122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13344

Learning from the World Trade Center Collapse – Use of a Failure Case Study in a Structures and Materials Laboratory Course

Dr. Tara Cavalline P.E., University of North Carolina, Charlotte

Assistant Professor of Civil Engineering Technology at UNC Charlotte

Dr. Norb Delatte P.E., Cleveland State University

Dr. Norbert J. Delatte, Jr., P.E., is Professor and Chair of the Department of Civil and Environmental Engineering at Cleveland State University. He is the author of Beyond Failure: Forensic Case Studies for Civil Engineers (ASCE Press, 2009). In addition, he is the Editor of ASCE's Journal of Professional Issues in Engineering Education and Practice. Dr. Delatte is a registered professional engineer in the States of Ohio and Alabama and in the Commonwealth of Virginia.

Learning from the World Trade Center Collapse – Use of a Failure Case Study in a Structures and Materials Laboratory Course

Abstract

The use of failure case studies has been shown to benefit technical, professional, and ethical student learning outcomes in undergraduate education. Recently, incorporation of failure case studies into undergraduate civil engineering, civil engineering technology, construction management, and architecture curricula has been facilitated by the development of educational resources as part of a National Science Foundation (NSF) grant. This paper outlines the approach utilized to incorporate the World Trade Center Collapse case study into a junior-level Structures and Materials Laboratory course in an engineering technology and construction management program, identifying the technical and professional component outcomes supported by this case study. Assessment techniques utilized to evaluate technical comprehension of the building performance, as well as to evaluate the impact of this case study on student's interest in the engineering profession, are presented and discussed.

Introduction

Failure case studies have been found to be a valuable addition to the undergraduate engineering curriculum, providing valuable support into technical, professional, and ethical issues[1]. During the past several years, a project funded by the National Science Foundation (NSF) has focused on the implementation of failure case studies into engineering curricula. Work has focused on developing teaching resources on a wide variety of failure cases for faculty to utilize in a variety of undergraduate engineering courses[1, 2, 3]. The project has extended from the lead institution, Cleveland State University, to eleven other university partners, including the university of the lead author, the University of North Carolina at Charlotte. The findings of this project are well documented, with assessments of student learning based on surveys, focus group discussions, and faculty questionnaires. The analysis of student survey data indicated 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 this way[4]." Additional details regarding the project can be found in a number of publications[4, 5, 6, 7, 8, 9, 10]. Findings of the project "confirm the value of including failure case studies in engineering courses," as "they can help in attainment of all 11 ABET criterion 3 outcomes[10]." Ultimately, information on a number of case studies that can be utilized in undergraduate engineering technology and construction management education has been published in technical journals[11, 12, 13, 14] and in other locations[2, 3]. This paper outlines one approach to utilizing the WTC to enhance student learning in an engineering technology course.

Course Description and Overview of Case Study Implementation

Failure case studies are most relevant, and their educational value most useful, when linked to specific course topics[2]. Failures of structures and other civil infrastructure are often related to structural design, mechanics of materials, and performance of materials under service (and severe) conditions. The Structures and Materials Laboratory course is a 1-credit writing-intensive laboratory course taught to students pursuing undergraduate degrees in civil engineering technology and construction management. Since students previously completed coursework in construction materials and construction methods, the purpose of this course is to facilitate an advanced understanding of construction materials and to reinforce key structural design concepts. Objectives include identifying various modes of failure as well as evaluating the role of materials in various modes of structural failure. For several years, a number of failure case studies have been incorporated into the course to enhance student learning. It has specifically been demonstrated that the incorporation of failure case studies into this course has supported the "Professional Component" of the engineering technology curriculum[4].

A study of the World Trade Center Towers 1 and 2 (WTC 1 and WTC 2) collapse has been successfully used in this course to illustrate a number of key concepts supporting technical course objectives, as well as reinforcing professional components of the engineering profession and forensics. This particular case study is seems to be particularly engaging to students because the event occurred during their lifetime, and the impacts of this event are still being felt. Presented during the first two sessions of the course, the WTC collapse case study immediately engages students, providing an excellent overview of how the performance of construction materials under a diverse set of loading and environmental factors influences structural performance. The technical components that can be addressed during the WTC case study can be directly linked to other topics and activities scheduled subsequently during the course.

