TABLE OF CONTENTS

@Seismicisolation

GENERAL DESIGN AND LOCATION FEATURES

Commentary is opposite the text it annotates.

2.1—SCOPE

Minimum requirements are provided for clearances, environmental protection, aesthetics, geological studies, economy, rideability, durability, constructability, inspectability, and maintainability. Minimum requirements for traffic safety are referenced.

Minimum requirements for drainage facilities and self-protecting measures against water, ice, and water-borne salts are included.

In recognition that many bridge failures have been caused by scour, hydrology and hydraulics are covered in detail.

C2.1

This Section is intended to provide the Designer with sufficient information to determine the configuration and overall dimensions of a bridge.

2.2—DEFINITIONS

Aggradation—A general and progressive buildup or raising of the longitudinal profile of the channel bed as a result of sediment deposition.

Check Flood for Bridge Scour—The flood resulting from storm, storm surge, tide, or some combination thereof having a flow rate in excess of the design flood for scour, but in no case a flood with a recurrence interval exceeding the typically used 500 years. The check flood for bridge scour is used in the investigation and assessment of a bridge foundation to determine whether the foundation can withstand that flow and its associated scour and remain stable with no reserve. See also superflood.

Clear Zone—An unobstructed, relatively flat area beyond the edge of the traveled way for the recovery of errant vehicles. The traveled way does not include shoulders or auxiliary lanes.

Clearance—An unobstructed horizontal or vertical space.

Degradation—A general and progressive lowering of the longitudinal profile of the channel bed as a result of long-term erosion.

Design Discharge—Maximum flow of water a bridge is expected to accommodate without exceeding the adopted design constraints.

Design Flood for Bridge Scour—The flood flow equal to or less than the 100-year flood that creates the deepest scour at bridge foundations. The highway or bridge may be inundated at the stage of the design flood for bridge scour. The worst-case scour condition may occur for the overtopping flood as a result of the potential for pressure flow.

Design Flood for Waterway Opening—The peak discharge, volume, stage, or wave crest elevation and its associated probability of exceedence that are selected for the design of a highway or bridge over a watercourse or floodplain. By definition, the highway or bridge will not be inundated at the stage of the design flood for the waterway opening.

Detention Basin—A storm water management facility that impounds runoff and temporarily discharges it through a hydraulic outlet structure to a downstream conveyance system.

Drip Groove—Linear depression in the bottom of components to cause water flowing on the surface to drop.

Five-Hundred-Year Flood—The flood due to storm, tide, or both having a 0.2 percent chance of being equaled or exceeded in any given year.

General or Contraction Scour—Scour in a channel or on a floodplain that is not localized at a pier or other obstruction to flow. In a channel, general/contraction scour usually affects all or most of the channel width and is typically caused by a contraction of the flow.

Hydraulics—The science concerned with the behavior and flow of liquids, especially in pipes and channels.

Hydrology—The science concerned with the occurrence, distribution, and circulation of water on the earth, including precipitation, runoff, and groundwater.

Local Scour—Scour in a channel or on a floodplain that is localized at a pier, abutment, or other obstruction to flow.

Mixed Population Flood—Flood flows derived from two or more causative factors, e.g., a spring tide driven by hurricane-generated onshore winds or rainfall on a snowpack.

One-Hundred-Year Flood—The flood due to storm, tide, or both having a 1 percent chance of being equaled or exceeded in any given year.

Overtopping Flood—The flood flow that, if exceeded, results in flow over a highway or bridge, over a watershed divide, or through structures provided for emergency relief. The worst-case scour condition may be caused by the overtopping flood.

Relief Bridge—An opening in an embankment on a floodplain to permit passage of overbank flow.

River Training Structure—Any configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a streambank to deflect current, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimens of the stream.

Scupper—A device to drain water through the deck.

Sidewalk Width—Unobstructed space for exclusive pedestrian use between barriers or between a curb and a barrier.

Spring Tide—A tide of increased range that occurs about every two weeks when the moon is full or new.

Stable Channel—A condition that exists when a stream has a bed slope and cross-section that allows its channel to transport the water and sediment delivered from the upstream watershed without significant degradation, aggradation, or bank erosion.

Stream Geomorphology—The study of a stream and its floodplain with regard to its land forms, the general configuration of its surface, and the changes that take place due to erosion and the buildup of erosional debris.

Superelevation—A tilting of the roadway surface to partially counterbalance the centrifugal forces on vehicles on horizontal curves.

Superflood—Any flood or tidal flow with a flow rate greater than that of the 100-year flood but not greater than a 500-year flood.

Tide—The periodic rise and fall of the earth's oceans that results from the effect of the moon and sun acting on a rotating earth.

Watershed—An area confined by drainage divides, and often having only one outlet for discharge; the total drainage area contributing runoff to a single point.

Waterway—Any stream, river, pond, lake, or ocean.

Waterway Opening—Width or area of bridge opening at a specified stage, and measured normal to principal direction of flow.

@Seismicisolation

2.3—LOCATION FEATURES

2.3.1—Route Location

2.3.1.1—General

The choice of location of bridges shall be supported by analyses of alternatives with consideration given to economic, engineering, social, and environmental concerns as well as costs of maintenance and inspection associated with the structures and with the relative importance of the above-noted concerns.

Attention, commensurate with the risk involved, shall be directed toward providing for favorable bridge locations that:

- fit the conditions created by the obstacle being crossed;
- facilitate practical cost-effective design, construction, operation, inspection, and maintenance;
- provide for the desired level of traffic service and safety; and
- minimize adverse highway impacts.

2.3.1.2—Waterway and Floodplain Crossings

Waterway crossings shall be located with regard to initial capital costs of construction and the optimization of total costs, including river channel training works and the maintenance measures necessary to reduce erosion. Studies of alternative crossing locations should include assessments of:

- the hydrologic and hydraulic characteristics of the waterway and its floodplain, including channel stability, flood history, and, in estuarine crossings, tidal ranges and cycles;
- the effect of the proposed bridge on flood flow patterns and the resulting scour potential at bridge foundations;
- the potential for creating new or augmenting existing flood hazards; and
- environmental impacts on the waterway and its floodplain.

Bridges and their approaches on floodplains should be located and designed with regard to the goals and objectives of floodplain management, including:

- prevention of uneconomic, hazardous, or incompatible use and development of floodplains;
- avoidance of significant transverse and longitudinal encroachments, where practicable;
- minimization of adverse highway impacts and mitigation of unavoidable impacts, where practicable;

C2.3.1.2

Detailed guidance on procedures for evaluating the location of bridges and their approaches on floodplains is contained in Federal Regulations and the Planning and Location Chapter of the *AASHTO Drainage Manual* (see Article C2.6.1). Engineers with knowledge and experience in applying the guidance and procedures in the *AASHTO Drainage Manual* should be involved in location decisions. It is generally safer and more cost effective to avoid hydraulic problems through the selection of favorable crossing locations than to attempt to minimize the problems at a later time in the project development process through design measures.

Experience at existing bridges should be part of the calibration or verification of hydraulic models, if possible. Evaluation of the performance of existing bridges during past floods is often helpful in selecting the type, size, and location of new bridges.

@Seismicisolation

- consistency with the intent of the standards and criteria of the National Flood Insurance Program, where applicable;
- long-term aggradation or degradation; and
- commitments made to obtain environmental approvals.

2.3.2—Bridge Site Arrangement

2.3.2.1—General

The location and the alignment of the bridge should be selected to satisfy both on-bridge and under-bridge traffic requirements. Consideration should be given to possible future variations in alignment or width of the waterway, highway, or railway spanned by the bridge.

Where appropriate, consideration should be given to future addition of mass transit facilities or bridge widening.

C2.3.2.1

Although the location of a bridge structure over a waterway is usually determined by other considerations than the hazards of vessel collision, the following preferences should be considered where possible and practical:

- Locating the bridge away from bends in the navigation channel. The distance to the bridge should be such that vessels can line up before passing the bridge, usually eight times the length of the vessel. This distance should be increased further where high currents and winds are prevalent at the site.
- Crossing the navigation channel near right angles and symmetrically with respect to the navigation channel.
- Providing an adequate distance from locations with congested navigation, vessel berthing maneuvers, or other navigation problems.
- Locating the bridge where the waterway is shallow or narrow and the bridge piers could be located out of vessel reach.

2.3.2.2—Traffic Safety

2.3.2.2.1—Protection of Structures

Consideration shall be given to safe passage of vehicles on or under a bridge. The hazard to errant vehicles within the clear zone should be minimized by locating obstacles at a safe distance from the travel lanes.

