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Public Roads

A Journal of Highway Research and Development

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COVER: Interstate 57 Mississippi River Bridge at Cairo, Illinois. Located six nautical miles up river from the confluence of the Mississippi and Ohio Rivers, the design of this three-span continuous truss bridge included consideration for Zone 3 earthquake loading (new Madrid fault) and utilized three open dredged caissons with follower cofferdams for the piers located in the river channel.

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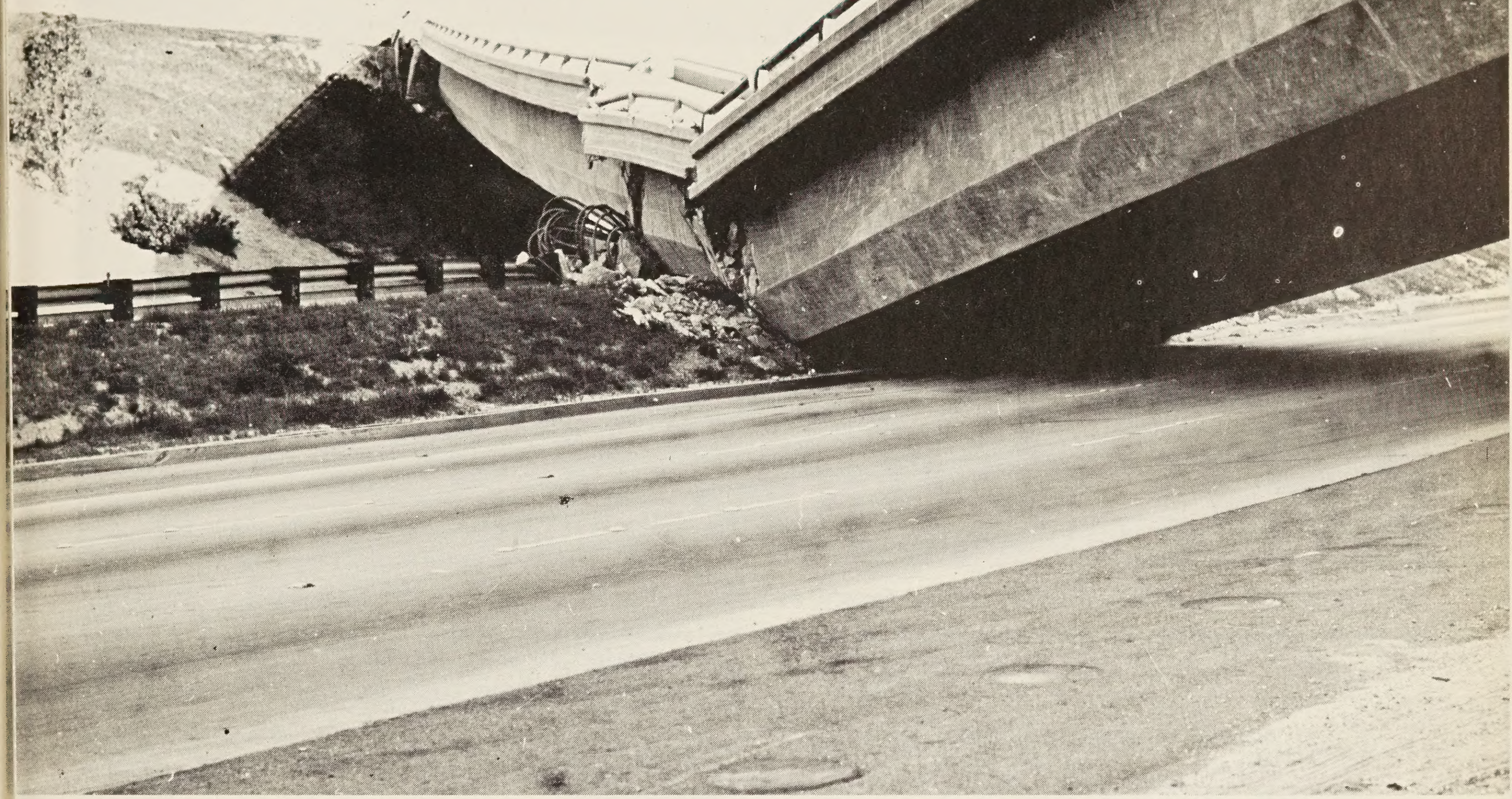
The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department.

Implementation of Seismic Design and Retrofit Procedures for Highway Bridges

by Thomas Krylowski and Ian G. Buckle



Introduction

In 1971, a major earthquake in San Fernando, California, damaged nearly 70 highway bridges. Seven of these collapsed or were so badly damaged that they had to be replaced. Total repair and replacement costs—including the indirect costs associated with closing the bridges—were an estimated $100 million (1984 dollars). (*1*)[1]

The spectacular collapse of these structures came as a surprise, given the then-recent advances made in bridge design and construction for vehicular loads (figure 1). However, vehicular ("live") load design emphasizes the superstructure; for earthquake ("seismic") loads, the critical bridge elements are the substructure and foundations and their connections to the superstructure.

Earthquakes occur more frequently than most people realize and it is not only the West Coast that is susceptible to earthquake damage (table 1). Earthquakes are, in fact, a serious problem in many parts of the U.S. and have been responsible for the complete or partial destruction of numerous bridges throughout the country (figure 2). This widespread vulnerability demonstrates the need for earthquake-resistant bridge design which takes into account the performance of substructures under high lateral loads. This article summarizes recent advances in such bridge design and the efforts by the Federal Highway Administration (FHWA) to provide training in the latest design and retrofit procedures.

Past Performance of Bridges

Horizontal rather than vertical ground motion causes most bridge failures. Damage can occur in the substructure (including columns, abutments, and foundations), superstructure, and approaches. A number of reports are available which document earthquake damage to bridges over the past several decades. (*3,4,5*) Typical types of damage to bridges are discussed below.

[1]Italic numbers in parentheses identify references on page 5.

Figure 1.—Damaged bridge, Golden State Freeway, San Fernando Earthquake, 1971.

Table 1.—Worldwide earthquakes per year (2)

MAGNITUDE M	AVERAGE NUMBER ABOVE M
8	2
7	20
6	100
5	3,500
4	15,000
3	More than 100,000

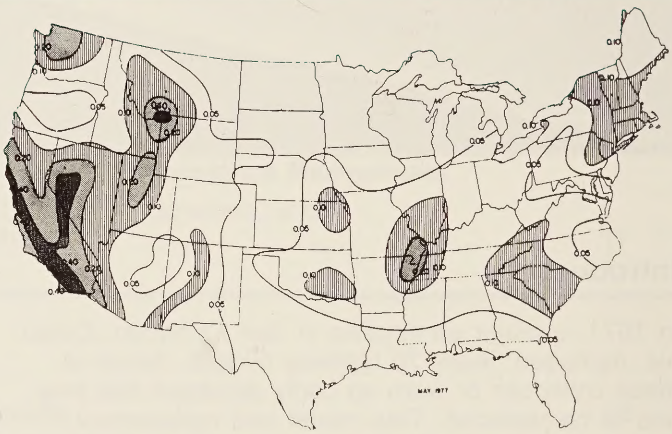


Figure 2.—Peak accelerations (shaded areas more susceptible to earthquakes).

Substructure

- Column damage may be caused by flexure, shear (figure 3) and anchorage failure of the longitudinal reinforcement. These failure modes also can cause bridge collapse by removing support for the superstructure.
- Abutments may attract the largest share of the seismic inertia forces developed in the superstructure. These forces can be very high and may cause severe, often brittle, failures.
- Foundation failures result from excessive ground deformation and/or loss of stability and bearing capacity of foundation soils. Consequently, substructures often tilt, settle, or overturn; this in turn causes severe cracking and complete failure. Typical failure modes for a spread footing are shown in figure 4.

Superstructure

The most severe form of superstructure damage comes from loss of support for the girders caused by lack of continuity, inadequate support lengths, skewed supports (which encourage rotation) or gross movements of the supports due to some form of soil failure under piers or abutments. A typical superstructure collapse is shown in figure 5.

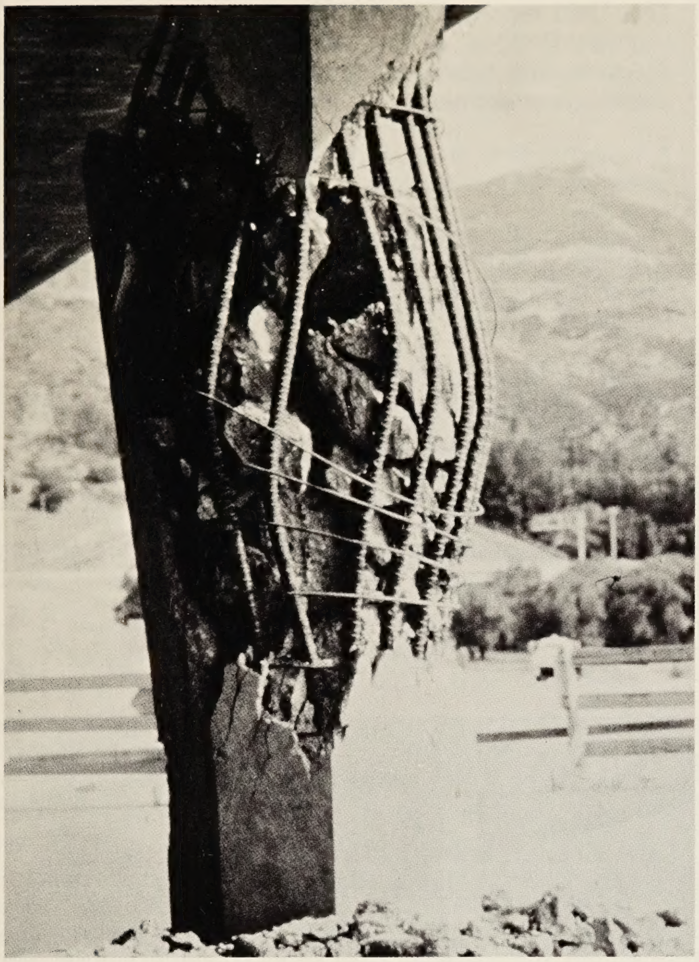


Figure 3.—Shear failure of column.

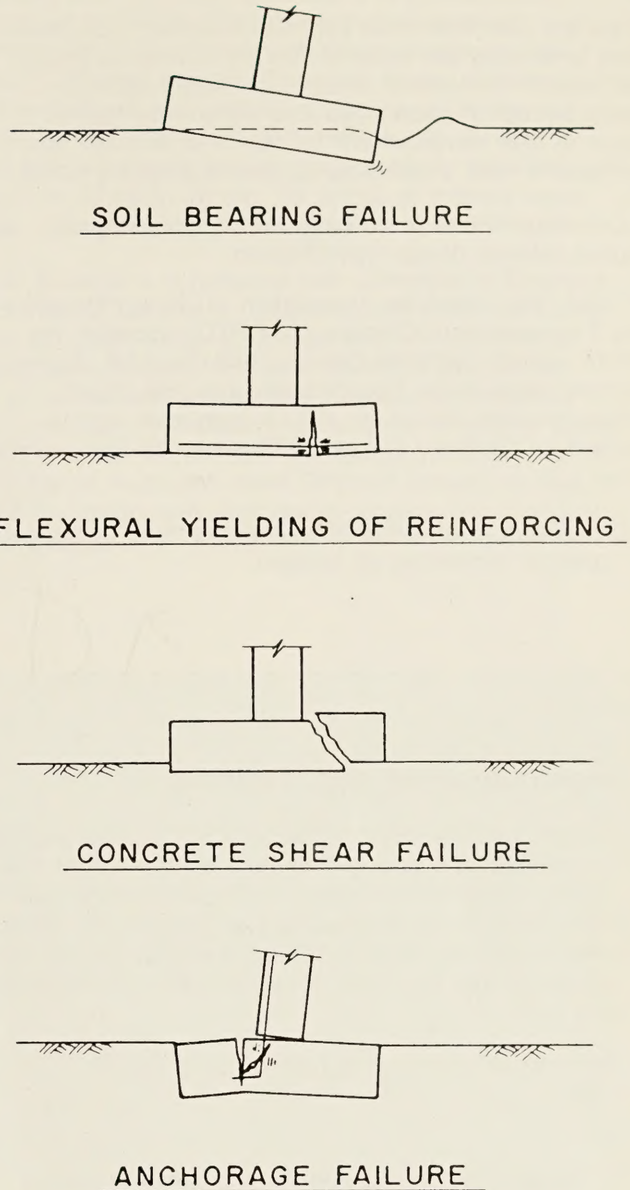


Figure 4.—Failure modes for spread footings.

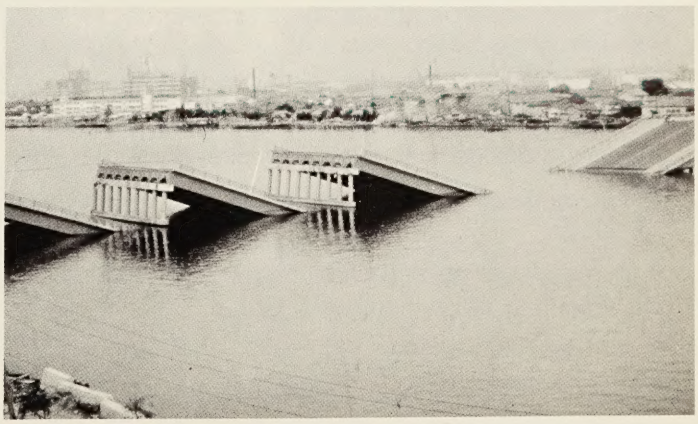


Figure 5.—Collapsed superstructure.

