Failures Education

The Key to Better Engineering Design

By M. Kevin Parfitt and Elizabeth E. Parfitt

Buildings and related structures that experience collapse, severe damage, performance problems or related forms of failure are not as rare as many engineers might imagine, or care to admit. A wide variety of structural failures occur every day throughout the world. These failures can be attributed to a number of factors including natural disasters, design oversights, construction mishaps, procedural and communication errors, material defects, deterioration, terrorism, and even lack of routine maintenance. Unfortunately, the aftermath of structural failures often receives more attention than the initial prevention. Many of these failures receive national publicity after the fact, when investigators or the media broadcast the cause and place the blame. However, with a more diverse background in structural failures education and awareness, most failures can be prevented, or at least reduced in magnitude.

Failures do not discriminate or target specific groups of individuals or structures. The largest of construction projects can be marred by the smallest of triggering events. This was the case in July 2006, when a woman was killed by the collapse of a concrete ceiling panel, set in motion by an anchor failure in the Interstate 90 Connector tunnel on a portion of Boston's $14.6 billion Big Dig. While nothing can compare to the loss of an innocent life due to a structural collapse, the cracking of a basement wall in a residential structure due to lateral soil pressure, which results in expensive repairs and a loss of equity, remains a serious matter to the homeowner.

Structural collapses are not the only type of failures that lead to building damage and economic loss. A broader view, popular with many forensic engineers, defines failure as any system that does not perform as intended. Under this definition, the number of failures we experience each year quickly expands and includes performance-related issues such as excessive deflections, floor vibrations, improper bracing or shoring during construction, exterior wall and roof problems, maintenance issues, deterioration of various building materials, and human factors.

Failures Education in the Classroom

The need for forensic education applies across the industry, starting in the colleges and universities training our next generation of engineers and construction professionals, and continuing to practicing engineers, architects, construction practitioners and even project owners.

A number of challenges and difficulties exist in developing failures-related courses or implementing significant failures modules in existing courses. Roadblocks include the availability of quality failures instructional information and case history modules for the classroom; a lack of course instructors with significant practical or forensic experience to teach failures courses; and, finding room in the curriculum to implement failures studies or a stand-alone course.

Despite these obstacles, many institutions are now offering forensic courses, as well as incorporating more failures information into their existing curriculums, including Cleveland State University, The University of Colorado at Denver, Mississippi State, Penn State University, Portland State University, Rose-Hulman Institute of Technology, Washington State University, and Worcester Polytechnic Institute. Each school customizes its efforts to fit the curriculum and available resources. For example, Cleveland State addresses failures education by concentrating on the valuable lessons that can be learned from case studies, while Rose-Hulman uses a service-learning technique, combining forensics with its engineering capstone design projects.

At Penn State, a course titled "Building Performance Failures and Forensic Techniques" is offered in the Department of Architectural Engineering, where it is available to graduate and upper-level undergraduate students. This course incorporates a study of structural failures and collapses, and also takes an architectural engineering approach that includes a focus on structural and architectural building systems and materials as follows:

- Building envelope failures (facades and roofs)
- Flashing, waterproofing, sealants, and related issues
- Structural failures – special loadings, damage assessment, full and partial collapses, and structural performance
- Historic preservation issues for buildings
- Durability, deterioration, maintenance, and repair of building materials
- Failures due to communication and procedural issues or errors
- Legal issues and the role/responsibilities of an expert witness
- Ethics in engineering practice

The exact number of institutions incorporating failures education concepts into their curricula is unknown, but is believed to be increasing. In an effort to document this trend,

Organizations Offering Failures-Related Publications, Training, and Workshops

- American Society of Civil Engineers: Technical Council on Forensic Engineering (TCFE), Structural Engineering Institute (SEI) and Architectural Engineering Institute (AEI) **http://www.asce.org**
- TCFE Faculty Workshop on Failure Case Studies in the Civil Engineering Curriculum. Contact: Norbert Delatte, Ph.D., P.E., Cleveland State University, **n.delatte@csuohio.edu**
- National Academy of Forensic Engineers (NAFE), **http://www.nafe.org** affiliated with the National Society of Professional Engineers (NSPE), **http://www.nspe.org**
- ASFE, Inc. Trade association of Member Firms that specialize in earth engineering and related applied science services. **http://www.asfe.org**
- Council of American Structural Engineers (CASE) **http://www.acec.org/coalitions/CASE**
- National Council of Structural Engineers Associations (NCSEA) **http://www.ncsea.com**

the Education Committee of the ASCE Technical Council on Forensic Engineering (TCFE) has initiated a project to gather information and statistics on failures education efforts by conducting a national survey of ABET-accredited architectural and civil engineering schools. Regardless of the educational format, practitioners and educators agree that failures education is extremely helpful in preparing future generations of civil, structural, and architectural engineers to be valuable members of the professional community.

