Guidance on QC/QA in Bridge Design In Response to NTSB Recommendation (H-08-17)

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Title: Guidance on Quality Control and Quality Assurance (QC/QA) In Bridge Design

Contents

1. Purpose

To provide guidance for developing and implementing a quality control and quality assurance program for the design of highway bridges.

2. Background

a. On Wednesday, August 1, 2007, the eight-lane, 1,907-foot-long I-35W highway bridge over the Mississippi River in Minneapolis, Minnesota, experienced a catastrophic failure in the main span of the deck truss. As a result, 1,000 feet of the deck truss collapsed, with about 456 feet of the main span falling 108 feet into the 15-foot-deep river. A total of 111 vehicles were on the portion of the bridge that collapsed. Of these, 17 were recovered from the water. As a result of the bridge collapse, 13 people died, and 145 people were injured.

The National Transportation Safety Board (NTSB) launched an investigation and determined the probable cause of the collapse of the I-35W bridge in Minneapolis, Minnesota, was the inadequate load capacity, due to a design error, of the gusset plates at the U10 nodes, which failed under a combination of (1) substantial increases in the weight of the bridge, which resulted from previous bridge modifications, and (2) the traffic and concentrated construction loads on the bridge on the day of the collapse. Contributing to the design error was the failure

of the design firm's quality control procedures to ensure that the appropriate main truss gusset plate calculations were performed for the I-35W Bridge and the inadequate design review by Federal and State transportation officials. Contributing to the accident was the generally accepted practice among Federal and State transportation officials of giving inadequate attention to gusset plates during inspections for conditions of distortion, such as bowing, and of excluding gusset plates in load rating analyses.

As a result of this accident investigation, the NTSB made four recommendations to FHWA and six recommendations to AASHTO. Two of the recommendations related specifically to the need to establish a bridge design QC/QA program as follows:

> **To the Federal Highway Administration:** Develop and implement, in conjunction with the American Association of State Highway and Transportation Officials, abridge design quality assurance/quality control program, to be used by the States and other bridge owners, that includes procedures to detect and correct bridge design errors before the design plans are made final; and, at a minimum, provides a means for verifying that the appropriate design calculations have been performed, that the calculations are accurate, and that the specifications for the load-carrying members are adequate with regard to the expected service loads of the structure.
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> **To the American Association of State Highway and Transportation Officials:** Work with the Federal Highway Administration to develop and implement a bridge design quality assurance/quality control program, to be used by the States and other bridge owners, that includes procedures to detect and correct bridge design errors before the design plans are made final; and, at a minimum, provides a means for verifying that the appropriate design calculations have been performed, that the calculations are accurate, and that the specifications for the load-carrying members are adequate with regard to the expected service loads of the structure.

The development of this guidance is in response to NTSB Recommendation No. 2 to FHWA (H-08-17) and Recommendation No. 1 to AASHTO (H-08-20). FHWA and AASHTO have worked together to develop a framework for implementing a QC/QA program for detecting and correcting design errors before the design plans and specifications are finalized.

AASHTO initiated and completed a study that would complement the NTSB investigation and supply FHWA and AASHTO with needed information on how to proceed with developing a QC/QA program that would work for all the States. The study conducted a literature search on QC/QA programs/procedures, and surveyed the U. S. transportation agencies and some consultant firms to assess the state-of-the-practice in quality control and assurance of bridge designs. The findings of the study are documented in detail in a report titled "**Quality Control and Assurance Practices in State DOT Bridge Design Offices: A Synthesis".** The synthesis paper focuses on procedures state transportation agencies use to ensure quality bridge designs, plans, and specifications prepared both in-house and consultant designs. A copy of the AASHTO synthesis paper may be obtained from the AASHTO website: http://transportation.org/.

The AASHTO study shows that all States have some sort of QC/QA policies for bridge design projects in place, whether they are formally documented, written procedures or traditional practices handed down from engineer to engineer in the department. The vast majority of state bridge design offices do have formal written procedures in place, some more detailed than others. The level and stages of reviews vary from state to state, from project to project and from design to design as necessary to conform to the States' QC/QA processes or procedures. These facts are factored into the development of this guidance, which establishes a general framework for a QC/QA program that will meet the intent of the NTSB recommendations and enable FHWA and AASHTO to assure quality in the constructed projects. The QC/QA program outlined herein is not intended to be a mandated national standard, but offers guidelines for the States and bridge owners to consider in developing and enhancing their QC/QA programs. Example model programs are included as appendices that can be used by bridge owners to establish their own if they do not yet have a formal QC/QA program in place. In any event, each state will be solely the judge of whether their QC/QA program is deemed to satisfy the intent of this guidance.

