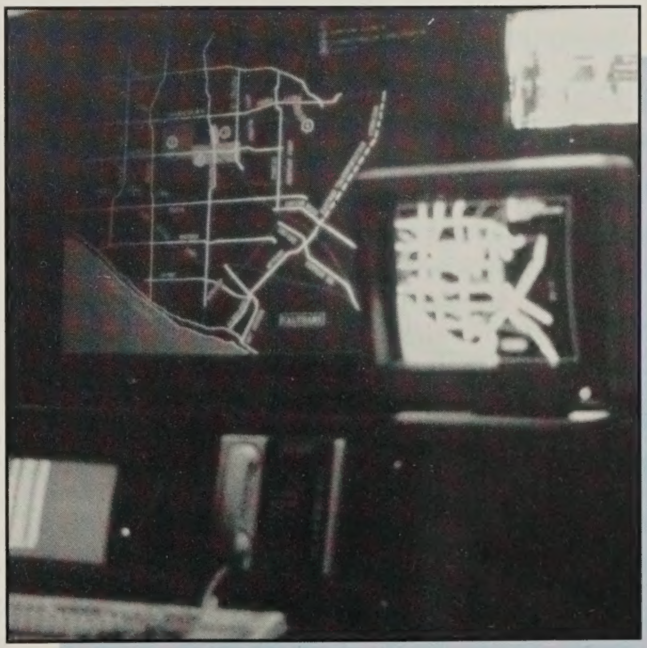
Within the first year of the Act, the Department will develop and implement a strategic plan for IVHS and submit it to Congress. This plan will include the goals, objectives, and milestones of the IVHS Program, and will provide for accelerated use of advanced technology to reduce traffic congestion.

Under the Act, a completely automated prototyped highway and vehicle system must be developed for future fully automated IVHS systems. The goal is to have the first fully automated roadway or test track in operation by the end of 1997. An IVHS Corridors Program will be established to provide for operational tests under "real world" conditions. Corridors that meet certain transportation and environmental criteria can participate in developing and implementing IVHS technologies.

Other provisions relating to IVHS include (1) the use of advisory committees to carry out the IVHS Program and (2) planning grants to State and local governments for studying the feasibility of IVHS development and implementation.

Collaborative Research

Within the highway community, substantial support has been demonstrated for additional R&D and the effective application of innovative technologies to solve highway problems. An important Act provision that supports this initiative is new authority for collaborative research and development with other public and private entities, with a Federal share of up to 50 percent of the activity costs. The IVHS Program has already released requests for proposals that suggest establishing consortia with public and private institutions to both share the costs and implement R&T projects.



Commercial Motor Vehicle Safety Technology

The ISTEA directs the Secretary of Transportation to conduct a study to evaluate technology designed for installation on a commercial motor vehicle. This technology will provide the vehicle operator with a warning if a turn, lane change, or other vehicle operator movement will place the vehicle in the path of an adjacent object or vehicle. This study's report will be submitted to Congress no later than December 18, 1993.

International Highway Transportation Outreach Program

A new International Highway Transportation Outreach Program will inform the United States highway community of foreign transportation innovations. The program will also promote U.S. highway transportation expertise internationally, and increase the use of United States highway transportation technology in foreign countries.

Education and Training

National Highway Institute

Under the new Act, the National Highway Institute (NHI), in cooperation with the State transportation or highway departments, will expand its highway education and training programs to include not only Federal, State, and local highway agencies, but also U.S. private sector citizens and foreign nationals involved in highway work of interest to the United States. The Act sets aside 1/16 of 1 percent of all surface transportation funds provided to a State to pay for up to 80 percent of the cost of training and education for State and local highway employees, excluding travel, subsistence, and salaries.

The NHI will develop and present a wide range of education and training programs related to highways on planning, environmental factors, acquisition of rights-of-way, relocation assistance, engineering, safety, construction, maintenance, contract administration, motor carrier activities and inspection. The Institute will continue to assess and collect fees to defray the cost of developing and administering its education and training programs. Fees for private agencies and individuals will reflect the full cost of the education and training received; others will be assessed a reduced amount. The Act also authorized the NHI to grant training fellowships.

Expanded Rural Technical Assistance Program

The Act establishes an education and training program that expands the existing Rural Technical Assistance Program (RTAP). The new program may include urban areas of up to 1 million population as well as the rural areas already covered under the RTAP. The program is authorized at $6 million for fiscal years 1992 through 1997.

The expanded program develops a transportation assistance program that will include grants and contracts for education and training, technical assistance, and related support services. These grants will assist rural local transportation agencies in developing expertise; improving roads and bridges; enhancing programs for moving passengers and freight; and preparing and providing training packages, guidelines, and other material. The grants will also develop a tourism and recreational travel technical assistance program.

In addition, the grants may identify, package, and deliver usable highway technology to assist urban transportation agencies to resolve road-related problems. The grants may also establish—in cooperation with State transportation agencies and universities—urban technical assistance centers programs in States with two or more urbanized areas of 50,000 to 1,000,000 population, and rural technical assistance centers.

University Transportation Centers Program/ Research Institutes

The Act establishes five additional centers under the University Transportation Centers Program. These will perform the following activities:

- The National Center for Transportation Management, Research, and Development at Morgan State University will focus on research, training, and technology transfer activities that will encourage highly skilled minority individuals and women to enter the transportation workforce.

- Through the use of transportation management systems, the Center for Transportation and Industrial Productivity at the New Jersey Institute of Technology will conduct R&D activities to increase surface transportation capacity and reduce congestion and costs for transportation system users and providers.

- The James and Marlene Howard Transportation Information Center at Monmouth College, New Jersey, will coordinate its work on transportation-related instruction and research in computer science, electronic engineering, mathematics, and software engineering with the Center for Transportation and Industrial Productivity at the New Jersey Institute of Technology.

- The National Rural Transportation Study Center at the University of Arkansas will conduct research, training, and technology transfer activities in the development, management, and operations of intermodal transportation systems in rural areas.

- The National Center for Advanced Transportation Technology at the University of Idaho will operate in partnership with private industry and will conduct industry-driven R&D activities focusing on transportation-related manufacturing and engineering processes, materials, and equipment.

The Act also creates five University Research Institutes. These are:

- Institute for National Surface Transportation Policy Studies.
- Infrastructure Technology Institute.
- Urban Transit Institute.
- Institute for Intelligent Vehicle-Highway Concepts.
- Institute for Research and Education.

Each of these institutes will specialize in an aspect of transportation research vital to the advancement of U.S. technology and innovation.

Other Programs

Other initiative established by the Act include the following.

- A new *Applied Research and Technology Program* is required to provide accelerated testing, evaluation, and implementation of technologies designed to improve the durability, efficiency, environmental impact, productivity, and safety of highway, transit, and intermodal transportation systems. Program guidelines from the Secretary are required within 18 months, and a total of $240 million is authorized over the next 6 years.

- A *Seismic Research Program* will be established to study the vulnerability of highways, tunnels, and bridges on the Federal-aid system to earthquakes and implement cost-effective methods to reduce such vulnerability. The program will cooperate with the National Center for Earthquake Engineering Research and agencies participating in National Hazards Reduction Program.

- A *Bureau of Transportation Statistics* will be created in DOT to enhance data collection, analysis, and reporting, and to ensure the most cost-effective use of transportation monitoring resources. A total of $90 million is provided over the 6 years of the Act. The Bureau will publish a Transportation Statistics Annual Report by January 1, 1994.

- A *National Transit Institute* will be established to conduct training programs for all involved in Federal-aid transit work. Funding is $18 million over the 6 years of the authorization.

Summary

The ISTEA of 1991 will significantly shape the future of the Federal Highway Administration's R&T program in four ways. First, the Act will give the *program visibility and development* by establishing a National Council on Surface Transportation Research to investigate current surface transportation research and technology here and abroad. In addition, an independent Research Advisory Committee will be created and an integrated National Surface Transportation Research and Development Plan developed.

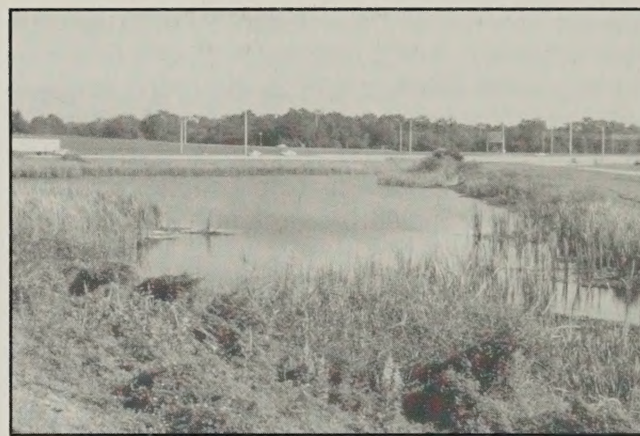
Second, the Act establishes and funds an *IVHS Program* with approximately $660 million. Among other things, the Act requires compatible standards and protocols to promote widespread IVHS technologies, both establishes IVHS evaluation guidelines for operational tests and an information clearinghouse and mandates a prototype IVHS.

Third, the ISTEA authorizes collaborative R&D with other public and private entities to improve, implement and cost-share research, development, and technology transfer projects.

Fourth, the Act creates a new International Highway Transportation Outreach Program, an education and training program to expand RTAP to urban areas and adds American Indians to the program, an Applied Research and Technology Program, a Seismic Research Program, a Bureau of Transportation Statistics, a National Transit Institute, and five additional University Transportation Centers and University Research Institutes. In addition, the Act expands the NHI program.

Together, these efforts will broaden, enhance, and improve the R&T projects and initiates of the Federal Highway Administration, enduring the U.S. ability to meet the transportation challenges of the next century.

A summary brochure (FHWA-PL-92-008) describing the provisions of the ISTEA is available from the Office of Policy Development, Federal Highway Administration, contact Bill Blessing, (202) 366-0690.



