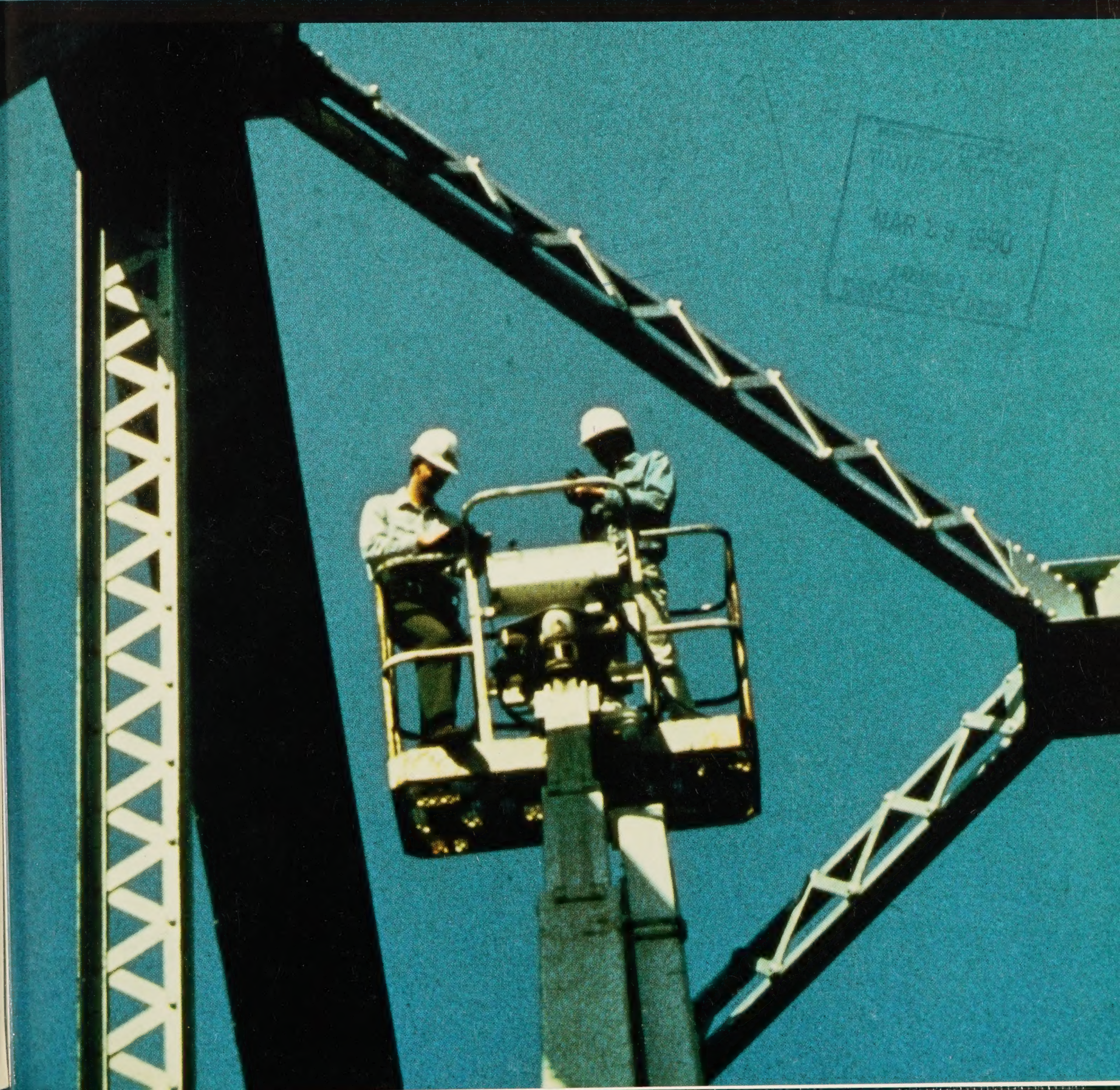
March 1990
Vol. 53, No. 4

U.S. Department
of Transportation

Federal Highway
Administration

Public Roads

A Journal of Highway Research and Development



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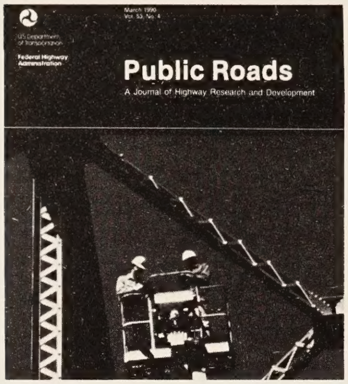

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COVER: Inspection crew using a "man-lift" hydraulic.

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

Public Roads **is published quarterly by the Office of Research, Development, and Technology**

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FASTBRID: An Expert System for Bridge Fatigue

by Hani G. Melhem and James A. Wentworth

Introduction

There are approximately 565,000 steel bridges in the United States. Of these, over 50 percent are more than 30 years old, and a large number are considered to be in a deteriorating condition. Many more are approaching a structurally unsafe condition each year. By detecting cracks early and performing the appropriate repair, problems in steel bridges can be avoided and unsafe conditions and repair costs reduced. This requires proper planning for the bridge inspection and a trained inspector who knows how to look and what to look for.

Since it is not feasible to check and scrutinize all parts and details of a bridge carefully, it is imperative to know the regions most susceptible to cracking. For this, an engineer with adequate knowledge and experience in fracture and fatigue would be needed at every site to analyze the results and findings of a bridge inspection. Such expertise is scarce, which suggests the need for more training in this area. Training bridge inspectors and novice bridge engineers in fatigue and fracture of bridges has become a major concern in the highway community.

Prototype FASTBRID

To demonstrate the feasibility of developing an integrated engineering training aid for bridge inspection and remedial actions, a prototype development project was undertaken at the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia, under the Grants for Research Fellowships program of the National Highway Institute. The prototype expert system is called FASTBRID (Fatigue Assessment of Steel BRIDges). The development of the expert system/training aid was planned in two stages:

- Development of a microcomputer-based prototype expert system that conforms with FHWA guidelines.

- Validation of the finished system in preparation for wide distribution.

Because a considerable amount of effort and time will be needed for domain experts to validate and verify the system, only the first stage has been completed. However, the potential for developing the finished system has been demonstrated.

The goal of the expert system/training aid is to serve as an advisor/consultant to the practitioners and as an interactive trainer to the less experienced in the area of bridge fatigue. Once completed, the expert system will be combined with an interactive videodisc-based training course on bridge fatigue inspection and corrective actions. When completely developed, this system will constitute both an advisory system for real-world evaluations and a training aid for bridge engineers and inspectors. The system will help detect and solve fatigue-related problems in steel bridges. Overall, FASTBRID will provide:

- Problem-solving capability.

- Bridge fatigue training program.

- Spot training for specific topics.

Overview of Expert Systems

Knowledge-based expert systems are computer programs designed to imitate reasoning and decision-making processes and to include facts and knowledge from human experts in a specific domain. These systems supplement—but do not replace—human experts.

Training potential

The training potential of the system was taken into consideration while developing the prototype. FASTBRID's usefulness as a training tool is accentuated by the possibility of running the program several times after changing one or more of the parameters to see how this would affect the results. Also, for training purposes, the explanation facility is a very important component of FASTBRID. It helps clarify the exact meaning, in the right context, of certain terms used during the system-user interaction, rather than let the user guess or allow the program to choose an average, standard, or most common value. The explanation facility will be enhanced by the use of the videodisc.

Components of an expert system

An expert system is composed basically of three modules: the knowledge base (long-term memory, or static memory), the inference engine (inference mechanism, or control mechanism), and the short-term (dynamic) memory. Three additional components that proved to be important in moving toward more accessible and durable systems are the knowledge acquisition facility, the explanation facility, and the user interface. These components and their relationship are shown in figure 1.

The *knowledge base* contains the encoded knowledge of the domain expert needed for understanding, formulating, and solving the problem. It includes facts (data base) and rules (heuristics) that direct the use of knowledge to solve a given problem.

The *inference engine* is the "brain" of the expert system. (*1*)[1] It embodies the problem-solving structure which is also called the control strategy. The majority of current systems use a rule-based control strategy. In expert systems, the domain-specific knowledge is explicitly exercised by a distinct and separate control strategy. In algorithmic or conventional systems, the domain knowledge only appears implicitly within the program code.

The *short-term memory* accumulates dynamic knowledge about the specific problem, user responses from questions asked by the system, etc. It is also called the working memory, context, or workplace.

The *knowledge acquisition process* is a subsystem of the knowledge base. Since the normal procedure in expert system development involves an incremental building and refining of the knowledge base, the process of knowledge acquisition must be made as efficient as possible. The main goals are to enable a domain expert to "educate" the system directly (i.e., to eliminate or reduce the interpreter role of the knowledge engineer) and to facilitate the assembly and maintenance of large knowledge bases.

[1] Italic numbers in parentheses identify references on page 116.

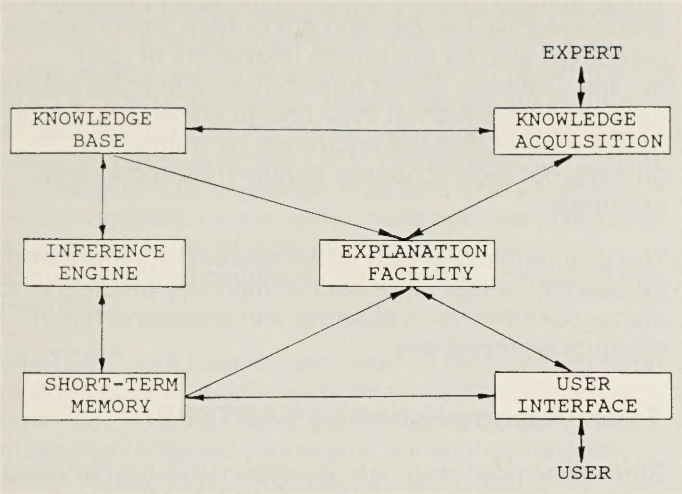

Figure 1.—Expert system components.

The *explanation facility* gives the system the capability to explain and justify its reasoning. An expert system is more likely to be accepted by experts in that domain, and by nonexperts seeking its advice, if the system can explain its actions. An explanation capability not only adds to the system's credibility, but also enables the nonexpert user to learn from the system. Also, clear explanations ease system debugging by allowing the domain expert to check the system's reasoning and find any areas in need of refinement.

The *user interface* is the module that allows the user to work comfortably and efficiently. Drawing the user into the problem-solving process is especially important in applications where the user is responsible for the actions recommended by the system.

Suitability of the expert system technology

Expert systems synthesize facts and heuristic knowledge to provide useful tools for problem solving. They are used as a means to formalize the knowledge in a certain domain to contribute to the advancement and clarity of the knowledge base. When the expertise is modeled and formalized in a computer program, knowledge about the area is synthesized, tested for consistency, and made available to a greater number of users. Expert systems are particularly applicable in civil engineering because many tasks require the use of knowledge gained through experience. Moreover, engineering practice, in general, involves the use of formal procedures as well as rules-of-thumb.

The specialized knowledge and subjective judgment of expert professionals are frequently required for bridge fatigue assessment. The scarceness of available expertise and the shortage of well-trained inspectors as compared to the large number of existing bridges call for quick and efficient guidance in bridge inspection, evaluation, and maintenance. The role of the FASTBRID system is to transfer experts' knowledge to the less trained persons who are in charge of inspecting bridges and making decisions about their status and who may not be aware of fatigue problems and their consequences.

Systems for fatigue design and assessment

Presently, there are three expert systems under development to accomplish certain fatigue-related tasks. They are described below.

Massachusetts Institute of Technology. A research prototype Consultant Reasoning About Cracking Knowledge (CRACK) system was developed in LPA MacProlog; it runs on a Macintosh II personal computer. (*2*) The area of bridge fatigue was chosen as an application domain to demonstrate new concepts in artificial intelligence. Specifically, the system takes a qualitative/quantitative reasoning approach to fatigue and fracture in bridges. (*3*)

The fundamental characteristic of the system is the coupling of symbolic and numeric computation; its two central contributions are the multilevel approach and the formalization of the domain knowledge. The system uses three layers to unite the disparate approach of rule-based, qualitative, and numerical analysis.

Lehigh University. The Bridge Fatigue Investigator (BFI) is a knowledge-based expert system developed at the Engineering Research Center for Advanced Technology for Large Structural Systems (ATLSS) at Lehigh University. (*4*) The purpose of the system is to assist inspection for fatigue damage in steel bridges and evaluation of such structures for their fatigue and fracture susceptibility.

The first system module has been developed on an IBM AT. Graphic displays are generated using GRAF-PAK–GKS, an advanced technology center application of the Kernel System. The second system module has been developed on a SUN 3/160 workstation. Both modules use the Quitus Computer System, Inc., version of PROLOG.

The problem scope is limited to steel girder bridges; its task is more analytic than generative, and is limited to visual inspection for cracking and preliminary evaluation of observed distress, if any. The knowledge base is derived primarily from case studies and interviews with experts at Lehigh.

Ecole Polytechnique Federale de Lausanne. At the Ecole Polytechnique Federale de Lausanne (EPFL) in Switzerland, a pilot expert system for fatigue design of steel structures was implemented. (*5*) The system conforms with the European Convention for Constructional Steelwork recommendations for the fatigue design of steel structures. It is used to help designers identify appropriate detail categories and can propose alternative designs if a detail is not satisfactory. The expert system shell EXSYS is used as the development tool.

Although the computer model was tested and verified during system development, further testing needs to be done by several fatigue experts before the system can be offered for general use.

Use of FASTBRID

> Perhaps the biggest error being made in expert system development is lack of consideration for the expected audience. Most systems do not consider the knowledge level of their intended audience; tutorial sections of programs are lacking; explanation features are incomplete; and terminology is usually undefined. (*6*)

Thus, after determining the suitability of the technology to the application domain, the next development step was to identify system users so as to design it in accordance with their needs and capabilities.

The anticipated system end user is the bridge engineer or unit leader who is in charge of organizing the bridge inspection, identifying critical components and their degree of criticality, and evaluating the inspection reports.[2]

The Manual for Inspection of Fracture Critical Bridge Members states that when it is necessary to evaluate a suspicious flaw discovered during bridge inspection, it may be helpful to seek assistance from a specialist. (*8*) For most average cases the role of the expert system FASTBRID would be to assist if the end user is not a specialist or if a specialist is not available.

In FASTBRID, it is assumed that the end user is familiar with computers and software packages such as finite element programs or numerical solvers. The user is expected to have a good knowledge about structures and bridges and to know (or be able to look up) such information as fatigue categories (A, B, B', etc.).

The proposed training program using an interactive laser videodisc can be used not only by the bridge engineer but also by the bridge inspectors or technicians. Different States have different policies for the degree of education of their bridge inspectors. Some States require that the inspectors be trained engineers, not high school or engineering technology graduates.

The problem-solver part of the system will more likely be used by bridge engineers or highway officials who are responsible for evaluating and assessing the inspection observations.

Tasks Accomplished by FASTBRID

Since the bridge engineer is responsible for planning the inspection and deciding what to do after the inspection is completed, FASTBRID will not be developed to do the failure analysis of collapsed bridges or broken members. It also will not try to find the causes of a defect or crack, and it is not intended to be used as an aid to design new connections or details of a bridge. However, FASTBRID will perform two basic tasks:

- Help the user in organizing the fatigue inspection.

- Assist the user in evaluating inspection results and determining what needs to be done.

Planning the fatigue inspection

This planning includes how to identify and classify the fracture critical members and determine how to do the inspection, where to look, and what to look for. This applies to the most common bridge types—plate girder, arch, or truss bridges. The videodisc will be most significant to this portion of the user interface. Displaying images of typical situations that deserve special attention and examples of frequently encountered conditions will be a very powerful tool for enhancing the system's advisory ability.

Analyzing the inspection report

After the fatigue inspection is done, the system can be used to analyze the inspection findings. This task is more complicated than the former, since each case is handled differently, and the measures taken in each situation will depend upon a variety of factors, including economic and political considerations.

[2] See the *National Bridge Inspection Standards* for a listing of unit leader qualification. (*7*)

The bridge inspector provides numerical ratings of the different bridge components and writes narrative descriptions of the conditions. The inspector also must write a narrative summary and list recommendations concerning repairs. Ideally, the bridge engineer should make sure that the fatigue defects are clearly reported in the summary with the appropriate degree of criticality. The engineer must also verify that the recommendations are appropriate and are given the adequate degree of priority. Finally, the engineer should check component ratings when reviewing the report.

FASTBRID will help the engineer in determining what to do in case of a deficiency or suspicious observation—i.e., whether to redo the inspection using a more sophisticated procedure, schedule more frequent inspections, recommend load posting the bridge, repair and strengthen the bridge under temporary traffic restrictions, or (worst case) close the bridge to traffic altogether and recommend replacement of the bridge.