Method of Instruction

Previous research into the use of case methods in civil engineering courses indicate that a suitable sequence of steps for presenting a case-study in engineering teaching includes[15]:

a. Brief overview of the case
b. Major characters, organizations and their relationships
c. Chronology of the events
d. Discussion of the failure and technical causes
e. Discussion of the non-technical causes
f. Discussion of the % of blame that could have been legally apportioned to the characters and organizations
g. Outcomes for the individuals and organizations

This approach is generally followed, with the exception of items e and f, which are mostly associated with ethical and communications issues impacting failures[15]. The textbook utilized to support implementation of this case study is Federal Emergency Management Agency (FEMA) Report 403, "World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations[16]." Written at a level appropriate for undergraduate engineering and construction management students, this free report provides excellent background information, schematics, and photographs that students find engaging and informative. FEMA 403 can be obtained in hard copy and digital version online[17]. To facilitate immediate engagement of students in the case study, the instructor has obtained enough hard copy editions of FEMA 403 to allow each student to borrow a copy for the course, allowing students to follow along, and utilize the information, schematics, and photographs to facilitate in-class learning and discussion. The case study is presented in a two-lecture format, with a reading assignment from FEMA 403 between the lectures.

It must be noted that the tragic events of 9/11 impacted, and continue to impact, many people. The loss of life occurring due to this event, along with the subsequent issues related to the health and well-being of those responding to and surviving the event, cannot be trivialized as part of this lecture. It is suggested that prior to beginning the lecture, the instructor ask the class if any student has been personally impacted by this tragedy, and appropriate action be taken to ensure the comfort of students with the material prior to beginning the case study. It is strongly encouraged that the instructor inform the students that this topic is being presented as an engineering study of building performance, and is not in any way meant to trivialize the significance of the human life lost during this horrific event.

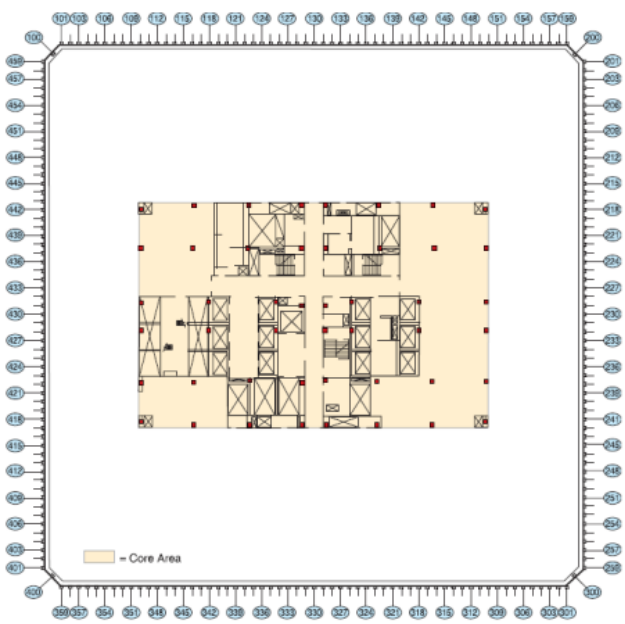
During the first lecture, students are instructed to read a portion of the Executive Summary of FEMA 403 (page 1 to the middle of page 2), which provides an overview of the event, summarizes the timeline and key statistics, and sets the scene for the forensic investigation. The course instructor then introduces the FEMA 403 report as a multi-disciplinary collaborative effort to study the performance of the building at the WTC site, and ultimately to present recommendations to "produce improved guidance and tools for building design and performance evaluation[16]." The diverse affiliations of the forensic investigation team and contributors are identified and discussed, and the rapid timeline of the forensic study, analysis, and preparation of the report.

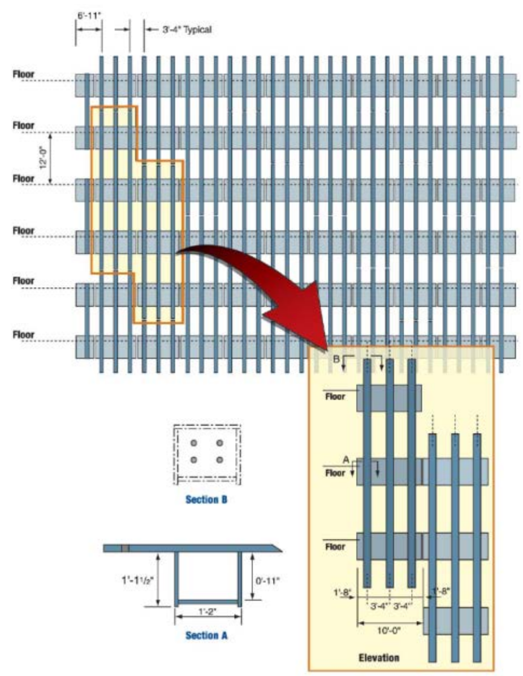
The instructor then opens the floor to a guided discussion of the parts of the Executive Summary read by the students. A key focus of this guided discussion is the fact that the performance of WTC 1 and WTC 2 after the attacks is widely seen as a success (differing from many failure case studies, in which the performance of the structure is truly seen as a "failure"). At the time of the attacks, it is estimated that 58,000 people were present at the WTC complex. Of those present, 2,830 people were killed, including 403 emergency responders. As stated in FEMA 403, "The fact that the structures were able to sustain this level of damage and remain standing for an extended period of time is remarkable, and the reason that most building occupants were able to evacuate safely.[16]" At this point, most students have typically not considered the structural performance of WTC 1 and WTC 2 as one that many have saved lives. Seeing these iconic structures in a new light, and students start to question why the structures' performance allowed so many to escape.