Current Seismic Design Philosophy

Generally, bridge design is based on elastic theory: a structure's capacity is designed to be sufficient to resist all loads within a specified factor of safety. The magnitude of earthquake loads, however, is such that to include them in this principle would be unrealistic for most bridges. Consequently, a new philosophy for seismic design of bridges has been adopted. First, for low to moderate earthquakes—which may be expected to occur several times throughout the life of a bridge—the structure is designed to resist these loads with only minor damage. Second, for severe earthquakes—which may occur once in the lifetime of a bridge—some structural damage is accepted but controlled so as to prevent collapse and preserve public safety. Where possible, damage that does occur should be readily detectable and accessible for inspection and, if feasible, repaired.

Seismic Design Standards

Since the San Fernando Earthquake, much has been done to elevate the state of the art in seismic design and retrofit of highway structures. These achievements based on knowledge and experience gained in research and development studies and through post-earthquake field investigations, are highlighted below.

- Development of a state-of-the-art, nationally accepted seismic design specification.

In 1983, the American Association of State Highway and Transportation Officials (AASHTO) adopted the FHWA report, "Seismic Design Guidelines for Highway Bridges" as a guide specification. (*6*) This report, which is widely known as ATC-6, was later supplemented by "Seismic Design of Highway Bridge Foundations." (*7*)

- Development of comprehensive, practical guidelines for seismic retrofitting of bridges.

The 1983 report, "Seismic Retrofitting Guidelines for Highway Bridges" (ATC-6-2), includes methods to identify potentially troublesome bridges, evaluate weaknesses, and define retrofit measures. (*8*)

- Development of a user-friendly microcomputer program for seismic analysis of bridges.

In 1984, a computer program for the seismic analysis of bridges (SEISAB) was developed. This program was written to accommodate the provisions of the guide specifications.

Finally, in May 1987, the report, "Seismic Design and Retrofit Manual for Highway Bridges" was published. (*1*) This document summarizes much of what is known about seismic design and retrofit of bridges and emphasizes the short- to medium-span bridges that are typical of current design practice in the U.S. Much of the material in this article was drawn from this report.

Implementation and Training

To help get the latest techniques for seismic design and retrofit of highway bridges into use across the country, the FHWA's Office of Implementation and the National Highway Institute are sponsoring the development of an intensive, 4 1/2-day training course. The course should be ready for presentation by mid- to late 1989.

The proposed outline for the training course follows.

1. Introduction to Seismic Design and Retrofitting of Bridges

- The effect of earthquakes on bridges.
- Seismic design and retrofitting since the 1971 San Fernando Earthquake.
- Seismic design and retrofitting philosophy.
- Planning considerations.
- Seismic design and retrofitting strategies.

2. Fundamental Design Concepts in Structural Dynamics

- Dynamic loading and basic equations of motion.
- Undamped free vibration.
- Structural damping.
- Forced vibration and support motion.

3. Seismic Loading

- Basic seismology.
- Characteristics of earthquake ground motion.
- Seismic design loadings.

4. Seismic Response Analysis

- Analysis methods used for design.
- Modeling for analysis.
- SEISAB.
- Design forces and displacements.
- Comparison of analysis methods.

5. Design Concepts

- Reinforced concrete columns and piers.
- Abutments.
- Foundations.
- Bearings, expansion joints, and restrainers.
- Other components.
- Ground stability considerations.

6. Retrofitting

- Preliminary screening.
- Detailed evaluation.
- Retrofitting concepts.

7. Advanced Topics

- Nonlinear analysis.
- Nonuniform support motion.
- Practical base isolation.

Conclusion

While we cannot predict specifically when and where an earthquake will occur, we now have the tools to design highway structures to resist them.

This article summarizes major accomplishments that have led to the development of a nationally accepted seismic design specification and the steps the Federal Highway Administration has taken to encourage design engineers to put these procedures into everyday practice.

References

(*1*) I.G. Buckle, et al. "Seismic Design and Retrofit Manual for Highway Bridges," Publication No. FHWA–IP–87–6, Federal Highway Administration, Washington, DC, May 1987.

(*2*) B.H. Bolt. *Earthquakes: A Primer*, W.H. Freeman and Co., 1978.

(*3*) T. Iwasaki, et al. "Literature Survey—Seismic Effects on Highway Bridges," Publication No. FHWA–RD–73–13, Federal Highway Administration, Washington, DC, November 1973.

(*4*) J.D. Cooper. "Bridge and Highway Damage Resulting from the 1976 Guatemala Earthquake," Publication No. FHWA–RD–76–148, Federal Highway Administration, Washington, DC, May 1976.

(*5*) R.A. Imbsen. "Highway Structure Damage Caused by the Trinidad—Offshore California Earthquake of November 8, 1980," Publication No. FHWA/RD–82/017, Federal Highway Administration, Washington, DC, December 1981.

(*6*) "Seismic Design Guidelines for Highway Bridges," Publication No. FHWA/RD–81/081, Federal Highway Administration, Washington, DC, 1981.

(*7*) Ignatius (Po) Lam and Geoffrey R. Martin. "Seismic Design of Highway Bridge Foundation," Vols. I, II, and III, Publication Nos. FHWA/RD–86/101, FHWA/RD–86/102, and FHWA/RD–86/103, Federal Highway Administration, Washington, DC, June 1986.

(*8*) "Seismic Retrofitting Guidelines for Highway Bridges," Publication No. FHWA/RD–83/007, Federal Highway Administration, Washington, DC, 1983.

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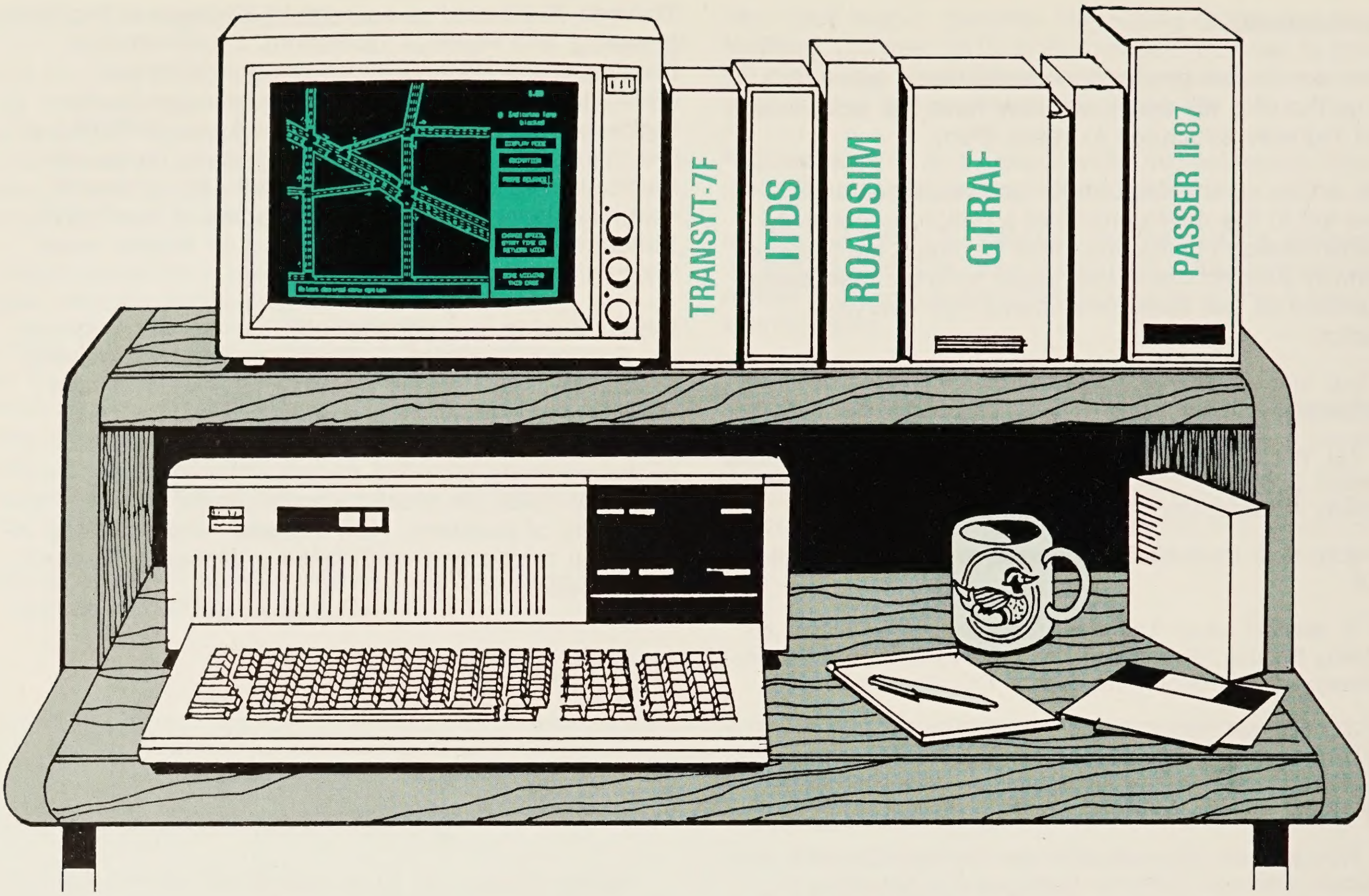
Ian G. Buckle is a principal with Computech Engineering Services, Berkeley, California and is the co-author of the FHWA's "Seismic Design and Retrofit Manual for Highway Bridges." He is a leading expert in the field of bridge and earthquake engineering and has published many technical papers. Prior to joining Computech in 1984, Dr. Buckle served on the faculty of the University of Auckland, New Zealand, where he was involved in bridge and earthquake engineering research for 15 years.



Getting Started—Selecting and Using Computerized Traffic Models

by Juan M. Morales, P.E.

Introduction

Today's practicing traffic engineer has many tools available to help combat the ever-increasing traffic congestion problem. Computer traffic models are one of these tools, assisting in the design of traffic control strategies while saving time and resources. Computer modeling allows traffic engineers to design traffic control strategies efficiently and effectively, thus optimizing the performance of the Nation's highway system. Although many traffic engineers still use manual techniques for this purpose, others are discovering that computer models offer substantial advantages in developing and evaluating alternative traffic control strategies.

Many traffic engineers are, for one reason or another, reluctant to use computerized tools. They may be unfamiliar with the various models, or believe they have to be computer experts to use them. Some doubt a computer model's reliability. Others are afraid of computers and don't want to become involved with them. All these reasons boil down to a lack of information: the facts must be known before the utility of computerized traffic modeling can be assessed.

This article presents some of these facts. It describes considerations involved in beginning to use computer models to simulate and optimize traffic flow; it also describes some of the models currently available and how to obtain them.

Background

Over the last 20 years, the Federal Highway Administration (FHWA) and others have developed a number of computer programs to evaluate and optimize traffic control strategies. These traffic models allow the user to *see* the effects of a strategy *before* committing resources to implement them in the field.

Some of the original models were rather rudimentary by today's standards. Most ran on mainframe computers where data had to be punched on cards and results found by searching through long printouts. It was hard and tedious work. However, many of today's traffic models run on microcomputers which are much easier to use. Additionally, some models have interactive data editors, where the user simply fills in blanks on the screen or responds to questions: the computer decides what to do with the data.

Other models have graphic output, allowing the user to literally see how traffic is moving. Newer models are faster and more efficient, have more capabilities, and are easier to use. Also, some of the older models have evolved and migrated from the mainframe to the microcomputer environment. This reliance on microcomputers has narrowed the gap between the theoretical development of traffic models and their practical application in the field.

The use of user-friendly microcomputer programs allows mathematical theories and terminology—often confusing to the average user—to be moved to the background. Users can now simply enter their data, run the model, and study the results in a matter of minutes.

Advantages of Traffic Models

Imagine being able to foresee the effects of a traffic control strategy. Further, imagine seeing what happens to a strategy when one or more variables (e.g., traffic volume, vehicle mix) are changed. These capabilities mean that traffic models save time and resources—both staffing and funding—while allowing the user to study the effects of changing variables before implementing the solution in the field.

Since we can no longer afford to build new facilities, we must instead improve the performance of existing facilities. Thus, techniques for increasing the traffic-carrying capacity of these facilities must be considered. Improvements to study include better signal timing and phasing, signal coordination, turn and parking prohibitions, exclusive turn lanes, ramp metering, high-occupancy-vehicle lanes, and others. With traffic modeling, the user can study the effect of one or more of these improvements with a minimum investment of cost and time.

The start up cost associated with the use of traffic models, e.g., training, equipment cost, is more than offset by the speed and flexibility of the results obtained. Training is usually a one-time cost per model and usually pays for itself with the first application. Furthermore, modeling provides the opportunity of evaluating alternative traffic control strategies with much of the same basic information required when using traditional methods.

Problems Associated with Traffic Models

To use computerized traffic models confidently, the practicing engineer must be familiar with their use and benefits. Such confidence can only be achieved through experience. While gaining this experience, however, problems and questions will arise. The ability to solve these problems—without excessive frustration on the user's part—will determine the resulting confidence level.

Traffic models are far from perfect. As in any other microcomputer program, they may contain programming errors that have not yet been encountered. On the plus side, however, computer models are much more accurate than traditional manual methods.

Another frequently occurring difficulty is the set of problems associated with data. Sometimes, required data are not available and must be collected. Other times, data are not in the correct units or format and must be converted. Similarly, the user may not have the appropriate computer to run a particular model.