System Development

After defining the expert system scope and end user, the prototype was developed at three demonstration levels in accordance with FHWA guidelines.

Stages of development

Demonstration 1 addressed the human factor and ensured that the intended user will consider using the system.

Prototype 1 was prepared after a substantial portion (at least three-fourths) of the rules were added, and the expert system was representative of the final product in terms of accuracy and scope.

Prototype 2 verified that the system operated as intended and was sufficiently easy to use. Once the system is booted, the expected end users should be able to operate it without developer assistance.

It should be noted that an evolution of thinking occurs during development of most expert systems. For example, in the initial stages of developing FASTBRID, it was assumed that, based on the crack dimensions and material properties, the system could perform a limited fracture mechanics analysis and estimate the approximate remaining life of the bridge.

Later, during the interviews and meetings with domain experts—in the development of Prototype 2—it was decided that this method was *not* used in a fatigue situation when a crack was found. Only when a crack is too large and occurs in a fracture critical member, or a substantial portion of the bridge is considered so structurally deficient that it would threaten the public safety, a detailed fatigue analysis is conducted accompanied by a finite element study and analysis of material properties and stress concentration. Normally, these are difficult tasks that require a considerable amount of time and effort. Moreover, they are more appropriately decided by higher level officials and engineering committees than the intended end user of this system.

Consequently, instead of following the fracture mechanics approach in cases where cracks are detected, the system searches for the most suitable methods of performing nondestructive tests and what the bridge engineer should do in such cases.

Building tools

The software-development tool (shell) was selected to meet desired system performance and distribution requirements. The FHWA guidelines specify that, in developing expert systems, the run-time versions should operate on an IBM-PC or -compatible microcomputer with MS-DOS 3.0 or higher. A 10Mb fixed drive and 640Kb usable RAM are assumed. The program should work with the most popular monochrome or color monitors. No special programs should be required (unless supplied with the expert system) once the microcomputer has been started with MS-DOS or PC-DOS.

It is usually recommended to use an empty expert system tool (shell) before programming in high-level language. These empty shells are the ideal tools for expert system development.

A demonstration package (Demonstration 1) was built using the shell EXSYS; it was composed of 22 rules. EXSYS has been used successfully in previous FHWA systems and supports a rule-based knowledge representation. EXSYS can call and receive data external programs via disk files, can chain knowledge bases, requires no external language, and uses probability factors to deal with uncertainty. Because EXSYS gave good results and the other tools studied—CLIPS, Auto-Intelligence, and TOPSI—showed no real advantage over EXSYS, this shell was used in developing the prototype stage of the expert system.

Source of domain knowledge

Part of the domain knowledge was extracted from FHWA fracture-critical courses. (*8,9*) The course entitled "Inspection of Fracture Critical Bridge Members," organized by the National Highway Institute was most helpful. Heuristics and judgment-type rules were provided by faculty members at the University of Pittsburgh as well as by the FHWA bridge engineers and technical staff.

The formalized knowledge of the expert system also was partially derived from published and unpublished case studies and reports such as those done at Lehigh University. (*10*) Some of these reports describe projects that have been and are now being conducted for the FHWA.

System Architecture

As discussed above, the tasks that can be accomplished by FASTBRID are grouped into two major functions:

- Planning the fatigue inspection.
- Analyzing the inspection report.

These functions are not normally performed simultaneously in real time. Since there could be several hours or days between planning the inspection and analyzing the results, the rules to accomplish these functions in FASTBRID are grouped into two separate modules.

- Module 1 contains the rules that allow planning and preparing the fatigue inspection.

- Module 2 contains the rules and external programs that analyze the inspection findings.

When the system is used to plan the fatigue inspection (module 1), data and information are saved from that run and stored on a "blackboard." Blackboarding permits chaining between knowledge bases. If the system is used to analyze the inspection report after the bridge inspection is done (module 2), inspection information is retrieved. This avoids asking the user the same questions again. It is also possible to run each module independently; e.g., to analyze cases for which module 1 was not used.

The operational sequence and interaction between the different system modules are depicted in the flow diagram shown in figure 2.

Module 1

This module has over 100 rules and can identify the fracture critical members in a bridge, the degree of criticality, the susceptibility to fatigue, and the adequate level of inspection. It determines where to look, what to look for, and how to look during the fatigue inspection. The system uses the ranking order built in the shell EXSYS that deals with degree of confidence or probability to prioritize the critical members and the places to scrutinize during the inspection. Figure 3 is an example of where to look during the inspection. It shows a fracture initiated from slag and voids in mispunched rivet holes that were improperly filled with weldment.

Lists of the most probable fracture critical members, places "where to look," and the "what to look for" are prepared. These lists are typical shot lists (or images) that can be used later in the videodisc interface. The items on these lists are not all used in every case, but they represent all the possibilities stored in the knowledge base. Different possibilities are investigated according to the individual case under consideration; only the adequate items are prioritized and presented to the user.

Module 2

This module, too, has nearly 100 rules and calls on 3 external computer programs (written in BASIC) to assess fatigue of the inspected bridge. Additional rules are being added in module 2 as the expert system development proceeds.

If a defect is found, the system will investigate its criticality, its potential consequences, and alternatives for resolving it. Such alternatives include load posting, conducting more frequent inspections (every year or every 6 months rather than every 2 years), doing more sophisticated inspections using nondestructive testing methods (NDT), performing short- or long-term rehabilitation measures, or closing the bridge to traffic. Figure 4 shows a crack that has formed as a reentrant corner in a poorly coped web. Dye penetrant, a typical NDT method for such a situation, was used to examine the extent of the crack. Recommended short-term repairs include drilling holes at crack tips, grinding, peening, rewelding, tungsten inert gas remelting, or replacing rivets.

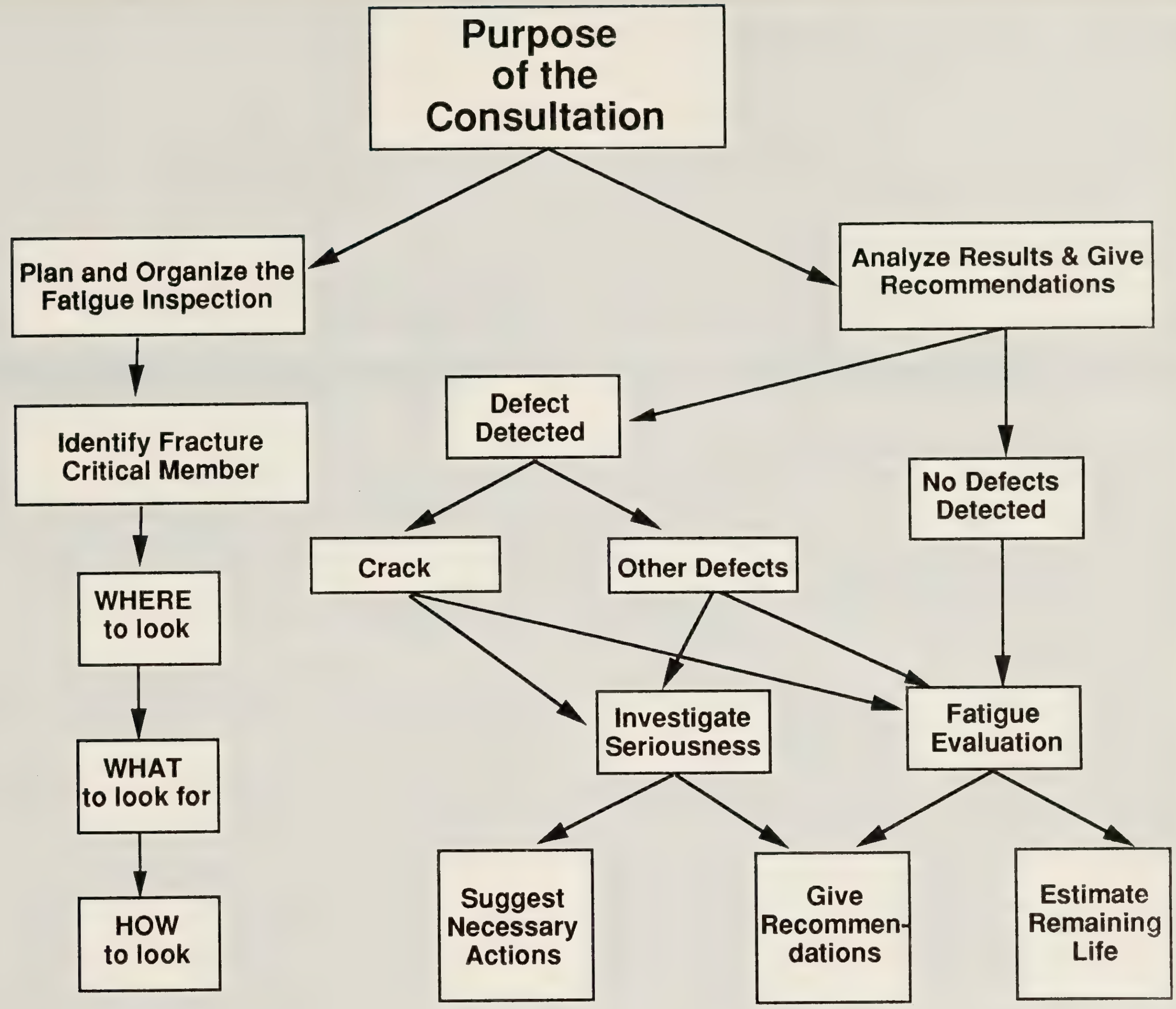

Figure 2.—Flow diagram of FASTBRID tasks.

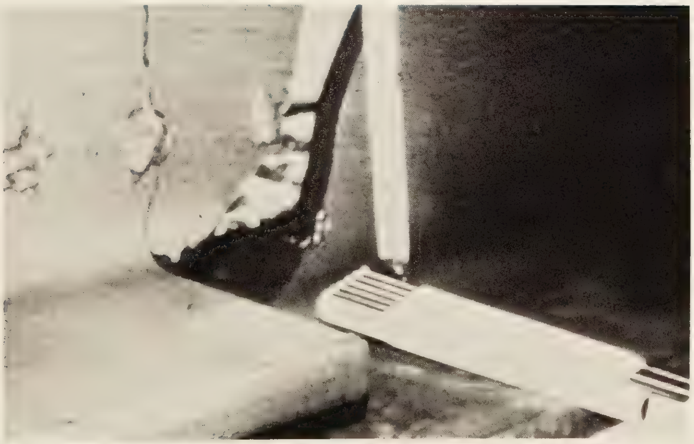

Figure 3.—Cracks initiated at plug-welded holes in main girder.

Figure 4.—Use of dye penetrant revealing the extent of a crack in a coped web.

In the absence of cracks, the system investigates other defects such as corrosion, nicks and gouges, bridge fatigue weld defects, and mechanical damage. If no defects are found, the system will do a fatigue evaluation using different procedures and calculate the approximate remaining life of the structure.

Calculation of the remaining fatigue life could be based on current American Association of State Highway and Transportation Officials (AASHTO) requirements, on locally measured and predicted load patterns, or on a nationwide weight-in-motion load spectrum. FASTBRID uses fatigue evaluation procedure proposed by Moses *et al.*, and expected to be adopted by AASHTO in the new *Manual for Maintenance Inspection of Bridges. (11)*

Future Extension: Integrating the Expert System into an Interactive Videodisc Program

Interactive video represents the fusion of video and computer technologies and results in a tremendous potential for information storage. An interactive video "delivery system" can use a videodisc controlled by a microprocessor built into the videodisc player, or by a separate computer. The control system computer program can be encoded on the videodisc, loaded temporarily into the videodisc player by means of its remote control keypad, or stored on a floppy disk of the external computer. Information can be accessed from any place within the recording.

The advantage of a videodisc is almost instantaneous random access to any frame on the disc. Moreover, discs have a very large storage capacity, and information can be stored on one disc in a variety of formats.

Random access on the disc allows branching to become an automatic feature of information storage. User selection on multiple choice menus and yes/no type of questions will determine—implicitly or explicitly—which path to follow on the videodisc program. When a video player is linked to a computer, the user controls the computer program; the latter in turn controls the video program.

Conclusions

Although the FASTBRID system is not yet completed, several conclusions can be drawn from the demonstration model and the prototype testing:

- It is possible to develop an expert system in a complex technical area such as bridge fatigue using available development tools.

- It is both possible and practical to combine expert systems with interactive videodisc training systems to develop a fully integrated decision aid/training system.

- The integrated decision aid/training system is a much-needed tool and will be accepted by the user community in the field of bridge fatigue.

- System evaluation and verification will be difficult but achievable. At present, there are no prescribed methods of accomplishing these except by extensive field testing.

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Evaluation of the PRORUT System

by Douglas Brown

Introduction

In 1983, the Federal Highway Administration's (FHWA's) Office of Research entered into a contract, "Methodology for Road Roughness Profiling and Rut Depth Measurement," with the University of Michigan Transportation Research Institute (UMTRI). This contract represented the first step toward the integration of different pavement condition measurements into a single system. Road roughness profiling and rut depth measurement use similar technologies. They were therefore selected to be combined in a prototype system, the basic concept of which had been developed under a contract with the Southwest Research Institute.

During the first phase of the UMTRI contract, currently available hardware and software which could be used to obtain road profiling information were assessed. Next, an economic analysis was conducted on highway departments' use of road roughness profiling equipment. From this, concepts and specifications were developed for a prototype system that would provide the required information at a minimal cost. This system—called PRORUT—was then designed, constructed, validated, and delivered to the FHWA. *(1,2,3)*[1]

PRORUT is an inertial profiling system which can be used to measure and record various roadway characteristics, including the longitudinal profiles, rutting, and roughness levels of the two wheel tracks. As shown in figure 1, the system is mounted in a van and uses commercially available components.

Laser sensors and accelerometers are used to obtain the profile measurements in each wheel track. A centrally mounted laser sensor is also included for measuring the crown between the wheel tracks and determining an average rut depth. (See figure 2.) The electronics and software system provided for two additional sensors so that the rut depth in each wheel track can be measured, if desired.

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

An IBM personal computer controls system operation and processes the data. The menu-driven software leads the operator through system calibration, component checks, and data collection. Data can then be analyzed and presented graphically and numerically. The graphic records are useful in further detailing the road profiles; on the other hand, the tabular outputs are preferable for listing the International Roughness Index (IRI) and the mean rut depth averaged over selectable lengths of the test sections. Figure 3 shows the system hardware.

Figure 1.—PRORUT device.

State Evaluations

After a few months of preliminary testing at the FHWA's Turner-Fairbank Highway Research Center, the PRORUT system was judged ready for several State evaluations. The Office of Implementation solicited State highway agencies for their interest; approximately 20 States responded. After carefully considering qualifications, past experience, and other factors, the FHWA selected three States (Georgia, Pennsylvania, and Indiana). Each State borrowed PRORUT for several weeks and conducted an evaluation on selected pavement sections. The objectives of the State evaluations were to document the system's operating characteristics, performance capabilities, and overall usefulness.

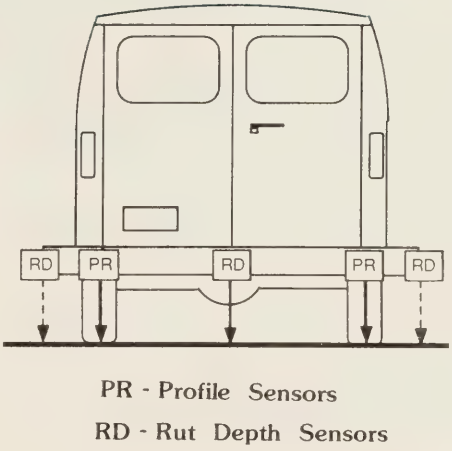

Figure 2.—Laser sensors.

Georgia evaluation

The Georgia Department of Transportation (DOT) was interested in comparing PRORUT's performance to that of other, typically-used roughness measuring equipment. (*4*) Forty-eight test sections were chosen for the evaluation, 8 of which were used as standard control sections for calibrating the DOT's 9 Mays meter trailers. To provide a variety of surface types, road conditions, and levels of roughness, the test sections were located on Interstate, primary, and secondary State routes, as well as on various county roads.

Profile data were correlated as a measure of roughness with the data from the modified Mays meters. PRORUT's ability to measure rutting was determined by correlating its results to those of a manual stringline survey.

Overall, PRORUT was found to be very easy to use and understand. Since the results of the roughness evaluation indicated that a correlation was possible between PRORUT and the Mays meter, PRORUT was considered a suitable instrument for measuring road profile/roughness. A correlation could not, however, be made with the rutting data.

