FHWA's Bridge Temporary Works Research Program

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Approximately 35,000 state or federal-aid highway bridges were built in the United States during the past decade. Most of these bridges were built without incident, which is a credit to the construction industry. During this period, however, several major bridge failures occurred during construction and were attributed to construction practices and procedures. Statistically, bridge falsework represents more than a third of the total recorded falsework collapses, most of which occurred during construction of conventionally reinforced concrete beam or box-girder bridges. Falsework design in the United States, because of its temporary nature, has traditionally been delegated to the contractor or contractor's engineer under the premise that the contractor is responsible for the means and methods of construction. Although there are potential economies in this type of assignment, the design engineer of record for the bridge relinquishes some control of the project, which, in turn, increases the probability of construction complications or failures. The possibility of construction problems is compounded by the fact that until recently very few detailed standards existed for the construction of these temporary systems and, in many cases, the design assumptions were left to individual engineering judgment. Following the collapse of the Route 198 bridge over the Baltimore Washington Parkway in 1989, FHWA determined that there was a need to reassess, on a national level, the specifications currently used to design, construct, and inspect falsework for highway bridge structures. Toward that end, FHWA sponsored a study to identify the existing information on this subject and develop a guide specification for use by state agencies to update their existing standard specifications for falsework, formwork, and related temporary construction. The results of this study, which included a survey of U.S. and Canadian highway departments and a comprehensive literature search, will be presented. The paper will focus on the current state of the practice in the United States and abroad. FHWA's *Guide Design Specification for Bridge Temporary Works* will be discussed in detail.

In 1991, FHWA initiated a study to identify the current state of the practice in the United States and abroad for designing, constructing, and inspecting the falsework and formwork used to construct highway bridge structures. The findings of this study were published in *Synthesis of Falsework, Formwork, and Scaffolding for Highway Bridge Structures* (*1*). The results of this study, which included a survey of U.S. and Canadian highway departments and a comprehensive literature search, are summarized in this paper. An overview of *Guide Design Specification for Bridge Temporary Works* (2) is also presented.

Existing National Standards

United States

In the United States, few existing national standards apply solely to falsework construction. Perhaps the most widely recognized standard is American National Standards Institute (ANSI) A10.9-1983, *American National Standard for Construction and Demolition Operations—Concrete and Masonry Work—Safety Requirements*. This standard was formulated by the ANSI Committee on Safety in Construction and Demolition Operations. The current version was based on the American Concrete Institute's (ACI's) 347-88, *Guide to Formwork of Concrete*, and therefore contains similar provisions (*3*).

The AASHTO Division II 1991 interim specifications contain a newly created section entitled "Temporary Works," which includes subsections on falsework and forms, cofferdams and shoring, temporary water control systems, and temporary bridges (*4*). This section was developed, in part, to update Division II and consolidate information found in other parts of the AASHTO *Standard Specifications for Highway Bridges* (*5*). The section on falsework and forms includes general design criteria as well as guidelines for removal of these temporary structures.

Canada

In 1975 the Canadian Standards Association (CSA) published a national standard entitled *Falsework for Construction Purposes*, designated CSA S269.1-1975 (*6*). As stated in its scope, this standard provides rules and requirements for design, fabrication, erection, inspection, testing, and maintenance of falsework. The falsework standard was prepared by the Technical Committee on Scaffolding for Construction Purposes and is one of the first national standards developed on this subject.

CSA S269.1 adopts the National Building Code of Canada and existing CSA standards by reference, including CSA S16, *Steel Structures for Buildings*; CSA 086, *Code of Recommended Practice for Engineering Design in Timber*; and CSA W59.1, *General Specification for Welding of Steel Structures*. Materials that cannot be identified as complying with specified standards are not allowed for falsework construction.

In addition to material and design standards, CSA S269.1 specifies design loads and forces, analysis and design methods, erection procedures, and test procedures for steel shoring systems and components. Vertical loads are prescribed generally in terms of a uniformly distributed load. Loads due to special conditions such as impact, unsymmetrical placement of concrete, and overpressures due to pneumatic pumping are discussed but not quantified. Horizontal loads are specified as either the lateral wind force found in the National Building Code of Canada or 2 percent of the total vertical load, whichever is greater. Design capacity is determined by existing CSA design codes or, where proprietary components are used, based on test results with prescribed factors of safety. Additional requirements for tubular scaffold frames and wood falsework are also specified.

