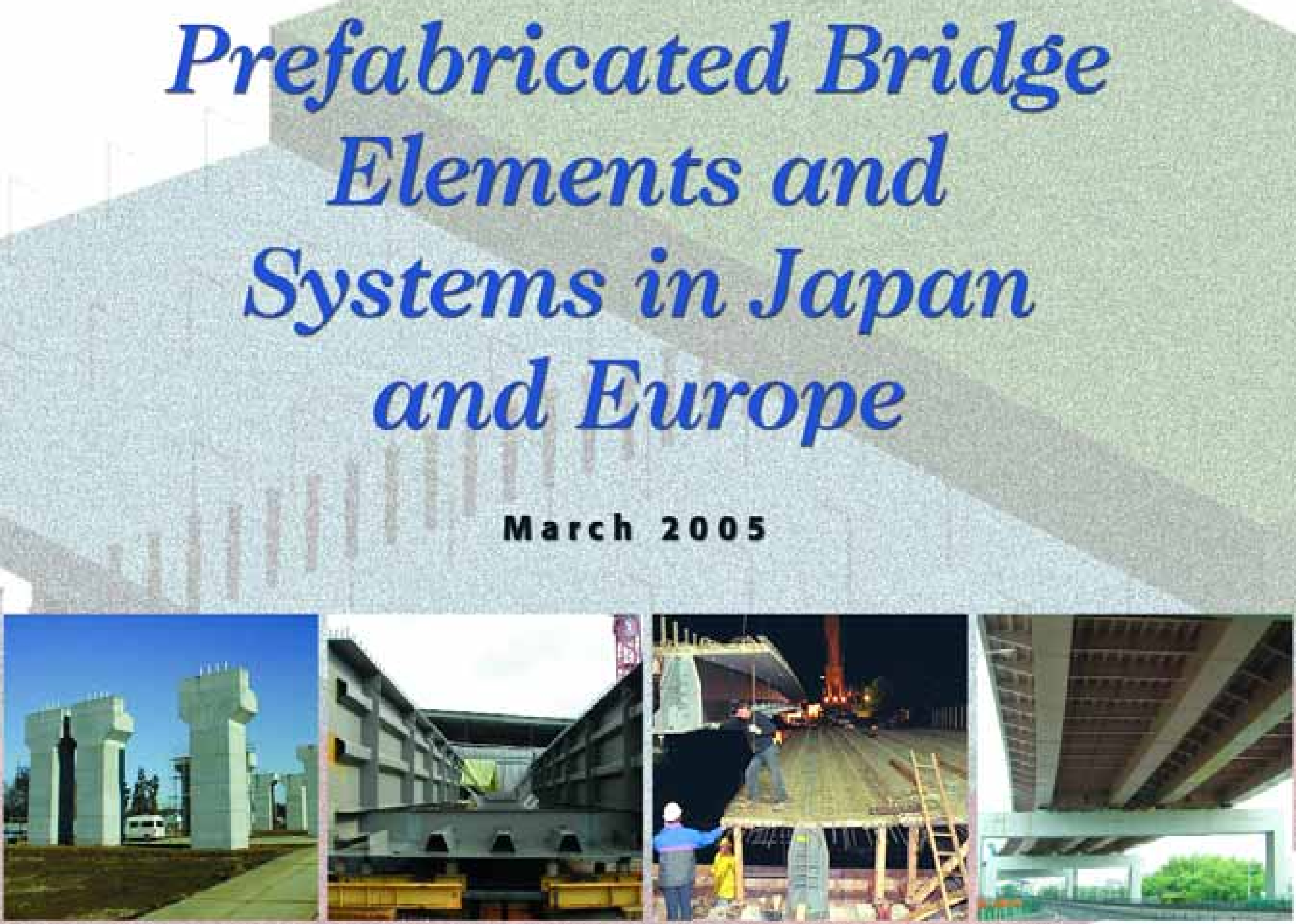
U.S. Department of Transportation
Federal Highway Administration

Prefabricated Bridge Elements and Systems in Japan and Europe

March 2005



INTERNATIONAL TECHNOLOGY EXCHANGE PROGRAM

Technical Report Documentation Page

1. Report No. FHWA-PL-05-003	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Prefabricated Bridge Elements and Systems in Japan and Europe	5. Report Date March 2005 6. Performing Organization Code
7. Author(s) Mary Lou Ralls, Ben Tang, Shrinivas Bhidé, Barry Brecto, Eugene Calvert, Harry Capers, Dan Dorgan, Eric Matsumoto, Claude Napier, William Nickas, Henry Russell	8. Performing Organization Report No.
9. Performing Organization Name and Address American Trade Initiatives P.O. Box 8228 Alexandria, VA 22306-8228	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-99-C-005
12. Sponsoring Agency Name and Address Office of International Programs Office of Policy Federal Highway Administration U.S. Department of Transportation American Association of State Highway and Transportation Officials	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

FHWA COTR: Hana Maier, Office of International Programs

16. Abstract

The aging highway bridge infrastructure in the United States must be continuously renewed while accommodating traffic flow, so new bridge systems are needed that allow components to be fabricated offsite and moved into place quickly. The Federal Highway Administration, American Association of State Highway and Transportation Officials, and National Cooperative Highway Research Program sponsored a scanning study in Japan and Europe to identify prefabricated bridge elements and systems that minimize traffic disruption, improve work zone safety, and lower life-cycle costs.

The U.S. delegation observed 10 technologies that it recommends for possible implementation in the United States. They include movement systems for transporting and installing prefabricated bridge components, such as self-propelled modular transporters. They also include superstructure systems that save time by eliminating the need to place and remove deck formwork.

The scanning team also learned about innovative deck and substructure systems that reduce construction time, including the Japanese SPER system of rapid construction of bridge piers. The team's recommendations for U.S. action include seeking demonstration projects on technologies it observed.

17. Key Words deck systems, prefabricated bridge elements, self-propelled modular transporter, SPER system, substructure, superstructure, traffic disruption, work zone safety	18. Distribution Statement No restrictions. This document is available to the public from the: Office of International Programs, FHWA-HPIP, Room 3325, U.S. Department of Transportation, Washington, DC 20590 *international@fhwa.dot.gov* *www.international.fhwa.dot.gov*

19. Security Classify. (of this report) Unclassified	20. Security Classify. (of this page) Unclassified	21. No. of Pages 64	22. Price Free

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Acknowledgments

The scanning team members wish to thank all of the host transportation agencies, researchers, contractors, associations, and private firms for their gracious hospitality and for sharing their time and experiences with the scanning team. Without exception, the team was warmly received in every country and by every person.

The team also appreciates the amount of professional preparation, effort, and attention to detail provided by the staffs of the organizations. Much was learned in each country. Furthermore, doors to future cooperation and technology transfer were opened.

The team also thanks the Federal Highway Administration Office of International Programs and the American Association of State Highway and Transportation Officials for their encouragement, guidance, and support, and American Trade Initiatives, Inc. for its organization and support in planning and executing the scanning study.

Prefabricated Bridge Elements and Systems in Japan and Europe

Prepared by the International Scanning Study Team:

Mary Lou Ralls
Texas DOT
Co-Chair

Ben Tang
FHWA
Co-Chair

Shrinivas Bhidé
Portland Cement Association

Barry Brecto
FHWA

Eugene Calvert
Collier County, FL

Harry Capers
New Jersey DOT

Dan Dorgan
Minnesota DOT

Eric Matsumoto
California State University,
Sacramento

Claude Napier
FHWA

William Nickas
Florida DOT

Henry Russell
Henry G. Russell, Inc.
Report Facilitator

and
American Trade Initiatives, Inc.
LGB & Associates, Inc.

for the **Federal Highway Administration, U.S. Department of Transportation**
and the **American Association of State Highway and Transportation Officials**

National Cooperative Highway Research Program (Panel 20-36)
of the Transportation Research Board

March 2005

FHWA International Technology Exchange Program

The Federal Highway Administration's (FHWA) Technology Exchange Program assesses and evaluates innovative foreign technologies and practices that could significantly benefit U.S. highway transportation systems. This approach allows for advanced technology to be adapted and put into practice much more efficiently without spending scarce research funds to recreate advances already developed by other countries.

The main channel for accessing foreign innovations is the International Technology Scanning Program. The program is undertaken jointly with the American Association of State Highway and Transportation Officials (AASHTO) and its Special Committee on International Activity Coordination in cooperation with the Transportation Research Board's National Cooperative Highway Research Program Project 20-36 on "Highway Research and Technology—International Information Sharing," the private sector, and academia.

FHWA and AASHTO jointly determine priority topics for teams of U.S. experts to study. Teams in the specific areas being investigated are formed and sent to countries where significant advances and innovations have been made in technology, management practices, organizational structure, program delivery, and financing. Scanning teams usually include representatives from FHWA, State departments of transportation, local governments, transportation trade and research groups, the private sector, and academia.

After a scan is completed, team members evaluate findings and develop comprehensive reports, including recommendations for further research and pilot projects to verify the value of adapting innovations for U.S. use. Scan reports, as well as the results of pilot programs and research, are circulated throughout the country to State and local transportation officials and the private sector. Since 1990, FHWA has organized more than 60 international scans and disseminated findings nationwide on topics such as pavements, bridge construction and maintenance, contracting, intermodal transport, organizational management, winter road maintenance, safety, intelligent transportation systems, planning, and policy.

The International Technology Scanning Program has resulted in significant improvements and savings in road program technologies and practices throughout the United States. In some cases, scan studies have facilitated joint research and technology-sharing projects with international counterparts, further conserving resources and advancing the state of the art. Scan studies have also exposed transportation professionals to remarkable advancements and inspired implementation of hundreds of innovations. The result: large savings of research dollars and time, as well as significant improvements in the Nation's transportation system.

For a complete list of International Technology Scanning Program topics and to order free copies of the reports, please see the list contained in this publication and at www.international.fhwa.dot.gov, or e-mail *international@fhwa.dot.gov.* ■

FHWA International Technology Exchange Reports

International Technology Scanning Program: Bringing Global Innovations to U.S. Highways

Safety

Traffic Safety Information Systems in Europe and Australia (2004)

Signalized Intersection Safety in Europe (2003)

Managing and Organizing Comprehensive Highway Safety in Europe (2003)

European Road Lighting Technologies (2001)

Commercial Vehicle Safety, Technology, and Practice in Europe (2000)

Methods and Procedures to Reduce Motorist Delays in European Work Zones (2000)

Innovative Traffic Control Technology and Practice in Europe (1999)

Road Safety Audits—Final Report and Case Studies (1997)

Speed Management and Enforcement Technology: Europe and Australia (1996)

Safety Management Practices in Japan, Australia, and New Zealand (1995)

Pedestrian and Bicycle Safety in England, Germany, and the Netherlands (1994)

Planning and Environment

Transportation Performance Measures in Australia, Canada, Japan, and New Zealand (2004)

European Right-of-Way and Utilities Best Practices (2002)

Geometric Design Practices for European Roads (2002)

Wildlife Habitat Connectivity Across European Highways (2002)

Sustainable Transportation Practices in Europe (2001)

Recycled Materials In European Highway Environments (1999)

European Intermodal Programs: Planning, Policy, and Technology (1999)

National Travel Surveys (1994)

Policy and Information

European Practices in Transportation Workforce Development (2003)

Intelligent Transportation Systems and Winter Operations in Japan (2003)

Emerging Models for Delivering Transportation Programs and Services (1999)

National Travel Surveys (1994)

All publications are available on the Internet at *www.international.fhwa.dot.gov*

Acquiring Highway Transportation Information from Abroad (1994)

International Guide to Highway Transportation Information (1994)

International Contract Administration Techniques for Quality Enhancement (1994)

European Intermodal Programs: Planning, Policy, and Technology (1994)

Operations

Superior Materials, Advanced Test Methods, and Specifications in Europe (2004)

Freight Transportation: The Latin American Market (2003)

Meeting 21st Century Challenges of System Performance Through Better Operations (2003)

Traveler Information Systems in Europe (2003)

Freight Transportation: The European Market (2002)

European Road Lighting Technologies (2001)

Methods and Procedures to Reduce Motorist Delays in European Work Zones (2000)

Innovative Traffic Control Technology and Practice in Europe (1999)

European Winter Service Technology (1998)

Traffic Management and Traveler Information Systems (1997)

European Traffic Monitoring (1997)

Highway/Commercial Vehicle Interaction (1996)

Winter Maintenance Technology and Practices—Learning from Abroad (1995)

Advanced Transportation Technology (1994)

Snowbreak Forest Book—Highway Snowstorm Countermeasure Manual (1990)

Infrastructure—General

European Practices in Transportation Workforce Development (2003)

Contract Administration: Technology and Practice in Europe (2002)

European Road Lighting Technologies (2001)

Geometric Design Practices for European Roads (2001)

Geotechnical Engineering Practices in Canada and Europe (1999)

Geotechnology—Soil Nailing (1993)

Infrastructure—Pavements

Pavement Preservation Technology in France, South Africa, and Australia (2003)

Recycled Materials In European Highway Environments (1999)

South African Pavement and Other Highway Technologies and Practices (1997)

Highway/Commercial Vehicle Interaction (1996)

European Concrete Highways (1992)

European Asphalt Technology (1990)

Infrastructure—Bridges

Prefabricated Bridge Elements and Systems in Japan and Europe (2005)

Bridge Preservation and Maintenance in Europe and South Africa (2005)

Performance of Concrete Segmental and Cable-Stayed Bridges in Europe (2001)

Steel Bridge Fabrication Technologies in Europe and Japan (2001)

European Practices for Bridge Scour and Stream Instability Countermeasures (1999)

Advanced Composites in Bridges in Europe and Japan (1997)

Asian Bridge Structures (1997)

Bridge Maintenance Coatings (1997)

Northumberland Strait Crossing Project (1996)

European Bridge Structures (1995)

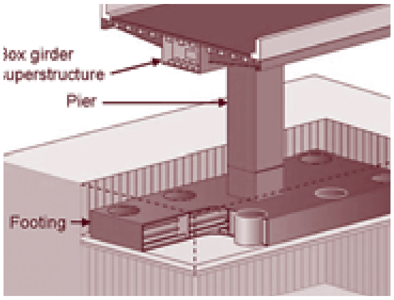
Contents

Executive Summary .xi
Introduction .xi
Findings and Recommendations .xi
    Movement Systems .xii
    Superstructure Systems .xii
    Deck Systems .xiii
    Substructure Systems .xiv
Implementation Activities .xiv

CHAPTER 1 | Introduction .1
Background .1
Objectives and Focus Areas .1
Locations Visited .1
Team Members .2
Amplifying Questions .2

CHAPTER 2 | Findings on Prefabricated Bridge Systems .3
Japan .3
    Background .3
    Anjo Viaduct .3
    Aritas Expressway (Route 23) and Nagoya-Minami Junction .5
    Full-Depth Prefabricated Concrete Decks .5
    Hybrid Steel-Concrete Deck Systems .6
    Orthotropic Steel Decks .6
    Furukawa Viaduct .6
    Arimatsu Viaduct .7
    Yahagigawa Bridge .7
    Extradosed Bridges .8
    Railroad Bridges .8
    Mitsuki Bashi Method .9
    Chofu-Tsurukawa Overbridge .11
    SPER Method .11
    Sound Barriers .12
Netherlands and Belgium .13
    Background .13
    Moving Systems .13
    Self-Propelled Modular Transporters .14
Germany .16
    Background .16
    Bavarian Road Administration .16
    Design and Construction Practices .17
    External Post-Tensioning .17
    Incremental Launching .17
    Prefabricated Elements for Bridges .18

p. 5



p. 11

p. 25

p. 27

p. 30

Partial-Depth Concrete Decks Prefabricated on Steel or Precast Concrete Beams 19
Multiple-Level Corrosion Protection Systems 20
Sound Barriers 21
Site Visits 21
France 24
Background—French National Railways 24
Railway Bridge Replacements 24
Site Visits 26
Background—French Highways 27
Poutre Dalle System 28
Dalle Preflex System 29
Full-Depth Precast Concrete Deck Panels 29
Ultra High-Performance Concrete 30
Performance-Based Durability Specifications 31
Summary 31
Bridge Movement Systems 31
Superstructure Systems 32
Deck Systems 32
Substructure Systems 32
Other Technologies 32

CHAPTER 3 | Assessment, Recommendations, and Implementation Strategy 33
Movement Systems 33
Self-Propelled Modular Transporters 33
Other Bridge Installation Systems 34
Superstructure Systems 34
Poutre Dalle System 34
Partial-Depth Concrete Decks Prefabricated on Steel or Concrete Beams 35
U-Shaped Segments with Transverse Ribs 35
Deck Systems 35
Full-Depth Prefabricated Concrete Decks 35
Deck Joint Closure Details 35
Hybrid Steel-Concrete Deck Systems 36
Multiple-Level Corrosion Protection Systems 36
Substructure Systems 36
SPER System 36

APPENDIX A | Contacts in Countries Visited 37

APPENDIX B | Team Members 41

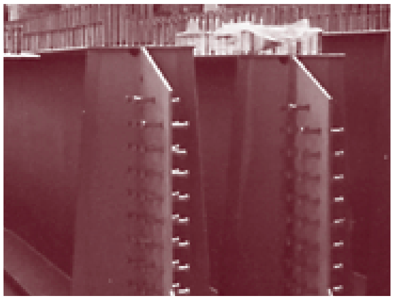
APPENDIX C | Amplifying Questions 45

APPENDIX D | Bibliography 47

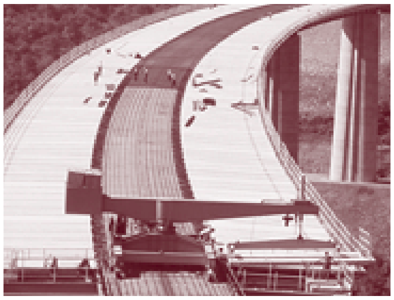
List of Figures and Tables

Figure 1. Map of bridge sites in Japan. 4
Figure 2. Anjo Viaduct. 4
Figure 3. Longitudinal joint on the Anjo Viaduct. 4
Figure 4. Elevated structure of Aritas Expressway. 5
Figure 5. Concrete column with a steel stub beam. 5
Figure 6. Full-depth prefabricated concrete deck. 6
Figure 7. Hybrid steel-concrete deck system. 6
Figure 8. Furukawa Viaduct. 7
Figure 9. Arimatsu Viaduct. 8
Figure 10. Extradosed bridges. 9
Figure 11. Use of temporary girders as part of the permanent structure. . . .9
Figure 12. Sequence of construction on the new Joban Line. 10
Figure 13. Mitsuki Bashi method. 11
Figure 14. Chofu-Tsurukawa Overbridge. 11
Figure 15. SPER method. 12
Figure 16. Sound barriers. 13
Figure 17. Moving large bridges with SPMTs. 14
Figure 18. Skidding a bridge into position. 14
Figure 19. A single SPMT. 14
Figure 20. Directional capability of an SPMT. 15
Figure 21. Incremental launching with precast concrete decks. 18
Figure 22. Temporary shoring for precast beams. 19
Figure 23. Partial-depth concrete deck prefabricated on steel beams. 20
Figure 24. Partial-depth concrete deck on concrete beams. 21
Figure 25. Bridge deck multiple-level corrosion protection system. 21
Figure 26. Construction of a noise protection gallery. 21
Figure 27. Variable-depth steel beam bridge. 22
Figure 28. Precast, prestressed concrete bridge. 23
Figure 29. Replacement sequence of the Pont de St. Denis. 24
Figure 30. Viaduc de Lamothe. 25
Figure 31. Floating a culvert into position. 25
Figure 32. Time-lapse photograph of rotating a balanced cantilever bridge. 26
Figure 33. Railway bridge moved using SPMTs. 26
Figure 34. Railway bridge before sliding into place. 26
Figure 35. Leading edge of upper slab before sliding. 27
Figure 36. Risle River Viaduct under construction. .27
Figure 37. Poutre Dalle system. 28
Figure 38. Overlapping bars in longitudinal joint. 29
Figure 39. Dalle Preflex system. 29
Figure 40. Full-depth, full-width precast deck panels. 30
Figure 41. Full-depth precast deck panels. 30

Table 1. Schedule of activities. 1-2
Table 2. Team members. 2
Table 3. Bridges near Munich, Bavaria. 22
Table 4. Mix proportions and properties of UHPC used on Bourg Les Valence bridges. 31



p. 20



p. 30

Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AFGC	French Association of Civil Engineers
BASt	Federal Highway Research Institute (Germany)
BMVBW	Federal Department of Transportation, Construction, and Housing
CERIB	Centre d'Étude et de Researches l'Industrie du Béton (Technical Center for the Concrete Industry)
CETE	Centres d'Etudes Techniques de l'Equipement (Technical Studies Center for Public Works)
CIP	Cast-in-place
DOT	Department of transportation
EU	European Union
EUR	Euro
FHWA	Federal Highway Administration
HPC	High-performance concrete
JHC	Japan Highway Public Corporation
LCPC	Laboratoire Central des Ponts et Chaussées (Central Laboratory for Public Works)
NCHRP	National Cooperative Highway Research Program
PCC	Portland cement concrete
SETRA	Service d'Étude Techniques des Routes et Autoroutes (Technical Department for Public Works and Transportation)
SNCF	French National Railway Authority
SPER	Sumitomo Precast form for resisting Earthquakes and for Rapid construction
SPMT	Self-propelled modular transporter
TRB	Transportation Research Board
UHPC	Ultra high-performance concrete
¥	Yen

Executive Summary

Introduction

The aging highway bridge infrastructure in the United States is being subjected to increasing traffic volumes and must be continuously renewed while accommodating traffic flow. The traveling public demands that this rehabilitation and replacement be done more quickly to reduce congestion and improve safety. Conventional bridge reconstruction is typically on the critical path because of the sequential, labor-intensive processes of completing the foundation, substructure, superstructure components (girders and decks), railings, and other accessories. New bridge systems are needed that will allow components to be fabricated offsite and moved into place for quick assembly while maintaining traffic flow. Depending on the specific site conditions, the use of prefabricated bridge systems can minimize traffic disruption, improve work zone safety, minimize impact to the environment, improve constructibility, increase quality, and lower life-cycle costs. This technology is applicable and needed for both existing and new bridge construction. The focus of this initiative is on conventional, routine bridges that make up the majority of the bridges in the United States.

To obtain information about technologies being used in other industrialized countries, a scanning study of five countries was conducted in April 2004. The overall objectives of the scanning study were to identify international uses of prefabricated bridge elements and systems, and to identify decision processes, design methodologies, construction techniques, costs, and maintenance and inspection issues associated with use of the technology. The scanning team, therefore, was interested in all aspects of design, construction, and maintenance of bridge systems composed of multiple elements fabricated and assembled offsite. The elements consisted of foundations, piers or columns, abutments, pier caps, beams or girders, and decks. Bridges with span lengths in the range of 6 to 40 meters (m) (20 to 140 feet (ft)) were the major focus, although longer spans were of interest if a large amount of innovative prefabrication was used.

The focus areas of the study were prefabricated bridge systems that provide the following:
1. Minimize traffic disruption.
2. Improve work zone safety.
3. Minimize environmental impact.
4. Improve constructibility.
5. Increase quality.
6. Lower life-cycle costs.

The scanning study was sponsored by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO). The 11-member team included three representatives from FHWA, four representatives from State departments of transportation (DOTs), one representative from the National Association of County Engineers, one university representative, and two industry representatives. The team visited Belgium, France, Germany, Japan, and the Netherlands, and held meetings and site visits with representatives of government agencies and private sector organizations. The countries were selected because of their known use of prefabricated systems. Visiting Japan was particularly important because of the country's seismic design requirements.

Findings and Recommendations

After completing the scanning study, the team had identified 33 bridge technologies that, in one or more aspects, were different from current practices in the United States. Not all of these related to the primary objectives of the scanning study. Using the six focus areas as selection criteria, the team identified 10 overall technologies that it recommends for further consideration and possible implementation in the United States. A brief description of each of the 10 technologies is given in the following sections.

Movement Systems

During the study, many different methods that can be used to remove partial or complete existing bridges and move bridge components or complete bridges into place were observed. These methods allow a new bridge to be built at one location near or adjacent to the existing structure and then moved to its final location in a few hours. Construction, therefore, can take place in an environment where construction operations are completely separated from the traveling public. These methods reduce traffic disruption times from months to days or hours, restore the use of existing highways in significantly less time, improve work zone safety, minimize environmental impact, improve constructibility, and lower life-cycle costs. The controlled environment off the critical path also facilitates improved quality of components. This concept of building bridges offline and then moving them into place needs to be developed for use in the United States.

Self-Propelled Modular Transporters

In Europe, it was observed that large bridge components or even complete bridges weighing several thousand metric tons have been built at one location and then lifted and transported to their final location using a series of vehicles known as self-propelled modular transporters (SPMTs). These multiaxle computer-controlled vehicles have the capability of moving in any horizontal direction with equal axle loads while maintaining a horizontal load with undeformed or undistorted geometry.