The instructor then presents information on how the WTC 1 and WTC 2 towers were designed. Applicable codes and loads are presented, along with a discussion on the implications of static loads vs. impact loads. Students are often surprised to learn the WTC towers were the first non-military and non-nuclear structures whose design included consideration of impact of an aircraft, (although the Boeing 707 considered in design was smaller and was expected to be traveling at significantly slower speeds than the Boeing 767 aircraft impacting the towers)[16].

The floor plans, elevations, and typical section details presented in FEMA 403 are then introduced. Students are encouraged to consider the performance requirements of composite structural systems and connections. Most junior-level students in this course have taken a construction materials, statics, and engineering mechanics, and this provides an excellent opportunity to review structural details illustrating the use of multiple materials in configurations more complex than those to which students have typically been previously exposed. FEMA 403 has many useful illustrations and photographs that can be utilized to guide the discussion and set the scene for learning about performance of the structure under impact loads and fire exposure.

First, students are introduced to the floorplan of the structures (Figure 1), which had a service core surrounded by space typically occupied by tenants. Key to this part of the introduction is directing the students' attention to the role and configuration of the each building's service core and the core columns. The exterior wall system, comprised of built-up box columns and spandrel panels, is discussed (Figure 2). Implications of the WTC towers designed with a steel "exoskeleton" are alluded to, foreshadowing what will be learned subsequently regarding building performance under loads experienced when the aircraft impacted the towers.





Figures 1 and 2: Representative floor plan for WTC1 (left) and partial elevation of exterior bearing wall-frame (right), (from FEMA 403).

FEMA 403 also presents information on the connections (as shown in Figure 3) and floor systems (Figure 4) that is easily understood by the junior-level students taking this course. Students are typically pursuing either a Civil Engineering Technology degree, a Construction Management degree, or both. Therefore, a brief discussion on the construction of the towers typically follows presentation of the typical details. Figures 5 and 6 are photographs of construction included in FEMA 403, which provides good insight into the scale and challenges related to high-rise construction.

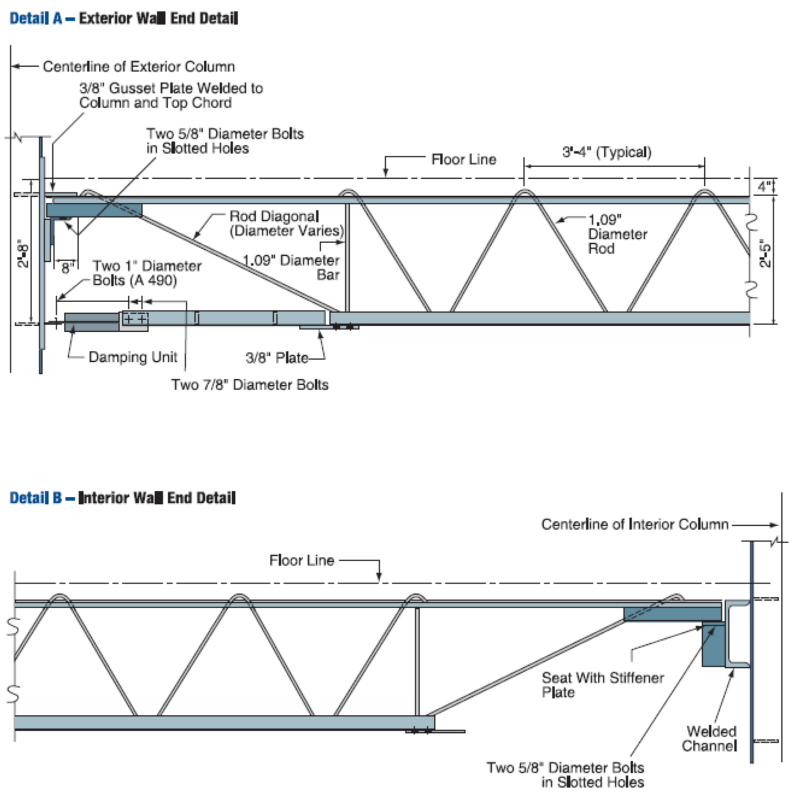


Figure 3: Details of floor truss members and end connections (from FEMA 403).