To minimize these problems, carefully select which models to use. The following sections describe some important factors to consider when selecting traffic models. Note that, even when things go smoothly, traffic modeling is not a substitute for engineering judgment. The user must study model results and decide whether they are reasonable. Strategies should never be implemented just because "the computer said so."

Model Types

There are two basic types of traffic models—*simulation models*, and *optimization models*. A simulation model is a mathematical representation of the sequence of events that comprise a process. In the application of a simulation model, the sequence of events is repeated several times to study the outcome. For example, suppose you wanted to find the probability that at least 2 people out of 50 have the same birthday. This could be solved analytically or through extensive sampling. Simulation is another solution method. Using a computer, you could assign birthdays randomly to 50 people and then check to see if the same data have been assigned to more than 1 person. This process could be repeated thousands of times to produce a "simulated" answer. (*1*)[1]

Because computers are able to perform repetitious calculations at incredible speeds, simulation models usually are written into a computer program. Simulation models simply reproduce the process as faithfully as possible and report the results. They are best used in comparing various differing strategies.

[1] Italic numbers in parentheses identify references on page 11.

To obtain an optimal solution using simulation, the model must be applied repetitively with different design parameters. Optimization models, on the other hand, seek the best solution by varying the design parameters automatically. Traffic optimization models are best suited for signal phasing.

Application and Level of Detail

Given their inherent volume of mathematical computations, traffic models tend to be large and rather slow. Limited microcomputer memory thus forces researchers to design models by application, i.e., to perform a specific function. It is rare to find both simulation and optimization models within a single computer program. As a consequence, the output of one model frequently is used as input for another model.

Most models are designed to perform independent functions (e.g., simulation or optimization) for different traffic scenarios (e.g., isolated intersections, arterials, freeways, two-lane roads, etc.). The level of detail varies by model. Some models are called *microscopic* because they have the ability to simulate individual vehicles; *macroscopic* models simulate groups of vehicles. The latter tend to be faster but less accurate. These limitations in function, application, and detail imply that more than one traffic model should be used to develop network-wide, comprehensive control strategies. (*2*)

Computer Requirements

The computer hardware and software needed to run a specific model are an important consideration. If the necessary equipment is unavailable, the user will have to upgrade the computer system in order to run a specific model.

Computer requirements to consider include:

- Type of computer (e.g., IBM-AT compatible).
- Screen displays (e.g., monochrome versus enhanced color graphics monitors).
- Available storage (e.g., hard disk space).
- Amount of memory (e.g., 640K).
- Software (e.g., a specific disk operating system (DOS) version).
- Other concerns (e.g., use of mouse, presence of math coprocessor, number of disk drives, etc.).

These requirements are included with the model's documentation.

Documentation and User Support

Documentation is defined as written information about the model. It may include general information—such as the model's underlying theory, assumptions[2], limitations, and constraints—and/or details on the methodology used to enable evaluation of the model by someone other than the model's developer. The type and extent of documentation provided is the responsibility of the developers; moreover, to be complete, documentation should cover the what, why, and how of the software's use.

The most important piece of documentation generally is the user manual. This manual describes how to install and use the model, how to input the data, and how to obtain results. The manual should be clear and should address any questions users might have including computer requirements and installation.

Availability of user support (e.g., assistance in case the user manual does not answer a given question) from the model developer is also important. User support may be provided via a telephone help line or through training courses. Developers usually provide user support for a given amount of time after a model is released. User support also can be obtained from user groups or other users familiar with the model. (*3*)

Data Requirements

What data are needed to run this model? The availability and compatibility of the data required by a given model are of vital importance. If the requisite data are not readily available or are not compatible, they must be collected in the field. Since data collection is usually expensive and time consuming, studying the data requirements of the various models can save time and money.

The output of a traffic model is only as good as the input data. The phrase "garbage in, garbage out" applies here. Factors such as data collection procedures (e.g., manual versus automatic), length of data collection periods, and equipment accuracy directly affect data quality and consequently, the representation of traffic resulting from the model. Quality data will ensure confidence in the results.

Data Coding

How difficult is it to enter the data into the computer? The process of manually entering data in a computer is called coding. Some older models, especially those that migrated from the mainframe environment, have complicated coding schemes. Data must be coded by entering numbers into specific fields (columns) of a "card." The procedure to generate a "deck" of these cards is tedious and time consuming.

[2]If the assumptions stated in a model's documentation are not valid for a specific application, the model should not be used.

Newer models have a separate front-end program to assist in entering and editing data. These programs usually are called data managers or input processors. Some input processors allow the user to enter data interactively by filling in blanks—a method similar to that used in preparing a spreadsheet. After the data are entered, the input processor generates the deck of cards automatically by putting the data in the appropriate fields. Using input processors, the user does not have to know the model's coding scheme; this saves a considerable amount of time.

If more than one model is used, the same data may need to be coded separately for each model. To avoid this problem, *families* of models have been created. A family is a group of models that shares the same coding scheme. Once the data are coded, they can be used with any of the models in the family.

Credibility and Utility of Results

Will this model give me reliable results? Does the model represent the real world? For a model to be useful, the output must produce credible results consistent with the input data. The user must "trust" the model in order to implement the results.

The *credibility* of a model is achieved through testing and validation. Before a model is distributed to the public, it should be validated. Validation is the process of verifying that the model behaves the way it is intended; this process is the responsibility of the software developers. To validate the model, the developers must have sufficient evidence to establish that:

- The transition from the theoretical model to the mathematical model has been made correctly.
- The mathematical and logical relationships are correct.
- The numerical results are accurate.
- The computer program is properly debugged.

To further ensure that the model produces real-world results, some models are field validated. Field validation is the process of comparing the model results to field observations. Validation also can be assisted by comparison to similar models.

Another factor to consider is the *utility* of the output. Is the output easy to interpret? Does it give the measures of effectiveness (MOEs) needed, e.g., delay, travel time, speed? Computer programs often generate substantially more information than people can absorb. Therefore, for the model they run routinely, users should carefully assess the character and extent of the output. In assessing the output's utility, the user should consider:

- Measures of effectiveness.
- Error messages.
- Input echo (e.g., the output includes an automatically produced listing of the input data).
- Graphical output supplements (e.g., time-space diagrams).

Available Models

Described below are some of the models which the FHWA has sponsored over the years. Most of these models are developed under contracts with private consultants. Upon contract completion, the models are delivered to the FHWA for testing, promotion, and distribution.

Signal Optimization Software

The following programs are the most widely used for signal timing optimization. As described below, each has its own particular area of application and signal timing design philosophy.

- **SOAP**. The SOAP program develops fixed-time signal timing plans for individual intersections. SOAP can develop timing plans for six design periods in a single run. It can also analyze 15-minute volume data for up to 48 continuous time periods, and determine which timing plan is best suited for each 15-minute period.

- **PASSER II and MAXBAND**. These programs, known as bandwidth optimization programs, develop timing plans that optimize the through progression band along arterials of up to 20 intersections. Both programs work best in unsaturated traffic conditions and where turning movements onto the arterial are relatively light. PASSER and MAXBAND also can be used to develop arterial phase sequencing for input into a stop and delay optimization model such as TRANSYT-7F.

The latest version of PASSER II features enhanced program output, explicit treatment of permitted left turns, and a menu-driven, graphical input/output processor. It also interfaces with the Highway Capacity Software.

- **TRANSYT-7F and SIGOP-III**. These two programs develop signal timing plans for arterials or grid networks. The objective of both programs is to minimize stops and delays for the system as a whole, rather than maximize arterial bandwidth.

An input processor is distributed with TRANSYT-7F to facilitate data entry on a microcomputer. The latest version of TRANSYT-7F (Release 6) features better treatment of actuated control, a program to aid in calibration, and several other new capabilities.

• **The Arterial Analysis Package (AAP)**. AAP allows the user to easily access SOAP, PASSER II, and TRANSYT-7F to perform a complete analysis and design of arterial signal timing. In a sense, AAP makes SOAP, PASSER II, and TRANSYT-7F a family, since users can access any of the models from a common data base. The package contains a user-friendly forms-display program which enables data to be entered interactively on a microcomputer. Through the AAP, the user can generate an input file for any of the three component programs to quickly evaluate various arterial signal timing designs and strategies. AAP includes an input processor which facilitates entry of data. A 3-day training course on AAP's use is available through the National Highway Institute.

Traffic Simulation Software

As discussed above, simulation models allow the traffic engineer to evaluate various proposed operational improvements before implementing these changes in the field.

• **TRAF-NETSIM**. This program is the latest version of NETSIM, a microscopic simulation model that provides a detailed evaluation of proposed operational improvements on urban networks. TRAF-NETSIM can evaluate the effects of converting a street to one-way operation, adding lanes or turn bays, moving the location of a bus stop, installing a new signal; or determine the operational effects of phasing and timing plans.

Related microcomputer programs are available to assist the user in inputting and analyzing the results of the TRAF-NETSIM simulation. These include NEDIT, a menu-driven input processor, and GTRAF which provides graphic displays of both input and output data (e.g., details of intersection geometrics, highlighting of potential problem areas or "hot spots," animation of simulated traffic flow).

• **CORFLO**. The CORFLO model, formerly called TRAFLO, provides a macroscopic simulation of a corridor containing both signalized intersections and freeways. It also contains a traffic assignment model that can redistribute traffic flows in response to control or geometric changes in the corridor. The model thus serves as a powerful tool in analyzing, for example, alternative traffic management strategies during construction or maintenance activities.

CORFLO currently is being tested by the FHWA; it is also being used as part of a Transportation System Management demonstration project in Seattle, Washington, to evaluate alternatives for managing traffic during a major freeway reconstruction project. GTRAF, the graphics package, will be expanded to interface with CORFLO in the near future. CORFLO will be released to the public in late 1989.

• **FRESIM**. FRESIM performs detailed simulation of traffic flow on freeways, and, as such, may be considered the freeway version of NETSIM. The model is capable of analyzing both surface streets and freeways at a level that is sensitive to both detailed geometrics (such as grade and curvature) and detailed traffic control (such as ramp metering). Measures of effectiveness include travel time, delay, lane changes, and fuel consumption. FRESIM is currently under development.

• **ROADSIM**. ROADSIM performs microscopic traffic simulation of two-lane roads. It is capable of analyzing the effect of volume changes (traffic mix and volumes) and geometric changes (grade, curvature, passing zones, sight distances, etc.) on traffic flow. MOEs include travel time, delay, platooning, and number of passes attempted and completed. The ROADSIM package includes a user-friendly interactive input processor.

Other Software

Included in this category are software programs for traffic data management, system integration, and capacity analysis.

• **The Integrated Traffic Data System (ITDS)**. The ITDS is not a model, but rather a sophisticated data management system that enables traffic engineers to store, maintain, and update traffic network data from a central data base. The ITDS is an input processor. Data can be entered and displayed both graphically and through menu-driven input screens. The ITDS can then be used to create input data sets from the same data base for TRANSYT-7F, PASSER II, TRAF-NETSIM, and other models. Thus, in a sense, ITDS makes these models a family. (*4*)

The ITDS program is aimed at those who wish to actively maintain a central data base of traffic information and use multiple optimization and simulation programs to analyze the same signalized network.

• **The Traffic Software Integrated System (TSIS)**. The TSIS is a utility package that enables various traffic software packages to be used within a single, user-friendly, menu-driven environment. As with most integrated systems, the components of TSIS are individual systems which must be acquired separately. Using the ITDS and NEDIT input processors, TSIS can interface, among others, with the TRAF family of simulation models, the AAP models, and the GTRAF output processor. With TSIS, the user could generate and manage traffic data using ITDS as an input processor, run the desired traffic model, and, if applicable, study the results using GTRAF. Figure 1 shows TSIS components and their relationship.

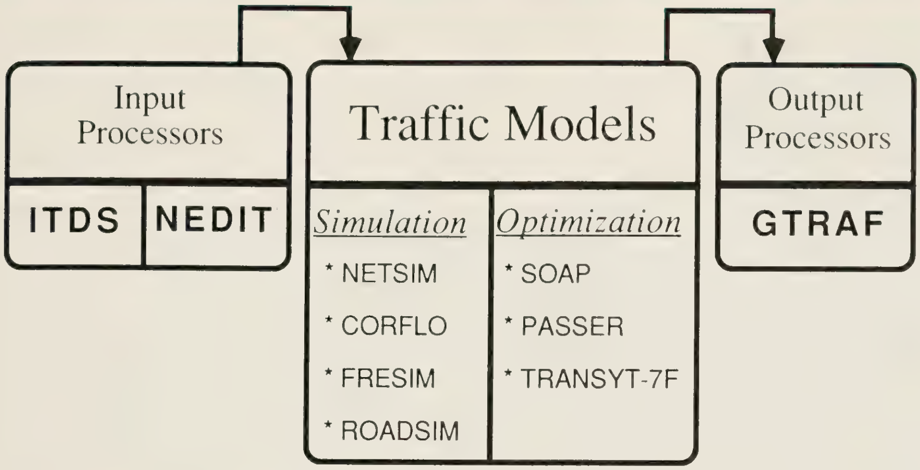


Figure 1.—TSIS components and their relationship.

• **Highway Capacity Software (HCS).** HCS is a tool that greatly increases productivity and accuracy. Replicating the procedures described in the *1985 Highway Capacity Manual*, HCS is designed to be used in conjunction with the *Manual*, not as a replacement for it. (*5*) The *Manual* may be acquired from the Transportation Research Board (tel: 202–334–2972) or the Institute of Transportation Engineers (tel: 202–554–8050).