Charles L. Miller is the Associate Administrator for Research and Development, Federal Highway Administration (FHWA). He is responsible for the FHWA's research and development program, which is administered from the FHWA's Turner-Fairbank Highway Research Center, in McLean, Virginia. A major element in FHWA's program is the Intelligent Vehicle-Highway Systems; other reseach efforts are in the areas of highway safety, improved pavements and structures, increased productivity, environmental interactions, and investigating better ways to market and deliver new technology to the States and to the highway community. Prior to joining FHWA, Mr. Miller was Director of the Arizona Department of Transportation. A registered professional engineer in Arizona and in West Virginia, Mr. Miller has a B.S.C.E. from West Virginia University and has done post-graduate work at West Virginia State College.

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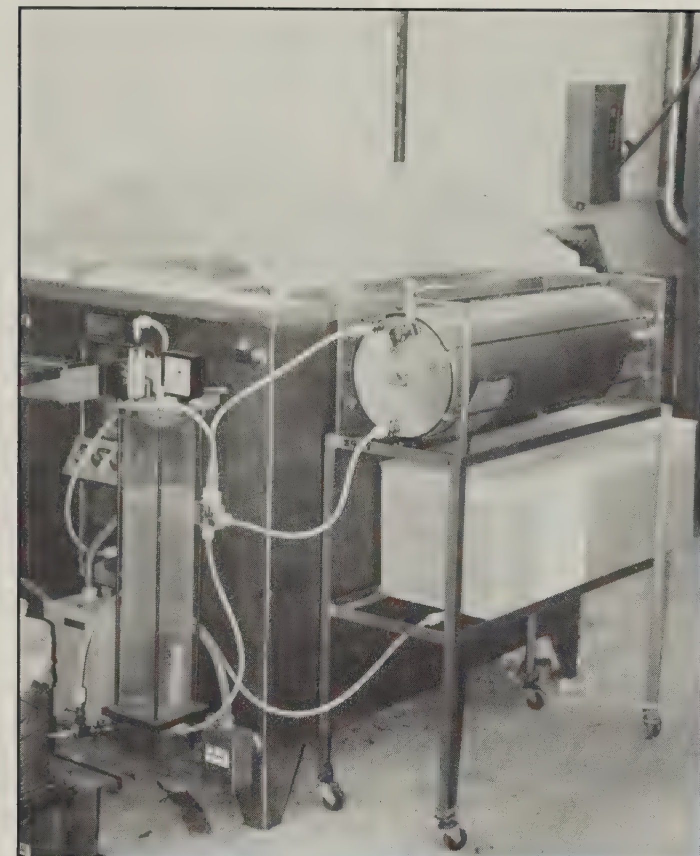

Evaluation of Low Volatile Organic Compound Coating Systems for Steel Bridges

by Shuang-Ling Chong

Introduction

Under the November 1990 Amendment to the Clean Air Act, the volatile organic compound (VOC) content for maintenance coatings on steel bridges will be regulated throughout the country within a few years. This VOC restriction will reduce smog formation to improve air quality. An architectural and industrial painting regulation could be proposed by the U.S. Environmental Protection Agency this year. Promulgation could follow as early as 1993. In anticipation of this regulation, many States already have limited 340 g/l (2.8 lb/gal) of VOC for industrial and architectural maintenance paints. The South Coast and Bay Area Air Quality Management Districts of California have established a 250 g/l (2.08 lb/gal) limit for VOC in traffic paints. The classification of lead and chromate anticorrosive pigments as hazardous materials and the mandated reduction of solvent in bridge paints have resulted in an immediate need for cost-effective and environmentally acceptable replacement materials for both bridge construction and maintenance painting. To this end, researchers are now developing high solid solvent-borne resins with the required viscosity and waterborne formulation to reduce solvent content while maintaining acceptable application characteristics. Due to the desperate need for replacement products, many of the new, reformulated low-VOC products are being marketed without thorough laboratory and field performance testing. To ensure against failures in the field and prevent any unnecessary repair and repainting, these new systems must be evaluated in depth. In response to this need, the Federal Highway Administration (FHWA) initiated the present study.

This study evaluated candidate low-VOC coating systems for steel bridges. Two accelerated weathering tests—a cyclic salt-fog/freeze test and an ultraviolet (UV)/condensation test were used in this evaluation. Currently used high-VOC bridge coating systems were used as controls. The corrosion results obtained by the FHWA's accelerated laboratory testing were carefully evaluated to predict long-term field performance. Additionally, because direct prediction of field performance is not possible, the candidate systems were also exposed to a natural marine environment at Ocean City Research Corporation's Sea Isle Test Site in Ocean City, New Jersey.

The findings of this study will be valuable in providing guidelines for selecting long-lasting low-VOC coating systems for both new construction and maintenance of steel bridges. Complete study details are reported elsewhere. (1)[1]

Experimental Procedure

The coating systems evaluated in this study are listed in table 1. Eleven low-VOC coating systems were chosen for evaluation; four high-VOC coating systems (code nos. 2, 4, 6, and 8) corresponding to four of the reformulated low-VOC products were used as controls. Two California Department of Transportation (CALTRANS) bridge coating systems were also included as controls. A 50.8-mm (2-in) diagonal scribe was made on one side of each of the salt-fog and Sea Isle panels to evaluate film undercutting.

Test methods

The following tests were performed:

1. *Cyclic salt-fog/freeze test (Singleton corrosion test cabinet)*
   - Test cycle: 6-day salt-fog/1-day freeze cycle.

Table 1.–Descriptions of tested coating systems

Code No.	Description	Dry film thickness (mil)[a]	VOC(g/l)
1	Low-VOC solvent-based modified inorganic zinc/ epoxy/acrylic epoxy	3.5/6.0/2.0	320/170/383
2	High-VOC solvent-based modified inorganic zinc/ epoxy/acrylic epoxy	3.5/8.0/2.0	458/287/527
3	Low-VOC epoxy mastic/acrylic epoxy	6.0/2.5	39/263
4	High-VOC epoxy mastic/polyurethane	6.0/6.0	86/383
5	Low-VOC organic zinc/epoxy/polyurethane	3.0/5.0/2.5	303/214/300
6	High-VOC organic zinc/epoxy/polyurethane	3.0/5.0/2.0	416/329/479
7	Low-VOC solvent-based inorganic zinc alkyl silicate/ epoxy/polyurethane	3.0/5.0/2.5	264/214/300
8	High-VOC solvent-based inorganic zinc alkyl silicate/ epoxy/polyurethane	3.0/5.0/2.0	514/329/479
9	Water-based inorganic zinc potassium silicate/ epoxy/polyurethane	3.0/5.0/4.0	0/213/267
10	Water-based inorganic zinc potassium silicate/ water-based acrylic/water-based acrylic	3.0/3.0/3.0	0/116/116
11	High-ratio water-based inorganic zinc potassium silicate/water-based acrylic	3.0/5.0	0/80
12	CALTRANS waterborne styrene acrylic/styrene acrylic/acrylic aluminum/acrylic aluminum	1.0/5.0/7.0/8.5	50/34/151/151
13	CALTRANS high solids phenolic/phenolic/acrylic aluminum/acrylic aluminum	1.5/6.0/8.0/10	260/260/151/151
14	Silicone rubber on sand-blasted steel	12	260
15	Silicone rubber on rusted and wire-brushed steel	12	260

[a]1 mil = .025 mm

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

- Salt-fog method: American Society for Testing and Materials (ASTM) method B117.
- Freeze temperature: -18 °C (0 °F).
- Panel position: vertical instead of 15 to 30° from vertical.

2. *UV/condensation test (QUV Weatherometer)*
   - Test cycle: 4-hour UV/4-hour condensation cycle.
   - UV lamp: QFS-40.
   - UV temperature: 70 °C (158 °F).
   - Condensation temperature: 40 °C (104 °F).

Table 2.–Results of salt-fog/freeze exposure

		Panel face		Scribe		
Code (mm)	Hour	Blisters	Rust	Rust	Blisters	Undercutting, mm
1	3,000	-	-	MOD	2M	4.5
1	3,000	-	-	MOD	2M	3.5
2	3,000	-	-	MOD	4MD	2.5
2	3,000	-	-	MOD	4MD	3.5
3	3,000	6M	-	SEV	2D	7.0[a]
3	3,000	6M	-	SEV	2D	6.5[a]
4	3,000	-	-	SEV	2D	9.0[b]
4	3,000	-	-	SEV	2D	9.5[b]
5	3,000	-	-	SEV	4M	4.0
5	3,000	-	-	SEV	4M	3.5
6	3,000	-	-	SEV	4M	3.5
6	3,000	-	-	SEV	4M	3.0
7	3,000	-	-	SEV	4M	3.0
7	3,000	-	-	SEV	4M	3.5
8	3,000	8VF	-	SL	4MD	3.5
8	3,000	8VF	-	SL	4MD	3.5
9	3,000	-	-	SL	6F	1.5
9	3,000	-	-	MOD	6F	1.5
10	3,000	-	-	-	-	0
10	3,000	-	-	-	-	0
11	3,000	1F[c]	-	VSL	-	0
11	3,000	1M[c]	-	VSL	-	0
12	3,000	-	-	SEV	4D	3.5
12	3,000	-	-	SEV	4D	4.5
13	3,000	-	SEV	SEV	2D	9.0[d]
13	3,000	-	SEV	SEV	2D	10.0[d]
14	2,000	2MD(edge)	SEV	SEV	2D	11.0[e]
14	2,000	4D(edge)	SEV	SEV	2D	11.0[e]
15	2,000	2M(edge)	SEV	SEV	2D	15.0[e]
15	2,000	4M(edge)	SEV	SEV	2D	15.0[e]

Notes: Testing was performed in accordance with ASTM method B117, "Standard Method of Salt Spray (Fog) Testing." Degree of blistering was determined based on ASTM method D714, "Evaluating Degree of Blistering of Paints."

M	=	medium	-	=	none
MD	=	medium dense	SEV	=	severe
D	=	dense	MOD	=	moderate
F	=	few	SL	=	slight
VF	=	very few	VSL	=	very slight

[a] Undercutting > 6.35 mm (0.25 in) after 3,000 hours.
[b] Undercutting > 6.35 mm (0.25 in) after 2,000 hours.
[c] Delamination.
[d] Undercutting > 6.35 mm (0.25 in) after 2,500 hours.
[e] Undercutting > 6.35 mm (0.25 in) after 1,000 hours.

