Using Failure Case Studies in Civil Engineering Courses

Norbert J. Delatte

**Associate Professor, Department of Civil and Environmental Engineering,
The University of Alabama at Birmingham**

Abstract

The study of engineering failures can offer students valuable insights into associated technical, ethical, and professional issues. Lessons learned from failures have substantially affected civil engineering practice. For the student, study of these cases can help place design and analysis procedures into historical context and reinforce the necessity of lifelong learning. Three approaches for bringing forensics and failure case studies into the civil engineering curriculum are available. These are stand-alone forensic engineering or failure case study courses, capstone design projects, and integration of case studies into the curriculum. Since it is not practical to add another required course to the crowded civil engineering curriculum, the latter approach will be more practical for most undergraduate programs. Some cases have been developed and used in courses at the United States Military Academy (USMA) and the University of Alabama at Birmingham (UAB), as well as at other institutions. Currently an NSF-funded research project is underway at UAB to develop and disseminate case study materials. Under this project, a web site has been developed to provide case study materials for faculty. The web site links courses, course topics, and case studies illustrating those course topics through hypertext. Summarized case studies are provided, with references, along with links to selected fully developed case studies. An online bibliography provides sources of case study materials including books, technical papers and magazine articles, videos, web sites, prepared PowerPoint presentations, and television programs.

Introduction

Engineers design. Engineering design is, at its core, an attempt to use science, mathematics, and other principles to prevent failures. Most of the time the attempt is successful – but the times it is not successful can provide useful lessons for students and practitioners. The lessons learned from failures have often led directly to changes to engineering codes and procedures. Students are more likely to appreciate advances in design and analytical procedures if they are placed in a historical context.

There are three ways to introduce failure analysis and failure case studies into civil engineering education. A small number of colleges and universities, probably only a few percent, offer courses in forensic engineering or failure case studies. Often, these are at institutions such as the University of Texas, Mississippi State University, or the University of Colorado at Denver that have practicing forensic engineers on the faculty[1]. Clearly, this approach depends on the availability of qualified and interested faculty.

Another method is to use case studies in capstone (Senior) design projects[1]. This is also dependent on interested and qualified faculty, as well as on the availability of appropriate projects (which must be sufficiently free of liability concerns).

These two approaches offer great depth in the topic, but due to their inherent limitations their application is likely to remain limited. As a result, even at colleges and universities where courses are offered in this area, few undergraduates are likely to be able to take them. While some might argue for a required stand-alone course in failure analysis for all undergraduate civil engineering students, the argument is likely to fall on deaf ears as programs shrink their credit hour requirements.

A more promising approach is to integrate failure case studies into courses throughout the curriculum. Many professors have done this on an informal basis for years. The author used this approach at the United States Military Academy (USMA) while teaching two courses in engineering mechanics, Statics and Dynamics and Mechanics of Materials[2, 3]. He continued the approach in engineering mechanics and civil engineering courses at the University of Alabama at Birmingham (UAB)[1, 4]. The cases discussed included the Tacoma Narrows Bridge (figure 1) and the Kansas City Hyatt Regency (figure 2).

Developing the Cases

This method, of course, depends on the availability of cases. Three of the best books of cases are by Kaminetsky[5], Levy and Salvadori[6], and Feld and Carper[7]. An extensive bibliography is provided in reference 1.

Although a lot of failure information is available, much of it has not been written in a format suitable for engineering educators. Fortunately, the author has been able to use undergraduate research assistants during the summer supported by the National Science Foundation through the UAB Research Experiences for Undergraduates (REU) Site in Structural Engineering since 1999. Each year, the students publish their cases on the UAB REU web site[8]. So far, two of the cases have been published in the ASCE Journal of Performance of Constructed Facilities[10, 11] and a third has been accepted for publication by the journal.

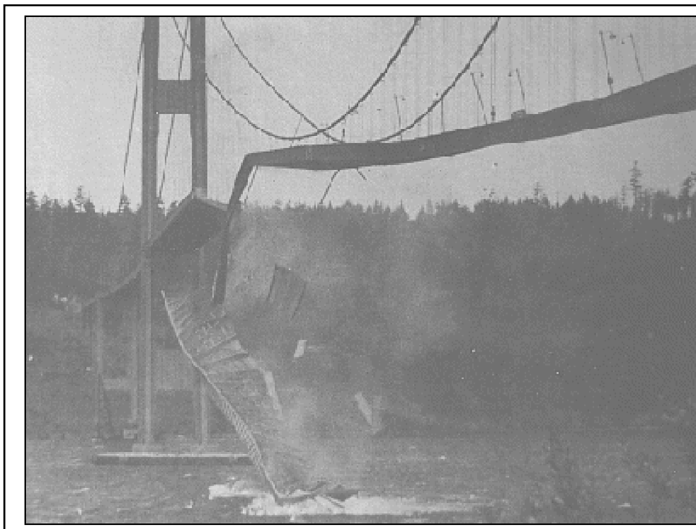

Figure 1: Tacoma Narrows Bridge[9]

