



Assessment Results: Incorporating Case Studies in the Civil Engineering Curriculum

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Lessons learned from case studies have had a significant impact on both education and practice of engineering and related disciplines. The history of practice in civil engineering is, in large part, the story of failures, both imminent and actual, and ensuing changes to designs, standards and procedures made as the result of timely interventions or forensic analyses. In addition to technical issues, professional and ethical responsibilities are highlighted by the relevant cases. Over the past five years the project extended the work of implementing and assessing case studies from Cleveland State University to eleven other university partners, and broadened the scope to cover engineering disciplines in addition to civil engineering, as well as the NSF Materials Digital Library. This paper reports on the results from including case studies in various courses at a diverse data set of universities. Student learning was assessed through surveys and focus group discussions. Students were asked specifically about the technical lessons learned, as well as their response to the case studies. Case study questions were included on homework assignments and examinations. Survey questions linked student achievement to learning outcomes. This year, the data from student focus groups and surveys of faculty that teach with case studies have been investigated as well. Case studies have potential for positive impacts in the affective domain as well as in the cognitive domain. The results have been evaluated against the ABET general student outcomes (criterion 3) as well as the Civil Engineering specific curriculum requirements. The results are also compared to the 2nd Edition of the American Society of Civil Engineers (ASCE) Civil Engineering Body of Knowledge as well as the ASCE Vision 2025. Furthermore, a number of workshops on incorporating failure case studies have been offered at ASCE annual meetings and elsewhere. Those workshops have helped shape the course of this research.

Introduction and Background

This paper continues reporting on a research project being carried out by twelve universities with National Science Foundation (NSF) funding. At these universities, failure case studies were integrated into existing courses. The degree programs included civil engineering, architectural engineering, civil engineering technology, and construction management. Complete details of the research project are provided elsewhere¹.

As part of this project, data were gathered from student surveys in the courses where failure case studies were used. Students were asked specifically about the technical lessons learned, as well as their response to the case studies. Case study questions were included on homework assignments and examinations. Survey questions linked student achievement to learning outcomes.

In addition, some student focus groups were held. Due to logistics, this was only possible at Cleveland State University. Student focus group findings are reviewed below.

One concern throughout the project has been how to address perceived barriers to faculty implementation of failure case studies. Therefore, the faculty that were part of the project at the different universities were surveyed by email. Results are provided below. While the student

survey results have been previously reported², the results from faculty surveys and student focus groups are new to this paper.

Importance to Civil Engineering Education

Previous work has suggested that failure case studies may be used to address Accreditation Board for Engineering and Technology Engineering Accreditation Commission (ABET EAC) general and civil engineering program specific criteria³, as well as Civil Engineering Body of Knowledge volume 1 and 2 (BOK and BOK2) criteria⁴. Some of the BOK2 outcomes that seem to be well supported by the use of failure case studies include:

“11: Contemporary issues and historical perspectives. Analyze the impact of historical and contemporary issues on the identification, formulation, and solution of engineering problems and analyze the impact of engineering solutions on the economy, environment, political landscape, and society.

12: Risk and uncertainty. Analyze the loading and capacity, and the effects of their respective uncertainties, for a well-defined design and illustrate the underlying probability of failure (or nonperformance) for a specified failure mode.

22: Attitudes. Demonstrate attitudes supportive of the professional practice of civil engineering.”⁵

Two other reports that are relevant to civil engineering education are “The Vision for Civil Engineering in 2025”⁶ and “Achieving The Vision for Civil Engineering in 2025: A Roadmap for the Profession.”⁷ The 2nd edition BOK has a direct linkage to the Vision.

The vision document notes (p. 3) that “For many years, civil engineering leaders sounded the alarm about the lack of investment in maintaining and improving the infrastructure. Some of those shortcomings were tragically illustrated by the death and destruction caused by failures in which engineering designs, government funding, and the community oversight systems were all called into question. Civil engineers are painfully aware of the consequences for public health, safety, and welfare when the infrastructure does not get the attention it requires.”⁶ Civil engineers should be (p. 9) “managers of risk and uncertainty caused by natural events, accidents, and other threats.”⁶

