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The Use of Failure Case Studies to Enhance Students' Understanding of Structural Behavior and Ethics

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Abstract - Structural failures occur from time to time, as seen from the recent (January 2006) rash of roof collapses in Germany, Poland, and Russia. However, many engineering and engineering technology students are not made aware of these failures in their analysis or design courses. In the author's structural analysis and design courses, students are required to research specific structural failures, and to report on these failures, detailing the causes of failure - illustrated with pictures and free-body diagrams, and any lessons learned. Articles on several structural failures are posted regularly on the course website to draw the students' attention to these failures and their consequences, as well as any lessons learnt; discussions of these failures on the course website discussion forum is also strongly encouraged. Our hypothesis is that studying specific structural failures has a positive impact on students' learning experiences. To verify this hypothesis, an end-of-term student survey was conducted in two structural design courses where failure case studies were used. Analysis of the survey results indicates a positive impact of failure case studies on students' educational experiences and awareness of ethical issues. The use of failure case studies in more engineering technology courses is also recommended.

Index Terms – Failure case studies, structural failures, structural behavior, student learning, engineering ethics

INTRODUCTION

Structural failures, whether man-made or due to natural events, unfortunately, do occur from time to time in our imperfect world, and sometimes with serious and dire consequences [1, 2, 3], but not many undergraduate engineering and engineering technology students are made aware of these failures in their structural design courses. Consequently, they cannot benefit from many of the lessons that can be learned from these structural tragedies [4]. This raises the question as to whether or not familiarizing students with the details of past structural failures has any beneficial effect on their learning and educational experiences.

Engineering failures, whether significant or small, can occur anywhere in the world, but if we are to keep these failure occurrences to a minimum and avoid repeating the

mistakes of past failures, we need to determine what is responsible for these engineering failures, and what needs to change as far as the teaching and practice of engineering is concerned. Past engineering failures “should be studied not for their own sake, but for the sake of understanding how better to succeed in future.” [5] One of the great challenges facing the engineering profession is “engineering ethics”[6], and although steps to ensure high quality work and more careful design in engineering have been established here in the United States and elsewhere, but in reality, not all engineering projects are carried out in an ethical fashion. Among the steps taken to promote safe design is the adoption of an Engineering Code of Ethics. [3] “Major engineering failures act as a catalyst for change in standards of practice and therefore create the opportunity for establishing better ethical practices for the profession.”[7] The requirement for a professional license to be legally qualified to seal and stamp specific engineering projects has raised awareness of the need for prudent and ethical engineering practice. Most engineers are ethical and realize their profession's responsibility to the public. [6] However, many different factors can contribute to the failure of any engineered product, but through the process of analyzing past failures and their causes, these factors can be more readily spotted and therefore avoided in practice. Of paramount importance is the “identification of potential deficiencies from past failure data.” [8].

The mission of any engineering or engineering technology program is to teach their students the current body of knowledge that will prepare them to successfully contribute to and eventually master their particular field. The intent is that the training they receive and the knowledge they acquire will help keep them abreast of their chosen field, as well as help them avoid making potentially serious and fatal mistakes in their future practice. Part of this training and knowledge could include exposing engineering and engineering technology students to the study of past structural failures within existing design courses or as a stand-alone course, but this raises a couple of questions: will the use of failure case studies have any positive impact on student learning and appreciation of ethical issues? Where in an already crowded curriculum should engineering and engineering technology programs incorporate such additional material?

Two surveys conducted in 1989 and 1998 by the Council on Forensic Engineering of the American Society of Civil Engineers (ASCE) found that 63% of engineering colleges

indicated that there was a dearth of in-depth studies of structural failures [9] in the literature and this prevented them from including failure awareness in their curriculum. [4] The survey also found that only 9% of the schools taught a course that included failure awareness. Some effort has been made recently to encourage college professors to incorporate real-world examples of ethical and engineering design problems in existing courses. One initiative by the National Science Foundation (NSF) involved several faculty members from institutions around the nation that were grouped with a number of undergraduate students at Texas A&M. The goal of the initiative was “to develop engineering ethics resource material that could be easily introduced at all levels of the engineering curriculum and in all engineering disciplines.” [10] In response to the ASCE survey, Rachel Martin [9] developed case studies on four major engineering failures in hopes that professors would use these case studies as teaching aids to explain how ethical responsibilities played a role in these failures. Rabins and Harris [11] have also developed a set of engineering ethics cases that are used as self-contained modules in a stand-alone “Ethics and Engineering” course at Texas A & M. They report positive student response in their course evaluations. Rouse [4] developed a set of failure case studies that could be used in the classroom “not only to establish important links between the classroom and the working environment, but also to help students realize the importance of professionalism and ethics in their field of interest.”

