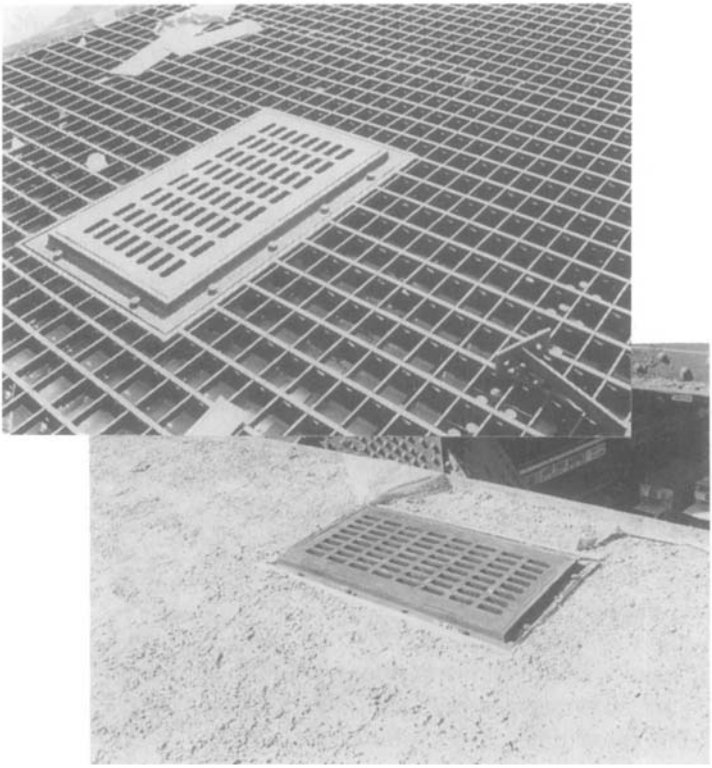

Fig. 6.1, a & b Concrete filled the steel grid deck on New York City's Manhattan Bridge and was later topped with an overlay.

Fig. 6.2. Precast exodermic modules form the deck of bridge over New York State Thruway near Albany.

ness. This is about 50–60% of the weight of a typical reinforced concrete slab. Overall thickness varies from 165–254 mm (6.5–10 in.) or more, depending on the grid main bearing bar selected and depth of concrete. Units have been designed to span up to 5.7 m (18 ft 8 in.), using standard components, although longer spans may be obtained using deeper main grid bars.

The typical steel grid is hot-dip galvanized after fabrication, and is composed of a two-way web of main bearing bars, I- or T-shaped, flat distribution bars at right angles, plus tertiary bars, parallel to the main bars, which project 25 mm (1 in.) above a galvanized pan that serves as the bottom form for the concrete. Vertical studs are welded to the tertiary bars and, together with the partial embedment of the tertiary bars, develop the horizontal shear transfer required to obtain composite behavior of grid and concrete.

Based on service-load (working stress) design in accordance with the AASHTO rules for filled grid decks and reinforced concrete slabs, design computation is straightforward and maximum stresses are conservative. The composite deck has an effective thickness at least equal to its overall depth, and the section modulus per unit of width is approximately 250% that of a grid filled with concrete of the same total weight. The deck provides extended fatigue life because the neutral axis is in the vicinity of the welds and stress-raisers in the steel grid.

Exodermic bridge deck is covered by name in ASTM specification D5484-94, Specification for Steel Grid Bridge Flooring. The 1994 AASHTO/LRFD specification includes exodermic decks as Unfilled, Grid Decks Composite with Reinforced Concrete Slabs in Section 9.8.2.4, combining the "advantages of a concrete deck and a steel grid deck."

History

Development of exodermic decks began in response to problems with concrete-filled steel grids that surfaced during the 1970s. These decks exhibited a "growth" phenomenon attributed to corrosion of the grid bars. At the same time, open grid decks were exhibiting poor skid resistance and early fatigue cracking. (Performance of both grid types has since been improved through research at West Virginia University and by the BGFMA.)

The first exodermic project was the 1984 roadway widening of the Driscoll Bridge on the Garden State Parkway in New Jersey. The exodermic lane filled the space between the separate northbound and southbound structures of the 4,400 ft long bridge. The new lane was cantilevered from the southbound side, and the work was accomplished by installing 500 precast deck modules in only six days.