A questionnaire distributed to Canadian provincial bridge engineers indicated that most provinces adopt the CSA standard for falsework. Four of the provinces' highway standards supersede sections of the CSA standards. Ontario is currently developing its own falsework manual.

Great Britain

In 1973 the British Standards Institution began to draft a code of practice for falsework; the draft British *Code of Practice for Falsework* was published in late 1975. The document was subsequently revised and published as the *Code of Practice for Falsework* (BS5975) in 1982 (*7*).

The British code is similar in format to the Canadian falsework standard in that the content is organized under the general headings of procedures, materials, and components, loads, foundations and ground conditions, design, and construction. However, it also contains a considerable amount of in-depth commentary and several detailed appendixes, which include properties of components in tube and coupler falsework, design of steel beams at points of reaction or concentrated load, effective lengths of steel members in compression, and so forth.

Like the Canadian standard, the British *Code of Practice for Falsework* references existing British design and material standards. One of the unique features of the British code is its distinction between maximum wind force during the life of the falsework, which represents an extreme condition, and maximum allowable wind force during construction operations. Forces from both of these conditions are used to check the stability of the falsework at appropriate stages of construction.

With the exception of piles, the British code is relatively complete with respect to foundations and ground conditions for temporary works. Pile foundations are addressed in a separate British standard on foundations. BS5975 includes allowable bearing pressures for a wide range of rock and soil types and modification factors that, depending on the reliability of site information, magnitude of anticipated settlement, and fluctuations in

groundwater level, are applied to the prescribed bearing pressure. The code also contains some specific guidelines for the protection of foundation areas.

Australia and New Zealand

Temporary structures for Australian bridge projects are governed by provisions in the *Bridge Design Specifications* as set forth by the National Association of Australian State Road Authorities (NAASRA) (*8*). Section 12, entitled "Design for Construction and Temporary Structures," reviews formwork and falsework design and is supplemented with appendixes on lateral concrete pressure and testing requirements for components. As in the United States, each Australian state transportation department has provisions tht supplement or supersede the national specifications.

Falsework for government bridge projects in New Zealand is regulated by the *Code of Practice for Falsework—Volumes 1 and 2*, which are internal documents. Volume 1 contains the code and appendixes, and Volume 2 serves as commentary. Like the Canadian and British standards, the content of the New Zealand code of practice is organized under the general headings of procedures, materials, foundation and soil conditions, loadings, design, and construction. The New Zealand code also contains several detailed appendixes, which include scaffold tube falsework, proprietary components, foundation investigation, and lateral concrete pressure on forms.

The New Zealand code of practice includes specific provisions for lateral loads generated by nonvertical support members and a horizontal seismic force. The latter force is obtained from a basic seismic coefficient multiplied by factors representing the risk associated with the falsework exposure period and the consequences of failure. The New Zealand code also includes detailed provisions for both working stress and ultimate strength design and prescribes load combinations and related load factors. The section on foundations and soil conditions is similar in detail to the British code of practice and includes a fairly comprehensive review of soil properties and foundation design.

State Specifications

As part of the FHWA study, a questionnaire was sent to the 50 U.S. highway departments. Information relating to design and administrative policies for falsework and formwork construction and the bridge construction activity for each state was requested. A summary of the findings is tabulated in Figures 1 and 2.

Virtually every state was found to have general requirements and guidelines for the construction and removal of falsework and formwork. However, only about half the states specified design criteria. Similarly, only 22 states had accompanying design or construction manuals that included specific design information. States that are more active in constructing cast-in-place concrete highway bridges generally were found to have more comprehensive specifications and guidelines. As evident in Figure 3, the complexity of these systems tends to dictate the need for more comprehensive standards.

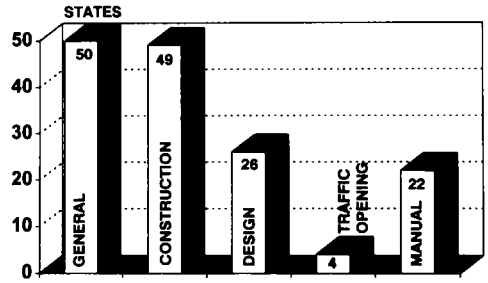

FIGURE 1 Summary of state specification requirements.