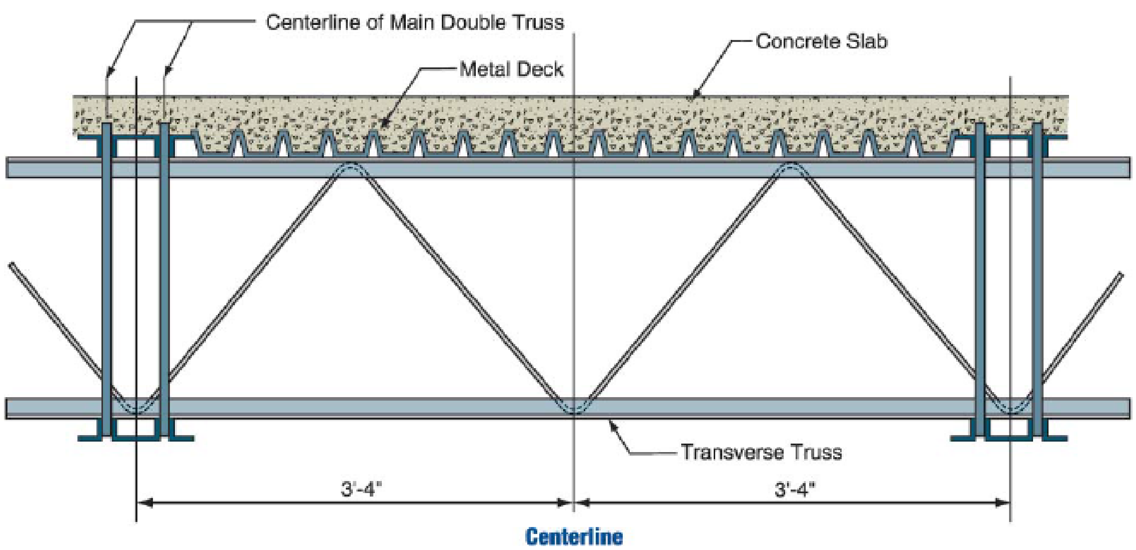


Figure 4: Cross-section of floor framing (from FEMA 403).

Figures 5 and 6: Photographs of erection of prefabricated exterior wall, floor decks, and floor framing during construction (from FEMA 403).

This introductory discussion is facilitated in a manner that, at conclusion of the first class period, ensures the students are familiar with the typical configuration of the WTC towers, and have a basic understanding of the structural components, materials, and construction techniques utilized. The students are then given a reading assignment of Chapter 1: Introduction, Chapter 2: WTC 1 and WTC 2, and the full Executive Summary (in that order), to be performed prior to the next class meeting.

The second lecture begins with a deeper review of the building codes applicable to the design of the structures and a discussion on design loads, presented in chapter 1 of FEMA 403. A simple model (Figure 7) is utilized in this second class period to demonstrate the configuration of the buildings' core and exterior columns, illustrate redundant framing members, and demonstrate responses of the structures to lateral loading. Differences between WTC 1 and WTC 2 are discussed, specifically the orientation of the core of each of the towers. The service core of WTC 1 was oriented east to west, while the service core of WTC 2 was oriented north to south. This orientation plays a key role in the damage each structure experienced (due to the number of core columns damaged during impact) and ultimately, the amount of time each structure was able to remain standing after the impacts of the planes.

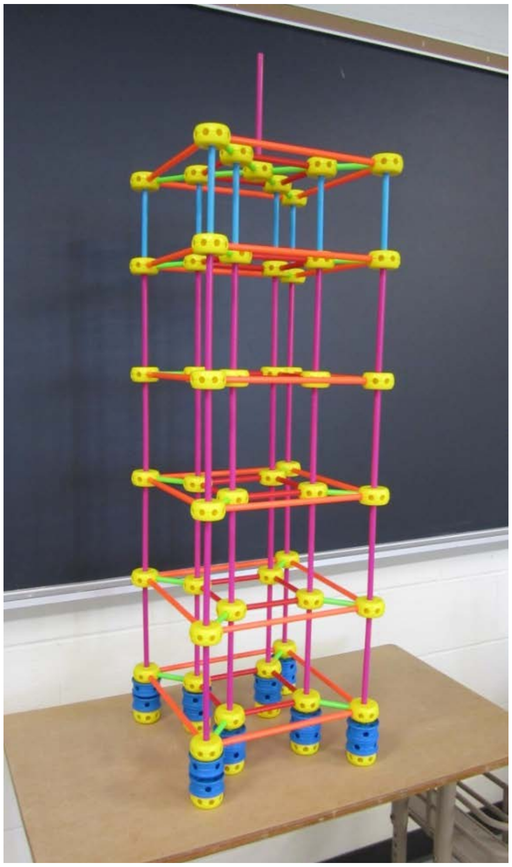


Figure 6: Simple model utilized to illustrate structural framing and to facilitate discussion.