The initial installation was preceded by a static and fatigue testing program carried out at Lehigh University. Later, exodermic modules were included in an extensive grid deck testing program at West Virginia University. Additional field tests, primarily on replacement projects, followed during the 1980s and 1990s.

Such tests showed that the exodermic design with tertiary bars develops full composite behavior, whereas other experimental designs that incorporated only headed studs welded to the relatively light grid members did not. Those studs, as well as those in other proposed deck types in which headed studs are welded to the top surface of thin flat steel plates, fail to develop the tensile and bending stresses at their bases that are required to produce the fixed-end condition of the studs, which is the basis for the original design and development of welded headed studs.

Two types of studs are used in the exodermic design. Short unheaded studs are welded to the tertiary bars at about 305 mm (12 in.) center to center. These studs prevent vertical separation of the two deck components. The second type of stud, with standard head, which creates the composite action between deck and superstructure, is installed in the field after the exodermic panels have been positioned. These headed studs are welded to stringers, floor beams, and main girders as appropriate. Their heads are embedded in the concrete haunch area, which is poured at the same time as the cast-in-place reinforced concrete deck or poured separately where precast panels are used.

The exodermic design might very well have been named "concrete orthotropic," as the "plate" is a thin element of reinforced concrete. The grid does not "support the plate" but instead, as in a steel orthotropic deck, the grid and the concrete are "welded" together into a composite unity.

The Exodermic Bridge Deck Institute (EBDI) (tel: 888/EXODERMIC) licenses steel grid fabricators to produce the deck panels that are considered generic in most jurisdictions because of availability to contractors from multiple, independent manufacturers. EBDI makes information about design and construction, including computer-aided-design files and analysis software, available to engineers at no charge.

Recent projects have included new decks on existing bridges in New York City and in Rockland County, N.Y., and emergency repairs to the New York Thruway's Tappan Zee Bridge. New construction includes a 520 m (1,700 ft) interim viaduct that will carry Interstate 93 southbound in Boston during construction of the new Central Artery in 1996.

STEEL ORTHOTROPIC DECKS

A singular type of deck made up of steel plates, the orthotropic deck, has been used on many long-span bridges, both for new construction and for redecking during renovations.

Roman Wolchuk, a Jersey City, N.J., consulting engineer, is the foremost proponent of orthotropic steel decks in the United States. He has contributed to the 1994 AASHTO/LRFD specification section that has been adopted for

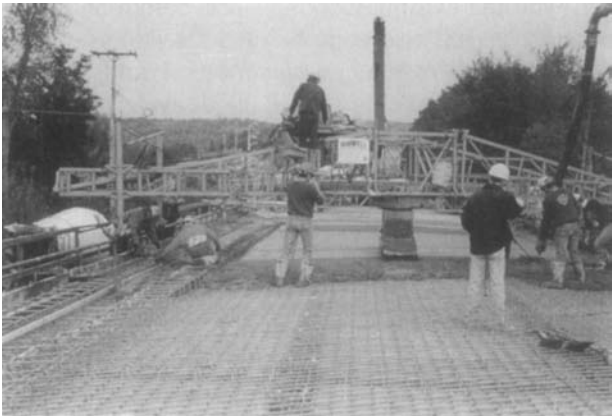

Fig. 6.3. Cast-in-place exodermic modules replaced decks of twin 600 ft bridges over Rt. 9W at Bear Mountain, NY.

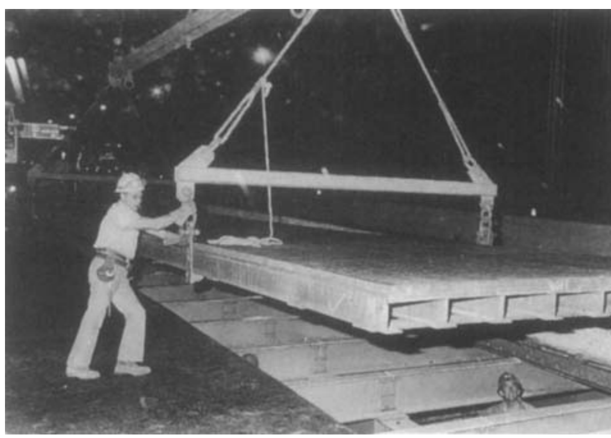

Fig. 6.4. Steel othotropic deck was chosen for replacement of second level deck on the George Washington Bridge.