Pier columns or walls for grade separation structures should be located in conformance with the clear zone concept as contained in Chapter 3 of the AASHTO *Roadside Design Guide*. Where the practical limits of structure costs, type of structure, volume and design speed of through traffic, span arrangement, skew, and terrain make conformance with the AASHTO *Roadside Design Guide* impractical, the pier or wall should be protected by the use of guardrail or other barrier devices. The guardrail or other device should, if practical, be independently supported, with its roadway face at least 2.0 ft from the face of the pier or abutment, unless a rigid barrier is provided.

The face of the guardrail or other device should be at least 2.0 ft outside the normal shoulder line.

C2.3.2.2.1

The intent of providing structurally independent barriers is to prevent transmission of force effects from the barrier to the structure being protected.

2.3.2.2.2—Protection of Users

Railings shall be provided along the edges of structures conforming to the requirements of Section 13.

C2.3.2.2.2

@Seismicisolation

All protective structures shall have adequate surface features and transitions to safely redirect errant traffic.

In the case of movable bridges, warning signs, lights, signal bells, gates, barriers, and other safety devices shall be provided for the protection of pedestrian, bicycle, and vehicular traffic. These shall be designed to operate before the opening of the movable span and to remain operational until the span has been completely closed. The devices shall conform to the requirements for "Traffic Control at Movable Bridges," in the *Manual on Uniform Traffic Control Devices* (MUTCD) or as shown on plans.

Protective structures include those that provide a safe and controlled separation of traffic on multimodal facilities using the same right-of-way.

Where specified by the Owner, sidewalks shall be protected by barriers.

Special conditions, such as curved alignment, impeded visibility, etc., may justify barrier protection, even with low design velocities.

2.3.2.2.3—Geometric Standards

Requirements of the AASHTO publication *A Policy on Geometric Design of Highways and Streets* shall either be satisfied or exceptions thereto shall be justified and documented. Width of shoulders and geometry of traffic barriers shall meet the specifications of the Owner.

2.3.2.2.4—Road Surfaces

Road surfaces on a bridge shall be given antiskid characteristics, crown, drainage, and superelevation in accordance with *A Policy on Geometric Design of Highways and Streets* or local requirements.

2.3.2.2.5—Vessel Collisions

Bridge structures shall either be protected against vessel collision forces by fenders, dikes, or dolphins as specified in Article 3.14.15, or shall be designed to withstand collision force effects as specified in Article 3.14.14.

C2.3.2.2.5

The need for dolphin and fender systems can be eliminated at some bridges by judicious placement of bridge piers. Guidance on use of dolphin and fender systems is included in the AASHTO *Highway Drainage Guidelines*, Chapter 7, "Hydraulic Analyses for the Location and Design of Bridges."

2.3.3—Clearances

2.3.3.1—Navigational

Permits for construction of bridges over navigable waterways shall be obtained from the U.S. Coast Guard and/or other agencies having jurisdiction. Navigational clearances, both vertical and horizontal, shall be established in cooperation with the U.S. Coast Guard.

C2.3.3.1

Where bridge permits are required, early coordination should be initiated with the U.S. Coast Guard to evaluate the needs of navigation and the corresponding location and design requirements for the bridge.

Procedures for addressing navigational requirements for bridges, including coordination with the Coast Guard, are set forth in the Code of Federal Regulations, 23 CFR, Part 650, Subpart H, "Navigational Clearances for Bridges," and 33 USC 401, 491, 511, et seq.

2.3.3.2—Highway Vertical

The vertical clearance of highway structures shall be in conformance with *A Policy on Geometric Design of Highways and Streets* for the functional classification of the highway or exceptions thereto shall be justified.

C2.3.3.2

The specified minimum clearance should include 6.0 in. for possible future overlays. If overlays are not contemplated by the Owner, this requirement may be nullified.

@Seismicisolation

Possible reduction of vertical clearance, due to settlement of an overpass structure, shall be investigated. If the expected settlement exceeds 1.0 in., it shall be added to the specified clearance.

The vertical clearance to sign supports and pedestrian overpasses should be 1.0 ft greater than the highway structure clearance, and the vertical clearance from the roadway to the overhead cross bracing of through-truss structures should not be less than 17.5 ft.

Sign supports, pedestrian bridges, and overhead cross bracings require the higher clearance because of their lesser resistance to impact.

2.3.3.3—Highway Horizontal

The bridge width shall not be less than that of the approach roadway section, including shoulders or curbs, gutters, and sidewalks.

Horizontal clearance under a bridge should meet the requirements of Article 2.3.2.2.1.

No object on or under a bridge, other than a barrier, should be located closer than 4.0 ft to the edge of a designated traffic lane. The inside face of a barrier should not be closer than 2.0 ft to either the face of the object or the edge of a designated traffic lane.

C2.3.3.3

The usable width of the shoulders should generally be taken as the paved width.

The specified minimum distances between the edge of the traffic lane and the fixed object are intended to prevent collision with slightly errant vehicles and those carrying wide loads.

2.3.3.4—Railroad Overpass

Structures designed to pass over a railroad shall be in accordance with standards established and used by the affected railroad in its normal practice. These overpass structures shall comply with applicable federal, state, county, and municipal laws.

Regulations, codes, and standards should, as a minimum, meet the specifications and design standards of the American Railway Engineering and Maintenance of Way Association (AREMA), the Association of American Railroads, and AASHTO.

C2.3.3.4

Attention is particularly called to the following chapters in the *Manual for Railway Engineering* (AREMA, 2003):

- Chapter 5—Track, Section 8—Highway/Railway Grade Crossings;
- Chapter 7—Timber Structures;
- Chapter 8—Concrete Structures and Foundations;
- Chapter 15—Steel Structures; and
- Chapter 28—Clearances.

The provisions of the individual railroads and the AREMA Manual should be used to determine:

- clearances,
- loadings,
- pier protection,
- waterproofing, and
- blast protection.

2.3.4—Environment

The impact of a bridge and its approaches on local communities, historic sites, wetlands, and other aesthetically, environmentally, and ecologically sensitive areas shall be considered. Compliance with state water laws; federal and state regulations concerning encroachment on floodplains, fish, and wildlife habitats; and the provisions of the National Flood Insurance Program shall be assured. Stream geomorphology, consequences of riverbed scour, removal of embankment stabilizing vegetation, and, where appropriate, impacts to estuarine tidal dynamics shall be considered.

C2.3.4

Stream, i.e., fluvial, geomorphology is the study of the structure and formation of the earth’s features that result from the forces of water. For purposes of this Section, this involves evaluating the streams, potential for aggradation, degradation, or lateral migration.

2.4—FOUNDATION INVESTIGATION

2.4.1—General

A subsurface investigation, including borings and soil tests, shall be conducted in accordance with the provisions of Article 10.4 to provide pertinent and sufficient information for the design of substructure units. The type and cost of foundations should be considered in the economic and aesthetic studies for location and bridge alternate selection.

2.4.2—Topographic Studies

Current topography of the bridge site shall be established via contour maps and photographs. Such studies shall include the history of the site in terms of movement of earth masses, soil and rock erosion, and meandering of waterways.

2.5—DESIGN OBJECTIVES

2.5.1—Safety

The primary responsibility of the Engineer shall be providing for the safety of the public. The Owner may require a design objective other than structural survival for an extreme event.

C2.5.1

Minimum requirements to ensure the structural safety of bridges as conveyances are included in these Specifications. The philosophy of achieving adequate structural safety is outlined in Article 1.3.

2.5.1.1—Structural Survival

The structure shall not collapse under the design event. The structure may undergo considerable displacement, settlement, or inelastic deformation. Elements of the structural system may be designated as sacrificial.

C2.5.1.1

The structural repairs may be extensive and require the structure to be replaced or out-of-service for an extended period of time.

2.5.1.2—Limited Serviceability

The structure shall remain stable under designated emergency vehicular live loads.

C2.5.1.2

Limited displacement, limited plastic deformation in steel members, and spalling in concrete columns may all occur. Sacrificial members may need to be replaced. Structural repairs may be extensive.

2.5.1.3—Immediate Use

The structure may be reopened to all traffic after inspection following an extreme event. All load-carrying members of the structure should remain essentially elastic.

C2.5.1.3

Minor spalling of concrete columns may occur.

@Seismicisolation

2.5.2—Serviceability

2.5.2.1—Durability

2.5.2.1.1—Materials

The contract documents shall call for quality materials and for the application of high standards of fabrication and erection.

Structural steel shall be self-protecting, or have long-life coating systems or cathodic protection.

Reinforcing bars and prestressing strands in concrete components, which may be expected to be exposed to airborne or waterborne salts, shall be protected by an appropriate combination of epoxy and/or galvanized coating, concrete cover, density, or chemical composition of concrete, including air-entrainment and a nonporous painting of the concrete surface or cathodic protection.

