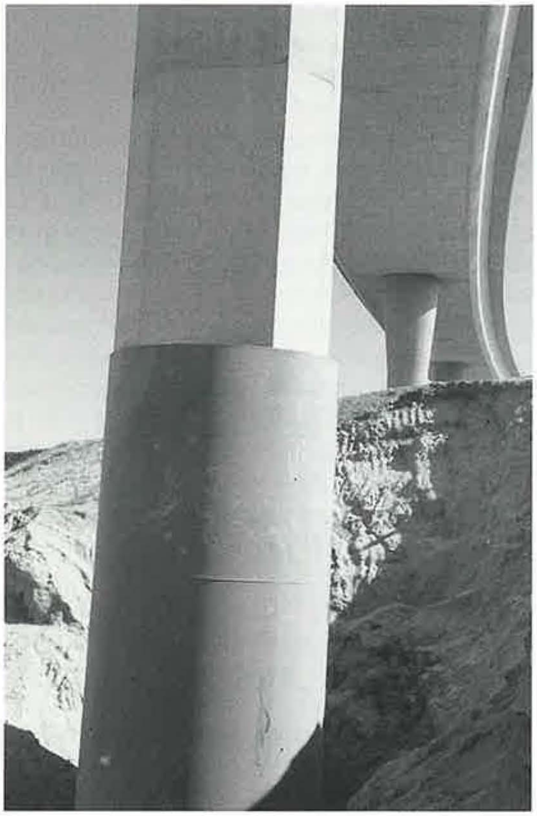

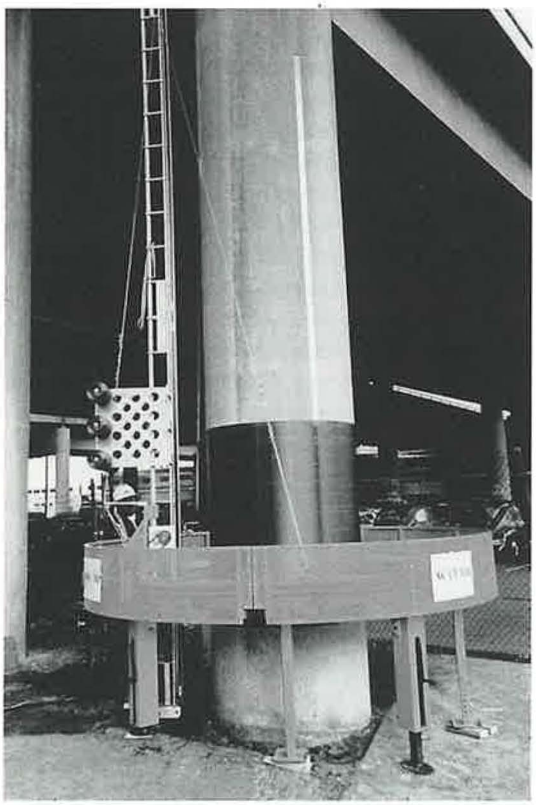

The Caltrans bridge seismic retrofit program includes partial-height steel jacketing of single-column bents *(top)* and a recently developed automated advanced composite jacketing system *(below)*.

ducted on joint, cap-beam, and superstructure strengthening at UCSD and various research universities across the United States and worldwide. The seismic design and retrofit concepts thus developed are now widely applied outside of California, modified to meet different seismic hazard scenarios in various regions.

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Strengthening and Rehabilitation Using Carbon Fiber Reinforced Polymer

F. WAYNE KLAIBER

In the United States more than 200,000 highway bridges are deficient, many because their load-carrying capacity is inadequate for today's traffic. Strengthening can often be used as a cost-effective alternative to replacement or posting of such bridges.

In 1987 a National Cooperative Highway Research Program study reviewed the methods being used to strengthen various types of bridges; the findings of this study were published in NCHRP Report 293, *Methods of Strengthening Existing Highway Bridges*. The report describes different methods of strengthening, such as providing composite action, reducing dead load, applying external post-tensioning, and modifying load paths.

The strengthening procedure of epoxy bonding steel plates to either steel members or reinforced concrete is mentioned only in an appendix to this report, and there is no mention of the use of carbon fiber reinforced polymer (CFRP) strips. CFRP strips are frequently used today instead of steel plates to restore various bridge elements to their original capacity, or if desired to provide additional capacity. Steel plates have several disadvantages, including susceptibility to corrosion, which necessitates corrosion protection, and heavy weight, which makes handling difficult. Although CFRP strips are expensive, they weigh less, have higher tensile strength, have no corrosion problems, are easier to handle and install, and have excellent fatigue properties.

Oberriet-Meiningen Bridge over Rhine River at Swiss-Austrian border.

In the plating strengthening procedure, CFRP strips (or the previously used steel plates) are bonded to the elements being strengthened where additional tensile strength is required. In the case of reinforced concrete, the externally bonded CFRP and the internal reinforcing steel carry the tension forces, while the compressive forces are carried by the concrete. In bonding CFRP strips or steel plates, one of the most critical considerations is the adhesive used. Two-component epoxy adhesive has been found to be well suited for this application. When surfaces are properly prepared, the epoxy distributes the transfer of force evenly over the entire contact area. This contrasts with the case in which elements are bolted together, and the majority of the force transfer occurs at the location of the bolts. Since the plate bonding strengthening procedure depends on the strength of the epoxied joint, it is important that only the best-quality epoxy adhesive be used in this type of application.