Fig. 6.5. Doweled glulam panels were field assembled to construct deck of all-timber bridge.

use as a parallel standard with the existing working stress design and load factor design AASHTO codes. He has also contribututed a section on steel plate deck bridges to the *Structural Engineering Handbook,* Fourth Edition (1995) published by McGraw-Hill. What follows is derived from the AASHTO/LRFD specification and Wolchuk's recent papers.

In its basic form, the orthotropic deck is an integral structure made up of stiffening ribs and transverse floor beams, with the deck plate serving as the structure's top flange. This deck structure acts as part of the main bridge structure, most often as the top flange of the main girders or trusses in box girder bridges.

For stiffening a suspension bridge, the steel deck may act as the upper flange of the stiffening girders, or may be used as the top part of a box section. In any bridge type, the steel orthotropic deck can add flexural and torsional rigidity through its closely spaced parallel ribs.

Orthotropic decks have also been used in rehabilitation of existing bridges. In these cases, the deck can either remain an independent element of the bridge or be made integral with the structure via shear connectors. Independent decks were used in redecking both the George Washington Bridge and the Golden Gate Bridge, and fully integrated orthotropic decks replaced the original on the Benjamin Franklin Bridge (Philadelphia to Camden).

There are two types of steel orthotropic decks: those with open ribs and those with closed ribs. They differ in lateral distribution of wheel loads, and the choice depends on their characteristic advantages and disadvantages.

The longitudinal ribs in open-rib decks are flat bars or bulb sections, or inverted tees and angles. Spans are 3 m (10 ft) or less. Although the last are strongest and most rigid, they accumulate dirt and offer perches for birds, causing serious maintenance problems. Other disadvantages include a large number of welds and large surface areas that are difficult to paint. Because open ribs are installed with simple fillet welds, the deck underside is completely accessible and there are no secondary local flexural stresses that sometimes cause fatigue problems in closed-rib decks.

To fabricate the ribs for closed-rib decks, trapezoids are bent from thin plates. Their rigidity increases the lateral load distribution capacity for the same amount of material, so the deck may be lighter than an open-rib deck. Spans can range up to 9.8 m (32 ft). The bevel groove welds are only half as long as required for open-rib construction, but are difficult to produce. Field splices are also difficult, and care must be taken to avoid secondary flexural stresses in the rib-deck junctions.

A prime reason for redecking an older bridge with a steel orthotropic structure is reduced dead weight. For a medium span of 90–180 m (300–600 ft), the reduction may be 15–30% of the original concrete deck. In new construction, such weight savings lead to design of thinner structural depths.

Construction time is also shortened because the steel deck can be prefabricated in large units. In turn, prefabrication makes a steel orthotropic deck suitable for redecking, as it may be installed in one lane while allowing traffic to continue on others.

Uniform reliability and safety of all bridge components is the guiding principle of the new specifications. In addition to the chosen safety index of 3.5, other important aims are redundancy, ductility, constructibility, maintainability, and long-term economy. The design is based on four limit states: strength, serviceability, fatigue, and extreme events. Each state is assigned appropriate load factors.

Sections of the 1994 AASHTO/LRFD specifications discuss general design principles, structural analysis, and specific design provisions. Section 9 includes provisions for orthotropic decks, although several other sections contain relevant provisions. Stipulated design details are based on studies of performance records and failure reports of orthotropic decks in the United States and other countries, including recent research on their fatigue strength.

The design provisions emphasize the importance of preventing fatigue cracks in the deck structure and surfacing failures on the decks. Specific provisions include the following:

1. The design load is a 325 kN truck with single axles of 35-145-145 kN superimposed on a uniform lane load of 9.3kN/m applied simultaneously to all traffic lanes on the bridge. This is heavier than the HS20-44 truck loading that governs design under current AASHTO specifications because it is a realistic view of actual current loads on U.S. highways and also takes future load increases into account.
2. Any suitable elastic analysis method—finite element, finite strip, or equivalent grillage—may be used for refined analysis. For approximate analysis, the Pelikan-Esslinger method as adapted in the American Institute of Steel Construction *Design Manual for Orthotropic Steel Plate Deck Bridges (1963)* may be used.
3. Detailing requirements include a minimum deck plate thickness 0.04 times the spacing of the rib webs, or at least 14 mm. This makes for a relatively stiff deck plate that helps reduce secondary stresses at the rib welds and improves performance of the wearing surface—an integral part of the deck. This requires determining the temperature-dependent mechanical properties of the surface—modulus of elasticity, tensile, shear, and bonding strength—over the service temperature range.
4. Cracking and bond failure can occur when tensile flexural stress exceeds the tensile strength of the surfacing, which de-

