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Case methods in civil engineering teaching¹

Timothy A. Newson and Norbert J. Delatte

Abstract: There have been significant changes in undergraduate civil engineering curricula in the last two decades. Key issues for university curriculum committees are selection and transference of appropriate skills and attributes for students to succeed in the industry. Despite significant changes occurring in teaching theories, civil engineering education still relies heavily on deductive instruction. Case-based teaching is one of the most widespread forms of inductive learning and this paper describes the differences between two of the most familiar types: 'case-histories' and 'case-studies'. These methods are presented using the Kansas City Hyatt Regency walkway collapse as an exemplar. The benefits of using this approach are improved retention of knowledge, better reasoning and analytical skills, development of higher-order skills, greater ability to identify relevant issues and recognize multiple perspectives, higher motivation and awareness of non-technical issues. Many of these outcomes are part of the expected attributes of civil engineers outlined by professional bodies.

Key words: civil engineering, education, pedagogy, inductive teaching, case-study, case-history, constructivism, failure, problem-solving, structures.

Résumé : Les programmes d'enseignement de premier cycle en génie civil ont subi de grands changements au cours des deux dernières décennies. Les questions clés pour les comités de programmes universitaires sont la sélection et le transfert des connaissances et des qualités appropriées aux étudiants pour qu'ils réussissent dans l'industrie. Malgré des changements importants dans les théories d'enseignement, l'éducation en génie civil est encore grandement fondée sur l'apprentissage déductif. L'enseignement basé sur des cas est l'une des formes les plus étendues de l'apprentissage inductif et le présent article décrit les différences entre les deux types les plus familiers : l'étude des dossiers individuels et la méthode des cas. Ces méthodes sont présentées en utilisant l'exemple de l'effondrement de la passerelle du Hyatt Regency de Kansas City. Les avantages d'utiliser cette approche sont une rétention améliorée des connaissances, de meilleures capacités analytiques et de raisonnement, le développement de capacités d'ordre supérieur, une meilleure capacité à identifier les questions pertinentes et à reconnaître les multiples points de vue, une meilleure motivation et une sensibilisation aux questions non techniques. Plusieurs de ces résultats font partie des qualités escomptées chez les ingénieurs civils, tels que soulignées par les corps professionnels.

Mots-clés : génie civil, éducation, pédagogie, enseignement inductif, méthode des cas, étude de dossiers individuels, constructivisme, défaillance, résolution de problèmes, structures.

1. Introduction

Over the last 20 years there have been significant changes in undergraduate civil engineering curricula in response to student, industry and societal needs, accrediting professional bodies and government organisations. In part this has been due to improvements in computational analysis and design in various fields, and greater recognition of the advantages of 'soft skills' to the engineering profession, but it has also been driven by research advocating more student-centred learning and teaching approaches (e.g., Entwistle 1988; Ramsden 1992; Biggs 1999; Fry et al. 1999). Hence a plethora of new and potentially contradictory educational theories are now entering our field, most of which have been developed in other disciplines. However, engineering is now beginning to generate its own body of specific literature, al-

lowing greater validation and confidence of the effectiveness of different educational approaches (e.g., Russell and McCullough 1990; Fitzgeard 1995; Richards et al. 1995; Chinowsky and Robinson 1997; Buch and Wolff 2000; Stahovich and Bal 2002; Felder and Brent 2004; Smith et al. 2005; Prince and Felder 2006).

Key issues for university curriculum committees are the selection and transference of a definitive group of skills and attributes that they expect students to acquire before graduation, to best prepare them for a career in the industry. There has been much research and discussion within academia and industry on this subject (e.g., Williams 1988; Henshaw 1991; Harvey et al. 1997; Yorke 1999; Blum 2000; Mills and Treagust 2003). Aktan et al. (2005) proposed a wide range of knowledge and competencies that they believed civil engi-