Prestress strands in cable ducts shall be grouted or otherwise protected against corrosion.

Attachments and fasteners used in wood construction shall be of stainless steel, malleable iron, aluminum, or steel that is galvanized, cadmium-plated, or otherwise coated. Wood components shall be treated with preservatives.

Aluminum products shall be electrically insulated from steel and concrete components.

Protection shall be provided to materials susceptible to damage from solar radiation and/or air pollution.

Consideration shall be given to the durability of materials in direct contact with soil, water, or both.

C2.5.2.1.1

The intent of this Article is to recognize the significance of corrosion and deterioration of structural materials to the long-term performance of a bridge. Other provisions regarding durability can be found in Article 5.14.

Other than the deterioration of the concrete deck itself, the single most prevalent bridge maintenance problem is the disintegration of beam ends, bearings, pedestals, piers, and abutments due to percolation of waterborne road salts through the deck joints. Experience appears to indicate that a structurally continuous deck provides the best protection for components below the deck. The potential consequences of the use of road salts on structures with unfilled steel decks and unprestressed wood decks should be taken into account.

These Specifications permit the use of discontinuous decks in the absence of substantial use of road salts. Transverse saw-cut relief joints in cast-in-place concrete decks have been found to be of no practical value where composite action is present. Economy, due to structural continuity and the absence of expansion joints, will usually favor the application of continuous decks, regardless of location.

Stringers made simply supported by sliding joints, with or without slotted bolt holes, tend to "freeze" due to the accumulation of corrosion products and cause maintenance problems. Because of the general availability of computers, analysis of continuous decks is no longer a problem.

Experience indicates that, from the perspective of durability, all joints should be considered subject to some degree of movement and leakage.

2.5.2.1.2—Self-Protecting Measures

Continuous drip grooves shall be provided along the underside of a concrete deck at a distance not exceeding 10.0 in. from the fascia edges. Where the deck is interrupted by a sealed deck joint, all surfaces of piers and abutments, other than bearing seats, shall have a minimum slope of 5 percent toward their edges. For open deck joints, this minimum slope shall be increased to 15 percent. In the case of open deck joints, the bearings shall be protected against contact with salt and debris.

Wearing surfaces shall be interrupted at the deck joints and shall be provided with a smooth transition to the deck joint device.

Steel formwork shall be protected against corrosion in accordance with the specifications of the Owner.

C2.5.2.1.2

Ponding of water has often been observed on the seats of abutments, probably as a result of construction tolerances and/or tilting. The 15 percent slope specified in conjunction with open joints is intended to enable rains to wash away debris and salt.

In the past, for many smaller bridges, no expansion device was provided at the "fixed joint," and the wearing surface was simply run over the joint to give a continuous riding surface. As the rotation center of the superstructure is always below the surface, the "fixed joint" actually moves due to load and environmental effects, causing the wearing surface to crack, leak, and disintegrate.

@Seismicisolation

2.5.2.2—Inspectability

Inspection ladders, walkways, catwalks, covered access holes, and provision for lighting, if necessary, shall be provided where other means of inspection are not practical.

Where practical, access to permit manual or visual inspection, including adequate headroom in box sections, shall be provided to the inside of cellular components and to interface areas, where relative movement may occur.

C2.5.2.2

The *Guide Specifications for Design and Construction of Segmental Concrete Bridges* requires external access hatches with a minimum size of 2.5 ft × 4.0 ft, larger openings at interior diaphragms, and venting by drains or screened vents at intervals of no more than 50.0 ft. These recommendations should be used in bridges designed under these Specifications.

2.5.2.3—Maintainability

Structural systems whose maintenance is expected to be difficult should be avoided. Where the climatic and/or traffic environment is such that a bridge deck may need to be replaced before the required service life, provisions shall be shown on the contract documents for:

- a contemporary or future protective overlay,
- a future deck replacement, or
- supplemental structural resistance.

Areas around bearing seats and under deck joints should be designed to facilitate jacking, cleaning, repair, and replacement of bearings and joints.

Jacking points shall be indicated on the plans, and the structure shall be designed for jacking forces specified in Article 3.4.3. Inaccessible cavities and corners should be avoided. Cavities that may invite human or animal inhabitants shall either be avoided or made secure.

C2.5.2.3

Maintenance of traffic during replacement should be provided either by partial width staging of replacement or by the utilization of an adjacent parallel structure.

Measures for increasing the durability of concrete and wood decks include epoxy coating of reinforcing bars, post-tensioning ducts, and prestressing strands in the deck. Microsilica and/or calcium nitrite additives in the deck concrete, waterproofing membranes, and overlays may be used to protect black steel. See Article 5.14.5 for additional requirements regarding overlays.

2.5.2.4—Rideability

The deck of the bridge shall be designed to permit the smooth movement of traffic. On paved roads, a structural transition slab should be located between the approach roadway and the abutment of the bridge. Construction tolerances, with regard to the profile of the finished deck, shall be indicated on the plans or in the specifications or special provisions.

The number of deck joints shall be kept to a practical minimum. Edges of joints in concrete decks exposed to traffic should be protected from abrasion and spalling. The plans for prefabricated joints shall specify that the joint assembly be erected as a unit.

Where concrete decks without an initial overlay are used, consideration should be given to providing an additional thickness of 0.5 in. to permit correction of the deck profile by grinding, and to compensate for thickness loss due to abrasion.

2.5.2.5—Utilities

Where required, provisions shall be made to support and maintain the conveyance for utilities.

@Seismicisolation

2.5.2.6—Deformations

2.5.2.6.1—General

Bridges should be designed to avoid undesirable structural or psychological effects due to their deformations. While deflection and depth limitations are made optional, except for orthotropic plate decks, any large deviation from past successful practice regarding slenderness and deflections should be cause for review of the design to determine that it will perform adequately.

If dynamic analysis is used, it shall comply with the principles and requirements of Article 4.7.

For straight skewed steel girder bridges and horizontally curved steel girder bridges with or without skewed supports, the following additional investigations shall be considered:

- Elastic vertical, lateral, and rotational deflections due to applicable load combinations shall be considered to ensure satisfactory service performance of bearings, joints, integral abutments, and piers.

C2.5.2.6.1

Service load deformations may cause deterioration of wearing surfaces and local cracking in concrete slabs and in metal bridges that could impair serviceability and durability, even if self-limiting and not a potential source of collapse.

As early as 1905, attempts were made to avoid these effects by limiting the depth-to-span ratios of trusses and girders, and starting in the 1930s, live load deflection limits were prescribed for the same purpose. In a study of deflection limitations of bridges (ASCE, 1958), an ASCE committee found numerous shortcomings in these traditional approaches and noted, for example:

> The limited survey conducted by the Committee revealed no evidence of serious structural damage that could be attributed to excessive deflection. The few examples of damaged stringer connections or cracked concrete floors could probably be corrected more effectively by changes in design than by more restrictive limitations on deflection. On the other hand, both the historical study and the results from the survey indicate clearly that unfavorable psychological reaction to bridge deflection is probably the most frequent and important source of concern regarding the flexibility of bridges. However, those characteristics of bridge vibration which are considered objectionable by pedestrians or passengers in vehicles cannot yet be defined.

Since publication of the study, there has been extensive research on human response to motion. It is now generally agreed that the primary factor affecting human sensitivity is acceleration rather than deflection, velocity, or the rate of change of acceleration for bridge structures, but the problem is a difficult subjective one. Thus, there are as yet no simple definitive guidelines for the limits of tolerable static deflection or dynamic motion. Among current specifications, the *Canadian Highway Bridge Design Code* (2014) contains comprehensive provisions regarding vibrations tolerable to humans.

Horizontally-curved steel bridges are subjected to torsion resulting in larger lateral deflections and twisting than tangent bridges. Therefore, rotations due to dead load and thermal forces tend to have a larger effect on the performance of bearings and expansion joints of curved bridges.

Bearing rotations during construction may exceed the dead load rotations computed for the completed bridge, in particular at skewed supports. Identification of this temporary situation may be critical to ensure the bridge can be built without damaging the bearings or expansion devices.

- Computed girder rotations at bearings should be accumulated over the Engineer's assumed construction sequence. Computed rotations at bearings shall not exceed the specified rotational capacity of the bearings for the accumulated factored loads corresponding to the stage investigated.
- Camber diagrams shall satisfy the provisions of Article 6.7.2 and may reflect the computed accumulated deflections due to the Engineer's assumed construction sequence.