Over 2,300 copies of the HCS have been distributed to date. It has generally been accepted as faithfully replicating all 1985 *Manual* procedures. There are several other highway capacity software packages available, both in the public domain and proprietary. These packages generally include some of the procedures contained in the HCS as well as certain new features. For more information, contact the software distribution centers listed below.

For More Information

These, and many other useful traffic engineering programs, can be obtained from software distribution centers. For catalogs and ordering information, call or write:

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References

(*1*) "Application of Traffic Simulation Models," Publication No. FHWA–TS–82–207, Conference Proceedings, Federal Highway Administration, Washington, DC, March 1982.

(*2*) "Handbook of Computer Models for Traffic Operations Analysis," Publication No. FHWA–TS–82–213, Federal Highway Administration, Washington, DC, December 1982.

(*3*) "Guidelines for Model Evaluation" (Exposure Draft), PAD–79–17, U.S. General Accounting Office, Washington, DC, January 1979.

(*4*) Alberto J. Santiago. "ITDS: A Data Base-Driven Interface to Traffic Models Using a Microcomputer," *Public Roads*, Vol. 49, No. 4, March 1986.

(*5*) *1985 Highway Capacity Manual*, Special Report 209, Transportation Research Board, National Research Council, Washington, DC, 1985.

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Corrosion and Weathering Steel Bridges

by Terry D. Halkyard

Introduction and Background

Weathering steel has been in use in highway bridges since 1964. To date, over 2,000 weathering steel structures have been erected all across the country. For the most part, these structures have performed well; however, some are deteriorating badly. The Michigan Department of Transportation considered its experience with weathering steel so unsatisfactory that in 1980 it issued a statewide ban on the use of weathering steel in the unpainted condition. More recently, concerns have arisen regarding design parameters for weathering steel structures based on research into the fatigue resistance of the material.

To provide a mechanism by which interested participants could discuss the pros and cons of weathering steel, the Federal Highway Administration (FHWA) sponsored the Forum on Weathering Steel for Highway Structures in Alexandria, Virginia, on July 12 to 13, 1988. The Forum's content and format were determined by a steering committee whose membership—to ensure that the views of all interested parties were represented adequately—included representatives of steel manufacturers and fabricators as well as Federal and State governments.

Forum speakers and topics focused on both good and bad experiences with weathering steel in order to educate participants on the correct use of this material. Some speakers were chosen to discuss locations and design details affecting (either positively or negatively) the successful use of weathering steel. Other speakers were chosen to stimulate discussion on the issue of fatigue resistance of unpainted weathering steel; a third group of speakers were selected to discuss the maintenance of weathering steel structures.

The Forum on Weathering Steel for Highway Structures was attended by over 130 participants representing the FHWA, State highway agencies, the Transportation Research Board, steel and coatings manufacturers, steel fabricators, trade associations, public utilities, and consulting engineers. The Forum sessions were organized so that presentations of interest to the entire group were made on the first day. On the second day, attendees could participate in sessions on either weathering steel design or maintenance considerations. The group was reassembled at the end of the second day for a brief summary session.

Design Considerations

Certain problem areas in and suggestions for improvement of design practices were mentioned repeatedly during the forum. These included:

Expansion Joints

Expansion joints are a major cause of problems in all types of structures. Leaking expansion joints pose a particular hazard for unpainted weathering steel structures, since they permit chloride-laden runoff from deicing chemicals direct access to the weathering steel superstructure elements. Chlorides are a major contributor to the accelerated corrosion of steel members. (*1*)[1]

In addition to deicing chemicals, dirt, sand, and other debris pass through leaking expansion joints. These materials accumulate on the flanges of the superstructure members as well as on diaphragms and around the bearings. Combined with moisture coming through the joints, the debris forms an atmosphere conducive to corrosion. If chlorides are also present, the environment becomes tremendously corrosive to the steel (figure 1).

Building jointless bridges, partially painting steel members, and simplifying expansion joint details were three identified measures for consideration in reducing the corrosion problem at expansion joints. The Tennessee Department of Transportation, a pioneer in the development of jointless steel bridges, made a presentation on its experience; this included discussion of a retrofit to an existing bridge with significant joint leakage problems to eliminate both the joint and the leak. (*2*)

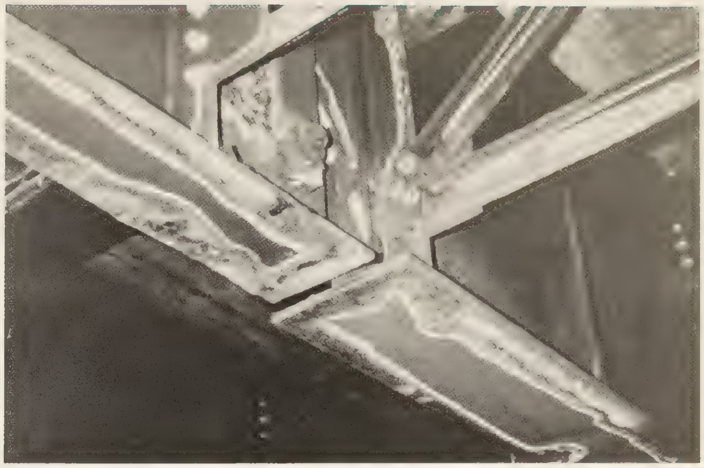

Figure 1.—A leaking expansion joint allowed road salts to deposit on these steel bridge members.

Figure 2.—Weathering steel members painted near an expansion joint.

Several States reported use of coatings on superstructure steel near expansion joints. Depending on the particular State's policy, these partial paintings are performed for distances of 5 to 15 ft (1.5 to 4.6 m) on each side of bridge deck joints (figure 2).

Scuppers

Many scuppers have been detailed on bridge plans with little regard to their design or effectiveness. Forum participants pointed out that some deck drainage systems installed in bridges can best be described as plumber's nightmares with numerous joints, bends, and shallow pipe slopes allowing debris to accumulate and block the passage of water. In one unusual instance, a construction error led to the bridge deck drainage being released directly to the interior of a steel box girder.

[1]Italic numbers in parentheses identify references on page 16.

Although numerous speakers identified scuppers as problem areas, only two speakers suggested to reduce or eliminate scuppers from bridge decks. This coincided with ideas presented in Dr. Dah-Cheng Woo's recent *Public Roads* article "Bridge Drainage System Needs Criteria." (*3*) The article presents design procedures which demonstrate that, for many bridges, a deck drainage system is not required. A gutter scupper requirement nomograph indicates that in some circumstances, scupper spacing may be increased to as much as 1,400 ft (426 m) (figure 3).

Design Details

Many miscellaneous considerations were brought up under this general topic. Avoiding water- and debris-trapping details was one such consideration (figure 4). For example, when there is concern that water may travel along the top of a bridge member's bottom flange and become trapped at the intersection with a vertical stiffener, copes are sometimes used to permit the water to pass through. A hole is left at the corner where the stiffener, web, and bottom flange meet by cutting off the corner of the stiffener. These holes, however, are easily plugged by debris; consequently, water is not only eventually trapped, but is retained against the steel for extended periods because of the debris' moisture-holding characteristics. A simple alternative in many instances would be to place the vertical stiffener at an angle other than 90° to the web so that the top of the bottom flange becomes self draining.

Another consideration is pigeon access to the interior of box girders. Nests, feathers, dead birds, eggs, and droppings not only hold moisture against the steel, but also make a close inspection of the steel very difficult (figure 5).

Environment

Many questions were raised as to just what constitutes a good or bad environment for using weathering steel. Numerous examples of each were provided. Utility companies, for example, encountered high corrosion

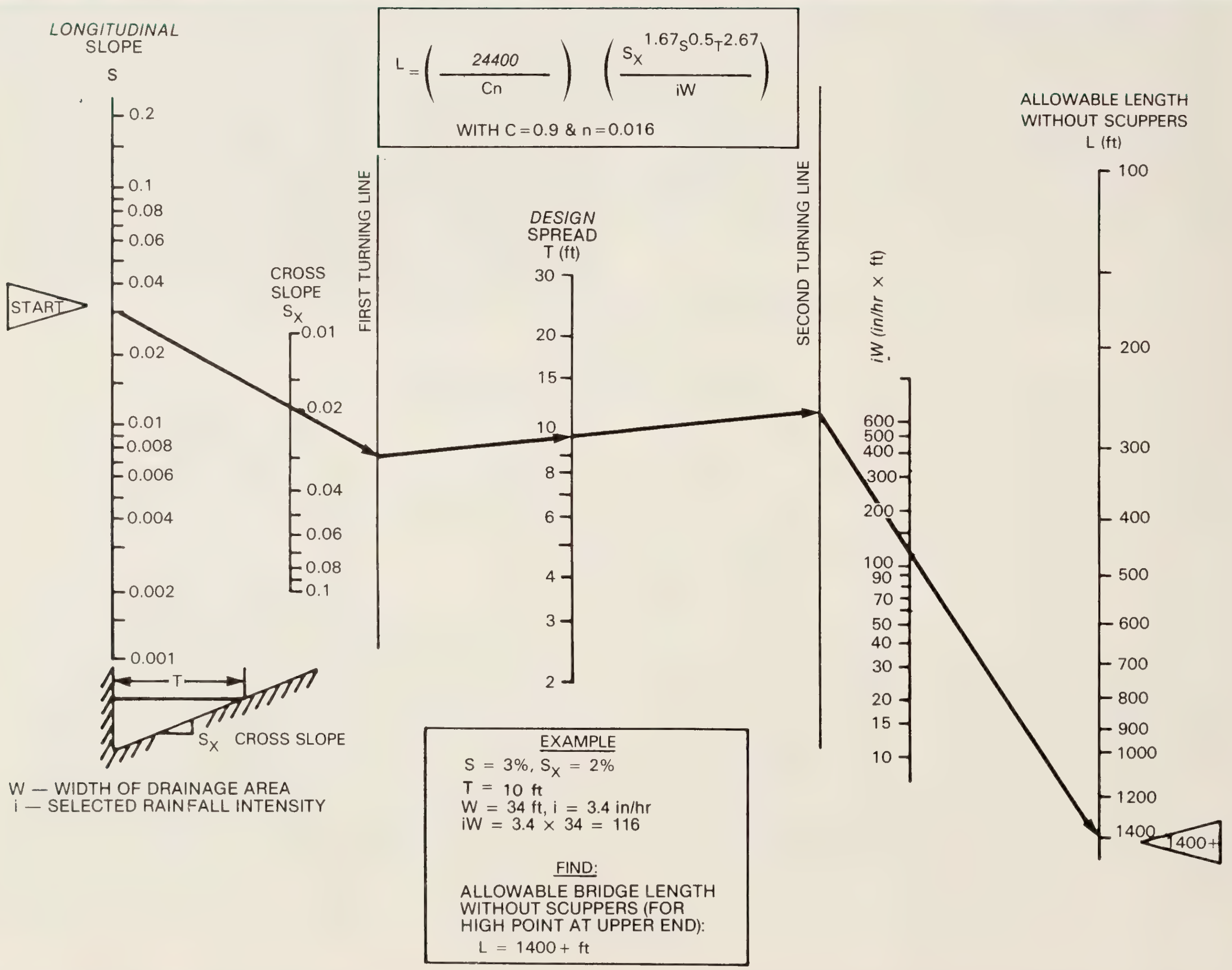

Figure 3.—Gutter scupper requirement nomograph.

Figure 4.—These stiffeners can trap water.

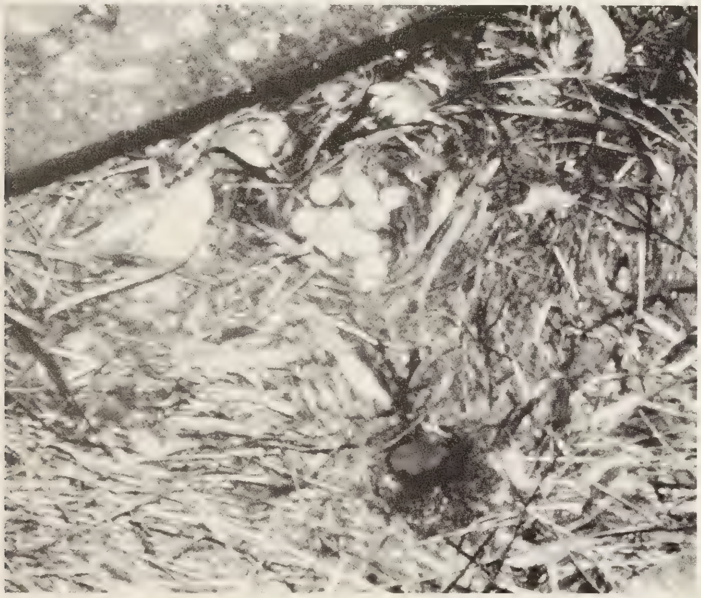

Figure 5.—Bird nest near a weep hole in a steel box girder bridge.

rates on weathering steel transmission towers when thick vegetation was permitted around tower legs. Presumably, the elevated humidity beneath the thick growth contributed to these accelerated corrosion rates. In Louisiana, extremely high corrosion rates of weathering steel were reported in locations where the high local humidity, accompanied by typical regional temperature changes, caused water to condense onto the steel surfaces regularly. However, other parts of the country (e.g., Washington DC) regularly experience high humidity without any noticeably elevated occurrence of accelerated weathering steel corrosion.