Experts in the field of fiber composites generally agree that the United States is behind Europe and Japan in the use of these materials for bridge strengthening in the areas of both research and implementation. Although there have been some composite repairs in North America, the majority of such repairs have taken place in Europe and Japan. The examples cited in the following paragraphs illustrate flexural strengthening. Fiber composites have also been used successfully in seismic strengthening of reinforced concrete columns, but examples of such applications are not included here.

In 1994 legal truck loads in Japan were increased 25 percent to 25 tons. A review of several concrete slab bridges revealed that they were inadequate for this increased load. Nearly 50 of these bridges were strengthened using CFRP sheets bonded to the tension face. The additional material not only reduced the stress in the reinforcing bars, but also reduced deflections in the slabs because of the high modulus of elasticity of the CFRP sheets.

Recently, a prestressed concrete beam in West Palm Beach, Florida, that had been damaged by an overheight vehicle was repaired using CFRP. This repair was accomplished in 15 hours during three consecutive nights, so that there was minimal disruption of traffic. The alternative to this repair technique was to replace the damaged prestressed concrete beam with a new one—a procedure that would have taken close to 1 month and would have required some road closures.

The Oberriet-Meiningen three-span continuous bridge over the Rhine River, completed in 1963, connects Switzerland and Austria. It was determined that this bridge needed strengthening because of increased traffic loading. Strengthening was accomplished in 1996 by increasing the deck thickness 8 centimeters and adding 160 CFRP strips (4 meters long at 75-centimeter intervals) to the underside of the deck. The combination of these two measures increased the capacity of the bridge so that it is in full compliance with today's safety and load requirements.

The Fürstenland Bridge, an open spandrel arch bridge in Switzerland, was opened to traffic in 1941. During a recent inspection it was determined that bottom flanges of the outer cells of the box girders needed to be replaced because of corrosion of the reinforcing steel and high chloride content in the concrete. To maintain the bridge's load-carrying capacity while the bottom flange was replaced in 1997, externally bonded CFRP laminates were added to the inside vertical forces of the webs.

Three severely deteriorated 70-year-old reinforced concrete frame bridges near Dreselou, Germany, were recently strengthened to provide increased flexure and shear capacity using CFRP plates. Before being strengthened, the bridges were

The youth gets together his materials to build a bridge to the moon, or, perchance, a palace or temple on the earth, and at length, the middle-aged man concludes to build a woodshed from them.

Henry David Thoreau,
Journal (July 14, 1852)

restricted to 2-ton vehicles. Since the strengthening, 16-ton vehicles have been permitted to use the bridges.

Numerous laboratory investigations and field installations of CFRP, such as those described here, suggest that it is the strengthening material of the future.

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Federal Highway Administration's Nondestructive Evaluation Validation Center

STEVEN B. CHASE

IMPROVING AND MAINTAINING the nation's aging surface transportation system is an enormous challenge. To succeed, decision makers will require one thing above all else—good information. Complete, accurate, and reliable information is essential to determine where best to allocate limited resources and to establish various policies.

One area in which current practice could be improved to provide more accurate and useful information is the condition assessment of highway structures. Standard practice is to perform a subjective visual inspection in order to identify and record obvious problems and deterioration. In most instances, this approach is effective and cost-efficient. However, there are some important and potentially critical deterioration processes that are not adequately detected by visual inspection. For example, it is not possible to detect and quantify the condition of an overlaid reinforced concrete bridge deck adequately through visual inspection alone; fatigue cracks in steel bridge members cannot be detected visually under paint; and it is difficult to detect loss of prestressing in prestressed concrete by visual inspection unless there are large deflections or distortions. To overcome these limitations of visual inspection, the Federal Highway Administration is developing nondestructive evaluation (NDE) technologies and methods.

Similar in concept to the routine or specialized procedures used by the medical profession to assess health or diagnose disease, NDE can provide previously unavailable information about the condition of the nation's highway infrastructure. NDE technologies are used routinely today in quality control and acceptance testing during fabrication or construction; examples are magnetic particle inspection and radiography, commonly used in welding. However, FHWA is working to expand the application of NDE to the condition assessment of the existing highway infrastructure. Existing NDE technologies commonly used in other industries, such as eddy current systems used to detect cracks in aircraft skins, are being evaluated for application to highway structures.

FHWA is also sponsoring the development of new and innovative technologies for the condition assessment and evaluation of highway structures. Some of these technologies will help ensure the safety of highway structures by detecting potentially serious deterioration before visible damage occurs. Other technologies will provide for the rapid, efficient, accurate, and quantitative assessment of invisible deterioration. Many of these technologies have been developed to the prototype stage and are ready for field testing and evaluation, which will be used to refine the design of the technology to the point where it is ready for validation.

Validation is a necessary step in the development process and is essential for widespread adoption of new technologies and methods. To achieve the objective of providing reliable information for decision makers, it is essential to know how good the information is. A formalized validation program can be used to answer this question. Such a program is similar in concept to the clinical trials medical diagnostic technologies undergo before they are accepted for widespread use by the medical profession. To support this work, FHWA is creating a new facility—the FHWA NDE Validation Center.

FEDERAL HIGHWAY ADMINISTRATION

This test bridge selected for the NDE Validation Center will serve as a full-scale laboratory for evaluation and validation of a wide range of nondestructive evaluation technologies and methods in a real-world environment.