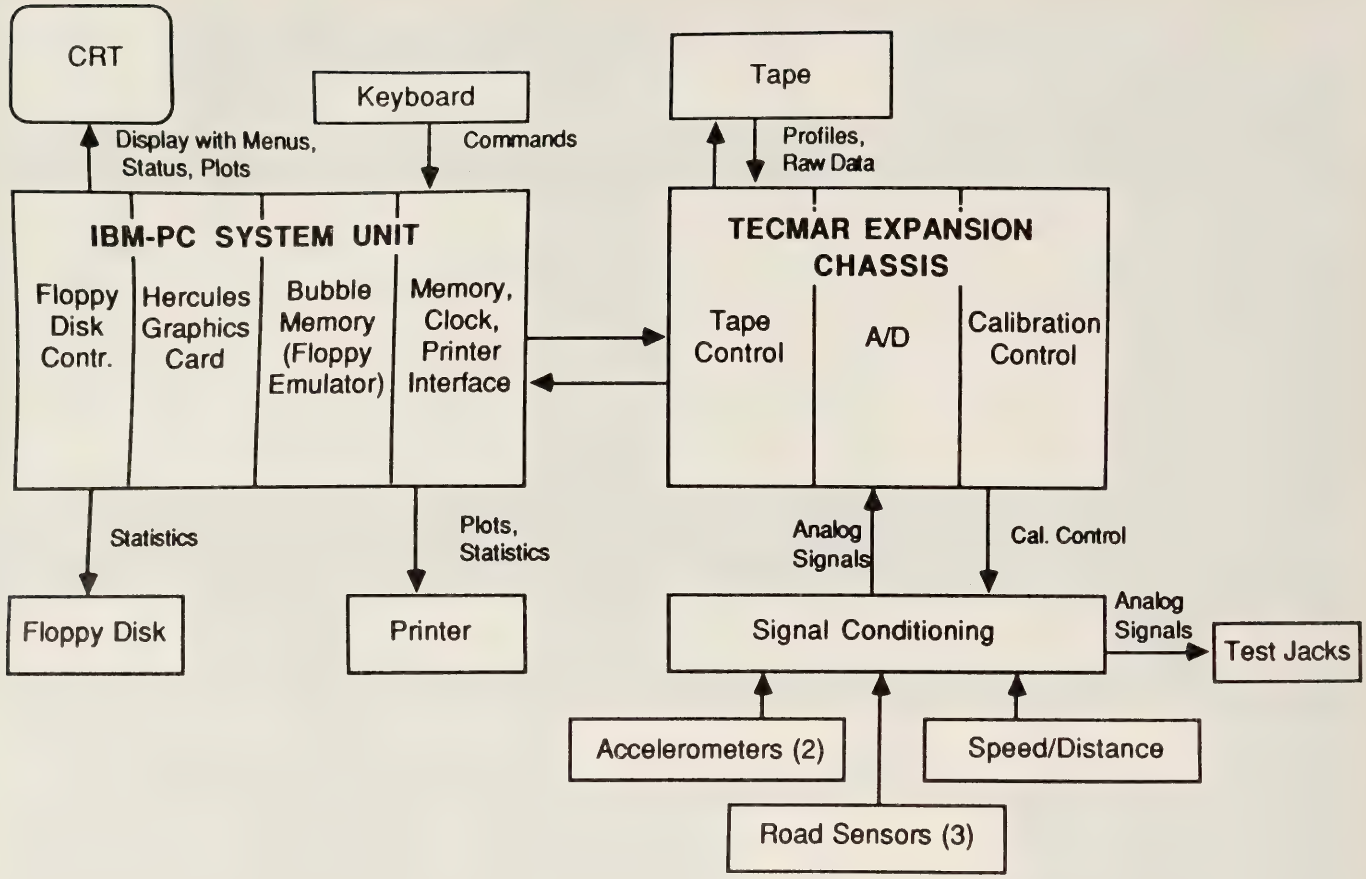

Figure 3.—System hardware.

The following recommendations were made based on the evaluation results:

- The on-board computer system should be upgraded so that data collection and processing can be performed at the same time.

- Five or more lasers could be used to detail more of the transverse profile and produce more accurate rutting estimates.

- Improvements should be made in the method of addressing the computer if a mistake is made when naming files.

- An indicator should be added to prompt the operator when a tape is nearing the end.

Overall, the Georgia DOT felt that work on PRORUT should be pursued and efforts made to further develop and enhance the system.

Pennsylvania evaluation

The Pennsylvania Department of Transportation (PennDOT) evaluated PRORUT and compared it against other systems used to measure pavement roughness and rut depth. (*5*) Systems included in the evaluation were the Mays ride meter, a portable universal roughness device (PURD), a GM profilometer, and a rod-and-level survey.

For the evaluation, 40 pavement sections were chosen. These consisted of both bituminous and concrete surfaces with various degrees of roughness, rut depths, and traffic volumes. Each of the systems was run several times on the pavement sections at various speeds. Roughness measurements were compiled and linear regressions run on the collected data. Repeatability was assessed over short and long time periods. PRORUT and rod-and-level surveys were used to determine rut depths at each test site.

The PRORUT device was found to have good operating characteristics and was considered applicable for research and calibration testing. The device had its limitations, though, as a production roughness measuring tool. During actual field testing, only 1 to 2 mi (1.6 to 3.2 km) of data could be collected on a standard floppy disk. When testing small sections, as in this study, personnel usually had enough time between site measurements to copy the data. For network-type surveys, however, this type of operation would not be acceptable. PRORUT's high-capacity tape system for data storage could not be used because PennDOT did not have compatible office equipment to process the raw data.

Test speed was found to affect the amount of data recording space. Determining the best test speed involves making tradeoffs among several technical limits. At high speeds, PRORUT sees longer wavelengths and captures a more complete profile. However, the data are measured faster, and sometimes the computer and recorder cannot maintain the pace. When this happens, the testing system automatically shuts down, indicating that a lower test speed is needed.

The best test speed for a 1- to 2-mi (1.6- to 3.2-km) section was usually the highest speed allowed by traffic conditions. Four test measurements per foot were recommended for high-quality profile measurements. PRORUT was validated at four measurements per foot; it may not be as accurate when lower measurement frequencies are used.

Based on its evaluation, PennDOT felt that PRORUT has the potential to be a valuable addition to any highway department's pavement management system. With the proper office equipment, PRORUT can be a useful tool for production-type testing. Even without this equipment, however, the device can still be used for research and calibration applications.

Indiana evaluation

The Indiana Department of Highways (DOH) evaluated PRORUT, comparing its results to those from a Cox roadmeter and a rod-and-level survey. (*6*) Pavement sections selected for the study represented a range of pavement types and levels of roughness. Testing was done at several sampling intervals and speeds. Evaluation data were statistically analyzed.

As indicated in figure 4, close agreement was found between the PRORUT profiles and the rod-and-level profiles in most cases. Changes in speed while collecting data did not affect the profile measurements, and generally the effects of number of samples per foot was considered statistically insignificant. Although the IRI's from PRORUT and the rod-and-level survey were very close, they were not statistically equal.

Evaluation results indicated that PRORUT is a useful profiling device. The following actions would, however, improve the system's productivity and overall operating characteristics:

- A new host vehicle to ensure a safer, more convenient working environment.
- A faster computer to replace the existing outdated system.

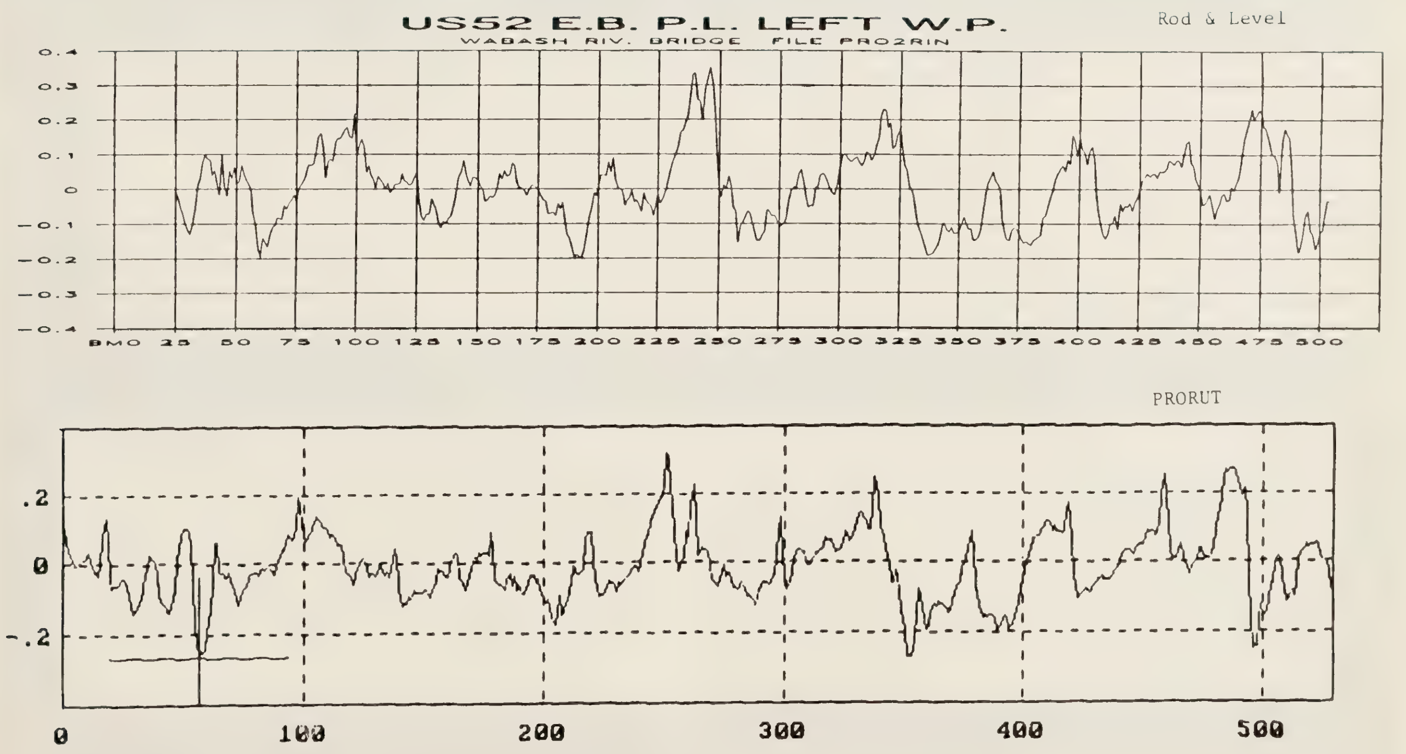

Figure 4.—Sample profiles from PRORUT and rod-and-level survey.

- Proper operation of the laser sensors for accurate rut-depth measurement.

- The wiring system maintained to prevent any problems that could lead to unexpected shutdowns of the system.

The Indiana DOH was impressed with PRORUT's operation and measurement repeatability. The device is recommended to other State and local highway agencies for gathering pavement comparative data.

Conclusion

Each of the State highway agencies that evaluated PRORUT was pleased with its overall performance. The device completed the tests and experienced only a few minor technical problems. The field tests, although limited, demonstrated that PRORUT provided useful pavement profile information and that its output could be correlated to several response-type measurement systems.

Unfortunately, the States were not able to obtain what they felt were good rut-depth measurements. Consequently, this area may require further development. One State recommended that additional laser sensors be used to improve PRORUT's rut measurement capability. Another pointed out that the PRORUT vehicle and onboard computer system were rapidly becoming outdated. A new vehicle would provide for safer, more reliable operations; an updated computer could significantly improve the system's data collection and processing capabilities.

Up to this point, the FHWA has provided all funding to develop and test PRORUT. This funding has produced an economical, user-friendly device with the potential of becoming a valuable pavement data collection tool for State and local highway agencies. The California Department of Transportation (Caltrans) is interested in PRORUT and has evaluated its potential for use in its pavement management program. As of this writing, Caltrans decided to build its own updated version of PRORUT. Other highway agencies should monitor Caltrans' progress and, based on their findings, consider building their own systems.

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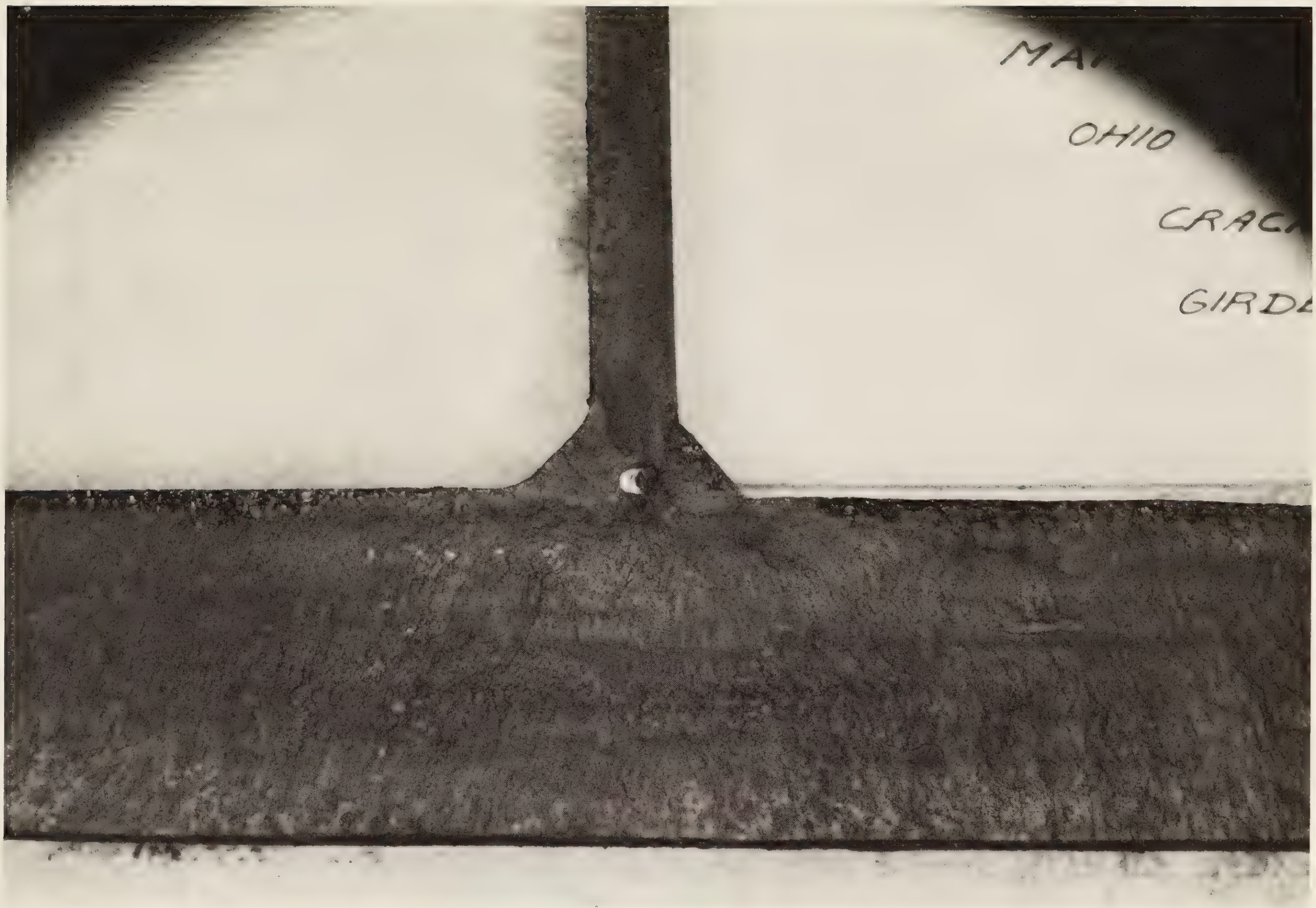

Laboratory Evaluation of a Fractured Steel Plate Girder Bridge

by Charles H. McGogney and Sheila Rimal Duwadi

Introduction

In January 1987, the Ohio Department of Transportation (ODOT) discovered a crack on a steel girder bridge in Cleveland. Unable to determine if it was caused by stress- or material-related factors the ODOT sought assistance from the Federal Highway Administration (FHWA). In response to this request by FHWA Ohio Division office, samples of the fractured girder were shipped to the Turner-Fairbank Highway Research Center (TFHRC). Here extensive examination of the fractured surfaces and analyses of the mechanical and chemical properties were planned and conducted to determine the source and causes for crack initiation.