2.5.2.6.2—Criteria for Deflection

The criteria in this Article shall be considered optional, except for the following:

- The provisions for orthotropic decks shall be considered mandatory.
- The provisions in Article 12.14.5.9 for precast reinforced concrete three-sided structures shall be considered mandatory.
- Metal grid decks and other lightweight metal and concrete bridge decks shall be subject to the serviceability provisions of Article 9.5.2.

In applying these criteria, the vehicular load shall include the dynamic load allowance.

If an Owner chooses to invoke deflection control, the following principles may be applied:

- When investigating the maximum absolute deflection for straight girder systems, all design lanes should be loaded, and all supporting components should be assumed to deflect equally;
- For curved steel box and I-girder systems, the deflection of each girder should be determined individually based on its response as part of a system;
- For composite design, the stiffness of the design cross-section used for the determination of deflection and frequency should include the entire width of the roadway and the structurally continuous portions of the railings, sidewalks, and median barriers;
- For straight girder systems, the composite bending stiffness of an individual girder may be taken as the stiffness determined as specified above, divided by the number of girders;
- When investigating maximum relative displacements, the number and position of loaded lanes should be selected to provide the worst differential effect;

C2.5.2.6.2

These provisions permit, but do not encourage, the use of past practice for deflection control. Designers were permitted to exceed these limits at their discretion in the past. Calculated deflections of structures have often been found to be difficult to verify in the field due to numerous sources of stiffness not accounted for in calculations. Despite this, many Owners and designers have found comfort in the past requirements to limit the overall stiffness of bridges. The desire for continued availability of some guidance in this area, often stated during the development of these Specifications, has resulted in the retention of optional criteria, except for orthotropic decks, for which the criteria are required. Deflection criteria are also mandatory for lightweight decks comprised of metal and concrete, such as filled and partially filled grid decks, and unfilled grid decks composite with reinforced concrete slabs, as provided in Article 9.5.2.

Additional guidance regarding deflection of steel bridges can be found in Wright and Walker (1971).

Additional considerations and recommendations for deflection in timber bridge components are discussed in more detail in Chapters 7, 8, and 9 in Ritter (1990).

For a straight girder system bridge, this is equivalent to saying that the distribution factor for deflection is equal to the number of lanes divided by the number of beams.

For curved steel girder systems, the deflection limit is applied to each individual girder because the curvature causes each girder to deflect differently than the adjacent girder so that an average deflection has little meaning. For curved steel girder systems, the span used to compute the deflection limit should be taken as the arc girder length between bearings.

@Seismicisolation

- The live load portion of Load Combination Service I of Table 3.4.1-1 should be used, including the dynamic load allowance, IM;
- The live load shall be taken from Article 3.6.1.3.2;
- The provisions of Article 3.6.1.1.2 should apply; and
- For skewed bridges, a right cross-section may be used, and for curved and curved skewed bridges, a radial cross-section may be used.

In the absence of other criteria, the following deflection limits may be considered for steel, aluminum, and/or concrete vehicular bridges:

- Vehicular load, general Span/800,
- Vehicular and pedestrian loads Span/1,000,
- Vehicular load on cantilever arms...... Span/300, and
- Vehicular and pedestrian loads on cantilever arms.. Span/375.

Other criteria may include recognized deflection-frequency-perception requirements such as that specified in the *Canadian Highway Bridge Design Code* (CSA, 2006). Application of the CSA criteria is discussed in Kulicki et al. (2015), including statistical data for live load based on WIM data, a load factor for the HL-93 live load, and a target reliability index.

For steel I-shaped beams and girders, and for steel box and tub girders, the provisions of Articles 6.10.4.2 and 6.11.4, respectively, regarding the control of permanent deflections through flange stress controls, shall apply. For pedestrian bridges, i.e., bridges whose primary function is to carry pedestrians, bicyclists, equestrians, and light maintenance vehicles, the provisions of Section 5 of AASHTO's *LRFD Guide Specifications for the Design of Pedestrian Bridges* shall apply.

In the absence of other criteria, the following deflection limits may be considered for wood construction:

- Vehicular and pedestrian loads .... Span/425, and
- Vehicular load on wood planks and panels (extreme relative deflection between adjacent edges) .. 0.10 in.

From a structural viewpoint, large deflections in wood components cause fasteners to loosen and brittle materials, such as asphalt pavement, to crack and break. In addition, members that sag below a level plane present a poor appearance and can give the public a perception of structural inadequacy. Deflections from moving vehicle loads also produce vertical movement and vibrations that annoy motorists and alarm pedestrians (Ritter, 1990).

Excessive deformation can cause premature deterioration of the wearing surface and affect the performance of fasteners, but limits on the latter have not yet been established.

The following provisions shall apply to orthotropic plate decks:

- Vehicular load on deck plate..................... Span/300,
- Vehicular load on ribs of orthotropic metal decks .... Span/1000, and
- Vehicular load on ribs of orthotropic metal decks (extreme relative deflection between adjacent ribs) .... 0.10 in.

The intent of the relative deflection criterion is to protect the wearing surface from debonding and fracturing due to excessive flexing of the deck.

The 0.10-in. relative deflection limitation is tentative.

@Seismicisolation

2.5.2.6.3—Optional Criteria for Span-to-Depth Ratios

Unless otherwise specified herein, if an Owner chooses to invoke controls on span-to-depth ratios, the limits in Table 2.5.2.6.3-1, in which S is the slab span length and L is the span length, both in feet, may be considered in the absence of other criteria. Where used, the limits in Table 2.5.2.6.3-1 shall be taken to apply to overall depth unless noted.

For curved steel girder systems, the span-to-depth ratio, L_{as}/D, of each steel girder should not exceed 25 when the specified minimum yield strength of the girder in regions of positive flexure is 50.0 ksi or less, and:

- When the specified minimum yield strength of the girder is 70.0 ksi or less in regions of negative flexure, or
- When hybrid sections satisfying the provisions of Article 6.10.1.3 are used in regions of negative flexure.

For all other curved steel girder systems, L_{as}/D of each steel girder should not exceed the following:

$$\frac{L_{as}}{D} \leq 25\sqrt{\frac{50}{F_{yt}}} \qquad (2.5.2.6.3\text{-}1)$$

where:

F_{yt} = specified minimum yield strength of the compression flange (ksi)

D = depth of steel girder (ft)

L_{as} = an arc girder length defined as follows (ft):

- arc span for simple spans;
- 0.9 times the arc span for continuous end-spans;
- 0.8 times the arc span for continuous interior spans.

C2.5.2.6.3

Traditional minimum depths for constant depth superstructures, contained in previous editions of the AASHTO *Standard Specifications for Highway Bridges*, are given in Table 2.5.2.6.3-1 with some modifications.

A larger preferred minimum girder depth is specified for curved steel girders to reflect the fact that the outermost curved girder receives a disproportionate share of the load and needs to be stiffer. In curved skewed bridges, cross-frame forces are directly related to the relative girder deflections. Increasing the depth and stiffness of all the girders in a curved skewed bridge leads to smaller relative differences in the deflections and smaller cross-frame forces. Deeper girders also result in reduced out-of-plane rotations, which may make the bridge easier to erect.

An increase in the preferred minimum girder depth for curved steel girders not satisfying the conditions specified herein is recommended according to Eq. 2.5.2.6.3-1. In such cases, the girders will tend to be significantly more flexible and less steel causes increased deflections without an increase in the girder depth.

A shallower curved girder might be used if the Engineer evaluates effects such as cross-frame forces and bridge deformations, including girder rotations, and finds the bridge forces and geometric changes within acceptable ranges. For curved composite girders, the recommended ratios apply to the steel girder portion of the composite section.

Table 2.5.2.6.3-1—Traditional Minimum Depths for Constant Depth Superstructures

Superstructure		Minimum Depth (Including Deck) When variable depth members are used, values may be adjusted to account for changes in relative stiffness of positive and negative moment sections	
Material	Type	Simple Spans	Continuous Spans
Reinforced Concrete	Slabs with Main Reinforcement Parallel to Traffic	$\frac{1.2(S+10)}{30}$	$\frac{S+10}{30} \geq 0.54 \text{ ft}$
	T-Beams	$0.070L$	$0.065L$
	Box Beams	$0.060L$	$0.055L$
	Pedestrian Structure Beams	$0.035L$	$0.033L$
Prestressed Concrete	Slabs	$0.030L \geq 6.5$ in.	$0.027L \geq 6.5$ in.
	CIP Box Beams	$0.045L$	$0.040L$
	Precast I-Beams	$0.045L$	$0.040L$
	Pedestrian Structure Beams	$0.033L$	$0.030L$
	Adjacent Box Beams	$0.030L$	$0.025L$
Steel	Overall Depth of Composite I-Beam	$0.040L$	$0.032L$
	Depth of I-Beam Portion of Composite I-Beam	$0.033L$	$0.027L$
	Trusses	$0.100L$	$0.100L$

2.5.2.7—Consideration of Future Widening

2.5.2.7.1—Exterior Beams on Girder System Bridges

Unless future widening is virtually inconceivable, the load-carrying capacity of exterior beams shall not be less than the load-carrying capacity of an interior beam.