The structural damage resulting from the initial impacts of the aircrafts is then presented and discussed. A summary of details presented in Table 1 is written on the board, supporting lecture information presented on the structural responses of WTC 1 and WTC 2 to the initial impact of each plane. It is emphasized that WTC 2 was struck lower in the tower, at a higher rate of speed. The model (Figure 7) is be used to illustrate the redistribution of load among structural members, particularly by removing "exterior" and "core" columns at higher and lower locations. The orientation of the core columns in relation to the face of the tower impacted is discussed, and it is pointed out that it is suspected that WTC 2 experienced damage to more core columns than WTC 1 .

Table 1: Summary of Initial Impacts on WTC 1 and WTC 2

Building	Speed of Aircraft Impact	Location of Impact	# exterior columns destroyed	Duration standing after impact
WTC1 (North Tower)	470 mph	94^{th} through 98^{th} floors	31-36 columns (all 4 stories)	1 hour 43 min
WTC2 (South Tower)	590 mph	78^{th} through 84^{th} floors	27-32 columns (all 5 stories)	56 min

The increased stresses experienced in structural members due to load transfer from damaged/destroyed members should be discussed, as well as the unintended types of loading (additional moments, torsion, etc.) resulting from the cantilevered structure remaining above the areas of the structures destroyed by the initial impact of the planes. FEMA 403 states that the actual loads experienced by some members was computed to be higher than the design loads[16], which facilitates discussion on safety factors, material properties, and redundancy in design. It is presented that despite significant structural damage, including localized collapse of substantial sections of the structure at the zone of impact, both WTC 1 and WTC 2 withstood the initial impact of the aircraft, and remained standing. This performance allowed time for a large number of occupants to exit the buildings and flee the site, and ultimately saving many lives.

It is stressed during this portion of the case study that the WTC attacks of 9/11 can be seen from a forensic standpoint as a two-part event. First, the impact of the aircraft, and second, the exposure of the structures to fire. Jet fuel from the aircraft ignited upon impact starting fires in both WTC 1 and WTC 2. As fuel flowed across floors and through elevator and utility shafts, fires spread through areas of the building adjacent to those directly impacted by the aircrafts[16]. Although the exact sequence of events leading to the collapse of WTC 1 and WTC 2 will likely never be identified, effects of the fire leading to the collapse are outlined in FEMA 403 in a manner that can be understood by undergraduate engineering technology and construction management students, and utilized to reinforce a number concepts previously learned in other courses. Details on structural fire protection are shown, and students can be introduced to the materials utilized in fireproofing. Discussion on the performance of fireproofing materials after the impact of the aircraft is facilitated, along with the impact of damage to fire prevention measures (sprinklers) and the locations of access/egress to the upper floors of the towers.

The presentation then moves to introducing the role of fire in softening and weakening of the structural steel. A discussion on the reduction of yield strength and modulus of elasticity is easily facilitated by the illustrations and discussion in FEMA 403. Implications of the extreme heat on the expansion of the concrete floor system, shown in Figure 8. Expansion of the floor systems placed excessive stresses on the floor framing connections, likely resulting in failures[16]. Caternary action, the result of temperature-induced weakening and sagging of floors also likely led to failure of end connections of the floor slabs[16], can also be presented and discussed, utilizing figures from FEMA 403. Progressive collapse, and its implications on current design practices, are also discussed, as this was the end result of the damage sustained[16].