Other Bridge Installation Systems

In addition to using SPMTs and conventional land or barge-mounted cranes to erect large structures, other methods of moving bridge components observed by the team included the following:

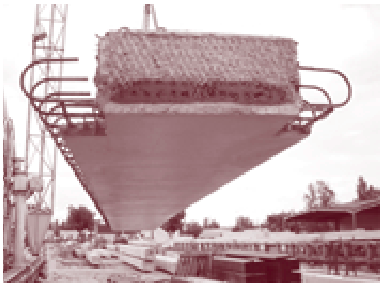
1. Horizontally skidding or sliding bridges into place
2. Incremental launching of bridges longitudinally across valleys or above existing highways

3. Floating bridges into place using barges or by building a temporary dry dock
4. Building bridges alongside an existing roadway and rotating them into place
5. Vertically lifting bridges

These systems can be used to minimize the time an existing bridge is out of service while it is replaced, in many cases within 3 to 48 hours.

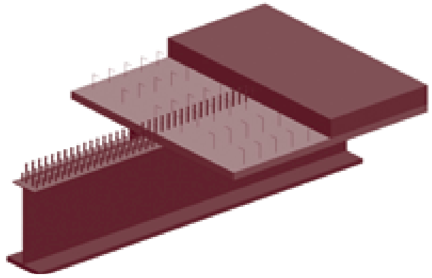
Superstructure Systems

The typical sequence of erecting bridge superstructures in the United States is to erect the concrete or steel beams, place either temporary formwork or stay-in-place formwork such as steel or concrete panels, place deck reinforcement, cast deck concrete, and remove formwork, if necessary. Eliminating the need to place and remove deck formwork after the beams are erected can accelerate onsite construction and improve safety. Three systems to accomplish this were identified during the study.



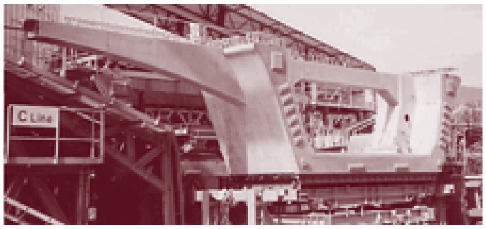
Poutre Dalle® System

One method to eliminate formwork and provide a working surface is the Poutre Dalle system developed in France. In this system, shallow, inverted tee-beams are placed adjacent to each other and then made composite with cast-in-place concrete placed between the webs of the tees and over the tops of the stems to form a solid member.



Partial-Depth Concrete Decks Prefabricated on Steel or Concrete Beams

One system in Germany involved the casting of partial-depth concrete decks on steel or concrete beams before erection of the beams. After the beams are erected, the edges of each deck unit abut the adjacent member, eliminating the need to place additional formwork for the cast-in-place concrete. This process speeds construction and reduces the potential danger of equipment falling onto the roadway below, because a safe working surface is available immediately after beam erection.



U-Shaped Segments with Transverse Ribs

To reduce the weight of precast concrete segments, the Japanese use a segment in which the traditional top slab is replaced with a transverse prestressed concrete rib. After erection of the segments, precast, prestressed concrete panels are placed longitudinally between the transverse ribs. A topping is then cast on top of the panels and the deck is post-tensioned transversely.

Deck Systems

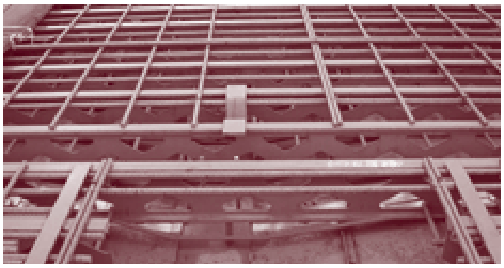
Four innovations for bridge deck systems were identified and are recommended for implementation in the United States.

Full-Depth Prefabricated Concrete Decks

The use of full-depth prefabricated concrete decks in Japan and France reduces construction time by eliminating the need to erect deck formwork and provide cast-in-place concrete. The deck panels are connected to steel beams through the use of studs located in pockets in the concrete deck slab. The use of full-depth prefabricated concrete decks on steel and concrete beams provides a means to accelerate bridge construction using a factory-produced product.

Deck Joint Closure Details

Prefabricated deck systems require that longitudinal and transverse joints be provided to make the deck continuous for live load distribution and seismic resistance. This is accomplished by using special loop bar reinforcement details in the joints. Various joint details observed during the scanning study should be evaluated for use in the United States to facilitate the use of prefabricated full-depth deck systems.



Hybrid Steel-Concrete Deck Systems

The Japanese have developed hybrid steel-concrete systems for bridge decks. The steel component of the system consists of bottom and side stay-in-place formwork and transverse beams. The transverse beams span over the longitudinal beams and cantilever beyond the fascia beam for the slab overhang. The bottom flanges of the transverse beams support steel formwork for the bottom of the slab while the top flanges support the longitudinal deck reinforcement. When filled with cast-in-place concrete, the system acts as a composite deck system. The system allows rapid placement of a lightweight deck stay-in-place formwork system complete with reinforcement using a small-capacity crane.

Multiple-Level Corrosion Protection Systems

In Japan, Germany, and France, concrete bridge decks are covered with a multiple-level corrosion protection system to prevent the ingress of water and deicing chemicals. The systems generally involve providing adequate concrete cover to the reinforcement, a concrete sealer, waterproof membrane, and two layers of asphalt. This type of corrosion protection system may be beneficial with prefabricated systems as a means of protecting the joint regions from potential corrosion damage, thereby ensuring a longer service life. The system may also be used to extend the service life of existing bridges.

Substructure Systems

Limited use of prefabricated substructures was observed during the scanning study, although such systems could provide significant benefits in minimizing traffic disruption. One substructure system is recommended for implementation in the United States.

SPER System

The SPER system (Sumitomo Precast form for resisting Earthquakes and for Rapid construction) is a Japanese method of rapid construction of bridge piers using stay-in-place, precast concrete panels as both structural elements and formwork for cast-in-place concrete. Short, solid piers have panels for outer formwork, and tall, hollow piers have panels for both the inner and outer formwork. Segments are stacked on top of each other using epoxy joints and filled with cast-in-place concrete to form a composite section. Experimental research in Japan has demonstrated that these piers have similar seismic performance to conventional cast-in-place reinforced concrete piers. The system has the advantage of reduced construction time and results in a high-quality, durable external finish.

Implementation Activities

In 2004 and 2005, the scanning team plans numerous written papers and technical presentations at national and local meetings and conferences to describe the overall results of the scanning study and details on specific technologies. The scanning team has also prepared a scanning technology implementation plan for each of the 10 technologies described above.

In general, the strategies involve obtaining more information about the technologies from the host countries, making this information available on FHWA's or other Web sites, seeking demonstration or pilot projects, and holding workshops in association with the pilot projects.

Introduction

Background

The aging highway bridge infrastructure in the United States is being subjected to increasing traffic volumes, and must be continuously renewed while accommodating traffic flow. The traveling public demands that this rehabilitation and replacement be done more quickly to reduce congestion and improve safety. Conventional bridge reconstruction is typically on the critical path because of the sequential, labor-intensive process of completing the foundation, substructure, superstructure components (girders and decks), railings, and other accessories. New bridge systems are needed that will allow components to be fabricated offsite and moved into place for quick assembly while maintaining traffic flow. Depending on the specific site conditions, the use of prefabricated bridge systems can minimize traffic disruption, improve work zone safety, minimize impact to the environment, improve constructibility, increase quality, and lower life-cycle costs. This technology is applicable and needed for both existing and new bridge construction. The focus of this initiative is on conventional, routine bridges that make up the majority of the bridges in the United States.

Objectives and Focus Areas

The overall objectives of the scanning study were to identify international uses of prefabricated bridge elements and systems, and to identify decision processes, design methodologies, construction techniques, costs, and maintenance and inspection issues associated with use of the technology. The scanning team, therefore, was interested in all aspects of design, construction, and maintenance of bridge systems composed of multiple elements fabricated and assembled offsite. The elements consisted of foundations, piers or columns, abutments, pier caps, beams or girders, and decks. Bridges with span lengths in the range of 6 to 40 m (20 to 140 ft) were the major focus, although longer spans were of interest if a larger amount of innovative prefabrication was used. The focus areas of the study were prefabricated bridge systems that provide the following:

1. Minimize traffic disruption.
2. Improve work zone safety.
3. Minimize environmental impact.
4. Improve constructibility.
5. Increase quality.
6. Lower life-cycle costs.

Locations Visited

The scanning team conducted its study of prefabricated bridge elements and systems in Japan, the Netherlands, Belgium, Germany, and France from April 19 to 30, 2004. The countries were selected because of their use of prefabricated systems. Visiting Japan was particularly important because of the country's seismic design requirements. The contacts in each country are listed in Appendix A. The locations, specific dates, and activities of the study are given in table 1.

Table 1. Schedule of activities.

Location	Date	Activities
Nagoya, Japan	Monday, April 19, 2004	Site visit to Anjo Viaduct, Aritas Expressway and Nagoya-Minami Junction, and Furukawa Viaduct.
Tokyo, Japan	Tuesday, April 20, 2004	Meeting with Japan Highway Public Corporation, East Japan Railway Company, Mitsubishi Heavy Industries, Sumitomo Mitsui Construction Company, Mitsui Engineering & Shipbuilding Company, Japan Bridge Engineering Center, Japan Bridge and Structures Institute, Kajima Corporation, Kawada Industries, Oriental Construction Company, and Yokogawa Bridge Corporation.

TABLE CONTINUED ON NEXT PAGE

TABLE CONTINUED FROM PREVIOUS PAGE

Location	Date	Activities
Schiedam, Netherlands	Thursday, April 22, 2004	Meeting with Mammoet Corporation.
Wolvertem, Belgium	Friday, April 23, 2004	Meeting with Sarens Group.
Munich, Germany	Monday, April 26, 2004	Meeting with Bavarian Department of Highways and Bridges, and site visits to bridges on the A9 and A8 autobahns.
Frankfurt, Germany	Tuesday, April 27, 2004	Site visits to two bridges on the A3 autobahn with Adam Hornig (contractor) and Elementbau Osthessen (prefabricator).
Bergisch Gladbach, Germany	Wednesday, April 28, 2004	Meeting with Federal Highway Research Institute and the German Association of Prefabricated Elements and Systems.
Paris, France	Thursday, April 29, 2004	Meeting with French National Railway Authority and site visits to three bridges in Normandy.
Paris, France	Friday, April 30, 2004	Meeting with Technical Department for Public Works and Transportation, Central Laboratory for Public Works, Technical Center for the Concrete Industry, Technical Studies Center for Public Works, CPCBTP, and Lafarge Cement.

Team Members

The scanning study was sponsored by FHWA and AASHTO. The 11-member team included three representatives from FHWA, four representatives from State DOTs, one representative from the National Association of County Engineers, one university representative, and two industry representatives. Team members and their representative organizations are listed in table 2. Contact information and biographical sketches for each team member are included in Appendix B.

Table 2. Team members.

Ben Tang (co-chair) Federal Highway Administration	Mary Lou Ralls (co-chair) Texas Department of Transportation
Dr. Shrinivas Bhidé Portland Cement Association	Barry Brecto Federal Highway Administration
Eugene C. Calvert Collier County, Florida	Harry Capers New Jersey Department of Transportation
Dan Dorgan Minnesota Department of Transportation	Dr. Eric Matsumoto California State University, Sacramento
Claude S. Napier, Jr. Federal Highway Administration	William Nickas Florida Department of Transportation
Dr. Henry G. Russell (report facilitator) Henry G. Russell, Inc.	

Amplifying Questions

The scanning team developed a series of amplifying questions to help focus the discussion with the foreign experts and to show them the topics of interest. The amplifying questions addressed prefabricated bridge systems to minimize traffic disruption, improve work zone safety, minimize environmental impact, improve constructibility, improve quality, and lower life-cycle costs. The questions provided to the hosts before the scanning study are included in Appendix C.

Findings on Prefabricated Bridge Systems

JAPAN

In Japan, the scanning team visited three highway bridge projects and met with representatives of the Japan Highway Public Corporation, East Japan Railway Company, Mitsubishi Heavy Industries, Sumitomo Mitsui Construction Company, Mitsui Engineering & Shipbuilding Company, Japan Bridge Engineering Center, Japan Bridge and Structures Institute, Kajima Corporation, Kawada Industries, Oriental Construction Company, and Yokogawa Bridge Corporation. The involvement of these companies in one meeting reflects the spirit of cooperation that exists among owners, designers, and contractors. The scanning team observed that work is performed as a partnership to achieve a common goal.

Background

The Japan Highway Public Corporation (JHC) is a special public corporation fully owned by the national government. It is responsible for constructing and operating expressways, ordinary toll roads, and toll parking facilities. It also is responsible for constructing rest areas, gas stations, and other facilities on expressways and expressway-related facilities, such as truck terminals and trailer yards. The corporation has about 9,000 employees and had an annual budget of ¥5,363 billion (US$50 billion) in 2001. The corporation is responsible for constructing the new Tomei Expressway between Tokyo and Nagoya and the new Meishin Expressway between Nagoya and Kobe. When completed, these two expressways will provide a 500-kilometer (km) (310-mile (mi)) long link between three metropolitan areas as part of the national expressway network. The standard number of lanes is six throughout the expressway and the design speed is 140 kilometers per hour (87 miles per hour).

Employing rapid bridge construction techniques on road projects is a high priority in Japan for the following reasons:

1. High project costs
2. High labor costs
3. Scarcity of skilled labor because of retirements
4. Weight limit of 30 metric tons (t) (33 tons) for non-permit loads
5. Impact of traffic throughout the work zones
6. Need for faster erection
7. Need for improved quality
8. Need for better work zone safety for contractors and the public

Ten years ago, Japan had adequate labor to perform cast-in-place construction economically, but the reduction in skilled labor and rising labor costs have fostered growth of factory-produced, prefabricated components for bridge construction. This situation has encouraged Japanese engineers to search for ways to lower the size and weight of prefabricated components to satisfy hauling restrictions.

The three highway bridge projects the scanning team visited were the Anjo Viaduct, the Aritas Expressway (Route 23) and Nagoya-Minami Junction, and the Furukawa Viaduct, as shown on the map in figure 1 (see next page). In addition, the team learned about other construction methods used in Japan. These projects and other construction methods are described in the following sections.

Anjo Viaduct

The Anjo Viaduct, shown in figure 2, is a horizontally curved bridge on the new Tomei Expressway and con-

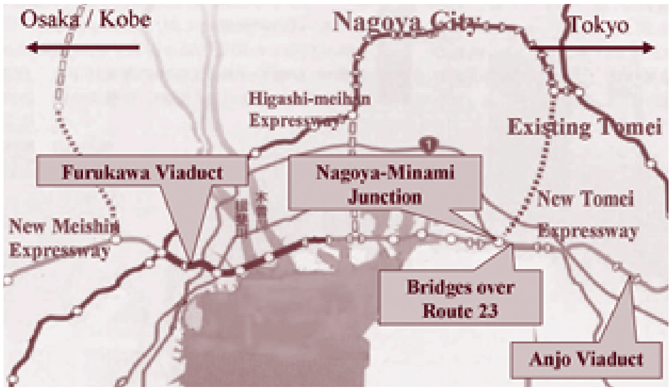


Figure 1. Map of bridge sites in Japan.

Figure 2. Anjo Viaduct.

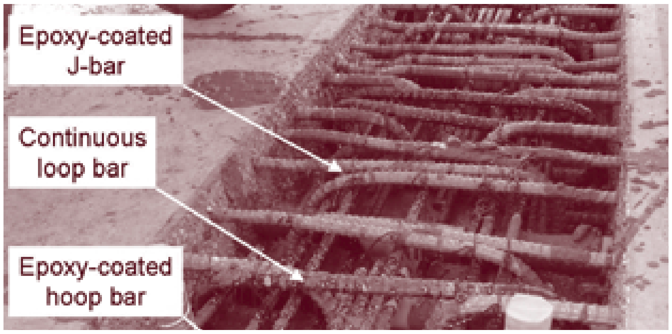


Figure 3a. Longitudinal joint on the Anjo Viaduct.

Figure 3b. Closure joint between segments.

sists of 24 spans ranging in length from 31.5 to 40.5 m (103 to 133 ft) for a total length of 916 m (3,000 ft). The bridge consists of two parallel structures. The cross section of each superstructure consists of two precast, prestressed concrete, single-cell, constant-depth box girders with a total depth of 2.6 m (8.5 ft). The segments were match cast using the short-line method of casting. The weight of each segment was limited to about 30 t (33 tons) so that segments could be transported to the construction site on the public highway without a special permit. The deck of each segment is transversely pretensioned—a method not used in the United States. After each segment is removed from the casting bed, measurements of the segment are made with a three-dimensional measuring system that uses the principals of photogrammetry with high-precision cameras. The system provides automatic output of the measured shape, corrections for the next segment, measurement of time-dependent deformations, and erection simulation. The system was identified during the 1997 scanning study on Asian bridge structures. At that time, it was being used by the Yokogawa Bridge Corporation for steel bridge component measurements and erection simulation in lieu of shop assembly.

The segments for the Anjo Viaduct were erected using the span-by-span method. An epoxy compound was applied to the joint surface of each segment, and the epoxy thickness was measured on each face before the segments were joined together. The span segments were connected to the pier segments using a cast-in-place (CIP) joint that contained stainless steel fibers and an expansive cement component. Each external longitudinal post-tensioning tendon consisted of 19 15.2-mm (0.6-in) diameter epoxy-coated strands located inside the box and passing through deviator blocks. For the pier segments, the transverse diaphragms were cast in place. Transverse post-tensioning was provided only at the pier diaphragms and in the deck above the deviator blocks. Pairs of side-by-side segments on each structure are connected together at the top flanges by a 600-mm (24-in) wide longitudinal joint to form a continuous top surface for the roadway. Within the joint, hoop bars and J-bars projecting from the top flange of each pair of adjacent boxes overlap each other and are overlapped by a continuous loop bar, as shown in figure 3a. The bars projecting from the top slab, shown in figure 3a, are epoxy-coated solely to prevent corrosion while the segments are in storage. Other bars pass through the loops to provide continuity. A cast-in-place concrete closure containing polyvinyl fibers is used to join adjacent segments. A photograph of the underside of the bridge showing the closure joint between segments is shown in figure 3b. A waterproof membrane and asphalt wearing surface will be applied to the deck surface.

Aritas Expressway (Route 23) and Nagoya-Minami Junction

One section of the New Tomei Expressway consists of an elevated structure that runs longitudinally above existing Route 23, which carries about 90,000 vehicles per day. Construction involved limiting the closure of Route 23 to 27 weekend nights for a total of 348 hours in 4 years. The new structure, therefore, was supported above the existing roadway, as shown in figure 4. Where sufficient working space existed alongside the highway, cast-in-place concrete piers were used. Where space was not available, prefabricated steel columns were used. Erection of the steel columns required lane closures.

For the erection of the steel beams across Route 23, steel stub beams were first attached to the columns on both sides of the highway, as shown in figure 5. Next, the highway was closed while prefabricated steel beams were connected between the ends of the stub beams to produce a span length of 33 m (108 ft).

Two methods were used to place the Aritas superstructure with minimum interruption to traffic. In the first method, each span was constructed on falsework alongside the existing roadway of Route 23. The superstructure units were slid horizontally sideways along the tops of the steel box beams to their final position above the existing highway. The second method involved prefabricating a curved steel girder and carrying it along the existing highway using special multiaxle transporters.

At the Nagoya-Minami Junction, three types of deck systems were observed—transversely prestressed, full-depth prefabricated concrete decks; a hybrid steel-concrete deck system; and orthotropic steel decks.

Full-Depth Prefabricated Concrete Decks

In recent years, the Japanese have started using precast, transversely pretensioned, full-depth concrete decks because of their improved durability, lower creep deformation, and faster construction, as shown schematically in figure 6 (see next page). In addition, wider girder spacings with fewer girders can be used compared to a CIP deck. The 2-m (6.6-ft) long, full-deck-width precast concrete panels are connected to steel girders using studs located in pockets in the panels, also shown in figure 6. The studs are designed to provide a positive connection for lateral load only and not for composite action between the deck and the girders. The transverse joint between the panels consists of overlapping hoop bars that project from each edge of the panel. Individual bars are threaded within the loop bars to complete the connections, which are then encased in concrete. A schematic drawing of the deck joint reinforcement is shown in figure 6c. The decks are not post-tensioned longitudinally. All bridge decks in Japan receive a waterproof membrane and asphalt riding surface. The use of full-depth decks reduces construction time by eliminating the need to erect deck formwork and provide cast-in-place concrete. It also uses the advantages of a factory-produced product.


PHOTO COURTESY OF JHC

Figure 4. Elevated structure of Aritas Expressway.

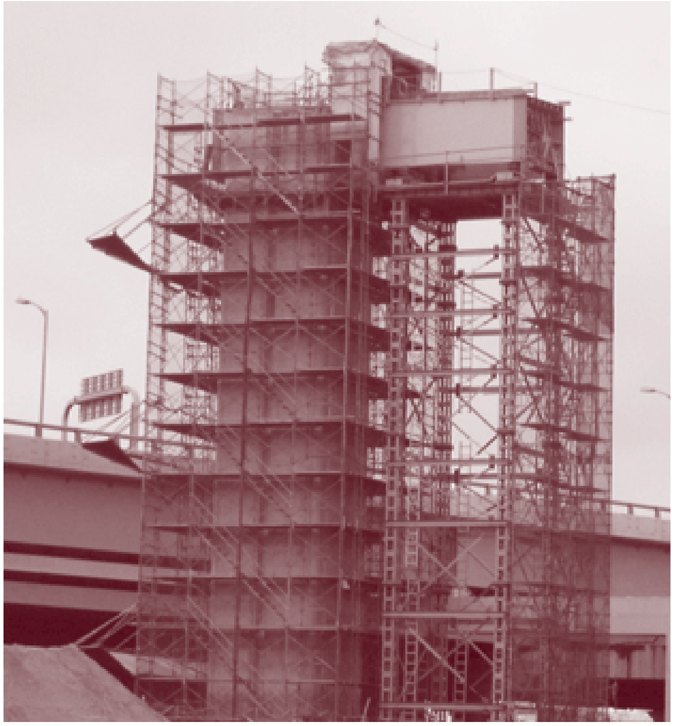


Figure 5. Concrete column with a steel stub beam.

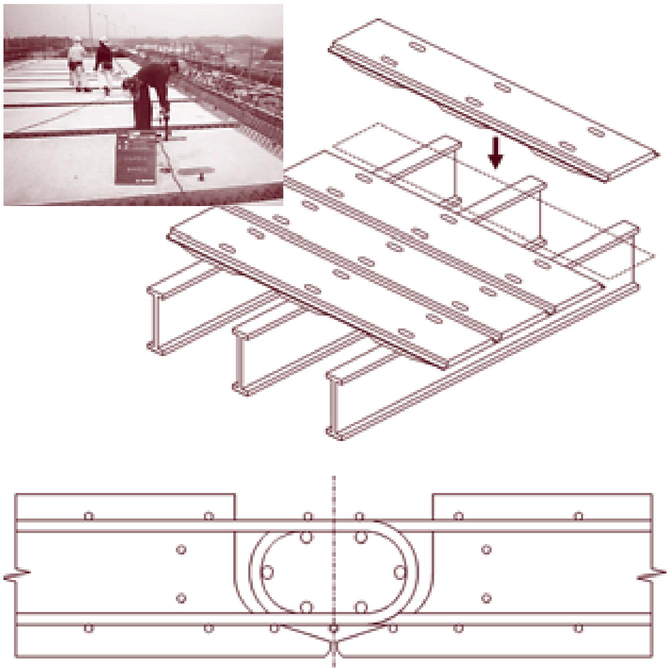


PHOTO AND DRAWINGS COURTESY OF JHC

Figure 6. Full-depth prefabricated concrete deck.

Hybrid Steel-Concrete Deck Systems

Several Japanese companies have developed hybrid steel-concrete deck systems for bridges. One system is shown in figure 7. The steel component of the system consists of bottom and side stay-in-place formwork and transverse beams. The transverse beams span over the longitudinal beams and beyond the fascia beam for the slab overhang. The bottom flanges of the transverse beams support the steel formwork for the bottom surface of the slab. The formwork is sloped to provide a haunched section over the girders. The longitudinal deck reinforcement is supported by the top flange of the transverse beams. Steel studs welded to the beam flange connect the deck and the beams. When filled with concrete, the system acts as a composite deck system. The system allows rapid placement with a small-capacity crane of a lightweight deck stay-in-place formwork system complete with reinforcement, including the overhang.