Besides identifying the content of state specifications, the survey also provided some insight into each state's administrative policies concerning falsework and formwork. About two-thirds of the states require the submittal of plans and calculations, sealed by a registered professional engineer, for any significant falsework construction. By definition, significant falsework was generally considered as anything that spans more than 4.9 m (16 ft) or rises more than 4.3 m (14 ft) in height. The survey showed that most states also conduct their own reviews and inspections, subject to availability of staff, complexity of design, and so forth.

Loads

Many state specifications are consistent with respect to minimum uniform load requirements and contain pro-

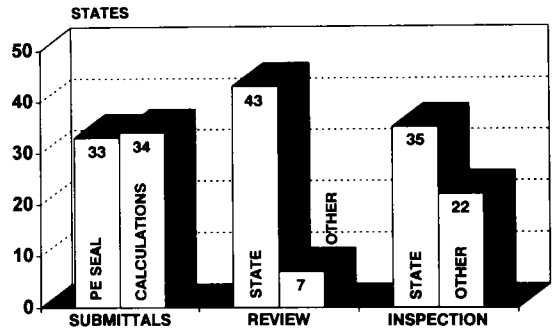

FIGURE 2 State administrative policies.

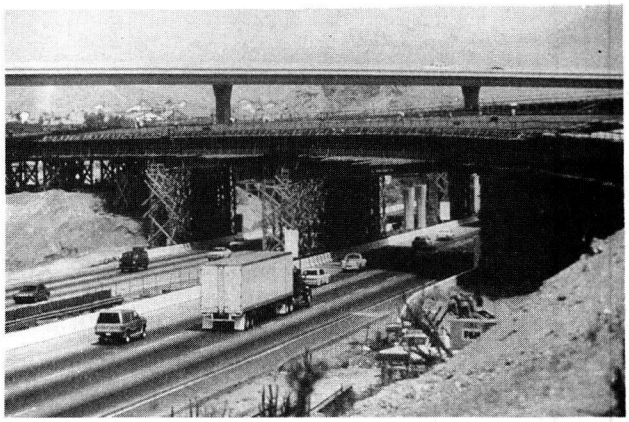

FIGURE 3 Falsework construction over existing roadway.

visions similar to both ANSI 10.9 and AASHTO's 1991 interim specifications. Dead loads include the weight of concrete, reinforcing steel, formwork, and falsework. The weight of concrete, reinforcing steel, and formwork is generally specified to be 2550 kg/m^3 (160 lb/ft^3) for normal-weight concrete or 2100 kg/m^3 (130 lb/ft^3) for lightweight concrete. Some states also specify a minimum vertical load requirement of 4.8 kN/m^2 (100 lb/ft^2).

Live loads typically consist of equipment weights applied as concentrated loads and a uniform load not less than 0.96 kN/m^2 (20 lb/ft^2), plus 1.1 kN/m (75 lb/ft) applied at the outside edge of the deck overhangs. In California, the latter requirement applies only to overhang falsework and not to falsework components below the deck overhang system. In order to avoid being overly conservative, the 1.1-kN/m (75-lb/ft) loading generally is distributed over a length of 6.1 m (20 ft) when falsework components are designed below the level of the bridge soffit.

The horizontal load used to design the falsework bracing system includes the sum of lateral loads due to wind; construction sequence, including unbalanced hydrostatic forces from fluid concrete; and stream flow, where applicable. Superelevation, inclined supports, out-of-plumbness, thermal effects, post-tensioning, and less predictable occurrences (such as impact of concrete during placement, stopping and starting of equipment, and accidental impact of construction equipment) can also introduce horizontal loads into the falsework system.

In general, AASHTO and many state specifications require that the horizontal design load correspond to the actual sum of potential lateral loads but not less than 2 percent of total dead load. Exceptions include Georgia, where "the assumed horizontal load shall be the sum of the actual horizontal loads due to equipment, construction sequence or other causes, and a wind load of 2.4 kN/m^2 (50 lb/ft^2), plus 1 percent of the vertical load to allow for unexpected forces, but in no case shall the assumed horizontal load to be resisted in any direction be less than 3 percent of the total dead load," and Kansas, which requires that "falsework supporting bridge roadways over 0.04 ft/ft superelevation shall use a minimum lateral load equal to 4 percent of the total dead load."