The second author regularly integrates structural failure case studies in his structural analysis and design courses. Students are required to conduct an internet research on a specific structural failure and write a minimum 5-page graded report detailing the cause of collapse - illustrated with free-body diagrams and sketches, the lessons learned, and any ethical or technical issues and concepts involved. In addition, articles on structural failures are posted regularly on the course website to encourage discussions of these failures online and in the face-to-face class sessions. To ensure that students actually study these failure cases, questions on these failure case studies are featured in the tests and/or final exam. We believe, as do others, that “integrating failure case studies and ethical concerns into already existing engineering courses provides the perfect solution,” [9] but the authors are not aware of any student surveys that have been done to show the effectiveness of this approach in an undergraduate engineering technology curriculum. Therefore, to assess the impact of these failure case studies on the educational experiences, an end-of-term survey was carried out in the structural steel and timber design courses in the winter quarter of the 2005-2006 academic year. The structural steel design course is a required 4-credit course while timber design is an elective 4-credit course in the Baccalaureate degree program in civil engineering technology (CET) at Rochester Institute of Technology (RIT). The overall goals of this study are as follows:

1. To determine the efficacy of using the failure case studies on students’ educational experiences in an engineering technology program.
2. To determine the impact of the liability issues arising from past engineering failures on students’ interest in pursuing a career in structural design.
3. To determine the impact of these failure case studies on the students’ motivation to do better quality work in college, and in their future professional life.

SURVEY INSTRUMENT

The survey instrument developed for this study, and shown in the Appendix, consists of nine questions that was administered to civil engineering technology (CET) students enrolled in the structural steel and timber design courses ($n = 30$) at Rochester Institute of Technology (RIT). This is approximately 75% of the senior class in the CET program at RIT. In the following sections, we present the analysis of the student responses for each of the questions in the survey.

ANALYSIS OF SURVEY RESULTS

Question #1: On a Scale of 1 to 5 (5 = most interested), how interested are you in a career in structural design/engineering (please circle one)?

In this question, the students were asked about their future career interests to get a sense of how many of them were already leaning towards a career in structural engineering and design, and the impact of the failure case studies on these students. Of the students surveyed, 77% were moderately or more interested in pursuing a career in structural design, while 23% were just slightly or not at all interested in a career in structural design. These results are presented graphically in the pie chart in Figure 1.

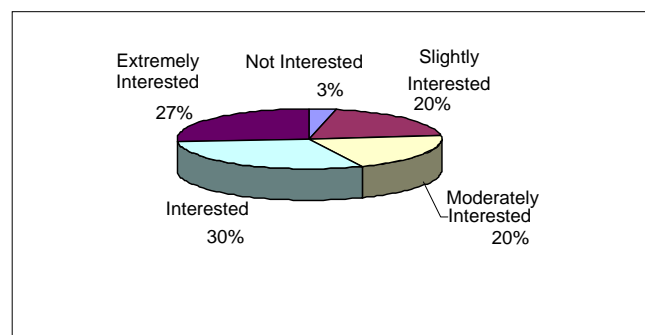


FIGURE 1
STUDENTS' INTEREST IN STRUCTURAL CAREERS

Question #2: Have you studied to a reasonable depth or read about any significant structural failure?

In this question, we solicited information on the various engineering failures studied by the students, and from the responses to this question which is depicted in Figure 2, we

found that all the students had studied at least one engineering failure to some reasonable depth; the most common structural failures studied include, the Hyatt Regency Walkway collapse in Kansas City, MO in 1981 - studied by 39% of the students, the Citi-Corp tower crisis - studied by 25%, and the Tacoma Narrows Bridge collapse – studied by 16%. Other structural failures studied by the students include the World Trade Center collapse and the Hartford Civic Center Arena collapse. 80% of the students did the failure case studies as part of the requirements for a course they were enrolled in, while 20% studied these failures for their personal interests.

