Changes in Codes, Standards and Practices Following Structural Failures

Part 1: Bridges

By Robert T. Ratay, Ph.D., P.E.

To the credit of our profession, failures have been and continue to be used to improve design and construction practices. We do not just pay up, rebuild and walk away – we delve, we learn, and we improve.

Following a failure, engineers often carry forensic investigations to great details, so as to have reasonable engineering certainty not only in the cause(s) of the failures but also in the identification of the responsible parties – needed for the frequently inevitable dispute resolution. A valuable peripheral benefit of the laborious search is a clearer understanding of structural behavior and a better appreciation of pitfalls in current practices. These can provide information and material to affect changes in design and/or construction practices, codes, standards, oversight and regulatory procedures.

The "lessons learned" from failures are interesting but worthless if not heeded and not acted upon to prevent their recurrence.

Failures of bridges result in reviews and changes in codes, standards and practices much more frequently than those of buildings. One reason for this seems to be the more centralized approval and oversight processes of bridge construction and maintenance by state and federal government agencies, in comparison to the fragmented involvement of local building departments in the approval and oversight of building construction and maintenance. A bridge collapse, or even just a temporary closure, affects a large number of people and is quickly picked up by the news media, while the consequences of the collapse of a building seldom reach beyond its occupants and the local news.

Illustrative Cases

The following are just a few examples of changes in design and/or construction codes, standards, regulations and practices that have been initiated in response to structural failures of bridges.

Figure 1: Silver Bridge at Point Pleasant, West Virginia.

Figure 2: I-95 Bridge over the Mianus River in Connecticut.

Figure 3: New York State Thruway Bridge over the Schoharie River.

- Introduction of the National Bridge Inspection Standards (NBIS) on May 1, 1979, applicable to all structures defined as bridges located on all public roads. This standard directed that each highway department shall include a bridge inspection organization capable of performing inspections, preparing reports, and determining ratings, in accordance with the provisions of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Maintenance Inspection of Bridges* at regular intervals not to exceed two years. This mandate followed the December 15, 1967 collapse of the U. S. 35 Highway Bridge connecting Point Pleasant, West Virginia, with Kanauga, Ohio (a.k.a. Silver Bridge), caused by the cleavage fracture in the lower limb of an eyebar in the suspension chain. Forty-six persons died, nine were injured, and thirty-one vehicles fell with the bridge. (*Figure 1*)
- The 1986 publication by the Federal Highway Administration (FHWA) of a manual of inspection of fracture-critical bridge members, and widespread retrofitting of steel bridge girders with a fail-safe assembly below their pin-and-hanger girder connections. This followed the June 28, 1983 cleavage fracture failure of a pin-and-hanger connection and catastrophic collapse of a highway bridge carrying Interstate 95 over the Mianus River in Connecticut. (*Figure 2*)
- The Surface Transportation and Uniform Relocation Assistance Act of 1987 expanded bridge inspection programs to include special procedures for the inspection of underwater components, such as piers, of bridges. This followed the April 3, 1987 collapse of a bridge of the New York State Thruway over the Schoharie River as a result of river-bottom scour. (*Figure 3*)
- Research and publication of new design specifications and construction practices for temporary works by the FHWA and changes in the provisions for temporary works in the AASHTO Standard Specifications for Highway Bridges. This followed the 1989 collapse of shoring in the construction of a highway bridge built to carry Maryland Route 198 over the Baltimore-Washington Expressway, injuring nine workers and five motorists, and killing one. (This case is discussed furthered below, because of its role in fueling changes in codes, standards and practices.)
- Review of New York State and AASHTO design guides for composite tub girders, review of New York State Department of Transportation (NYSDOT) bridge construction approval and oversight procedures, and changes in the New York State and AASHTO bridge design specifications. This followed the October 10, 2002 collapse during construction of the Marcy Pedestrian Bridge in Utica, New York. (*Figure 4*)

Figure 4: Marcy Pedestrian Bridge in Utica, NY.

Figure 5: I-70 Overpass at Golden, CO.

Figure 6: I-35W Bridge over the Mississippi River.