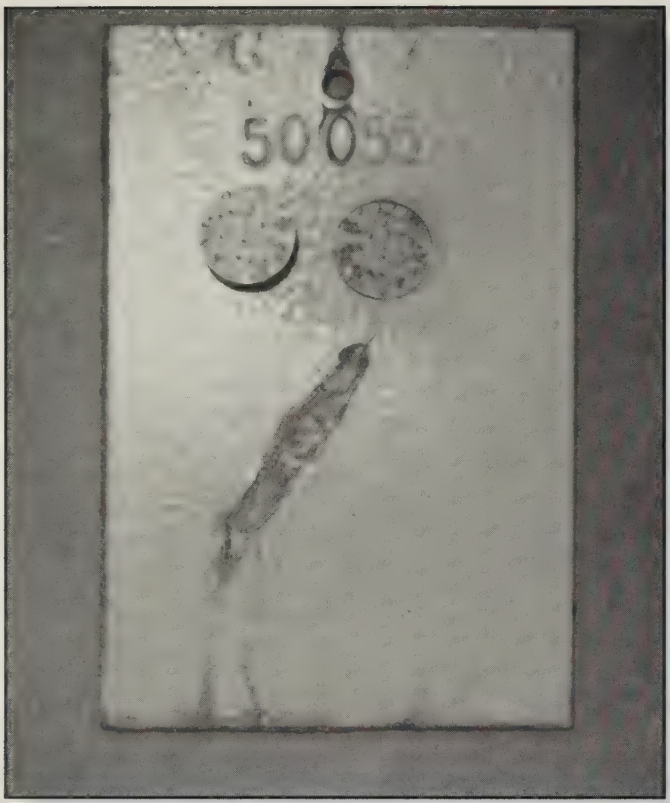

Figure 1.–Condition of high-ratio water-based inorganic zinc potassium silicate/water-based acrylic system after 2,000 hours of cyclic salt-fog/freeze exposure.

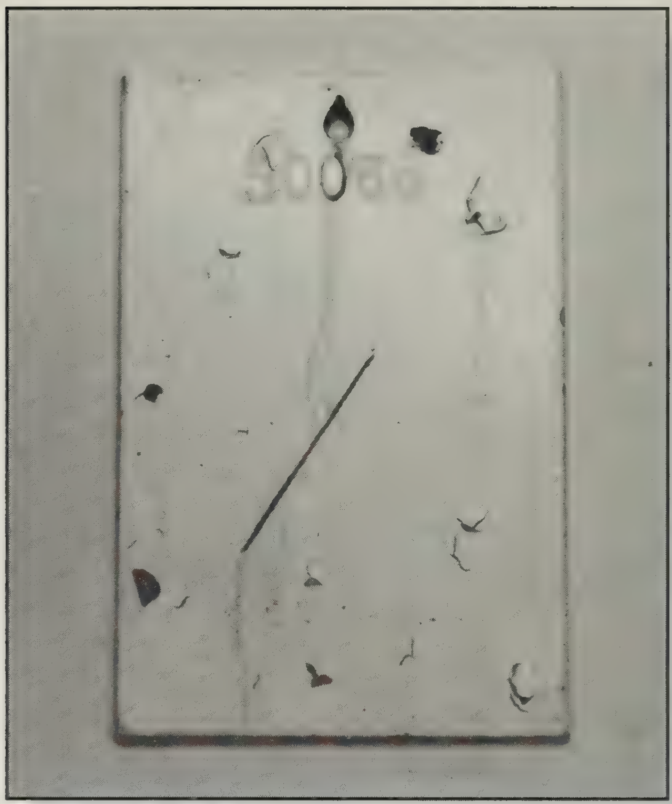

Figure 2.–Condition of the low-VOC epoxy mastic/acrylic epoxy after 3,000 hours of cyclic salt-fog/freeze exposure.

3. *Outdoor exposure*
   - Exposure site: southern New Jersey coast, near Sea Isle City; approximately 30.5 m (100 ft) from Atlantic Ocean and bordered on the west by Ludlum's Bay.
   - Panel position: 45° angle on wooden racks, facing directly south.
   - Each panel was sprayed three times daily with seawater.

Physical properties

Adhesion pull-off tests were made according to ASTM method D4541. Gloss was measured using ASTM method D525. Other phenomena such as chalking, color fading, and peeling were also examined and noted.

Evaluation of performance

All panels for accelerated tests were evaluated and photographed every 500 hours. The evaluation parameters used were surface rusting, surface blistering, scribe blistering, and scribe undercutting determined according to ASTM methods D1654 and D714. Blisters were described in terms of size and frequency. Blistering numbers 6, 4, and 2 represented progressively larger sizes. Frequency of occurrence was presented as dense (D), medium dense (MD), medium (M), few (F), and very few (VF).

The test panels for outdoor exposure were examined and graded by Ocean City Research Corporation personnel. Blistering was rated in terms of both blister size and density. To obtain this rating, blister size was rated as designated in ASTM method D714. Blister density was rated as follows: none = 10, few = 8, medium = 6, medium dense = 4, dense = 2. The blister size and density ratings were summed and divided by 2. This method produced a rating scale of 0 to 10.

Results and Discussion

Cyclic salt-fog/freeze test

Most of the tested coating systems exhibited failures from the attack of salt and moisture after 3,000 hours of cyclic salt-fog/freeze exposure. They also generally lost some adhesion strength and gloss. The extent of surface failure and scribe undercutting for all the tested coating systems are presented in table 2. Good data repeatability between samples was obtained in all cases; for example, the standard deviation for undercuttings was calculated to be 0.5 mm (0.02 in).

Surface failure. Only three coating systems developed significant surface blistering or rusting after 3,000 hours of cyclic salt-fog/freeze exposure.

The high-ratio water-based inorganic zinc potassium silicate with a topcoat of water-based acrylic showed significant delaminations of the topcoat. Several circular areas of acrylic topcoat delamination started to appear after 2,000 hours of cyclic salt-fog/freeze exposure, demonstrating a poor adhesion of the topcoat to the primer (figure 1). The intercoat adhesion failure is probably the result of either the moisture sensitivity of the acrylic polymer or a sensitivity of the acrylic topcoat to the surface chemistry of the high-ratio zinc potassium silicate primer. This failure, however, did not result in rusting or undercutting because the inorganic zinc primer protected the panel's scribed area cathodically.

The low-VOC epoxy mastic/acrylic epoxy system exhibited surface blistering of 6M after 3,000 hours of exposure. When the epoxy mastic failed cohesively during the adhesion pull-off test, extensive subfilm corrosion and rust staining of the coating was found on the exposed plane area and the pulled plug (figure 2). This subfilm corrosion is similar to that found by Smith using an epoxy polyamide primer after 1,000 hours of salt-fog exposure. (*2*) Trimber found residual salt to be a major contributor to the failure of a similar paper mill maintenance coating system through undercutting. (*3*) The adverse effect of sodium chloride contaminated steel on the coating life was also reported recently by the Steel Structure Painting Council. (*4*)

Severe subfilm corrosion was observed for the CALTRANS high solids phenolic system after 3,000 hours of exposure. The phenolic resin primer disbonded completely from the steel surface during the adhesion test. When pulled off, the primer film had a rusted color instead of the original red brick color of the iron oxide pigment.

Scribe undercutting. Most of the coating systems developed blistering and rusting at the scribes after 3,000 hours of cyclic salt-fog/freeze exposure.

The coating performance of silicone rubber was extremely poor; severe blistering and rusting developed at the scribes after 2,000 hours of cyclic salt-fog/freeze exposure. The film has been undercut to depths of 11 and 15 mm (0.43 and 0.59 in) for code nos. 14 and 15 systems, respectively. On the stripping of the coating, a large rust nodule was noted under the film. Rust was also observed at the edges. The rust pattern on the steel surface is shown in figure 3. Of all the coating systems tested, silicone rubber specimens exhibited the greatest tendency to corrode at the scribes and edges.

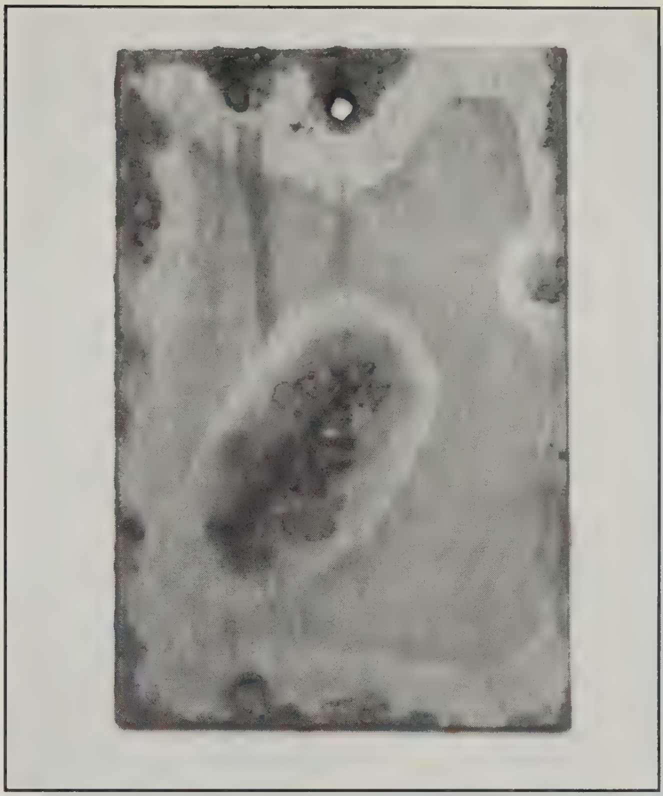

Figure 3.–Condition of stripped silicone rubber (code no. 14) after 2,000 hours of cyclic salt-fog/freeze exposure.

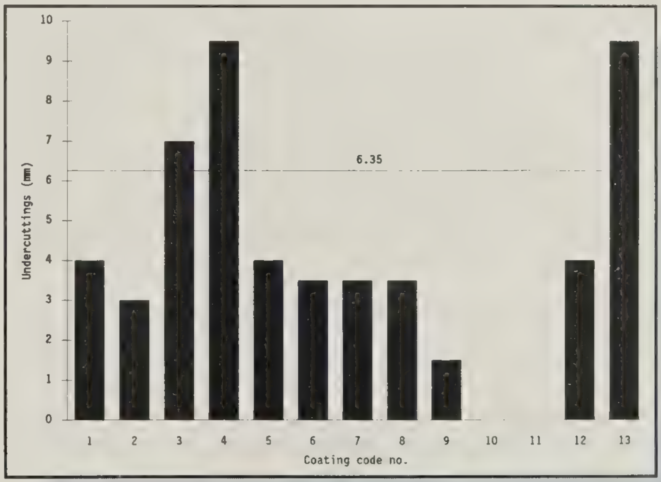

Figure 4.–Plots of undercuttings versus coating systems.

