AC 2007-783: FINDINGS FROM WORKSHOPS ON FAILURE CASE STUDIES IN THE CIVIL ENGINEERING AND ENGINEERING MECHANICS CURRICULUM

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Findings from Workshops on Failure Case Studies in the Civil Engineering and Engineering Mechanics Curriculum

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 life-long learning. Three approaches for bringing forensics and failure case studies into the civil engineering curriculum are possible. These are stand-alone forensic engineering or failure case study courses, capstone design projects, and integration of case studies into the curriculum. The ASCE TCFE Education Committee held four annual one-day workshops in Birmingham, Alabama and in Cleveland, Ohio for a total of approximately 75 engineering educators. The participants estimated that over 135 courses and nearly 4,000 students would be affected by the project per year. The participant workbook had case studies in engineering mechanics, structural engineering, other civil engineering courses, ethics/professional issues/capstone design courses, and forensic engineering/failure analysis courses. Presentations for classroom use were provided on a CD. The materials have also been disseminated on a web site. This paper also reviews how the use of case studies can help programs meet ABET accreditation requirements.

Introduction

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 life-long learning.

Engineering education is about teaching students to design. The Accreditation Board for Engineering and Technology (ABET) defines engineering design as "the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs."[1]

A simplified definition of engineering design might be:

- Anticipate everything that can possibly go wrong (identify all possible failure modes)
- Devise a system, component, or process that will have satisfactory performance, measured against these failure modes.

This definition must be tempered by the awareness of the need to balance safety and economy. In order to design safely, therefore, it is necessary to know all of the applicable failure modes. This, in turn, demands knowledge of how structures and systems fail.

This paper discusses work to integrate forensics and failure case studies into the civil engineering and engineering mechanics curriculum in order to teach design and address ABET as well as ASCE Body of Knowledge (BOK) criteria. This work has been presented to about 75 university faculty through a series of four annual one day workshops.

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 existing courses throughout the curriculum. Many professors have done this on an informal basis for years.

Are failure case studies merely tangential to civil engineering education, or are they in fact a fundamental aspect of engineering education? Are failure case studies simply interesting, or should they be an essential component of a civil engineering curriculum?

Three approaches for bringing forensics and failure case studies into the civil engineering curriculum are possible. These are

- New stand-alone forensic engineering or failure case study courses,
- New capstone design projects, and
- Integration of failure case studies into the existing curriculum.

The first two alternatives have been implemented at several institutions, including the University of Texas, Mississippi State University and the University of Colorado at Denver, where practicing forensic engineers are members of the faculty. Clearly, this approach depends on the availability of qualified and interested faculty. Use of forensic projects in capstone (Senior) design courses requires the availability of appropriate projects free of liability concerns.[2, 3, 4, 5, 6]

These alternatives 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 enroll in them. In fact, some of these courses require graduate standing.

The importance of failure analysis, or forensic engineering, was recognized in an important article published by ASCE in 1983[7]. A survey of the ASCE membership, with 106 respondents, found strong support for:

- Need for ASCE to be concerned about failures,
- Developing model procedures for investigating failures,
- Improving professional practice to prevent failures, and
- A journal on failure case histories.

Each of these items received 72 – 98 % “yes” votes. One item specifically mentioned was inclusion of failure case studies in college and university engineering curricula[7].

Since then, the American Society of Civil Engineers Technical Council on Forensic Engineering (ASCE TCFE) Education Committee has put considerable effort into examining this issue. The ASCE TCFE was founded around 1986 following a number of historical failures, including the Hartford Coliseum and Hyatt Regency walkway collapses, and a concern among Civil Engineering practitioners that there were too many failures, and something more needed to be done[7].

ASCE TCFE Education Committee surveys of civil engineering departments reported in 1989[8, 9, 10] and 1998[11] found that many respondents indicated a need for detailed, well-documented case studies. 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 ABET criteria it is likely to be a low priority for inclusion in a curriculum.