The depressed roadway—or so-called "tunnel condition"—was defined in a 1982 American Iron & Steel Institute report as "an environment in which a spray of roadway water thrown up by high-speed traffic is confined to a restricted volume by vertical adjoining abutments and/or embankments and the overpassing bridge." (*4*) The amount of salt spray affecting a bridge depends on several factors, including vertical adjoining abutments, how far off the underpass roadway the abutments are, the extent to which the abutments are sloped, the length of the depressed condition along the underpass roadway, and the height of the underpass opening. Obviously, any given structure site involving a depressed roadway will possess some of these factors to a varying degree, but there has been little guidance available to designers to aid them in deciding if conditions are sufficient to result in a tunnel condition.

Knowledge about acceptable levels of airborne chlorides also is lacking. The point is made frequently that weathering steel should not be used in coastal areas. However, what determines the limits of a coastal area? Distance alone is not the answer, since prevailing winds will cause airborne salts to be carried farther inland along the West Coast than the East. Air can be tested and geographic and weather patterns examined to determine the likelihood and extent of airborne chlorides, but guidance is needed to establish the chloride levels at which unpainted weathering steel should no longer be considered.

Maintenance Considerations

There are some maintenance activities that can be performed to reduce the likelihood of excessive corrosion in weathering steel structures. These include:

Water Flushing

Periodic flushing out of expansion joints and scuppers helps to ensure that they operate as intended and helps to keep water away from steel members and bearings. Any accumulated debris, whether caused by birds, leaky joints or scuppers, or high water—that accumulates on weathering steel surfaces—should be flushed off. Most participants felt it was ineffective to flush entire weathering steel surfaces since the water was unlikely to remove chlorides from beneath or within rusted layers.

Cleaning and Painting of Steel

Cleaning and painting the bridge steel near expansion joints is believed by many to be an effective method of reducing excessive corrosion at these problem points. The FHWA currently is conducting research to validate proposed substrate cleaning and surface preparation methods and to evaluate coatings for contaminated weathering steel substrates.

Summary

The following points summarize key issues brought out during the Forum:

- Weathering steel is an important construction material which, with proper use, has its place in the bridge construction industry.
- Engineers must be educated as to the proper uses of weathering steel.
- Further research must be performed to provide guidance on the tunnel condition.
- Further research is needed to determine threshold levels for adverse effects due to airborne chlorides.

References

(*1*) N.D. Burke and J.B. Bushman. "Corrosion and Cathodic Protection of Steel Reinforced Concrete Bridge Decks," Publication No. FHWA–IP–88–007, Federal Highway Administration, Washington, DC, December 1988.

(*2*) Edward P. Wasserman. "Jointless Bridges With Weathering Steel," Presented at the *Forum on Weathering Steel for Highway Structures*, Federal Highway Administration, Washington, DC, July 1988.

(*3*) Dah-Cheng Woo. "Bridge Drainage System Needs Criteria," *Public Roads*, Vol. 52, No. 2, Federal Highway Administration, Washington, DC, September 1988.

(*4*) American Iron & Steel Institute. "Performance of Weathering Steel in Highway Bridges—A First Phase Report," Publication No. PS–288–0782–5M–SS, American Iron & Steel Institute, Washington, DC, August 1982.

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Expert System for Pavement Maintenance Management

by Hamid Aougab, Charles W. Schwartz, and James A. Wentworth

Introduction

Maintenance and preservation of the Nation's highway networks is a major problem facing the highway community today. Most of our highway network was built decades ago, and the current rate of pavement deterioration—due to materials used, traffic and climate conditions, age, etc.—is exceeding the rate of repair. Over the last 40 years, investment in the U.S. highway system exceeded $1 trillion. Annual maintenance costs for this investment were estimated in 1976 by the Federal Highway Administration (FHWA) at $6 billion with forecast increases of about $300 million per year. In fact, maintenance of the total network cost State and local governments in 1984 approximately $15 billion annually: this was much higher than was previously predicted. (*1*)[1] Overall, the FHWA has reported that actual maintenance expenditures have increased 195 percent from 1972 to 1985. Nevertheless, 42 percent of the total road mileage was in deteriorating or deteriorated condition in 1985. (*2*)

Unfortunately, maintenance work is neither as exciting nor as visible as new construction and therefore lacks political prestige and priority. The enormity of the costs and the lack of adequate finances mandate the development of systematic approaches and programs for careful and appropriate funds allocation. This approach to pavement management should provide data

[1]Italic numbers in parentheses identify references on page 23.

on current and future pavement conditions and identify logical methods for evaluating relevant repair alternatives within budgetary constraints. Unfortunately, the development of sophisticated monitoring programs is costly and many highway authorities do not have sufficient resources to develop or implement optimal programs. Thus, there is a need for improved pavement maintenance and rehabilitation systems that can function with incomplete and/or poor quality data.

Many of the components of pavement maintenance management are complex and poorly structured and thus make algorithmic computations difficult. Pavement maintenance management really requires the knowledge and expertise of experienced pavement engineers. Expert systems offer great potential as a tool for addressing pavement maintenance management needs. An expert system can systematically formalize and utilize the thought processes and experience of experts as well as incorporate algorithmic computations where appropriate.

Overview of Expert Systems

Expert systems are computer programs designed to include a simulation of the reasoning and decision-making processes of human experts. In other words, they are computer programs that incorporate the knowledge, heuristics (rules of thumb), and reasoning processes of human experts; interact with users in evaluating a situation; and aid users in decision making or problem solving. Under ideal conditions, an expert system would contain the exact knowledge and reasoning processes of a human expert and would thus reach, for a given problem, the same conclusions/solutions as the human expert.

Expert systems differ from conventional programs in that they deal with knowledge manipulation, whereas conventional programs are limited to fixed and precisely defined algorithms and data. In a conventional program, the operations never vary: the problem-solving sequence and procedures are predetermined by the programmer, and the program will not run if any element is missing. In contrast, an expert system is divided into a generalized solution strategy component—the inference engine—and the knowledge base. The power of the generalized control strategy allows the expert system to operate with uncertain and incomplete data.

The inference engine is the problem-solving component of the expert system. It combines the user's inputs and responses to questions with the information and rules contained in the knowledge base to develop a proposed solution or identify additional information which may be needed.

The knowledge base contains the facts and rules (or other representations) that capture the experts' knowledge and enable the expert system to do useful work. The benefits of a knowledge base are:

- The knowledge base is separate from the program's control strategies and is thus much easier to change and maintain.
- The knowledge base is usually represented by rules and facts and is much more readable and understandable than knowledge that, in the traditional program, is encoded.
- The knowledge base includes heuristics—the assumptions, rules of thumb, judgment, and reasoning (i.e., the experience) of the expert—not the algorithms and data of conventional programs.

In addition to the inference engine and knowledge base, expert systems usually contain other components, such as the knowledge acquisition subsystem, the explanation subsystem, and the user interface.

The knowledge acquisition subsystem helps translate the knowledge obtained from the human expert into the internal format of the knowledge base. The explanation subsystem helps the user understand the expert system's logic, actions, and reasoning. It allows the user to question the system at any time about its problem-solving methods, as well as the need for and use of information. The user interface expedites communication between the user and the expert system. With this interface, the user can request explanations, give information, check system performance and progress, and redirect problem-solving reasoning processes. Interface is accomplished through user-friendly menus, lists, graphics, natural language queries, and, in the future, pictorials or images.

Various tools are available for developing expert systems. These range from the Artificial Intelligence (AI) languages such as LISP and PROLOG to conventional languages like PASCAL or C and to knowledge engineering tools and shells. AI languages offer the most capability and flexibility, but they also require substantial programming effort and specialized hardware. Conventional languages offer good capability, but have limited flexibility and are difficult to maintain. Knowledge engineering tools offer good capability, flexibility, and ease of maintenance, but often have specific hardware requirements. Finally, shells—while often limited in knowledge representation schemes, power, and flexibility—are easy to work with, and allow the developer to concentrate on the technical aspects of development, rather than on the programming. In addition, they are generally PC compatible. The knowledge engineering tools and shells vary greatly in cost, power, and useability with little relationship among the three.

Expert Systems Applications in Pavement Maintenance Management

There are several reasons to develop pavement maintenance management systems. First, they provide a general framework for maintaining pavements at both network and project levels. Second, maintenance management systems can assist highway agencies in determining the most appropriate maintenance and/or rehabilitation strategy and in prioritizing projects while taking budgetary constraints into account. Additional features include the ability to ascertain the causes of pavement deterioration, predict future problems, and help select the solution with the most potential benefits.

There are several existing expert systems in different stages of development which attempt to tackle the problems and costs associated with the maintenance and rehabilitation of roadway surfaces.

ROSE was developed for the Ontario Ministry of Transportation and Communication so as to prioritize a multitude of asphalt concrete pavement sections for routing and sealing operations in cold areas. ROSE has two versions, an interactive version using the EXSYS shell and an automatic version in FORTRAN. The latter was applied to 900 pavement sections representing 4,474 mi (7,200 km) of road. Although ROSE has been tested in several cases, its developers recognize that applying ROSE in other jurisdictions would be difficult, if not completely inadvisable. (*3*)

EXPEAR, an expert system for concrete pavement evaluation and rehabilitation, was developed under FHWA sponsorship at the University of Illinois at Urbana-Champaign to help State highway engineers in evaluating and rehabilitating high

Pavement sections with high alligator cracking.

volume (Interstate) concrete pavements. EXPEAR uses information provided by pavement engineers to determine the type and cause of distress so that an appropriate rehabilitation strategy can be selected. The system was originally developed as a prototype using the shell INSIGHT2+, but has been rewritten in PASCAL. EXPEAR addresses jointed reinforced concrete, jointed plain concrete, and continuously reinforced concrete. (*4*)

SCEPTRE, a surface condition expert system for pavement rehabilitation, was developed by Ritchie, et al., to assist highway engineers in determining flexible pavement rehabilitation strategies. (*5*) The system was developed to address State-maintained pavements; it reflects local conditions in Washington State and uses distresses compatible with those used in Washington's pavement management system. SCEPTRE encompasses 10 basic strategies which, when combined, yield a total of 24 rehabilitation alternatives.

Many other systems are still in the development and implementation phases. One of these, PRESERVER, is a demonstration prototype system developed for the Ontario Ministry of Transportation and Communication to help field engineers and supervisors analyze pavement distress data and propose routine maintenance strategies. (*6*) PRESERVER is similar to SCEPTRE except that its focus is routine maintenance rather than major rehabilitation. Alternative maintenance procedures are the focus of an expert system being developed in France; another system, being planned at Purdue University, will be capable of considering several failure phenomena and predicting pavement performance with more accuracy and consistency than existing conventional methods. Finally, at the Massachusetts Institute of Technology, a system currently is being created to select appropriate pavement maintenance and rehabilitation techniques.

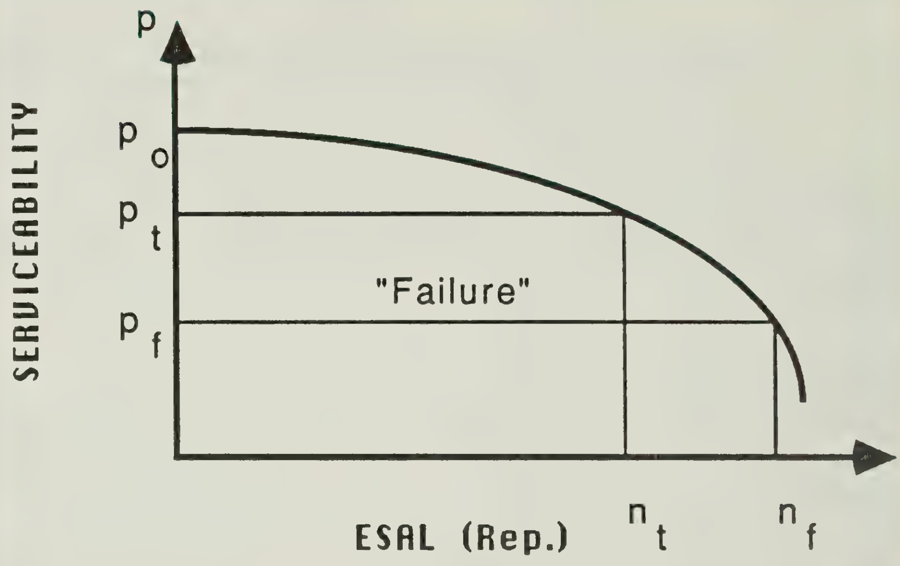


Figure 1.—Serviceability concept.

To summarize, most of these expert systems are still under development and have not, as yet, advanced beyond the early prototypes. ROSE, EXPEAR, and SCEPTRE are the only systems in this field which have reached an advanced stage of development; of these, SCEPTRE is the only one which deals with the maintenance and rehabilitation of flexible pavements.

PAMEX: Expert System for Maintenance Management of Flexible Pavements

The PAMEX system builds on the pavement condition indicators devised by Jugo and the decision tree knowledge formulation which he subsequently created. (*1*) Jugo's pavement condition indicators combined information obtained from ride quality, structural condition, and functional performance surveys. These condition indicators were then used to develop and refine a sequence of decision trees for evaluating pavement performance, identifying pavement problems and their probable causes, and recommending appropriate corrective measures. The selection of pavement condition indicators was based upon two main objectives: the common use of the parameter by local highway agencies and the ease of determining the parameters. Included among the selected pavement indicators are the widely known and used present serviceability index (PSI), pavement condition index (PCI), and skid resistance. Other parameters also are included to refine the formulation of the decision system.