b. The Quality Control and Quality Assurance Program in Design

The bridge owner plays the most important role in the quality and success of a project from design through construction. This applies to the in-house design, consultant design as well as design–build design. The bridge owner must clearly establish the requirements and expectations of a project through the contract plans and documents. These requirements and expectations must be communicated and understood by the designer and the contractor. The owner, the designer, and contractor are then expected to work together to meet the requirements and expectations

A Quality Control/Quality Assurance (QC/QA) program establishes the formal office or organizational procedures or practices for ensuring the owner's requirements and expectations are fully met. A QC/QA program provides checks and balances within an organization to assure quality in the final contract plans and specifications. QC/QA programs are implemented at different levels or phases of project activities. In the design phase, the bridge designer is responsible for making sure his/her calculations and drawings are accurate and meeting the requirements of the design. The bridge designer performs QC of his/her own work by establishing procedure for self-checking the work for accuracy and correctness. On the other hand, the reviewer, practicing QA, is responsible for independently checking the work of the bridge designer to assure accuracy and correctness in meeting the design requirements and expectations of the bridge owner. In construction, QC is the responsibility of contractor to ensure that the quality of the work is carried out in compliance with the contract provisions. On the other hand, the owner is responsible for practicing QA to assure that the contractor is carrying the work in accordance with the contract.

A good QC/QA program is a deliberate and systematic approach to reduce the risk of introducing errors and omissions into a design. The likelihood of errors in any design process is increased if office policies and standardized procedures are not established and followed. In rare cases, the root cause of a bridge failure can be traced back to a failure to create or follow a good QC/QA program. The rigor and level of resource allocation invested in QC/QA

application to a given bridge should be tempered by the size, complexity, and degree of redundancy in the Structural system involved.

For major projects involving unusual, complex, and innovative features, a peer review may be desirable to raise the level of confidence in the quality of design and construction. A peer review is generally a high-level QA review by a special panel of professionals specifically appointed by the bridge owner to meet the demands for quality and accuracy, recognizing the complexity of the design. Peer review is an effective way to improve quality and to reduce the risk of errors and omissions. The need for such peer reviews is at the discretion of the bridge owner.

c. Current Practices of State Highway Agencies (SHA)

In review of the current State DOTs' QC/QA practices of bridge design, it is found that the practices vary from State by State. Most States have formal written procedures in place, some have more details and some have less. There is no consistent policy in the design QC/QA process. Two States, Washington and Delaware, QC/QA programs were selected and included in the appendices to provide examples of the current State Transportation Agencies' practice as a starting point for other agency to consider.

3. Definitions of Quality Control and Quality Assurance in Bridge Design

a. Quality Control (QC): Procedures of checking the accuracy of the calculations and consistency of the drawings, detecting and correcting design omissions and errors before the design plans are finalized, and verifying the specifications for the load-carrying members are adequate for the service and operation loads.

b. Quality Assurance (QA): Procedures of reviewing the work to ensure the quality control are in place and effective in preventing mistakes, and consistency in the development of bridge design plans and specifications.

c. Designer. An individual directly responsible for the development of design calculations, drawings, specifications and contract documents and review of shop drawings related to a specific bridge design with a level of technical skills and experience commensurate with the complexity of the subject structure or structures being designed.

d. Checker. An individual responsible for performing a full technical review of the structural design calculations, drawings, specifications and contract documents.

e. Reviewer. An individual responsible for performing QA procedures for assuring that QA procedures have been performed.

f. Engineer of Record. An individual responsible for all bridge structural aspects of the design of the structure including the design of all of the bridge's systems and components. This individual is appointed by the bridge owner, and generally is a licensed professional engineer. The Engineer of Record normally seals and signs the final contract plans and specifications.

Note: The specific definitions of those roles should be found in the bridge owner's design manual.

4. Requirements for Implementing QC/QA Procedures

Bridge design is the first line of defense of bridge safety. To ensure bridges are designed correctly with no errors before the design plans are finalized, the following items are recommended to be included and used in developing State Highway Agency (SHA) bridge design QC/QA procedures:

a. QC procedures should include:

1) A supervisor or team leader is responsible for determining the necessary technical knowledge and experience of the designer/checker for that specific design; Designers & checkers are assigned to bridge projects by matching experience to project complexity.
2) All bridge plan sheets shall include the names or initials and dates of the appropriate designer and checker, and may include their signatures. Including the names or initials of the drafter and reviewer is also good practice. Sealing of the bridge plans by the engineer in responsible charge of the work should follow state requirements.
3) All relevant special provisions shall be identified by the appropriate author in responsible charge and checker. Sealing of special provisions should follow state requirements.
4) Design calculations, check calculations, review comments/resolutions and other pertinent documents as discussed above shall be retained in the permanent bridge design file. Including other important documents like QC checklists, cost estimates, and supporting reports in the design file is good practice.
5) A documented program which details the procedures, standards, and policies to be used in the oversight of bridge design.