Orthotropic Steel Decks

In recent years, the Japanese have developed an orthotropic steel deck with larger members for use with wider girder spacing. The deck is covered with 35 mm (1.4 in) of gussasphalt and 40 mm (1.6 in) of open gap-graded asphalt as the riding surface, based on German technology. Orthotropic steel decks are used when the superstructure is launched longitudinally to lower the weight and to eliminate casting concrete over traffic. The orthotropic steel deck also provides a secure working surface immediately after erection.

Furukawa Viaduct

The Furukawa Viaduct is located on the new Meishin Expressway between the Kawagoe and Asahi interchanges, and was built between 1999 and 2002. The viaduct consists of two side-by-side precast, prestressed concrete box girder bridges. It has 41 spans with span lengths ranging from 34 to 45 m (112 to 148 ft) for a total length of 1,475 m (4,839 ft). To reduce the weight of each precast segment to 30 t (33 tons) for transport by road, the traditional top slab of each segment was replaced with a transverse prestressed rib, as shown in figure 8a.

The viaduct was built using the span-by-span method with an overhead truss, as shown in figure 8b. A CIP joint is provided between the span segments and the pier segments at both ends of each span. The longitudinal external post-tensioning is located inside the box to permit easy maintenance and replacement. The tendons were stressed in several stages. Precast, prestressed con-

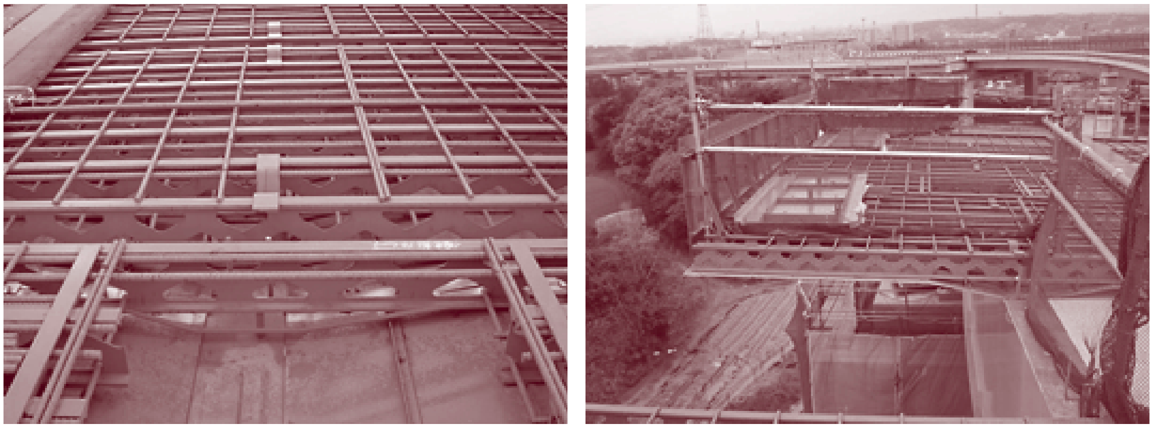


PHOTO COURTESY OF JHC

Figure 7. Hybrid steel-concrete deck system.

crete deck panels span longitudinally between the transverse ribs, as shown in figure 8c. A CIP topping, which is transversely post-tensioned, is used to complete the system. A second feature to reduce the weight of each segment and to increase durability was the use of concrete with a specified concrete compressive strength of 60 megapascals (MPa) (8,700 pounds per square inch (psi)). A photograph of the underside of the completed bridge is shown in figure 8d. Because this was the first application of this method, a full-scale test was performed for each construction phase to ensure safety. This superstructure design concept allows for future deck removal.

Arimatsu Viaduct

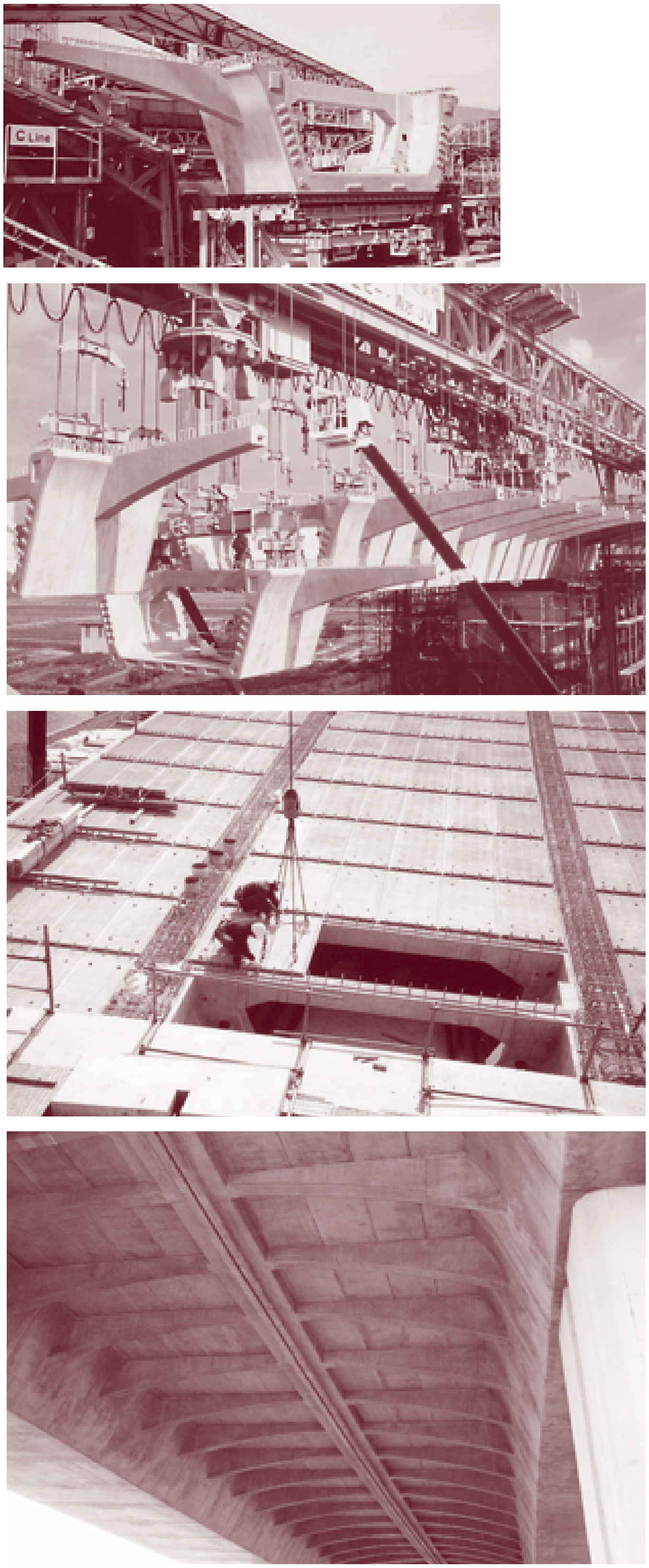
The Arimatsu Viaduct consists of two side-by-side, six-span continuous steel box girder bridges with orthotropic decks and runs above Route 23. The viaduct, with three lanes in each direction, has a length of 655 m (2,150 ft) and a weight of 12,000 t (13,200 tons). The longest span length is 130 m (427 ft). The substructure for the viaduct is similar to that of the Aritas Expressway. The superstructures for both bridges were assembled on falsework in span-length increments at the end of the viaduct and launched longitudinally above Route 23, as shown in figure 9 (see next page), using a special automated launching system. Each of the six spans had to be launched within a 12-hour window between 8 p.m. and 8 a.m. Both bridges were launched side by side.

The automated launching system used a centralized control system to maneuver 100 jacks, including 56 synchronized jacks each with a 500-t (550 ton) capacity and a 230-mm (9-in) stroke. The synchronized jacks were used to control the up-and-down movement, left-to-right directions, and height differences. A course correction device was provided at each bent to maintain a gap of 40 mm (1.6 in) between the two bridges during the launch.

The bridge construction contract did not contain any financial penalties for not completing the launch in the designated time. The contractor, however, was required to absorb all additional costs associated with delays after the allowed time and was not allowed an additional traffic interruption without issuing a public notification 60 days before the closure. At the time of the team's visit, the contractor had completed every closure event on time.

Yahagigawa Bridge

The Yahagigawa Bridge is a four-span, composite hybrid steel and concrete cable-stayed bridge with corrugated steel webs constructed across the Yahagigawa River between Toyota and Togoto-Higashi Junction. The bridge



PHOTOS COURTESY OF SUMITOMO MITSUI CONSTRUCTION COMPANY

Figures 8a, 8b, 8c, and 8d. Furukawa Viaduct.

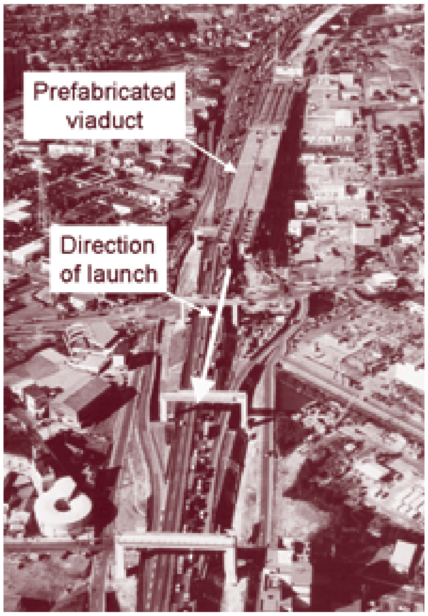


PHOTO COURTESY OF MITSUBISHI HEAVY INDUSTRIES

Figure 9. Arimatsu Viaduct.

consists of two pylons with an intermediate pier situated between the pylons to give span lengths of 173.4, 235, 235, and 173.4 m (569, 771, 771, and 569 ft). A single plane of stay cables is used. The portion of the hybrid superstructure supported directly by the cables consists of a 43.8-m (144-ft) wide five-cell box with top and bottom concrete flanges and corrugated steel webs. The portion of the superstructure above the central pier is a five-cell steel box girder. It is claimed to be the world's longest single span and total length prestressed concrete bridge with corrugated webs. The concrete towers, which are 109.6 m (360 ft) tall, are claimed to be the tallest concrete bridge towers in Japan. It is the first cable-stayed bridge in the world to use corrugated steel webs and steel box girders.

The use of corrugated steel webs is reported to have the following advantages:

- Has high resistance against buckling.
- Allows the longitudinal force to go into the concrete flanges because of the accordion effect in the webs.
- Reduces the weight of the structure.
- Reduces construction time and costs.

Extradosed Bridges

Two extradosed bridges are located on the new Meishin Expressway across the Kiso River and Ibi River. From the exterior, extradosed bridges resemble cable-stayed bridges with short pylons, but the structural characteristics are more comparable to post-tensioned box girder bridges. The Japanese described the following features for extradosed bridges:

- The girder depth can be less than that for conventional girder bridges.
- The cable stays need no tension adjustment.
- The pylon height can be half of the conventional cable-stayed pylon height.
- The anchorage method for the stays can be the same as that for post-tensioned anchorages inside the girder.

The Kiso River Bridge is a five-span bridge with four pylons and the Ibi River Bridge is a six-span structure with five pylons (figure 10). Both bridges use a single plane of cables, a concrete box girder for the cross section to which the stay cables are attached, and a steel box girder for the superstructure beyond the ends of the stay cables. One factor in the selection to use extradosed bridges was the need to complete all pile-driving and substructure work in one dry season from October to May. The use of extradosed bridges allowed for longer span lengths and fewer foundations.

Railroad Bridges

The Japanese economy is very dependent on the railway system for transportation of materials and people. About 50 percent of the Japanese population uses the railways each day. Consequently, any interruption to traffic flow must be minimized. In addition, working space is very limited alongside the railway lines in urban areas. For improvements on the Chuo Line at the Tokyo station, new structures were built alongside the existing railroad bridge and then jacked laterally into place. The Japanese also have found it feasible to incorporate temporary girders into permanent girders, as depicted in figure 11. A temporary bridge was first erected alongside an existing multiarch viaduct using span lengths equal to those of the original viaduct. Train traffic was diverted to the temporary bridge (figure 11a) while the original viaduct was demolished. The depth of the temporary girder was then increased by adding girders below the temporary girders. Formwork was then added (figure 11b) and the two girders were encased in concrete while the bridge was still in service (figure 11c). Finally, the new bridge was moved laterally to replace the previous viaduct. Intermediate piers were then removed so that the four original arches were replaced with a two-span bridge. This method reduced the period of railway service interruption, nighttime work with closed tracks, site work, and total cost.

On the new Joban Line near the Kita-Senju station, segmental precast girders were used to construct a bridge for a new railway line between two existing lines while keeping the lines in service. The sequence of construction is shown in figure 12 (see page 10). After construction of the first two spans, the next girder was assembled on top of these spans (figure 12a). A temporary steel erection girder was then placed in the next span (figure 12b) and a suspension girder positioned above the span (figure 12c). The concrete girder was moved across the span on the erection girder and hung from the suspension girder (figure 12d). The erection girder was moved forward to the next span. The concrete girder was lowered into its final elevation (figure 12e). The concrete girder was moved laterally to its final position and the sequence repeated for a second parallel concrete girder. The whole process was repeated on the next span.

Mitsuki Bashi Method

The Mitsuki Bashi (Three-Month Bridge) method is a quick construction system developed by Mitsui Engineering & Shipbuilding Co, Ltd., for roadway overcrossings in an urban area. The system includes a steel hull footing, a steel bridge pier and cap, and a steel box girder superstructure, as shown in figure 13a (see page 11). In the first stage of construction, the steel hull footing is placed in an excavated foundation. The footing has a short stub pier on top and vertical holes through which piles can be driven. The system allows the piles to be placed through the steel footing while the steel pier and pier cap are being erected. The hull can then be filled with concrete to create a composite foundation. At the same time, the main span is being assembled offsite. The main span is moved into place as a single unit using a special transportation vehicle.

Construction of the approach portion of the bridge is depicted in figure 13b. First, H-section columns are driven alongside the final approach road location. Soil of the same dead weight as the approach portion is excavated. A precast concrete slab is placed between the columns in the excavated areas. Expanded polystyrene is installed above the slab and vertical precast panels are placed between the columns. Finally, a concrete slab and riding surface

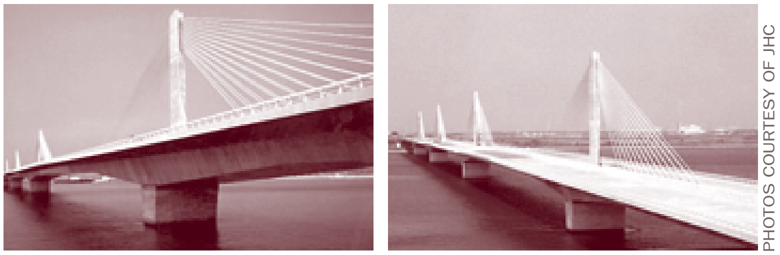
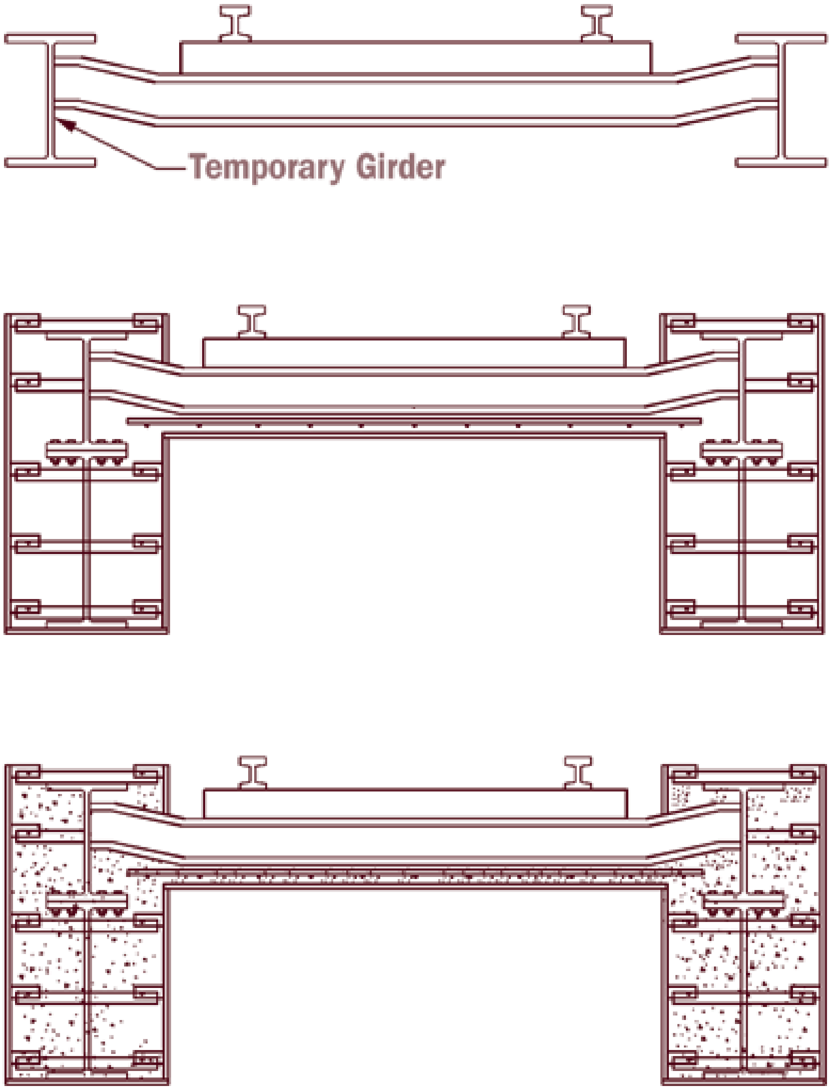
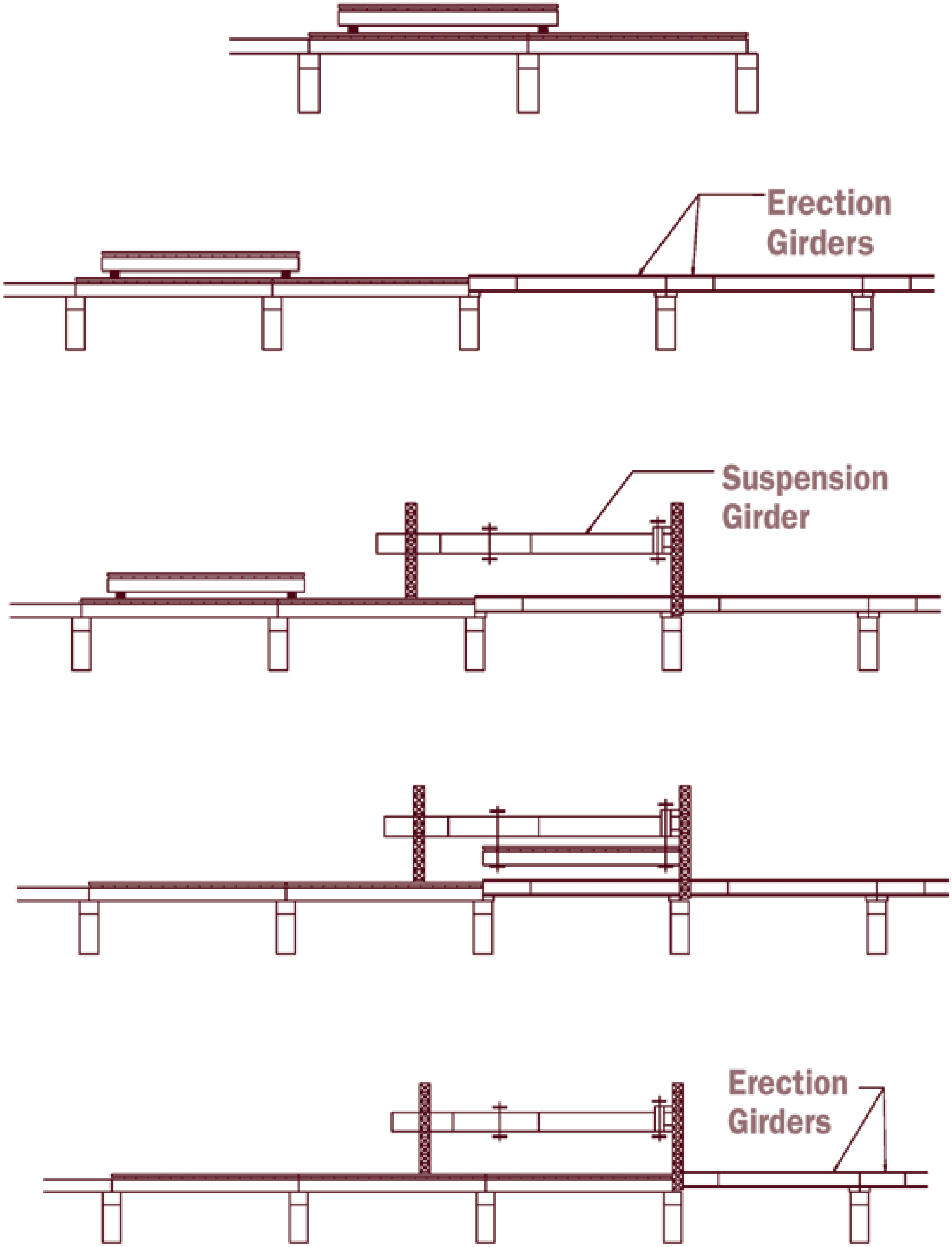

PHOTOS COURTESY OF JHC

Figure 10. Extradosed bridges.



Figures 11a, 11b, and 11c. Use of temporary girders as part of the permanent structure. *(Based on drawings by East Japan Railway Co.)*



Figures 12a, 12b, 12c, 12d, and 12e. Sequence of construction on the new Joban Line. *(Based on drawings by East Japan Railway Co.)*

are placed on top. Although the system has not been used, the shortest estimated construction time is 3.5 months for a 400-m (1310-ft) long crossover at an estimated cost of $7 million.

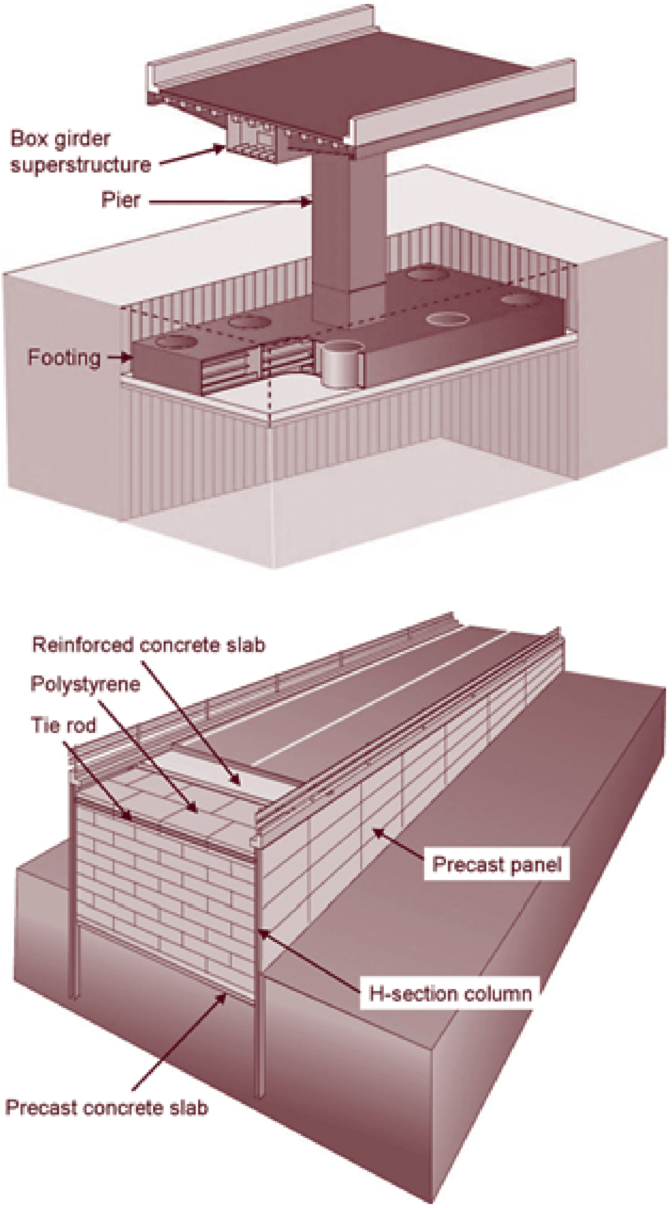
Chofu-Tsurukawa Overbridge

The Chofu-Tsurukawa Overbridge, shown in figure 14, is a temporary bridge built in 11 months to eliminate a grade crossing causing traffic congestion.
The requirements for the project included a short construction period, environmental restrictions, traffic restrictions, and future removal of the bridge. The bridge is a nine-span, continuous rigid frame, steel girder bridge with span lengths ranging from 8.0 to 26.0 m (26 to 85 ft) for a total length of 163 m (534 ft). Construction of the bridge involved the use of liquefied soil stabilization, precast concrete footings, rubber bearings beneath the column base to reduce seismic forces, steel piers, precast deck panels post-tensioned longitudinally on the approach spans, and precast concrete retaining walls. Environmental protection involved the use of a low-noise crane, drilled foundations instead of driven piles, multipulley pile extractor, and low-noise drift pins. The precast deck panels and retaining walls were installed at night to minimize traffic disruption. In the future, the railroad tracks will be placed below grade and the bridge removed. As a result of this construction, the travel time to cross the railroad has been reduced by 65 percent and the number of cars detouring to nearby roads has dropped by 20 percent. The economic benefit of the bridge is estimated to be about $10 million per year.