One of these additional indicators is the damage level (DL), which indicates the percentage of consumed life of the pavement at any given time. During its design life, a pavement structure will sustain a certain number of load repetitions. Accumulation of load repetitions causes pavement serviceability (defined here by PSI) to deteriorate (figure 1). A "failure" results when the pavement condition reaches a minimum PSI value, designed as p_f. This failure level is subjective and may vary from one

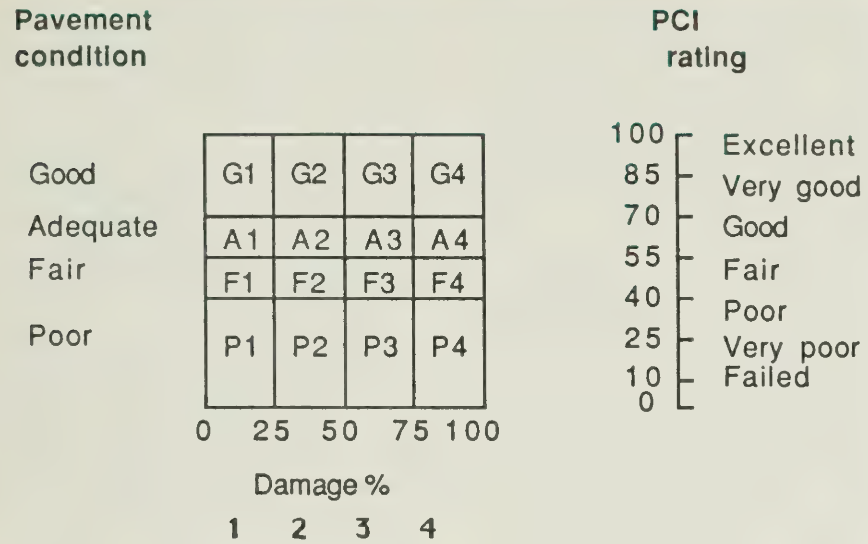


Figure 2.—General performance indicator (GPI).

situation to another depending upon the highway's importance and intended use. Once the p_f is known, the number of repetitions to "failure" n_f can be estimated. If at any point in time the number of Equivalent Single Axle Load (ESAL) repetitions n_t is estimated, the damage can be determined as:

$$DL(t) = n_t / n_f$$

and the remaining life (RL) as:

$$RL(t) = 100\% - DL(t)$$

The American Association of State Highway and Transportation Officials' (AASHTO) "Guide for Design of Pavement Structures" includes five different methods for evaluating the damage (or remaining life) factor, among these, three are used in the expert system. They are: the Time Approach; the Serviceability Approach; and the Traffic Approach.

A primary derived parameter in Jugo's decision tree system is the general performance indicator (GPI), which is defined for a given PSI range as a function of the PCI and the damage of the section under consideration. This parameter provides information about the shape of the pavement deterioration curve and thus alerts the system to anomalous performance requiring special maintenance and rehabilitation strategies.

The GPI is also used in combination with the PSI at the major branch points in the decision tree logic. In developing the GPI, the spectrum of pavement performance was divided into 16 regions based upon a subdivision of PCI and damage level into 4 intervals each (figure 2). (*1*)

Another derived parameter in Jugo's system is the deterioration cause indicator (DCI), which provides insight into the cause of pavement deterioration. Pavement deterioration can be associated with structural failure, weather severity, construction quality, or a combination of all of these. The DCI parameter is used to trigger special maintenance and rehabilitation alternatives whenever one of these factors is the major cause of deterioration. In reality, determining the deterioration cause requires experience and engineering judgment. In Jugo's system, the DCI is determined by using empirical weighting factors based upon engineering judgment for each of the PCI distress categories.

Jugo developed secondary parameters for use in those special cases where primary indicators failed to conclusively indicate the cause of the specific pavement problem and/or its solution. There are three secondary indicators: the cracking indicator, the deformation indicator, and the nonpavement related indicator. Secondary indicators are determined using various combinations of deduct values for individual PCI distress types. The indicators estimate the proportion of the particular distress mode with respect to the total distresses in the pavement section.

In addition, deduct values for individual distresses are occasionally used to trigger special situations and/or to aid in the diagnostic process in Jugo's system.

Once the pavement conditions are defined and any problems diagnosed, the system generates a set of feasible maintenance and/or rehabilitation alternatives. These strategies are selected from a set of 30 actions and their combinations, yielding a total of 160 different alternatives. Strategies are divided into two categories: (1) routine maintenance alternatives, which include localized repairs; and (2) major maintenance alternatives, which include surface treatments, overlays, surface recycling, structural recycling, and reconstruction. The alternatives are presented to the system user as individual and/or combined strategies.

As a first step in reaching a particular strategy, PSI is used to divide the search domain into three main branches:

- PSI > 2.8, representing good pavement conditions where no major maintenance or rehabilitation is required as long as the pavement surface is safe.

- PSI 2.8 to 2.2, representing acceptable pavement conditions where major maintenance and/or rehabilitation are not required but might be advantageous.

- PSI < 2.2, representing poor pavement conditions where major maintenance and/or rehabilitation are required to bring pavement condition to an acceptable level.

From this point, the GPI is used to direct the search along a particular path, with the other secondary indicators used to assist this search in the final, detailed stages.

The prototype expert system has been implemented in a microcomputer-based program using a combination of the expert system shell EXSYS for the knowledge representation and inference components and various algorithmic computation modules for determining the quantitative parameters used in the decision-making process. (*7*) The knowledge base consists of a set of 300 rules covering the search domain.

The EXSYS shell supports many facilities to enhance the user input/output process. These facilities include context-sensitive help screens that explain the different qualifiers, their definitions, and their evaluation. EXSYS also allows the user to ask, at any time, about the logic chain the system is trying to apply and to request to see the rules. This is a powerful feature, since it provides the user with an understanding of the reasons behind the selected conclusions.

Validation and System Enhancements

One of the most important aspects in developing an expert system is system validation. A review of the literature on existing systems and those under development in pavement engineering suggests that the validation process has not been stressed: this is a major shortcoming of most of these systems. For PAMEX, an extensive validation program is being conducted involving workshops and follow-up efforts with experts and end users. Field cases are being analyzed and system recommendations compared against the maintenance and rehabilitation strategies selected and/or planned by responsible local highway agencies.

Last spring, the FHWA convened a workshop of experts and end users from State highway agencies and the FHWA to review and critique the prototype expert system and provide input to enhance the decision tree structure and knowledge base. Workshop conclusions suggested several revisions to the decision tree structure:

1. Add a safety check in every branch of the decision trees regardless of the pavement section's state of deterioration.
2. Modify the table of weighting factors for the DCI evaluation.
3. Modify the list of maintenance and rehabilitation strategies.
4. Revise the use of the damage level and the intervals of the GPI to make the system better reflect actual practice.
5. Expand the end-node rules for all branches in the decision trees to reduce the number of possible solutions and/or to further categorize them (i.e., short-term, low-cost, long-term, etc.).
6. Include certain optional items such as using the system when damage data are not available, customizing the PSI intervals for each State or agency, etc.

Of the above recommendations, items one, two, three, and six were readily implemented. However, additional direction was required from the workshop experts for items four and five. This was accomplished through individual meetings and a second workshop held in the autumn of 1988. Based on the results of the second workshop, the expert system was modified so the user could select between two modes of operation. The first of these uses estimated pavement condition and damage level (figure 2); the second uses simplified inputs based on estimated pavement condition.

When the six revisions suggested had been implemented, field evaluation of the system was begun. Several more accomplishments are anticipated during and following field evaluation, including:

- Enhancement of the knowledge base (including the parameters considered and their interrelationships).
- Evaluation of the logic used in developing the decision trees.
- Development of new heuristics and the selection of maintenance and rehabilitation strategies. Refinement of the heuristics will be made based on inputs from experts and typical end users—i.e., local highway engineers and officials.

Conclusions

Field evaluation of the PAMEX system is not yet completed. However, a number of conclusions can be drawn from the process of developing PAMEX and early indications from field trials:

- It is possible to develop an expert system in a complex technical area using available development tools.
- Expert systems offer great potential in assisting highway professionals. These systems can perform many tasks more efficiently than is possible with current tools and engineering aids.
- Pavement maintenance management is an ideal application area for expert systems technology; this gives PAMEX a high probability of acceptance when it is fully developed and can operate as intended.
- State workshop participants have indicated that PAMEX will be valuable to local agencies which lack the in-house staff or financial resources to utilize conventional pavement management systems.
- System verification and validation are complex issues; at present, there are no prescribed methods of accomplishing these except by extensive field testing.

• In the future, expert systems will have a major role as training aids in pavement management and other areas of highway engineering and management.

References

(*1*) A. Jugo. "Development of a Rehabilitation Methodology Approach Hierarchy for Flexible Pavements," Ph.D. dissertation, University of Maryland, College Park, MD, 1986.

(*2*) *Our Nation's Highways, Selected Facts and Figures*, Federal Highway Administration, Washington, DC, 1987.

(*3*) J.J. Hajek, et al. "ROSE: A Knowledge-Based Expert System for Routing and Sealing," In *Second North American Conference on Managing Pavement, Proceedings*, Volume 2, Toronto, Canada, 1987.

(*4*) K.T. Hall, et al. "Development of an Expert System for Concrete Pavement Evaluation and Rehabilitation," In *Second North American Conference on Managing Pavement, Proceedings*, Volume 2, Toronto, Canada, 1987.

(*5*) G.S. Ritchie. "Applications of Expert Systems for Managing Pavements," In *Second North American Conference on Managing Pavement, Proceedings*, Volume 2, Toronto, Canada, 1987.

(*6*) C. Haas and H. Shen. "PRESERVER: A Knowledge-Based Pavement Maintenance Consulting Programmer," In *Second North American Conference on Managing Pavement, Proceedings*, Volume 2, Toronto, Canada, 1987.

(*7*) H. Aougab, C.W. Schwartz, and J.A. Wentworth. "Expert System for Management of Low Volume Flexible Pavements," Paper presented at the *Fifth Conference, Computing in Civil Engineering: Microcomputers to Supercomputers*, 1988.

Bibliography

Andriole, S.J., editor. *Applications in Artificial Intelligence*, Petrocelli Books, Inc., Princeton, NJ, 1985.

Avron, B. and E.A. Feigenbaum. *The Handbook of Artificial Intelligence*, Vols. 1 and 2, William Kaufmann, Inc., Los Altos, CA, 1987.

Hayes-Roth, F., D.A. Waterman, and D.B. Lenat. *Building Expert Systems*, Addison Wesley, Reading, MA, 1982.

Hendrickson, C.T. and B.N. Jason. "Expert System and Pavement Management," In *Second North American Conference on Managing Pavement, Proceedings*, Volume 2, Toronto, Canada, 1987.

Highway Statistics—1986, Publication No. FHWA-PL-88–002, Federal Highway Administration, Washington, DC, 1986.

Kostem, C.N. and M.L. Maher, editors. *Expert Systems in Civil Engineering*, American Society of Civil Engineers, New York, NY, 1986.

Nagy, T., D. Gault, and M. Nagy. *Building Your First Expert System*, Ashton-Tate, Torrance, CA, 1985.

Tandon, R.P. and K.C. Sinha. "An Expert System to Estimate Highway Pavement Routine Maintenance Work Load," Transportation Research Board Annual Meeting, Washington, DC, 1988.

Winston, P.H. and R.H. Brown. *Artificial Intelligence: An MIT Perspective*, Vols. 1 and 2, MIT Press, Cambridge, MA, 1979.

Hamid Aougab is an engineer/systems analyst with STATCOM, Inc. Before joining STATCOM, Inc., he spent a year as a student in the Graduate Research Fellowship (GRF) program at the Federal Highway Administration (FHWA) and worked for SRA Technologies Inc. Mr. Aougab is a Ph.D. student in civil engineering at the University of Maryland, College Park, MD.

Dr. Charles W. Schwartz is an associate professor in the Civil Engineering department at the University of Maryland, College Park campus. His areas of interest are numerical analysis, computer applications in engineering and expert systems.

James A. Wentworth is a highway engineer and manager of the Advanced Implementation Methods Facility, Office of Implementation, Federal Highway Administration. The Facility evaluates new technology for its potential in applications and training. Guidance is then provided to the FHWA Headquarters staff. Before joining the FHWA in 1972, Mr. Wentworth spent 11 years in private industry as an engineer.

Recent Research Reports You Should Know About

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

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

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

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

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

Measuring Pedestrian Volumes and Conflicts, Vol. I: Pedestrian Volume Sampling, Publication No. FHWA–RD–88–036 and Measuring Pedestrian Volumes and Conflicts, Vol. II: Accident Prediction Model, Publication No. FHWA–RD–88–037

by Safety Design Division

This report presents the findings, conclusions, and recommendations of the study conducted to develop a model to predict pedestrian volumes using small sampling schemes and to investigate whether there is a relationship between pedestrian conflicts with motor vehicles and pedestrian accidents. This research produced four pedestrian volume prediction models (i.e., 1-, 2-, 3-, and 4-hour models) using 5-, 10-, 15-, and 30-minute volume counts. The volume counts best predicted the hour and multi-hour volumes when sampled at the midpoint of the sampling period. A validation study was conducted to determine the level of accuracy of the models. Recommendations for further research are suggested to investigate the validity and reliability of the developed models using data from other cities.

Data on pedestrian/motor vehicle conflicts were gathered at intersections in Washington, DC and Seattle, Washington. Volume data for pedestrian and vehicular traffic were also collected. A methodology was developed for relating pedestrian volumes and conflicts to the number of pedestrian/motor vehicle accidents in a city. This relationship varies from one city to another. Using the methodology developed in this effort, these relationships can be determined for other cities. This information can be used to predict pedestrian accident locations and to prioritize locations for safety improvements for pedestrians.