Most states do not prescribe wind loads in their falsework and formwork specifications, and there are inconsistencies between states that have established values. Several states adopt a slightly modified version of the *Uniform Building* Code provisions for open-frame towers (*9*).

For posttensioned construction, it is generally recognized that redistribution of gravity load occurs after the superstructure is stressed. The distribution of load in the falsework after posttensioning depends on factors such as spacing and stiffness of falsework supports, foundation stiffness, superstructure stiffness, and tendon profile. The amount of load redistribution can be significant and may be a governing factor in the falsework design. The AASHTO 1991 interim specifications and some state specifications recognize this potential but do not offer specific design guidelines.

Similar problems have been identified with respect to the redistribution of vertical load due to deck shrinkage. This problem has been researched by the California Department of Transportation (Caltrans) and is addressed indirectly in its specification. Caltrans found that depending on the falsework configuration, type of construction, and construction sequence, the maximum load imposed on the falsework developed within 4 to 7 days after the concrete was placed and varied between 110 and 200 percent of the measured load at 24 hr (*10*).

Stresses

Twenty-two of the 50 states specify design criteria for falsework that includes allowable stresses for steel and timber construction. Most states with established design criteria adopt the AASHTO provisions for structural steel, and the rest use the American Institute of Steel Construction (AISC) allowable stress provisions (*11*). Because AASHTO adopts the *National Design Specification for Wood Construction* (NDS), only the distinctions between this and other specifications will be discussed (*12,13*).

Table 1 gives a summary of the allowable stresses for structural steel prescribed by AISC, AASHTO, and several states with variations of these provisions. For the states, provisions for axial tension, tension in flexure, and shear provisions are generally consistent with either

TABLE 1 Allowable Stress for Structural Steel (lb/in.^{2})

Specification	Axial Tension "F_t"	Flexure, "F_b" Tension	Compression	Axial Compression "F_a"	Shear "F_v"
AISC [a]	0.60 F_y	0.60 F_y	0.60 F_y [b]	AISC Eqn E2-1 [c]	0.40 F_y
AASHTO [d]	0.55 F_y	0.55 F_y	20,000 - [e] 7.5 $(L/b)^2$	16,980 - [e] 0.53 $(KL/r)^2$	0.33 F_y
Iowa [f] (F_y = 30 kip/in^2)	0.55 F_y	0.55 F_y	16,500 - 5.2 $(L/b)^2$	14,150 - 0.37 $(KL/r)^2$	0.33 F_y
Kansas [g]	-	18,000	$\frac{12{,}000{,}000}{Ld/bt} \leq 18{,}000$	16,000 - 0.38 $(L/r)^2$	11,000
Kentucky [h]	-	0.55 F_y	-	AISC Eqn E2-1	0.40 F_y
Maryland [i]	24,000	0.55 F_y	20,000 - 7.5 $(L/b)^2$	16,980 - 0.53 $(KL/r)^2$	0.33 F_y
Minnesota [j]	1.33(0.55F_y)	25,000	1.33(AASHTO Eqn)	16,980 - 0.53 $(KL/r)^2$	1.33(0.33F_y)

1 lb/in^2 = 6895 Pa, 1 kip/in^2 = 6.895 MPa, 1 ft = 0.305 m, 1 in = 25.4 mm

[a] California, Colorado, Georgia, Idaho, and Nevada adopt AISC allowable stresses for identifiable grades of steel. Louisiana, Maryland and South Dakota permit AISC, subject to approval.
[b] Refer to AISC Manual of Steel Construction - Allowable Stress Design for compact sections or compact and non-compact sections with unbraced length greater than L_c.
[c] AISC Eqn E2-1:

$$F_a = \frac{F_y}{F.S.}\left[1 - \frac{(KL/r)^2 F_y}{4\pi^2 E}\right] \quad \text{when } KL/r < C_c$$

$$F_a = \frac{\pi^2 E}{F.S.(KL/r)^2} \quad \text{when } KL/r > C_c$$

[d] States not identified in table or footnote a. adopt AASHTO provisions.
[e] Corresponds to A36 steel.
[f] Iowa adopts AASHTO provisions, but specifies F_y = 30 kip/in^2.
[g] Allowable stresses discussed in Bridge Manual, but not specified in Standard Specifications.
[h] Allowable stresses discussed in Construction Manual, but not specified in Standard Specifications.
[i] Maryland specifies allowable axial tension and adopts AASHTO for remaining stresses.
[j] Standard specifications adopt AASHTO with an allowable one-third increase. Exceptions noted in Bridge Construction Manual.