C2.5.2.7.1

This provision applies to any longitudinal flexural members traditionally considered to be stringers, beams, or girders.

2.5.2.7.2—Substructure

When future widening can be anticipated, consideration should be given to designing the substructure for the widened condition.

2.5.3—Constructability

Constructability issues should include, but not be limited to, consideration of deflection, strength of steel and concrete, and stability during critical stages of construction.

Bridges should be designed in a manner such that fabrication and erection can be performed without undue difficulty or distress and that locked-in construction force effects are within tolerable limits.

When the designer has assumed a particular sequence of construction in order to induce certain stresses under dead load, that sequence shall be defined in the contract documents.

Where there are, or are likely to be, constraints imposed on the method of construction, by environmental

C2.5.3

An example of a particular sequence of construction would be where the designer requires a steel girder to be supported while the concrete deck is cast, so that the girder and the deck will act compositely for dead load as well as live load.

@Seismicisolation

considerations or for other reasons, attention shall be drawn to those constraints in the contract documents.

Where the bridge is of unusual complexity, such that it would be unreasonable to expect an experienced contractor to predict and estimate a suitable method of construction while bidding the project, at least one feasible construction method shall be indicated in the contract documents.

If the design requires some strengthening and/or temporary bracing or support during erection by the selected method, indication of the need thereof shall be indicated in the contract documents.

Details that require welding in restricted areas or placement of concrete through congested reinforcing should be avoided.

Climatic and hydraulic conditions that may affect the construction of the bridge shall be considered.

An example of a complex bridge might be a cable-stayed bridge that has limitations on what it will carry, especially in terms of construction equipment, while it is under construction. If these limitations are not evident to an experienced contractor, the contractor may be required to do more prebid analysis than is reasonable. Given the usual constraints of time and budget for bidding, this may not be feasible for the contractor to do.

This Article does not require the designer to educate a contractor on how to construct a bridge; it is expected that the contractor will have the necessary expertise. Nor is it intended to restrict a contractor from using innovation to gain an edge over the competitors.

All other factors being equal, designs that are self-supporting or use standardized falsework systems are normally preferred to those requiring unique and complex falsework.

Temporary falsework within the clear zone should be adequately protected from traffic.

2.5.4—Economy

2.5.4.1—General

Structural types, span lengths, and materials shall be selected with due consideration of projected cost. The cost of future expenditures during the projected service life of the bridge should be considered. Regional factors, such as availability of material, fabrication, location, shipping, and erection constraints, shall be considered.

C2.5.4.1

If data for the trends in labor and material cost fluctuation are available, the effect of such trends should be projected to the time the bridge will likely be constructed.

Cost comparisons of structural alternatives should be based on long-range considerations, including inspection, maintenance, repair, and/or replacement. Lowest first cost does not necessarily lead to lowest total cost.

2.5.4.2—Alternative Plans

In instances where economic studies do not indicate a clear choice, the Owner may require that alternative contract plans be prepared and bid competitively. Designs for alternative plans shall be of equal safety, serviceability, and aesthetic value.

Movable bridges over navigable waterways should be avoided to the extent feasible. Where movable bridges are proposed, at least one fixed bridge alternative should be included in the economic comparisons.

2.5.5—Bridge Aesthetics

Bridges should complement their surroundings, be graceful in form, and present an appearance of adequate strength.

C2.5.5

Significant improvements in appearance can often be made with small changes in shape or position of structural members at negligible cost. For prominent bridges, however, additional cost to achieve improved appearance is often justified, considering that the bridge will likely be a feature of the landscape for 75 or more years.

Comprehensive guidelines for the appearance of bridges are beyond the scope of these Specifications.

@Seismicisolation

Engineers should seek more pleasant appearance by improving the shapes and relationships of the structural components themselves. The application of extraordinary and nonstructural embellishment should be avoided.

The following guidelines should be considered:

- Alternative bridge designs without piers or with few piers should be studied during the site selection and location stage and refined during the preliminary design stage.
- Pier form should be consistent in shape and detail with the superstructure.
- Abrupt changes in the form of components and structural type should be avoided. Where the interface of different structural types cannot be avoided, a smooth transition in appearance from one type to another should be attained.
- Attention to details, such as deck drain downspouts, should not be overlooked.
- If the use of a through structure is dictated by performance and/or economic considerations, the structural system should be selected to provide an open and uncluttered appearance.
- The use of the bridge as a support for message or directional signing or lighting should be avoided wherever possible.
- Transverse web stiffeners, other than those located at bearing points, should not be visible in elevation.
- For spanning deep ravines, arch-type structures should be preferred.

Engineers may refer to such documents as the Transportation Research Board's *Bridge Aesthetics Around the World* (Gottemoeller, 1991) for guidance.

The most admired modern structures are those that rely for their good appearance on the forms of the structural component themselves:

- Components are shaped to respond to the structural function. They are thick where the stresses are greatest and thin where the stresses are smaller.
- The function of each part and how the function is performed is visible.
- Components are slender and widely spaced, preserving views through the structure.
- The bridge is seen as a single whole, with all members consistent and contributing to that whole; for example, all elements should come from the same family of shapes, such as shapes with rounded edges.
- The bridge fulfills its function with a minimum of material and minimum number of elements.
- The size of each member compared with the others is clearly related to the overall structural concept and the job the component does, and
- The bridge as a whole has a clear and logical relationship to its surroundings.

Several procedures have been proposed to integrate aesthetic thinking into the design process (Gottemoeller, 1991).

Because the major structural components are the largest parts of a bridge and are seen first, they determine the appearance of a bridge. Consequently, engineers should seek excellent appearance in bridge parts in the following order of importance:

- Horizontal and vertical alignment and position in the environment;
- Superstructure type, i.e., arch, girder, etc.;
- Pier placement;
- Abutment placement and height;
- Superstructure shape, i.e., haunched, tapered, depth;
- Pier shape;
- Abutment shape;
- Parapet and railing details;
- Surface colors and textures; and
- Ornament.

The Designer should determine the likely position of the majority of viewers of the bridge, then use that information as a guide in judging the importance of various elements in the appearance of the structure.

Perspective drawings of photographs taken from the important viewpoints can be used to analyze the appearance of proposed structures. Models are also useful.

The appearance of standard details should be reviewed to make sure they fit the bridge's design concept.

@Seismicisolation

2.6—HYDROLOGY AND HYDRAULICS

2.6.1—General

Hydrologic and hydraulic studies and assessments of bridge sites for stream crossings shall be completed as part of the preliminary plan development. The detail of these studies should be commensurate with the importance of and risks associated with the structure.

Temporary structures for the Contractor's use or for accommodating traffic during construction shall be designed with regard to the safety of the traveling public and the adjacent property owners, as well as minimization of impact on floodplain natural resources. The Owner may permit revised design requirements consistent with the intended service period for, and flood hazard posed by, the temporary structure. Contract documents for temporary structures shall delineate the respective responsibilities and risks to be assumed by the highway agency and the Contractor.

Evaluation of bridge design alternatives shall consider stream stability, backwater, flow distribution, stream velocities, scour potential, flood hazards, tidal dynamics where appropriate, and consistency with established criteria for the National Flood Insurance Program.

C2.6.1

The provisions in this Article incorporate improved practices and procedures for the hydraulic design of bridges. Detailed guidance for applying these practices and procedures is contained in the *AASHTO Drainage Manual*. This document contains guidance and references on design procedures and computer software for hydrologic and hydraulic design. It also incorporates guidance and references from the AASHTO *Highway Drainage Guidelines*, which is a companion document to the *AASHTO Drainage Manual*.

Information on the National Flood Insurance Program is contained in 42 USC 4001-4128, the *National Flood Insurance Act* (see also 44 CFR 59 through 77, *National Flood Insurance Program*) and 23 CFR 650, Subpart A, *Location and Hydraulic Design of Encroachment on Floodplains*.

Hydrologic, hydraulic, scour, and stream stability studies are concerned with the prediction of flood flows and frequencies and with the complex physical processes involving the actions and interactions of water and soil during the occurrence of predicted flood flows. These studies should be performed by an Engineer with the knowledge and experience to make practical judgments regarding the scope of the studies to be performed and the significance of the results obtained. The design of bridge foundations is best accomplished by an interdisciplinary team of structural, hydraulic, and geotechnical engineers.