b. QA procedure should include:

1) Independent check of design calculations. The depth and extent of this review may be defined based on bridge size, complexity, and level of risk.
2) Participation in field engineering reviews during design, construction, and in-service.

c. In-House Design Quality Assurance

All bridges designed by a SHA should be reviewed in conformance with a QC/QA program. The policies and procedures of the SHA's QC/QA program should be documented. The QC/QA procedures for in-house design should meet the minimum procedures and documentation described herein.

d. Consultant Design Quality Assurance

All design consultants associated with the project should have a documented Quality Assurance (QA) program for its design, which shall include Quality Control (QC) measures as discussed herein. This applies to the Engineer of Record and any and all of its

subconsultants. In lieu of subconsultants having their own documented QA program, the Engineer of Record should assume that responsibility for their subconsultants associated with the project. The QA program documentation should be furnished to the SHA upon request. The SHA should request this documentation as often as necessary to be familiar with the firm's program and ensure it meets the intent of the SHA's QC/QA Program.

e. Qualification of the Designer, Checker, and Reviewer

The designers, checkers, and reviewers are the key personnel to provide well-designed and constructible plans to build good quality bridges. The designers, checkers, and reviewers must be experienced in structural designs and familiar with the current AASHTO Bridge Design and Construction Specifications and the State's Bridge Design Code.

1) Designer and Checker: The following are the desirable requirements for a bridge designer and checker:

- Possess a Professional License as a Civil Engineer or Structural Engineer of the State; or
- If the designer and checker does not have PE license, he or she should be under the direct supervision of a PE/SE licensed engineer who is in responsible charge for the design;
- The designer and checker's experience should be commensurate with the complexity of the bridge being designed.

2) Reviewer: The reviewer should be familiar with the SHA's construction practices, procedures, and policies.

f. Minimum Items/Areas Required to Be Checked

As indicated in the previous section, design and design drawings are required to be checked by a checker with a thorough and comprehensive review/check. In particular, the following minimum items/areas are required to be checked:

1) Design Computations and Checks. All primary structural components, including superstructure, bearing, joints, and substructure components. The assumptions of the bridge design including general conditions and loadings should be documented. .

2) Bridge Contract Drawings Checks. All primary structural components (as described above) of bridge design drawings should be checked in detail. In cases where the designer is not the drawing checker, the designer must at least review the drawings to ensure that they are in conformance with the design. After any required changes are made, names or initials shall be placed on the drawings indicating the individual who prepared the drawing, the drawing checker (if different than the designer), the designer, the design checker, and reviewer, if applicable.

3) Calculations. At the completion of the contract drawings, provide a set of design calculations for all structural elements, sealed/stamped and signed by the Engineer of Record for the project, who is licensed in the state in which the project is located in accordance with the requirements of the State.

The checker should perform sufficient independent design checks to assure the adequacy of the design. The reviewer's primary role is to provide Quality Assurance on the design. Further, any questionable designs or disputes with the checker must be resolved by the designer to the reviewer's satisfaction. The checker's experience should be commensurate with the complexity of the bridge design.

In the case of Consultant designs, the design check should be performed by a checker meeting the qualifications detailed above using a process consistent with a QC/QA Plan approved by the SHA.

5. FHWA's Role

a. Initial Review and Approval of Program

The general role of FHWA Division Office is to review each SHA QC/QA Program and to ensure the QC/QA program is thorough, effective, documented, and followed. Further, it is the role of the Office of Bridge Technology to assure uniformity within Division Offices regarding implementation of this guidance.

b. Periodic Program Reviews

FHWA Division Offices may perform periodic reviews of SHA's programs. The SHA will provide project documents to the FHWA Division Office for review in accordance with the Federal-aid Stewardship Agreement upon request. The need of periodic reviews depends on the complexity of the bridge projects.

References

1. *AASHTO Guide to Quality in Preconstruction Engineering* (2003).