- Revisions by the Colorado Department of Transportation (CDOT) to its Standard Specifications for Road and Bridge Construction requiring that an erection plan be developed at least 4 weeks prior to erection of a structural steel member, that a conference be held at least 2 weeks before beginning an erection, and that the contractor's Professional Engineer provide written approval of each phase of the installation; and, subsequent recommendations by the National Transportation Safety Board (NTSB) to the FHWA, to the Office of Safety and Health Administration (OSHA), and to AASHTO "to make consistent and compatible [their] organizations' regulatory requirements for and guidance to construction contractors concerning the design and certification of falsework, formwork, and bracing for the erection of highway structures". This followed the May 15, 2004 lateral stability failure of a fabricated steel girder installed a few hours earlier for the overpass of Route C-470 over Interstate Highway I-70 in Golden, Colorado, killing a family of three in a vehicle. (*Figure 5*)
- As a result of its extensive investigation, the NTSB made recommendations to the FHWA and AASHTO regarding, among other things, quality control procedures for the design of bridges by bridge design firms, and regarding safety inspection procedures. This followed the August 1, 2007 catastrophic collapse, of an eight-lane 1,900-foot long I-35W highway bridge over the Mississippi River in Minneapolis, Minnesota, caused by inadequate load capacity, due to a design error, of gusset plates at a node of the main span of the deck truss that was subjected to loads during roadway work. Four-hundred fifty-six feet of the main span fell 108 feet into the 15-foot deep river carrying one hundred eleven vehicles. Thirteen people died and one-hundred forty five people were injured. The NTSB also faulted inadequate design review by Federal and State transportation officials, and the generally accepted practice at the time among Federal and State transportation officials of paying inadequate attention to gusset plate distortions during inspections. (*Figure 6*)

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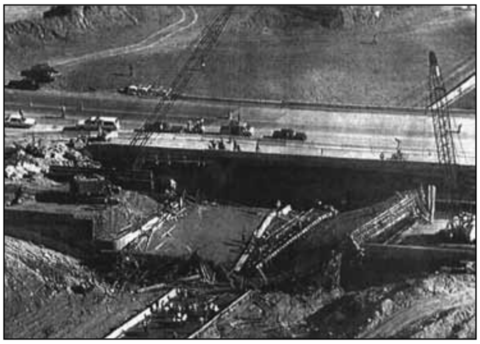

Figure 7: Baltimore-Washington Parkway. Aerial view of collapse. (From The New York Times, September 1, 1989)

Figure 8: Baltimore-Washington Parkway. Side view of collapse. (From ENR, September 7, 1989)

MD Route 198 Bridge over the Baltimore – Washington Expressway

A highway bridge, built to carry Maryland Route 198 over the Baltimore-Washington Expressway, collapsed during construction on August 31, 1989, injuring nine workers and five motorists and killing one. The superstructure was designed as five parallel post-tensioned box girders spanning 100 feet between simple-support abutments. The bottom slab of the box girders was cast in early July and the webs were cast between July 21 and August 4. On the day of the collapse, workers were pouring the 8-inch deck slab. The collapse occurred five hours into the pour, when 120 of the 160 cubic yards total was in place. The shoring collapsed "in a flash" without warning, landing all the formwork and 400 tons of steel and concrete on the roadway below. (*Figures 7, 8* and *9*)

The concrete was poured into timber formwork supported on three simple spans of parallel steel beams that, in turn, were supported on steel shoring towers placed so as to create a 35-foot center span over the roadway and two 28-foot outboard spans. The formwork shoring (falsework) system was erected with a number of changes from the original drawings, including the steel beam locations, the deck overhang supports, the concrete foundation slabs below the shoring towers, and the use of hardwood blocking under the beams. The formwork shoring had been used earlier to cast the westbound structure.

Figure 9: Baltimore-Washington Parkway. End view of collapsed falsework. (From ENR, September 7, 1989)

A forensic investigation by the FHWA and its consultant, T. Y. Lin International, was performed, and their findings were presented in their report (*Report of the Investigation into the Collapse of the Route 198 Baltimore-Washington Parkway Bridge*) on December, 1989. They evaluated nine possible causes of the collapse, and systematically eliminated all but one. They concluded that the failure originated in one of the shoring towers and the most likely cause was the use of 5-ton screw jacks rather than the 12.5-ton screw jacks, shown on the approved drawings, on the tops of the shoring towers supporting the bridge. They also noted that "the top screw jacks were rusty", that much of the cross-bracing had "large amounts of rust and heavy pitting" and that, in one section, the cross-brace pieces were connected by nails instead of the required bolts.

Based on the report of the investigators, an FHWA review board concluded that the failure occurred probably because the shoring tower assemblies were not constructed in accordance with the approved plans. The review board found no evidence that the FHWA (the owner) had not lived up to its contractual responsibilities, and ruled that it was the responsibility of the contractor to assemble the falsework system in accordance with the approved design. (It is to be noted that the FHWA did then, and does now, require a contractor's engineer to certify that falsework has been assembled according to approved drawings before it is loaded.) As a result, a fine of over $900,000 was levied by the state against the contractor. Additionally, of course, the injured individuals filed lawsuits of their own.