Cases that have been developed at the UAB REU site include:

- Tacoma Narrows Bridge (figure 1)
- Hyatt Regency Walkway, Kansas City (figure 2)
- L' Ambiance Plaza (figure 3)
- Hartford Civic Center
- Lacey V. Murrow Floating Bridge
- Ronan Point (figure 4)

Figure 2: Hyatt Regency Walkway, Kansas[12]

Other cases were developed in fall 2002 as part of the new case studies project. These include:

- Quebec Bridge
- Teton Dam (figure 5)
- Schoharie Creek Bridge (figure 6)

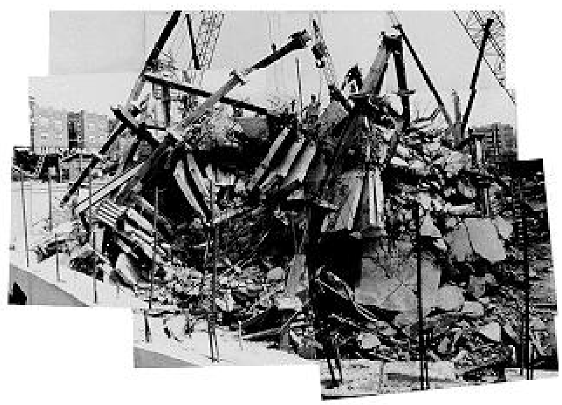

Figure 3: L'Ambiance Plaza[13]

Part of the challenge has been to develop a consistent case study format in order to make the materials of value to engineering educators. Typical elements of a fully developed case study include:

- Introduction
- Description of the design and construction of the project
- Narrative describing the failure. For a complicated case, this may include a chronological table of events.
- Discussion of any investigations undertaken and the results. This may include a review of who the investigators were, who hired them (and why), and any limits on the scope of the investigation.
- Technical lessons learned. Special attention is paid to any changes in engineering codes or procedures.
- Procedural and ethical lessons learned, particularly legal repercussions
- Educational aspects of the case
- A detailed reference list including investigation reports, published papers, and newspaper and journal accounts

Figure 4: Ronan Point[14]

Figure 5: Teton Dam[15]

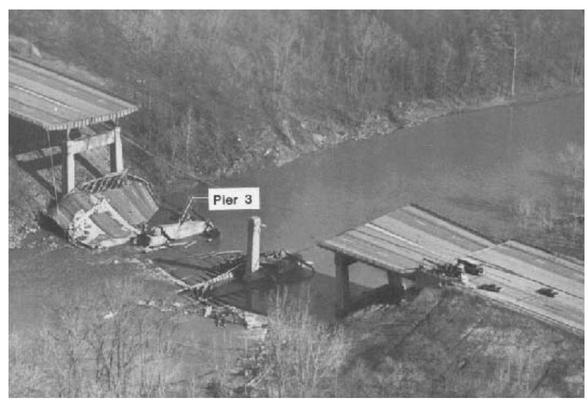

Figure 6: Schoharie Creek Bridge[16]

Obviously the elements are varied to meet the needs of the specific cases. One ongoing area of work on the project is determining what elements to include in case studies.

Throughout the remainder of the project, which continues until February 2004, additional cases will be identified and developed.

Linking Courses, Topics, and Cases

In order to make cases more useful, it is necessary to link them to specific courses and course topics. It has been demonstrated how specific cases may be linked to engineering mechanics course topics[2, 3]. Later, a more comprehensive plan linking courses, topics, and cases within the USMA civil engineering curriculum was developed, although this has not been published.

Based on this earlier work, a more comprehensive master plan was published in 2000[4]. The plan was developed further, adding more topics and cases, and the revised version was published in 2002[1].

Table 1: Courses, Topics, and Case Studies[1]