SPER Method

The Sumitomo Precast form for resisting Earthquakes and for Rapid construction (SPER) system is a method developed by Sumitomo Mitsui Construction Company for rapid construction of short and tall bridge piers in seismic regions using stay-in-place 100-mm (3.9-in) thick precast concrete panels as both formwork and structural elements. For short solid piers, panels with pre-installed cross ties, as shown in figure 15a (see next page), serve as exterior formwork. Segments are stacked on top of each other using epoxy joints and filled with cast-in-place concrete to form a solid pier (figure 15b).

For taller hollow piers, inner and outer forms are used to produce a hollow section, shown in figure 15c. To reduce weight and size for hauling, panels form two channel-shaped sections. Lateral reinforcement



Figures 13a and 13b. Mitsuki Bashi method.

Figure 14. Chofu-Tsurukawa Overbridge.

PHOTO AND DRAWINGS COURTESY OF MITSUI ENGINEERING & SHIPBUILDING COMPANY

Figure 15a. SPER method.

Figure 15b.

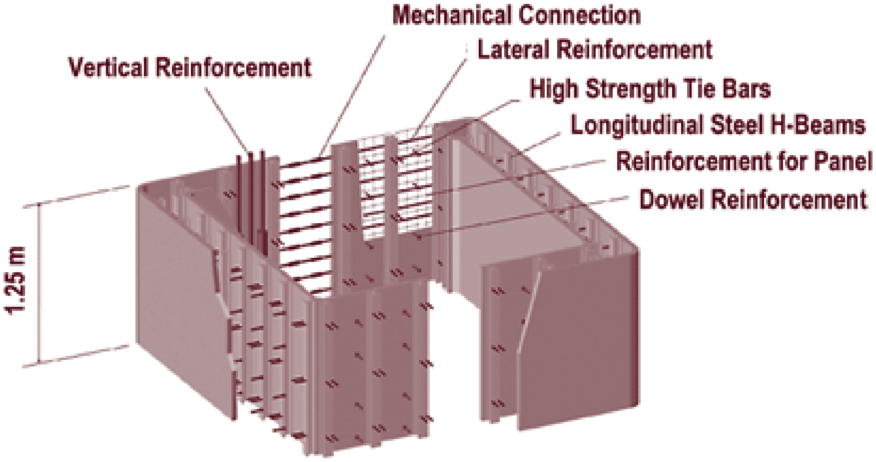


Figure 15c.

Figure 15d.

Figure 15e.

PHOTOS AND DRAWING COURTESY OF MITSUI ENGINEERING & SHIPBUILDING COMPANY

is embedded in the channel sections and joined together in the field using couplers. Assembling channel-shaped forms in the field is shown in figure 15d. After inner and outer precast forms are set around vertical reinforcement, cross ties (transverse reinforcement) are placed and concrete is cast within the section. A completed hollow pier is shown in figure 15e. Use of high-strength bars for cross ties reduces congestion and fabrication time. Special details are used to transfer the force from the transverse reinforcement into the panels. Cast-in-place concrete is used to connect the piers to the superstructure.

The SPER system has been used on four bridge projects, including the Otomigawa Bridge in Ayabe City, Kyoto Prefecture, with pier heights of 15.6, 32.5, 51.1, and 32.5 m (51, 107, 168, and 107 ft). The system can shorten construction time to 60 to 70 percent of the time required for conventional cast-in-place construction for 10-m (33-ft) tall piers. This is attributed to the elimination of formwork and reduction in curing time. For 50-m (164-ft) tall piers, reduction in placement time for lateral reinforcement and cross ties resulted in a one-third decrease in construction time. Experimental research in Japan has demonstrated that stay-in-place forms develop composite action with the CIP concrete and that piers achieve a seismic performance comparable to conventional reinforced concrete piers. Use of high-performance concrete (HPC) panels results in a high-quality, durable external finish and an aesthetic appearance. A similar system reportedly has been developed by Kajima Corporation.

Sound Barriers

While traveling in Japan, the team noticed numerous uses of sound walls along the sides of highways and on bridges. Most sound walls appeared to be prefabricated of lightweight materials. A feature of many sound barriers on bridges was the use of transparent panels. This not only allowed the bridge user to see out, but also allowed sunlight to penetrate through so that the shadow of the bridge on the ground was not as big. At the same time, people on the ground could see the sky and sunshine through the panels. A sound barrier at ground level alongside the Furukawa Viaduct is shown in figure 16a. In some cases, the sound barriers formed complete tunnels, as shown in figure 16b.

Figures 16a and 16b. Sound barriers.

NETHERLANDS AND BELGIUM

In the Netherlands and Belgium, the team visited the head offices and facilities of two worldwide companies that specialize in lifting and moving heavy equipment and structures, including bridges. In the Netherlands, the team visited the Mammoet Corporation. In Belgium, the team visited the Sarens Group. In terms of lifting capacity, Mammoet ranks second in the world and Sarens ranks fifth.

Background

Mammoet has annual revenues of about EUR300 million (US$360 million) and 1,700 employees at 42 locations in Europe, North and South America, Asia, Middle East, and Africa. In the United States, the company's offices are located near Atlanta, GA; Baton Rouge, LA; Houston, TX; and Los Angeles, CA. Its equipment includes 650 cranes with capacities ranging from 30 to 4,400 t (33 to 4,850 tons), jacking and skidding equipment with a lifting capacity of up to 25,000 t (27,500 tons), tower systems with a capacity of up to 4,000 t (4,400 tons) and 2,000 axle lines of platform trailers, as well as other lifting and transporting equipment. Mammoet is involved in heavy lifting for the petrochemical, offshore, power, and civil engineering industries.

Sarens is a group of 30 companies with annual revenues of about EUR150 million (US$180 million) and 830 employees located in Belgium, the Netherlands, France, United Kingdom, Germany, Scandinavia, Southern Europe, Eastern Europe, Africa, Middle East, United States, South America, Asia, and Australia. Sarens' equipment includes 600 hydraulic cranes with capacities ranging from 20 to 1,000 t (22 to 1,100 tons), 110 crawler cranes of 50-to-2,000-t (55- to-2,200-ton) capacity, 500 axle lines of self-propelled modular transporters, and four 120-m (393-ft) tall, 1,000-t (1,100-ton) capacity lifting towers, as well as other lifting and transporting equipment. About 50 percent of Sarens work is for the civil engineering industry, with the rest for the power, harbor works, and petroleum industries.

Both Mammoet and Sarens have their own engineering departments that develop detailed plans for moving heavy equipment. Staff training and safety of people and equipment are high priorities for both companies. Based on the information provided to the team, both companies have excellent qualifications and experience for moving both small and large bridges and bridge components. Their competitive edge is their ability to lift or move large structures.

Moving Systems

In general, moving bridges or bridge components from their location of prefabrication to their final position involves one or more of the following basic methods:

- Driving
- Lifting
- Pushing or pulling
- Skidding or sliding
- Pivoting

PHOTOS COURTESY OF MAMMOET CORP. AND SARENS GROUP

Figures 17a and 17b. Moving large bridges with SPMTs.

The advantage of the driving method is that the bridge can be assembled at a location independent of its final position. It is moved from its assembly location to its final position using self-propelled modular transporters (SPMTs). In addition, height differences are adjusted easily using special support equipment, and differences in ground elevations are accommodated easily. The moving time can be relatively short. Two examples of moving large bridges are shown in figure 17. The bridge shown in figure 17a weighed about 3,300 t (3,600 tons), and was moved 120 m (390 ft) in about 2 hours to its final position across the A4/A5 expressway near Amsterdam's Schipol Airport. SPMTs with 134 axle lines were used.

PHOTO COURTESY OF MAMMOET CORP.

Figure 18. Skidding a bridge into position.

Figure 19. A single SPMT.

In figure 17b, twin steel arch bridges are being moved across a canal using a combination of SPMTs and barges. Each bridge had a span length of 119 m (390 ft) and weighed about 800 t (880 tons).

The lifting method involves moving a bridge vertically using either hydraulic jacks or cranes. The method is largely place independent; height differences are easily accommodated but overhead wires and crane outriggers must be considered. The method is relatively quick, but crane capacity can be a limiting factor.

Pushing or pulling a bridge with hydraulic jacks from its point of fabrication to its final location requires a flat, well-built foundation, is limited to linear movement, and cannot compensate for any changes in height during the pushing or pulling operation. It can also be very time consuming compared to moving with SPMTs. Skidding along a specially prepared track requires a well-built foundation and is limited to a linear movement. Small differences in height can be tolerated by changes in the shape of the bridge. The process is also time consuming compared to moving with SPMTs. As part of the Channel Tunnel Rail Link in the United Kingdom, a 9,500-t (10,500-ton) bridge including abutments and piers, shown in figure 18, was skidded into position in 72 hours. During transportation, only 16 mm (0.63 in) of deflection over the full length of the deck was permitted.

Pivoting is a technique in which the bridge is built alongside the highway, railroad, or river, and then rotated around a vertical axis into its final position. It avoids constructing over the existing right-of-way.

Self-Propelled Modular Transporters

Of particular interest to the team for driving and lifting bridges were the computer-controlled, self-propelled modular transporters. A single SPMT, shown in figure 19, has either six or four axle lines. Each axle line consists of four wheels arranged in pairs and can support a maximum load of 30 t (33 tons) in addition to its own weight when ground conditions permit. Each pair of wheels can pivot 360 degrees around their support point. As a result, an SPMT has complete freedom of movement in all horizontal directions, as shown in figure 20.

Through its hydraulic suspension system, equal loads are maintained independently on each axle even on irregular surfaces. The bed of the SPMT can be raised by 600 mm (24 in) and tilted in both directions to maintain a horizontal bed on an inclined surface. Grades as steep as 8 percent have been used, but the maximum grade depends on site-specific friction. Vertical lifting equipment can be mounted on the SPMT platform if required. The SPMT is self propelled and can be coupled longitudinally and laterally to form multiple units all controlled by one driver. The driver walks with the units and carries a controller connected to the units by an umbilical cord. The controller has four basic commands: steering, lifting, driving, and braking. The approximate cost of one axle line is EUR125,000 (US$150,000). The SPMTs can be transported to the bridge site on normal flatbed trailers or shipped in flat rack containers. The units have been used on several bridges in the United States, including the Lewis and Clark Bridge in Washington State; the Wells Street Rapid Transit Viaduct in Chicago, IL; and the 3rd Avenue Bridge in New York, NY.

In relocating bridges using SPMTs, the following factors need to be considered:

- Specific geometric distortion tolerances for moving must be specified with appropriate penalties for exceeding them.
- Geometric tolerances must be strict enough to avoid excessive stresses on the bridge, yet reasonable enough to permit an optimum speed of movement.
- Loads and reactions imposed on the structure during moving are different from those when the bridge is in its final position, and need to be considered as part of the original design.
- Geometric distortion must be monitored during the moving operation.
- Temporary structures are needed to support the bridge before and during the move.
- Ground-bearing capacity needs to be considered.
- SPMT owners with appropriate expertise and experience should be specified to do the move, as subcontractors to the prime contractor.
- SPMT owners should be included in the initial planning process to ensure a cost-effective approach.
- Bonuses and penalties should be included in the contract for early and late completion, respectively.

Figure 20. Directional capability of an SPMT.

GERMANY

In Germany, the team met with representatives of the Federal Highway Research Institute, State of Bavaria Department of Highways and Bridges, German Association of Prefabricated Elements and Systems, Adam Hornig (contractor), and Elementbau Osthessen (prefabricator).

Background

The road construction administrations in Germany are subject to the European Community's public procurement directives. Consequently, all road construction contracts must meet the available requirements of the European Union's (EU) technical specifications. These specifications are European standards, authorizations, and general technical specifications that have been incorporated into national standards. Where no European technical specifications exist, an EU member country can deviate from the standards. Certain products used for the construction of roads and bridges are governed by the European Construction Products Directive, which has been integrated into the Construction Products Act in Germany.

In 2003, 36,971 of the approximately 120,000 bridges in Germany were within the jurisdiction of the federal government. The federal bridges comprised 27.2 million m^2 (293 million ft^2) of bridge deck, of which 18.8 million m^2 (202 million ft^2) used prestressed concrete superstructures. The remaining bridges include 5.2 million m^2 (56.0 million ft^2) of reinforced concrete superstructures, 1.9 million m^2 (20.5 million ft^2) of steel superstructures, and 1.2 million m^2 (12.9 million ft^2) of composite structures. The annual maintenance cost for federal bridges is EUR350 million (US$420 million).

Germany has recognized the importance of accelerating construction on the autobahns that are particularly problematic or have heavy traffic volume. Therefore, when bidding on projects, contractors are invited to offer construction times shorter than those specified by the client. This "acceleration" is considered when awarding the contract.

The Federal Highway Research Institute (BASt) is a technical and scientific institute responsible to the Federal Ministry of Transport. Its overall objective is to improve the safety, economy, and operational efficiency of roads and to make them more environmentally friendly. Its staff of about 400 is involved in research, testing, certification, accreditations, and technical advice. Current research at BASt on concrete bridges includes the use of exchangeable pre- and post-tensioned cables, high-strength concrete to reduce self weight, and self-consolidating concrete.

Bavarian Road Administration

The Department of Highways and Bridges in the Bavarian Road Administration is responsible for maintaining, operating, and improving a network of major roads in Bavaria—Germany's largest state. These include 2,300 km (1,400 mi) of federal motorways, 6,800 km (4,200 mi) of federal highways, 14,000 km (8,700 mi) of Bavaria's own highways, and 18,700 km (11,600 mi) of roads for which maintenance has been transferred to the Bavarian Road Administration, for a total length of about 42,000 km (26,000 mi).

Bavaria has closely tracked vacation traffic patterns and has established policies against lane closures during peak holiday periods. In particular, construction work is not allowed on the autobahn from July 18 to September 14, a peak travel period. Regulations also have been established to ensure that traffic keeps moving. The maximum length of any lane restriction is 12 km (7.5 mi) to allow a recovery distance. Minimum lane widths are 3.25 m (10.7 ft) for truck traffic and 2.75 m (9.0 ft) for cars. This regulation must be followed unless an exemption is obtained from the federal government.

Four levels of work operation have been established as follows:

1. For 24-hour operation, the minimum working time is 120 hours per week (5 days per week).
2. For daylight operation only, the working time is 75 to 90 hours per week.
3. For nighttime operation only, the working time is 30 to 40 hours per week.
4. For normal operation, the working time is 50 to 60 hours per week.

Nighttime operation is used only in special situations because of increased costs and concerns about quality. Working in daylight hours only is generally the most economical.

The state is willing to pay a premium to accelerate construction because the loss of production time caused by road construction is estimated to cost EUR1 billion (US$1.2 billion) per year. The maximum bonus for early completion or penalty for late completion of a project is 20 percent.

Bavaria follows the directive of the 1993 general circular described below in selecting types of construction. This means only 27 percent of the bridges use precast, prestressed concrete because they have to meet the same standards as CIP bridges. Consequently, it is easier to build a CIP bridge unless other criteria apply.

Design and Construction Practices

In 1993, the secretary of transportation issued a General Circular to the Principal Road Construction Authorities in Germany on the use of prefabricated, prestressed concrete beams for bridges on federal highways. The circular requested that prefabricated, prestressed concrete components be used only under the following conditions:

- Single span length less than 35 m (115 ft).
- Bridge skew less than 36 degrees.
- Radius of curvature for multispan bridges greater than 500 m (1,640 ft).
- Not for large bridges crossing valleys or rivers.
- Monolithic connections of precast elements with the cast-in-place pier caps and the bridge deck.
- Continuity in the longitudinal direction for multispan bridges.
- No transverse prestressing of diaphragms or pier caps.
- Minimal number of bearings.
- Use only members with a tee-shaped cross section. I-beams are not permitted because bird droppings and salt collect on the top surface of the bottom flange.

Finally, all prefabricated, prestressed components must adhere to the same principles for design, accessibility, inspectability, replaceability, and durability as cast-in-place concrete bridges.

The 1993 circular, together with previous experience and practices have led to the following principles for design and construction of concrete bridges in Germany:

- Beams are made as continuous as possible.
- Number of expansion joints is minimized.
- Number of bearings is minimized.
- Separate superstructures are provided for each roadway.
- Concrete decks are protected with a waterproof membrane and asphalt protective layer and wearing surface.
- Bridge is designed for bearing replacement with an allowance of 10 mm (0.4 in) for lifting the structure.
- Standard details are used as much as possible.
- For aesthetic reasons, pier caps that extend minimally below the bottom of the longitudinal beams are preferred over locating the beams on top of the pier caps.
- External longitudinal post-tensioning is preferred over locating the tendons inside the webs.
- Desired bridge life is 100 years.
- A smooth riding surface needs to be provided on the high-speed autobahns.
- Small hollow sections are not desirable because the insides cannot be inspected.

As a result of these practices, the majority of bridge structures are built using cast-in-place concrete. Only 23 percent of modern bridges contain prefabricated elements with 15 percent of the bridges using prefabricated main beams. Different construction methods used in Germany are described in the following sections.

External Post-Tensioning

With concrete box girder bridges, external post-tensioning inside the box is preferred because maintenance and inspection are easier, tendons can be removed, grouting has been a problem with internal tendons, tendons can be added, and the cost is less.

Incremental Launching

In Germany, the technique of incremental launching has been well developed. It is used for constructing multispan bridges across valleys and where it is desirable to minimize interference with traffic. Typical span lengths are 20 to 40 m (65 to 130 ft), although span lengths up to 140 m (459 ft) have been used with steel girders. The launching of a steel box girder on a horizontal curve has been successfully completed.

One example of an incrementally launched bridge is the Wupper Valley Bridge on Autobahn 1. This project involved expanding the existing expressway from four to six lanes, plus adding an emergency shoulder in each direction. The only solution was to build a second bridge parallel to the existing one. The new bridge is a seven-span structure with span lengths ranging from 44 to 72.8 m (144 to 239 ft) for a total length of 4,18.3 m (1,372 ft). The cross section of the bridge consists of a rectangular steel U-shaped box beam (shown in figure 21a on next page) with deck cantilevers beyond the webs supported by inclined struts (shown in figure 21b). Partial-depth, precast concrete deck slabs were used to eliminate the need for falsework. The slabs were placed on soft polymer strips to seal the joints. Shear studs from the steel beams projected into openings in the precast slabs. These openings were filled with high-strength concrete before placing a CIP concrete deck.

The structure was incrementally launched using hydraulic jacks that pushed on the end of the steel box beam. The piers were equipped with sliding bearings to facilitate the launching. The nose at the front of the structure was equipped with a hydraulically controlled lifting device that was used to raise the front of the structure as it reached each pier. Before launching, the precast concrete slabs in the midspan region were placed. The slabs over the supports were then placed from the other slabs. If the steel construction had been moved without the concrete slabs, the slabs would have had to be placed on the bridge from the side—resulting in additional impact on traffic. If all concrete slabs had been placed before launching the structure, the existing hydraulic equipment would not have had sufficient capacity. This structure was reported to be the first to use precast deck slabs of this size.

Prefabricated Elements for Bridges

Historically, bridges with prefabricated elements were limited to pedestrian bridges. More recently, the industry has developed practices to address the design and construction requirements. Longitudinal continuity is provided by using CIP concrete decks and making the girders integral with the pier cap. Transverse continuity and evenness of the deck are also provided by the CIP deck. To provide the integral connection with the pier cap, the beams are temporarily supported on shoring, as shown in figure 22. The end of the beam is then encased in the pier cap and made integral with it. Longitudinal post-tensioning tendons over the pier cap may also be provided to increase the continuity. These tendons may also extend into the positive moment region. It has been found that the optimum economic solution is to provide about 50 percent of the prestressing in the precast, prestressed concrete beams and 50 percent as post-tensioning after erection.

This method of construction also means that the bent cap has little protrusion below the bottom of the beams—an aesthetic condition that Germany prefers to

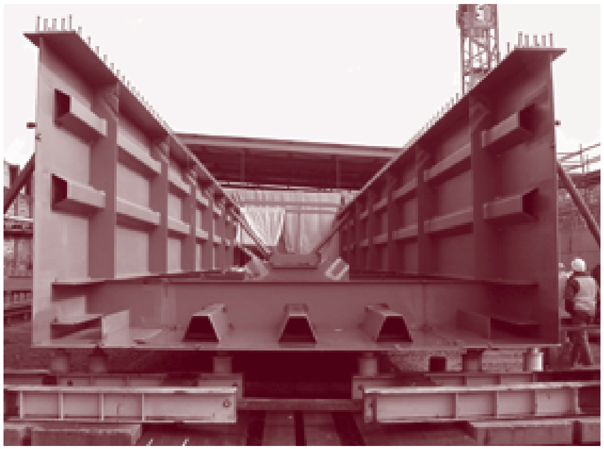


Figure 21a. Incremental launching with precast concrete decks.


Figure 21b.


Figure 21c.

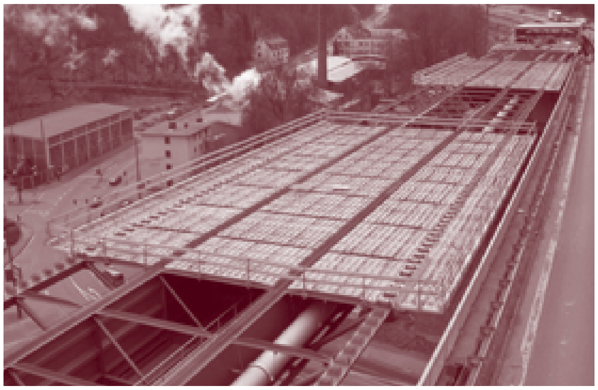


Figure 21d.

PHOTOS COURTESY OF STRASSEN NRW

Figure 22. Temporary shoring for precast beams.

increase the apparent slenderness of the bridge. It was observed in Europe that many bridges in residential neighborhoods have sound barriers. From the exterior elevation, these bridges look much deeper than equivalent span bridges without sound barriers.

Prefabricated concrete elements are used only in situations where a short construction time is needed, restrictions to traffic have to be minimized, or there is not enough space for formwork and falsework. Bridge construction cost data indicate that bridges using precast concrete are about 25 percent more expensive than cast-in-place concrete bridges.

The precast concrete industry is considering the use of high-strength concrete up to 100 MPa (14,500 psi) in beams, high-strength concrete in bridge decks in combination with steel beams, high-strength lightweight concrete, self-compacting concrete, and internal fabric grouted tendons that can be replaced.

Partial-Depth Concrete Decks Prefabricated on Steel or Precast Concrete Beams

This system involves the casting of a partial-depth concrete deck on steel beams or concrete beams before erection of the beam. The system for a steel beam is illustrated schematically in figure 23a (see next page). With a steel I-beam, the prefabricated concrete deck is connected to the steel beams through studs welded to the beam. After the beams are erected, the edges of each deck unit almost touch each other so there is no need for additional formwork for the cast-in-place concrete. The system under construction is shown in figure 23b. In accordance with German practice, the ends of the steel girders are made integral with the bent cap either through studs connected to an end plate on the girder or by extending the web into the abutment with studs attached to the web, as shown in figure 23c. With an inverted steel tee-beam, the details shown in figure 23d may be used to connect the beam to the prefabricated concrete deck.

An alternative arrangement of the same system is shown in figure 23e. In this arrangement, the steel girder consists of two inverted steel tee-beams placed side by side and connected along their bottom flanges. The space between the two webs is filled with concrete at the same time the prefabricated deck is cast. Appropriate reinforcement is provided to make the member composite.

The same partial-depth concrete deck system is also used on prestressed concrete beams, as shown in the completed bridge in figure 22. Before erection, the beam resembles a deck bulb-tee beam, except the deck is not full depth. A typical cross section is shown in figure 24.