pends on the local curvature of the deck plate, material properties, temperature, and surfacing thickness. The AASHTO specification stipulates that the wearing surface be selected on the basis of appropriate mechanical properties, fatigue strength, and resistance to rutting, wearing, solar radiation, water penetration, and deicing salts.

TIMBER BRIDGE DECKS

For hundreds of years, sawn lumber plank decks were laid across all types of bridge structures to serve as the bearing surface for foot, hoofed, and wheeled traffic. These decks varied only in size, strength, and resistance to splintering and decay.

At present, however, timber bridge decks are generally used only where traffic volumes are extremely low, or where all-timber bridges are constructed to meet requirements of aesthetics and economy. Timber decks are not restricted to bridges with timber superstructures. In rural areas it is quite common to see bridges composed of two rolled steel beams topped by a one-lane timber deck.

The use of high-tech timber decks; glued-laminated panels and/or framing members, and prestressed/posttensioned assemblies of lumber, have been developed for the benefit of the timber industry and its customers. These decks of preservative-treated timber offer an option that should not be overlooked for construction of extremely low volume bridge decks.

Durable overlays might make timber decks suitable for other than extremely low volume service, but none have been developed to date. Asphaltic concrete overlays are frequently used on timber decks to improve skid resistance, particularly in wet pavement conditions, but they do not stand up to any substantial volume of traffic.

Two types of timber decks are included in this book: glulam decks and stress-laminated decks. Information prepared by the engineering staff of the United States Department of Agriculture (USDA) Forest Service, excerpts of which follow, is the most complete material available on timber deck design.

Glulam Decks

Nail lamination was the first main improvement over sawn plank decks. These were generally 50 mm (2 in.) thick and from 100–300 mm (4–12 in.) deep, placed side by side and nailed or spiked together to form a continuous surface. They performed well over closely spaced supporting beams and were popular from the 1920s to the 1960s. Development of glulam decks, however, have made them all but obsolete.

Glulam deck panels are normally 130–220 mm ($5^1/_8$–$8^3/_4$ in.) thick and 900–1,500 mm (3–5 ft) wide. They may be placed edge to edge without interconnections to form the deck or interconnected with steel dowels that improve load distribution and reduce differential displacements at the panel joints. The dowels also permit design of thinner decks and improve the performance of asphalt wearing surfaces.

Noninterconnected glulam decks are more commonly used because they are easy to install with unskilled labor and without special equipment. Each panel acts individually to resist the stresses and deflection from applied loads. The deck is assumed to act as a simple span between beams and is designed for the stresses acting in the direction of the deck span as well as for deflection. Although deflection, rather than bending stress, controls most applications, the designer may establish different levels of acceptable deflection for different applications.

Design procedures are similar for noninterconnected and doweled deck panels, although the design loads differ. For noninterconnected panels, under special AASHTO provisions for timber decks, the HS 20-44 and H 20-44 design load is a maximum 53.4 kN (12,000 lb) wheel load. These provisions do not apply for doweled panels, which are designed for HS 20-44 and H 20-44 with 71 kN (16,000 lb) and for HS 15-44 and H 15-44 with 53.4 kN (12,000 lb) wheel loads. Specific design procedures and sample calculations are given in *Timber Bridges: Design, Construction, Inspection and Maintenance* (1992), published by the USDA's Forest Service.

Procedures and calculations are given separately for noninterconnected and doweled panels. The latter are more expensive because they require precise fabrication for proper installation and performance. The panels are designed for the primary moment, shear, and deflection requirements, with appropriate dowel size and placement preventing differential panel deflection under wheel loads.

The design procedures for doweled panels were developed by the USDA Forest Products Laboratory and adopted by AASHTO in 1975. They are based on analyses of the deck as an orthotropic plate acting as a simple span between two supports.