Of the bridge coating systems presently being used, the CALTRANS high solids phenolic system and the high-VOC epoxy mastic/polyurethane systems had the poorest resistance to scribe undercuttings (9.5 mm [0.37 in] and 9.3 mm [0.36 in], respectively). The low-VOC epoxy mastic/acrylic epoxy system developed an undercutting that was 6.8 mm (0.27 in) which is also relatively poor.

Seven coating systems—the low-VOC and high-VOC modified inorganic zinc/epoxy/acrylic epoxy, the low-VOC and high-VOC organic zinc/epoxy/polyurethane, the low-VOC and high-VOC solvent-based inorganic zinc/alkyl silicate/epoxy/polyurethane, and the CALTRANS waterborne acrylic system—showed a moderate degree of undercutting at the scribes (3.0 to 4.0 mm [0.12 to 0.16 in]) after 3,000 hours of the cyclic salt-fog/freeze exposure.

The best corrosion performance was provided by the water-based inorganic zinc potassium silicate/water-based acrylic/water-based acrylic (code no. 10), which did not undercut at the scribe or develop any rusting or blistering. The high-ratio water-based inorganic zinc potassium silicate/water-based acrylic (code no. 11) did not undercut, but did—as noted above—exhibit a poor topcoat adhesion. A different topcoat for the water-based inorganic potassium silicate may improve overall performance. The water-based inorganic zinc potassium silicate/epoxy/urethane (code no. 9) developed only minute undercutting at the scribe 1.5 mm (0.06 in). The superior rust and scribe undercutting resistance in accelerated salt-fog/freeze testing of the water-based inorganic zinc primer system reconfirmed the idea that a zinc-rich primer is an essential coating system element for high performance in a salt environment.

The two low-VOC solvent-based inorganic zinc systems did not protect against underfilm corrosion at the scribes as well as did the water-based inorganic zincs. The low-VOC solvent-based inorganic zinc (code no. 7) developed 3.3-mm (0.13-in) undercutting; the low-VOC solvent-based modified inorganic zinc (code no. 1) developed 4.0 mm (0.16 in) of undercutting.

An overall comparison of the average undercutting (U) for the candidate coating systems is shown in figure 4. A dividing line is drawn at an undercutting of 6.35 mm (0.25 in), which is generally considered as a standard criterion for a pass/fail classification: Undercutting of greater than 6.35 mm (0.25 in) is considered a failure in many rating systems. Using this criterion, the low-VOC epoxy mastic/acrylic epoxy, high-VOC epoxy mastic/polyurethane, and CALTRANS high solids phenolic system (code nos. 3, 4, and 13) failed after 3,000, 2,000, and 2,500 hours in the cyclic salt-fog/freeze exposure, respectively. The high undercuttings of silicone rubber (code nos. 14 and 15) are not shown here because they are off the scale.

The underfilm corrosion as measured at the scribe of four generic, similar low- and high-VOC coating pairs was compared to study the effect of the reduction of solvents and increase of solids. The average undercutting from the

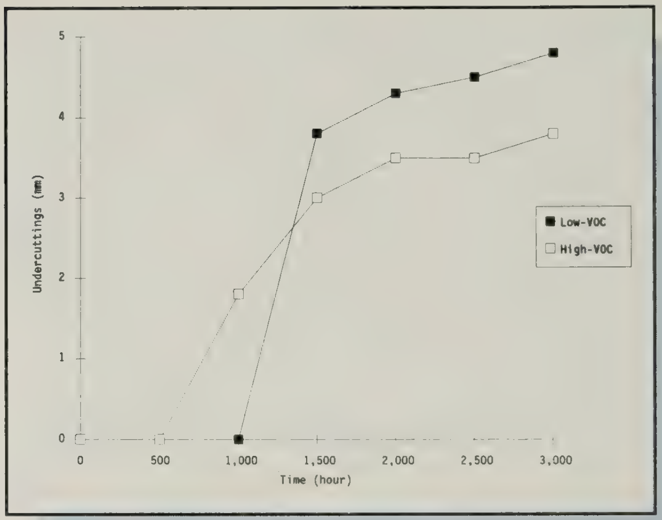

Figure 5.–Undercutting versus time for low- and high-VOC modified inorganic zinc/epoxy/urethane systems after 3,000 hours of cyclic salt-fog/freeze exposure.

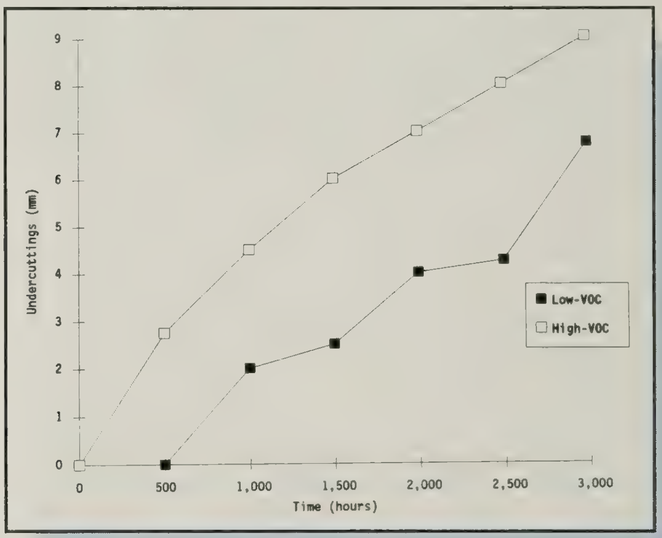

Figure 6.–Undercutting versus time for low- and high-VOC epoxy/mastic/urethane systems after 3,000 hours of cyclic salt-fog/freeze exposure.

scribes of duplicated panels was correlated with cyclic salt-fog/freeze exposure time (figures 5, 6, 7, and 8). For the epoxy mastic/polyurethane and the solvent-based inorganic zinc/epoxy/polyurethane, low-VOC systems outperformed the corresponding high-VOC systems. A comparison of the low- and high-VOC organic zinc/epoxy/polyurethane coating systems produced almost superimposed curves; this indicates similar durability. Only the low-VOC modified inorganic zinc/epoxy/polyurethane system performed less well than its counterpart high-VOC coating system at exposure times greater than 1,300 hours; it did however, have a later initial failure time. In general, the new low-VOC coating systems performed better than—or at least as well as—their high-VOC counterparts.

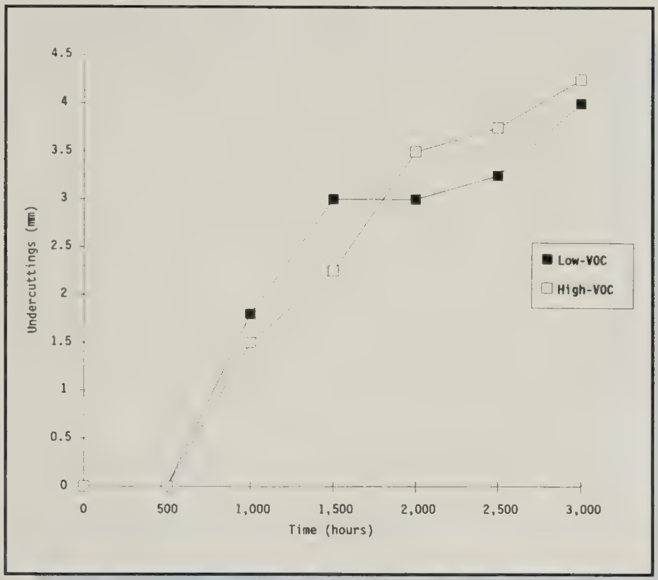

Figure 7.–Undercutting versus time for low- and high-VOC organic zinc/epoxy/urethane systems after 3,000 hours of cyclic salt-fog/freeze exposure.

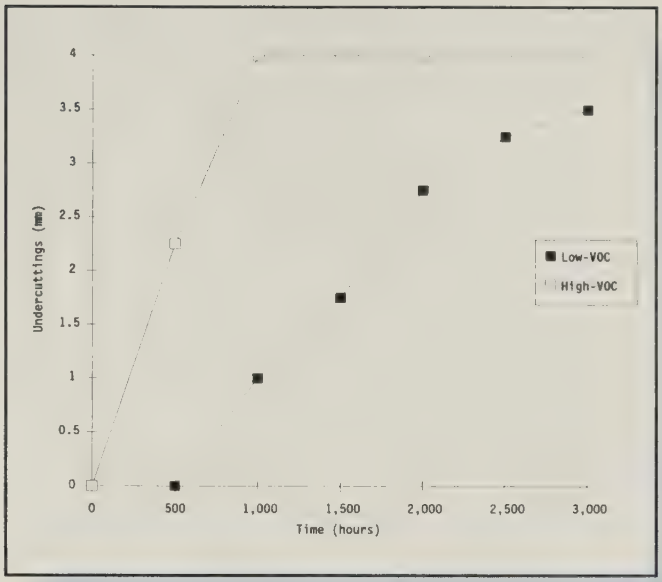

Figure 8.–Undercutting versus time for low- and high-VOC solvent-based inorganic zinc alkyl silicate/epoxy/urethane systems after 3,000 hours of cyclic salt-fog/freeze exposure.

UV/condensation test

Virtually all the candidate coating systems showed color fading, chalking, and gloss reduction after 2,000 hours of the UV/condensation exposure. These changes are due to the light sensitivity of organic polymers: these tend to degrade or oxidize to form unsaturated or carbonyl compounds in the presence of ultraviolet light. (*5*) Of all the coatings, only one—the CALTRANS waterborne acrylic coating system—actually failed after 2,000 hours of exposure; the entire coating rusted and peeled (figure 9). The precursor for this drastic failure was the severe blistering of 2MD which developed after 1,500 hours of exposure (figure 10). This blistering suggested a poor resistance of this coating system to moisture transfer in high-temperature, high-humidity environments. The moisture permeated through the coating resulting in loss of adhesion and formation of blisters.