These publications may only be purchased from the NTIS. (Vol. I: PB No. 89–117014/AS, Price code: A07; and Vol. II: PB No. 89–117022/AS, Price code: A06.)

Trends in Highway Information, Publication No. FHWA–RD–88–055

by Traffic Safety Research Division

The publication provides an evaluation of the quantity, quality, and availability of traffic accident and other safety-related data and their effects on the ability of Federal, State, and local governments to successfully perform highway safety missions. Practices in the collection, processing, and use of accident, traffic, and roadway inventory data in a sample of States and local jurisdictions are reviewed in terms of their effect on highway safety planning, implementation, and evaluation. The study notes the increasing use of microcomputers, the increased amount and quality of traffic volume and roadway inventory data, and the integration of traffic, roadway, and accident data bases. Other findings include reduced reporting of property-damage-only accidents, increased numbers of tort liability claims, insufficient local data in State files, level of police training and inter-agency coordination, deficient local traffic and roadway inventories, and errors in the use of highway location reference systems. The study contains recommendations for accommodating and/or reversing some of these practices.

This publication may only be purchased from the NTIS. (PB No. 89–133359/AS, Price code: A04.)

Literature Review Summary Examination of Truck Accidents on Urban Freeways, Publication No. FHWA–RD–88–167

by Safety Design Division

This report summarizes a review of the literature relating to accidents involving large trucks in the United States. The review was conducted to determine what data on large truck accidents existed and whether it was adequate for determining the magnitude of these accidents on urban freeways. It was found that the published literature does not provide the information required to assess the magnitude of these accidents.

This publication may only be purchased from the NTIS. (PB No. 89–118012/AS, Price code: A06.)

Pavement Crack Recording (PCR) by Slit Integration, Vol. I: Final Report, Publication No. FHWA–RD–88–168; Vol. II: Technical Design Document, Publication No. FHWA–RD–88–169; Vol. III: Prototype Operator's Manual, Publication No. FHWA–RD–88–170

by Pavements Division

This publication includes a description of a research program and first prototype development for an electro-optical system to provide automated pavement surface crack density ratings. The program objective was to develop an affordable system, suitable for daylight use at highway speeds, and retrofittable to existing State DOT data collection vehicles. The design exploits an optical preprocessing technique called "slit integration," which allows real-time data reduction, yielding statistical indices of transverse and longitudinal crack densities. Several road tests with the prototype gave inconclusive results. Crack count, especially of longitudinal crack, was inconsistent. The problems may yield to further development, but the effort has been terminated. FHWA has offered exclusive rights to the system to any organization ready to continue the development.

These publications may only be purchased from the NTIS. (Vol. I: PB No. 89–117816/AS, Price code: A05; Vol. II: PB No. 89–117824/AS, Price code: A08; Vol. III: PB No. 89–117832/AS, Price code: A04.)

High-Speed Film Motion Analysis System, Publication No. FHWA–RD–88–187

by Safety Design Division

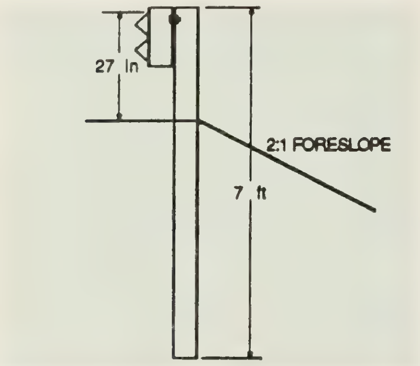
Due to the high volume of testing, and the attendant requirement for a film motion analysis capability at the Federal Outdoor Impact Laboratory (FOIL), a system capable of quickly digitizing projected images from high-speed film was developed. This report documents the procedures used in determining the equipment used, namely, the NAC Model 160F film motion analyzer and an IBM PC-AT. This report also shows how the equipment was interfaced, and how the software was developed for data acquisition and manipulation.

This report may only be purchased from the NTIS. (PB No. 89–135883/AS. Price code: A06.)

Force-Deflection Characteristics of Guardrail Posts, Publication No. FHWA–RD–88–193

by Safety Design Division

This publication presents the results of research to develop and validate a post-soil interaction model and a chart of post-length versus foreslope rate and distance to slope. A total of 57 pendulum, 6 static, and 4 full-scale tests were conducted using instrumented



posts, and standard and nonstandard guardrail installations. Tests indicate a standard G4(1S) guardrail system can successfully redirect a 4,500-lb (2.0 Mg) vehicle when installed at the slope break point, although the posts do not develop their maximum load. The same system with 7-ft (2.1 m) posts developed maximum post load and experienced less deflection.

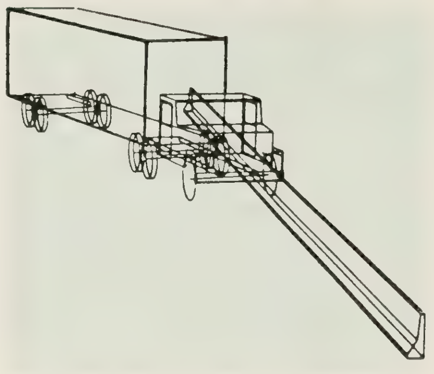
This report may only be purchased from the NTIS. (PB No. 89–101984/AS, Price code: A12.)

Numerical Analysis of Roadside Design (NARD), Vol. I: Users Manual, Publication No. FHWA–RD–88–210; Vol. II: Programmers Manual, Publication No. FHWA–RD–88–212; Vol. III: Validation Procedure Manual, Publication No. FHWA–RD–88–213; Vol. IV: Validation Report, Publication No. FHWA–RD–88–214

by Safety Design Division

These publications represent the results of research to incorporate extensive modifications to a computer program called CRUNCH. The new version has been called Numerical Analysis of Roadside Design (NARD).

NARD is a finite element code with the capability of simulating vehicle dynamics and maneuvering, and vehicle crashes with roadside objects.



The vehicle is modeled as a three-dimensional object represented by displacement finite elements. Large deflections and rotations and nonlinear material behavior are accommodated in the program. The vehicle/barrier interaction is modeled by geometrically determining the interference between the two surfaces.

These publications may only be purchased from the NTIS. (Vol. I: PB No. 89–132526/AS, Price code: A14; Vol. II: PB No. 89–132534/AS, Price code: A12; Vol. III: PB No. 89–132542/AS, Price code: A07; Vol. IV: PB No. 89–132559/AS, Price code: A04.)

Investigation of Exposure-Based Pedestrian Accident Areas, Publication No. FHWA/RD–87/038

by Safety Design Division

This report presents the findings of research into four areas that are particularly hazardous for pedestrians: arterial streets, local streets, locations lacking sidewalks, and sites without pedestrian crosswalks. Recommended countermeasures for each of the four situations are presented in the report. Of particular interest are the guidelines presented on when to provide pedestrian sidewalks and those presented on when to install pedestrian crosswalks.

This publication may only be purchased from the NTIS. (PB No. 89–115661/AS, Price code: A08.)

Evaluation of Design Analysis Procedures and Acceptance Criteria for Roadside Hardware, Vol. I: Executive Summary, Publication No. FHWA/RD–87/096; Vol. II: The Effect of Soil Strength on Longitudinal Barrier Performance, Publication No. FHWA/RD–87/097; Vol. III: Evaluating Pre-*Report 230* Crash Tests, Publication No. FHWA/RD–87/098; Vol. IV: The Importance of Occupant Risk Criteria, Publication No. FHWA/RD–87/099; Vol. V: Hazards of the Redirected Car, Publication No. FHWA/RD–87/100

by Safety Design Division

This research was conducted to identify and investigate aspects of NCHRP *Report 230* which require additional technical research. This publication deals with five broad areas of concern: (1) replacement of the 4,500-lb (2.0 Mg) test car, (2) methods for reevaluating pre-*Report 230* test results in light of the current *Report 230* criteria, (3) the importance and effect of soil conditions on the dynamic performance of barriers, (4) linking the occupant risk factor to "real-world" accident causes, and (5) assessing the potential hazards of the redirected vehicle.

These reports may only be purchased from the NTIS. (Vol. I: PB No. 88–169610/AS, Price code: A03; Vol. II: PB No. 88–174479/-AS, Price code: A06; Vol. III: PB No. 88–174487/AS, Price code: A04; Vol. IV: PB No. 88–145867/-AS, Price code: A06; Vol. V: PB No. 88–158449/AS, Price code: A04.)

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

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

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McLean, Virginia 22101–2296
Telephone: (703) 285–2144

Safety Resource Allocation Programs Implementation Technique, Publication No. FHWA–TS–88–019; Safety Resource Allocation Programs and Input Processor Users Manual, Publication No. FHWA–IP–88–020

by Office of Implementation

This report summarizes the testing and implementation experience of the Iowa Department of Transportation (DOT) with three resource allocation computer programs for prioritizing safety improvement projects. The three resource allocation programs, i.e., incremental benefit-cost analysis, integer programming, and dynamic programming, were developed by the FHWA to address the major question faced by highway safety administrators: Where and which safety improvement or accident countermeasures should be installed? The programs have been field-tested in Iowa. They provide decision-making tools for maximizing the net benefit of highway safety improvement projects for a given budget.

The microcomputer version of the resource allocation models and its accompanying input processor program are documented separately in a users manual, "Safety Resource Allocation Programs and Input Processor Users Manual," Publication No. FHWA–IP–88–020.

Limited copies of the reports are available from the RD&T Report Center. Copies also may be purchased from the NTIS. (FHWA–TS–88–019, PB No. 89–124291/AS, Price code: A04; FHWA–IP–88–020, PB No. 89–124309/AS, Price code: A04.) The microcomputer diskette may only be purchased from the NTIS. (PB No. 89-167274/-AS, Price code: D01.)

Long-Term Evaluation of the Acoustic Emission Weld Monitor, Publication No. FHWA–TS–88–021

by Office of Implementation

The Kentucky Transportation Center conducted an extended 10-month evaluation of the Acoustic Emission Weld Monitor (AEWM) in a bridge fabrication shop. The device was used to detect welding flaws during typical production of butt-welds on flanges and webs used in steel bridges. A total of 153 welds were monitored.

AEWM test results were compared with visual inspection and double-blind results of conventional nondestructive testing routinely conducted on welds. The AEWM did not miss any flaws detected visually or by nondestructive testing. Three AEWM flaws indications were confirmed by conventional nondestructive testing (radiography).

A large number of AEWM flaw indications were not related to any detected flaws (228 of 263 indications). Those were attributed to AE noise that occurs away from the weld and small flaws that were either missed or overlooked by visual and nondestructive inspection or were removed prior to inspection by normal fabrication procedures.

The AEWM has shown the sensitivity to detect AWS code-rejectable defects. In part, the high number of overcalls was caused by use of excessive system sensitivity. Due to the success of the unit in detecting flaws, further development is warranted. Specific recommendations for further research are provided.

This publication may only be purchased from the NTIS. (PB No. 89–122642/AS, Price code: A04.)

Full-Scale Uninstrumented Test of Brick Mailbox Structures, Publication No. FHWA–TS–88–023

by Office of Implementation

This report of test results highlights the severity of vehicle collisions with masonry mailbox structures. Crash test results conclusively confirm that both hollow core and solid masonry mailbox structures are hazards along the roadside which, upon impact, can cause death or serious injury to vehicle occupants.

This report is suitable for State and local maintenance engineers or supervisors to use in discussing the mailbox safety problem and potential liabilities with local officials and residents.

This publication may only be purchased from the NTIS. (PB No. 89–133342/AS, Price code: A03.)

New Research in Progress

The following new research studies reported by FHWA's Office of Research, Development, and Technology are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description and contact the following: Staff and administrative contract research—*Public Roads*; Highway Planning and Research (HP&R)—performing State highway or transportation department; National Cooperative Highway Research Program (NCHRP)—Program Director, NCHRP, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418; Strategic Highway Research Program (SHRP), 818 Connecticut Avenue, NW, Fourth floor, Washington, DC 20006.

NCP Category A—Highway Safety

NCP Program A.5: Design

Title: Influence of Traffic, Surface Age, and Environment on Skid Number. (NCP No. 4A5G0292)
Objective: Develop a statistically based model of skid resistance as a function of time, traffic, local climatic variables, aggregate properties, and initial skid resistance.
Performing Organization: University of Toledo, Toledo, OH 43606
Funding Agency: Ohio Department of Transportation
Expected Completion Date: December 1989
Estimated Cost: $103,000 (HP&R)

Title: Development of a Methodology to Identify and Correct Slippery Pavements. (NCP No. 4A5G0312)
Objective: Examine the use of a wet pavement index to provide an improved method to define segments of highway having a high potential for wet-weather accidents. Develop a priority rating scheme to determine the expenditure of maintenance funds to reduce accidents.
Performing Organization: Pennsylvania Transportation Institute, University Park, PA 16802
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: June 1990
Estimated Cost: $143,000 (HP&R)

NCP Category B—Traffic Operations

NCP Program B.1: Traffic Management Systems

Title: Photovoltaic Technology Applied to Transportation Facilities. (NCP No. 4B1B0062)
Objective: Develop a comprehensive data base on both photovoltaic (PV) hardware and the weather conditions throughout California which affect PV design, and determine the PV application with the greatest potential for implementation and dollar savings to the State.
Performing Organization: California Department of Transportation and Transportation Research Laboratory, Sacramento, CA 95819
Funding Agency: California Department of Transportation
Expected Completion Date: July 1991
Estimated Cost: $95,000 (HP&R)

Title: Access Management Policies and Guidelines for Activity Centers. (NCP No. 5B2B1022)
Objective: Develop policies and guidelines to preserve and improve the capacity and safety of the overall highway system within the vicinity of the activity centers through better management of access control. These guidelines would apply to:

- Modification of access control on streets and highways where activity center development has already occurred.
- Planning access control in newly developed areas or for new highways being constructed in existing developed areas.
- Management of access control within activity centers.