The ASCE TCFE Education Committee held four one-day workshops in Birmingham, Alabama on July 12, 2003 and in Cleveland, Ohio on September 17, 2004, July 15, 2005, and October 6, 2006 for approximately two dozen engineering educators per workshop. This paper discusses how these workshops have addressed the needs identified above.

ABET Accreditation Criteria

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 students attain:

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multi-disciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice." [1]

Programs often struggle with how to document 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). These outcomes can be difficult to demonstrate. One method of documenting these particular outcomes is to include case studies of failed engineering works in the curriculum. Many case studies show the direct societal impact of failures, and demonstrate the need for life-long learning by highlighting the evolutionary nature of engineering design procedures.

Case studies also address the revised criterion c, design within realistic constraints. Case studies, and specifically failure case studies, illuminate how "economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" [1] impact design, behavior, and performance of engineered systems.

Criteria for civil engineering programs are more specific. Students must demonstrate "an understanding of professional practice issues such as: procurement of work, bidding versus quality-based selection processes, how the design professionals and the construction professions interact to construct a project, the importance of professional licensure and continuing education, and/or other professional practice issues." [1] These professional issues are integral to many of the case studies addressed through the workshops. As an example, some project failures may be traced to poor interaction and communications between the designers and the builders.

Civil Engineering Body of Knowledge

The ASCE report *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future* [12], prepared by the Body of Knowledge Committee of the Committee on Academic Prerequisites for Professional Practice, goes beyond ABET. The Body of Knowledge (BOK) defines 12 outcomes. The first 11 are identical to the ABET a – k. BOK outcomes 12 – 15 are:

"12. an ability to apply knowledge in a specialized area related to civil engineering.
13. an understanding of the elements of project management, construction, and asset management.
14. an understanding of business and public policy and administration fundamentals.
15. an understanding of the role of the leader and leadership principles and attitudes." [12]

For those failures with complex technical causes, failure case studies may be used to deepen understanding within specialized civil engineering areas (outcome 12). Failures can expose and highlight the subtleties of structural and system behavior that are the province of the specialist. Some specialties, such as earthquake and geotechnical engineering, have historically relied heavily on failure case studies to advance the state of the practice.

Outcomes 13, 14, and 15 may also be addressed through failure case studies. In many failures, the technical issues involved may not be particularly complex or unusual. Instead, breakdowns may come in the project management and construction processes, or in the management of the facility by the owner (outcome 13). Pressures of business and public interests may encourage engineers to take short cuts, with harmful consequences (outcome 14). Some failures might have been averted with stronger leadership (outcome 15).

Case Studies Workshops

Each of the four workshops lasted one day. Participants were given the following materials:

- A binder with photocopies of papers, board notes, presentation slides, and other printed materials.
- A CD-ROM with presentations and other electronic materials (board notes, etc.).

When copies and budget resources were available, participants were also given a copy of Shepherd, R., and Frost, J. D. (1995) *Failures in Civil Engineering: Structural, Foundation, and*

Geoenvironmental Case Studies,[13] Feld, J., and Carper, K. (1997) *Construction Failure*[14] and/or Carper, K. (2001) *Why Buildings Fail*[15].

The workshop agenda is provided in Table 1. Breaks are not shown. It is obvious that not all of the material in Table 1 can be covered thoroughly in a one-day workshop. Two or three days would probably be the minimum.

Consequently, in each block, one or two cases were covered in 20 to 30 minutes per case. The participant notebook contained the other case study presentations and all of the references listed. The approach was to discuss some of the case studies in detail, while providing the basic information and resources for the workshop participants to also use the additional cases. The point was also made that there is pedagogical value in having students look up the particulars of the cases on their own and report back to the class.

The main agenda change between the 2003 and 2004 workshops was the addition of the panel sessions. Participant feedback indicated that more time for group discussion would be useful. For the 2006 workshop, an assessment block developed in consultation with faculty from the Cleveland State University (CSU) College of Education and Human Resources was added to the program.