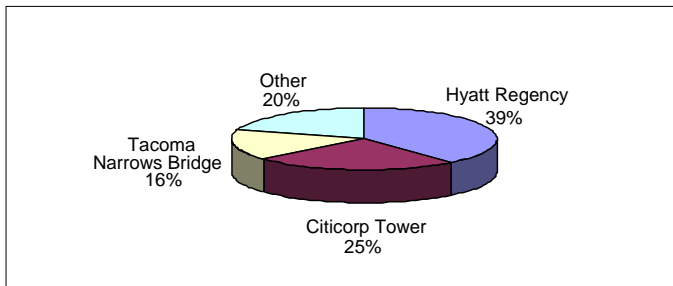


FIGURE 2
FAILURE CASE STUDIES BY STUDENTS

Question #3: What was the cause of the failure?

In this question, we asked the students to indicate what factors contributed to the structural failures in the cases they studied. The students’ responses to this question, as depicted in Figure 3, shows “human factors” as the most common cause of structural failures and was cited by 62% of the students surveyed. This is in agreement with the observation by Schlager [12] that “it has become evident that human behavior, ethically and accidentally, is not just a factor that affects improved safety and economic growth, but that it entirely controls such developments.” 9% of those surveyed indicated “extreme environmental conditions” as the cause of the failures, 6% indicated “material defect”, and 23% indicated a combination of all of the above factors as the cause of failures in their case studies.

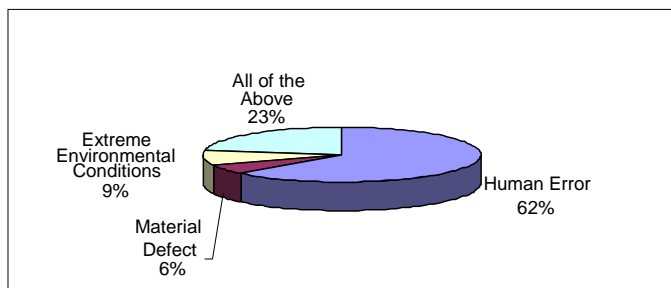


FIGURE 3
CAUSE OF STRUCTURAL FAILURES

Question #4: Did the structural designer(s) face any legal or professional repercussions as a result of the failure? Where you surprised by these consequences?

This question pertains to the consequences faced by the engineers involved in the failure case studies. 67% of the students surveyed indicated that the engineers involved in the engineering failures they studied faced legal repercussions, while 33% of the of the students indicated that the engineers involved in their failure case studies did not face any legal repercussions. Many of these design engineers were stripped of their professional licenses and subjected to lawsuits and fines. The survey showed that these students have become more aware of the serious repercussions for professional negligence or incompetence in engineering designs through these failure case studies.

Question #5: How do the consequences or liability that structural designers/engineers are faced with affect you in regards to any aspirations of becoming a structural designer/engineer?

This question pertains to the effect of the consequences faced by the design engineers of the failed projects on the students’ interest in further pursuing a career in structural engineering. The results, shown in Figure 4, indicates that 57% of the students felt that the failure case studies had a positive effect on their aspirations of becoming a structural engineer and designer, while 30% of felt that the failure case studies impacted them negatively, and as a result would not pursue a career in structural engineering; 13% indicated that the failure case studies had no impact on their career interest.

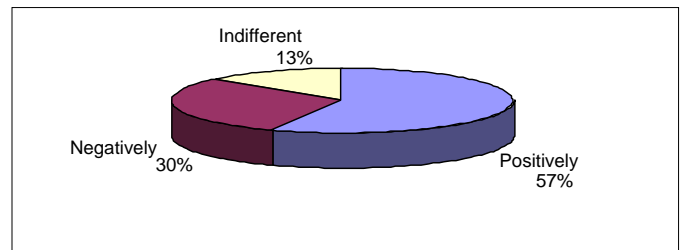


FIGURE 4
EFFECT OF CHOOSING A CAREER INVOLVING STRUCTURAL DESIGN

Question #6: Does the reviewing of past structural failures make you more inclined to do good quality work in the classroom regarding homework?