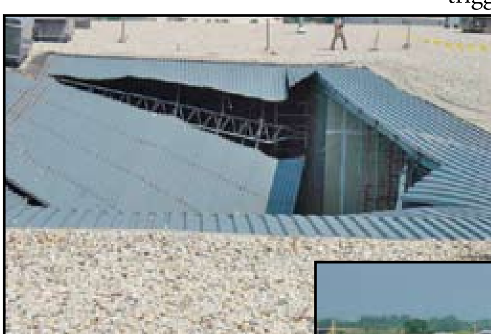
Educating Practitioners about Failures

Most engineers, even those who have been involved in the profession for a number of years, recognize the need for life-long learning. For these professionals, the goal when studying failures is not to become forensic engineers, but to learn from failures in order to become better engineering designers.

For practicing engineers, failures education takes on a number of different forms, usually encompassing a combination of self-study, continuing education programs, workshops, structural and forensic-related conferences, seminars targeting specific practice areas (such as designing for natural hazards, building assessment due to deterioration-related distress or historic preservation), and more formal classroom or web-based courses. Many of these educational activities serve the dual role of enhancing the skills of those practicing in the area of forensic engineering or failures analysis, along with educating practicing engineers on how to avoid failures on their own projects by learning from historical mistakes that have taken place in the industry.

A Breadth of Knowledge is Required

Failures education for students or practicing structural engineers should not be limited to collapses or even the structural discipline. Those who study failures as a topic, or who have looked at an extensive number of failure case histories, recognize that failures involving severe damage and collapse usually occur when a number of factors, not all of them necessarily technical in nature, go wrong at the same time. In reality, collapses resulting from a single design error by an engineer are rare. Miscommunication, procedural issues, lack of coordination, and poor attention to details often must combine in some manner to overcome the built-in safety factors and redundancies of our designs.



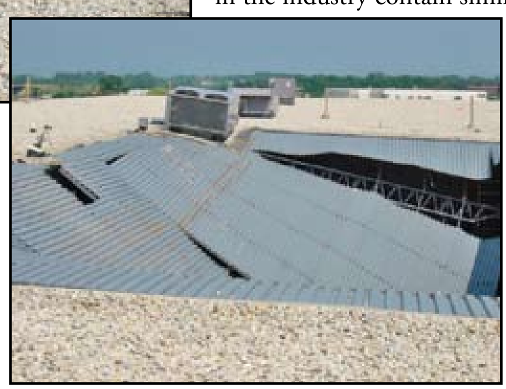


Figure 1: Failures may be the result of a variety of causes that are not necessarily directly tied to the structural design.

Recognizing what can go wrong from a variety of perspectives is the first step in learning how to prevent failures and improve the quality of engineering designs. Consider the example of a roof failure that took place at a large, one-story, multi-use communications office/service center located in the Midwest (*Figure 1*) as the result of a sudden violent wind and rainstorm. Was the collapse a structural issue related to strength design of the roof framing; failure to design the framing for ponding; a fabrication issue centering on the girder support detail at the column; a problem with drainage resulting from the overall slope of the roof surface or the number and spacing of the internal roof drains; an installation problem with the EPDM roof membrane where it interfaces with the drain; or some combination of these factors? Each of the potential failure factors mentioned requires specific design and construction applications knowledge that must be used together to create an overall safe and properly functioning roof structure. This demonstrates how important failures education can be, particularly in the initial design stage.