Background

The steel girder bridge is an 805-ft (245.5-m) five-span bridge erected approximately 30 years ago. The span lengths are 140 ft, 175 ft, 175 ft, 175 ft, and 140 ft (42.7 m, 53.3 m, 53.3 m, 53.3 m, 42.7 m). All are simple spans except the second and third, which are continuous. The cross section consists of four welded beams, possibly A7 steel with weldable properties. Each beam has 84- by ½-in (2133.6- by 12.7-mm) webs and 20- by 1 7/8-in (508- by 47.6-mm) flanges. (See figures 1 and 2.) The bridge was designed for a basic allowable stress of 18 ksi (124 105 kPa). The crack was in an interior girder of the third span, approximately four-tenths of the span length from pier 2. It had opened to a ½-in (12.7-mm) wide gap in the bottom flange and had traveled up the web and into the top flange before being detected. (See figure 3.) A

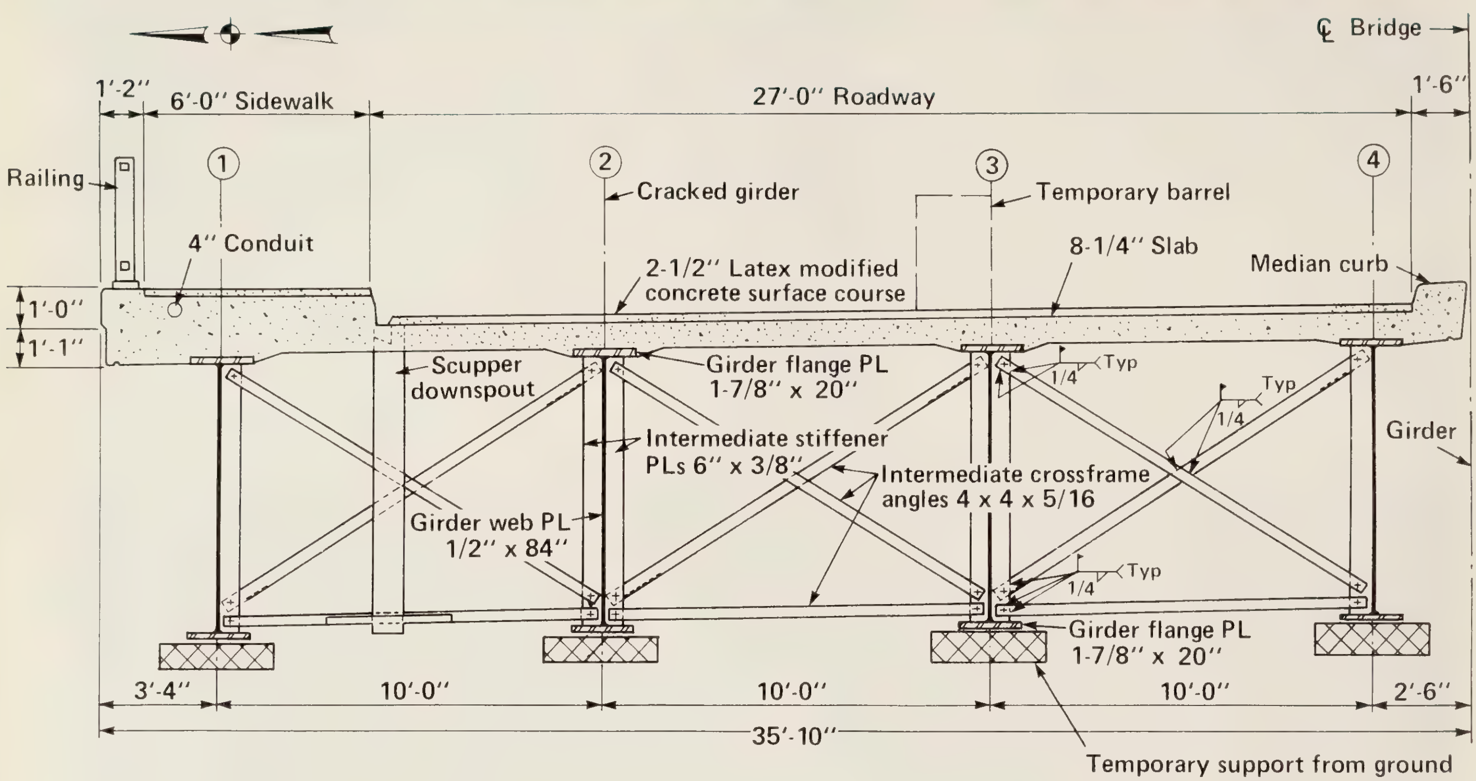

Figure 1.—Half transverse section.

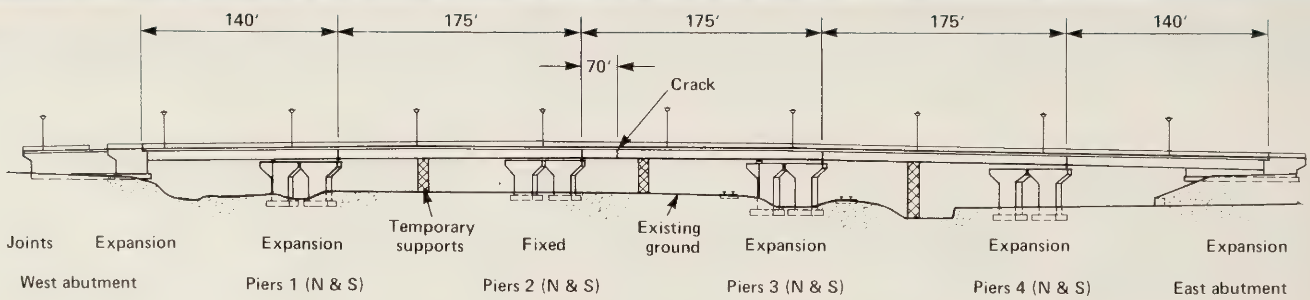

Figure 2.—Elevation.

welded web splice was located within 4 to 5 in (101.6 to 127.0 mm) of the crack. The girders were unpainted but exhibited no apparent section loss.

Specimen Testing

A portion of the fractured girder was received at the TFHRC. It included at least 3 in (76.2 mm) of material on adjacent sides of the crack with the lower 18 in (457.2 mm) of web. (See figure 4.) Upon receipt of this sample, plans were made to etch the fractured surface chemically to clean any rust that had formed on the open face and better expose the fractured area. Next, a series of tests were planned and conducted as follows:

- The welds were visually examined to see if there were any weld repairs, inclusions, etc., around the fractured area.
- Charpy V-notch (CVN) impact specimens were prepared and tested per American Association of State Highway and Transportation Officials (AASHTO) and American Society of Testing and Materials

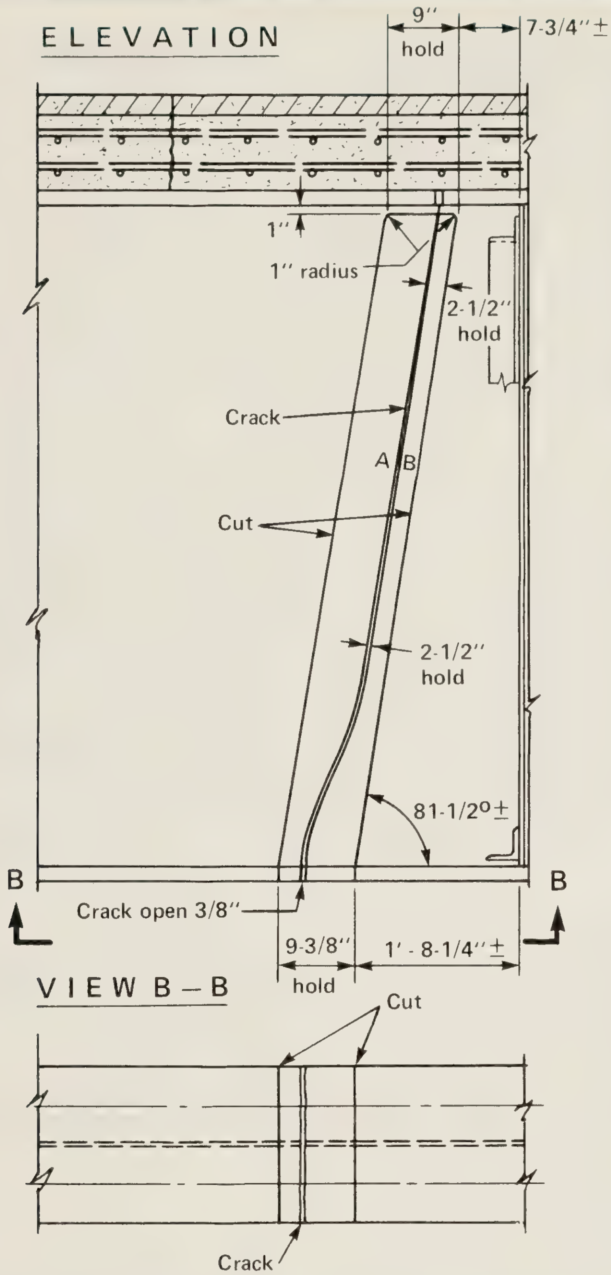

Figure 3.—Location of crack.

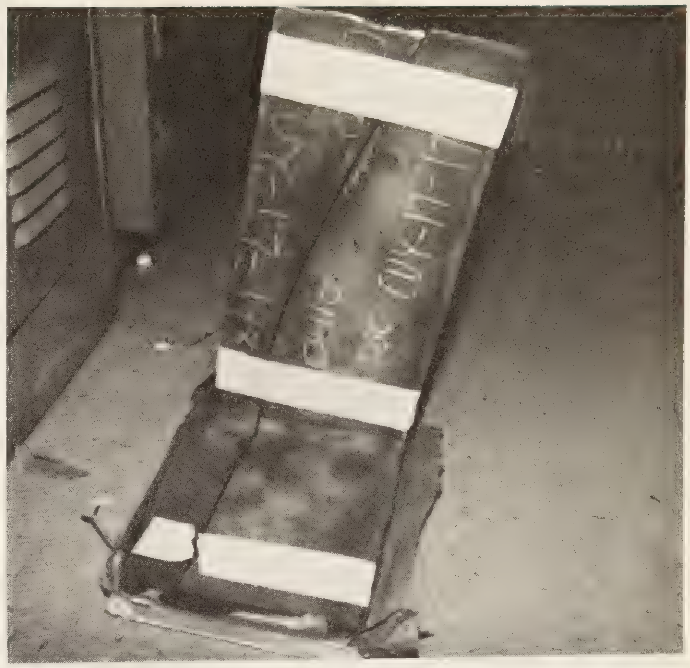

Figure 4.—Cracked section as received in the laboratory.

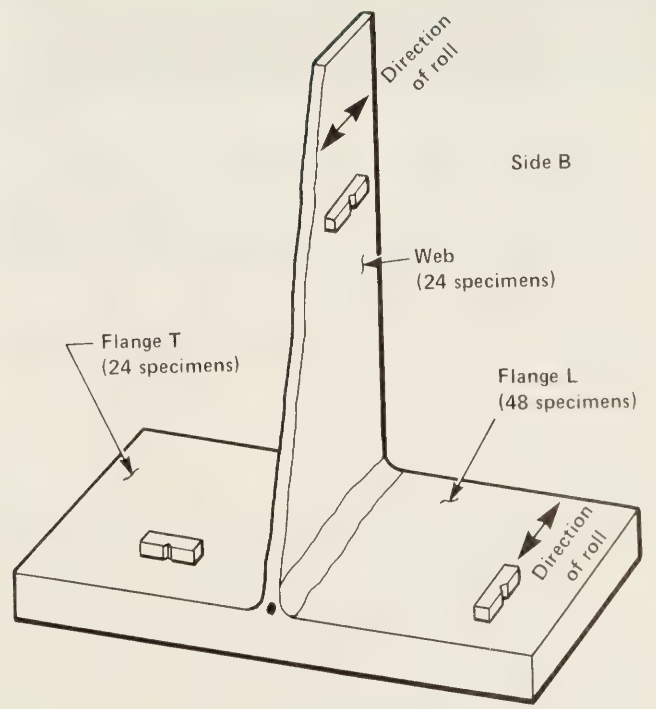

Figure 5.—Orientation of Charpy specimens.

(ASTM) standards. (*1,2*)[1] Ninety-six Charpy specimens were fabricated. The length of the notch was oriented perpendicular to the rolling direction or extension of the material as prescribed in the standards. (See figure 5.)

- Hardness tests were performed on the girder's polished and etched surface.

- The flange and web were chemically analyzed—using spectrographic methods—by the Chicago Spectro Service Laboratory, Inc., an independent laboratory.

[1]Italic numbers in parentheses identify references on page 130.

- Using the scanning electron microscope (SEM) areas of approximately 1-in (25.4-mm) radius around the inclusion from both faces of the fractured surface were examined.

- Finally, an analysis of crack growth was conducted using fracture mechanics concepts.

Results

Visual examination

Visual examination revealed a weld repair at the site of the crack. Also, after one of the fractured faces was etched, a white inclusion was found in the web-to-flange connection of the weld. (See figure 6.) This was deemed a prime suspect of crack initiation. The etching also revealed fatigue striations and chevron marks; all the indications of crack initiation pointed to the inclusion area.

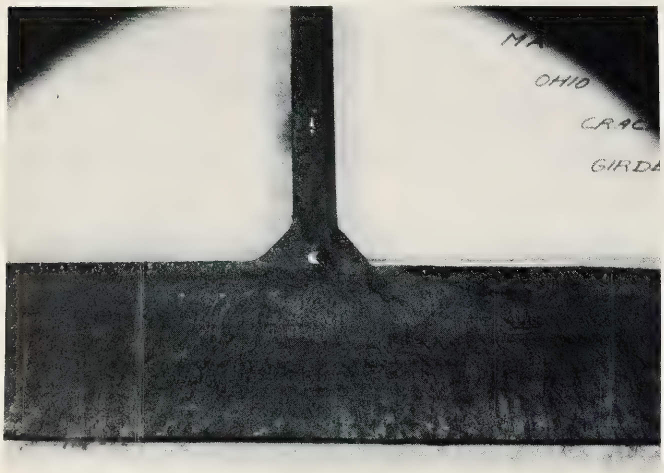

Figure 6.—Etched fracture surface revealing inclusion.

The polished and etched surface of the opposite face showed details of the welded connection. From this, it was concluded that this was a beveled full-penetration groove weld. However, there was some lack of fusion in the weld, and a void of approximately 3/16-in (4.8 mm) diameter was found to run through the weld area of the girder.

Toughness test

There was very little scatter in the CVN dial energy values at both the lower and upper shelves; there was some scatter, however, in the transition zone. Test results show that the CVN values for the flange's transverse specimens (flange T) have the least toughness. (See figure 7.) This is as expected, since crack propagation is parallel to the grain boundaries. The CVN values for the flange's longitudinal specimens (flange L) are slightly higher since they represent shearing across the grains; values for the web are highest because the web was rolled thinner, compressing the grains. The curves show that the transition temperature is approximately 80 $^{\circ}$F (26.7 $^{\circ}$C).

Per AASHTO designation M161, the bridge is in a Zone 2 area where the minimum service temperature is from 0 to -30 $^{\circ}$F (-17.8 to -34.4 $^{\circ}$C). (*1*) For this zone, the toughness requirement is such that the CVN energy should be 15 ft • lb at 40 $^{\circ}$F (20.3 N-m to 4.4 $^{\circ}$C). The curve in figure 7 shows that this requirement is not satisfied by flange L values (9 ft • lb [12.2 N-m]), is barely satisfied by flange T values (15 ft • lb [20.3 N-m]), and is exceeded only by the web values (17 ft • lb [23.0 N-m]). In this fracture, the flange L values are of importance because the fracture surface of the girder shows the fatigue crack originated in the flange before progressing into the web. Therefore, the steel does not quite satisfy the current AASHTO requirement for Zone 2.

Hardness test

Hardness values were obtained using the Wilson Rockwell hardness tester with a 1/16-in (1.6-mm) diameter ball. (See table 1.) The weld is much harder than either the flange or the web and corresponds to a higher tensile strength. The flange is the next hardest material, corresponding to a 66-ksi (455 054-kPa) tensile strength.

Chemical analysis

Since this bridge was built in the 1950's, the applicable ASTM specification is ASTM A373. The chemical constituents of A373 steel together with the results of the spectrographic analysis are given in table 2. From this, it can be seen that—except for copper—the material satisfies the then-current ASTM standard. Thus, it was concluded that the steel in the bridge is A373 or A7, with chemistry suitable for welding.