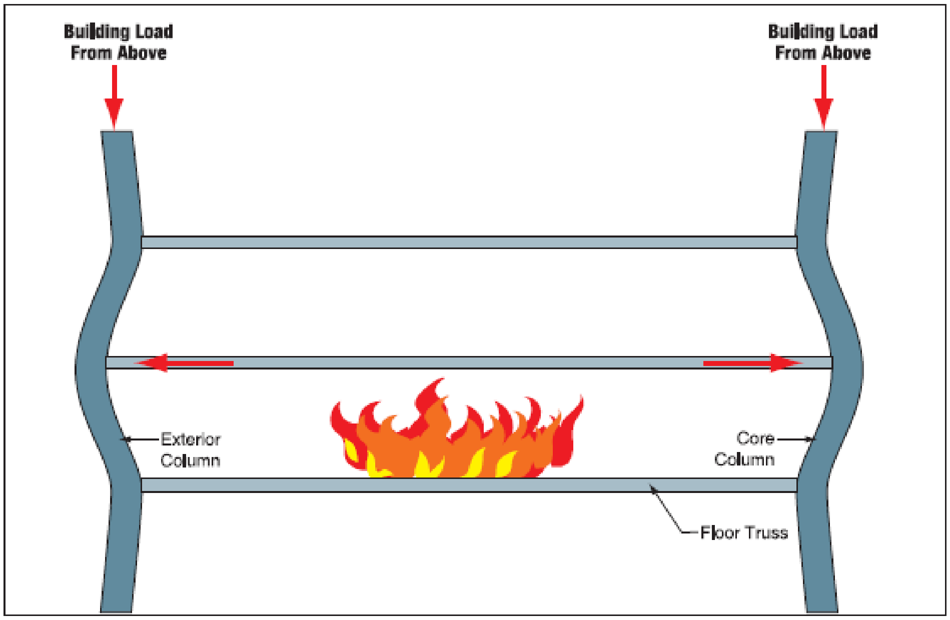


Figure 8: Effects of fires on expansion of floor slabs (from FEMA 403).

At this point in the lecture, it is appropriate to restate that the findings of the investigation indicated that despite the massive initial damage, WTC 1 and WTC 2 were able to remain standing for “remarkable” lengths of time, allowing most of the occupants to evacuate. The combined effects of the aircraft impacts and the subsequent fires ultimately resulted in collapse after fires spread and some length of time of exposure occurred. Ultimately, the overall performance of the WTC 1 and WTC 2 structures was overwhelmingly effective, with FEMA 403 noting that “many buildings with other design and construction characteristics would have been more vulnerable to collapse in these events than the two towers[16].”

Recommendations of the report are presented and class discussion is facilitated. A key finding presented in FEMA 403 is that the redundancy and robustness of the WTC structural framing systems allowed the structures to remain standing after initial impact[16]. Recommendations for additional study of the performance of connections under impact and fire loads are discussed. Considerations related to fire performance (fireproofing, fire protection systems, and access/egress design) are also included in FEMA 403, and can be identified and discussed.

As stated previously, the WTC towers case study is used as the first and second lectures in the Structures and Materials Laboratory course. Subsequent exercises in the course include materials testing experiments and structural experiments utilizing small-scale load frames. In addition to providing an engaging introduction to the key structural and materials-related performance issues supporting the course objectives, Appendix D of FEMA 403 provides information on the data collection methodology used to support the performance study. This can be directly linked to good laboratory practices that are taught and reinforced in this and other laboratory courses in the undergraduate engineering technology and construction management curriculum. Appendix D details the efforts of the Building Performance Study Team and the Structural Engineers Association of New York (SEAoNY) to identify pieces of steel that may provide insight into the performance of the WTC strucutres, and be preserved for future study[16].

The strategies used to select pieces of interest, as well as documentation methodologies are presented. A portion of a detailed spreadsheet summarizing some of the steel pieces identified, selected, and cataloged provides a useful tool for illustrating the importance of documentation and notetaking. Ultimately, Appendix D is utilized in this case study as an introduction to forensic engineering, reinforcing the value of learning from failure.

Assessment

At the conclusion of the WTC case study, students are quizzed to evaluate their technical understanding of the material. Two different types of quizzes have been utilized. One type of assessment tool (included as Appendix A) is a written response assignment, asking students to explain the 9/11 WTC events and collapse from a structural perspective. The second assessment tool (included as Appe**n**dix B) is a multiple-choice quiz, focusing on terminology and key concepts. For several years, as part of the NSF Case Studies project, surveys to evaluate the impact of this case study (and several others introduced later in this course), on students' interest in the engineering profession have been administered. Data from these studies is presented in a previous publication[2].

Summary and Conclusions

Ultimately, it has been shown that lessons learned from failure case studies have improved civil engineering practice[9]. Based on qualitative student feedback obtained verbally and from end-of-semester course evaluations, the WTC case study captures attention and supports the course objectives of this undergraduate engineering technology and construction management course. As part of the NSF Case Studies project, surveys taken at the conclusion of the course assessed the students' perceptions of the case study's impact on their interest in, and their understanding of, the engineering profession. It was found that understanding gained from this case study (and others incorporated more briefly in the course) reinforce both the Technical Component and Professional Component of ABET Criterion 3 student outcomes[4]. Incorporation of the WTC collapse, as presented in FEMA 403, into a junior-level engineering technology course has been shown to support student learning outcomes[4]. The authors hope that this case study has provided sufficient detail for others to integrate it into their courses.