Composite test rating for accelerated weathering tests

The cyclic salt-fog/freeze test using a scribed panel is a more effective accelerated testing regimen for evaluating coating systems than is the UV/condensation test; this is because the former test provided more and quicker blistering, rusting, and scribe undercutting. In most cases, differences in performance could be noted after 1,500 hours of cyclic salt-fog/freeze exposure. However, a combination of testing regimens should provide more information on field performance and failure modes. Therefore, a composite test rating was developed from the results of all of the accelerated testings to better define the comparative performance of the candidate materials.

For this composite rating, coating systems were rated based on the three types of failures evaluated in this study:

- Undercutting at the scribe of the cyclic salt-fog/freeze exposed panels (R1).
- Blistering and rusting of the scribed side of the cyclic salt-fog/freeze exposed panels (R2).
- Blistering and rusting of the UV-exposed side of the QUV panels (R3).

For each test, a rating of 10 was considered to be a perfect performance; a rating of 0 was considered a total failure. These ratings were summed to yield a composite rating. A rating of 26 to 30 is good, 20 to 25 is medium, and below 20 is considered poor. These composite test rating results, along with comparative ranks, are presented in table 3.

The water-based inorganic zinc potassium silicate/water-based acrylic/water-based acrylic, water-based inorganic zinc potassium silicate/epoxy/polyurethane, and high-ratio water-based inorganic zinc potassium silicate/water-based acrylic all *performed well* (ratings of 26 to 30), even though the high-ratio water-based inorganic zinc potassium silicate/water-based acrylic exhibited poor topcoat performance.

The coating systems that performed *moderately well* were the low- and high-VOC solvent-based inorganic zinc alkyl silicate/epoxy/polyurethane, low- and high-VOC modified inorganic zinc/epoxy/

polyurethane, and low- and high-VOC organic zinc/epoxy/polyurethane (ratings of 24 to 25).

Poorly performing systems were the CALTRANS waterborne acrylic, CALTRANS high solids phenolic, low-VOC epoxy mastic/acrylic epoxy, and high-VOC epoxy mastic/polyurethane systems (ratings of 15 to 18).

Outdoor exposure

Accelerated corrosion testing—with judiciously selected controls and exposure regimens—can provide significant information to predict coatings' general comparative field performance. Because such performances may vary significantly in specific field environments, in this study, marine exposure at Sea Isle City, New Jersey was selected as a way of comparing the accelerated test results with those obtained in a salt-rich natural environment.

After 22 months of outdoor marine exposure at Sea Isle, the general appearances of all the coating systems were fairly good with regard to peeling, checking, cracking, surface blistering, and surface rusting. They all faded and lost gloss to some degree. The major failures observed were those of rusting and blistering at the scribes. All panels developed rust at the scribes, but only six coating systems exhibited blistering at the scribes. The blistering results at 15 and 22 months of outdoor exposure are presented in table 4. The undercutting results were not measured.

The preliminary failure trends agree with the performance obtained in the accelerated cyclic salt-fog/freeze results. In particular, the high-VOC epoxy mastic/polyurethane system developed severe blistering (size 0 blisters with high density, see figure 11) at the scribe extending as far as 16 mm (0.63 in) after both 15 and 22

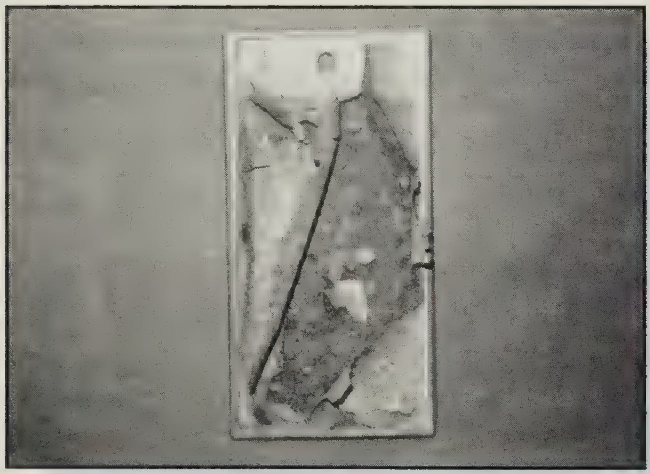

Figure 9.—Condition of CAL/TRANS water-borne acrylic system after 2,000 hours of UV/condensation exposure.

Figure 10.—Condition of CALTRANS water-borne acrylic system after 1,500 hours of UV/condensation exposure.

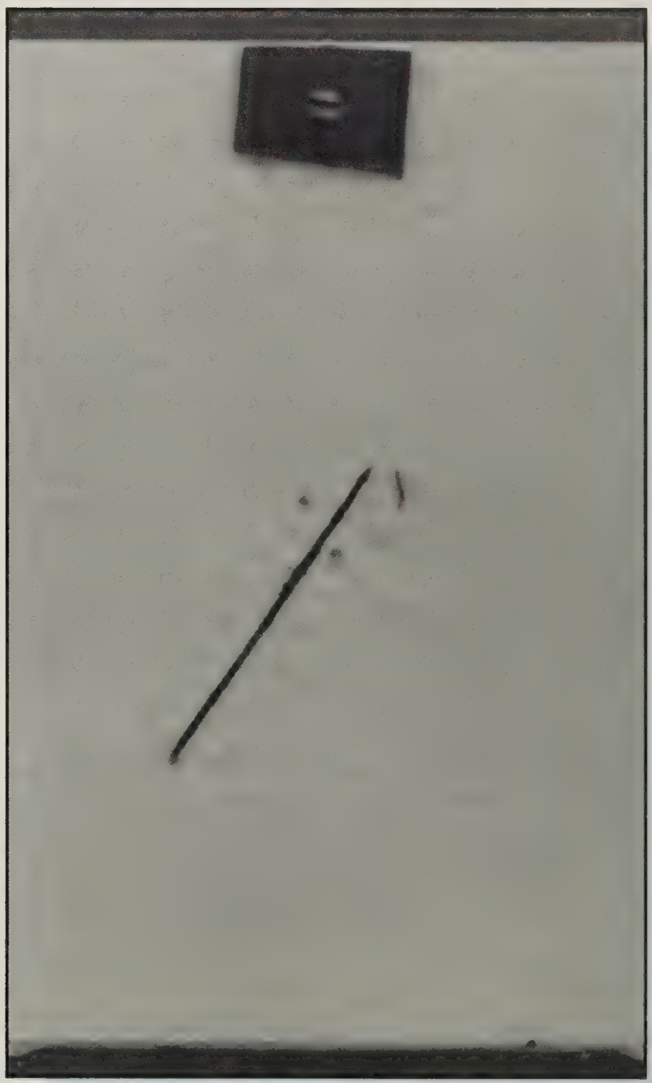

Figure 11.—Condition of low-VOC epoxy mastic/urethane systems after 15 months of outdoor marine exposure at Sea Isle, New Jersey.

Table 3.—Overall rating and rank of tested coating systems

	Salt-fog/freeze test		UV/condensation test		
Code no.	R1, Scribe	R2, Plane	R3, Plane	Overall Rating	Rank
1	5	10	10	25	4
2	5	10	10	25	4
3	4	4	10	18	7
4	3	10	10	23	6
5	5	10	10	25	4
6	5	10	10	25	4
7	5	10	10	25	4
8	5	9	10	24	5
9	7	10	10	27	2
10	10	10	10	30	1
11	10	6	10	26	3
12	5	10	0	15	10
13	3	3	10	16	9
14	2	5	10	17	8
15	1	5	10	16	9

Notes: Rating conducted in accordance with ASTM method D714 (R1), "Evaluating Degree of Blistering of Paints" and ASTM method D1654, "Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments" (R2 and R3).

Table 4.–Blistering rating at scribe for outdoor exposure panels

Rating System	15 Months	22 Months
High-VOC epoxy mastic/polyurethane	0, 0	0, 0
Low-VOC epoxy mastic/acrylic epoxy	8, 8	8, 8
CALTRANS waterborne acrylic system	8, 8	8, 8
CALTRANS high solids phenolic system	8, 9	6, 9
Silicone rubber on sandblasted steel	10, 10	8, 8
Silicone rubber on rusted & brushed steel	10, 10	8, 8

months. However, two silicone rubber systems did not develop any blistering after 15 months of outdoor exposure. They exhibited slight blistering (3.72 mm [0.15 in]) after 22 months of exposure, whereas blisters started to form at the scribes after only 1,000 hours of cyclic salt-fog/freeze exposure. This difference in behavior is not well understood and demonstrates that salt-fog testing is not always a good indicator of field performance. *(6,7)*

Conclusions

Based upon accelerated test data generated and the short-term (22 months) outdoor test results, the following conclusions can be made:

- Coating formulations with reduced solvent content performed as well as similar higher VOC-containing materials.
- The water-based inorganic zincs performed better than the solvent-based inorganic and the ep-

oxy organic zinc-rich candidates tested; this low-VOC coating system is strongly recommended for a high salt marine environment.

- Both the low- and high-VOC epoxy mastic did not perform well in the salt-fog evaluation; this was evidenced by excessive undercutting at the scribe and general subfilm corrosion on surfaces away from the scribe. Poor performances with identical failure modes have been reported for similar formulations on some bridges exposed to high salt environments. Both these epoxy mastic materials developed blistering at the scribe. The high-VOC product exhibited extreme blistering at the scribe that extended much farther than 6.35 mm (0.25 in) after 22 months of Sea Isle exposure.

- Both CALTRANS low-VOC systems did not perform well in the accelerated testing. However, these materials are reported to perform reasonably well in the California field environments where they are used. Other investigations have also found that the performance of organic waterborne materials in the field is better than that predicted by salt-fog results.

References

(*1*) S-L. Chong and J. Peart. *Evaluation of Volatile Organic Compound (VOC)—Compatible High Solids Coating System for Steel Bridges*, Publication Number FHWA-RD-91-054, Washington, DC: Federal Highway Administration, August 1991.

(*2*) T. Smith, "New Generation Epoxies for the Pulp and Paper Industry," *Journal of Protective Coatings and Linings*, Vol. 6, No. 8, August 1989, p. 25.