Studying Case Histories

Experience is one of the most valuable educational formats available, and most engineers learn from their previous experiences, including problems and setbacks. Learning from the mistakes of others is also a valuable method for supplementing an engineer's personal work background, especially for younger engineers with less professional experience. Of particular value to practicing engineers is the large number of available case history studies, which can provide insight into patterns of failure that may develop in certain types of systems or materials. Many case studies of this nature have been published in the past in the pages of STRUCTURE®. Studying past failures is particularly helpful in identifying the human component of failure, which encompasses communication problems and procedural errors.

Case studies of failures in buildings and other structures reveal what is often a complex interaction of technical issues, miscommunication, procedural errors and missed opportunities to prevent the failure in the first place. The case of the collapse of the Kansas City Hyatt walkways in July of 1981 is a good example of a failure providing a textbook example for learning what not to do. Procedural errors, ethical lapses, and many missed opportunities for catching the problem prior to collapse have made the Hyatt walkway failure one of the most valuable and frequently studied case histories in the structural engineering profession. With 114 deaths and over 180 injuries, the failure was the worst unintentionally triggered structural building collapse in United States history. The steel rod hanger connection, a simple statics problem that could be solved by any entry-level engineer, was simply the physical trigger mechanism in a failed project procedural system.

In the years following the collapse of the walkways, many individuals acknowledged that problems existed with the meaning of "shop drawing review" and the overall responsibility of the Structural Engineer of Record for connection design. To this day, some engineers question how well we learned the lessons of this and other tragic, well-known case histories. Considering that many of the more recent structural failures experienced in the industry contain similar ingredients for failure, especially where systems interface and signs of flawed procedural systems are present, this question is valid.

Technical failures are often just the outward sign of more basic problems, such as poor practice management skills. A recent study by the insurance industry firm XL Design Professional, which involved an analysis of claims reviewed between 1989 and 2000, revealed that communication issues were a contributing factor in 27% of the claims filed. An in-depth evaluation of many failure case histories often reveals problems with communication among participants; confusing or missing documentation; and poorly executed construction observation.

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The Next Step

An excellent source of failures education for practicing engineers is attendance at the many conferences, development programs, and seminars offered by professional societies and continuing education providers associated with our industry. (*See Sidebar on page 10*)

Practicing engineers who are interested in obtaining more information on failures and forensics practice or failures continuing education should focus on the 2007 Structures Congress hosted by SEI. The congress is scheduled for Long Beach, California, May 16-20, 2007, and will feature a variety of structural engineering topics related to improving engineering design to prevent failures, such as structural design for natural hazard and blast loadings, and the assessment of distressed and historical buildings. Also included at the congress is a forensics track with workshops and presentations on failures education, case studies, forensic investigations, fracture mechanics, geotechnical engineering failures, and the latest information on the forensic studies performed in the aftermath of Hurricane Katrina.

For educators who would like to begin offering forensic courses, the most concentrated and comprehensive source of information is the TCFE Education Committee's "Faculty Workshop on Failure Case Studies in the Civil Engineering Curriculum". This day-long workshop features speakers experienced in failures education programs from throughout the United States, and the participants are provided with a workbook featuring failure case history teaching modules in electronic and paper form, as well as a wealth of references and back-up material. Current plans call for the next session of this workshop to be offered in Denver this summer. (*See Sidebar for Contact Information*)

Learning from Failures Remains the Key to Prevention

Major high-profile structural collapses — such as the concrete flat plate Skyline Plaza building at the Bailey's Crossroads housing development in 1973, the Kemper Memorial Arena space frame suspended roof in 1979, lift slab construction of the L'Ambiance Plaza in 1987, the Murrah Federal Building in Oklahoma City in 1995, and the Pentagon and World Trade Center in 2001 — have led to changes in industry standards, design codes, and overall methods of practice.

There will always be failures and structural collapses. Our duty is to work to improve the quality of our constructed facilities and eliminate as many cases of failure as possible.

Some of the more recent well-publicized failures — including the fire that killed 100 people at The Station nightclub in West Warwick, Rhode Island in 2003, the collapse of sections of Terminal 2E at the Charles de Gaulle Airport in 2004, and the de la Concord Boulevard highway overpass near Montreal in 2006 — will continue to provide new knowledge and engineering lessons learned in the coming months and years. The degree to which we learn from these events, and in turn educate within our own profession, will directly impact how many more catastrophic failures will occur in the future.▪

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Reference Publications on Failures and Failures Education

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