2. *AASHTO Consultant Contracting Guide* (2008)

Appendix A: Washington State QC/QA Program

Washington State Department of Transportation (WSDOT)

The following excerpt outlines the review process for consultant bridge plans in Washington State:

The following procedure is used in reviewing consultant prepared bridge plans:

A senior WSDOT bridge engineer is assigned as a point of contact and reviewer.
WSDOT Design Reviewer's responsibilities include:

- Early in the project, review consultant's design criteria and standard details for consistency with WSDOT practices and other bridge designs in project.
- Review the job file as prepared by the Preliminary Plan Engineer.
- Identify resources needed to complete work.
- Initiate a project start-up meeting with the Consultant to discuss design criteria, submittal schedule, and expectations and also to familiarize himself/herself with the Consultant's designers.
- Reach agreement early in the design process regarding structural concepts and design methods to be used.
- Identify who is responsible for what tasks and when all intermediate constructability, Bridge Plans, and Bridge PS&E review submittals are to be made.
- Monitor progress.
- Facilitate communication, including face-to-face meetings.
- Verify that the Consultant's design has been checked by the Consultant's checker at the 100 percent submittal. The checker's calculations should be included in the designer's calculation set.
- Review consultant's design calculations and plans for completeness and conformance to Bridge Office design practice. This may also be done through independent calculations. The plans shall be checked for constructability, consistency, clarity, and compliance. Also, selectively check dimensions and elevations.
- Resolve differences.

Consultant PS&E—Projects on County and City Right of Way:

Counties and cities frequently hire Consultants to design bridges. WSDOT Highways and Local Programs Office determine which projects are to be reviewed by the Bridge and Structures Office. A WSDOT Design Reviewer or Coordinator will be assigned to the project and will review the project as outlined above. Comments are treated as advisory, although major structural issues must be addressed and corrected. An engineer from the county, the city, or the consultant may contact the reviewer to discuss the comments.

Washington State also has a section of their bridge manual dedicated to in-house designs.

The relevant excerpt of the manual is included in Appendix C.15. The manual outlines the design team make-up, the designer responsibilities, and checker responsibilities. The checker is described in the following excerpt:

The checker is responsible to the Unit Supervisor for quality assurance of the structural design, which includes checking the design, plans, and specifications to assure accuracy and constructability. The Unit Supervisor works with the checker to establish the level of checking required. The checking procedure for assuring the quality of the design will vary from project to project.

The in-house review manual excerpt provided also outlines the Design Unit Supervisor Responsibilities, and the Bridge Design Engineer's Responsibilities in Washington State's QA/QC program.

In Washington State, it is assumed that every consultant has its own in-house QA/QC process in place that is used on every project. WSDOT reserves the right to ask for their written QA/QC policy.

WSDOT does not review consultant plans concurrently with the FHWA. The expectation is that FHWA will be performing a similar type of review independently. PS&E prepared for signature or special bridge projects will follow a similar review and QC/QA procedure as other WSDOT bridges. An additional independent design and independent check is often required. Constructability of signature or special bridge projects are discussed with the AGC and often with a special expert panel during the early stages of design. WSDOT seldom uses a third party to review consultants except for CRIPs (Cost Reduction Incentive Proposals), where the contractor proposes an alternative design that is more economical. Generally, the short timeframe on CRIPs necessitates a third party review. Bridge engineers with a PE license perform the in-house reviews for ordinary bridges and those with an SE license perform them for signature or special bridges.

For record retention in Washington State, the Bridge Plans Engineer will collect the Design File (Job File), Specifications & Estimate (S&E) File, and Design Calculations. Files are placed in a temporary storage space marked as Design Unit Document Temporary Storage. These cabinets are locked and only the Bridge Plans Engineer, the Scheduling Engineer, and the Office Administrator have keys to them. The Design Files, S&E Files, and Design Calculations are stored under the contract number. Upon contract completion, the designer places a job file cover label on the file folder and updates the file with any contract plan changes that have occurred during construction. Two years after physical completion of the contract, the Bridge Plans Engineer will box and send the documents to the Office of Secretary of State for archive storage, except as otherwise approved by the State Bridge Design Engineer.

A Bridge and Structures staff member may access the Design Files, S&E Files, or Design Calculations by requesting the files from the Bridge Plans Engineer or the Scheduling Engineer, who will check out the files and note the date and person's name. If a person other than a Bridge and Structures Office staff member requests these documents, the approval of the Bridge Design Engineer or Bridge Projects Engineer will be required for release of the documents. The Bridge and Structures Office is the owner of only two types of official records:

- Design Calculations (until they are turned over to the State Archives Office) and
- Bridge Inspection Documents.

No records are disclosed without a written request.

The Bridge and Structures Office is centrally organized in Tumwater, Washington. There are no districts or regional bridge offices within the State. Consultant prepared Bridge plans are reviewed at the central bridge office. Currently, most bridge design work is being performed in-house, with only about ten percent of all bridge projects being performed by consultants.