(*3*) K.A. Trimber. "Detection and Removal of Chemical Contaminants in Pulp and Paper Mills," *Proceedings of the Pulp and Paper II Industry Seminar of the Steel Structures Painting Council.* New Orleans, LA, July 28-29, 1988.

(*4*) S.K. Boocock, *et. al. Effect of Surface Contaminants on Coating Life.* Publication Number FHWA-RD-91-011, Washington DC: Federal Highway Administration, November 1990.

(*5*) G. Gupta and C.P. Chiang. "Correlating Accelerated with Natural Weathering Through FT-IR Spectroscopy," *Proceeding of the ACS Division of Polymeric Materials: Science and Engineering*, Vol. 63, Washington, DC, August 26-31, 1990, p. 667.

(*6*) B.R. Appleman. "Survey of Accelerated Test Methods for Anti-Corrosion Coating Performance," *Journal of Coatings Technology*, August 1990, pp. 57-67.

(*7*) J.A. Ellor and R. Kogler. "Evaluation of Selected Maintenance Coatings for Hand and Power Tool-Cleaned Surfaces," *Journal of Protective Coatings and Linings*, Vol. 7, No. 12, December 1990, p. 46.

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Testing of a Concrete Sealer Using the Rapid Chloride Permeability Technique

by Yash Paul Virmani and Dennis G. Sixbey

Introduction and Background

Sealers and penetrants are used primarily to prevent the corrosion of reinforcing steel caused by aggressive chloride ions when concrete bridge members are exposed to deicers or marine environments. The effectiveness of sealers and penetrants in preventing chloride ions from entering the concrete matrix depends on their own ability to penetrate—and thereby protect—the matrix. This ability is largely dependent on the matrix's void system and quality. For normal quality bridge concrete, the depth of penetration by most sealers is not significant unless the concrete has been thoroughly dried by continuous heating at elevated temperatures. In those circumstances, the sealers would penetrate much as they do in the polymer impregnation process (in which the polymer replaces the evaporated water from the heated concrete matrix).

Manufacturers and distributors claim that their sealants and penetrants can penetrate into the concrete matrix. To evaluate such claims, the Federal Highway Administration (FHWA) tested one type of sealer product under a realistic outdoor environment at the Turner-Fairbank Highway Research Center (TFHRC). The supplier claimed a penetration of 102 to 127 mm (4 to 5 in) into the concrete from the surface. The product is an aqueous solution of sodium silicate containing specific activators to achieve penetration and chemical bonding to the cementitious part of concrete.The experiment was designed to evaluate:

- The effectiveness of the penetrant in reducing the permeability of hardened concrete.
- The depth of penetration of the sealant into the concrete.

Study Design

A piece of a reinforced concrete bridge deck from the I-395 spur ramp "D" over Howard Street in Baltimore, Maryland, was used to test the sealer. This tined deck section was taken from a negative moment region of the span directly over a pier. The bridge was constructed in 1980-81 and recently removed to permit construction of a new baseball stadium. The total area of the removed deck section was approximately 12.2 m² (40 ft²). The deck section was furnished to the FHWA in January 1991; it was subsequently stored on the TFHRC grounds without a cover or other protection.

The weather for the 5 days prior to sealer application was generally sunny. The temperature at the time of treatment was moderate. The reinforced concrete slab section was sandblasted to remove dirt, oil, and other loose debris and also to expose the aggregate slightly; the goal was to provide a clean surface for the application of the sealer (figure 1). Only 7.6 m² (25 ft²) of the prepared section was used in the study; this was subdivided into five equal 0.6 by 0.8 m (2 by 2.6 ft) sections (figure 2). These five sections were treated as follows:

- Section 1: Concrete surface was wetted and then air-dried; 250 g of the sealer was then then brushed on in two coats.
- Section 2: Same as section 1, except that after 1 week, section 2 was sand blasted heavily to eliminate the surface sealing and expose a fresh concrete surface.
- Section 3: Concrete surface was not wetted; 250 g of the sealer was brushed on in two coats.
- Section 4: Control section (no sealer applied).
- Section 5: Concrete surface was wetted and then air-dried; sealer was sprayed instead of brushed on. This application procedure is the one recommended by the manufacturer.

Four full-depth nominal 102-mm (4-in) diameter cores were then extracted from each section. An additional core was from section 2 for a total of 17 cores taken from the four sections. All of the cores were sawed into 51-mm (2-in) thick concrete disks for testing by American Association of State Highway and Transportation Officials (AASHTO) standard T-277, "Rapid Determination of the Chloride Permeability of Concrete." (*1*)[1]

Figure 1.—Concrete desk section under sandblast.

[1]Italic numbers in parentheses identify references on page 121.

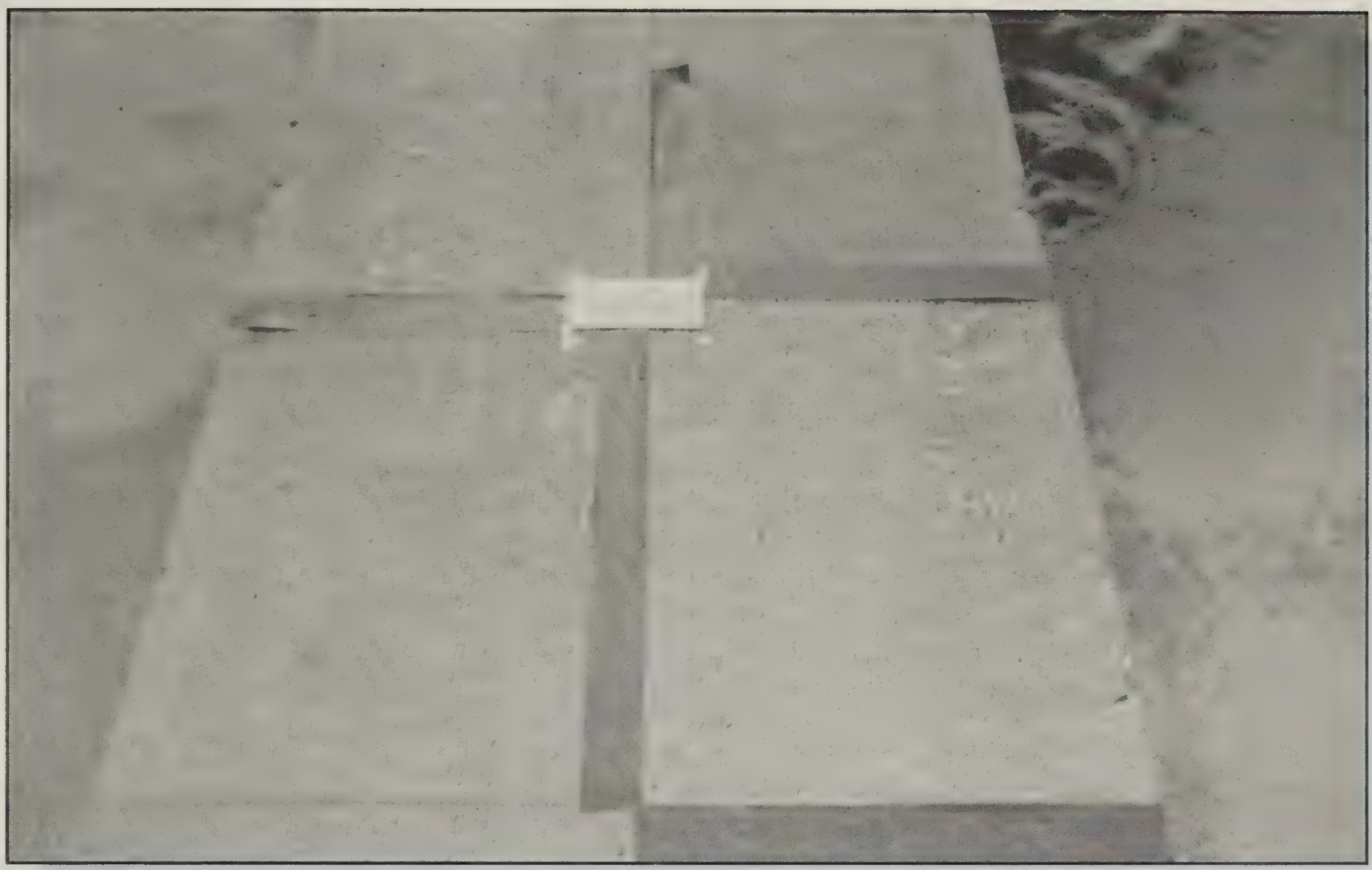

Figure 2.—Subdivided concrete deck sections prior to sealer application.

Table 1.

	Deck section I		Deck section 2		Deck section 3		Deck section 4		Deck section 5	
CORE	Disk section (cm)	Total charge passed (coulombs)	Disk section (cm)	Total charge passed (coulombs)	Disk section (cm)	Total charge passed (coulombs)	Disk section (cm)	Total charge passed (coulombs)	Disk section (cm)	Total charge passed (coulombs)
A	0-5	1,083	0-5	2,313	0-5	1,810	0-5	2,101	0-5	1,603
A	5-10	686	5-10	2,757	5-10	2,285	5-10	2,647	5-10	1,423
B	0-5	1,965	0-5	1,775	0-5	1,781	0-5	1,931	0-5	1,909
B	5-10	2,296	5-10	1,767	5-10	1,740	5-10	1,529	5-10	2,917
C	0-5	2,001	0.64-5.72[a]	2,334	0-5	1,398	0-5	2,071	0-5	1,263
C	5-10	2,606	5.72-10.8[a]	2,253	5-10	2,400	5-10	2,228	5-10	1,656
D	0-5	1,690	0-5	2,194	0-5	1,666	0-5	1,871	0-5	816
D	5-10	1,598	5-10	2,212	5-10	2,615	5-10	2,618	5-10	1,915
E			0.64-5.72[a]	2,215						
E			5.72-10.8[a]	2,285						

[a]top 0.64 cm of disk section sawed off prior to running the chloride permeability test.

1 in = 2.54 cm

A 6.35-mm (.25-in) segment of the top concrete surface was sliced from two of the five cores from the sealer treated and then heavily sandblasted section 2 before performing the permeability test. The remaining section 2 cores were not altered. Each core had three or four 51-mm (2-in) thick disk sections available for the test. Initially, the two top disks from each core were used in the permeability tests. If needed, additional sliced disk samples will be used to fulfill the study objectives.