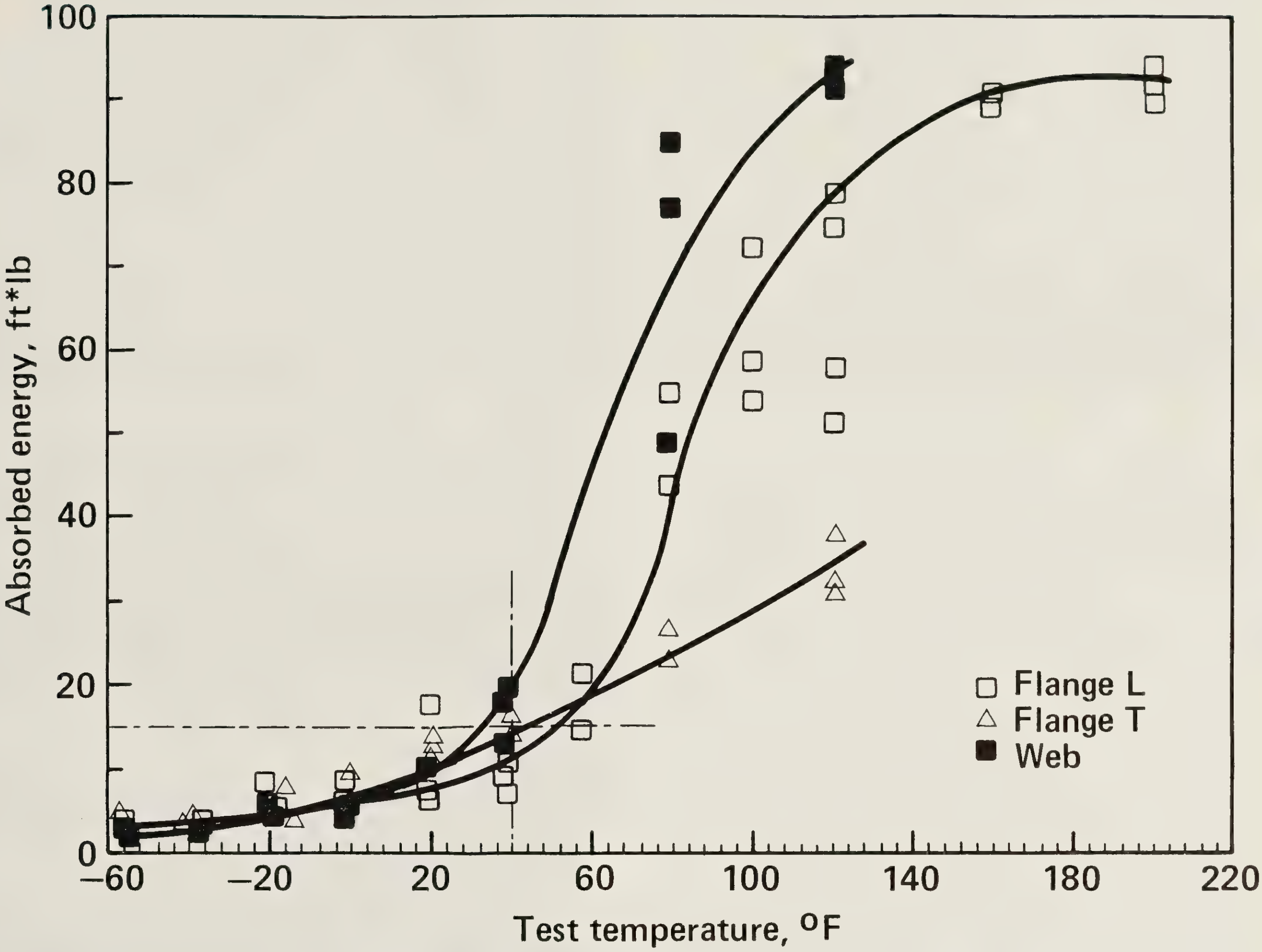

Figure 7.—Energy absorbed versus temperature.

Table 1.—Rockwell hardness test "B" scale

	Hardness	Average Hardness	Tensile Strength[1]
Flange	72, 71, 78, 78, 76, 73, 76, 78, 74, 73, 74, 74, 74, 76	75	66 ksi
Web	73, 71, 73, 71, 71, 68, 67, 67, 69, 67, 73, 74, 67, 71, 75	70	61
Weld	92, 91, 93, 94, 93, 99, 98, (101), (102), (103), (100), 97, 97, 92, 94, 94	96	102

[1] Based on conversion tables found in references (*2*) and (*5*).

Table 2.—Chemical analysis

Sample	Flange	Web	A-373 (1954)	A-36 (1970)
Carbon	0.24%	0.24%	0.30 max	0.30 max
Manganese	0.62	0.47		
Phosphorus	0.009	0.009	0.05 max	0.05 max
Sulfur	0.022	0.031		0.063 max
Silicon	0.21	0.07		
Nickel	0.05	0.02		
Chromium	0.10	0.01		
Molybdenum	0.02	< 0.01		
Copper	0.05	0.05	0.18 min	0.18 min

SEM analysis

The scanning electron microscope revealed fatigue lines in the flange, but none in the web, at 670X magnification. (See figures 8 and 9.) The chemical constituents of the inclusion were also obtained. These showed that there was primarily aluminum in the outer areas of the inclusion and silicon in the inner areas.

Fracture mechanics analysis

The analysis assumed the 3/16-in (4.8-mm) inclusion in the weld was the initial flaw size, and a fatigue crack, resembling a semielliptical surface crack, grew within the flange from this initial flaw. (*3,4*) (See figures 10 and 11.) The fracture surface showed tearing in the flange outer edges and brittle fracture in the web. (If fatigue occurred in the web, it could not be seen with the magnification available.) The stress range for crack propagation was taken to be from zero to the maximum tensile live load stress at the location of the flaw under HS-20 truck loading.

The girder experienced approximately 1.6 million cycles. With a 30 year life span, this would be about 146 cycles per day.

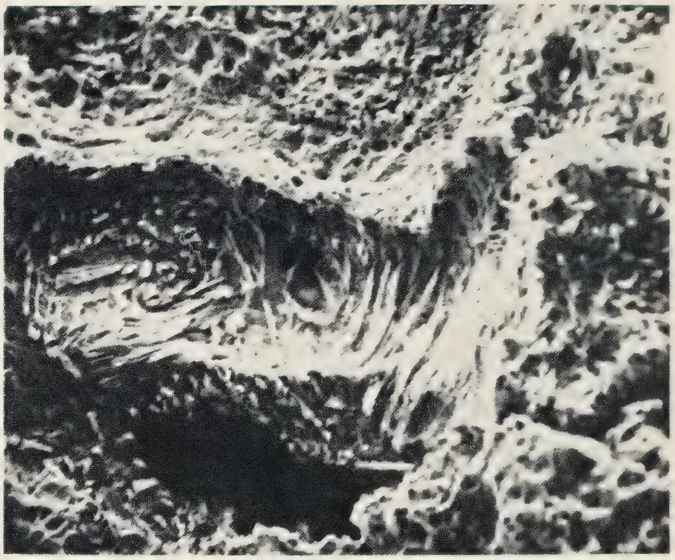

Figure 8.—Striations in flange, magnification 670X.

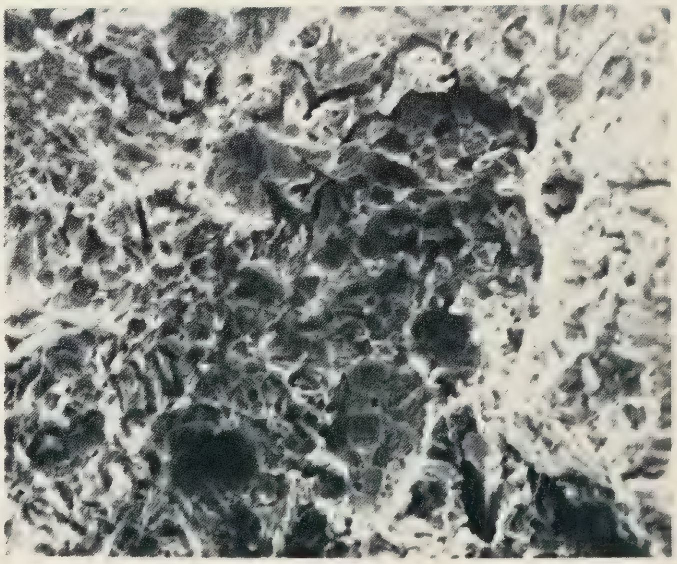

Figure 9.—No striations in web, magnification 670X.

Conclusions

Based on the results from the above-discussed macro and micro examinations of the fractured surfaces, mechanical tests, and chemical analyses—as well as from published information on fractures of this type—the following conclusions were drawn.

- The etched fracture surfaces revealed a lack of penetration in the welded area that extended for the length of a repair weld.

- The etched fracture surface revealed an inclusion in the center of the weld area.

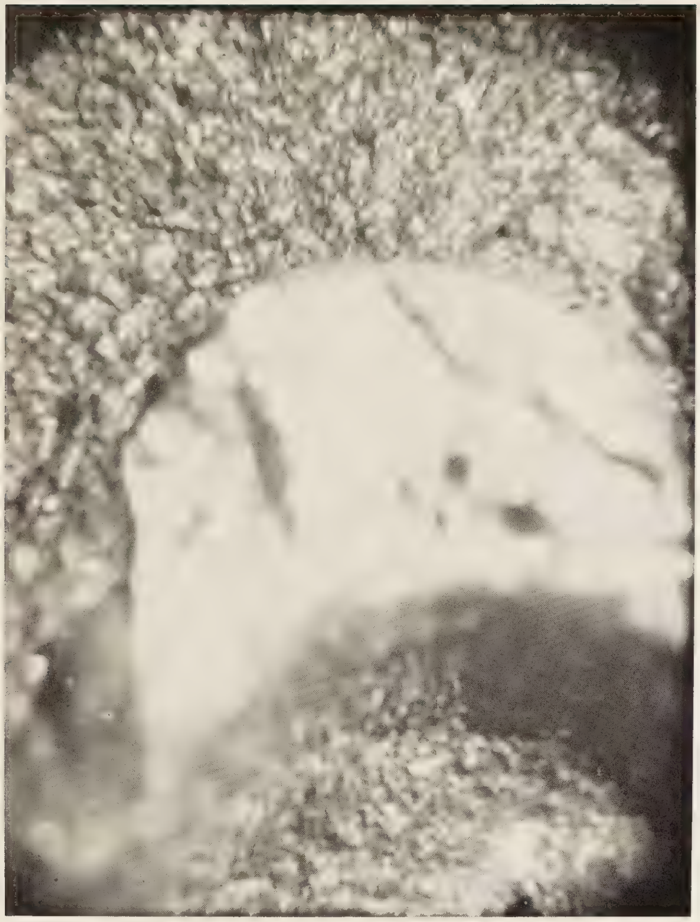

Figure 10.—Inclusion, magnification 20X.

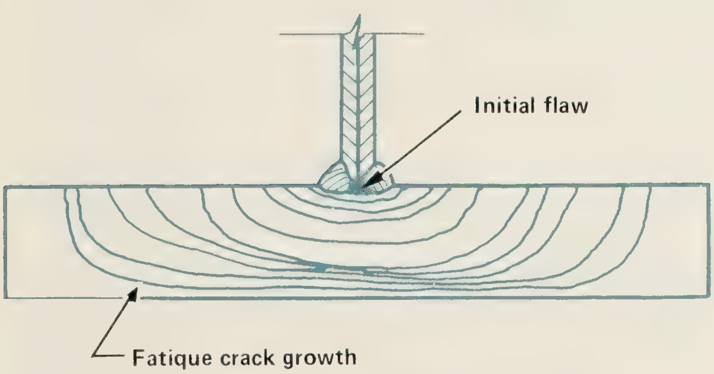

Figure 11.—Semielliptical crack growth.

- A weld repair had been made in the area of the inclusion.

- Fatigue striations were identified under the SEM in the flange weld area sample.

- Overall features on the fracture surfaces—i.e., fatigue striations, herringbone, or chevron patterns—all point to the inclusion as the source of fracture initiation.

- The configuration and chemical composition of the inclusion are typical of a section of an unfused welding rod.

- The fracture growth examined by visual and SEM methods most resembled a semielliptical pattern.

- Assuming the fracture growth to be semielliptical for fracture mechanics analysis and with an HS-20 truck loading, the total number of cycles to failure was calculated to be 1.6 million.

- The Charpy V-notch analyses revealed that the steel failed to meet the requirements of AASHTO M161 for Zone 2 (15 ft • lb at 40 °F [20.3 N-m at 4.4 °C]).

Recommendations

This study demonstrates that weld repairs may do more harm than good, especially if they are field repairs.[2] All weld repairs require close scrutiny. The following specific recommendations are offered for consideration:

- Visual inspections of all welded details on the bridge should be performed to identify areas of weld repair and/or any unusual weld patterns.

- Weld areas identified as suspect should be examined ultrasonically and/or radiographically.

- Weld areas with "rejectionable" inclusions and/or anomalies should be scheduled for core extraction for further chemical, mechanical, and metallographic examinations.[3]

[2] The detailed report, "Laboratory Evaluation of Fractured Steel Plate Girder—Maple Heights, Ohio," was written by Charles McGogney and Sheila Duwadi. FHWA Laboratory Report No. 89-002, Federal Highway Administration, Washington, DC, December 1987.

[3] Core drill and bits are available from the FHWA Turner-Fairbank Highway Research Center, McLean, Virginia.

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Motorist Compliance With Standard Traffic Control Devices

by Martin T. Pietrucha, P.E., Richard L. Knoblauch, Kenneth S. Opiela, Ph.D., and Kristy Crigler

Traffic control devices (TCD's) are the primary means of regulating, warning, and guiding vehicles and pedestrians. Motorist disregard of TCD's has become a concern in the highway safety community. Many believe it seriously undermines the safety and efficiency of the Nation's streets and highways.

Figures 1 through 4 show typical acts of motorist noncompliance. Common forms of such noncompliance include:

- Speeding.
- Not coming to a full stop at STOP signs.
- Failing to yield right-of-way to pedestrians.
- Ignoring active railroad crossing devices.
- Making illegal turns.
- Using lanes improperly.
- Violating traffic signal indications.
- Driving too fast through work zones.
- Encroaching on centerlines.
- Violating passing zone restrictions.

Project Objectives and Approach

A recent research effort analyzed motorist noncompliance, focusing on three basic questions: (*1*)[1]

- Is there a motorist compliance problem?
- If there is a problem, how critical is it?
- If there is a problem, how can it be addressed?

To answer these questions, a multifaceted research program was conducted. It included a review of past studies of compliance; interviews with motorists; observations of motorist behavior; discussions with professionals in engineering, enforcement, and motor vehicle administration; and countermeasure identification and testing.

Literature Review

The research began with a comprehensive review of available literature. While considerable information was found in the areas of highway safety, driver behavior, and traffic control device effectiveness, data quantifying motorist compliance were limited.

The following general conclusions were drawn from the literature:

- Driver behavior is a function of the need to adapt to traffic conditions and meet the psychodynamic requirements of the driver. Although certain personality traits may lead to noncompliance with traffic controls, driver groups with those characteristics do not necessarily have more accidents.

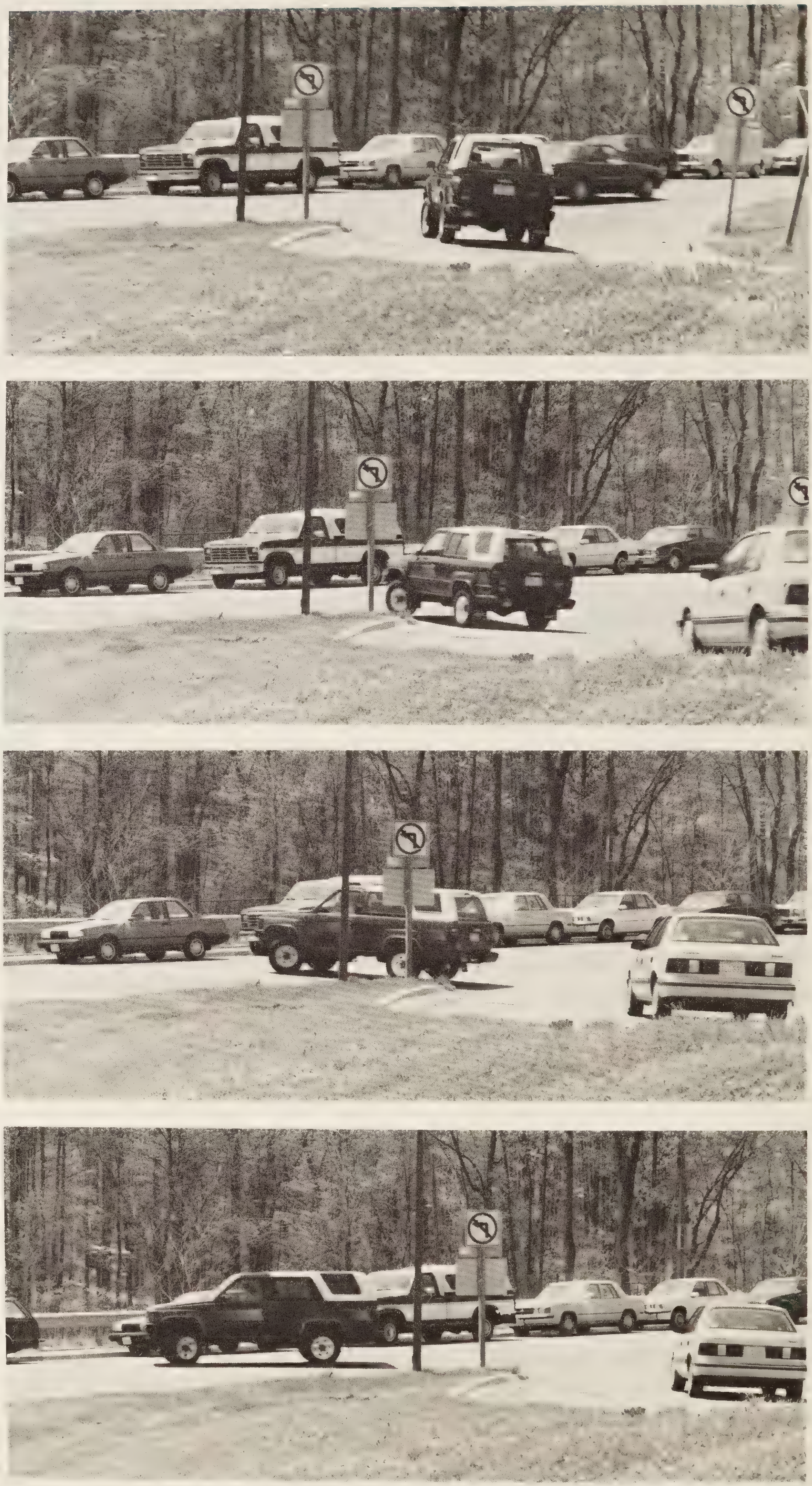


Figure 1.—Sequence of photographs shows a driver violating a clearly visible NO-LEFT-TURN sign.