AISC or AASHTO, whereas allowable axial compression and compression in flexure tend to vary. Despite the difference in the constants used in these expressions, most of the equations have the same form and predate the 1963 specifications, when the Structural Stability Research Council formula (AISC Equation E2-1) was adopted (*14*).

Some states also specify allowable stresses for unidentified, or salvaged, steel grades, as indicated in Table 2. For salvaged steel, states tend to subscribe to older and more conservative allowable stress criteria as opposed to using more current criteria with a reduced yield stress. The exception is Iowa, which appears to acknowledge the likelihood of salvaged steel being used in falsework construction by limiting the maximum design yield strength to 207 MPa (30 ksi), roughly corresponding to the A7 steel common in older bridge construction.

With respect to timber falsework, 16 states reference AASHTO or NDS in their standard specifications. In addition, several states specify allowable unit stress values and, in some cases, note exceptions to the national standards. These states and their prescribed stresses are presented in Table 3. In general, the tabulated values

TABLE 2 Allowable Stress for Salvaged Steel (lb/in.^{2})

Specification	Axial Tension "F_t"	Flexure, "F_b" Tension	Flexure, "F_b" Compression	Axial Compression "F_a"	Shear "F_v"
California, Georgia, Idaho, Nevada	0.60 F_y	0.60 F_y	$\frac{12{,}000{,}000}{Ld/bt} \leq 22{,}000$	$16{,}000 - 0.38\,(L/r)^2$	0.40 F_y
Colorado	18,000	18,000	$\frac{20{,}000}{1 + \frac{L^2}{2{,}000\,b_f^2}}$ [a]	$\frac{18{,}000}{1 + \frac{L^2}{18{,}000\,r^2}} \leq 15{,}000$ [b]	12,000

1 lb/in^2 = 6895 Pa, 1 kip/in^2 = 6.895 MPa, 1 ft = 0.305 m, 1 in = 25.4 mm

[a] 18,000 for $L < 15b_f$
[b] 18,000 for $L/r < 25$

are unit stresses and subject to modification due to slenderness, moisture content, and other factors. However, contrary to NDS, some states do not require an allowable stress reduction for wood with a moisture content greater than 19 percent. California also allows a 50 percent increase in design values for bolts in single-shear connections, a specification based on in-house research (*15*). The allowable stresses specified by Wisconsin and Minnesota include a 25 percent increase to account for short-term load duration.

Deflection

Many specifications, including the AASHTO 1991 interim specifications, prescribe a maximum allowable deflection for falsework flexural members corresponding to $^1/_{240}$ of their span. Idaho limits deflection to $^1/_{500}$ of the span. The limitation is intended to ensure a reasonable degree of rigidity in the falsework, in order to minimize distortion in the forms. The *California Falsework Manual* states that deflection generally is based on the assumption that all the concrete in the bridge superstructure is placed in a single pour (*16*). However, most specifications are not specific as to how this deflection should be determined. The actual deflection will depend on the sequence of construction when two or more concrete placements are required for a given span.

Caltrans has conducted research on curing effects and concrete support periods on dead load deflections of reinforced concrete slab bridges. Its findings indicate that variation in curing time from 7 to 21 days did not significantly affect deflections; however, the difference between 7- and 10-day support periods and 10- and 21-day support periods was significant. The end result was a revision to the "effective modulus" used to calculate ultimate deflections (*17*).

Stability

Stability is not addressed in detail by any of the state specifications. However, some of the accompanying bridge design or construction manuals contain related commentary. The *California Falsework Manual* contains perhaps the best available commentary (*16*).

In falsework construction, overall stability is a function of both internal and external conditions. Internally, falsework can be subject to a wide variety of local horizontal forces produced by out-of-plumb members, superelevation, differential settlement, and so forth. Therefore, the falsework assembly must be connected adequately to resist these forces. In practice, however, the inherent temporary nature of falsework construction does not always translate to a well-connected assembly. Although friction often provides means of load transfer, so-called positive connections eliminate or at least reduce the probability of underestimating the necessary restraint. The need for positive load transfer is particularly apparent when superelevation exists or the soffit is inclined.