There is considerable emphasis on the attributes for the Civil Engineer of 2025. By way of explanation (p. 10) “Attributes may be defined as desirable knowledge, skills, and attitudes... Attitudes reflect an individual’s values and determine how he or she perceives, interprets, and approaches the world. Attitudes conducive to effective professional practice include commitment, curiosity, honesty, integrity, objectivity, optimism, sensitivity, thoroughness, and tolerance.”⁶ Ethical behavior is particularly important (p. 11): “Ethical behavior, including client confidentiality, codes of ethics within and outside of engineering societies, anticorruption and the differences between legal requirements and ethical expectations, and the profession’s responsibility to hold paramount public health, safety, and welfare.”⁶ Furthermore, (p. 12) “Thoroughness and self-discipline in keeping with the public health, safety, and welfare implications for most engineering projects and the high-degree of interdependence within project teams and between teams and their stakeholders.”⁶

As the title would imply, “Achieving The Vision for Civil Engineering in 2025: A Roadmap for the Profession” provides detail on implementation. Risk management is a critical responsibility of civil engineers (p. 29) – “It is impossible to completely eliminate risk from our daily lives. One just cannot do it. However, one can work to minimize it. That is where civil engineers come in. Envisioning the year 2025, civil engineers will take the lead and make the tough risk management calls for the built and natural environment, with the clear goal of minimizing catastrophic failures and the resulting human tragedy.”⁷

To do this, some specific tactics and potential actions are suggested:

- “Embed risk assessment and risk management methodologies as a core knowledge and skill for civil engineers throughout their education and practice.” (p. 30)
- “Reinforce civil engineering as a lead discipline for risk assessment and risk management of the built and natural environment.” (p. 31)
- “Promote a general understanding that risk is an inherent part of all programs and projects and requires rational evaluation and effective management.” (p. 32)
- “Incorporate the concept of resilience as a tool for mitigating the effects of natural and manmade disasters.” And “Learn from disasters by disseminating forensic analyses and publicizing innovative mitigating measures to the civil engineering community.” (p. 56)
- “Develop standards for reviewing failures in constructed projects and encourage dissemination of lessons learned.” And “Promote the consideration of resilience in the design and construction procurement process.” (p. 57)⁷

Failure case studies provide an opportunity for in depth discussions of the civil engineer as leader and risk manager, development of attitudes supportive of civil engineering professionalism, and developing designs that are resilient against natural and man made hazards. Thus, failure case studies are important to Vision 2025 and its achievement.

Student Surveys

Over the course of several years, student survey data were gathered from multiple universities, most of which used cases in multiple courses. A total of 718 student responses from seven universities was analyzed. The analysis of the student survey data was completed in 2013 and has already been reported in detail.²

“The results from multiple universities and multiple course offerings demonstrate that failure case studies can be used to provide indirect, quantitative assessment of multiple student learning objectives. Several outcomes that constitute the professional component of the curriculum may be assessed in this way.

The strongest results were for student outcomes (f) an understanding of professional and ethical responsibility, (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, and (j) a knowledge of contemporary issues. Although student outcomes (d), an ability to function on multidisciplinary teams, and (g), an ability to communicate effectively also generated reasonable results, it would probably be more effective to assess these particular outcomes elsewhere within the curriculum.”²

Student Focus Groups

A series of student focus groups were conducted over a four-year period in multiple engineering classes at University X, where failure case studies were discussed. The focus group guiding questions were selected in order to allow students in these courses to provide their views of the effectiveness of inclusion of case studies in the course. In order to ensure openness in students' discussions, these focus groups were conducted independently at the absence of the course instructor. The sample courses where these focus group discussions were conducted included:

- CVE 312 – Structural Analysis I
- CVE 403 – Construction Planning and Principles of Estimating
- CVE 422 – Reinforced Concrete Design
- ESC 211 – Strength of Materials

Discussions in these courses occurred at multiple times, across different courses, over time, thereby capturing the views of a wide range of students, the views expressed seemed to be consistent over time. A summary of these focus group discussions is provided in the remaining part of this section under the subheadings: Failure Cases Discussed, Usefulness of Cases, Challenges, and Suggestions for Improvement.

Failure Cases Discussed

Students accurately recalled a wide range of failure cases that had been discussed in class. Some prominent ones such as the Montreal Olympic Games and the Quebec Bridge were mentioned more often. Students also remembered discussing other more recent cases such as L'Ambiance Plaza, the CitiCorp Building non-collapse, the Pittsburgh convention center, and the Hartford civic center. Complete details about these cases are provided elsewhere^{8, 9}. But perhaps more importantly, students seemed to recall the discussions they had in attempting to explain the possible causes of failure, for each case, and how the failure could have been avoided.

According to the student focus groups, one of the recurring themes in explaining the causes of failure was human error. Students seemed to cite cases where failure would be attributed to human factors such as complaints or observations of problems being ignored, the engineer being absent from the construction site during critical times, insufficient supervision, poor attitudes, lack of communication, and attempts to reduce costs by using cheap and inferior materials.