[1] Italic numbers in parentheses identify references on page 138.

• Drivers observe—or ignore—traffic controls based on the control's "perceived reasonableness" and the "perceived chance" of being caught violating the control.

• Compliance with speed limits has been studied extensively over the years. If speed limits are reasonable, they seem to be accepted by drivers. Although enforcement efforts result in significant increases in compliance, the effect is temporary.

• Studies dating back to the 1930's indicate that over 50 percent of motorists fail to come voluntarily to a complete stop at STOP signs. Data from these studies, however, are not sufficiently consistent among studies to determine if there has been a significant change in compliance over the years.

• The relatively recent implementation of right-turn-on-red (RTOR) legislation has led to several compliance studies. These studies have found consistent levels of noncompliance; however, traffic conflicts rarely result from this form of noncompliance.

• Red-signal violators have been similarly quantified and associated conflicts were found to be rare.

• Considerable research has focused on motorist compliance at railroad-highway grade crossings. Studies indicate that motorists often question the credibility of the controls.

• Studies of controls such as protected-permissive left turn signalization note good compliance when the motoring public understands the controls.

Table 1.—Summary of traffic control devices/laws and noncompliance actions selected for investigation

Traffic Control Device/Law (MUTCD Reference Code)	Noncompliant Action
Traffic Signals	• Running the red.
	• Right turn on red without full stop.
STOP Signs (MUTCD R1-1)	• Failure to come to complete stop.
NO-LEFT-TURN Signs (MUTCD R3-2)	• Left turns where prohibited or restricted.
Advisory Speed Panel (MUTCD W13-1)	• Exceeding the advised speed.
School Bus Operations	• Passing stopped school buses displaying flashing lights.

• Selective enforcement, remedial driver training, and driver points systems are effective in promoting motorist compliance. However, the literature review provided very little information on the extent of motorist noncompliance and whether it has been changing over time.

In addition to the literature review, several other activities were conducted to identify relevant information. Current research projects were reviewed to determine the nature of other efforts related to motorist compliance with TCD's. Unfortunately, the reviews provided no relevant information. Several agencies associated with highway safety, traffic enforcement, and driver licensing were contacted to determine whether a motorist compliance problem exists. While there was consensus that a problem does exist, few agencies have attempted to quantify the extent of noncompliance to correlate it to safety.

Additionally, various national accident data bases, a State accident/citations data base, and the data base created to monitor compliance with the national maximum speed limit were all reviewed to determine the extent of the noncompliance problem and to measure changes in noncompliance over time. It was concluded, however, that existing data bases could only provide limited insights into the nature and extent of noncompliance.

Despite this extensive background research, overall results were somewhat disappointing. For example, almost all of the information received from various police agencies, motor vehicle administrations, State highway departments, and user groups was subjective or anecdotal. Also, while there was agreement regarding which TCD's are violated most frequently, little specific information was available on the extent of motorist noncompliance. The efforts of the first phase of the research therefore failed to identify a specific set of TCD's or laws that was a problem.

Thus, based on professional expertise—and to avoid duplication with other on-going projects—six traffic control devices or laws were chosen for indepth study. These six and their associated compliance problems are noted in table 1.

Attitudinal Studies

To develop insights as to the reasons for traffic violations, 185 drivers were asked how often they violate TCD's. Their responses clearly indicated that noncompliance occurs; in some cases, frequently. The "chronic violators" interviewed were less inclined to comply with TCD's and laws than typical drivers. A major influence on compliance or noncompliance was the driver's assessment of the reasonableness of a TCD. Drivers doubt reasonableness when a device appears to be overly restrictive, not functioning, or poorly placed. Thus, when deciding whether to comply, drivers assess the safety risks for themselves. While the chance of being caught by the police is also considered, it is secondary to the perceived reasonableness of the TCD. These findings agree with the literature reviewed.

Behavioral Studies

It became apparent after the first two phases of the project that the motorist compliance problem could be quantified only through structured field studies. Measurements of compliance were established by gathering traffic operations data at a number of similar sites in four different States. The sites were classified as either experimental or control based on local perceptions as to where problems existed. Table 2 describes the noncompliant behavior observed, the number of sites, the number of vehicles observed, and the amount of noncompliance observed. For each problem situation, data were gathered using special procedures developed for this study.

Problem: Running through red lights at signalized intersections

Motorist efforts to stretch the green phase at signalized intersections often result in vehicles running through red signals. This problem is most serious in the case of vehicles that have not had to slow or stop at the intersection: they are properly entering the intersection on the green, while cross traffic may still be improperly entering the intersection. This situation can lead to serious right-angle conflicts. (A conflict was defined as any action by a study vehicle that caused a change in the speed or travel path of the study vehicle and/or another vehicle or pedestrian.)

To determine the extent of this problem, 79,055 vehicles were observed at 156 intersection approaches. Violations occurred at the rate of 5.1 per hour; and 688 vehicles entered intersections on the red signal, either early or late. Only 10.8 percent of these violations resulted in a conflict with other vehicles (N=74).

The data were statistically analyzed to determine if noncompliance was associated with traffic levels, intersection type, or other factors. In these analyses, the effects of cycle length, approach volume, vehicle type, speed limit, and time (peak/off-peak) were not significant.

Problem: Failing to come to a full stop at STOP signs

Proper STOP sign compliance requires the motorist to come to a complete stop. However, rolling stops are very common at stop controlled intersections. Because a rolling stop gives the motorist less time to determine if it is safe to proceed, noncompliant behavior theoretically could lead to an increased chance for conflicts. The field observations were noted for situations when cross-street vehicular or pedestrian traffic necessitated a full stop versus when no cross-street traffic was present.

Field observations were made at 142 intersection approaches (table 2). The observers counted and categorized vehicles by type, turning movement, and kind of stop made. Full stops were observed most often when cross-street traffic was heavy. Rolling stops were noted for 21,110 vehicles; this implies that violations occurred at the rate of 68 percent. Conflicts resulting from a failure to come to a complete stop occurred for only 1.9 percent of the vehicles observed.

Statistical analyses of the field data showed a difference between high-violation locations and controls for certain conditional subsets. However, the difference between all experimental and control sites was not significant: the rate of conflict involvement varied from 0.17 percent for high-violation locations to 0.05 percent for control locations. The effect of cross-street volumes was also analyzed. The conflict involvement rate increased up to 900 vehicles per hour and then decreased. This may be considered a natural consequence of the need to stop as the traffic volumes increase. The statistical analysis also indicated that the incident rate increases with the number of lanes on the cross street. This may be explained by the driver's increasing difficulty in judging the position of vehicles in multiple lanes. Compliance rates did not increase when sidewalks, and possibly pedestrians, were present.

Table 2.—Summary of data collection effort

Noncompliant Behavior	Hours of Observation	Number of Sites	Number of Vehicles	Number of Violations	Violation Rate[1]	Number of Conflicts	Conflict Rate[2]
Running the Red Signal	135	156	79,055	688	.009	74	.108
Failure to Come to Complete Stop at STOP Sign	528	142	31,212	21,110	.676	407	.019
Right Turn on Red	440	146	21,434	13,142	.613	303	.023
Violating NO-LEFT-TURN Sign	152	115	53,165	881	N/A[3]	137	.156
Violating Advisory Curve Speed		113	5,573				
Passing Stopped School Buses		2,615		184			

[1] Number of violations observed divided by total number of vehicles observed.
[2] Number of conflicts observed divided by number of violations observed.
[3] N/A = not applicable.

Problem: Failing to stop completely at signals when turning right on red

Violations of the RTOR law take the form of rolling stops and failures to yield to pedestrians in the crosswalks. Observers noted drivers' use of signaling as well as whether a voluntary full stop was made.

During 440 hours of field work at 146 intersections, 51,056 right-turning vehicles were observed—21,434 of which were turning right on red. The observers counted and categorized vehicles by type, turning movement, and kind of stop made. About 61 percent (N=13,142) of the RTOR vehicles failed to make a full stop. However, only 1.4 percent of all right-turning motorists, and 3.1 percent of those turning right on red, caused a conflict. In fact, more of the vehicles that came to a complete stop caused a conflict (3.4 percent) than did those that turned without making a complete stop (2.8 percent). This low rate of conflicts is consistent with a recent study. (*2*)

Statistical analyses of these data revealed a difference between high-violation and control sites. Incident rates varied from 0.005 to 0.001 percent per vehicle. This suggests, to some degree, that perceptions about high-noncompliance locations are accurate. The analyses indicated that cross-street volume had a main effect, but it failed to show any difference in compliance rates relative to approach street volumes and the presence of sidewalks or pedestrian signals.

Problem: Ignoring NO-LEFT-TURN restrictions

Many experts regard NO-LEFT-TURN violations to be a serious problem. Motorists often turn left illegally, at locations with posted full or time-based left-turn restrictions.

Field data were collected at 115 intersection approaches for over 150 hours. For the 53,165 vehicles observed, there were 881 illegal left turns. About 16 percent of the illegal left turns resulted in a conflict; most of these (75 percent) involved vehicles that were traveling in the same direction as the illegally turning vehicle and that were forced to slow or turn to avoid the vehicle. Only 4 percent of all illegal left turns resulted in a conflict with traffic approaching in the opposite direction.

The statistical analyses of the left-turn compliance data found a difference in the rate of incidence between high-violation locations (2.99 percent of the vehicles) and control locations (1.07 percent). However, approach volume, time-based restrictions, type of intersection control, and State made no significant difference. Apparently, the occurrence of illegal left turns is not directly related to any of these factors. It was also noted that, as approach volumes increased, the number of left-turn violations decreased. This may be due to an increased fear of getting caught when more traffic is present, a desire to avoid conflict-producing situations, or other factors.

Problem: Ignoring advisory speed panels at roadway curves

Advisory speed panels provide supplemental information to motorists about situations that warrant slower speeds. Motorists frequently ignore safe speeds for curves posted on advisory speed panels.

Radar measurements of vehicle speeds were taken on 5,573 vehicles at 113 curves with advisory curve speeds posted. Speeds were recorded on the approach to the curve before vehicles begin to decelerate and at the point of curvature. The vehicles observed exceeded the advisory limit by an average of 5 to 6 mi/h (8.05 to 9.66 km/h). Analysis of variance was used to determine what factors might be associated with noncompliance. No significant interaction was found for pavement condition, vehicle type, horizontal curvature, pedestrian accommodations, or State. There was, however, a significant main effect for speed reduction and the use of curve versus turn signs and a significant interaction between them. This is not surprising since turn signs are used at curves posted at 25 mi/h (40.23 km/h) or less, and the actual speed drop at sharper curves must be greater. Analysis also revealed that the degree of horizontal curvature and the existence of pedestrian facilities also are significantly related to compliance. Motorist compliance appears to be highest in built-up areas as opposed to remote locations and at locations where the curves are more severe.

Problem: Passing school buses loading/unloading children

All States require motorists to come to a complete stop for school buses displaying flashing lights while loading or unloading students. Violations of this law were a concern by a panel of experts.

Observers rode on 234 school bus "runs" and noted motorist behavior at 2,615 school bus stops. At 94 percent of the stops, no vehicles passed the bus; at 4 percent of the stops, one vehicle passed; at 2 percent of the stops, two or more vehicles passed. Chi-square analysis indicated that drivers are significantly more likely to pass a bus when children are getting *off* than when they are getting *on*. It is not known if this is because motorists are less patient in the afternoon or less willing to pass a bus in the morning when they see a child waiting. Chi-square analysis also indicated that noncompliance is significantly higher at intersections than at midblock locations. This is possibly due to motorist confusion about the law regarding stopping for a school bus stopped at an intersection. There was no significant correlation between violations from the analysis of flasher mode, auxiliary bus equipment (i.e., swing-arms), vehicle passing direction, roadway type, land use, or terrain.

Development of Practical Countermeasures

The behavioral studies indicated that motorist noncompliance exists, but that the associated safety risk (as indicated by traffic conflicts) appears to be low. However, accidents can occur even if the rate of conflict incidence per vehicle is low; this is particularly true in highway situations where design or terrain features increase risks.

A panel of experts assessed the findings of the initial phases of the project and identified practical countermeasures to address motorist noncompliance. Their conclusions are reflected in the following recommendations.

Conclusions and Recommendations

Is there a motorist compliance problem?

The collective memory seems to recall a past when there was more respect for traffic control devices. However, the literature review and contacts made during the first phase of this project provided little historical information regarding noncompliance rates for different TCD's. There are, thus, few ways to determine if violation rates have been increasing.

Figure 2.—Parking controls are often necessary for the safe and efficient movement of traffic. These photos show blatant disregard for parking regulations.

Figure 3.—This sequence of photographs shows a driver making a prohibited U- TURN at an intersection that has severe congestion.

Figure 4.—Even large vehicles operated by professional drivers ignore traffic control devices as in the case of this NO U-TURN sign.

In one of the few areas where relevant past research was discovered, a review of research on driver behavior at STOP signs suggests a progressive increase in the level of motorist noncompliance. (*3*) Analysis of noncompliance data gathered in this study suggests a rollback in rates to 1935 levels. The differences in noncompliance rates cited in the various studies may not reflect actual changes in motorist behavior, but simply differences in experimental procedures.

A recent study found that 64.4 percent of the drivers making a right turn on red did so without stopping. (*2*) In the present project, 61.3 percent of the motorists making a right turn on red did not stop. Since these projects used similar procedures, the results can be compared directly. In the 10 years between these two studies, there was no significant change in motorist noncompliance.

The behavioral studies collected compliance and other data at a large number of typical sites over extended periods of time. In the process, hundreds of thousands of motorists were observed. The clear conclusion was that motorist noncompliance *does* take place. Whether it is a serious problem cannot be ascertained. The relative frequency of conflicts (a surrogate measure of accidents) resulting from noncompliance was very low. These low levels are attributed to motorists assessing the risks associated with noncompliance. It appears that the majority of drivers assess risk correctly and act prudently. It was not possible to determine whether noncompliance poses a more serious problem in nontypical situations.

In general, motorist noncompliance is indicative of a larger problem. This problem may be due to some failing on the part of traffic engineers or a lack of understanding by the driver. Seldom is noncompliance the result of the motorist's wanton disregard of the law.

What does this mean to traffic engineers and planners?

The ultimate purpose of research is to provide information or tools for practitioners to use to maintain a safe and efficient roadway network. The following general recommendations are provided to improve efforts to implement traffic control devices and laws. These address traffic control needs from a multidisciplined approach involving engineering, enforcement, and education.

Engineering

- Be cognizant of changes in the traffic system: traffic volumes, traffic characteristics, and the condition of TCD's.

- Apply TCD's consistently to ensure they command respect.

- Compile noncompliance data to develop thresholds for determining when noncompliance rates are above acceptable limits.

Enforcement

- Target enforcement to high-accident locations.

- Set uniform enforcement policies.

- Compile data for monitoring compliance levels and accidents.

Education

- Educate drivers about the reasons for traffic control devices.

- Continually reinforce motorist compliance.

To ensure that the motoring public maintains a healthy respect for TCD's, traffic professionals must use them prudently. Through concerted efforts of the nature outlined above, the safety and efficiency of our streets and highways can be maximized.