Multiple-Level Corrosion Protection Systems

A typical bridge deck multiple-level corrosion protection system, shown in figure 25, consists of the following layers of material from top to bottom:

- 35-to-40-mm (1.4-to-1.6-in) thickness of asphalt wearing surface
- 35-to-40-mm (1.4-to-1.6-in) thickness of asphalt protective layer
- 4.5-to-8-mm (0.18-to-0.31-in) thickness of bituminous fabric sheet material welded to the concrete deck by heat and pressure
- Epoxy-coating primer
- 40-mm (1.6-in) concrete cover to the steel reinforcement

The system has been used since the mid 1980s. Previously, a system of asphalt overlay on a sheet of mastic on glass fleece had been used, but the system did not provide the necessary protection against the ingress of water containing deicing salts. The use of waterproofing systems in other European countries is discussed in NCHRP Report 381—*Report on the 1995 Scanning Review of European Bridge Structures.*

Gussasphalt is one material used on bridge decks. It consists of a dense mix of filler, sand, grit or gravel, and bitumen. Various categories of hardness are available, depending on the anticipated stresses and indentation depths. Requirements for Gussasphalt when used as a protective or intermediate layer on bridges are given in ZTV-BEL-B (*Additional Technical*

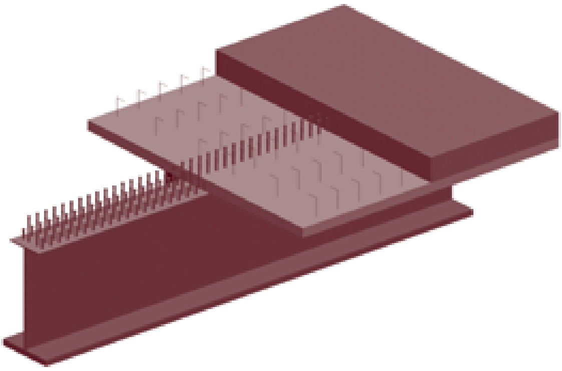


Figure 23. Partial-depth concrete deck prefabricated on steel beams.

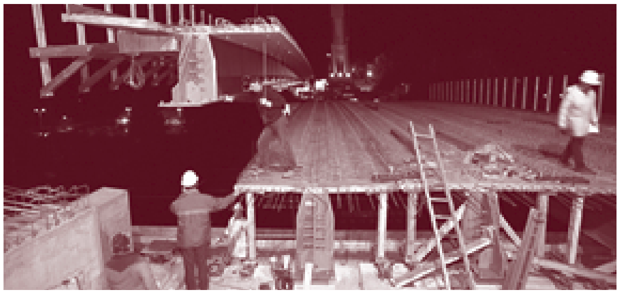


Figure 23b.

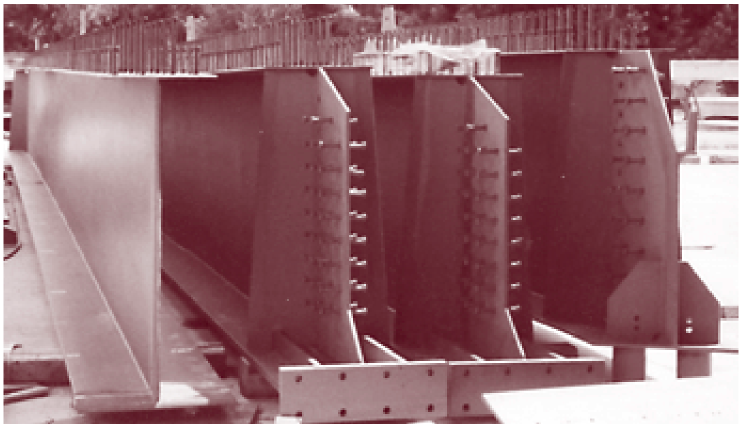


Figure 23c.

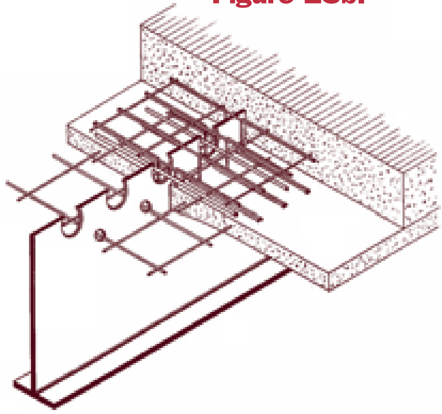


Figure 23d.

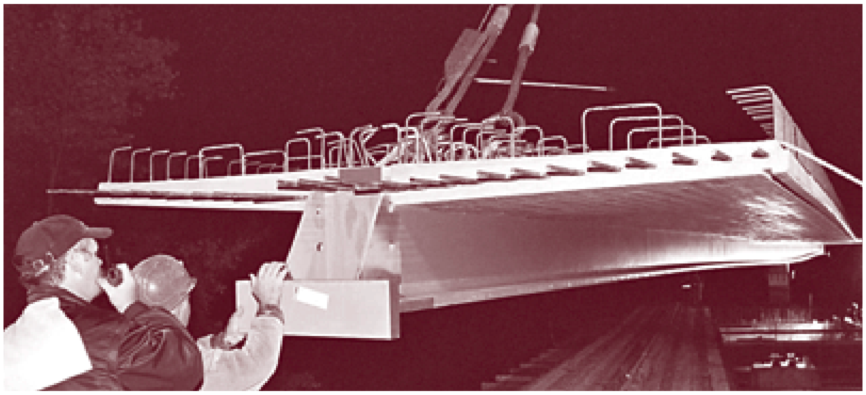


Figure 23e.

DRAWINGS PHOTOS COURTESY OF BAVARIAN DEPARTMENT OF HIGHWAYS AND BRIDGES

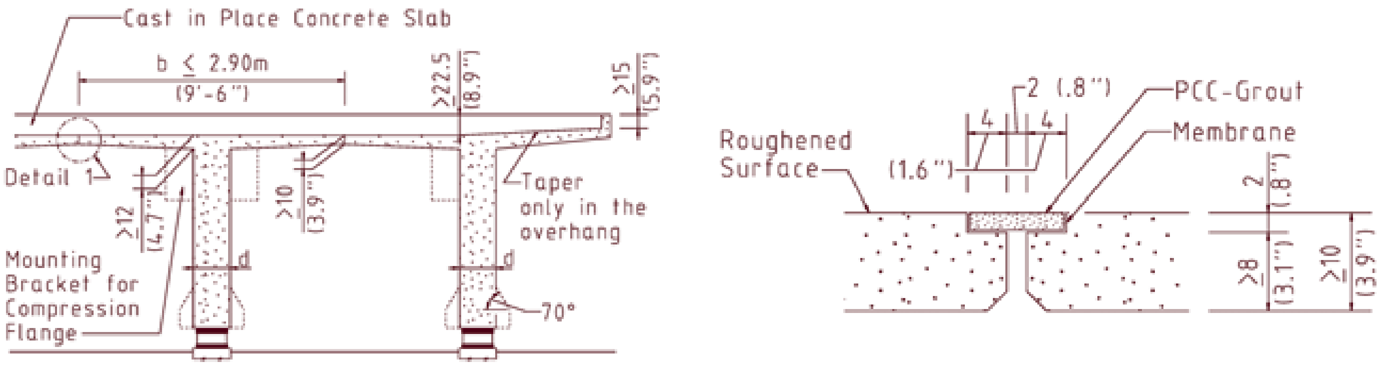


Figure 24. Partial-depth concrete deck on concrete beams.

BASED ON DRAWINGS SUPPLIED BY BAVARIAN DEPARTMENT OF HIGHWAYS AND BRIDGES

Contract Conditions and Guidelines for Production of Concrete Bridge Decks) and ZTV-BEL-ST (*Additional Technical Contract Conditions and Guidelines for Production of Steel Bridge Decks*). Both documents are published by the Federal Department of Transportation, Construction, and Housing (BMVBW).

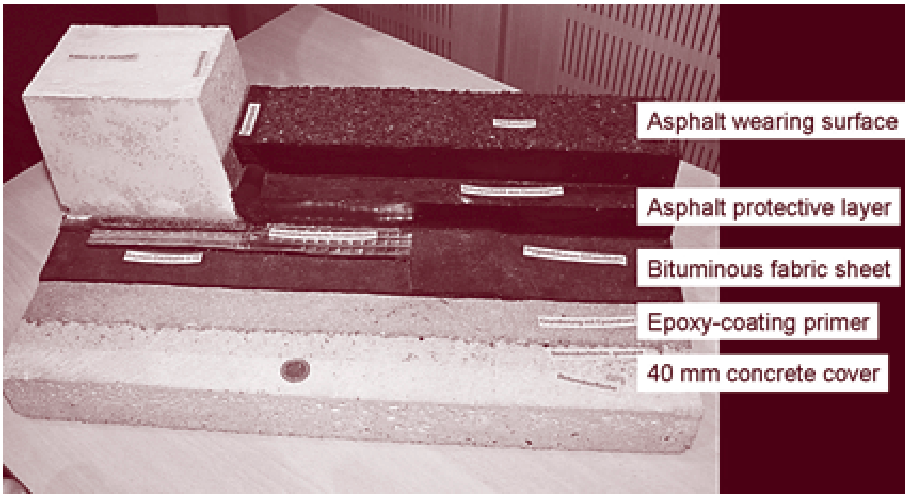


Figure 25. Bridge deck multiple-level corrosion protection system.

Sound Barriers

In Germany, a detailed description of the noise protection "galerie" on Hansa Street, Wuppertal, was provided. The gallery consisted of a noise protection cover over half of an existing expressway with an existing retaining wall on one side. It involved construction of an edge beam attached to the retaining wall, precast L-beams supported on columns on the other side of the expressway, precast tee-beams spanning the highway, a CIP-reinforced concrete deck, and sound-absorbent precast concrete wall panels. A photograph of the construction is shown in figure 26.

PHOTO COURTESY OF STRASSEN NRW

Figure 26. Construction of a noise protection gallery.

Site Visits

The team also visited several bridge sites to view completed bridges and one bridge under construction. These included the BW116, BW117, BW108, and BW101 bridges on the A9 near Munich; BW 19 and BW20 on the A8 West near Munich; and two bridges on the A3 Anschlussstelle Frankfurt Sud near Frankfurt. A summary of the six bridges visited in Bavaria is given in table 3. One common feature of these bridges is that separate formwork was not required to support the concrete deck. As a result, a working surface was available as soon as the beams were erected. This provided a platform for workers above the active highway and protected the traveling public from falling objects. Speed of construction was also increased because placement of deck reinforcement could begin immediately.

Table 3. Bridges near Munich, Bavaria.

Bridge No.	Spans, m (ft)	Bridge Type	Year Built
BW116 on A9	One at 11.5 (37.7)	Adjacent inverted precast tee-beams, 600 mm (23.6 in) deep, with the entire void filled with CIP concrete.	1976
BW117 on A9	One at 6 (19.7)	Adjacent precast slabs, 250 mm (9.8 in) thick and 1.75 m (5.75 ft) wide, with a 350-mm (13.8-in) thick CIP slab.	1976
BW108 on A9	Two at 22.9 (75)	Adjacent precast deck bulb-tee type beams, 900 mm (35.4 in) deep, with a 3.5-m (11.5-ft) wide top flange and 200-mm (7.9-in) thick CIP slab.	1976
BW101 on A9	Two at 26.0 (85)	Adjacent precast deck tee-beams, with a 2.3-m (7.6-ft) wide top flange and 230-mm (9.1-in) thick CIP slab.	1977
BW19 on A8 West	Two at 24.7 (81)	Adjacent precast deck tee-beams, 1.05 m (3.44 ft) deep with a 2.71-m (8.88-ft) wide top flange and 250-mm (9.8-in) thick CIP slab.	1976
BW20 on A8 West	One at 46.5 (153)	Variable depth steel I-beam with a prefabricated concrete top flange, 100 mm (3.9 in) thick, and 250-mm (9.8-in) thick CIP slab.	2002

Bridge BW19 was originally designed as a CIP structure, but the contractor proposed a precast alternate to speed construction and reduce traffic interruption on the autobahn. Longitudinal continuity was established with reinforcement projecting from the end of the prestressed concrete beams into the diaphragm.

Bridge BW20, shown in figure 27, is a 46.5-m (153-ft) long single-span structure across six lanes of autobahn, two shoulders, and a central reservation. The ends of the beams, shown in the inset, are anchored into the abutment to provide fixed end supports. The bridge used the concept of prefabricating a 2.45-m (8-ft) wide, 100-mm (3.9-in) thick partial-depth concrete deck on the girders before erection. The top flange served as the compression flange as well as stay-in-place slab formwork for the CIP deck.

The scanning team visited two bridges near Frankfurt. The first bridge (No. 5917-895) carries Federal Route B44 over BAB A3 that connects Munich to Cologne. The successful contractor had bid the original design, which used steel girders and a concrete deck. The same contractor also provided a lower bid for a precast, prestressed concrete design-build alternate.
The alternate was selected because it minimized

Figure 27. Variable-depth steel beam bridge.

Figure 28. Precast, prestressed concrete bridge.

traffic disruption and could be built faster than the original steel girder bridge design.

The bridge, shown in figure 28, is a two-span continuous structure with a width of 23.5 m (77.1 ft) and span lengths of 25.45 and 28.20 m (83.5 and 92.5 ft) at a 37-degree skew. The five precast, prestressed concrete tee-beams for each roadway are spaced at 2.28 m (7.48 ft) and are made integral with the CIP pier cap and abutments. The CIP deck thickness is 230 mm (9.1 in).

The cross-section of each girder resembles a tee-shaped section with a total depth of 1.40 m (55 in). The top flange has a width of 2.26 m (7.41 ft) and a thickness of 120 mm (4.72 in). The web has a width of 660 mm (25.4 in) at its lower edge and tapers to a width of 460 mm (18.1 in) at the intersection with the top flange. Two-stage prestressing for the girders was used because of limitations of the prestressing bed. The girders were initially pretensioned and then post-tensioned before shipping. Specified compressive strengths were 45 and 55 MPa (6,500 and 8,000 psi) at release and 28 days, respectively. Each girder weighed about 85 t (94 tons).

For erection, the girders were placed on the temporary erection towers shown in figure 22. Each girder required only 10 minutes to place. After the girders were made integral with the pier caps and the abutment, the temporary towers were removed. The bridge is being built in two phases. At the time of the site visit, the west side of the structure was complete, the old bridge was demolished, and construction was proceeding on the east side. Corrosion protection for the deck consisted of 60 mm (2.4 in) of concrete cover to the reinforcement, a sprayed-on polymer seal, a waterproof membrane, and two layers of asphalt with thicknesses of 35 and 40 mm (1.4 and 1.6 in). For aesthetics, the concrete surfaces were cast against wooden boards and the abutment wing walls included a masonry brick inlay.

The second bridge visited was BAB A3 bridge over a connector road to A66. The bridge is a three-span, precast, prestressed concrete girder bridge with a cast-in-place concrete deck. The intermediate piers consist of four columns with a bent cap supported on bearings, as shown in figure 28. Overall, the bridge system was similar to the previous bridge, except for the method of construction. Before the precast girders were erected, the bent caps were cast with a ledge to support the precast girders. The cross section of the intermediate bent cap, therefore, was very similar to an inverted tee-beam and the bent cap at the abutment resembled a ledger beam. The precast girders were then erected and additional reinforcement was placed in the bent caps to make the girders integral. The remaining portions of the bent caps were cast at the same time as the deck.

The contractor stated that the use of precast, prestressed concrete tee-beams reduces construction time compared to the use of steel girders with a prefabricated concrete deck. In both cases, the use of the prefabricated decks on the girders before erection reduces construction time compared to the use of conventional formwork.

FRANCE

In France, the team met with representatives of the National Engineering Division of the French National Railway Authority (SNCF), Technical Department for Public Works and Transportation (SETRA), Central Laboratory for Public Works (LCPC), Technical Center for the Concrete Industry (CERIB), Technical Studies Center for Public Works (CETE), CPCBTP (producer), and Lafarge Cement. The team visited three bridge sites.

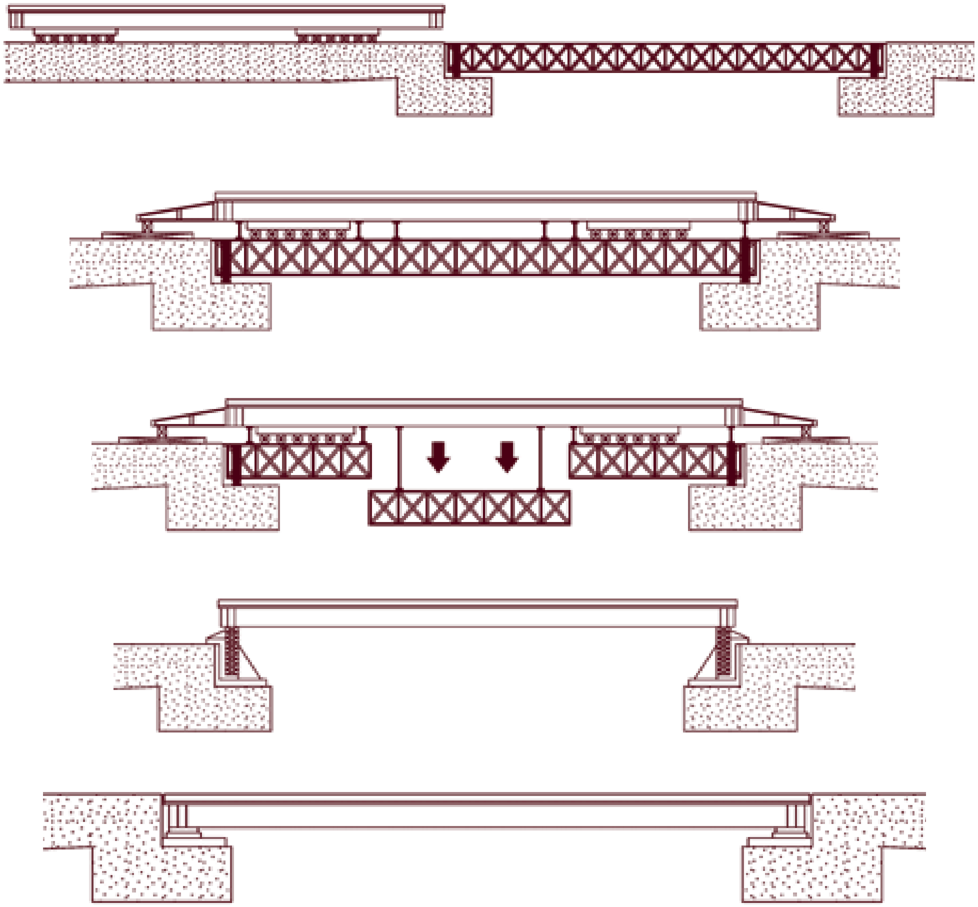
Background—French National Railways

The main criterion for bridge repair, replacement, or new construction on the French railways is to minimize the disturbance to rail traffic. Consequently, a wide range of construction techniques is used, depending on the type of structure, site constraints, and available access.

Continuous structures are preferred because of improved dynamic performance, reduced deflection and rotation, absence of joints, use of a single line of bearings, and reduced maintenance. These factors are very important for the high-speed rail system. The structural system is selected to meet the design criteria. No tensile stresses are allowed in the concrete, and the reinforcing steel stress is limited to either 200 or 240 MPa (29,000 or 34,800 psi). Limits are also placed on the vertical acceleration of the deck.

Contractors pay a penalty if completion of construction is delayed. The penalty is based on the extent of actual costs to the railroad for diverting trains and modifying operations.

The traditional method of installing a railway bridge that has been in use for 50 years is to build the foundations, piers, and abutments while the existing track is in service. The new bridge is then built alongside the existing railway line. With a short interruption to railway traffic, the bridge is then moved laterally into its final position.



BASED ON DRAWINGS BY SNCF

Figures 29a, 29b, 29c, 29d, and 29e.
Replacement sequence of the Pont de St. Denis.

For span lengths up to about 12 m (39 ft), quick bridge replacements can be made using conventional heavy-duty cranes. If two rail tracks are available, the work is performed in two phases, while the traffic in both directions uses one track with speed restrictions. Where access is limited, the new bridge may be delivered to the site along the railroad track using a special train. The desire to further reduce interruptions to traffic has led SNCF to additional innovative methods as described in the following sections.

Railway Bridge Replacements

The Pont de St. Denis was a 19th century steel truss bridge spanning a canal, and needed to be replaced because of fatigue problems and the use of higher axle loads. One track was closed to trains while the new bridge was delivered to the site along the track using SPMTs, as depicted in figure 29a. Extension brackets were mounted on both ends of the new bridge. Once in position above the old bridge, the extension brackets were used to support the new bridge on the abutments, as shown in figure 29b. The old bridge was supported by suspension rods from the new bridge so the old bridge could be cut into sections and lowered onto barges in the canal to be taken away (figure 29c). The new bridge was supported by bearings and jacks on the abutments while the extension brackets were removed (figure 29d). Finally, the new bridge was lowered into its final position (figure 29e). The bridge was replaced in 3 days.

The Viaduc de Lamothe was a 19th century steel lattice bridge near Toulouse in southwest France and required replacement. The new bridge was built inside the lattice bridge, and the old bridge was then removed. Replacement was completed in 4 to 5 weeks. The old and new bridges are shown in figure 30.

At St. Pierre du Vauvray, an original method of laterally launching was used to eliminate a grade crossing and provide a road underpass with only a 22-hour interruption to train traffic. The contractor excavated a large pit next to the railroad tracks and built a reinforced concrete box culvert in the pit. Then, 1,250 m^3 (1635 yd^3) of soil was excavated from beneath the railroad tracks. The excavation was sealed to form a cofferdam, and the excavation was flooded. The 855-t (950-ton) culvert was floated into position, as shown in figure 31. This method is mainly useful where there is an ample water supply.

An unusual technique was used on the Viaduc do Ventabren, south of Avignon in Provence. A variable-depth, CIP balanced cantilever bridge was built on a pier alongside the existing highway. The 2,400-t (2,650-ton), 80-m (262-ft) long superstructure was then rotated about 45 degrees to span the highway. The superstructure was supported on eight Teflon® bearing pads to reduce the friction to 5 percent. A guide pin in the center of the pier acted as a pivot. Three synchronized hydraulic jacks were used to rotate the superstructure, while eight vertical jacks were used to lift the bridge periodically to allow restroking of the jacks and repositioning of the bearings. After the bridge was in its final position, the sliding bearings were replaced with permanent ones.


PHOTOS COURTESY OF SNCF

Figure 30. Viaduc de Lamothe.

A time-lapse photograph of the rotation is shown in figure 32 (see next page).

The French railways have used SPMTs to move bridges into place. The Viaduc de Mornas is a steel bowstring bridge for high-speed rail and crosses a river. The bridge was built on the bank and, using SPMTs, rolled across the river with one end on a barge before arriving on the other bank. Tolerances of final placement using the SPMTs were 0 mm (0 in) in the longitudinal and


PHOTO COURTESY OF SNCF

Figure 31. Floating a culvert into position.

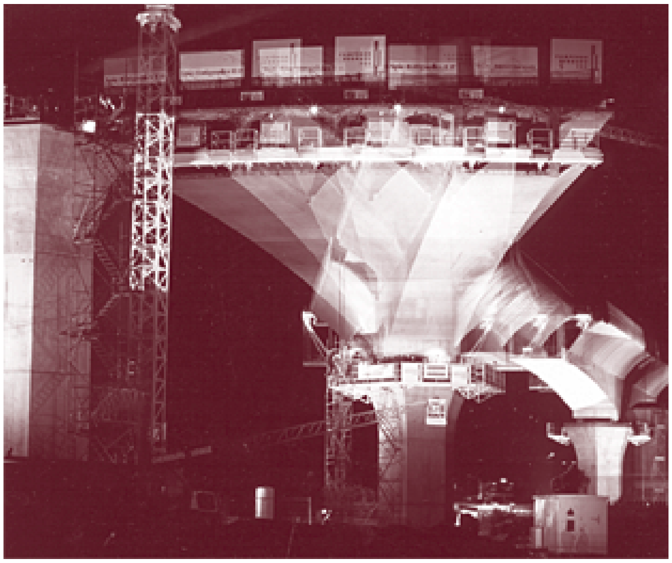


PHOTO COURTESY OF SNCF

Figure 32. Time-lapse photo of rotating a balanced cantilever bridge.

Figure 33. Railway bridge moved using SPMTs.

Figure 34. Railway bridge before sliding into place.

transverse directions and 50 mm (1.97 in) vertically. For skidding, a tolerance of 50 mm (1.97 in) is allowed in all directions.

Site Visits

Site visits were made to two railroad bridges and one highway bridge under construction. During travel for the site visits, the team observed that the French also use transparent sound barriers on their bridges.

The first railroad bridge, identified as PRA 1309, was a four-span structure across a new highway at Nonant le Pin. The bridge was constructed on the concrete slab shown in the foreground of figure 33. It was moved 44.5 m (146 ft) into position using SPMTs. To accomplish the move, pairs of temporary concrete beams were cast between the three piers. SPMTs then lifted the beams and moved the bridge. After the bridge was positioned, the beams were dismantled by being cut into sections to reduce their hauling size and weight. In figure 33, the center portions of the beams from each span are lying on the ground, while stub beams remain protruding from the piers. These subsequently will be removed. To accomplish the bridge placement, the track was closed for 48 hours. Total time for moving the 2,000-t (2,200-ton) bridge was 8 hours. The average speed of travel was 200 mm/min (7.9 in/min).