Course	**Topic**	**Case Study**
Statics	Free-Body Diagram	Hyatt Regency Walkway Collapse
		T. W. Love Dam Cantilever Form Failure
Dynamics	Mass Moment of Inertia and Stiffness	Tacoma Narrows Bridge Collapse
Mechanics of Materials (Solids)	Kinetics: Dynamic Forces	Bomber Crash into Empire State Building
	Stress and Strain	Shrinkage of Concrete Masonry Units and Swelling of Brick Masonry
	Structural Deformation as Warning of Impending Collapse	Hartford Civic Center
	Elastic Buckling	Stepped Roof Structure, Elwood, Long Island
Structural Analysis	Loads on Structures	Bomber Crash into Empire State Building
	Load Paths	L'Ambiance Plaza Collapse
	Structural Deformation	Quebec Bridge
		Hartford Civic Center
	Checking Computer Results	Hartford Civic Center
Reinforced Concrete Design	Structural Integrity of Formwork	New York Coliseum
	Strength Development of Concrete	Willow Island cooling tower
		2000 Commonwealth Avenue, Boston
		Bailey's Crossroads, Virginia
	Punching Shear in Concrete Slabs	Harbor Cay Condominium, Florida
	Reinforcement Development Length	Pittsburgh Midfield Terminal Precast Beam Collapse
Steel Design	Connections	Hyatt Regency Walkway Collapse
		Steel Frame Connections in Northridge Earthquake
	Buckling	Stepped Roof Structure, Elwood, Long Island
		Quebec Bridge
Introduction to Engineering or Capstone	Professional Ethics	Citicorp Tower

It should be emphasized that Table 1 represents a work in progress. The cases currently under development have not yet been incorporated. A particular focus as research moves forward is cases that illuminate topics in courses other than engineering mechanics and structural engineering.

For example, the Teton Dam case (figure 5) deals with engineering geology and geotechnical engineering topics including the suitability of foundation and borrow materials, the importance of compaction, and movement of water within rock and soil masses. The Schoharie Creek Bridge collapse (figure 6), illustrates points in hydraulic engineering such as stream velocity and scour as well as structural engineering topics including the advantage of continuity and redundancy of structures. As these and other cases are developed further, they will be incorporated into the case studies project web site[17]. This web site is an expansion of table 1 in hypertext format.

The Case for Full Integration

This work raises the question of whether failure analysis is merely tangential to, or is in fact fundamental to, civil engineering education. Put another way, are failure case studies simply interesting, or should they be an essential component of a civil engineering curriculum? The American Society of Civil Engineers Technical Council on Forensic Engineering (ASCE TCFE) Education Committee is beginning to examine this issue.

ASCE TCFE Education Committee surveys of civil engineering departments reported in 1989[18, 19, 20] and 1998[21] found that many respondents indicated a need for detailed, well-documented case studies. However, some of those replying felt strongly that incorporation of failure case studies should not become part of accreditation evaluations. However, unless something is specifically mandated by the Accreditation Board for Engineering and Technology (ABET), it is likely to be a low priority for inclusion in a curriculum.

However, there is certainly an argument to be made that failure analysis should be mandated by ABET – it may also be argued that, in a sense, it already is. Under Criterion 3, Program Outcomes and Assessment, engineering programs must demonstrate that their graduates understand the impact of engineering solutions in a global and societal context, engage in life-long learning, and demonstrate knowledge of contemporary issues (criteria h, i, and j, respectively)[22]. These outcomes can be difficult to document – unless case studies are included in the curriculum. Many case studies show the direct societal impact of failures, and demonstrate the need for lifelong learning by highlighting the evolutionary nature of engineering design procedures.

Criteria for civil engineering programs are more specific. Students must demonstrate "understanding of professional practice issues such as: procurement of work… how the design professionals and the construction professionals interact to construct a project; the importance of professional licensure and continuing education; and/or other professional practice issues." (page 7[22]). These professional practice issues, and other outcomes such as the ability to critically analyze and interpret data, can easily be addressed through the study of failure cases. Poor interactions between design and construction professionals often have a direct bearing on failures.

One issue, raised in the introduction, is the qualification of faculty to teach failure case studies. However, it does not taken an experienced forensic engineer to present the lessons from the case if well-developed case materials are available. The availability of case study materials through the present case study project, as well as other sources, will make it easier for faculty to present failure analysis information in the classroom.

Assessment

So far, the impact of using case study materials in courses has not been formally assessed. While surveys have found widespread agreement that faculty consider failure case studies important and useful[18 – 21], there is no empirical data available to show the benefits. Later phases of this case studies project will attempt to develop assessment instruments to measure the impact of this work.

Summary and Conclusions

Engineering failures have had a substantial impact on practice. The study of failure cases can improve civil engineering education and make it easier to include discussion of professional practice issues (as mandated by ABET). A considerable amount of failure case study information is already available to engineering educators. Additional cases are being developed to fill out a comprehensive framework linking courses, topics, and case studies.

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Biographic Information

NORBERT J. DELATTE, Jr., P.E., is an Associate Professor in the Department of Civil and Environmental Engineering at the University of Alabama at Birmingham. He received his degrees from The Citadel in 1984, The Massachusetts Institute of Technology in 1986, and The University of Texas at Austin in 1996. He served for eleven years in the United States Army Corps of Engineers. He is a member of ASEE, ASCE, and ACI.