Appendix B: Delaware State QC/QA Program

Delaware State Department of Transportation

Consultant design projects go through the same QA/QC procedures as in-house design projects. Delaware has developed a QA/QC Plan which includes forms and checklists that are to be filled out at different stages of the project.

Delaware's QA/QC policy is that the "completion of a successful project requires good planning, coordination, and thorough reviews of all documents." The QA/QC Plan focuses on the plan development portion of a project and outlines QA/QC procedures for both in-house designs and consultant designs. The Plan also includes a Plan Submission checklist, as well as several other checklists including right-of-way issues and storm water issues. Standardized forms are used to record reviewer comments.

Consultants in Delaware are not required to prequalify to obtain bridge design work; however, consultants are requested to provide their QA/QC procedures to the Department as part of their proposals and contracts. Delaware performs design reviews with the understanding that FHWA will perform their own independent reviews. Third party reviews are rarely used and usually only for significant or complex structures. Reviewers within Delaware's bridge department are management level engineers with at least five years' experience. As-built plans and other project documents are archived and kept indefinitely. The archived information is considered public information and is available by request.

Delaware does approximately 70 percent of their bridge design projects in-house, with 30 percent of bridge designs being performed by consultants. The bridge office is centrally organized at the main administrative building. All bridge design work goes through this office, including review of consultant designed projects. Delaware also has a separate Quality Section, likewise centrally located, that has a position specifically dedicated to reviewing structure plans (In-house and consultant projects)

Appendix C: Current Guidance on QC/QA in Preconstruction Engineering and Contracting

a. AASHTO References

In review of current available references from AASHTO, the *Guide to Quality in Preconstruction Engineering* (2003) and the *AASHTO Consultant Contracting Guide* (2008) are more relevant to the design issues, and are briefly explained as the following.

1) AASHTO Guide to Quality in Preconstruction Engineering

The AASHTO *Guide to Quality in Preconstruction Engineering* was released in February of 2003. This Guide focuses specifically on each of the preconstruction processes including right of-way, utilities, geometric design, drainage design, and structures design. The Guide provides information about defining, developing, and assessing quality; and continuing improvement. The most relevant issues discussed in the publication include a section (p. 42) on "Determining Process and Product Quality." This section includes information on evaluating process quality on issues such as the amount of rework that must be done and the total cost to produce a deliverable. It also gives information on evaluation of the final product quality (p. 45).

2) AASHTO Consultant Contracting Guide

In March 2008, AASHTO released its *Guide for Consultant Contracting*. This Guide covers a broad range of topics including agency preparations for engaging consultants, consultant selection, negotiating and contracting guidelines and procedures, and managing consultants, including a section on dealing with errors and omissions. (Relevant pages are noted below.)

The Guide advises that consultant design contracts should have clauses protecting the owner agency from design errors and omissions by providing that the consultant's work should meet "sound, prudent, appropriate, and required professional standards and practices," and that the consultant will promptly redo work that does not meet agency criteria, at no additional cost to the agency (p. 38). The Guide also recommends that the consultant should generally be given an opportunity to help resolve problems that arise in project construction, whether due to possible errors or omissions or to other reasons such as unforeseen conditions. The Guide describes an example process for dealing with errors and omissions. The major actions included in this process include, among other things, the following:

- Alert both the next higher level of agency management about the potential errors and omissions issue, and the subordinates involved in project management regarding the need for more detailed documentation than normally required on the work already performed.
- Notify the consultant design professional of the errors and omissions issue and provide the firm the opportunity to assist in resolving the problem.

b. Guidance from Other Resources

1) Quality in the Constructed Project, Second Edition (ASCE Manuals and Reports on Engineering Practice No. 73)

This Manual provides information and recommendations on principles and procedures that are effective in enhancing the quality of constructed projects. The Manual discusses the roles, responsibilities, requirements, and limits of authority of participants in the design and construction process, highlighting concepts and practices that are valuable to each in achieving project goals and objectives.

2) Quality Assurance of Structural Engineering Design

This document was published as a two-part article in *Structure Magazine* in 2008. It outlines the need for quality assurance in design, as well as providing real life examples and checklists for a quality program for structural design. The articles suggest that all design firms or organizations should (Cai, 2008):

1) Develop a comprehensive codes index, including all codes or specifications that may be applicable to the work;
2) Develop check-lists regarding loads and load combinations, key factors in modeling of members, connections, etc.;
3) Set up appropriate job performance thresholds to determine when a team member requires additional training;
4) Implement pragmatic review procedure for internal peer review, and
5) Develop comprehensive lists of contacts of relevant design and construction professionals and keep all records of all communications.