A key feature of the workshop binder and CD-ROM is that the case studies have been extensively developed to be useful to educators with a minimum of additional effort. Professors can hand students copies of the technical papers to read ahead of time and use the presentations to review the cases in class. The ASCE TCFE Education surveys documented a broadly based desire for well developed case study materials for educators.

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

Table 1: Workshop Agenda

Time	Agenda – Topics
9:30 a.m.:	Introduction[4] – ½ hour • Why use case studies? • How to use the case studies • Case studies developed so far
10:00 a.m.:	Sources for case materials[4] – 1 hour • Books, Forensics Congress proceedings, Journals • TV programs and videos, web materials • Obtaining reports
11:00 a.m.	Engineering Mechanics cases – 1 hour • Statics and Dynamics – Case study, Hyatt Regency[16, 17, 18, 19](and integration through curriculum) • Mechanics of Materials – Case study, Quebec Bridge[20] • Mechanics of Materials – Case study, Hartford Civic Center[21] • Mechanics of Materials – Silver Bridge Collapse (Point Pleasant)[22]
1 p.m.	Assessing the Impact of Case Studies – 1 hour, new for 2006 workshop
1:00 p.m.	Forensic engineering courses – ½ hour • Syllabi and textbooks • Preparations and coordination • Course content, student investigations and reports[6] • Pitfalls and cautions
2:00 p.m.:	Other CE courses – 1 hour • Soil Mechanics and Geotechnical Engineering – Case study, Teton Dam[23] • Fluid Mechanics and Hydraulics – Case study, Teton Dam[23] • Soil Mechanics, Geotechnical Engineering, and Hydraulics – Case study, Schoharie Creek Bridge[24] • Construction Materials – Case study, Willow Island Cooling Tower[25, 26, 27]
3:00 p.m.:	Structural Engineering cases – 1 hour • Structural Analysis – Agricultural Product Loads[28] • Structural Analysis – Case study, Ronan Point[29, 30] • Design of Reinforced Concrete Structures – Case study, 2000 Commonwealth Avenue[31] • Structural Analysis – L'Ambiance Plaza[32]
4:00 p.m.:	Ethics, Professional Issues, and Capstone Design – ¾ hour • How cases can address ABET requirements • Ethical aspects and professional issues, codes of ethics[33] • Use of cases as capstone design projects • Ethics – Citicorp Tower[34, 35] • Ethics – Quebec Bridge and Hyatt Regency[36, 20]
5 p.m.:	Final evaluation and wrap up

One issue that often comes up in workshop discussions is the qualification of faculty to teach failure case studies. However, it does not take 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. As mentioned above, students may also be assigned to do the basic legwork and hunt up sources.

A failure case study web site has also been developed to more broadly disseminate the case study materials. The web address is http://www.csuohio.edu/civileng/faculty/delatte/new_case_studies_project/csuweb.htm. The web site contains a bibliography.

The online bibliography is an important element requested by respondents to the ASCE TCFE Education Committee surveys. So far the bibliography lists the following references:

- 17 books and 2 periodicals
- 20 journal papers on use of case studies
- 28 journal papers describing case studies
- 5 investigation reports
- Web sites, videos, television programs.

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 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 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. Whereas historically there has been an emphasis on structural and geotechnical cases in forensic engineering, the 1983 ASCE paper noted "transportation and hydraulic systems – these need emphasis as well as buildings and bridges."[7]

Serviceability failures and small scale problems "which do not generate headlines but clog the courts" [7] are also important. Often, these types of cases may be found in the local newspaper.

Assessment and Implementation of Workshops

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 [8, 9, 10, 11], there is no empirical data available to show the benefits. Several of the workshop participants have reported back that the case studies have been excellent for motivating their students to learn.