The second railway bridge, identified as PRA 3265, was a four-span, 3,300-t (3,600-ton) structure across the new A28 highway. At the time of the site visit, construction of the bridge adjacent to the railroad track was almost complete, as shown in figure 34. The bridge will be slid from its construction location to its final position. To accomplish the move, the bridge has been built on two foundation slabs—one on top of the other. The top slab is connected to the piers. The base slab provides a foundation for building the bridge and a sliding surface for the upper slab. The bridge will be moved into its final position now occupied by the embankment in the background of figure 34 by sliding the top slab over the bottom one. To reduce friction between the two slabs, a waxed and greased plastic membrane is placed between them. Bentonite is pumped through tubes in the top slab to the interface to act as a lubricant and to fill voids in the soil as the top slab slides off the base slab onto the ground. The same tubes are later used for grouting underneath the top slab when it is in its final position. In its final location, the bearing pressure beneath the slab is less than the soil pressure before removal of the embankment. Consequently, a slab foundation could be used.

The base slab also provides directional guidance to the top slab, as shown in figure 35. The top slab sits in a slight recess in the base slab. Plastic sheets separate the vertical faces of the two slabs. The leading edge of the top slab is tapered on the underside and is reinforced with a steel angle.

The railroad bridge will be pushed into place using four strand jacks pulling on tendons anchored at the leading edge of the base slab. Each tendon consists of 37 15.2-mm (0.6-in) diameter strands. The anticipated rate of movement is 8 m/h (26 ft/h) over a 6-hour period. Final placement tolerance is plus or minus 20 mm (0.8 in). The contractor chose the sliding method rather than SPMTs because of greater familiarity with the sliding method.

The highway bridge under construction was a curved continuous 13-span, composite steel girder, concrete deck bridge across the Risle River Valley, as shown in figure 36. Span lengths are about 60 m (197 ft). The girders were assembled behind each abutment in 180-m (590-ft) lengths and launched longitudinally in increments of 120 m (394 ft). The girders were precambered for dead load deflection. The nose at the leading edge of each pair of beams is guided laterally by jacking at every other pier. Lateral adjusted roller bearings are used to accommodate the lateral movement as the bridge is launched.

After the complete superstructure is launched, formwork for supporting the deck will be rolled forward. A deck-casting sequence to minimize cracking in the negative moment region will be used. The longitudinal launching method of construction is common in France for multi-span structures across valleys and was reported to be economical.

Background—French Highways

The Ministry of Public Works' Directorate of Roads and Directorate of Road Safety and Traffic are responsible for 9,700 km (6,000 mi) of motorways and 27,000 km (17,000 mi) of national roads in France. Although national roads constitute only 4 percent of the total road network, they carry 40 percent of the traffic. The technical network of the Directorate of Roads and the Directorate of Road Safety and Traffic includes SETRA, LCPC, and CETE.

Figure 35. Leading edge of upper slab before sliding.

Figure 36. Risle River Viaduct under construction.

Service d'Étude Techniques des Routes et Autoroutes (SETRA) operates under the Ministry of Public Works and has a staff of about 400. Its mission is to generate and define French road doctrine, guarantee the quality of projects, develop partnerships, and cooperate with the international community.

The Laboratoire Central des Ponts et Chaussées (LCPC) is a state-owned institute under the authority of the Ministry of Public Works and the Ministry for Research.

Under its 2001 to 2004 contract, the five priorities of LCPC are as follows:

- Maintain and develop the existing infrastructure.
- Ensure road user safety.
- Mitigate the environmental impact of the infrastructure during its service life and better control natural hazards.
- Optimize civil engineering structures in urban environments.
- Promote the introduction of new materials and new technologies in civil engineering.

The eight Centres d'Etudes Techniques de l'Equipement (CETE) are part of the technical network headed by LCPC. LCPC has an annual budget of EUR43 million (US$52 million) and 600 permanent employees. It has partnerships with various other organizations in France, Europe, North America, and Asia.

The Centre d'Étude et de Researches l'Industrie du Béton (CERIB) is a nonprofit public sector organization with a mission to contribute to technical progress, improve productivity, and develop quality in the concrete industry. It is funded from a mandatory tax paid by all French concrete manufacturers and revenues from various services.

The main owners of road bridges in France are the national government, local authorities, and tollway authorities. Each retains the right to deploy its own bidding procedures. The bidding process may involve competitive bidding, design-build competition, or performance guarantees. Selection criteria for contracts include operating costs, technical validity, construction time, aesthetic and functional features, and price. The owner defines the weighting of each criterion before bidding. The following is a typical sequence of relative importance:

1. Technical performance
2. Aesthetics
3. Cost
4. Construction time

Contractors are allowed to submit alternate designs, but must conform to certain criteria such as span lengths, environmental impact, and construction time. For most projects, initial cost is the leading criterion, but life-cycle cost is considered for about 10 percent of the projects.

Prefabrication of bridges in France began after World War II with a progression from reinforced concrete beams to prestressed and post-tensioned concrete beams. Nevertheless, most bridges are still built using CIP concrete because each architect wants a different structure, each bridge has different dimensions, and sizes have not been standardized. Most contractors are well equipped to build post-tensioned bridges. In the past 50 years, 1,600 post-tensioned bridges have been built in France, including the Saint-Nazaire sur la Loire Bridge with 50 spans of 50 m (164 ft). Some bridges built in the period before 1965 to 1970 have experienced problems because of underestimated prestress losses, insufficient reinforcement, poor quality of grout injection in ducts, and lack of sealing of the decks where salt is used. Membranes were not used before 1970, but are now used on bridge decks together with asphalt wearing surfaces.

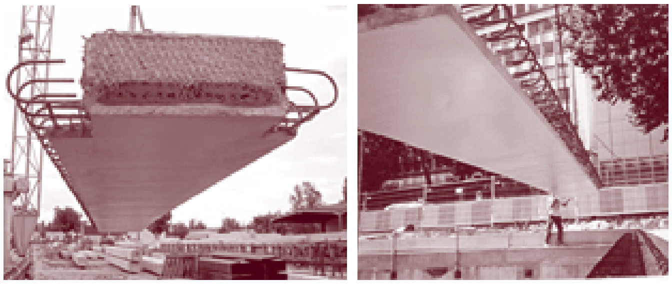

PHOTOS COURTESY OF CPC

Figure 37. Poutre Dalle system.

A typical pretensioned concrete bridge for a span length of 20 m (65 ft) consists of I-beams at 1-m (39-in) centers with a CIP concrete slab having a thickness of 180 to 200 mm (7 to 8 in). For spans of 10 to 15 m (33 to 49 ft) and possibly up to 20 m (66 ft), rectangular or trapezoidal section members are used. For spans of 15 to 25 m (49 to 82 ft), I-beams are used. For spans of 20 to 30 m (65 to 98 ft), I-beams with thickened ends to accommodate the higher shear forces are used. Other types of sections used to a lesser extent include double-tee and adjacent box beams. The latter have experienced problems with infiltration of water at the CIP longitudinal joint between boxes when membranes were not used.

The French prefer to minimize the number of bearings at supports and provide continuity by casting and connecting the ends of the precast beams into the cast-in-place bent caps or diaphragms. Positive moment connections are provided. This method is similar to that used in Germany and requires temporary supports for the beams before casting the bent cap or abutment diaphragm. The French also indicated that a single transverse line of bearings provides a more aesthetic appearance than having bearings under each beam at an intermediate support.

The following sections provide information on other systems described to the scanning team.

Poutre Dalle System

The Poutre Dalle System consists of shallow, precast, prestressed concrete inverted tee-beams, as shown in figure 37. The beams are placed next to each other, connected with a longitudinal joint, and covered with CIP concrete. Continuity along the longitudinal joint is established through the use of 180-degree hooks that protrude from the sides of the webs. The hooks overlap those from the adjacent beam, as shown in figure 38.

The hooked bars are positioned precisely to avoid conflicts at the jobsite. Additional rectangular stirrups may be placed in the space between the webs of adjacent beams. Longitudinal reinforcement is placed inside the stirrups and hooked bars.

The system is appropriate for span lengths of 6 to 25 m (20 to 82 ft), but can be extended to 32 m (105 ft). The overall depth including the CIP concrete for simple spans is 1/28 to 1/30 of the span length. The beam width is selected based on a 25-t (27.5-ton) shipping weight and varies from 400 to 2,000 mm (16 to 79 in). The ends of the beams can be made integral with the bent cap or abutment. A typical bridge can be erected in one day.

The system was reported to have the following advantages:

- Provides a precast solution with a range of sizes.
- Does not require falsework.
- Can be placed across highways in service.
- Has short delivery time.
- Does not require skilled labor for erection.
- Has smooth bottom surface.
- Has thinner deck resulting in higher vertical clearance.
- Allows fast construction.
- Allows economical construction.
- Provides a safe working platform.

The system is certified by SNCF and SETRA and is proprietary in Europe.

Dalle Preflex System

The Dalle Preflex system is similar to the Poutre Dalle system, but uses steel I-beams with their bottom flanges precast in a 150-mm (5.9-in) thick prestressed concrete slab, as illustrated in figure 39. The units are placed next to each other. Hooked bars passing through the steel web overlap hooked bars from the adjacent members to provide lateral continuity. Additional reinforcement—including rectangular stirrups, transverse reinforcement through the hooked bars and stirrups, and longitudinal and transverse reinforcement in the top—are used to provide continuity. Cast-in-place concrete is used to complete the system. The system has similar advantages as the Poutre Dalle system and is proprietary in Europe.

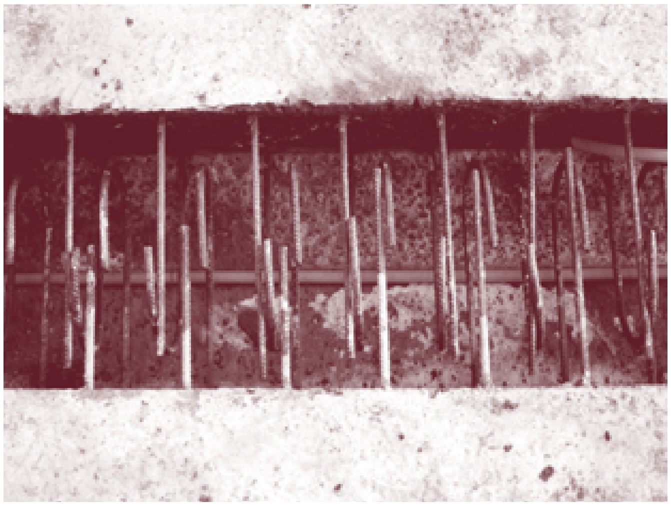
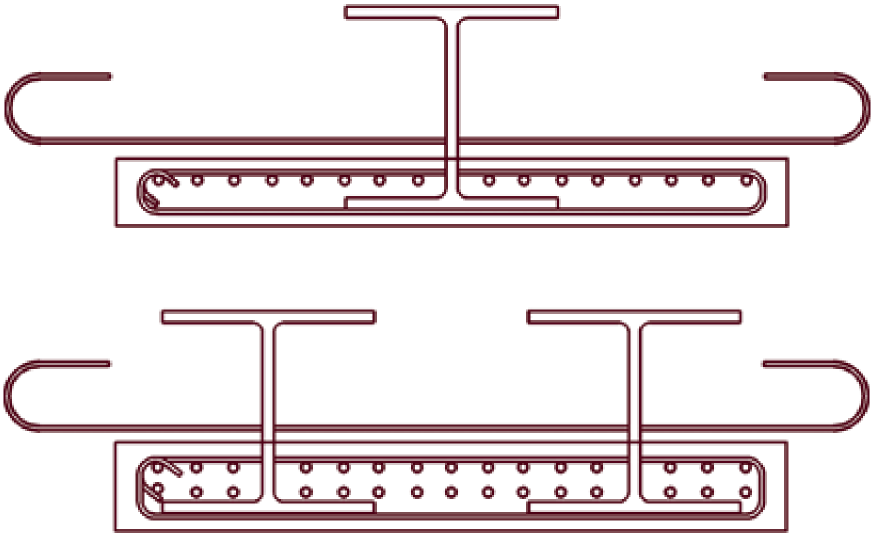


PHOTO COURTESY OF CPC

Figure 38. Overlapping bars in longitudinal joint.

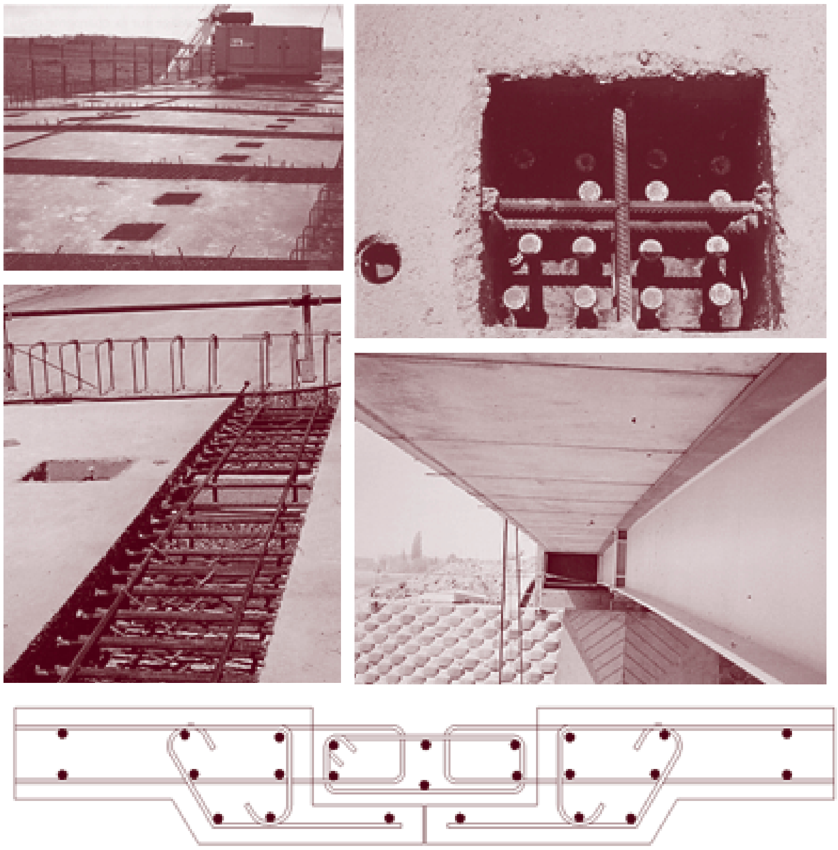
Full-Depth Precast Concrete Deck Panels

One form of construction used in France consists of two longitudinal steel beams supporting full-width, full-depth precast concrete deck panels. The concrete panels, which are usually 12 m (39 ft) long and 2.5 m (8.2 ft) wide, are match cast, epoxied together, and longitudinally post-tensioned. Screws located in the panels are used to adjust elevations. As an alternate to match casting, a transverse CIP joint is used between panels. Reinforcement extending from the edges of adjacent panels overlaps within the joint to provide continuity. Studs are welded to the steel beams through pockets in the panels. The panels sit on continuous elastomeric pads that also provide a seal for the grouting between the



BASED ON DRAWINGS SUPPLIED BY CPC

Figure 39. Dalle Preflex system.



PHOTOS AND DRAWING COURTESY OF LCPC

Figure 40. Full-depth, full-width precast deck panels.

PHOTO COURTESY OF LCPC

Figure 41. Full-depth precast deck panels.

panels and the steel girder. The grout is injected through the stud pockets before the pockets are filled with concrete. Photographs of the system are shown in figure 40. Another variation of full-depth precast deck panels is illustrated in figure 41. The center portion of the bridge consists of CIP concrete on the top flanges of a 6-m (19-ft) wide steel box girder. Precast panels on both sides of the box girder extend the deck width to 23 m (75 ft). The panels are prestressed in the transverse direction to prevent cracking. Cast-in-place joints above the transverse steel beams are used to provide longitudinal continuity and to connect the concrete panels to the steel beams.

Ultra High-Performance Concrete

Ultra high-performance concrete (UHPC) is a combination of fine materials that produces a highly durable concrete with compressive strengths in excess of 150 MPa (22,000 psi) and as high as 250 MPa (36,000 psi). The first research was conducted by Bouygues on reactive powder concretes in 1990 to 1995. Several different formulations are available and have been used in practical applications. Worldwide bridge-related applications include the following:

- Footbridge in Sherbrooke, Canada
- Two road bridges at Bourg Les Valence, France
- Footbridge in Seoul, Korea
- Footbridge at Sakata Mirai, Japan
- Footbridge at Lauterbrunner, Switzerland
- Tollgate at Millau Viaduct, France
- Road bridge at Shepherd's Creek, New South Wales, Australia

The two road bridges at Bourg Les Valence consist of two simple spans of 22 m (72 ft). The superstructure consists of precast, prestressed concrete beams that resemble a double-tee beam, but the webs and bottom flanges are similar to an AASHTO girder cross section. A CIP longitudinal joint is provided between the flanges of the beams. The use of UHPC permitted a reduced deck thickness. The UHPC mix proportions and concrete properties are given in table 4.

Before construction of the bridges, a trial section of a beam was cast and then cut into pieces to produce specimens for full-size flexural tests. In concrete production, the water, high-range water reducer, and fibers were added to the other premixed ingredients. Average mixing time for 1 m^3 (1.3 yd^3) of material in a pan mixer was 15 minutes. In concrete placement, care was needed to limit the flow of the concrete to prevent segregation.

The Shepherd's Creek Bridge in New South Wales, Australia, is a single 15.4-m (50.5-ft) span bridge, 21 m (69 ft) wide, that carries four lanes of traffic. The superstructure consists of 16 precast, prestressed, UHPC beams with a depth of 600 mm (23.6 in), spaced at 1,300 mm (51 in); 25-mm (1-in) thick precast UHPC stay-in-place formwork panels; and a 170-mm (6.7-in) thick CIP concrete deck. The precast panels were heat cured at 60 to 90 degrees Centigrade (140 to 194 degrees Fahrenheit) for 2 to 3 days to eliminate shrinkage and significantly reduce creep.

Further details on the behavior and mechanical properties, structural design methods, and durability of HPC are available in a report entitled *Ultra High-Performance Fibre-Reinforced Concretes—Interim Recommendations,* published by SETRA and the French Association of Civil Engineers (AFGC).

Performance-Based Durability Specifications

The goal of the French program is to develop performance-based specifications for durability to be able to proportion concrete mixtures capable of protecting structures against a given degradation for a specified service life in given environmental conditions. The process involves identifying the relevant parameters related to the durability of concrete and reinforced concrete structures and developing performance criteria for the parameters. The parameters (called indicators by the French) are divided into universal indicators and indicators specific to a given degradation. Universal indicators are water porosity, chloride ion diffusion, gas permeability, water permeability, and calcium hydroxide content. Specific indicators related to alkali-silica reactivity, for example, are the amount of reactive silica released from aggregates with time and the total amount of alkalis. For each indicator, a standard test that can be easily performed in the laboratory is needed.

For the universal indicators, performance criteria for five levels of durability have been developed for each indicator. The performance criteria also have been related to service life ranging from less than 30 years to more than 120 years under different environmental conditions such as exposure to salt spray, immersion in seawater, or presence in a tidal zone.

The next step in the process is to monitor actual performance of bridges so that the "residual" durability life can be determined. Several field studies are underway to verify the approach. The prediction model was used in the design of the Vasco Da Gama cable-stayed bridge across the Tagus River at Lisbon, Portugal. It is expected that the methodology will be introduced into the Eurocode in the near future. Based on its research, LCPC has concluded that high-performance concretes provide a more durable concrete and better protection of the reinforcement against corrosion.

Table 4. Mix proportions and properties of UHPC used on Bourg Les Valence bridges.

Materials	**kg/m³**	**lb/yd³**
Cement	1,114	1,878
Silica fume	169	285
Aggregate 0 to 6 mm	1,072	1,807
Fibers	234	394
High-range water reducer	40	67
Water	209	352
Water-cement ratio	0.19	0.19
Properties		
Compressive strength at 28 days	175 MPa	25,400 psi
Direct tensile strength at 28 days	8 MPa	1,160 psi
Post-cracking direct tensile strength at 28 days	9.1 MPa	1,320 psi
Modulus of elasticity	64 GPa	9,280 ksi
Density	2,800 kg/m³	175 lb/ft³

SUMMARY

Based on the scanning study, the following technologies were identified as different from current practices in the United States or incorporated refinements not common in the United States. The countries where the technology was identified are also listed.

Bridge Movement Systems

- Incremental launching *(Japan, Germany, France)*
- Vertical lifting *(Japan, France)*
- Horizontal sliding using strand jacks *(Netherlands, France)*

- Self-propelled modular transporters *(Japan, Netherlands, Belgium, France)*
- Floating methods using the dry dock approach or barges *(Belgium, France)*
- Pivoting *(France)*

Superstructure Systems

- External longitudinal post-tensioning of box girder bridges *(Japan, Germany)*
- U-shaped segments with transverse ribs *(Japan)*
- Corrugated steel webs *(Japan)*
- Mixed use of steel and concrete superstructure systems in the same bridge *(Japan)*
- Extradosed bridges *(Japan)*
- Use of temporary girders as part of the finished structure *(Japan)*
- Mitsuki Bashi method *(Japan)*
- Integral bent caps for appearance and continuity *(Germany, France)*
- Partial-depth decks prefabricated on steel and concrete beams *(Germany)*
- Multistage prestressing *(Germany)*
- Poutre Dalle system *(France)*
- Dalle Preflex system *(France)*
- Ultra high-performance concrete beams and stay-in-place panels *(France)*

Deck Systems

- Transverse pretensioning of concrete decks for precast segmental box girders *(Japan)*
- Deck joint closure details *(Japan, France)*
- Full-depth prefabricated concrete decks *(Japan, France)*
- Hybrid steel-concrete deck systems *(Japan)*
- Multiple-level corrosion protection systems *(Japan, Germany, France)*

Substructure Systems

- SPER method (Japan)
- Expanded polystyrene as subgrade material *(Japan)*
- Multipulley pile extractor *(Japan)*

Other Technologies

- Photogrammetry with high-precision cameras *(Japan)*
- Epoxy-coated reinforcement for corrosion protection during storage *(Japan)*
- Epoxy-coated strands without duct protection *(Japan)*
- Design validation by testing *(Japan)*
- Sound barriers *(Japan, Germany, France)*
- Performance-based specifications for durability *(France)*

Assessment, Recommendations, and Implementation Strategy

At the completion of the scanning study, the team had identified 33 bridge technologies that, in one or more aspects, were different from current practices in the United States. Not all of these related to the primary objectives of the scanning study. Using the six focus areas of minimizing traffic disruption, improving work zone safety, minimizing environmental impact, improving constructibility, increasing quality, and lowering life-cycle costs as selection criteria, the team identified 10 overall technologies that it recommends for possible, immediate implementation in the United States. Although it is expected that all technologies can be beneficial in most focus areas, the particular benefits will depend on the circumstances of each project and may not always be applicable. The reduced construction time that can be achieved with these technologies could result in a substantial savings in traffic control costs and inconvenience costs to the traveling public.

Brief descriptions of the 10 technologies are given in the following sections, together with the team's assessment of the benefits of each technology and an implementation strategy. In general, the strategies involve obtaining more information about the technologies from the host countries, making the information available on Web sites, seeking demonstration or pilot projects, and holding workshops in association with the pilot projects. In addition, the scanning team has planned numerous papers and presentations at national and local meetings and conferences in 2004 and 2005. The purpose of the papers and presentations is to describe the overall results of the scanning study and details of specific technologies for participants to consider implementing in their States.

MOVEMENT SYSTEMS

During the study, many different methods that can be used to remove partial or complete existing bridges and move bridge components or complete bridges into place were observed. These methods allow a new bridge to be built at one location near or next to the existing structure and then moved to its final location in a few hours. Construction, therefore, can take place in an environment where construction operations are completely separated from the traveling public. These methods reduce traffic disruption times and lane closures from months to days or hours, restore the use of existing highways in significantly less time, improve work zone safety, minimize environmental impact, improve constructibility, and lower life-cycle costs. The controlled environment off the critical path also facilitates improved quality of components. The concept of building bridges offline and then moving them into place needs to be developed for use in the United States.

Self-Propelled Modular Transporters

In Europe, it was observed that large bridge components or even complete bridges weighing several thousand metric tons have been built at one location and then lifted and transported to their final location using a series of vehicles known as self-propelled modular transporters. These multiaxle computer-controlled vehicles are capable of moving in any horizontal direction with equal axle loads while maintaining a horizontal load with undeformed or undistorted geometry.

The scanning team was impressed by the opportunity this technology offers to minimize traffic disruption, improve work zone safety, improve constructibility, improve quality, and lower life- cycle costs. The technology is employed frequently by highway and railway owners to reduce construction impact to days or hours from the months required by traditional construction methods. The usual approach is to construct the superstructure offsite and then move it into place using SPMTs. The same equipment can also be used to remove existing bridges in a very short time rather than demolishing the bridge above existing traffic. Although use of this equipment may be perceived as increasing initial construction costs, the offsetting benefits are a substantial reduction in traffic control costs and inconvenience costs to the traveling public, resulting in lower life-cycle costs.