The *AASHTO Drainage Manual* also contains guidance and references on:

- Design methods for evaluating the accuracy of hydraulic studies, including elements of a data collection plan;
- Guidance on estimating flood flow peaks and volumes, including requirements for the design of Interstate highways as per 23 CFR 650, Subpart A, "Encroachments;"
- Procedures or references for analysis of tidal waterways, regulated streams, and urban watersheds;
- Evaluation of stream stability;
- Use of recommended design procedures and software for sizing bridge waterways;
- Location and design of bridges to resist damage from scour and hydraulic loads created by stream current, ice, and debris;
- Calculation of magnitude of contraction scour, local scour, and countermeasures thereto;
- Design of relief bridges, road overtopping, guide banks, and other river training works; and
- Procedures for hydraulc design of bridge-size culverts.

2.6.2—Site Data

A site-specific data collection plan shall include consideration of:

- Collection of aerial and/or ground survey data for appropriate distances upstream and downstream from the bridge for the main stream channel and its floodplain;
- Estimation of roughness elements for the stream and the floodplain within the reach of the stream under study;
- Sampling of streambed material to a depth sufficient to ascertain material characteristics for scour analysis;
- Subsurface borings;
- Factors affecting water stages, including high water from streams, reservoirs, detention basins, tides, and flood control structures and operating procedures;
- Existing studies and reports, including those conducted in accordance with the provisions of the National Flood Insurance Program or other flood control programs;
- Available historical information on the behavior of the stream and the performance of the structure during past floods, including observed scour, bank erosion, and structural damage due to debris or ice flows; and
- Possible geomorphic changes in channel flow.

C2.6.2

The assessment of hydraulics necessarily involves many assumptions. Key among these assumptions are the roughness coefficients and projection of long-term flow magnitudes, e.g., the 500-year flood or other superfloods. The runoff from a given storm can be expected to change with the seasons, immediate past weather conditions, and long-term natural and man-made changes in surface conditions. The ability to statistically project long recurrence interval floods is a function of the adequacy of the database of past floods, and such projections often change as a result of new experience.

The above factors make the check flood investigation of scour an important, but highly variable, safety criterion that may be expected to be difficult to reproduce, unless all of the Designer's original assumptions are used in a post-design scour investigation. Obviously, those original assumptions must be reasonable given the data, conditions, and projections available at the time of the original design.

2.6.3—Hydrologic Analysis

The Owner shall determine the extent of hydrologic studies on the basis of the functional highway classification, the applicable federal and state requirements, and the flood hazards at the site.

The following flood flows should be investigated, as appropriate, in the hydrologic studies:

- For assessing flood hazards and meeting floodplain management requirements—the 100-year flood;
- For assessing risks to highway users and damage to the bridge and its roadway approaches—the overtopping flood and/or the design flood for bridge scour;
- For assessing catastrophic flood damage at high risk sites—a check flood of a magnitude selected by the Owner, as appropriate for the site conditions and the perceived risk;
- For investigating the adequacy of bridge foundations to resist scour—the check flood for bridge scour;
- To satisfy agency design policies and criteria—design floods for waterway opening and bridge scour for the various functional classes of highways;
- To calibrate water surface profiles and to evaluate the performance of existing structures—historical floods; and
- To evaluate environmental conditions—low or base flow information, and in estuarine crossings, the spring and tide range.

C2.6.3

The return period of tidal flows should be correlated to the hurricane or storm tide elevations of water as reported in studies by FEMA or other agencies.

Particular attention should be given to selecting design and checking flood discharges for mixed population flood events. For example, flow in an estuary may consist of both tidal flow and runoff from the upland watershed.

If mixed population flows are dependent on the occurrence of a major meteorological event, such as a hurricane, the relative timing of the individual peak flow events needs to be evaluated and considered in selecting the design discharge. This is likely to be the case for flows in an estuary.

If the events tend to be independent, as might be the case for floods in a mountainous region caused by rainfall runoff or snow melt, the Designer should evaluate both events independently and then consider the probability of their occurrence at the same time.

@Seismicisolation

Investigation of the effect of sea level rise on tidal ranges should be specified for structures spanning marine/estuarine resources.

2.6.4—Hydraulic Analysis

2.6.4.1—General

The Engineer shall utilize analytical models and techniques that have been approved by the Owner and that are consistent with the required level of analysis.

2.6.4.2—Stream Stability

Studies shall be carried out to evaluate the stability of the waterway and to assess the impact of construction on the waterway. The following items shall be considered:

- Whether the stream reach is degrading, aggrading, or in equilibrium;
- For stream crossing near confluences, the effect of the main stream and the tributary on the flood stages, velocities, flow distribution, vertical and lateral movements of the stream, and the effect of the foregoing conditions on the hydraulic design of the bridge;
- Location of favorable stream crossing, taking into account whether the stream is straight, meandering, braided, or transitional, or control devices to protect the bridge from existing or anticipated future stream conditions;
- The effect of any proposed channel changes;
- The effect of aggregate mining or other operations in the channel;
- Potential changes in the rates or volumes of runoff due to land use changes;
- The effect of natural geomorphic stream pattern changes on the proposed structure; and
- The effect of geomorphic changes on existing structures in the vicinity of, and caused by, the proposed structure.

For unstable streams or flow conditions, special studies shall be carried out to assess the probable future changes to the plan form and profile of the stream and to determine countermeasures to be incorporated in the design, or at a future time, for the safety of the bridge and approach roadways.

@Seismicisolation

2.6.4.3—Bridge Waterway

The design process for sizing the bridge waterway shall include:

- The evaluation of flood flow patterns in the main channel and floodplain for existing conditions, and
- The evaluation of trial combinations of highway profiles, alignments, and bridge lengths for consistency with design objectives.

Where use is made of existing flood studies, their accuracy shall be determined.

C2.6.4.3

Trial combinations should take the following into account:

- Increases in flood water surface elevations caused by the bridge,
- Changes in flood flow patterns and velocities in the channel and on the floodplain,
- Location of hydraulic controls affecting flow through the structure or long-term stream stability,
- Clearances between the flood water elevations and low sections of the superstructure to allow passage of ice and debris,
- Need for protection of bridge foundations and stream channel bed and banks, and
- Evaluation of capital costs and flood hazards associated with the candidate bridge alternatives through risk assessment or risk analysis procedures.

2.6.4.4—Bridge Foundations

2.6.4.4.1—General

The structural, hydraulic, and geotechnical aspects of foundation design shall be coordinated and differences resolved prior to approval of preliminary plans.

C2.6.4.4.1

To reduce the vulnerability of the bridge to damage from scour and hydraulic loads, consideration should be given to the following general design concepts:

- Set deck elevations as high as practical for the given site conditions to minimize inundation by floods. Where bridges are subject to inundation, provide for overtopping of roadway approach sections, and streamline the superstructure to minimize the area subject to hydraulic loads and the collection of ice, debris, and drifts.
- Utilize relief bridges, guide banks, dikes, and other river training devices to reduce the turbulence and hydraulic forces acting at the bridge abutments.
- Utilize continuous-span designs. Anchor superstructures to their substructures where subject to the effects of hydraulic loads, buoyancy, ice, or debris impacts or accumulations. Provide for venting and draining of the superstructure.
- Where practical, limit the number of piers in the channel, streamline pier shapes, and align piers with the direction of flood flows. Avoid pier types that collect ice and debris. Locate piers beyond the immediate vicinity of stream banks.
- Locate abutments back from the channel banks where significant problems with ice/debris buildup, scour, or channel stability are anticipated, or where special environmental or regulatory needs must be met, e.g., spanning wetlands.
- Design piers on floodplains as river piers. Locate their foundations at the appropriate depth if there is a likelihood that the stream channel will shift during the life of the structure or that channel cutoffs are likely to occur.

- Where practical, use debris racks or ice booms to stop debris and ice before it reaches the bridge. Where significant ice or debris buildup is unavoidable, its effects should be accounted for in determining scour depths and hydraulic loads.

2.6.4.4.2—Bridge Scour

As required by Article 3.7.5, scour at bridge foundations is investigated for two conditions:

- For the design flood for scour, the streambed material in the scour prism above the total scour line shall be assumed to have been removed for design conditions. The design flood storm surge, tide, or mixed population flood shall be the more severe of the 100-year events or an overtopping flood of lesser recurrence interval.
- For the check flood for scour, the stability of the bridge foundation shall be investigated for scour conditions resulting from a designated flood storm surge, tide, or mixed population flood not to exceed the 500-year event or from an overtopping flood of lesser recurrence interval. Excess reserve beyond that required for stability under this condition is not necessary. The extreme event limit state shall apply.