We used this question to gauge the impact of failure case studies on the students’ motivation to be more conscientious in their school work, assignments and projects. The responses depicted, in Figure 5, shows that 90% of the students indicated that they were more inclined to produce better quality course work because of reviewing these failure case studies, while 10% percent felt the failure case studies will have no impact on the quality of their course work.

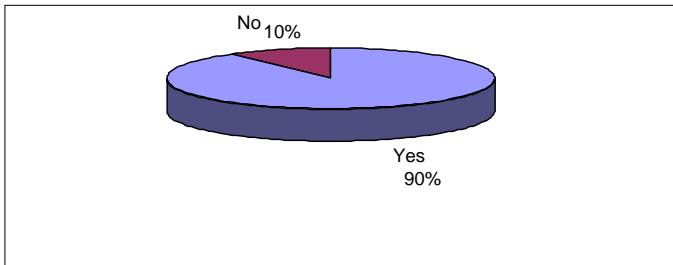


FIGURE 5
DOES REVIEWING FAILURE CASE STUDIES AFFECT THE EFFORT STUDENTS PUT INTO THEIR HOMEWORK?

Question #7: Does the reviewing of past structural failures make you more inclined to produce good quality work and abide by a code of ethics when engaged in full-time work later on in life? Has your study of structural failures enhanced your understanding of the code of ethics for engineers?

We used this question to measure the impact of failure case studies on the students' future professional practice. In response to this question, all the students indicated that reviewing failure case studies motivated them to more careful and conscientious in their future professional practice. As shown in Figure 6, 90% of the students believed that the use of failure case studies have enhanced their understanding of the Engineers' Code of Ethics, 7% felt it did not help them understand the code of ethics, while 3% felt it had no impact on their understanding of the code of ethics.

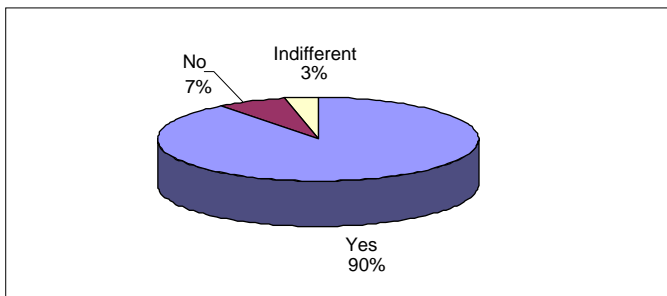


FIGURE 6
DOES REVIEWING FAILURE CASE STUDIES ENHANCE STUDENTS' UNDERSTANDING OF ETHICS?

Question #8: Should more civil engineering technology classes include review of civil engineering system failure case studies? (Please indicate the reason(s) for your answers)

This question was used to gauge the students' perception of the effectiveness of using failure case studies in existing courses. The results, depicted in Figure 7, show that 97% of the students believed it was a good idea to review failure case studies because they bring real life situations into the classroom, and they reinforce the need for strict quality controls on all engineering designs, while also enhancing the student's awareness of ethical issues and understanding of structural behavior. One student commented that "there are

practical lessons to be learned from failures that might not otherwise be taught in the classroom." The students' responses to this question points to the effectiveness of integrating failure case studies in existing courses and their positive impact on the students' educational experiences.

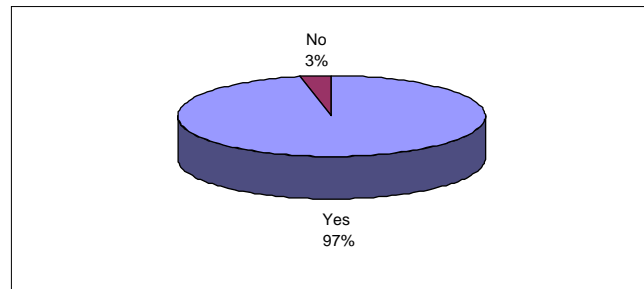


FIGURE 7
SHOULD FAILURE CASE STUDIES BE USED MORE OFTEN IN ENGINEERING CLASSES?