Usefulness of Cases

In assessing the usefulness of having the opportunity to discuss failure case studies in their engineering courses, the student focus groups highlighted two themes. First is the importance of professional ethics and accountability. Through the inclusion of failure cases in the engineering courses, students recognized that technical knowledge, while necessary, is by no means sufficient without professional ethics and accountability. As one student in the Construction and Planning course put it,

“... reviewing failure cases helps us appreciate the need to be more careful and the need to make everyone accountable.”

The second theme was linking technical knowledge to practice and real life situations. Student focus groups indicated that reviewing failure cases added a real-life dimension to what happens when things go wrong. One student in the Strength of Materials course had this to say:

“... Reviewing failure cases provides real-life examples of how engineers can make very costly mistakes. This makes us aware of the consequences of what they do and how it can have far-reaching effects on social lives.”

Challenges

When asked, the students did not seem to identify any significant challenges to including failure case studies in the courses. Some students wished they had been provided with multimedia presentations of actual failure occurrences and others wished that cases studies content was reflected more in the course test and examinations. Other than those observations, there were no problems or challenges in including case studies in the courses.

Suggestions

Some suggestions and recommendations emerged from the student focus groups about how inclusion of case studies could be made more effective. They included:

- Creation of a separate class that focuses on Failure Cases Studies, perhaps as an elective, would allow for an increased number of case studies covered. Such a course is offered as an elective at Pennsylvania State University.
- Instructors should select cases that span over a wider period of time (old ones as well as recent ones) in order to show trends.
- Students would like case studies that resulted from computer design failures to be reviewed as well, especially given the fact that, of late, a number of procedures are highly computerized. The Hartford Civic Center represents an example of such a case⁸.
- It would be best if case studies were integrated with the other course content. An example was given of how the Pittsburgh case was well integrated throughout the ESC 211 course.
- Attempts should be made to illustrate graphical representations of cases as they actually occurred. Most the case studies were helpful, and having pictures or video clips would be even more helpful. Of course, these are difficult if not impossible to find in most cases.
- It would be beneficial to discuss and review success cases as well as the failure cases.
- Provide students with opportunities to go on field trips, to see where and how some failure cases occurred.
- If possible, have a guest speaker come in and speak about his/her work on a failure. Guest speakers are an important part of the elective course at Pennsylvania State University.

Faculty Surveys and Results

Faculty members from several universities who had incorporated failure case studies in their teaching in a variety of engineering courses were contacted by e-mail. They were asked to comment on their perceived effectiveness of incorporating such case studies in their teaching. These faculty members were provided with guiding questions. At least 90 % of those contacted responded. All faculty participants in this survey indicated that incorporating failure case studies

in the teaching was very helpful and inclusion of such case studies did not raise issues or cause problems in the courses they taught. Other than concerns for lack of time to effectively integrate failure case studies into the course materials, without displacing other course content, faculty participants did not express any difficulties in including failure case studies in the courses.

Type of courses

Failure case studies were included in at least 12 different undergraduate courses, ranging from the freshman level introductory seminar ENGR 100 – Introduction to Engineering, to the advanced level CVE 422 – Reinforced Concrete Design. The sample course number and titles of the courses that faculty participants taught are (Table 1):

Table 1: Courses Incorporating Failure Case Studies in this Project

Course Number	Course Title and Offering University
ESC 211	Strength of Materials (Cleveland State University)
CVE 312	Structural Analysis (Cleveland State University)
CVE 322	Structural Steel Design (Cleveland State University)
CVE 403	Construction Planning & Estimating (Cleveland State University)
CVE 422	Reinforced Concrete Design (Cleveland State University)
ECIV 330	Soil Mechanics (Case Western Reserve University)
ECIV 431	Special Topics in Geotechnical Engineering: Pavement Design and Materials (Case Western Reserve University)
AE 537	Building Performance Failures and Forensic Techniques (Pennsylvania State University)
CIVE 302	Evaluation of Civil Engineering Materials (Colorado State University)
CIVE 367	Structural Analysis (Colorado State University)
CM 1S	Construction Management Orientation Seminar (California State University Fresno)
ENGR 100	Introduction to Engineering (Pennsylvania State University)