If the site conditions, due to ice or debris jams, and low tail water conditions near stream confluences dictate the use of a more severe flood event for either the design or check flood for scour, the Engineer may use such flood event.

Spread footings on soil or erodible rock shall be located so that the bottom of footing is below scour depths determined for the check flood for scour. Spread footings on scour-resistant rock shall be designed and constructed to maintain the integrity of the supporting rock.

Deep foundations with footings shall be designed to place the top of the footing below the estimated contraction scour depth where practical to minimize obstruction to flood flows and resulting local scour. Even lower elevations should be considered for pile-supported footings where the piles could be damaged by erosion and corrosion from exposure to stream currents. Where conditions dictate a need to construct the top of a footing to an elevation above the streambed, attention shall be given to the scour potential of the design.

When fendering or other pier protection systems are used, their effect on pier scour and collection of debris shall be taken into consideration in the design.

C2.6.4.4.2

A majority of bridge failures in the United States and elsewhere are the result of scour.

The added cost of making a bridge less vulnerable to damage from scour is small in comparison to the total cost of a bridge failure.

The design flood for scour shall be determined on the basis of the Engineer's judgment of the hydrologic and hydraulic flow conditions at the site. The recommended procedure is to evaluate scour due to the specified flood flows and to design the foundation for the event expected to cause the deepest total scour.

The recommended procedure for determining the total scour depth at bridge foundations is as follows:

- Estimate the long-term channel profile aggradation or degradation over the service life of the bridge;
- Estimate the long-term channel plan form changes over the service life of the bridge;
- As a design check, adjust the existing channel and floodplain cross-sections upstream and downstream of bridge as necessary to reflect anticipated changes in the channel profile and plan form;
- Determine the combination of existing or likely future conditions and flood events that might be expected to result in the deepest scour for design conditions;
- Determine water surface profiles for a stream reach that extends both upstream and downstream of the bridge site for the various combinations of conditions and events under consideration;
- Determine the magnitude of contraction scour and local scour at piers and abutments; and
- Evaluate the results of the scour analysis, taking into account the variables in the methods used, the available information on the behavior of the watercourse, and the performance of existing structures during past floods. Also consider present and anticipated future flow patterns in the channel and its floodplain. Visualize the effect of the bridge on these flow patterns and the effect of the flow on the bridge. Modify the bridge design where necessary to satisfy concerns raised by the scour analysis and the evaluation of the channel plan form.

Foundation designs should be based on the total scour depths estimated by the above procedure, taking into account appropriate geotechnical safety factors. Where necessary, bridge modifications may include:

@Seismicisolation

- relocation or redesign of piers or abutments to avoid areas of deep scour or overlapping scour holes from adjacent foundation elements,
- addition of guide banks, dikes, or other river training works to provide for smoother flow transitions or to control lateral movement of the channel,
- enlargement of the waterway area, or
- relocation of the crossing to avoid an undesirable location.

Foundations should be designed to withstand the conditions of scour for the design flood and the check flood. In general, this will result in deep foundations. The design of the foundations of existing bridges that are being rehabilitated should consider underpinning if scour indicates the need. Riprap and other scour countermeasures may be appropriate if underpinning is not cost-effective.

The stability of abutments in areas of turbulent flow shall be thoroughly investigated. Exposed embankment slopes should be protected with appropriate scour countermeasures.

Available technology has not developed sufficiently to provide reliable scour estimates for some conditions, such as bridge abutments located in areas of turbulence due to converging or diverging flows.

2.6.4.5—Roadway Approaches to Bridge

The design of the bridge shall be coordinated with the design of the roadway approaches to the bridge on the floodplain so that the entire flood flow pattern is developed and analyzed as a single, interrelated entity. Where roadway approaches on the floodplain obstruct overbank flow, the highway segment within the floodplain limits shall be designed to minimize flood hazards.

Where diversion of flow to another watershed occurs as a result of backwater and obstruction of flood flows, an evaluation of the design shall be carried out to ensure compliance with legal requirements in regard to flood hazards in the other watershed.

C2.6.4.5

Highway embankments on floodplains serve to redirect overbank flow, causing it to flow generally parallel to the embankment and return to the main channel at the bridge. For such cases, the highway designs shall include countermeasures where necessary to limit damage to highway fills and bridge abutments. Such countermeasures may include:

- relief bridges,
- retarding the velocity of the overbank flow by promoting growth of trees and shrubs on the floodplain and highway embankment within the highway right-of-way or constructing small dikes along the highway embankment,
- protecting fill slopes subject to erosive velocities by use of riprap or other erosion protection materials on highway fills and spill-through abutments, and
- use of guide banks where overbank flow is large to protect abutments of main channel and relief bridges from turbulence and resulting scour.

Although overtopping may result in failure of the embankment, this consequence is preferred to failure of the bridge. The low point of the overtopping section should not be located immediately adjacent to the bridge, because its failure at this location could cause damage to the bridge abutment. If the low point of the overtopping section must be located close to the abutment, due to geometric constraints, the scouring effect of the overtopping flow should be considered in the design of the abutment. Design studies for overtopping should also include evaluation of any flood hazards created by changes to existing flood flow patterns or by flow concentrations in the vicinity of developed properties.

@Seismicisolation

2.6.5—Culvert Location, Length, and Waterway Area

In addition to the provisions of Articles 2.6.3 and 2.6.4, the following conditions should be considered:

- passage of fish and wildlife,
- effect of high outlet velocities and flow concentrations on the culvert outlet, the downstream channel, and adjacent property,
- buoyancy effects at culvert inlets,
- traffic safety, and
- the effects of high tail water conditions as may be caused by downstream controls or storm tides.

C2.6.5

The discussion of site investigations and hydrologic and hydraulic analyses for bridges is generally applicable to large culvert installations classified as bridges.

The use of safety grates on culvert ends to protect vehicles that run off the road is generally discouraged for large culverts, including those classified as bridges, because of the potential for clogging and subsequent unexpected increase in the flood hazard to the roadway and adjacent properties. Preferred methods of providing for traffic safety include the installation of barriers or the extension of the culvert ends to increase the vehicle recovery zone at the site.

2.6.6—Roadway Drainage

2.6.6.1—General

The bridge deck and its highway approaches shall be designed to provide safe and efficient conveyance of surface runoff from the traveled way in a manner that minimizes damage to the bridge and maximizes the safety of passing vehicles. Transverse drainage of the deck, including roadway, bicycle paths, and pedestrian walkways, shall be achieved by providing a cross slope or superelevation sufficient for positive drainage. For wide bridges with more than three lanes in each direction, special design of bridge deck drainage and/or special rough road surfaces may be needed to reduce the potential for hydroplaning. Water flowing downgrade in the roadway gutter section shall be intercepted and not permitted to run onto the bridge. Drains at bridge ends shall have sufficient capacity to carry all contributing runoff.

In those unique environmentally sensitive instances where it is not possible to discharge into the underlying watercourse, consideration should be given to conveying the water in a longitudinal storm drain affixed to the underside of the bridge and discharging it into appropriate facilities on natural ground at the bridge end.

C2.6.6.1

Where feasible, bridge decks should be watertight and all of the deck drainage should be carried to the ends of the bridge.

A longitudinal gradient on bridges should be maintained. Zero gradients and sag vertical curves should be avoided. Design of the bridge deck and the approach roadway drainage systems should be coordinated.

Under certain conditions, open bridge railings may be desirable for maximum discharge of surface runoff from bridge decks.

Chapter 13, "Storm Drainage Systems," of the *AASHTO Drainage Manual* contains guidance on recommended values for cross slopes.

2.6.6.2—Design Storm

The design storm for bridge deck drainage shall not be less than the storm used for design of the pavement drainage system of the adjacent roadway, unless otherwise specified by the Owner.

2.6.6.3—Type, Size, and Number of Drains

The number of deck drains should be kept to a minimum consistent with hydraulic requirements.

In the absence of other applicable guidance, for bridges where the highway design speed is less than 45 mph, the size and number of deck drains should be such that the spread of deck drainage does not encroach on more than one-half the width of any designated traffic lane. For bridges where the highway design speed is not less than 45 mph, the spread of deck drainage should not encroach on

C2.6.6.3

For further guidance or design criteria on bridge deck drainage, see Chapter 13, "Storm Drainage Systems," of the *AASHTO Drainage Manual*, *Policy on Geometric Design of Highways and Streets*, and AASHTO/FHWA Research Report RD-87-014, *Bridge Deck Drainage Guidelines*.

any portion of the designated traffic lanes. Gutter flow should be intercepted at cross slope transitions to prevent flow across the bridge deck.