External stability and overturning due to lateral or longitudinal loads are generally considered synonymous. If a falsework frame or tower is theoretically stable, external bracing is not necessarily required. However, if the resisting moment is less than the overturning moment, the difference must be resisted by bracing, cable guys, or another means of external support. Depending on the applicable standard, the minimum factor of safety against overturning can vary anywhere

TABLE 3 Allowable Unit Stress for Structural Lumber (lb/in.^{2})

Specification	Extreme fiber in bending "F_b"	Tension parallel to grain "F_t"	Horizontal shear "F_v"	Compression perpendicular to grain "$F_{c\perp}$"	Compression parallel to grain "F_c"	Modulus of elasticity "E"
AASHTO [a]	1450 [b]	850	95	625	1000	1,700,000
California [c]	1500-1800	1200	140	450	$\frac{480{,}000}{(L/L_d)^2} \leq 1600$	1,600,000
Indiana [d]	1800	-	185	-	$1800\left(1-\frac{L}{60d}\right)^{e}$	1,600,000
Iowa [f]	1200	1000	120	390	1000	1,600,000
Kansas [g]	1200	-	120	250	850 [h]	1,500,000
Kentucky [i]	1600	-	125	405	1000	1,600,000
Maryland [j]	1.3(AASHTO) $\leq$ 1800	-	150-200	1.25(AASHTO)	1.25(AASHTO)	Ref. AASHTO
Minnesota [k]	1875	-	120	480	1560	1,800,000
Wisconsin [l]	1875	-	150	500	1500	-

1 lb/in^2 = 6895 Pa, 1 kip/in^2 = 6.895 MPa, 1 ft = 0.305 m, 1 in = 25.4 mm

[a] The current AASHTO Specifications (14th Edition) are based on the National Design Specification for Wood Construction (NDS), 1982 Edition. The allowable unit stresses in this table correspond to No. 2 Douglas Fir - Larch used at 19-percent maximum moisture content.
[b] Allowable stress corresponds to single member use.
[c] Georgia, Idaho and Nevada have similar specifications.
[d] The tabulated values correspond to Douglas-Fir.
[e] L = length of column, d = least dimension.
[f] Allowable stresses correspond to lumber 5 in thick or greater.
[g] Allowable stresses discussed in Bridge Manual, but not specified in Standard Specifications.
[h] Refers to NDS Section 3.7 for intermediate and long columns.
[i] Allowable stresses discussed in Construction Manual, but not specified in Standard Specifications.
[j] Maryland references AASHTO and prescribes allowable increases.
[k] MnDOT adapts AASHTO. Tabular values correspond to No. 1 Douglas Fir - Larch and include 25-percent increase for short-term load duration.
[l] Allowable stresses correspond to No. 1 Douglas Fir and includes 25-percent increase for short term load duration.

between 1 and 2. Many states also require the falsework system to be stable enough to resist overturning before the concrete is placed.

Foundations

In general, the contractor is responsible for designing temporary foundations. Beyond this type of assignment, however, many state specifications are vague with respect to foundation requirements. As with permanent structures, the type of foundations required for temporary works is a function of soil conditions and design loads. Depending on the falsework system, foundation loads can be distributed over the entire length of a supported span or concentrated at temporary bents. In either case, simple foundation pads may be adequate to support the falsework and construction loads.

With an increase in leg load, the method of foundation support on intermediate and heavy-duty shoring towers becomes more significant. Some states require that foundations be designed for uniform settlement under all legs of the tower and under all loading conditions. For heavy-duty shoring, this necessitates the use of concrete mats or pile foundations, as opposed to timber cribbing or simple pads. Pile foundations are required when site conditions preclude timber cribbing or concrete pads and generally are specified to support

falsework for bridge structures over water or where conventional pad foundations are not feasible because of poor soil conditions. In some cases, temporary construction loads are supported by brackets off the permanent piers and abutments, but several states do not permit this practice.

The AASHTO *Standard Specifications for Highway Bridges* contains several sections that relate to foundations (*5*). Many of these provisions, however, apply to permanent pier construction and sections applicable to falsework construction, for example, pile and framed bents, and timber cribbing, generally are more qualitative. For the most part, basic design information for both permanent and temporary construction is limited to pile design criteria and forces due to stream current and ice loads. The AASHTO Division II interim specifications for temporary works do not contain specific guidelines for foundation design (*4*).