Question #9: Please include any other pertinent comments regarding the use of structural failure case studies and their impact on student learning

We used this question to solicit additional comments from the students regarding the use of failure case studies. A majority of the students felt that the failure case studies makes them aware of the mistakes made by other engineers in the past, and thus helps them avoid repeating those same mistakes in future. They also indicated that it prepares them for the real-world, and motivates them to be more cautious in their engineering designs. They also felt that failure case studies highlights the seriousness of the engineering field, and reinforces the Engineers' Code of Ethics. One student suggested replacing an existing course currently required for graduation in the civil engineering technology curriculum with a stand-alone course consisting of civil and structural engineering failure case studies, and another summed it up this way: "sometimes what not to do is the best example."

DISCUSSIONS

The results of the survey suggests that reviewing of failure case studies should be incorporated more frequently in engineering technology courses to enhance the students' understanding of ethics and engineering behavior. Failure case studies, as used in the structural analysis and design courses taught by the one of the authors, have provided the students the opportunity to see how seemingly insignificant factors can at times be the root cause of engineering failures. The survey also revealed that the more familiar the students were with past engineering failures, the more they felt confident that they would not repeat the same mistakes.

This survey also revealed that studying past engineering failures will not deter students interested in structural engineering from continuing on that path, inspite of the consequences and liability faced by structural engineers in these failure case studies. Fifty percent of the students felt

these consequences did not reduce their interest in pursuing a career in structural design and engineering.

As a result of these failure case studies, most of the students realized the need to pay more careful attention to the details involved in their homework assignments and design projects, and the need to check their work thoroughly. All of the students surveyed were convinced that reviewing these failure case studies would benefit them in their future careers, motivating them to be more careful and prudent in their future design projects. A great majority of the students felt failure case studies was necessary and beneficial to their learning, and some thought it should be used in other civil engineering technology courses as well.

CONCLUSIONS

The authors have used structural failure case studies in structural analysis and design courses at Rochester Institute of Technology for at least two years, but the effectiveness of using these case studies had not been established. The authors conducted surveys of students in two structural design courses, and the survey results indicate that the use of failure case studies enhances the students’ understanding of ethics and structural behavior, and exposes the students to past mistakes of other engineers, thus helping them avoid making similar mistakes in their future professional practice.

The use of failure case studies in the classroom could ultimately contribute to a future where engineering failures and unethical behavior by engineers - though not completely eradicated - can be reduced to a minimum. The authors recommend that structural failure case studies be incorporated into existing analysis and design courses or as a stand-alone course to enhance the students’ educational experiences and enable them benefit from the many lessons learned from past engineering failures.

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APPENDIX

Survey Instrument

Dear CET Student:

We are conducting a survey on the impact of structural failure case studies on engineering technology students. In this regard, please answer the following questions as honestly as possible. Your participation is appreciated.

- 1) On a Scale of 1 to 5 (5 = most interested), how interested are you in a career in structural design/engineering (please circle one)?

1	2	3	4	5
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- 2) Have you studied to a reasonable depth or read about any significant structural failure?

Yes	No
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If so, what structural failure?

Was this a class assignment?	Yes
No	

- 3) What was the cause of the failure? (Check all that apply)

<input type="checkbox"/> Human factors (ethical , design error, accidents)
<input type="checkbox"/> Material defect
<input type="checkbox"/> Extreme environmental conditions
<input type="checkbox"/> All of the above

- 4) Did the structural designer(s) face any legal or professional repercussions as a result of the failure? Where you surprised by these consequences?

- 5) How do the consequences or liability that structural designers/engineers are faced with affect you in regards to any aspirations of becoming a structural designer/engineer?

Positively	Negatively
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- 6) Does the reviewing of past structural failures make you more inclined to do good quality work in the classroom regarding homework?

Yes

No

- 7) Does the reviewing of past structural failures make you more inclined to produce good quality work and abide by a code of ethics when engaged in full-time work later on in life?

Yes

No

Has your study of structural failures enhanced your understanding of the code of ethics for engineers?

Yes

No

- 8) Should more civil engineering technology classes include review of civil engineering system failure case studies?

Yes

No

Please indicate the reason(s) for your answer:

- 9) Please include any other pertinent comments regarding the use of structural failure case studies and their impact on student learning.