Scuppers or inlets of a deck drain shall be hydraulically efficient and accessible for cleaning.

The minimum internal dimension of a downspout should not normally be less than 6.0 in., but not less than 8.0 in. where ice accretion on the bridge deck is expected.

2.6.6.4—Discharge from Deck Drains

Deck drains shall be designed and located such that surface water from the bridge deck or road surface is directed away from the bridge superstructure elements and the substructure.

If the Owner has no specific requirements for controlling the effluent from drains and pipes, consideration should be given to:

- a minimum 4.0-in. projection below the lowest adjacent superstructure component,
- location of pipe outlets such that a 45 degree cone of splash will not touch structural components,
- use of free drops or slots in parapets wherever practical and permissible,
- use of bends not greater than 45 degrees, and
- use of cleanouts.

Runoff from bridge decks and deck drains shall be disposed of in a manner consistent with environmental and safety requirements.

C2.6.6.4

Consideration should be given to the effect of drainage systems on bridge aesthetics.

For bridges where free drops are not feasible, attention should be given to the design of the outlet piping system to:

- minimize clogging and other maintenance problems and
- minimize the intrusive effect of the piping on the bridge symmetry and appearance.

Free drops should be avoided where runoff creates problems with traffic, rail, or shipping lanes. Riprap or pavement should be provided under the free drops to prevent erosion.

2.6.6.5—Drainage of Structures

Cavities in structures where there is a likelihood for entrapment of water shall be drained at their lowest point. Decks and wearing surfaces shall be designed to prevent the ponding of water, especially at deck joints. For bridge decks with nonintegral wearing surfaces or stay-in-place forms, consideration shall be given to the evacuation of water that may accumulate at the interface.

C2.6.6.5

Weep holes in concrete decks and drain holes in stay-in-place forms can be used to permit the egress of water.

2.7—BRIDGE SECURITY

2.7.1—General

An assessment of the priority of a bridge should be conducted during the planning of new bridges and during rehabilitation of existing bridges. This should take into account the social/economic impact of the loss of the bridge, the

C2.7.1

At the time of this writing, there are no uniform procedures for assessing the priority of a bridge to the social/economic impact and defense/security of a region. Work is being done to produce a uniform procedure to prioritize bridges for security.

availability of alternate routes, and the effect of closing the bridge on the security/defense of the region.

For bridges deemed critical or essential, a formal vulnerability study should be conducted, and measures to mitigate the vulnerabilities should be considered for incorporation into the design.

In the absence of uniform procedures, some states have developed procedures that incorporate their own security prioritization methods which, while similar, differ in details. In addition, procedures to assess bridge priority were developed by departments of transportation in some states to assist in prioritizing seismic rehabilitation. The procedures established for assessing bridge priority may also be used in conjunction with security considerations.

Guidance on security strategies and risk reduction may be found in the following documents: Science Applications International Corporation (2002), The Blue Ribbon Panel on Bridge and Tunnel Security (2003), Winget (2003), Jenkins (2001), Abramson et al. (1999), and Williamson (2006).

2.7.2—Design Demand

Bridge Owners should establish criteria for the size and location of the threats to be considered in the analysis of bridges for security. These criteria should take into account the type, geometry, and priority of the structure being considered. The criteria should also consider multi-tier threat sizes and define the associated level of structural performance for each tier.

Design demands should be determined from analysis of a given size design threat, taking into account the associated performance levels. Given the demands, a design strategy should be developed and approved by the Bridge Owner.

C2.7.2

It is not possible to protect a bridge from every conceivable threat. The most likely threat scenarios should be determined based on the bridge structural system and geometry and the identified vulnerabilities. The most likely attack scenarios will minimize the attacker's required time on target, possess simplicity in planning and execution, and have a high probability of achieving maximum damage.

The level of acceptable damage should be proportionate to the size of the attack. For example, linear behavior and/or local damage should be expected under a small-size attack, while significant permanent deformations and significant damage and/or partial failure of some components should be acceptable under larger size attacks.

The level of threat and the operational classification of the bridge should be taken into account when determining the level of analysis to be used in determining the demands. Approximate methods may be used for low-force threats and low-importance bridges, while more sophisticated analyses should be used for high-force threats to priority bridges.

2.8—REFERENCES

23 CFR 650, Subpart A.

44 CFR 59 through 77.

AASHTO. *Highway Drainage Guidelines*, 4th ed. HDG-4. American Association of State Highway and Transportation Officials, Washington, DC, 2007.

AASHTO. *AASHTO Guide Specifications for Bridges Vulnerable to Coastal Storms*, 1st ed. BVCS-1. American Association of State Highway and Transportation Officials, Washington, DC, 2008.

AASHTO. *AASHTO Guide Specifications for LRFD Seismic Bridge Design*, 2nd ed. with Interims. LRFDSEIS-2. American Association of State Highway and Transportation Officials, Washington, DC, 2011.

AASHTO. *Roadside Design Guide*, 4th ed. RSDG-4. American Association of State Highway and Transportation Officials, Washington, DC, 2011.

AASHTO. *AASHTO Drainage Manual*, 1st ed. ADM-1. American Association of State Highway and Transportation Officials, Washington, DC, 2014.

@Seismicisolation

AASHTO and FHWA. *Bridge Deck Drainage Guidelines*. Research Report RD-87-014. American Association of State Highway and Transportation Officials/Federal Highway Administration, Washington, DC, 1987.

Abramson, H. N., et al. *Improving Surface Transportation Security: A Research and Development Strategy*. Committee on R & D Strategies to Improve Surface Transportation Security, National Research Council, National Academy Press, Washington, DC, 1999.

AREMA. *Manual for Railway Engineering.* American Railway Engineers Association, Washington, DC, 2003.
ASCE. Deflection Limitations of Bridges: Progress Report of the Committee on Deflection Limitations of Bridges of the Structural Division. *Journal of the Structural Division*, Vol. 84, No. ST 3. American Society of Civil Engineers, New York, NY, May 1958.

The Blue Ribbon Panel on Bridge and Tunnel Security. *Recommendations for Bridge and Tunnel Security*. Special report prepared for FHWA and AASHTO, Washington, DC, 2003.

CSA. *Canadian Highway Bridge Design Code*. CAN/CSA-S6-14. Includes Supplement 1, Supplement 2, and Supplement 3. Canadian Standards Association International, Toronto, ON, Canada, 2014.

FHWA. *Evaluating Scour at Bridges*, 5th ed. Hydraulic Engineering Circular No. 18. FHWA-1P-90-017. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2012.

FHWA. *Stream Stability at Highway Structures*, 4th ed. Hydraulic Engineering Circular No. 20. FHWA-HIF-12-004. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2012.

Gottemoeller, F. Aesthetics and Engineers: Providing for Aesthetic Quality in Bridge Design. In *Bridge Aesthetics Around the World*, Transportation Research Board, National Research Council, Washington, DC, pp. 80–88, 1991.

Jenkins, B. M. Protecting Public Surface Transportation Against Terrorism and Serious Crime: An Executive Overview. MTI Report 01-14. Mineta Transportation Institute, San Jose, CA, 2001.
Available from http://transweb.sjsu.edu/mtiportal/research/publications/summary/0114.html.

Kulicki, J. M., W. G. Wassef, D. R. Mertz, A. S. Nowak, N. C. Samtani, and H. Nassif. *Bridges for Service Life Beyond 100 Years: Service Limit State Design*. Report S2-R19B-RW-1. Transportation Research Board, National Research Council, Washington, DC, 2015.

National Flood Insurance Act. 1968. U.S. Code. Title 42, Secs. 4001–28.

NRC. *Bridge Aesthetics around the World*. Transportation Research Board, National Research Council, Washington, DC, 1991.

Ritter, M. A. *Timber Bridges, Design, Construction, Inspection, and Maintenance*. EM7700-B. Forest Service, U.S. Department of Agriculture, Washington, DC, 1990.

Science Applications International Corporation (SAIC), Transportation Policy and Analysis Center. *A Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection*. Report prepared for The American Association of State Highway and Transportation Officials' Security Task Force, Washington, DC, 2002.

Winget, D. G., E. B. Williamson, K. A. Marchand, and J. C. Gannon. Recommendations for Blast Design and Retrofit of Typical Highway Bridges. Pooled Fund Project TPF-05(056) Final Report. University of Texas, Austin, TX, 2004.

Wright, R. N., and W. H. Walker. Criteria for the Deflection of Steel Bridges. *AISI Bulletin*, No. 19, Washington, DC, November 1971.

@Seismicisolation