Traffic Openings

Traffic openings in falsework are relatively common, particularly for bridge construction over public roads. As such, the specifications of California and three other states contain special provisions for traffic openings, including clearance requirements and special load conditions. Clearance requirements are also identified in a related ACI-ASCE committee report (*18*). California devotes a chapter of its falsework manual to this subject (*16*) and has some of the most comprehensive specifications. Falsework over or adjacent to roadways or railroads, which are open to traffic, must be designed and constructed so that the falsework remains stable if subjected to accidental impact.

FHWA'S Guide Design Specification

FHWA's *Guide Design Specification for Bridge Temporary Works* was developed for use by state agencies to update their existing standard specifications for falsework, formwork, and related temporary structures. The guide specification provides unified design criteria that reflect the current state of practice. The specification was prepared in a format similar to AASHTO's *Standard Specifications for Highway Bridges.*

For the purposes of this document, "falsework" is defined as temporary construction used to support the permanent structure until it becomes self-supporting. "Shoring" is generally considered a component of falsework, such as horizontal or vertical support members, and the term is often used interchangeably with falsework. "Formwork" is a temporary structure or mold used to retain plastic or fluid concrete in its designated shape until it hardens. "Temporary retaining structures" are both earth-retaining structures and cofferdams. These definitions are not intended to be exclusive, but generally consistent with the common use of these terms.

Falsework

The FHWA falsework provisions include four general topics: materials, loads, design considerations, and construction. Allowable stress provisions for steel and timber, as well as modification factors for salvaged (used) materials, are identified. Safety factors and limitations of manufactured (proprietary) components are also specified. Four general load categories, including environmental loads, are defined. The basic reference for computation of wind load is the *Uniform Building Code* (*9*). General design topics such as load combinations, stability against overturning, traffic openings, and foundations are addressed. Presumptive soil-bearing values are also provided. Construction topics include foundation protection, erection tolerances, clearances of traffic openings, adjustment methods, and removal.

The guide design specification is supplemented with commentary and several detailed appendixes, which include design values for ungraded structural lumber, provisions for steel beam webs and flanges under concentrated forces, design wind pressures from selected model codes, and foundation investigation and design.

Formwork

ACI 347-88 (*3*) along with ACI SP-4, *Formwork for Concrete* (*19*), served as the principal reference documents for this section. The objective is to address many of the common bridge forming methods, such as those shown in Figures 4 and 5. Formwork includes materials, loads, and construction. Requirements for sheathing, form accessories, prefabricated formwork, and stay-in-place formwork are specified, as are minimum vertical and horizontal loads. The ACI equations for lateral pressure of fluid concrete are adopted, and the limitations of these equations are discussed in the commentary. Construction topics such as form removal, placement of construction joints, and tolerances are also discussed.

Temporary Retaining Structures

Although developed primarily to address earth-retaining systems more common to bridge construction, such as the soldier pile/lagging shown in Figure 6, this section

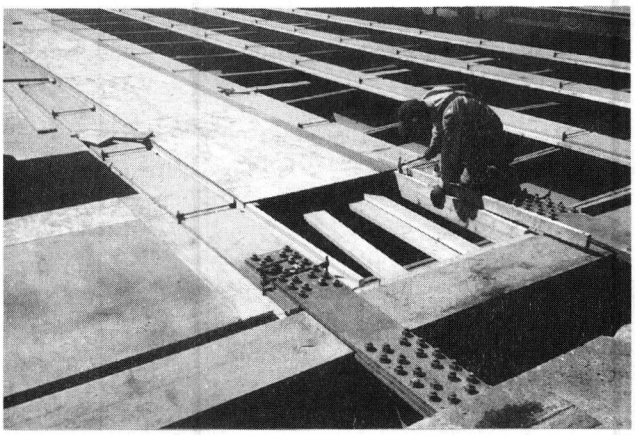

FIGURE 4 Bridge deck formwork.