References

(*1*) M.T. Pietrucha, K.S. Opiela, R.L. Knoblauch, and K.L. Crigler. "Motorist Compliance With Standard Traffic Control Devices," Publication No. FHWA–RD–89–103, Federal Highway Administration, Washington, DC, April 1989.

(*2*) W.E. Baumgaertner. "Compliance With Right Turn on Red After Stop," *ITE Journal*, Vol. 51, No. 1, Washington, DC, January 1981, pp. 19-23.

(*3*) W. Stockton, R. Brackett, and J. Mounce. "Stop, Yield, and No Control at Intersections," Publication No. FHWA/RD–81/084, Federal Highway Administration, Washington, DC, June 1981.

Martin T. Pietrucha, P.E., was a senior transportation engineer at the Center for Applied Research, Inc. He worked on the research study "Motorist Compliance With Standard Traffic Control Devices," upon which this article is based. He is currently a program officer at the Transportation Research Board.

Richard L. Knoblauch is the director of the Center for Applied Research, Inc. He has been active in highway safety and human factors research for more than 20 years, including 9 years in his present position.

Kenneth S. Opiela, Ph.D., joined the Center for Applied Research Inc. in June 1988 as a senior transportation engineer. He played an active role in the data analysis and preparation of this article.

Kristy Crigler has been a senior technical editor at the Center for Applied Research, Inc. for 5 years. She has an M.S. degree in Human Factors. She played a key role in conducting the literature review and in preparing all the project documentation.

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 publication number) and the publication 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

Salt Penetration and Corrosion in Prestressed Concrete Members, Publication No. FHWA–RD–88–269

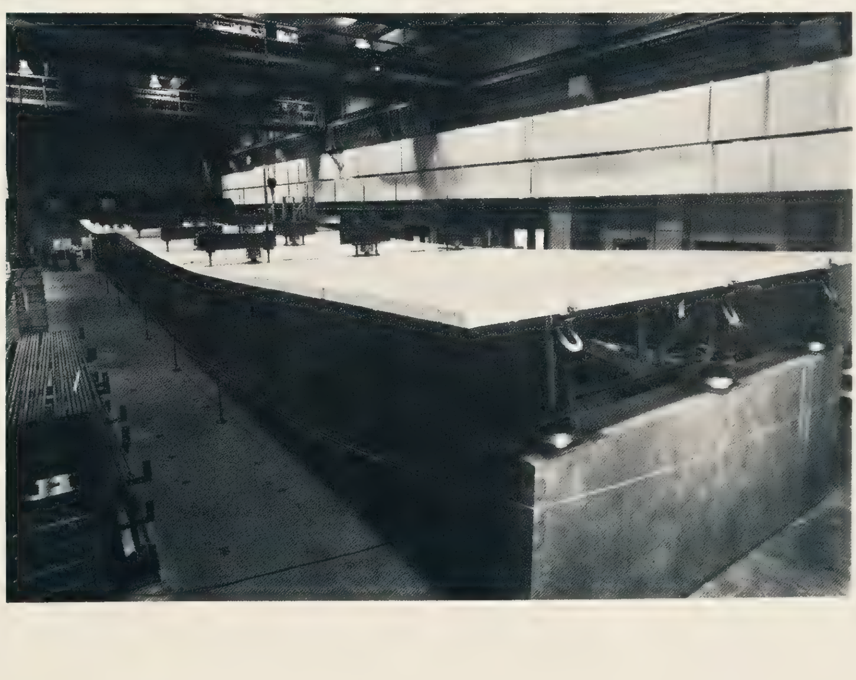
by Structures Division

The condition of prestressed concrete (PS/C) bridge elements located in adverse, potentially corrosive environments was studied. Five bridges were subjected to detailed surveys. Bridges were located both in northern climates subjected to application of roadway deicing salts and in southern areas subjected to marine spray.

Results indicated that, in northern areas, the primary cause of deterioration of PS/C members is caused by the penetration of solutions containing chloride ions through concrete cover and through anchorage zones. Improperly designed and maintained joints and drainage systems are the main pathways for the salt ingress. In southern areas, the primary cause of deterioration is marine salt sprayed directly onto substructural elements by wave action.

Recommendations concerning procedures, parameters, and threshold values for assessing the condition of prestressing steel in bridge components are included.

Limited copies are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No.90-115502/AS, Price code:A10.)



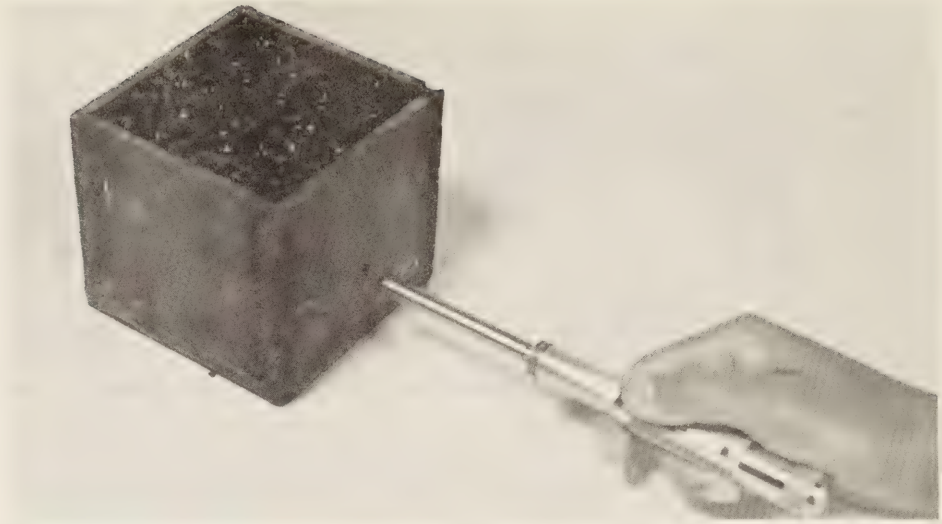
Load Distribution in a Two-Span Continuous Bridge, Publication No. FHWA–RD–89–101

by Structures Division

The Federal Highway Administration (FHWA) and the American Iron and Steel Institute conducted a joint research study in the FHWA's structures laboratory entitled "Structural Modeling for Autostress by Loading through a Precast Deck." The bridge under investigation is a two-span continuous three steel girder 0.4 scale model—113 ft (34.4 m) long. The deck, consisting of transversely pretensioned panels, posttensioned longitudinally, is composite with the steel girders. This report focuses on determining the elastic influence surfaces and wheel load distribution coefficients for reactions and moments.

In general, the experimentally determined parameters compared well with calculations by a finite element analysis. The experimentally determined parameters did not compare nearly as well with calculations using American Association of State Highway and Transportation Officials' methods or methods developed by others.

This publication may only be purchased from the NTIS. (PB No. 89-218432/AS, Price code:A13.)



More Effective Cold, Wet-Weather Patching Materials for Asphalt Pavements, Publication No. FHWA–RD–88–001

by Pavements Division

Most pothole repairs made during the winter months are short-lived, and constant repairs are costly. One reason for the short life of repairs done during the winter is that the commonly used repair mixtures cannot withstand the cold, wet weather. The objective of this project was to develop and test improved cold-mix, stockpile patching mixtures. To satisfy this objective, the predominant failure mechanisms and concomitant performance requirements were established. Binder performance was identified as the most promising area of study. More than 40 experimental binders were evaluated in the laboratory, and 5 of these binders were chosen for field trials. Current mix designs for cold-mix, stockpiled patching materials are inadequate, and, therefore, a new mix design procedure was adopted for use in the study. Field trials were conducted in which 410 repairs were made and then monitored over a 1-year period. Mixtures employing certain high-float, medium-set emulsion binders performed demonstrably better than companion control mixtures.

Limited copies are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 90-108580/AS, Price code:A08.)

HYDRAIN—Integrated Drainage Design Computer System, Vol. I: System Shell, Publication No. FHWA-RD-88-120; Vol. II: HYDRO—Hydrology, Publication No. FHWA-RD-88-121; Vol. III: PFP-HYDRA—Storm Drains, Publication No. FHWA-RD-88-122; Vol. IV: CDS—Culvert Design and Analysis, Publication No. FHWA-RD-88-123; Vol. V: WSPRO—Step Backwater and Bridge Hydraulics, Publication No. FHWA-RD-88-124; Vol. VI: HY8—Culvert Analysis, Publication No. FHWA-RD-88-125

by Structures Division

This project report, in six volumes, documents a system of computer programs for the design of drainage components such as culverts, storm drains, and open channels. The system includes an input generator to estimate design rainfall, hyetographs, design flow, and hydrographs. Programs are facilitated with semiexpert system shells that generate input data for engineering problems. The system is expandable and designed for personal computers that operate in an MS-DOS environment.

Volume I documents the control of the entire system of the pooled-fund project programs. The system shell is intended to support the analysis and design programs and facilitate communication—data transfer—between programs. It is also designed to provide a basis for file and disk management as well as permitting tutorial modules. Any MS-DOS file, input, output, or program file can be reviewed within this shell. To operate all the software, the user needs all six volumes.

Volume II documents the computer program HYDRO. Written in FORTRAN, it is based on the Federal Highway Administration (FHWA) Highway Engineering Circular (HEC) No. 19, *Hydrology*, and is an effort to combine existing approaches for rainfall and runoff analysis into one system. HYDRO generates point estimates or a single design event. HYDRO uses the probable distribution of natural events, such as rainfall or stream flow, as a controlling variable. HYDRO should be considered as a computer-based subset of HEC No. 19. To operate HYDRO, the user needs vols. I and II.

Volume III documents PFP-HYDRA which is a storm drain analysis and design program. This report is intended to introduce PFP-HYDRA and guide the user through the necessary steps toward designing or analyzing stormwater drains and/or sanitary sewer systems. Given certain design criteria, PFP-HYDRA will select the pipe size, slope, and invert elevations. Additionally, PFP-HYDRA will perform analyses on an existing system of pipes and/or ditches. The user needs vols. I and III to operate PFP-HYDRA.

Volume IV is a technical, user, and program supplement to more extensive available documentation for culvert design and analysis (CDS). It consists of three sections. The first section introduces CDS, describes its intent, and provides a system overview. The second section investigates the technical and operational methods used by CDS to analyze a culvert. The final section provides user documentation, and guides the user through the steps required to design or review a culvert without detailed technical explanation. The user needs vols. I and IV to operate CDS.

Volume V is a user supplement to existing, more detailed documentation for water-surface profile computation model microcomputer program (WSPRO); this code has been designed to provide a water-surface profile for six major types of flow situations: unconstricted flow, single-opening bridge, bridge opening(s) with spur dikes, single-opening embankment overflow, multiple alternatives for a single job, and multiple openings. The U.S. Geological Survey developed WSPRO for the FHWA. The user needs vols. I and V to operate WSPRO.

Volume VI is a technical reference guide for HY8 which is an interactive culvert analysis program that uses FHWA analysis methods and information published by pipe manufacturers. An important feature of HY8 is that it follows the logic of HDS-5, "Hydraulic Design of Highway Culverts." HY8 allows user-defined culverts to be analyzed by selecting appropriate parameters from menus. The program will compute culvert hydraulics for circular, rectangular, elliptical, arch, and user-defined geometry. The user needs vols. I and VI to operate HY8.

These publications may only be purchased from the NTIS.
Vol. I (PB No. 90-120841/AS, Price code:A04.)
Vol. II (PB No. 90-120858/AS, Price code:A04.)
Vol. III (PB No. 90-120866/AS, Price code:A06.)
Vol. IV (PB No. 90-120874/AS, Price code:A05.)
Vol. V (PB No. 90-120882/AS, Price code:A04.)
Vol. VI (PB No. 90-120890/AS, Price code:A03.)

Measurement of Heavy Vehicle Impact Forces and Inertia Properties, Publication No. FHWA–RD–89–120

by Safety Design Division

The research presented in this report designed and constructed an instrumented wall capable of measuring the impact forces associated with heavy vehicles. The design was based on a previous instrumented wall that was developed to measure the impact forces associated with lighter vehicles. The wall consists of four concrete segments which are supported on low friction teflon pads and instrumented with load cells and accelerometers. The instrumented wall measured the impact forces associated with a variety of vehicles—a full-size automobile, two pickups, two Chevrolet Suburbans, an intercity bus, a single-unit truck, and three tractor-trailer rigs.

In addition to the direct measurement of the impact forces associated with the various vehicles, an approximate technique was developed which allows the impact force to be estimated using the results of onboard vehicle accelerometers. Results for the approximate analysis are shown to compare favorably with the results from the instrumented wall.

This publication may only be purchased from the NTIS. (PB No.90-115502/AS, Price code:A10.)

Test and Evaluation of Traffic Barriers, Publication No. FHWA-RD-89-119

by Safety Design Division

A series of crash tests were conducted to evaluate several types of guardrails and bridge rails. Two bridge rails were tested and showed acceptable performance when evaluated in accordance with NCHRP 230.

A three-cable guardrail was modified, and an end terminal was redesigned to obtain good performance. The guardrail safely redirected a large and small vehicle traveling at 60 mi/h (96.6 km/h) and impacting at 25 and 30 degrees, respectively. The terminal design was tested for snagging by directly impacting the downstream end. Although the device released, the vehicle rolled over.

A new PL3 median barrier was designed and tested in accordance with the new American Association for State Highway and Transportation Officials' bridge rail test criteria. A 50,000-lb (22 700-kg) tractor-trailer impacted the median barrier at 50 mi/h (80.5 km/h) and 15 degrees. The truck was redirected and contained, but rolled over and the barrier penetrated the occupant compartment.

An 18,000-lb (8 162-kg) truck test was conducted on the modified thrie beam median barrier. The results indicated good performance.

This publication may only be purchased from the NTIS. (PB No.90-115502/AS, Price code:A10.)

Improvement of the GUARD/NARD Computer Programs, Publication No. FHWA-RD-89-175

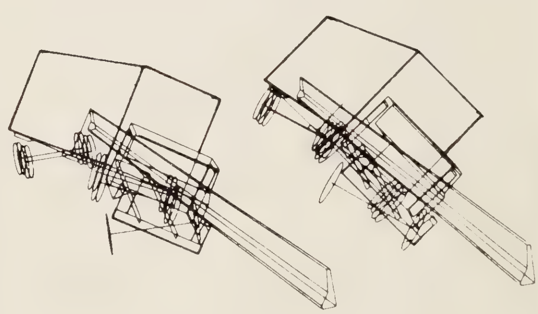
by Safety Design Division

Improvements and modifications were made to the existing computer programs—GUARD, NARD, GRAFIX, and PREP—used to simulate vehicle impacts into roadside hardware. These consisted of improving the terrain model in GUARD and NARD, improving the input and output formats for GUARD and NARD, and modifying GRAFIX and PREP to make them interactive. This report outlines the changes made to these programs.

Additional manuals resulting from this project include:

FHWA-RD-89-176 GRAFIN—Interactive GRAFIX Program
FHWA-RD-89-177 INPREP—Interactive PREP Program
FHWA-RD-89-178 GUARD Version 3.1—Users and Programmers Manual
FHWA-RD-89-179 Numerical Analysis of Roadside Design (NARD) NARD 2.0—Volume I: Users Manual
FHWA-RD-89-180 NARD 2.0—Volume II: Programmers Manual
FHWA-RD-89-181 NARD 2.0—Volume III: Engineering Manual

This publication may only be purchased from the NTIS. (PB No.90-115502/AS, Price code:A10.)



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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RD&T Report Center, HRD-10
6300 Georgetown Pike
McLean, Virginia 22101–2296
Telephone: (703) 285–2144

Preliminary Analysis System for Water Surface Profile Computations (PAS)—User Manual, Publication No. FHWA-IP-89-013

by Office of Implementation

This report describes and illustrates the use of a microcomputer program to assist in stream geometry data development for water surface profile computations. The program implements the findings of the research project "Accuracy of Computed Water Surface Profiles," (Hydrologic Engineering Center, 1986) and incorporates features for preliminary hydraulic computations based on limited data.

This publication may only be purchased from the NTIS. (PB No. 90-1127239/AS, Price code: A05.)

Evaluation of the PRORUT Equipment to Measure Road Profile and Rutting, Publication No. FHWA–TS–89–031

by Office of Implementation

This study was performed to evaluate the device constructed by the University of Michigan Transportation Research Institute known as the PRORUT. A correlation was performed between the PRORUT and the Georgia modified Mays meter trailer (GMMT) to evaluate the PRORUT's ability to measure roughness. Manual rutting measurements were used to determine the device's ability to detect rutting.

Forty-eight test sites were selected for this correlation study encompassing a variety of roughness levels and pavement surface types. The correlation results for the PRORUT versus GMMT were good, but the correlation of rut was not. Even though the profile measuring system and computer programs are very innovative, the rut-depth measuring system should be reevaluated. This system should have no less than five lasers to detail the transverse profile.

This publication may only be purchased from the NTIS. (PB No. 90-1156199/AS, Price code: A05.)