Acknowledgements

Support for this research was provided by the National Science Foundation under the project "Developing Case Studies in Failures and Ethics for Engineering Educators," project number DUE 0127419 and "Implementation and Assessment of Failure Case Studies in the Engineering Curriculum," project number DUE 0919487. Opinions expressed are solely those of the authors and not of the National Science Foundation.

Appendix A – Writing-Based Assessment Tool

ETCE 3163L – WTC Building Performance Study Quiz
You are at a lunch meeting with a business client, and the events of 9/11 come up in conversation. The client, who is an intelligent person but is not an engineer, asks you to:

- briefly describe the structural damage caused by the initial aircraft impacts and immediate ignition of jet fuel (just to the towers, WTC Buildings 1 and 2)
- briefly describe what happened to individual structural components (after initial impact) that contributed to the progressive sequence of failures that resulted in total collapse of the WTC 1 and 2 structures

Appendix B – Multiple Choice Assessment Tool

1. True or false: Failure of the connections between the concrete slab and the columns caused progressive collapse of the WTC 1 and WTC 2 structures.

2. True or false: Cohesive failure of the fireproofing caused decreased resistance of steel structural members to the effects of heat and fire.

3. True or false: Concrete floor slabs contracted due to the elevated temperatures near the fires, causing connections to fail.

4. True or false: Interior (core) columns in WTC 1 and WTC 2 were oriented in the same direction.

5. True or false: Structural members not damaged or destroyed by the impact of the planes were subjected to additional loads from the damaged/destroyed members.

6. True or false: Professionals involved in preparing this report had no recommendations regarding emergency egress and placement of stairwells.

7. True or false: The authors of this report feel that given the circumstances involved in the terrorist attacks, WTC 1 and WTC 2 performed remarkably well (from a structural perspective)

8. True or false: A spandrel beam is a beam that spans between columns on the exterior face of a frame structure.

9. From a structural perspective, which of the following terms means “capable of performing without failure under a wide range of conditions.”

   a. redundant
   b. durable
   c. robust
   d. permeable

10. WTC 2, which was hit by the second plane, collapsed before WTC 1. Which is NOT a contributing reason:

a. the plane that hit WTC 2 was travelling at a greater speed than the plane that hit WTC 1
b. the plane that hit WTC 2 hit at a lower point on the structure than the plane that hit WTC1
c. fewer core columns in WTC 2 were damaged/destroyed than in WTC 1
d. more core columns in WTC 2 were damaged/destroyed than in WTC 1

Appendix C – End of Semester Survey on the Impact of Case Studies

Student Course Survey

Course: ETCE 3163L **Instructor:** **Term: Fall 2013**

Please rate the following with respect to your overall perception of the use of failure case studies in this class:

	The case studies will contribute to:	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
A	my ability to apply knowledge of mathematics, science, and engineering;	5	4	3	2	1
B	my ability to design and conduct experiments, as well as to analyze and interpret data	5	4	3	2	1
C	my ability to design a system, component, or process to meet desired needs, using the principles of equilibrium;	5	4	3	2	1
D	my ability to function on multi-disciplinary teams	5	4	3	2	1
E	my ability to identify, formulate, and solve engineering problems;	5	4	3	2	1
F	my understanding of professional and ethical responsibility	5	4	3	2	1
G	my ability to communicate my problem solutions effectively;	5	4	3	2	1
H	the broad education necessary to understand the impact of engineering solutions in a global and social context	5	4	3	2	1

I	my recognition of the need for, and an ability to engage in life-long learning	**5**	**4**	**3**	**2**	**1**
J	my knowledge of contemporary issues	**5**	**4**	**3**	**2**	**1**
K	my ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	**5**	**4**	**3**	**2**	**1**

If you marked "disagree" or "strongly disagree" on any of the above, please identify as specifically as possible what you perceive as problems and ways of correcting the problems. Also, please provide any other comments related to the class and your preparedness to complete it successfully.

Will the failure case studies contribute to your INTEREST in the course material for ETCE 3163 (lecture) and/or ETCE 3163L (laboratory)?

	Very High	High	Moderate	Low	Very Low	Not Applicable
Textbook readings	**5**	**4**	**3**	**2**	**1**	**N/A**
Classroom lectures	**5**	**4**	**3**	**2**	**1**	**N/A**
Homework and problem sets	**5**	**4**	**3**	**2**	**1**	**N/A**
Projects	**5**	**4**	**3**	**2**	**1**	**N/A**

Will the failure case studies contribute to your UNDERSTANDING of the course material for ETCE 3163 (lecture) and/or ETCE 3163L (laboratory)?