The incident raised increased awareness of deficiencies in the design-review-approval-execution-inspection process of public roads and bridges. Several other collapses of bridge temporary works occurred following the 1989 Baltimore-Washington incident, which added urgency to the need for better guidelines.

Productive Actions after the Failure

The falsework collapse of the Maryland Route 198 bridge over the Baltimore/Washington Parkway on August 31, 1989, prompted Congress to direct the Secretary of the U.S. Department of Transportation to develop specifications and guidelines for use in constructing bridge temporary works.

This followed the FHWA review board's recommendation that, in order to prevent similar occurrences in the future, falsework specifications should be revised to define more clearly the responsibilities of material suppliers, contractors, and engineers. This recommendation was signed into law by the US Department of Transportation and Related Agencies Appropriations Bill of Fiscal Year 1991, which states in part that "...the Committee on Appropriations directs the Federal Highway Administration to undertake the research project recommended in the 1991 report entitled *Investigation of Construction Failure Maryland Route No. 198 Bridge Over the Baltimore-Washington Parkway*." The bill goes on to specify that the research project should produce approved guidelines, improved specifications, and a falsework construction handbook.

In March 1990, the FHWA established a multidisciplinary Scaffolding, Shoring, and Forming Task Group to develop and guide the mandated falsework research program. (The author was a member of that Task Group.) The ensuing activities were described in a September 1991 article (*Bridge Temporary Works Research Program*) by the FHWA.

The FHWA also retained the engineering firm of Wiss Janney Elstner Associates, Inc. (WJE) to assist the Task Group and, in essence, to prepare the Design Specifications and the Construction Handbook. The end products of the Task Group and WJE's work under the FHWA's program were a series of five documents: the *Synthesis of Falsework, Formwork, and Scaffolding for Highway Bridge Structures*, the *Guide Standard Specification* *for Bridge Temporary Works,* the *Guide Design Specifications for Bridge Temporary Works,* the *Certification Program for Bridge Temporary Works*, and the *Construction Handbook for Bridge Temporary Works*.

Changes by the FHWA and AASHTO as a Consequence of the Failure

On October 29, 1993, the FHWA issued a Technical Advisory for *Bridge Temporary Works* to the design-construction industry encouraging the use of the four FHWA documents, with the stated purpose "To provide State highway and transportation agencies with guide standards and design specifications, a construction handbook and a certification program to assist owner agency and industry performance in achieving the safe construction of bridge temporary works. These documents may by used in conjunction with Section 3, "Temporary Works, of Division II of the latest edition of the AASHTO Standard Specifications for Highway Bridges."

In Paragraph 1 of its Background section, the Technical Advisory notes that "Heretofore, there were [no] national standard code or specification available on bridge temporary works. The only available national standard which addressed this type of construction (ANSI A10.9-1983) was applicable primarily for building construction."

Subsequent editions of the AASHTO *LRFD Bridge Design Specifications* and the *LRFD Bridge Construction Specifications* adopted provisions for temporary works based on the FHWA research program that grew out of the 1989 collapse and investigation of the Maryland Route 198 Bridge over the Baltimore-Washington Expressway. Highway bridge specifications of several States followed suit. Review and updating of the FHWA documents are presently underway by the National Cooperative Highway Research Program (NCHRP) as part of its Bridge Construction Practices for Temporary Works project.

For a detailed discussion of the Maryland Route 198 Bridge over the Baltimore-Washington Expressway, including its design and construction, the collapse scenario, and the subsequent investigations, the reader is referred to a recent fourteen-page article in *Public Roads*. (See the list of references included in the online version of this article; **www.STRUCTUREmag.org**.)

Conclusion

Structural failures are the result of human activities which, in the design-construction industry, are prescribed in part by codes, standards, regulations and industry practices. Therefore, when a structural failure occurs, investigators review the adherence of the failed structure to the governing codes, standards, regulations and industry practices. If it is found that those governing documents and practices contributed to or, indeed, created the cause of the failure, then it makes "good sense" to review those codes, standards, regulations and industry practices and, if warranted, to start a process to revise them. The "good sense" is followed sometimes but not always. The effort is undertaken usually by city, state or federal agencies with the assistance and talents of professional societies, trade organizations, and volunteers from private engineering firms and construction companies.▪

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