BOXCAR User and Programmer Manual, Version 1.0, Publication No. FHWA–IP–89–018

by Office of Implementation

This manual presents an overview, user instructions, and technical backup for BOXCAR. BOXCAR is a computer program for the structural analysis and design of reinforced concrete box culverts. Written for IBM or IBM-compatible microcomputers, the user-friendly input routines require minimal experience with computers to operate. Most parameters can be controlled by a user familiar with structural design codes for culverts. BOXCAR completes structural analysis for loads due to box weight, soil weight, internal gravity fluid weight, live loads, and user-specified surcharge loads.

Forces resulting from each load condition may be printed out separately. Structural design is in accordance with the American Association of State Highway and Transportation Officials. Design criteria include ultimate flexure, diagonal tension, service load crack control, and service load fatigue.

Limited copies are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 90-115486/AS, Price code: A11.)

PIPECAR User and Programmer Manual, Version 1.0, Publication No. FHWA–IP–89–019

by Office of Implementation

This manual presents an overview, user instructions, and technical backup for PIPECAR. PIPECAR is a computer program for the structural analysis and design of circular and horizontal reinforced concrete pipe. Written to run on IBM or IBM-compatible microcomputers, the user-friendly input routines require minimal experience to operate.

PIPECAR completes structural analyses for loads due to pipe weight, soil weight, internal gravity fluid weight, live loads, and internal pressures up to 50 ft (15.2 m) of head. Loads may be applied via the radial load system, the uniform load system, or the manual load system which is a modified uniform system.

Forces resulting from each load condition may be printed out separately. Structural design is in accordance with the American Association of State Highway and Transportation Officials, Section 17.4. Design criteria include flexure, radial tension and diagonal tension, and service load crack control. Most variables can be controlled by the user. Knowledge of structural design codes for culverts is required.

Limited copies are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 90-115478/AS, Price code: A12.)

Forum on Weathering Steel for Highway Structures: Summary Report, Publication No. FHWA–TS–89–016

by Office of Implementation

On July 12-13, 1988, the Office of Research, Development, and Technology of the Federal Highway Administration (FHWA) hosted a forum on "Weathering Steel for Highway Structures." The major objectives of this forum were to examine the state of the art in weathering steel use and maintenance, to develop rules for its use in new construction, and for maintenance of existing structures.

The forum brought together 131 participants representing Federal and State governments and industry. It was organized into four main sessions including a panel discussion and several individual presentations. This report summarizes the forum.

This publication may only be purchased from the NTIS. (PB No. 89-221063/AS, Price code: A09.)

Design of Riprap Revetment, Publication No. FHWA–IP–89–016

by Office of Implementation

This version of Hydraulic Engineering Circular (HEC) No. 11, represents major revisions to the earlier (1967) edition of HEC No. 11. Recent research findings and revised design procedures have been incorporated resulting in an expanded, comprehensive design publication. The revised manual includes discussions on recognizing erosion potential, erosion mechanisms, riprap failure modes, and riprap types—rock riprap, rubble riprap, gabions, preformed blocks, grouted rock, and paved linings. Design concepts included are: design discharge, flow types, channel geometry, flow resistance, extent of protection, and toe depth. Detailed design guidelines are presented for rock riprap, and design procedures are summarized in charts and examples. Design guidance is also presented for wire-enclosed rock (gabions), precast concrete blocks, and concrete paved linings.

This publication may only be purchased from the NTIS. (PB No. 89-218424/AS, Price code: A09.)

New Research in Progress

The following new research studies reported by the 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:

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

NCP Category A—Highway Safety

NCP Program A.4: Special Highway Users

Title: Integrated Truck Monitoring System (NCP No. 4A4A3272)
Objective: Develop functional specifications for an integrated truck monitoring system in Kentucky. Determine the extent to which the Kentucky numbers are not being displayed. Determine the impact of the Kentucky numbering system on motor carrier operations. Determine the magnitude of the problem relating to trucks using bypass routes to avoid weight-distance tax monitoring.
Performing Organization: Kentucky Transportation Cabinet, Frankfort, KY 40622
Expected Completion Date: September 1991
Estimated Cost: $69,000 (HP&R)

NCP Category B—Traffic Operations

NCP Program B.1: Traffic Management Systems

Title: Forecasting Freeway and Ramp Data for Improved Real-Time Control and Data Analysis (NCP No. 4B1E2022)
Objective: Develop methods to forecast freeway data obtained from surveillance systems. Create short-term algorithms to predict measures such as volume and occupancies from surveillance data.
Performing Organization: Washington State University, Pullman, WA 99164
Funding Agency: Washington Department of Transportation
Expected Completion Date: December 1991
Estimated Cost: $95,000 (HP&R)

NCP Program B.2: Traffic Analysis and Operational Design Aids

Title: Incorporating Intersection Design Elements into Subregional Traffic Assignment Models (NCP No. 4B2B1201)
Objective: Incorporate intersection specific design features to a subregional traffic assignment model. The features include: multiphas-

ing, green times, coordination, number of approach lanes, presence of turning lanes, etc.
Performing Organization: University of Illinois-Chicago, Chicago, IL 60607
Funding Agency: Illinois Department of Transportation
Expected Completion Date: September 1991
Estimated Cost: $70,000 (HP&R)

NCP Category C—Pavements

NCP Program C.4: Management Strategies

Title: Pavement Damage Prediction Models—Extension, Calibration, Verification (NCP No. 3C4B3162)
Objective: Obtain services to improve the Federal Highway Administration's current pavement associated models and related computer programs to increase their accuracy, efficiency, and utility so they may be easily and effectively used by State and Federal highway agency operational staff. This requirement includes modifying selected programs to convert mainframe exclusive-use programs to microcomputer-use programs.
Performing Organization: Computer Communications and Graphics Associates, Gaithersburg, MD 20877
Expected Completion Date: November 1991
Estimated Cost: $300,000 (FHWA Administrative Contract)

NCP Category D—Structures

NCP Program D.1: Design

Title: An Investigation of New (Bridge) Weigh-In-Motion Technologies and Applications (NCP No. 2D1A1012)
Objective: Evaluate new instrumentation for in-motion weighing of heavy trucks using highway bridges. Develop new or improved techniques to enhance existing technology. Investigate new applications for this technology in the bridge engineering field.
Performing Organization: Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, VA 22101
Expected Completion Date: September 1993
Estimated Cost: $70,000 (FHWA Staff Research)

NCP Program D.2: Bridge Management

Title: Full-Scale Bridge Testing to Monitor Vibrational Signatures (NCP No. 4D2A1030)
Objective: Give evidence that vibrational monitoring of highway bridges is possible and can be used to detect structural failure in any full-scale bridge.
Performing Organization: Connecticut Department of Transportation
Expected Completion Date: September 1991
Estimated Cost: $131,000 (HP&R)

NCP Program D.3: Hydraulics and Hydrology

Title: Bridge Scour Prediction Methods Applicable to Streams in Pennsylvania (NCP No. 4D3C1592)
Objective: Review Pennsylvania Department of Transportation bridge inspection reports. Visit at least 15 sites and take soil borings and subbottom geotechnical soundings. Analyze data from other sources such as the U.S. Geological Survey field studies. Develop scour prediction methods that account for bed material characteristics.
Performing Organization: The Pennsylvania State University, University Park, PA 16802
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: November 1991
Estimated Cost: $149,952 (HP&R)

NCP Category E—Materials and Operations

NCP Program E.2: Cement and Concrete

Title: Accelerated Strength Testing for Concrete (NCP No. 4E2C1103)
Objective: Investigate the feasibility of accelerated strength testing for concrete quality control and quality assurance. Use statistical concepts in test planning and data analysis. Establish relations between early accelerated strength and 28-day strength of concrete. Base relations on parameters such as mix type, material properties, and ambient conditions.
Performing Organization: Florida Department of Transportation, Gainsville, FL 32601
Expected Completion Date: September 1991
Estimated Cost: $73,000 (HP&R)

NCP Program E.3: Geotechnology

Title: Modification of Highway Soil Subgrades (NCP No. 4E3B0662)
Objective: Determine the long-term benefits of chemical and mechanical soil subgrade modification. Develop and evaluate: laboratory testing procedures, a method of designing thickness of soil subgrade treated with chemical additives, and criteria to determine when subgrade modification is necessary. Observe long-term modified subgrade field strengths. Compare field and laboratory modified subgrade strengths as well as treated and untreated specimen strengths.
Performing Organization: Kentucky Transportation Cabinet, Frankfort, KY 40622
Expected Completion Date: September 1993
Estimated Cost: $302,101 (HP&R)

NCP Program E.5: Highway Maintenance

Title: The Service Life and Costs of Pavement Maintenance Practices for Locally Funded Roadways in Small Cities and Towns of New England (NCP No. 4E5F1132)
Objective: Develop a set of guidelines on service life and costs of pavement maintenance practices on locally funded roads for towns in New England (population under 50,000). Gather information from public works directors and highway superintendents. Determine effective service lives for different activities. Present results for potential integration into local pavement management programs. Develop and present a workshop and video.
Performing Organization: University of Massachusetts, Amherst, MA 01003
Funding Agency: Massachusetts Department of Transportation
Expected Completion Date: February 1991
Estimated Cost: $75,417 (HP&R)

Turner-Fairbank Highway Research Center's Award-Winning Staff

Secretary's Award

John M. Hooks received the Department of Transportation's highest honor—the Secretary's Award for Meritorious Achievement. His outstanding contributions for a successful Structures Implementation Program were the basis of his award.

John M. Hooks, recipient of the Secretary's Award, with his family and the Federal Highway Administrator, Tom Larson.

Administrator's Award

The highest honor award within the Federal Highway Administration is the Administrator's Award. Eight members of the Turner-Fairbank Highway Research Center staff were distinguished:

Rudolph R. Hegmon—for his outstanding leadership and insight in the development of highway pavement equipment and instrumentation.

Harry H. Hersey—for his continued excellent support and accomplishments in Rural Technical Assistance and University Transportation Centers Programs.

Thomas F. Krylowski—for his outstanding contributions to the Structures Implementation Program.

Charles F. McDevitt—for his special and valued contributions to the States in the form of advice and guidance in roadside safety.

Charles Churilla, David Phillips, Deborah Freund, and Roger Surdahl at the presentation of the annual Technical Accomplishment Award.

Marian I. Money—for her unselfish dedication and professional service and support to the National Highway Institute.

Alberto J. Santiago—for his outstanding contributions in the development of improved traffic computer tools for analyzing and assessing traffic control strategies and geometric improvements.

Marian H. Simpson—for her performance of assigned duties as Program Assistant for the Safety and Traffic Operations Research and Development Program.

Yash Paul Virmani—for his technical leadership in developing methods to reduce reinforcing steel corrosion rates, thereby extending the service life of our Nation's bridges.

Research, Development, and Technology Award: Special Recognition for an Outstanding Technical Accomplishment

This annual award is given to recognize professional and technical excellence in the achievement and presentation of research and development activities.

James A. Wentworth earned the award for his study on "Developing Expert Systems."

Deborah M. Freund, Charles J. Churilla, Ramon F. Bonaquist, Roger W. Surdahl, and Walaa S. Mogawer collaborated their efforts for their award-winning study on "The Effects of Load, Tire Pressure, and Tire Type on Flexible Pavement Response."

Jeffrey F. Paniati received an honorable mention for his study: "Redesign and Evaluation of Selected Work Zone Sign Symbols."

James Wentworth receives the Technical Accomplishment Award from David Phillips, Associate Administrator for Research, Development, and Technology.

Administrator's Award winners with David Phillips: Seated: Marian Money and Marian Simpson Standing (l to r): A. Santiago, T. Krylowski, Y.P. Virmani, D. Phillips, R. Hegmon, H. Hersey, and C. McDevitt.

U.S. Postal Service

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION

Required by 39 U.S.C. 3685)

1A. Title of Publication	1B. PUBLICATION NO.	2. Date of Filing
PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT		September 22, 1989

3. Frequency of Issue	3A. No. of Issues Published Annually	3B. Annual Subscription Price
QUARTERLY	FOUR	$6.00/yr (domestic) $7.50/yr (foreign)

4. Complete Mailing Address of Known Office of Publication *(Street, City, County, State and ZIP+4 Code) (Not printers)*

Federal Highway Administration
400 7th Street SW, Washington, DC 20590

5. Complete Mailing Address of the Headquarters of General Business Offices of the Publisher *(Not printer)*

Same as item 4 above

6. Full Names and Complete Mailing Address of Publisher, Editor, and Managing Editor ***(This item MUST NOT be blank)***

Publisher *(Name and Complete Mailing Address)*

Same as item 4 above

Editor *(Name and Complete Mailing Address)*

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6300 Georgetown Pike, McLean, VA 22101-2296

Managing Editor *(Name and Complete Mailing Address)*

William Zaccagnino Federal Highway Administration, HRD-10
6300 Georgetown Pike, McLean, VA 22101-2296

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Full Name	Complete Mailing Address
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8. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages or Other Securities *(If there are none, so state)*

Full Name	Complete Mailing Address
n/a U.S. Government Publication	400 7th Street, SW, Washington, DC 20590

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(2) ☐ Has Changed During Preceding 12 Months

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10. Extent and Nature of Circulation *(See instructions on reverse side)*	Average No. Copies Each Issue During Preceding 12 Months	Actual No. Copies of Single Issue Published Nearest to Filing Date
A. Total No. Copies *(Net Press Run)*	5282	5216
B. Paid and/or Requested Circulation 1. Sales through dealers and carriers, street vendors and counter sales	0	0
2. Mail Subscription *(Paid and/or requested)*	850	850
C. Total Paid and/or Requested Circulation *(Sum or 10B1 and 10B2)*	850	850
D. Free Distribution by Mail, Carrier or Other Means Samples, Complimentary, and Other Free Copies	4119	4116
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F. Copies Not Distributed 1. Office use, left over, unaccounted, spoiled after printing	313	250
2. Return from News Agents	0	0
G. TOTAL *(Sum of E, F1 and 2—should equal net press run shown in A)*	5282	5216

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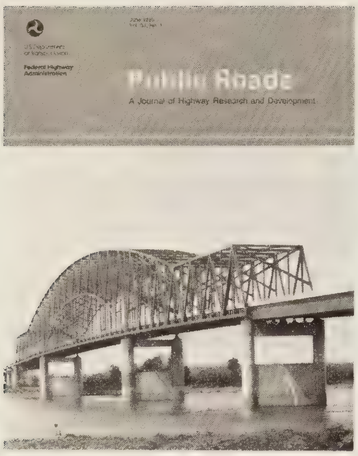
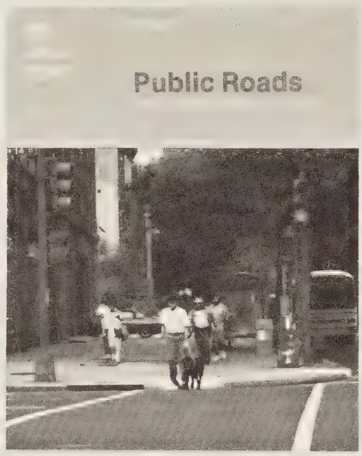
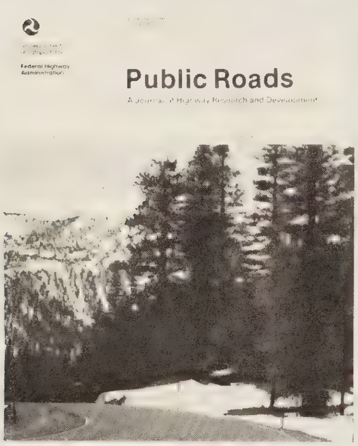
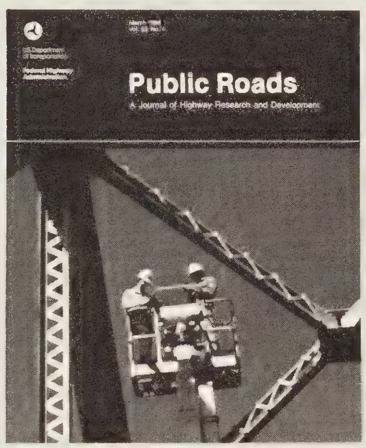
PS Form **3526**, Feb. 1989 *(See instructions on reverse)*

TITLE SHEET, VOLUME 53









PUBLIC ROADS

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RESEARCH AND
DEVELOPMENT

VOLUME 53

U.S. Department of Transportation
Federal Highway Administration

June 1989—March 1990

The title sheet for volume 53, June 1989—March 1990, of *Public Roads* contains a chronological list of article titles and an alphabetical list of authors' names.

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(and volume page references)

U.S. Department
of Transportation

**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

Official Business
Penalty for Private Use $300

Second Class Mail
Postage and Fees Paid
Federal Highway Administration
ISSN No. 0033–3735

in this issue