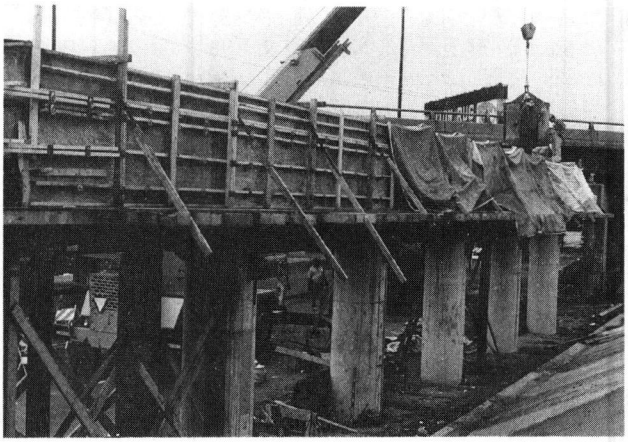

FIGURE 5 Job-built formwork.

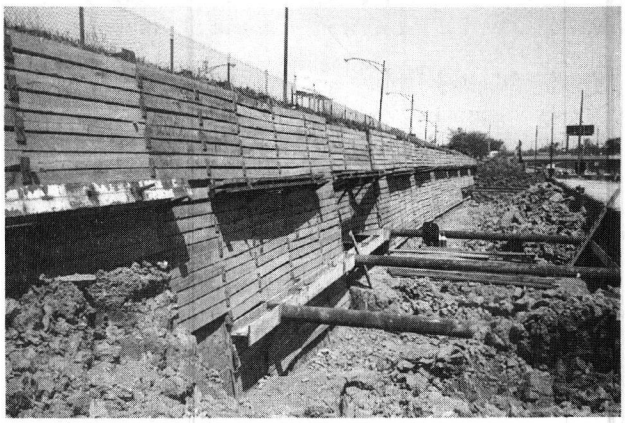

FIGURE 6 Soldier piles retained with soil anchors.

also applies to temporary cofferdams. General requirements and types of excavation support are identified. Federal standards of the Occupational Safety and Health Administration and other regulations are referenced. Empirical methods for determining design lateral pressures in various soils and their limitations are identified. The simplified earth pressure distributions presented in the AASHTO's 1991 interim specifications are adopted. Related topics such as stability, sealing and buoyancy control, seepage control, and protection are discussed in a companion document (*20*).

Summary

The objective of this paper has been to familiarize the reader with existing standards and specifications for temporary works used to construct highway bridge structures. In the United States, these standards include AASHTO's 1991 interim specifications (*4*) and ANSI A10.9-1983. Since the first edition in 1977, the *California Falsework Manual* (*16*) has also served as an authoritative document on this subject and has influenced the specifications of other states as well as the development of standards abroad.

In 1975 and 1982, respectively, Canada and Great Britain produced model standards for falsework that apply to bridge and building construction. As noted in its foreword, the British standard represents "a standard of good practice which has drawn together all those aspects that need to be considered when preparing a falsework design, and in so doing has included recommendations for materials, design and work on site." Since then, the Works and Development Services Corporation in New Zealand has produced a similar code of practice.

In 1991 FHWA initiated a study to identify the current practice in the United States and abroad for designing, constructing, and inspecting the falsework and formwork used to construct highway bridge structures. The findings of this study were published in the *Synthesis of Falsework, Formwork, and Scaffolding for Highway Bridge Structures* (*1*). More recently, FHWA has published the *Guide Design Specification for Bridge Temporary Works* (*2*), which is summarized briefly in this paper. Three other publications—*Guide Standard Specification for Bridge Temporary Works* (*21*), *Certification Program for Bridge Temporary Works* (*22*), and *Construction Handbook for Bridge Temporary Works* (*23*)—were also developed as part of the Bridge Temporary Works Research Program.

The reports produced under this program are available through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

NOTATION

b = actual width of stiffened or unstiffened compression element,
b_f = flange width of rolled beam,
d = overall depth of steel member or least dimension of timber member,
E = modulus of elasticity,
F_a = allowable axial compressive stress,
F_b = allowable bending stress,
F_c = allowable axial compressive stress parallel to grain,
$F_{c\perp}$ = allowable axial compressive stress perpendicular to grain,
F_y = specified minimum yield stress of steel,
F_t = allowable axial tension stress,
F_T = allowable axial tension stress parallel to grain,
F_v = allowable shear stress,
F.S. = factor of safety,
I = moment of inertia,
K = effective length factor,
L = unbraced length of column or compression flange,
r = governing radius of gyration,
t = thickness of compressed element.

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