Performing Organization: Metro Transportation Group, Inc., Bloomington, IL 60108
Expected Completion Date: June 1990
Estimated Cost: $125,000 (NCHRP)

NCP Category C—Pavements

NCP Program C.1: Evaluation of Rigid Pavements

Title: Final Evaluation of the Field Performance of the Ross 23 Experimental Concrete Pavements. (NCP No. 4C1A2182)
Objective: Test extensively 12 different sections of 9-in (229 mm) portland cement concrete pavement constructed in 1972 on the southbound roadway of Route 23 in Chillicothe, Ohio, to understand better the behavior of rigid pavements. Will develop recommendations for improved joint design.
Performing Organization: University of Cincinnati, Cincinnati, OH 45221
Funding Agency: Ohio Department of Transportation
Expected Completion Date: September 1991
Estimated Cost: $584,000 (HP&R)

NCP Program C.2: Evaluation of Flexible Pavements

Title: Layer Coefficient Determination for Flexible Pavements. (NCP No. 4C2B1232)
Objective: Solve for the American Association of State Highway and Transportation Officials (AASHTO) layer coefficients from inservice pavement performance and thickness design. Relate pavement performance to fundamental material properties, such as, moduli.
Performing Organization: ERES Consultants, Inc., Champaign, IL 61820
Funding Agency: Wisconsin Department of Transportation
Expected Completion Date: June 1990
Estimated Cost: $165,000 (HP&R)

NCP Program C.4: Pavement Management Strategies

Title: Pavement Management System Enhancements. (NCP No. 4C4C2112)
Objective: Develop methods and systems for life-cycle cost analysis of pavements, particularly with reference to maintenance decisions. Conduct user requirements analysis, develop algorithms, enhance existing data base management system, test and evaluate economic analysis and DBMS techniques developed over the course of the project.
Performing Organization: University of Massachusetts, Amherst, MA 01003
Funding Agency: Massachusetts Department of Public Works
Expected Completion Date: December 1989
Estimated Cost: $70,000 (HP&R)

Title: Guidelines for Pavement Management Systems. (NCP No. 5C4C3172)
Objective: Revise and expand the American Association of State Highway and Transportation Officials (AASHTO) *Guideline on Pavement Management*, incorporating the latest theory and practice.
Performing Organization: Austin Research Engineers, Inc., Austin, TX 78746
Expected Completion Date: December 1989
Estimated Cost: $75,000 (NCHRP)

Title: Field Sampling and Testing—North Atlantic. (NCP No. 8C4C3562)
Objective: Inventory and field test certain preselected pavement test sections located throughout the United States and Canada. The work will be accomplished by drilling, sampling, and field testing of the designated test sections. The SHRP's Long-Term Pavement Performance program will include an extensive data collection effort. Data collection within regions will be divided among State and provincial highway agencies, the regional coordination offices, SHRP contractors for distress and profile measurements, and SHRP contracts for field sampling/testing and laboratory testing.
Performing Organization: Soil and Material Engineers, Raleigh, NC 27658
Expected Completion Date: March 1993
Estimated Cost: $2,400,000 (SHRP)

Title: Field Sampling and Testing—Southern. (NCP No. 8C4C3572)
Objective: Inventory and field test certain preselected pavement test sections located throughout the United States and Canada. The work will be accomplished by drilling, sampling, and field testing of the designated test sections. The SHRP's Long-Term Pavement Performance program will include an extensive data collection effort. Data collection within regions will be divided among State and provincial highway agencies, the regional coordination offices, SHRP contractors for distress and profile measurements, and SHRP contracts for field sampling/testing and laboratory testing.
Performing Organization: Law Engineering/Southwestern Laboratories, Atlanta, GA 30324
Expected Completion Date: March 1993
Estimated Cost: $1,100,000 (SHRP)

Title: Field Sampling and Testing—Western. (NCP No. 8C4C3592)
Objective: Inventory and field test certain preselected pavement test sections located throughout the United States and Canada. The work will be accomplished by drilling, sampling, and field testing of the designated test sections. The SHRP's Long-Term Pavement Performance program will include an extensive data collection effort. Data collection within regions will be divided among State and provincial highway agencies, the regional coordination offices, SHRP contractors for distress and profile measurements, and SHRP contracts for field sampling/testing and laboratory testing.
Performing Organization: Chen-Northern, Inc., Denver, CO 80223
Expected Completion Date: March 1993
Estimated Cost: $1,200,000 (SHRP)

Title: Laboratory Testing of Soils and Bituminous Materials—Southern. (NCP No. 8C4C3602)
Objective: Perform and record the results of specified tests on samples collected by others from preselected pavement test sections located throughout the United States, Canada, and other participating countries. The SHRP's Long-Term Pavement Performance program will include an extensive data collection effort. Data collection within regions will be divided among State and provincial highway agencies, the regional coordination offices, SHRP contractors for distress and profile measurements, and SHRP contracts for field sampling/testing and laboratory testing.
Performing Organization: Law Engineering/Southwestern Laboratories, Houston, TX 77009
Expected Completion Date: June 1993
Estimated Cost: $2,100,000 (SHRP)

Title: Laboratory Testing of Soils and Bituminous Materials—Western. (NCP No. 8C4C3612)
Objective: Perform and record the results of specified tests on samples collected by others from preselected pavement test sections located throughout the United States, Canada, and other participating countries. The SHRP's Long-Term Pavement Performance program will include an extensive data collection effort. Data collection within regions will be divided among State and provincial highway agencies, the regional coordination offices, SHRP contractors for distress and profile measurements, and SHRP contracts for field sampling/testing and laboratory testing.
Performing Organization: Western Technologies, Inc., Phoenix, AZ 85036
Expected Completion Date: April 1993
Estimated Cost: $2,300,000 (SHRP)

Title: Laboratory Testing of Soils and Bituminous Materials—North Central. (NCP No. 8C4C3602)
Objective: Perform and record the results of specified tests on samples collected by others from preselected pavement test sections located throughout the United States, Canada, and other participating countries. The SHRP's Long-Term Pavement Performance program will include an extensive data collection effort. Data collection within regions will be divided among State and provincial highway agencies, the regional coordination offices, SHRP contractors for distress and profile measurements, and SHRP contracts for field sampling/testing and laboratory testing.
Performing Organization: Braun Engineering Testing, Inc., Eden Prairie, MN 55344
Expected Completion Date: April 1993
Estimated Cost: $1,400,000 (HP&R)

NCP Category D—Structures

NCP Program D.1: Bridge Design

Title: Concrete Filled Steel Grid Bridge Decks—Phase III. (NCP No. 4D1A3292)
Objective: Develop an understanding of the overall behavior of a concrete-filled steel grid deck system by studying the following: 1. Transverse load distribution between conventional concrete-filled steel grid decks and their supporting beams; 2. Fatigue of welded connections or studs; 3. Roles of clear concrete cover; 4. Chloride concentration at various depths; 5. Causes of deck growth; and 6. Ability to transfer in-plane forces within grid decks and their supporting beams.
Performing Organization: West Virginia University, Morgantown, WV 26506
Funding Agency: West Virginia Department of Highways
Expected Completion Date: February 1991
Estimated Cost: $87,000 (HP&R)

NCP Program D.2: Bridge Management

Title: Recommended Revisions to the American Association of State Highway and Transportation Officials Manual for Maintenance Inspection of Bridges. (NCP No. 5D2A2042)
Objective: Develop proposed revisions to the American Association of State Highway and Transportation Officials (AASHTO) "Manual for Maintenance Inspection of Bridges," providing: guidance for inspection, evaluation, and load rating of existing bridges; a recommended method of load rating along with acceptable alternative methods; appropriate consideration of inspection requirements and preparation of inspection reports; a methodology for assessing safe load from load tests; and consideration of fatigue and other serviceability requirements. Consider also factors, such as scour, redundancy, and detail criticalness and evaluation procedures, applicable to bridge management systems.
Performing Organization: Lichtenstein and Associates, Fair Lawn, NJ 07410
Expected Completion Date: January 1991
Estimated Cost: $200,000 (NCHRP)

NCP Program D.4: Corrosion Protection

Title: Applications of Biopolymers for Improved Concrete. (NCP No. 4D4C0512)
Objective: Investigate the application of biopolymers for improved concrete. Many natural biopolymers are water soluble, and limited investigation to date has shown that those biopolymers enhance the durability and decrease the permeability of concrete. The concrete containing successful biopolymers will be used for pothole repairs and rehabilitation of deteriorated bridge decks.
Performing Organization: Northeastern University, Boston, MA 02115
Funding Agency: Massachusetts Department of Public Works
Expected Completion Date: December 1990
Estimated Cost: $60,000 (HP&R)

NCP Category E—Materials and Operations

NCP Program E.2: Cement and Concrete

Title: Concrete Strength Determination at Early Ages in the Field. (NCP No. 4E2C1083)
Objective: Develop an overall quality assurance program by which the highway engineer in the field will evaluate the strength and quality of the concrete as placed and cured in the field. Develop a set of guidelines and a manual for use by highway engineers in the field, including guidelines for equipment calibration, installation, test procedures, data analysis, and evaluation of test results. Develop guidelines for correlating the test results obtained by using a given nondestructive test procedure with the existing Texas concrete specifications for given job conditions.
Performing Organization: Center for Transportation Research, Austin, TX 78712–1075
Funding Agency: Texas Department of Highways and Public Transportation
Expected Completion Date: November 1990
Estimated Cost: $202,000 (HP&R)

NCP Program E.3: Geotechnology

Title: Stability of Existing Bridge Abutments. (NCP No. 4E3A0682)
Objective: Evaluate the stability of existing granite block bridge abutments by field observations and finite element analysis. Develop a procedure for determining whether existing abutments are safely able to support an increased height even though conservative conventional analysis shows an unacceptable factor of safety.
Performing Organization: University of Massachusetts, Amherst, MA 01003
Funding Agency: Massachusetts Department of Public Works
Expected Completion Date: January 1990
Estimated Cost: $93,000 (HP&R)

Title: A Laboratory Freeze-Thaw Test for Highway Design. (NCP No. 4E3B0582)
Objective: Build, assemble, and adapt for State use the equipment to perform the new Cold Regions Research and Engineering Laboratory (CRREL) freeze-thaw test and train State personnel to operate the equipment.
Performing Organization: Tufts University, Medford, MA 02155
Funding Agency: Massachusetts Department of Public Works
Expected Completion Date: July 1990
Estimated Cost: $107,000 (HP&R)

Title: Multi-Objective Design of Service Routes. (NCP No. 4E5F2022)
Objective: Design a computer support system to aid in the planning and management of snow and ice removal with emphasis on efficient maintenance vehicle routing. Apply support system to scheduling and routing of mowing, painting, weed control, facilities and equipment servicing, inspection, and possibly some pavement maintenance activities. Train State engineers in the use of the computer system and in the development of an automatic data management system that will avoid the need for extensive data collection and model calibration in the future.
Performing Organization: Purdue University, Indiana Joint Highway Research Project (JHRP), West Lafayette, IN 47906
Funding Agency: Indiana Department of Highways
Expected Completion Date: July 1991
Estimated Cost: $133,000 (HP&R)

☆U.S. Government Printing Office: 1989—241-682/00003

Technology Transfer (T^2) Achievement Award Presented

Mr. Wilson J. "Red" Lindsay recently received an Outstanding Technology Transfer Achievement Award from the Associate Administrator for Research, Development, and Technology. Because technology transfer is an important mission of the Federal Highway Administration (FHWA) field offices, a Federal Highway Administrator's Award has been established, beginning in 1989, for the most outstanding field technology transfer achievement. This award will recognize a significant accomplishment in promoting new technologies; directing tests and evaluations of products for which research and development has been recently completed; aiding States, counties, cities, and townships in technology transfer efforts; developing training courses for use of new highway technologies; or other notable technology transfer efforts.

Each year, FHWA field offices will, as part of FHWA's normal award system solicitation, be asked to nominate candidates for this award. Each eligible candidate will be judged on excellence, creativity, and the contribution of the T^2 effort to the highway community and to the general public.

Red Lindsay, a highway engineer (retired) in Region 6's Planning and Program Development Office, received the Outstanding Technology Transfer Award for his efforts in promoting a "safe" mailbox design. He was instrumental in alerting both the American Association of State Highway and Transportation Officials (AASHTO) and the United States Postal Service to methods for countering poorly designed mailboxes, a serious accident hazard which has resulted in about 400 highway deaths each year. During the last year, Red obtained funds from the Office of Implementation to perform critical tests of mailbox designs, secured accident data and other records and visual materials, and set up logistics for shooting a videotape titled, "Mailboxes May Be Hazardous To Your Health." The resulting videotape, released early this spring, provides an excellent representation of the danger imposed by inadequately designed or constructed mailboxes and demonstrates convincingly how these appurtenances can be designed to reduce the danger if struck.

Mr. Wesley S. Mendenhall, Jr., Region 6 Administrator, presents Mr. Wilson J. ("Red") Lindsay his Outstanding Technology Transfer Award.

Red's contributions to technology transfer go far beyond those mentioned above. Because of his contributions, the new Federal Highway Administrator's Technology Transfer Award is being established to inspire similar excellence on the part of all FHWA field personnel involved in technology transfer.

U.S. Department
of Transportation

**Federal Highway
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