Construction

Glulam decks are attached to supporting beams with bolts, screws, and other mechanical fasteners. The attachments must hold the panels securely and transmit longitudinal and transverse forces from the deck to the beams. Because preservative treatment is best done after the modules are fully fabricated, the connections should not require holes or cuts to be made in the field.

Glulam decks are placed directly on glulam beams and attached with bolted brackets that connect to the beam sides or with lag screws placed through the deck into the beam tops. Lag screw attachments are not recommended because they require field boring and they are not accessible for future tightening if the deck is paved.

Panels may be placed directly on steel beams and secured with a bracket that bolts through the panel and under the top beam flange. Bolting through the flange is not recommended because it allows little or no tolerance for minor variations in panel moisture content or steel thermal expansion.

Glulam decks can be made watertight by sealing the joints with roofing cement or other sealer. Long bridges and those in warm, humid climates may require a 13 mm (1/2 in) transverse joint between every third or fourth panel. Galvanized steel nosing angles are placed on the edge of end panels to minimize damage from vehicle impact and abrasion.

Stress-Laminated Decks

In longitudinal stress-laminated deck superstructures, lumber is placed edgewise between supports and compressed transversely so that the deck acts as a continuous slab without transverse or longitudinal joints. Load transfer between laminations is developed by friction due to initial compression, without glue or nails. Compression is achieved by the same type of high-strength steel rods used for prestressing concrete, placed at regular intervals through prebored holes and stressed in tension by a hydraulic jack. Investigation of the possible use of composite rods instead of steel is underway.

For deck rehabilitation, the rods may be placed externally, over and under the lumber rather than through the laminations. In both methods, the rods are held in place by anchorages that distribute the tension force along the edge of the bridge deck. The steel rods and anchorage devices must be protected against corrosion.

Stress lamination was developed by the Ontario Ministry of Transport more than a decade ago, and by the USDA Forest Products Laboratory during the mid-1980s. FPL researchers worked with the University of Wisconsin, the University of West Virginia, and other state universities. The decks have proved successful in short-span bridges, but the need for longer spans has spurred research into using parallel-chord trusses in place of sawn lumber or glulam deck girders. Trusses will provide a stiffer system, using the same (or smaller) volume of lumber as would be required in a solid girder of similar carrying capacity.

Research into use of wood for bridges and other structures is continuous at the Forest Products Laboratory and at several universities. American Laminators, in Drain, Ore., owns the rights to a fairly recent development researched at Oregon State University. High-strength fibers such as aramids and carbon are extruded into a plastic matrix to form fiber-reinforced plastic panels, trademarked as *FiRP.*

Positioning the product in the high-stress portion of laminated timber beams increases bending strength and stiffness. Such beams have been widely tested in new timber bridges, and testing is underway to develop FiRP glulam bridge decks. Further information is available from Wood Science & Technology Institute, Inc., 2031 NW Monroe St., Corvallis, OR 97330.

CHAPTER 7

A GUIDE TO THE GUIDE SPECIFICATIONS

All persons involved with the selection, design, construction, and rehabilitation of bridge decks must be fully conversant with the specifications that apply in their jurisdiction. In addition, they may profit from the knowledge contained in other guides.

The American Association of State Highway and Transportation Officials AASHTO has promulgated design specifications for many decades. These specifications, adopted throughout the United States, have been updated periodically.

AASHTO's 15th Edition, *Standard Specifications for Highway Bridges,* published in 1992, is the current specification. Because of growing use of LRFD specifications (see below), the 15th Edition will probably not be revised in the forseeable future. It does, however, contain valuable information for those who deal with bridge decks. Some of the more pertinent sections are

- Section 3.24, Distribution of Loads and Design of Concrete Slabs, which carries a footnote stating, "The slab distribution set forth herein is based substantialy on the 'Westergaard' theory," citing publications in *Public Roads* and several University of Illinois bulletins (See chapter 2 of this book).
- Section 8.6, All About Concrete, which discusses protection of concrete from environmental conditions.
- Sections 8.17–8.32: Concrete reinforcement.
- Section 9: Prestressed concrete.
- Section 10.38: Composite girders, structures composed of steel girders with concrete slabs connected by shear connectors.
- Section 10.39: Composite box girders.
- Section 10.40: Hybrid girders, where lower strength steel is used in the web rather than in one or both flanges—composite and noncomposite plate girders, and composite box girders.
- Section 10.41: Orthotropic decks, steel.