Results

Table 1 provides rapid chloride permeability data on 42 sawed concrete disks from the 17 cores. Table 2 shows the average total charge passed through depths of 0 to 51 and 51 to 102 mm (0 to 2 and 2 to 4 in) for the five deck sections.

Table 2.—Average total charge passed

Disk section	Deck section (in)	Average total charge passed (coulombs)
1	0-2	1,685
	2-4	1,797
2	0-2	2,166
	2-4	2,254
3	0-2	1,663
	2-4	2,260
4-control	0-2	1,993
	2-4	2,255
5	0-2	1,397
	2-4	1,977
All deck sections (excluding control)	0-2	1,727
	2-4	2,072

Table 3.—Relationship between quality of concrete and charge passed

Chloride permeability	Charge passed (coulombs)	Type of concrete
High	>4,000	High water-cement ratios (≥0.6)
Moderate	2,000 - 4,000	Moderate water-cement ratios (0.4 - 0.5)
Low	1,000 - 2,000	Low water-cement ratios; "Iowa" dense concrete
Very Low	100 - 1,000	Latex-modified concrete; internally sealed concrete
Negligible	<100	Polymer-impregnated concrete; polymer concrete

Discussion and Conclusions

The AASHTO T-277 procedure was developed to assess the quality of concrete matrix. Table 3, taken from the AASHTO procedure, shows total charge values established for 51-mm (2-in) thick disk samples of various concretes. (*2*) These values serve as a rough guide for interpreting the test data to determine the quality of untreated and sealer-treated disk samples.

Based on the test data and the information in table 3, the following conclusions about the tested sealer can be made.

1. *When applied on a good quality concrete surface, this sodium-silicate-based sealer produced a slight—but not significant—reduction in permeability.* The average permeability of the 17 disk samples measuring 0 to 51 mm (0 to 2 in) was 1,727 coulombs compared to 1,993 for the control (untreated) disk sections. Similarly, the average permeabilities of the 51- to 102-mm (2- to 4-in) samples and controls were 2,072 and 2,255 coulombs, respectively.

2. *The sealer reduced the permeability of the concrete surface slightly more when it was sprayed rather than brushed on.* The average permeability for deck sections 1 and 2 (wetted; sealer brush-applied) samples were 1,925 coulombs for the 0- to 51- mm (0- to 2-in) sections and 2,025 coulombs for the 51- to 102-mm (2- to 4-in) sections, respectively. In contrast, deck sections 5 (sprayed) had average permeabilities of 1,397 and 1,977 coulombs for the 0- to 51-mm (0- to 2-in) and 51- to 102-mm (2- to 4-in) sections, respectively.

3. *The sealer penetrated less than 6.35 mm (0.25 in) into the concrete surface.* The average permeability of the two sawed disk samples 6.35 to 57 mm (0.25 to 2.25 in) (top 6.35 mm [0.25 in] of concrete removed before running the chloride permeability test) was 2,274 coulombs; in contrast, the control disk samples 0 to 51 mm (0 to 2 in) has an average permeability of 1,993 coulombs. Clearly, the sealer applied to the concrete surface did not penetrate into the concrete matrix.

4. *The treated deck sections did not achieveda "very low" chloride permeability level.* The quality of the untreated removed deck section showed that the concrete had a low water-cement ratio and a low chloride permeability with a value of about 2,000 coulombs. None of the sealer-treated disk samples achieved the very low permeability level of 100 to 1,000 coulombs as observed for latex-modified and internally sealed concretes.

References

(*1*) Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part I, "Specifications" and Part II, "Tests," (fifteenth edition), American Association of State Highway and Transportation Officials, Washington, DC, 1990.

(*2*) D. Whiting. "Rapid Determination on the Chloride Permeability of Concrete," Publication No. FHWA/RD-81/119, Federal Highway Administration, Washington, DC, August 1991.

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In-Vehicle Navigation Devices: Effects on the Safety and Driver Performance, Publication No. FHWA-RD-90-053

by IVHS Research Division

Seven navigational devices were tested in the Federal Highway Administration Highway Driving Simulator (HYSIM) for their effects on safe driving performance. Younger middle-aged and older drivers navigated a 41.8-km (26-mi) route through simulated streets of Detroit, Michigan, using one of seven devices. A control group used strip maps. The other six used either an audio or visual device which was of either low, medium, or high complexity. The difficulty of the driving task (workload) was increased in three successive sections by adding cross-winds, another vehicle, gauge monitoring, and mental arithmetic problems, and by narrowing the lanes. Measures included speed, average and variance of lateral placement, heart rate, and reaction time to gauge changes. Results indicate an interaction of age group and level of difficulty, such that higher levels of difficulty affected older drivers to a greater extent. Device differences suggest that audio devices are somewhat more effective than visual devices, and moderate levels of complexity are preferable to higher levels. In sections where navigation tasks were performed, the complex visual device had the longest reaction times and the slowest speeds.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 92-117878/AS, price code: A06.)Griffith

Application of New Accident Analysis Methodologies, Volume I: General Methodology, Publication No. FHWA-RD-90-091; Volume II: A Users Manual for BEATS, Publication No. FHWA-RD-91-014; and Volume III: Theoretical Development of New Accident Analysis Methodology, Publication No. FHWA-RD-91-015.

by Information and Behavioral Systems Division

Researchers in the field of accident analysis have long been aware of the problems associated with using accident data to draw statistical inference on safety. Aside from the problems of accessibility and quality, accident data present a real challenge when it comes to statistical analysis. One of the most serious problems in accident analysis is the regression-to-the-mean bias which occurs due to the non-random site selection process in safety measure evaluations. This study presents a new empirical Bayes method (EBEST) which identifies and corrects the regression-to-the-mean bias. A simulation study was completed to determine the conditions under which this new method would produce results superior to traditional statistical methods. Three particular safety applications are featured:

- The evaluation of safety treatments,
- The identification of high hazard locations, and

- The assimilation of information from multiple safety measure studies (meta-analysis).

A menu-driven microcomputer program (BEATS) was developed to allow easy use of this new analysis technique. The program includes a mini-tutorial that explains the data requirements and statistical assumptions for implementing the methodology. This report describes the EBEST (Empirical Bayes Estimation of Safety and Transportation) methodology and presents examples of how the method works for each of the three accident analysis applications. This report appears in three volumes. Volume I, General Methodology, is a nonstatistical review of the study; Volume II, A Users Manual for BEATS, is a user's manual for BEATS computer program, and Volume III, Theoretical Development of New Accident Analysis Methodology, contains the theoretical development of the procedure.

Limited copies of these publications are available from the R&D Report Center. Copies may also be purchased from the NTIS. (for Volume I: PB No. 92-115161/AS, price code: A05; for Volume II: PB No. 92-115179, price code: A03; for Volume III: PB No. 92-115195, price code: A03.)

Operational Impacts of Wider Trucks on Narrow Roadways, Publication No. FHWA-RD-90-103

by Design Concepts Research Division

This study was conducted to determine the differences in performance between 25.9 mm (102 in) wide and 24.4 mm (96 in) wide trucks and the impact that these trucks have on other traffic. Truck data were collected on rural two-lane and multilane roads which included curve and tangent sections and a variety of roadway widths and traffic conditions. The data collection effort resulted in approximately 100 hours of videotape and 9,000 slides from which various measures of effectiveness (MOE's) were extracted.

A number of MOE's were used to test for the operational effects of differential truck widths, lengths, and configurations. Such measures included:

- Lateral placement of the truck and the opposing or passing vehicle.
- Lane encroachments by the truck or opposing vehicle.
- Edgeline encroachments by the truck or opposing vehicle.

Analysis of variance (ANOVA) and regression modeling techniques were used to determine the significance of and the relationship among the variables used.

This final report summarizes the different operational effects of the 24.4-mm (96-in) trucks versus the wider trucks as a function of roadway width, curvature, and other site parameters. These variables may have implications for the safe handling of trucks as well as for the safety of other traffic. The results of this study should be helpful to organizations who develop guidelines specifing the geometric and operational parameters under which wider trucks may safely operate.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 92-117860/AS, price code: A07.)

Soil Nailing for Stabilization of Highway Slopes and Excavations, Publication No. FHWA-RD-89-198

by Materials Division

This report presents the findings of a comprehensive research study to evaluate, summarize, interpret, and extend the state of the art in soil nailing design and technology. The report also provides construction control guidelines and recommended specifications for highway projects using this technology.

Design based on local stability considerations using the Kinematical method is developed; design charts are provided for implementation.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 92-117696/AS, price code: A10.)

The following new research studies reported by the FHWA's Office of Research and Development are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description:

- **FHWA Staff and Administrative Contract Research contact *Public Roads.***
- **Highway Planning and Research (HP&R) contact the performing State highway or transportation department.**
- **National Cooperative Highway Research Program (NCHRP) contact the Program Director, NCHRP, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418.**
- **Strategic Highway Research Program (SHRP) contact the SHRP, 818 Connecticut Avenue, NW, 4th floor, Washington, DC 20006.**

NCP Category A—Highway Safety
A.5: Design

Title: State-of-the-Practice Geometric Design Consistency (NCP No. 3A5a0342)

Objective: Obtain and compare information on existing design practices in Europe and the United States. Verify, both theoretically and through case studies, which of these practices will lead to designs that create speed expectancy problems for drivers. From the review and case studies, develop a procedure that can be used to detect inconsistencies in highway design. This procedure would be applicable to roadway sections presently in operation or under design. Develop recommendations for changes in the commonly used design procedures and geometric criteria, leading to more consistent highway design.

Performing Organization: Texas A&M (TTI), College Station, TX 77843

Expected Completion Date: October 1993

Estimated Cost: $298,285 (FHWA Administrative Contract)

NCP Category B—Traffic Operations
B.3: Motorist-Highway System Interactions

Title: Design Characteristics of Older Adult Pedestrians (NCP No. 3B3a0172)

Objective: To determine what is known concerning the capabilities and limitations of older persons, to determine what part of this knowledge is transferable to designing pedestrian facilities with older persons in mind, to determine where necessary information is lacking, and to conduct research to fill in the gaps in our knowledge. Information on the physical and mental characteristics of older persons is becoming available in the medical and older-driver fields. This study will help determine if some of this information is directly applicable to the design of pedestrian facilities.