	Very High	High	Moderate	Low	Very Low	Not Applicable
Textbook readings	**5**	**4**	**3**	**2**	**1**	**N/A**
Classroom lectures	**5**	**4**	**3**	**2**	**1**	**N/A**
Homework and problem sets	**5**	**4**	**3**	**2**	**1**	**N/A**
Projects	**5**	**4**	**3**	**2**	**1**	**N/A**
Exams	**5**	**4**	**3**	**2**	**1**	**N/A**

References:

[1] Delatte, N., and Rens, K., “Forensics and Case Studies in Civil Engineering Education: State-of-the-Art,” *ASCE Journal of Performance of Constructed Facilities*, Vol. 16, No. 3, August, 2002.

[2] Failure Case Studies: Civil Engineering and Engineering Mechanics, http://matdl.org/failurecases/Main_Page.

[3] Delatte, Norbert J., (2009) *Beyond Failure: Forensic Case Studies for Civil Engineers*, ASCE Press.

[4] Delatte, N.J., Bagaka's J.G., Roberts, M.W., Atadero, R.A., Zoghi, M. Johnson, P.W., Cavalline, T.L., and Thompson, M.K. (2013). “Results from Implementation and Assessment of Case Studies in the Engineering Curriculum,” Proc., 2013 American Society for Engineering Education Annual Conf. & Exposition, Atlanta, Georgia, June 2013.

[5] Delatte, N., Bosela, P., Rens, K., Carper, K., and Sutterer, K., *Findings from Workshops on Failure Case Studies in the Civil Engineering and Engineering Mechanics Curriculum*, 2007 ASEE Annual Meeting

[6] Delatte, N., Sutton, R., Beasley, W., and Bagaka’s, J., *Assessing the Impact of Failure Case Studies on the Civil Engineering and Engineering Mechanics Curriculum*,, 2007 ASEE Annual Meeting

[7] Delatte, N., Bosela, P., Sutton, R., Beasley, W., and Bagaka’s, J., *Assessing the Impact of Case Studies on the Civil Engineering and Engineering Mechanics Curriculum, Phase II,* 2008 ASEE Annual Meeting

[8] Delatte, N.J., Roberts, M., Ralston, P., Brady, P., Zoghi, M., Hagerty, D.J., and Yu, X. (2010). “Implementation and Assessment of Case Studies in the Engineering Curriculum: Work in Progress” *Proc., 2010 American Society for Engineering Education Annual Conf. & Exposition,* Louisville, Kentucky, June 2010.

[9] Delatte, N.J., and Bagaka's, J.G. (2014), “Assessment Results: Incorporating Case Studies in the Civil Engineering Curriculum,” *Proceedings of the 2014 American Society for Engineering Education Annual Conference & Exposition,* Indianapolis, Indiana, June 2014.

[10] Bagaka’s, J.G., Delatte, N.J., and Bosela, P.A. (2012), “The Role of Exposure to Failure Case Studies on Students’ Technical and Professional Growth: A Mixed Method Approach,” *Proc., 2012 American Society for Engineering Education Annual Conf. & Exposition,* San Antonio, Texas, June 2012.

[11] Norbert J. Delatte, “Failure Case Studies in the Civil Engineering and Engineering Mechanics Curriculum: A New Textbook,” *Proceedings of the 2009 American Society for Engineering Education Annual Conference & Exposition,* Austin, Texas, June 2009

[12] Pearson, C. and Delatte, N. (2006) “The Collapse of the Quebec Bridge, 1907,” ASCE Journal of Performance of Constructed Facilities, February 2006.

[13] Ashish Patel; Paul Bosela; Norbert J. Delatte (2013). “The 1976 Montreal Olympics: A Case Study of a Project Management Failure.” ASCE Journal of Performance of Constructed Facilities, 27(3), 362-369.

[14] Jeffrey Schellhammer; Norbert J. Delatte, and Paul Bosela, (2013). “Another Look at the Collapse of Skyline Plaza at Bailey's Crossroads, Virginia.” ASCE Journal of Performance of Constructed Facilities, 27(3), 354-361.

[15] Newson, T.A., and Delatte, N.J. (2011). “Case methods in civil engineering teaching.” Canadian Journal of Civil Engineering, 38(9), 1016-1030.

[16] McAllister, T., (editor) (2002). “World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations.” Federal Emergency Management Agency (FEMA) Report 403. Washington, D.C.

[17] Federal Emergency Management Agency (FEMA) 403, World Trade Center Building Performance Study (2002). https://www.fema.gov/media-library/assets/documents/3544.