For implementation, a project-planning guide for bridge owners will be developed. This will emphasize the necessity for early project planning, right-of-way needs for construction, and contract provisions, such as maximum lane closure times, to support and encourage the use of SPMTs. Draft specifications will be developed for DOTs to consider for their projects. The intent is to detail the required qualifications for lifting contractors and appropriate tolerances for placement and distortions of the structure being moved. Information on the technology will be made available to all interested States. Pilot projects will be solicited and workshops held in association with the projects.

Other Bridge Installation Systems

In addition to using SPMTs and conventional land or barge-mounted cranes to erect large structures, other methods of moving bridge components include the following:

1. Horizontally skidding or sliding bridges into place
2. Incremental launching longitudinally across valleys or above existing highways
3. Floating bridges into place using barges or by building a temporary dry dock
4. Building bridges alongside an existing roadway and rotating them into place
5. Vertically lifting bridges

These systems can be used to minimize the time an existing bridge is out of service while it is replaced, many within 3 to 48 hours. A limited amount of transverse and longitudinal launching has been done in the United States. Some bridges have been floated into place. In Europe and Japan, these methods are more commonplace and accepted by bridge designers and contractors. The scanning team believes that the variety of methods observed can be applied more frequently in the United States, especially to remove and replace bridges in urban areas, minimize traffic disruptions and environmental impact, improve work zone safety, and improve constructibility.

For implementation, the information on a variety of bridge projects observed during the study will be posted on Web sites to stimulate consideration of creative alternatives to conventional construction methods. Pilot projects will be solicited and workshops held in association with the projects.

SUPERSTRUCTURE SYSTEMS

The typical sequence of erecting bridge superstructures in the United States is to erect the concrete or steel beams, place either temporary formwork or stay-in-place formwork such as steel or concrete panels, place deck reinforcement, cast deck concrete, and remove formwork, if necessary. Eliminating the need to place and remove formwork for the deck above traffic after the beams are erected can accelerate onsite construction, reduce lane closures, and improve safety. The following systems to accomplish this were identified during the study.

Poutre Dalle System

One method to eliminate formwork and provide a safe working surface is provided by the French Poutre Dalle system. In this system, shallow, inverted tee-beams are placed next to each other and then made composite with cast-in-place concrete placed between the webs of the tees and over the tops of the stems to form a solid member. A typical Poutre Dalle bridge can be erected in a day. A similar inverted tee-beam has been used on a few bridges in the United States, but the scanning team believes that the Poutre Dalle system offers a faster, more reliable, and more durable system. Adjacent box beams are used in the United States with limited continuity between adjacent units. As a result, deterioration occurs along the longitudinal joint. The loop joint detail used to join adjacent members in the Poutre Dalle system is expected to provide better continuity than details now used in the United States. As a result, reflective cracking along the joint will be less and durability will be enhanced.

For implementation, sample drawings, specifications, and photographs of construction details and completed bridges will be obtained and posted on a Web site. Research will be proposed to validate the loop joint detail and States will be solicited for demonstration projects.

Partial-Depth Concrete Decks Prefabricated on Steel or Concrete Beams

One system in Germany involved the casting of partial-depth concrete decks on steel or concrete beams before erection of the beams. The use on prestressed concrete beams is similar to a deck bulb-tee beam except the deck is not full depth. After the beams are erected, the edges of each deck unit abut the adjacent member, eliminating the need to place additional formwork for the cast-in-place concrete. This process speeds construction, immediately provides a safe working surface, and reduces the potential danger of equipment falling onto the roadway below.

For implementation, sample drawings and photographs of construction details and completed bridges will be obtained and posted on a Web site as resource material for bridge designers. One demonstration project with steel girders and one with concrete girders will be sought. If appropriate, workshops for FHWA and DOT engineers, contractors, and consultants will be held.

U-Shaped Segments with Transverse Ribs

To reduce the weight of precast concrete segments, the Japanese use a segment in which the traditional top slab is replaced with a transverse prestressed concrete rib. After erection of the segments, precast, prestressed concrete panels are placed longitudinally between the transverse ribs. A topping slab is then cast on top of the panels and the deck post-tensioned transversely. In addition to reducing the shipping weight, the U-shaped segment allows for longer segments and, therefore, fewer segments per span. The lighter weight allows the capacity of the erection equipment to be reduced. The use of precast panels spanning longitudinally between the transverse ribs eliminates the need for deck formwork and means that the CIP concrete slab can be removed if it needs to be replaced.

For implementation, sample drawings and photographs of construction and completed bridges will be obtained and posted on a Web site as resource material for bridge designers. Available information will be disseminated to the American Segmental Bridge Institute.

DECK SYSTEMS

Four innovations for bridge deck systems were identified and are recommended for implementation in the United States.

Full-Depth Prefabricated Concrete Decks

The use of full-depth prefabricated concrete decks in Japan and France reduces construction time by eliminating the need to erect deck formwork and provide cast-in-place concrete. The deck panels are connected to steel beams by studs located in pockets in the concrete deck slab. The use of full-depth prefabricated concrete decks on steel and concrete beams provides a means to accelerate bridge construction using a factory-produced product, eliminates placing and removing formwork above traffic, and reduces lane closures. Although similar systems have been used in the United States, the Japanese system has proved to be low maintenance and durable. One reason for the success may be the use of a multiple-level corrosion protection system. The transverse joint between panels is made with CIP concrete placed over overlapping loops of reinforcement with additional reinforcement threaded through the loops. The Japanese no longer use longitudinal post-tensioning because of previous corrosion problems. They now prefer to use the joint detail.

For implementation, the design basis, test reports, and sample drawings and specifications for both steel and concrete girder bridges will be obtained and posted on a Web site. Research will be proposed to validate the loop joint details and states will be solicited for pilot projects.

Deck Joint Closure Details

Prefabricated deck systems require that longitudinal and transverse joints be provided to make the deck continuous for live load distribution and seismic resistance. This is accomplished by using special loop bar reinforcement details in the joints. Various joint details observed during the study should be evaluated for use in the United States to facilitate the use of prefabricated full-depth deck systems. The CIP deck joint may provide better continuity between adjacent precast elements compared to details now used in the United States. It is expected that the joint details will provide better control of cracking along the joint and result in a more durable and longer-lasting structure.

For implementation, the design basis, test reports, and sample drawings and specifications will be obtained and posted on a Web site. A literature search and research, as necessary, will be conducted to validate and enhance standard connection details. The research will address longitudinal joint details for the Poutre Dalle system and transverse joint details for the full-depth prefabricated decks. The work will be coordinated with ongoing activities of NCHRP, State DOTs, and the Precast/Prestressed

Concrete Institute. Critical issues to be addressed are concrete cover, loop bar bend radius, type of reinforcement, properties of concrete used for the closure placement, sealing of the interface between the precast and CIP concrete, and the need for a protective overlay. States will be solicited for pilot projects.

Hybrid Steel-Concrete Deck Systems

The Japanese have developed hybrid steel-concrete systems for bridge decks. The steel component of the system consists of bottom and side stay-in-place formwork and transverse beams. The transverse beams span over the longitudinal beams and cantilever beyond the fascia beams for the slab overhang. The bottom flanges of the transverse beams support steel formwork for the bottom of the slab, while the top flanges support the longitudinal deck reinforcement. When filled with cast-in-place concrete, the system acts as a composite deck system. The system allows rapid placement of a lightweight deck stay-in-place formwork system complete with reinforcement using a small-capacity crane. The system eliminates the need to erect formwork over traffic. The scanning team noted that this system was more versatile than conventional stay-in-place steel formwork because the system included the internal beam support system to form the slab overhang. It also allowed the reinforcement to be placed offsite, which reduces onsite construction time.

For implementation, sample drawings and specifications together with photographs of systems will be obtained and posted on a Web site. Details will be evaluated and potential suppliers contacted through the National Steel Bridge Alliance. If suppliers are available, States to build pilot projects will be sought.

Multiple-Level Corrosion Protection Systems

In Japan, Germany, and France, concrete bridge decks are covered with a multiple-level corrosion protection system to prevent the ingress of water and deicing chemicals. The systems generally involve providing adequate concrete cover to the reinforcement, a concrete sealer, waterproof membrane, and two layers of asphalt. This type of corrosion protection system may be beneficial with prefabricated systems as a means of protecting the joint regions from potential corrosion damage and ensuring a longer service life. The system may also be used to extend the service life of existing bridges. In Germany, these systems have been used since the mid 1980s and are expected to provide a 100-year service life. Maintenance of the system requires that the riding surface of the asphalt be replaced periodically. Use of these systems, however, will increase the design dead loads for bridges not currently designed for these loads. The other disadvantage of these systems is that they prevent visual inspection of the deck surface. Nevertheless, the scanning team concluded that the systems should be compared with systems now being used in the United States, since these systems are used throughout Japan, Germany, and France. One difference may be the quality of workmanship and attention to detail in these countries, which appeared to be higher than in the United States.

For implementation, a translation of the German specifications will be posted on a Web site as resource material for bridge maintenance, construction, and design engineers. Demonstration projects will be sought from States that now use waterproof membrane systems.

SUBSTRUCTURE SYSTEMS

Limited use of prefabricated substructures was observed during the study, although such systems could provide significant benefits in minimizing traffic disruption during bridge construction. One substructure system is recommended for implementation in the United States.

SPER System

The Japanese SPER system is a method of rapid construction of bridge piers using stay-in-place precast concrete panels as both structural elements and formwork for cast-in-place concrete. Short, solid piers have panels for outer formwork, and tall, hollow piers have panels for both the inner and outer formwork. Segments are stacked on top of each other using epoxy joints and filled with cast-in-place concrete to form a composite section. Experimental research in Japan has demonstrated that these piers have similar seismic performance to conventional cast-in-place reinforced concrete piers. The system has the advantage of reduced construction time and results in a high-quality, durable external finish.

For implementation, sample drawings together with photographs of construction and completed bridges will be posted on a Web site as resource material for bridge engineers. Demonstration projects will be sought and workshops conducted for FHWA and DOT engineers, contractors, and consultants.

Contacts in Countries Visited

JAPAN

Dr. Satoshi Kashima,
Executive Director
Japan Bridge Engineering Center
Sumitomo 2nd Bldg.
2-2-23 Kouraku, Bunyo-ku
Tokyo 112-0004
JAPAN
E-mail: *kashima@boea.or.jp*

Kazuyuki Mizuguchi,
Deputy Director
Bridge Engr. Div., Japan Highway
Public Corporation
Shin-Kasumigaseki Bldg. 15F West
3-3-2 Kasumigaseki, Chiyoda-ku
Tokyo 100-8979
JAPAN
E-mail: *kazuyuki.mizuguchi@jhnet.go.jp*

Dr. Akio Kasuga, Chief Engineer
Sumitomo Mitsui Construction Co., Ltd.
1-38-1 Chuo Nakano-ku
Tokyo 164-0011
JAPAN
E-mail: *akasuga@smcon.co.jp*

Yoshihiko Taira
Sumitomo Mitsui Construction Co., Ltd.
1-38-1 Chuo Nakano-ku
Tokyo 164-0011
JAPAN
E-mail: *ytaira@smcon.co.jp*

Dr. Kikuo Koseki, Assistant Director
Kajima Technical Research Institute
19-1 Tobitakyu, 2-chome, Chofu-shi
Tokyo 182-0036
JAPAN
E-mail: *kkoseki@kajima.com*

Yoshihiro Hishiki, General Manager
Kajima Technical Research Institute
19-1 Tobitakyu, 2-chome, Chofu-shi
Tokyo 182-0036
JAPAN
E-mail: *hishiki@kajima.com*

Takeshi Tsuyoshi, Group Leader
Concrete Structure Group
East Japan Railway Co.
2-2-2 Yoyogi, Shibiya-ku
Tokyo 151-8578
JAPAN
Phone: (011–81) 3–5334–1288
Fax: (011–81) 3–5334–1289

Shinichi Tatsuki, Engineer
Concrete Structure Group
East Japan Railway Co.
2-2-2 Yoyogi, Shibiya-ku
Tokyo 151-8578
JAPAN
Phone: (011–81) 3–5334–1288
Fax: (011–81) 3–5334–1289

Hiroaki Okamoto, Group Manager
Kajima Corp.
5-30 Akasaka 6-chome, Minato-ku
Tokyo 107-8502
JAPAN
E-mail: *okamotohi@kajima.com*

Hiroshi Hagiuda, Construction Manager, Chiba Prefecture
Steel Structure and Logistic Systems Headquarters
Mitsui Engineering & Shipbuilding Co., Ltd.
4-6 Nishikasai, 8-chome, Edogawa-ku
Tokyo 134-0088
JAPAN
E-mail: *hagiuda@mes.co.jp*

Ryuchi Minata, Assistant Manager
Steel Structure and Logistic Systems Headquarters
Mitsui Engineering & Shipbuilding Co., Ltd.
4-6 Nishikasai, 8-chome, Edogawa-ku
Tokyo 134-0088
JAPAN
E-mail: *minata@mes.co.jp*

Kentaro Shima, Overseas Project Department
Steel Structure and Logistic Systems Headquarters
Mitsui Engineering & Shipbuilding Co., Ltd.
4-6 Nishikasai, 8-chome, Edogawa-ku
Tokyo 134-0088
JAPAN
E-mail: *ken@mes.co.jp*

Dr. Haruhito Maeda, Design Office #2
Japan Bridge & Structure Institute
E-mail: *h-maeda@jbsi.co.jp*

Takuya Mori, General Manager
Civil Technical Dept.
P.S. Mitsubishi Construction Co., Ltd.
G-7 Bldg, 10F
7-16-12 Ginza, Chuo-ku
Tokyo 104-8215
JAPAN
E-mail: *t-mori@psmic.co.jp*

Meguru Tsunomoto, Consulting Engineer
Oriental Construction Co., Ltd, Technical Div.
4-2-31 Tenjin, Chuo-ku
Fukuoka 810-0001
JAPAN
E-mail: *meguru.tsunomoto@oriken.co.jp*

Hidetomo Sasaki, Assistant Manager.
Kawada Industries, Bridge Structure Div.
1-3-11 Takinogawa, Kita-ku
Tokyo 114-8562
JAPAN
E-mail: *hidetomo.sasaki@ kawada.co.jp*

Yohei Koike, Engineer
Yokogawa Bridge Corp., Research Laboratory
No. 27, Yamano-cho
Funabishi-shi, Chiba-ken
273-0026
JAPAN
E-mail: *koike@yokogawa-bridge.co.jp*

Keiji Hatano, Assistant Manager.
Bridge & Steel Structure Facilities Dept.
Mitsubishi Heavy Industries, Ltd.
5-1, Eba-Oki-machi, Naka-ku
Hiroshima 730-8642
JAPAN
E-mail: *keiji_hatano@mhi.co.jp*

Shinya Yamamoto, Acting Manager
Bridge & Steel Structure Facilities Dept.
Mitsubishi Heavy Industries, Ltd.
5-1, Eba-Oki-machi, Naka-ku
Hiroshima 730-8642
JAPAN
E-mail: *shinya_yamamoto@mhi.co.jp*

Takehiro Kuribayashi (Nagoya host)
Sumitomo Mitsui Construction Co., Ltd.
E-mail: *takekuri@smcon.co.jp*

THE NETHERLANDS

Patrick van Seumeren,
Managing Dir. (Global)
Mammoet
Karel Doormanweg 47
Haven 580, 3115 JD
3100 AN Schiedam
THE NETHERLANDS
E-mail: *patrick.van.seumeren@mammoet.com*

Jurjen Hoogstra, Proposal Engineer
Mammoet
Karel Doormanweg 47
Haven 580, 3115 JD
3100 AN Schiedam
THE NETHERLANDS
E-mail: *jurjen.hoogstra@mammoet.com*

Piet Nooren,
Exec. Vice-Pres & Managing Dir.
Mammoet USA, Inc.
20525 FM 521
Rosharon, TX 77583
E-mail: *piet.nooren@mammoet.com*

Bill Halsband, Vice President
North American Business Development
Mammoet
170 Turnbull Court
Cambridge, ON N1T 1J2
CANADA
E-mail: *bill.halsband@mammoet.com*

BELGIUM

Dirk Verwimp, Sales Manager
Sarens NV
Autoweg 10
B-1861 Wolvertem
BELGIUM
E-mail: *dirk.verwimp@sarens.com*

Steven Sarens, Unit Manager
Sarens NV
Autoweg 10
B-1861 Wolvertem
BELGIUM
E-mail: *steven.sarens@sarens.com*

GERMANY

Munich

Hans Pfisterer, Sachgebiet IID8
Oberste Baubehoerde im Bayer
Staatsministerium des Innern
Franz-Josef-Strauss-Ring 4
80539 Munich
GERMANY
E-mail: *hans.pfisterer@ stmi.bayern.de*

Reinhard Wagner, Sachgebiet IID8
Oberste Baubehoerde im Bayer
Staatsministerium des Innern
Franz-Josef-Strauss-Ring 4
80539 Munich
GERMANY
E-mail: *reinhard.wagner@stmi.bayern.de*

Dr. Uwe Willberg, Abteilungsleiter
Bruecken und Ingenieurbau
Autobahndirektion Suedbayern
Seidlstrasse 7-11
80335 Munich
GERMANY
E-mail: *uwe.willberg@abdsb.bayern.de*

Frankfurt

Dr. Andreas Nitsch, Technische Geschaftsfuhrer
Fachvereinigung Deutscher Betonfertigteilbau e.V.
Schlossallee 10
53179 Bonn
GERMANY
E-mail: *nitsch@fdb-fertigteilbau.de*

Dr. Martin Krips, Leiter des Konstruktionsburos
Adam Hornig Baugesellschaft GmbH & Co.
Magnolienweg 5
63471 Aschaffenburg
GERMANY
Phone: (011–49) 6021–844–269
Fax: (011–49) 6021–844–200

Eberhard Bauer, Geschaftsfuhrer
Elementbau Osthessen GmbH & Co.
Am Langen Acker 1
36124 Eichenzell
E-mail: *bauer@elo-beton.de*

BASt

Dr. Fritz Grossmann, Director
Bundesanstalt fuer Strassenwesen
Bruederstr 53
51427 Bergisch-Gladbach
GERMANY
E-mail: *fgrossmann@bast.de*

Dr. Arnold Hemmert-Halswick, Head of Section
Bundesanstalt fuer Strassenwesen
Bruederstr 53
51427 Bergisch-Gladbach
GERMANY
E-mail: *hemmert-halswick@bast.de*

Peter Gusia
Bundesanstalt fuer Strassenwesen
Bruederstr 53
51427 Bergisch-Gladbach
GERMANY
E-mail: *gusia@bast.de*

Dr. Rudiger Beutel
Hegger & Partner Ingenieurburo
Schurzelterstr 25
52074 Aachen
GERMANY
E-mail: *rbeutel@huping.de*

Wolfgang Prehn, Section Leader
Landsbetrieb Strassenbau Nordrhein-Westfalen
Mindenerstr 2
50679 Koln
GERMANY
E-mail: *wolfgang.prehn@koeln.strassen.nrw.de*

Christine Kellermann, Office of International Relations
Bundesanstalt fuer Strassenwesen
Bruederstr 53
51427 Bergisch-Gladbach
GERMANY
E-mail: *kellermannc@bast.de*

Guenter Zimmermann, Office of International Relations
Bundesanstalt fuer Strassenwesen
Bruederstr 53
51427 Bergisch-Gladbach
GERMANY
E-mail: *zimmermann@bast.de*

FRANCE

SNCF

Didier Martin, Departement des Ouvrages d'Art
SNCF
6 ave. Francois Mitterand
93574 La Plaine St. Denis cedex
FRANCE
E-mail: *didier.martin@sncf.fr*

Bernard Pitrou, Departement des Ouvrages d'Art
SNCF
6 ave. Francois Mitterand
93574 La Plaine St. Denis cedex
FRANCE
E-mail: *bernard.pitrou@sncf.fr*

Patrick Meyer, Interpreter
Direction du Development International
SNCF
6 ave. Francois Mitterand
93574 La Plaine St. Denis cedex
FRANCE

Vu Le Khac, Technical Director
Division des Grands Ouvrages
SETRA
46 ave. Aristide Briand
92225 Bagneux cedex
FRANCE
E-mail:
vu.lekhac@equipement.gouv.fr

Daniel Lecointre,
Deputy Chief of Division
Division des Grands Ouvrages
SETRA
46 ave. Aristide Briand
92225 Bagneux cedex
FRANCE
E-mail: *daniel.lecointre@equipement.gouv.fr*

Yann-Mikel Jaffre, Ingenieur
Division des Grands Ouvrages
SETRA
46 ave. Aristide Briand
92225 Bagneux cedex
FRANCE
E-mail: *yann-mikel.jaffre@equipement.gouv.fr*

Vanessa Minard,
Office of International Relations
Division des Grands Ouvrages
SETRA
46 ave. Aristide Briand
92225 Bagneux cedex
FRANCE
E-mail: *vanessa.minard@equipement.gouv.fr*

Pierre Passeman,
Building Design Dept.
CERIB
BP 23059
28231-Epernon
FRANCE
E-mail: *conception@cerib.com*

Renaud Montes
CPC (Composants Pre-Contraints)
Parc Descartes – Bat. A
ave. Gay Lussac
33370 Artigues
FRANCE
E-mail: *dalle@cpcbtp.com*

Mouloud Behloul,
Ductal Technical Director
Lafarge Co.
61, rue des Belles Feuilles, BP 40
75782 Paris cedex 16
FRANCE
E-mail: *mouloud.behloul@lafarge.com*

Thierry Kretz, Tech. Dir. for Structural Engineering
LCPC
58 blvd. Lefebvre
75732 Paris cedex 15
FRANCE
E-mail: *thierry.kretz@lcpc.fr*

Veronique Baroghel-Bouny,
Head of Concrete Microstructure and Durability Unit
LCPC
58 blvd. Lefebvre
75732 Paris cedex 15
FRANCE
E-mail: *baroghel@lcpc.fr*

Brigitte Mahut,
Head of Durability of Structures Section
LCPC
58 blvd. Lefebvre
75732 Paris cedex 15
FRANCE
E-mail: *mahut@lcpc.fr*

Robin Sebille,
Office of International Affairs
LCPC
58 blvd. Lefebvre
75732 Paris cedex 15
FRANCE
E-mail: *robin.sebille@lcpc.fr*

Sylvie Proeschel,
Office of International Affairs
LCPC
58 blvd. Lefebvre
75732 Paris cedex 15
FRANCE
E-mail: *sylvie.proeschel@lcpc.fr*

Brigitte Porëe,
Delegation for International Affairs
LCPC
58 blvd. Lefebvre
75732 Paris cedex 15
FRANCE
E-mail: *brigitte.poree@lcpc.fr*

Jacques Resplendino,
Division Chief
CETE
46, rue Saint-Theobald, BP 128
38081 l'Isle d'Abeau cedex
FRANCE
E-mail: *jacques.resplendino@equipement.gouv.fr*

Team Members

Ben Tang (Co-Chair)
Senior Structural Engineer
FHWA (HIBT-10), Room 3202
400 Seventh Street, SW.
Washington, DC 20590
Phone: (202) 366–4592
Fax: (202) 366–3077
E-mail: *benjamin.tang@fhwa.dot.gov*

Mary Lou Ralls (Co-Chair)
State Bridge Engineer
Texas DOT
125 East 11th St.
Austin, TX 78701
Phone: (512) 416–2183
Fax: (512) 416–3144
E-mail: *mralls@dot.state.tx.us*

Dr. Shrinivas Bhidé
Program Manager—Bridges
Portland Cement Association
5420 Old Orchard Rd
Skokie, IL 60077–1083
Phone: (847) 972–9100
Fax: (847) 972–9101
E-mail: *sbhide@cement.org*

Barry Brecto
Division Bridge Engineer
FHWA, HNWR-WA
711 South Capitol Way, Suite 501
Olympia, WA 98501–1235
Phone: (360) 753–9482
Fax: (360) 753–9889
E-mail: *barry.brecto@fhwa.dot.gov*

Eugene C. Calvert
Principal Project Manager
Collier County Transportation
Services Division
Engineering and Construction
Management Dept.
2685 Horseshoe Drive South,
Suite 212
Naples, FL 34104
Phone: (239) 659–5773
Fax: (239) 213–5885
E-mail: *eugenecalvert@colliergov.net*

Harry Capers
Manager of Structural Engineering
(State Bridge Engineer)
New Jersey DOT
1035 Parkway Ave.
Trenton, NJ 08625
Phone: (609) 530–2557
Fax: (609) 530–5777
E-mail: *harry.capers@dot.state.nj.us*

Dan Dorgan
State Bridge Engineer
Minnesota DOT, Bridge Office
3485 Hadley Ave. North,
Mail Stop 610
Oakdale, MN 55128–3307
Phone: (651) 747–2101
Fax: (651) 747–2108
E-mail: *dan.dorgan@dot.state.mn.us*

Dr. Eric Matsumoto
Assistant Professor
Dept. of Civil Engineering
California State University,
Sacramento
6000 J St.
Sacramento, CA 95819–6029
Phone: (916) 278–5177
Fax: (916) 278–7957
E-mail: *ematsumoto@csus.edu*

Claude S. Napier, Jr.
Division Bridge Engineer
FHWA, HBR-VA
400 North 8th St.
PO Box 10249
Richmond, VA 23240–0249
Phone: (804) 775–3363
Fax: (804) 775–3356
E-mail: *claude.napier@fhwa.dot.gov*

William Nickas
State Structures Design Engineer
Florida DOT
605 Suwannee St., MS 33
Tallahassee, FL 32399-0450
Phone: (850) 414–4260
Fax: (850) 414–4955
E-mail: *william.nickas@dot.state.fl.us*

Dr. Henry G. Russell
(Report Facilitator)
Henry G. Russell, Inc.
720 Coronet Road
Glenview, IL 60025
Phone: (847) 998–9137
Fax: (847) 998–0292
E-mail: *hgr-inc@att.net*

Biographical Sketches

Dr. Shri Bhidé is the chairman of the National Concrete Bridge Council, an association of 11 allied organizations dedicated to the promotion of concrete bridges. Bhidé directs the bridge program at the Portland Cement Association (PCA) in Skokie, IL, which includes conducting research and educational seminars, and disseminating information on design, construction, and performance of concrete bridges. He was instrumental in developing a strategic plan for widespread implementation of high-performance concrete bridges in the United States. His research interests include structural behavior, design aids, and life cycle cost analysis. Before joining the PCA staff in 1998, he worked as a senior structural engineer in Chicago, IL, -based consulting engineering firms. Bhidé is a graduate of the Indian Institute of Technology, Mumbai, and holds master's and doctoral degrees in structural engineering from the University of Toronto. He is a licensed structural engineer in Illinois and a licensed professional engineer in Illinois, Indiana, Wisconsin, and Ohio. He serves on several technical committees of the Transportation Research Board, Precast/Prestressed Concrete Institute, Post-Tensioning Institute, and American Concrete Institute.