Performing Organization: Center for Applied Research, Great Falls, VA 22066.

Expected Completion Date: November 1993

Estimated Cost: $129,999 (FHWA Administrative Contract)

NCP Category C—Pavements
C.1: Evaluation of Rigid Pavements

Title: Performance Evaluation of Experimental Concrete Pavements—Data Collection and Analysis (NCP No. 3C1a2192)

Objective: Collect the necessary data and evaluate specified pavement test sections in various locations. The emphasis will be on jointed concrete pavements, but the performance of continuously reinforced test sections adjacent to JPCP or JRCP will be used to improve guidance on the selection of pavement type. Develop an expanded SHRP-compatible database and develop and verify improved performance prediction equations. Prepare interim and final reports.

Performing Organization: ERES Consultants, Inc., Champaign, IL 61820

Expected Completion Date: October 1994

Estimated Cost: $815,837 (FHWA Administrative Contract)

NCP Category D—Structures

D.4: Corrosion Protection

Title: Rehabilitation of Prestressed Concrete Bridge Components by Non-Electrical Methods (NCP No. 3D4c1111)

Objective: Investigate the extent of corrosion-induced deterioration in PS/C bridge components and based on in-depth field data analysis, perform a detailed laboratory study to develop durable and cost-effective corrosion-protection systems for the rehabilitation of existing PS/C bridges.

Performing Organization: Construction Technology Laboratories, Inc., 5420 Old Orchard Road, Skokie, IL 60077-1030

Expected Completion Date: September 1995

Estimated Cost: $463,102 (FHWA Administration Contract)

NCP Category E—Materials and Operations

E.1: Asphalt and Asphaltic Mixtures

Title: Evaluation of NCHRP Asphalt Aggregate Mixture Analysis System (AAMAS) (NCP No. 2E1b2252)

Objective: Evaluate the NCHRP Asphalt Aggregate Mixture Analysis System (AAMAS) in NCHRP Report 338. The procedures will be verified using mixtures with known field performance.

Performing Organization: Federal Highway Administration (FHWA)

Expected Completion Date: September 1992

Estimated Cost: $55,000 (FHWA Administration Contract)

NCHRP Projects Scheduled for Fiscal Year 1993

The American Association of State Highway and Transportation Officials (AASHTO) sponsored National Cooperative Highway Research Program announces the following 12 new projects for fiscal year 1993.

Project Number	Title
1-29	Enhanced Surface Drainage of Multilane Pavements
1-30	Support Under PC Concrete Pavements
3-45	Research Program in Highway Capacity—Coordination of Freeway Research
3-46	Research Program in Highway Capacity—Unsignalized Intersections Procedures
8-30	Characteristics and Growth of Freight Demand
8-31	Long Term Availability of Corridor Capacity
10-38	Fatigue Design and Evaluation for Signal, Sign, and Light Support Structures
10-39	Essential Testing and Inspection Levels
12-38	Research Needs for Horizontally Curved Girder Bridges
12-39	Debris Loads on Highway Bridges
24-6	Expert System for Bridge Scour Evaluation and Prevention
25-6	Evaluation of Vehicular Modal Emissions and Their Consideration in an Intersection Air Quality Model

Project Statements, inviting proposals for research on these problems, are scheduled to be issued early in 1992, and research is expected to begin in late 1992. A preliminary announcement containing more details on these problems was distributed to all those on the NCHRP project-statement mailing list; copies are also available through the Transportation Research Board.

Prospective proposers may be added to the NCHRP mailing list by writing to Program Officer, Cooperative Research Programs, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418.

Annual Report: Office of Research and Development 1991, Publication No. FHWA-RD-91-098

The Office of Research and Development (R&D) will soon release its 1991 annual report. This report is a continuation of the series of annual and biennial reports published since 1974.

For fiscal year 1991—October 1990 through September 1991—the report covers exclusively the offices of research and development housed at the Turner-Fairbank Highway Research Center. Along with an overview of the research center, this report includes summaries of the various research programs managed or performed by the staff. The back section includes a list of research and development publications for 1991.

While supplies last, individual copies of the reports in the series are available without charge from the Federal Highway Administration, R&D Report Center, HRD-11, 6300 Georgetown Pike, McLean VA 22101-2296. Telephone: (703) 285-2144.

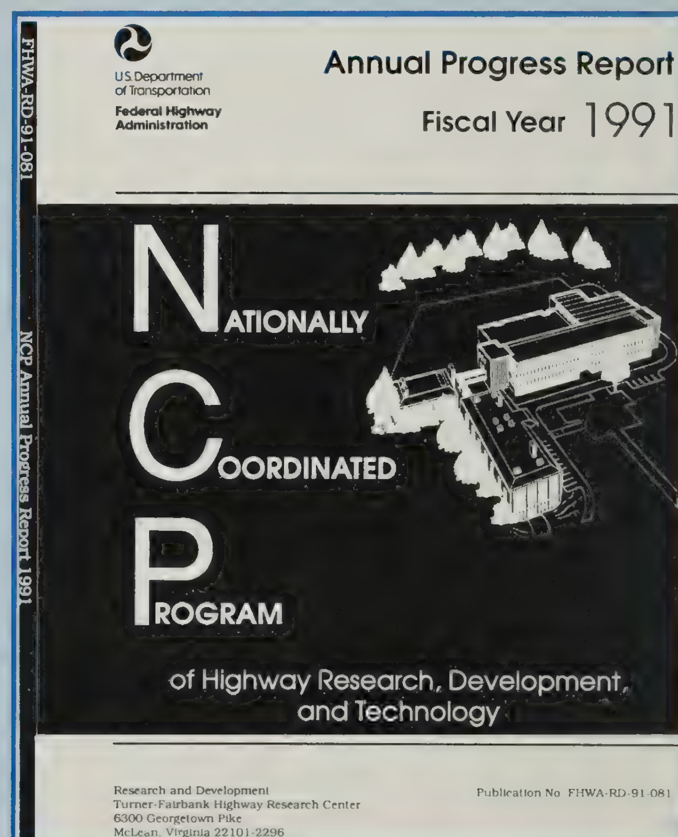
Nationally Coordinated Program of Highway Research, Development, and Technology: Annual Progress Report, Fiscal Year 1991, Publication No. FHWA-RD-91-081

This report gives an overview of progress being made under the Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology from October 1, 1990 through September 30, 1991. The Office of R&D uses the NCP as a management framework for highway research activities. The objectives of the NCP are to:

- Ensure resource concentration on common problems
- Minimize duplicated efforts among researchers
- Identify and highlight gaps in research
- Provide lists of Federally-supported highway research activities

This report covers technologies for highway design, construction, and operations including the specific categories of: Highway Safety, Traffic Operations Intelligent Vehicle-Highway Systems, Pavements, Structures, Materials and Operations, Policy and Planning, and Motor Carriers Transportation.

Limited copies of this Annual Progress Report are available from the R&D Report Center, HRD-11, 6300 Georgetown Pike, McLean VA 22101-2296. Telephone: (703) 285-2144.



GPO Subject Bibliography

To get a complete free listing of publications and periodicals on highway construction, safety, and traffic, write to the Superintendent of Documents, Mail Stop : SSOP, Washington, D.C. 20402-9328, and ask for Subject Bibliography SB-03 Highway Construction, Safety, and Traffic.

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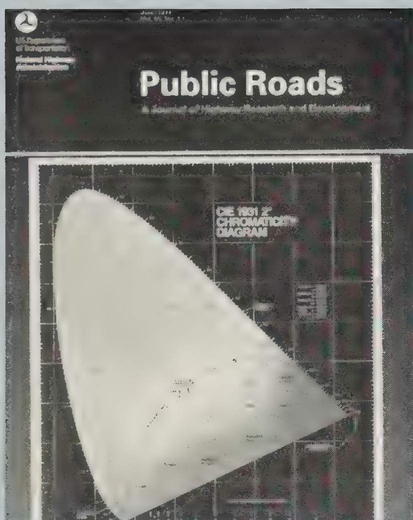

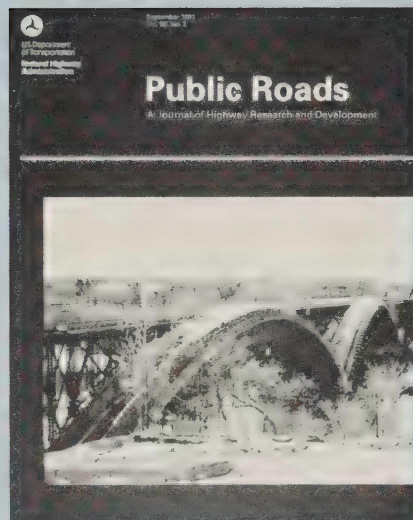

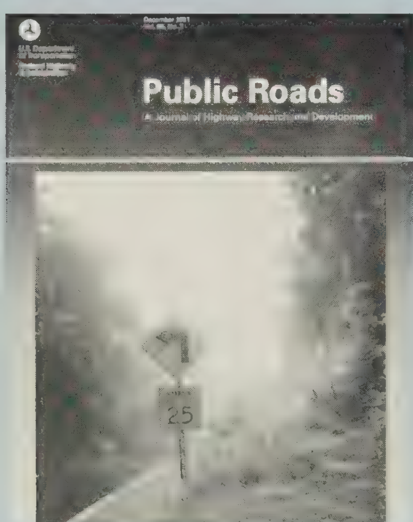

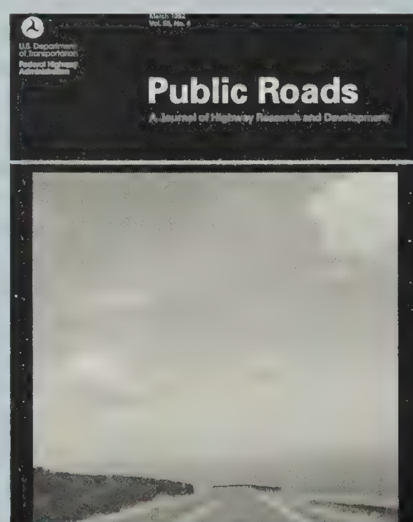

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(and volume page reference)

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