Failure Cases Cited

Though a few more commonly known failure cases such as the Montreal Olympic Stadium and the Quebec Bridge were discussed across different courses, each faculty member tended to include different cases. The cases included in the courses were the Montreal Olympic Stadium, Hyatt Regency Walkway, L'Ambiance Plaza, Quebec Bridge, World Trade Center, Agricultural Building, Pittsburgh Convention Center, Citicorp, Hartford Coliseum, 2000 Commonwealth Avenue, and the leaning tower of Pisa. At one university, cases such as the Hancock Building Glass Failure, WTC, Boston Big Dig, Ronan Point, Sampoong Plaza Department Store were included, and students were required to select a failure case from the Failures Wiki¹⁰ and write about it. In other instances, visiting lectures were invited to cover less well known cases such as

concrete deterioration failures and collapses during construction, wood truss failures etc. Other cases included in courses were Hartford Civic Center roof collapse, Kansas City Hyatt Regency, and the Hyatt Regency Skywalk Collapse.

Time Commitment

The amount of time spent discussing failure case studies varied. Some spent as little as 20 minutes while others reported spending as much as 7 class periods, but a range of 4-5 hours per semester seemed typical. The time it took to prepare for case studies did not seem to be a problem. Several faculty members indicated that it took minimal time to prepare and others estimated it to be 1-2 hours per case. Moreover, several participants indicated that, though it initially takes time to prepare, the time of preparation reduces substantially with the repeated use of case studies. Faculty participants also commented about the amount of outside reading and assignments that were assigned for case studies in the course. Time commitment in this area also took a variety of forms, ranging from 1-2 assignments or assigned readings to assigning students to research and write on selected failure cases.

Recommendations

Faculty participants offered a number of recommendations for using failures case studies in the courses. Some of the recommendations were:

- Incorporating failures case studies significantly improves the courses, but it is important to address professional and technical components. Case studies improve student interest and awareness of responsibilities and potential consequences.
- Case studies are important ways to relate fundamentals of engineering design to real world problems. It is very helpful to keep students interested in the subject and learn what they accomplish from lessons learned from case studies.
- One professor reported “I teach an entire course on failures of all kinds. For those using them in other courses, that can be used selectively to demonstrate a point. For example, I use the KC [Kansas City] Hyatt in a freshman course on beginning structures to Architects. I have them work out the statics before and after, as an example before I tell them it was one of the worst failures in history.” More details about this approach are provided in another paper¹¹.
- Adding new case studies to the existing ones on the MATDL web site⁹.
- Commit to the importance of teaching students about subjects in addition to technical content, and don't just try to squeeze the case studies in to the existing schedule. Find some course content to remove.

Suggestions to modify the use of case studies

Faculty participants seemed to generally suggest an increase in the use of case studies in certain engineering course curriculum and engaging students in discussions. Some of the specific suggestions to modify the use of case studies were:

- Use more classroom discussions to have students engaged.
- Would like to continue to add contemporary structures that have failed.
- I think students are more likely to benefit if case studies are closely tied to course material and we make sure to spend some time discussing them each week.

Workshops

The research group has also led faculty development workshops over the course of a decade to promote the integration of failure case studies into engineering education. These have been funded by NSF and ASCE. Workshops were originally held on university campuses, and later switched to the ASEE annual meeting and other venues. Workshop locations were Birmingham 2003 (University of Alabama at Birmingham), Cleveland 2004, 2005, 2006 (Cleveland State University), Denver 2007 (University of Colorado – Denver), ASEE Annual Convention Pittsburgh, PA 2008, ASEE Annual Convention Austin, TX, 2009, ASEE Annual Convention Louisville, KY, 2010, ASEE Annual Convention Atlanta, GA, 2013, and the National Building Museum, Washington, D.C., 2013.

Initially, the workshops focused on providing faculty with failure case study materials. Subsequently, as the research project has continued, the focus has shifted to discussing how to use the materials in the classroom and how to assess the impacts. Workshop participants are provided with a CD of case study PowerPoint presentations, which can also be made available through a Dropbox folder. Depending on budget constraints, participants have also been provided with a copy of *Beyond Failure*⁸. The Materials Digital Library also provides an important resource for workshop participants⁹.

Summary and Conclusions

Case studies have potential for positive impacts in the affective domain as well as in the cognitive domain. The results have been evaluated against the ABET general student outcomes (criterion 3) as well as the Civil Engineering specific curriculum requirements. Survey results indicate that failure case studies are very effective at supporting student learning outcomes.

The deeper and richer analysis shows that, in addition to the learning benefits from failure case studies, there are also important impacts on student attitudes. This has important implications for the leadership expected of a civil engineer under Vision 2025.

The faculty survey results are also quite encouraging. These suggest that the materials developed under this research project have been very valuable in the classroom, and that the barriers to implementation may be easily overcome.

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