Surveys were carried out after the workshops to assess the likely impact. Results from one workshop follow up survey of attendees (2004) are shown in Table 2. Evaluation results from other years were similar. Participants believed that it would be relatively easy to add the case studies to the courses they taught, but that it would be more difficult to influence the curriculum by adding new courses. All of the topic modules were rated highly.

Table 2: Sample Workshop Participant Survey Results

On a scale of 0 to 5, with 5 being very high impact, what impact do you expect this workshop to have on your teaching?	3.95
On a scale of 0 to 5, with 5 being very high impact, what impact do you expect this workshop to have on your curriculum?	2.88
On as scale of 0 to 5, with 5 being very difficult, how difficult do you expect it to be to implement the use of case studies in your program?	2.74
On a scale of 0 to 5, with 5 being very valuable and 0 being of no value, how valuable did you find each of these modules?	
Background of ASCE TCFE, sources for case materials	3.95
Introduction to use of Case Studies	4.41
Engineering Mechanics Cases	4.27
Structural Engineering Cases	4.14
Other CE Courses	4.14
Ethics, Professional Issues, and Capstone Design	4.48
Forensic Engineering Courses	4.10
Group Discussion and Brainstorming	4.29
On a scale of 0 to 5, with 5 being a very important reason and 0 being not a reason, please indicate whether these were your reasons for wanting to attend this workshop	
Details of individual cases	3.33
Teaching tips for using case studies	4.33
Opportunity to discuss approaches with other faculty	3.76
Inclusion of ethics in cases	3.10
Learn about forensic engineering for professional/consulting purposes	2.47
Opportunity to obtain the course workbook, the books, and the CD-ROM of presentation materials	3.81

The most important reason given for workshop attendance was the opportunity to obtain teaching tips for using case studies. The group discussions and course materials were also rated relatively highly, with case details and ethical aspects slightly lower (but still considered important).

Other survey results were:

- Participants taught a wide variety of courses in both engineering and engineering technology programs
- Participants had from 1 to 39 years of teaching experience, with an average of 15.8 years
- The participants expected 1 to 14 of their undergraduate courses to be affected over the next two years, with an average of 3.6, and 20 to 325 students, with an average of 102

Therefore, 75 faculty participants would be expected to impact approximately 135 courses and nearly 4,000 students per year. Follow up conversations and emails with past workshop participants have indicated that they continue to use the case studies and find them valuable.

Next Steps

Workshop participants have provided interesting and useful anecdotes about the benefits of using case studies. However, anecdotes are not enough, and there is need for more formal assessment.

The next logical step in implementation is to assess the impact on students in the classroom. The authors are just beginning this work, assisted by faculty from the CSU College of Education and Human Resources. This work began with the 2006 workshop, and included discussion of several items:

- What do we expect students to learn from the failure case studies?
- What sort of assignments should we give them to document what they've learned?
- What experiences have workshop participants had with using case studies in class?

Assessment instruments have been developed and will be pilot tested, along with focus groups, throughout 2007. Findings from the assessment will be fed back into future workshops. At present, workshops are planned for 2007 and 2008. Rubrics for scoring case analyses were discussed in the 2006 workshop as part of the assessment module.

The case study binder is also being developed as a book through ASCE Press, with an anticipated publication date of late 2007. The book will roughly follow the Table 1 outline, with additional cases developed.

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 and the ASCE BOK).

A considerable amount of failure case study information is already available to engineering educators. Much of that information has been developed specifically for the workshops discussed in this paper. Additional cases are being developed to fill out a comprehensive framework linking courses, topics, and case studies.

An NSF-funded research project to develop and disseminate case study materials has been completed. Under this project, a web site was 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.

A series of four annual workshops for engineering educators has been used to integrate failure case studies into the civil engineering and engineering mechanics curriculum. The 75 faculty participants are expected to impact approximately 135 courses and nearly 4,000 students per year. The fifth workshop will be held at the University of Colorado at Denver Health Science Center in July 2007.

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