Barry Brecto is the bridge engineer for FHWA's Washington Division in Olympia, WA. Brecto directs the Federal program for bridges in Washington State, overseeing design, construction, inspection, and maintenance. He is also the lead engineer for the $4.9 billion Alaskan Way Viaduct project, which will replace an aging 2-mile-long urban double-deck viaduct structure with tunnel and bridge alternates in downtown Seattle, WA. Before joining the Washington Division in 1990, Brecto served as the regional structural engineer for FHWA Region 10 in Portland, OR. Brecto holds a bachelor's degree in civil engineering from Washington State University. He is a licensed professional engineer in Oregon. Brecto is a member of the local Associated General Contractors bridge construction task force and has served on AASHTO's and FHWA's high-performance concrete teams since 1996.

Eugene Calvert is principal project manager of the Transportation Engineering and Construction Management Department for Collier County, FL. He has more than 26 years of experience in highway engineering and administration of bridges, city streets, and county highways, including low-volume rural roads. This has included working with consulting engineering firms and Federal, State, regional, and local government agencies for project development, approval, construction, and implementation. He has had numerous technical transportation articles published in regional and national magazines and newsletters, and is a member of the National Association of County Engineers, Transportation Research Board, Institute of Transportation Engineers, National Local Technical Assistance Program, and American Road & Transportation Builders Association. Calvert holds bachelor's and master's degrees in civil engineering from the University of Wyoming, and did post-graduate work at the University of Idaho. He is a registered professional engineer and land surveyor in several States.

Harry Capers is the State bridge engineer and manager of the Bureau of Structural Engineering for the New Jersey Department of Transportation in Trenton, NJ. Capers directs all matters pertaining to highway structures and geotechnical engineering, including bridge management, design and inspection of fixed and movable bridges, policies and design standards, scope of work, and capital investments. He is on the AASHTO Subcommittee on Bridges and Structures and the Movable Bridge Committee, and serves as chairman of the Loads Technical Committee and vice chairman of the Seismic Committee. He is also chairman of the Transportation Research Board's Committee AFF10 on General Structures and serves on Committee AHD35 on Bridge Management Systems. Capers has published and presented over a dozen state-of-the-practice papers on bridge management, construction, and design for various conferences in the United States Japan, and China. Capers has bachelor's and master's degrees in civil engineering from Polytechnic University in Brooklyn, NY, and a master's degree in public administration from Rutgers University in Newark, NJ. He is a licensed professional engineer in New Jersey and New York, and a certified public manager in New Jersey.

Dan Dorgan is the State bridge engineer and director of the Bridge Office at the Minnesota Department of Transportation. The Bridge Office is responsible for design of all State highway bridges, and determines the types of structures approved for use on Minnesota State, county, and city road systems. The Bridge Office directs implementation of new structure types and any necessary research on bridge designs and structural materials. Dorgan is a 1974 graduate of the University of Minnesota with a bachelor's degree in civil engineering, and also holds a master's degree in business administration from the University of Minnesota. He is a licensed professional engineer in Minnesota. Dorgan represents the Minnesota

DOT on the AASHTO Subcommittee on Bridges and Structures. He also serves on several bridge technical committees, the AASHTO Technical Implementation Group for Prefabricated Structures, TRB Committees AFF20 on Steel Bridges and AFF30 on Concrete Bridges, and the American Segmental Bridge Institute board of directors.

Dr. Eric Matsumoto is assistant professor in the Department of Civil Engineering at California State University, Sacramento, where he has been on the faculty since 2000. Matsumoto teaches structural engineering classes and conducts experimental research focusing on structural concrete. His research includes development of a precast bent cap system for seismic regions, an extension of his Texas Department of Transportation-sponsored dissertation research, as well as development of drill and bond design guidelines for the California Department of Transportation. Matsumoto has a Ph.D. from the University of Texas at Austin and bachelor's and master's degrees from Cornell University. Before entering academia, he worked as a structural engineer for Fluor-Daniel and served in the U.S. Air Force. He is a licensed professional engineer in California and serves on technical committees of the Precast/Prestressed Concrete Institute and the National Concrete Bridge Council.

Claude Napier is a structural engineer in FHWA's Virginia Division Office. Napier is responsible for administering the Federal-aid highway bridge program for design, safety inspections, and maintenance, and for bridges, concrete and high-performance materials technology, and research for the State of Virginia. He provides technical assistance and promotes improvements in the planning, design, construction, and maintenance practices of highway bridges, tunnels, and other structures. Before joining the Virginia Division staff in 1988, he served as a structural engineer in FHWA headquarters reviewing designs and specifications for major bridges, and served as design leader for the bridge design standards section. In addition, he was a bridge designer for FHWA and the Virginia Department of Transportation from 1972 to 1981. Napier holds bachelor's and master's degrees in civil engineering from Virginia Polytechnic Institute and State University. He is a licensed professional engineer in Virginia, and serves on several technical committees of the Precast/Prestressed Concrete Institute and the Mid-Atlantic Prestressed Concrete Economical Fabrication Committee and Structural Steel Committee for Economical Fabrication. He also serves on the FHWA Accelerated Construction Technology Transfer team.

William Nickas is the State structures design engineer for the Florida Department of Transportation. He is responsible for initiating and implementing policies, procedures, and standards for use on all structures on the State and Federal highway systems in Florida, which has the fourth-largest inventory of bridges in the Nation and is constructing more than 200,000 square meters of bridges annually. Under Nickas' leadership, the State Structures Office is responsible for research and bridge testing, reviewing major bridge plans, providing geotechnical guidance and support, and developing new technologies and design tools. He received a bachelor's degree in civil engineering from the Citadel in 1983 and is a professional engineer. He serves as a Transportation Research Board panel chair. He is the voting member for the State of Florida on the AASHTO Subcommittee on Bridges and Structures. He also serves that group as chairman of the Technical Committee for Concrete Design (T-10), and as a member of the Technical Committee for Fiber Reinforced Polymer Composites (T-6), Technical Committee on Movable Bridges (T-8), and Technical Committee for Corrosion (T-9).

Mary Lou Ralls (AASHTO co-chair) is the State bridge engineer for Texas and the director of the Bridge Division at the Texas Department of Transportation. Under her direction, the Bridge Division develops policy, standards, manuals, and guidelines for the design, construction, maintenance, and inspection of the 49,000 on-system and off-system bridges in the State. She serves as chair of the AASHTO Technology Implementation Group's Implementation Panel on Prefabricated Bridge Elements and Systems, and has been active in the implementation of prefabricated bridges in Texas. Ralls earned bachelor's and master's degrees in civil engineering from The University of Texas at Austin in 1981 and 1984, respectively, and became a licensed professional engineer in Texas in 1987. She is a member of the AASHTO Subcommittee on Bridges and Structures and is chair of the Transportation Research Board's Division A-Group F Structures Section.

Dr. Henry G. Russell (report facilitator) is an engineering consultant who specializes in concrete design, construction, and research. Russell's recent activities include the use of high- performance concrete in bridge structures, specifications for long-span bridges, and performance of concrete bridge decks. Russell was affiliated with the Portland Cement Association and its subsidiary, Construction Technology Laboratories, Inc., in Skokie, IL, for more than 25 years. He managed numerous projects involving field, laboratory, and analytical investigations of concrete performance in long-span reinforced and prestressed concrete bridges. He has authored many papers related to the structural applications of concrete. Russell is a graduate of the University of Sheffield, England, with a Ph.D. in civil and structural engineering. He is a licensed structural engineer in Illinois and serves on technical committees of the American Concrete Institute and the Precast/Prestressed Concrete Institute.

Benjamin Tang (FHWA co-chair) is principal bridge engineer and team leader for the FHWA Office of Bridge Technology in Washington, DC. Tang serves as the technical expert and review authority for all bridge and structural matters for the Federal-aid bridge program. He is responsible for drafting Federal polices and regulations, as well as developing the national bridge technology program. His focus is promoting the use of high-performance materials and accelerated bridge construction technologies. Tang has spent his entire career in bridge engineering, including bridge inspection, design, construction, and program management. He is a graduate of University of Maryland and holds a master's degree in structural engineering from the University of Illinois. He is a licensed professional engineer in Maryland and serves on several technical committees of the Transportation Research Board and AASHTO.

Amplifying Questions

The following questions apply to prefabricated bridge systems that incorporate traditional materials such as steel and concrete or innovative materials such as fiber-reinforced polymers. The bridge systems are composed of multiple elements that are fabricated and assembled offsite. The elements are foundations, piers or columns, abutments, pier caps, beams or girders, and decks. Bridges with spans in the range of 6 to 40 m (20 to 140 ft) are the major focus of the panel, although longer spans are of interest if a large amount of innovative prefabrication is used. The panel is interested in all aspects of design, construction, and maintenance.

If possible, the panel would like to spend about 25 percent of its time visiting bridges that have used prefabricated systems. If project reports or other documents are available, the panel would like to obtain copies.

1. Introductory Topics

1.1 How prevalent is the use of prefabricated systems in your country and how has the technology been implemented?
1.2 What types of prefabricated systems, materials, and equipment are used by your agency or country for bridge foundations, substructures, and superstructures for routine or special bridges?
1.3 What materials are used in prefabrication to enhance durability, reduce weight, increase speed of construction, minimize environmental impact, and improve constructibility?
1.4 What are the reasons and criteria for selecting the systems and what are the benefits, costs, and results?
1.5 What lessons about design, fabrication, construction, and maintenance of prefabricated systems have you learned? Please comment on the positive and negative aspects of short-term and long-term performance.
1.6 How do you factor initial costs, life-cycle costs, user costs, incentives, and penalties into your system selection and bidding process?
1.7 What special standards or specifications do you have for prefabricated systems?
1.8 If applicable, what systems have you developed for seismic regions? Please comment on the positive and negative aspects of short-term and long-term performance.
1.9 What contract provisions allow the contractor to use prefabricated systems as an alternative to conventional construction?
1.10 What is the public involvement in selecting prefabricated systems?

2. Prefabricated Bridge Systems That Minimize Traffic Disruption

2.1 How is traffic disruption considered in your planning, design, and bidding processes?
2.2 What methods are used to minimize traffic disruption during construction of new bridges or replacement and maintenance of existing bridges?
2.3 What methods have proved effective and ineffective in minimizing traffic disruption?
2.4 How has prefabrication affected construction methods, construction time, initial and user costs, and public perception? How has it benefited owners?

3. Prefabricated Bridge Systems That Improve Work Zone Safety

3.1 What safety problems do you have in construction work zones and how are they addressed?
3.2 What project planning processes and construction methods are used to improve work zone safety and have they been successful?
3.3 What prefabricated systems have you used to improve work zone safety and what was the impact on costs and safety?
3.4 For those prefabricated systems that were most successful, how have they impacted work zone safety?

4. Prefabricated Bridge Systems That Minimize Environmental Impacts

4.1 What are the environmental constraints in your country?

4.2 What systems are used to minimize environmental impact?
4.3 What have been the beneficial and detrimental effects on the environment of using prefabricated systems?

5. Prefabricated Systems That Improve Constructibility

5.1 What issues do you have related to constructibility?
5.2 What improvements in constructibility have been achieved through the use of prefabricated systems? What methods have not worked?
5.3 What are the design and construction challenges with using prefabricated systems?
5.4 What procedures or techniques are used to seal joints, standardize details, join prefabricated elements, reduce weight, control tolerances, and ensure structurally sound innovative solutions?
5.5 What special techniques and equipment are used for lifting, transporting, and erecting prefabricated systems? What are the restrictions in transporting prefabricated systems?
5.6 If applicable, what connections and other details have you used in prefabricated bridges in seismic regions? Please identify those that worked and those that did not work.

6. Prefabricated Bridge Systems That Increase Quality and Lower Life-Cycle Costs

6.1 What improvements in quality and life-cycle costs have been achieved through the use of prefabricated systems?
6.2 What strategies or innovative materials are used to improve quality, improve long-term durability, and minimize maintenance? What strategies or materials did not work well?
6.3 What methods are used to ensure a smooth ride on the completed bridge?
6.4 How are service life and life-cycle costs determined for different systems?
6.5 To what extent are performance specifications and warranties used?

Bibliography

This appendix contains a list of the resource material that was made available to the team before, during, and after the scanning study. For further information, contact a member of the scanning team.

Japan

Published Documents

“Anjo Viaduct” *(brochure)*
“Design and Construction of Furukawa Viaduct,” by S. Ikeda, H. Ikeda, K. Mizuguchi, K. Muroda, and Y. Taira *(paper)*
“Design of Precast Segmental Box Girder Bridge with Strutted Wing Slab,” by N. Terada, A. Homma, T. Kuroiwa, and K. Saito *(paper)*
“Development of Technology For Expressway Bridges JHC” *(brochure)*
“Development of Technology for Highway Bridges 2001 JHC” *(brochure)*
“Experimental Study on Seismic Behavior of Precast Segmental Bridge Columns,” by T. Mori, N. Suzuki, Y. Tada, and N. Hamada *(paper)*
“Extradosed Prestressed Concrete Bridge with Corrugated Steel Webs” *(brochure)*
“Furukawa Viaduct” *(brochure)*
“Isewangan Expressway” *(brochure)*
“Kamikazue Viaduct” *(brochure)*
“Kinokawa Viaduct” *(brochure)*
“Kiso & Ibi River” *(brochure)*
“Mitsuki Bashi Method” *(information sheet)*
“Prestressed Concrete by Sumitomo Mitsui Construction Co.” *(brochure)*
“SPER Method” *(information sheet and brochure)*
“Streamlined Construction Method for Corrugated Steel Web Bridges” *(brochure)*
“The New Tomei Expressway” *(brochure)*
“The Second Tokyo-Nagoya Expressway” *(brochure)*
“Yahagigawa Bridge” *(brochure)*

Unpublished Documents

Drawings of Kita-Senju girders
Outline of Manufacturing Method of Anjo Viaduct

Technical Presentation Material

“Applications of Precast Concrete Members for Railway Structures” *(handout)*
“Applications of Prefabricated Structures for Bridges” *(PowerPoint® presentation)*
“Construction near Kita-Senju Station of the New Joban Line” *(handout)*
“Elevated Railway Bridge using Temporary Girders” *(handout)*
“Erection of 12,000-Ton Bridge, The Second Tomei Expressway Arimatsu Viaduct” *(PowerPoint presentation)*
“Mitsuki Bashi Method” *(PowerPoint presentation)*
“New Tomei Expressway, Anjo Viaduct” *(handout)*
“New Tomei Expressway, Kamikazue Viaduct” *(handout)*
“Prefabricated Bridges of New Tomei and Meishin Project” *(PowerPoint presentation)*
“Quick Construction of Chofu-Tsurukawa Overbridge” *(PowerPoint presentation)*

The Netherlands

Published Documents

“Mammoet” *(brochure)*
Mammoet World 3 (newsletter)

Technical Presentation Material

Five video clips on moving bridges
“Mammoet” *(PowerPoint presentation)*
“The Installation of Bridges” *(PowerPoint presentation)*

Belgium

Published Documents

Heavyweight News from Sarens, Issue No. 1, October 2003 *(newsletter)*
“Sarens Group” *(brochure)*
Sarens information sheets on moving bridges

Unpublished Documents

Drawings of BRUG 025, Pont Rail 24 de Panten, and Ringvaart Gent

Drawings of erection towers for Millau Viaduct

Presentation Material

Photographs of 11 bridges
“Sarens Group Company Presentation” *(PowerPoint presentation)*

Germany

Published Documents

“A99 Autobahnring Munchen” *(brochure)*
“A99 Autobahnring Munchen Westabschnitt” *(brochure)*
“About the BASt” *(brochure)*
“Der Tunnel Allach A99 Autobahnring Munchen” *(brochure)*
“Federal Highway Research Institute” *(brochure)*
“General Circular on Road Construction No. 23/1993”
“Gussasphalt from A to Z” *(information sheet)*
“Highway Structures, Testing and Inspection DIN 1076”
“Principal Building Authority within the Bavarian State Ministry of the Interior” *(brochure)*
“Renovation of the Wupper Valley Bridge via Composite Method of Construction Using Prefabricated Components,” by M. Hamme *(paper)*

Technical Presentation Material

“Bearings” *(PowerPoint presentation)*
“Composite Bridges” *(PowerPoint presentation)*
“Concrete Bridges with External Prestressing” *(PowerPoint presentation)*
“Concrete Structures” *(PowerPoint presentation)*
“Construction with Incremental Launching Technique” *(PowerPoint presentation)*
Drawings and photographs of Bridge Nos. BW15, BW18, BW19, BW20, BW25, BW101, BW108, BW116, and BW117
Drawings of Bridge No. 5917-895 Anschlussstelle Frankfurt Sud
“Einsatz von Fertigteilen” *(PowerPoint presentation)*
“Einsatz von Verbundfertigteilen bei der Erneuerung einer Uberfuhrung uber die Bundesautobahn A8 Ost Munchen-Salzburg” *(PowerPoint presentation)*
“Fabrication of Prefabricated Elements and Systems” *(PowerPoint presentation)*
“German Concrete Bridge Construction Principles” *(PowerPoint presentation)*

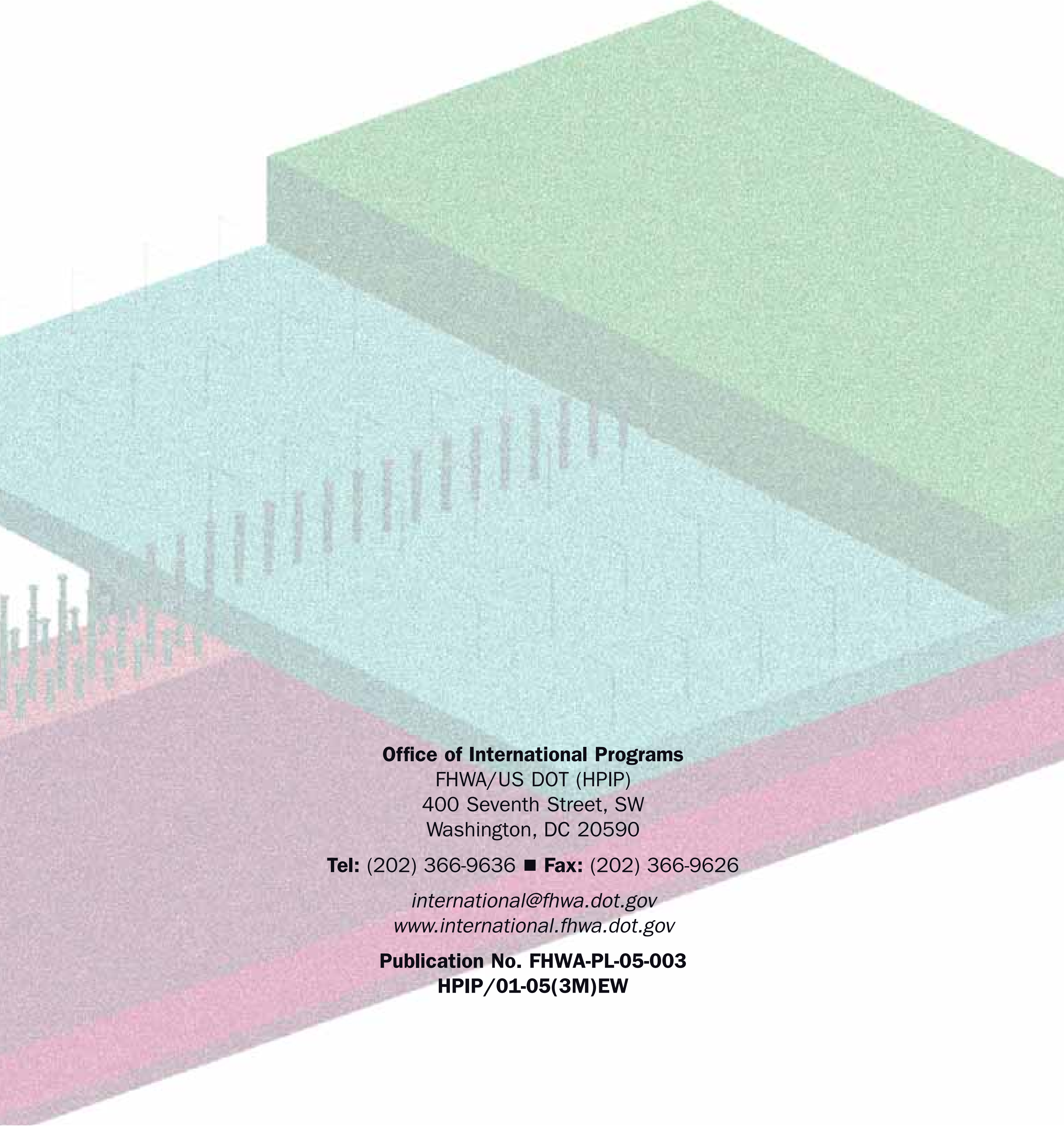
France

Published Documents

“Characterization of the Porous Structure of Hardened Concrete—Objectives and Methods,” by V. Baroghel-Bouny and J. Gawsewitch *(paper)*
“Engineering, Achievements, and Key Figures by SNCF” *(brochure)*
“Laboratoire Central des Ponts et Chaussées” *(brochure)*
“Rapport General d’Activite, Laboratoire Central des Ponts et Chaussées” *(brochure)*
“The Partner in Your Performance—CERIB” *(brochure)*

Technical Presentation Material

“Central Laboratory for Public Works” *(handout)*
“Composite Pre-Constraints” *(PowerPoint presentation)*
“Composite Two-Girder Bridges” *(PowerPoint presentation)*
“Dalle Preflex” *(PowerPoint presentation)*
“Ductal Shepherd’s Traffic Bridge, Australia” *(handout)*
“Les Ouvrages de Bourg Les Valence” *(PDF document)*
“Performance and Predictive Approach of RC Durability based on Durability Indicators—Application to HPCs and Reinforcement Corrosion” *(PowerPoint presentation)*
“Poutre Dalle” *(PowerPoint presentation)*
“Prefabricated Bridges, Elements, and Systems” *(PowerPoint presentation)*
“Prefabrication dans le Domaine des Ouvrages d’art” *(handout)*
“Presentation du SETRA” *(handout)*
“Observations Preliminaires” *(handout)*
“Offres Multiples de l’Industrie du Béton” *(handout)*
“Response aux Questions” *(handout)*
“Short Review of the Use of Ultra-High-Performance Concrete” *(PDF document)*



Office of International Programs
FHWA/US DOT (HPIP)
400 Seventh Street, SW
Washington, DC 20590

Tel: (202) 366-9636 ■ **Fax:** (202) 366-9626

international@fhwa.dot.gov
www.international.fhwa.dot.gov

Publication No. FHWA-PL-05-003
HPIP/01-05(3M)EW