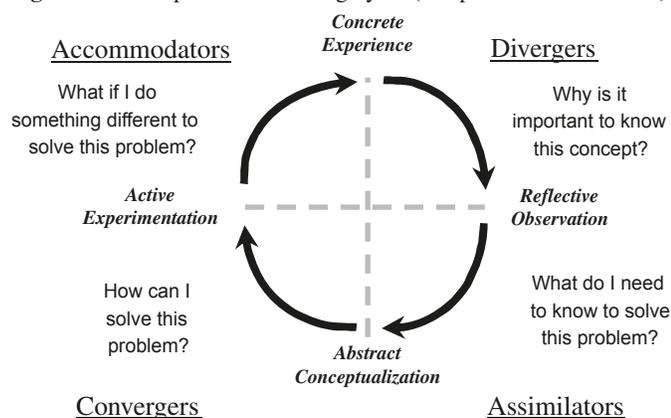
Table 1. Educational outcomes from the ASCE ‘Body of Knowledge’ first edition (ASCE 2004; ABET 2007).

	Educational outcomes
1	An ability to apply knowledge of mathematics, science and engineering.
2	An ability to design and conduct experiments, as well as analyze and interpret data.
3	An ability to design a system, component or process to meet desired needs.
4	An ability to function on multi-disciplinary teams.
5	An ability to identify, formulate and solve engineering problems.
6	An understanding of professional and ethical responsibility.
7	An ability to communicate effectively.
8	The broad education necessary to understand the impact of engineering solutions in a global and societal context.
9	A recognition of the need for, and an ability to engage in, life-long learning.
10	A knowledge of contemporary issues.
11	An ability to understand the techniques, skills, and modern engineering tools necessary for engineering practice.
12	An ability to apply knowledge in a specialized area related to civil engineering.
13	An understanding of the elements of project management, construction, and asset management.
14	An understanding of business and public policy and administration fundamentals.
15	An understanding of the role of the leader and leadership principles and attitudes.

Table 2. Epistemological Reflection Model (Baxter-Magolda 1992).

Domains	Absolute knowing	Transitional knowing	Independent knowing	Contextual knowing
Role of learner	Obtains knowledge from instructor	Understands knowledge	Thinks for self Shares views with others Creates own perspectives	Exchanges and compares perspective Thinks through problems Integrates and applies knowledge
Role of peers	Share materials Explain what they have learned to each other	Provide active exchanges	Share views Serve as a source of knowledge	Enhance learning via quality contributions
Role of instructor	Communicates knowledge appropriately Ensures that students understand knowledge	Uses methods aimed at understanding Employs methods that help apply knowledge	Promotes independent thinking Promotes exchange of options	Promotes application of knowledge in context Promotes evaluative discussion of perspectives Student and teacher critique each other
Assessment	Provides vehicle to show instructor what was learned	Measures students understanding of the material	Rewards independent thinking	Accurately measures competence Student and teacher work towards goal and measure progress
Nature of knowledge	Is certain or absolute	Is partially certain and partially uncertain	Is uncertain – everyone has their own beliefs	Is contextual; judged on basis of evidence in context

Fig. 1. Kolb’s experiential learning cycle (Adapted from Kuri 1998).



neers should possess in the 21st century, given the changing needs of society. Their discussion included the role and the current state of civil engineering education in North America. Central to this dialogue are educational criteria developed by professional engineering bodies, such as the ASCE ‘Body of Knowledge’ first and second editions (ASCE 2004, 2008) and ABET (2007), which are shown in Table 1. In this table, outcomes 1 through 11 were provided by ABET and outcomes 12 through 15 were added to these in the first edition of the ASCE Body of Knowledge (ASCE 2004). Similar criteria are published by other professional accrediting bodies around the world (e.g., *Canadian Engineering Accreditation Board* [CEAB], *Standards and Routes to Registration* [SAR-TOR, UK] and *Institution of Engineers Australia* [IEAust]). All of the learning outcomes in these schemes are designed to develop substantial depth and breadth of knowledge, skills

Fig. 2. Kansas City Hyatt Regency atrium walkways (NBS/NIST).



Fig. 3. Rod, connection, and deck details – ‘designed’ and ‘as-built’ (Adapted from Marshall et al. 1982).

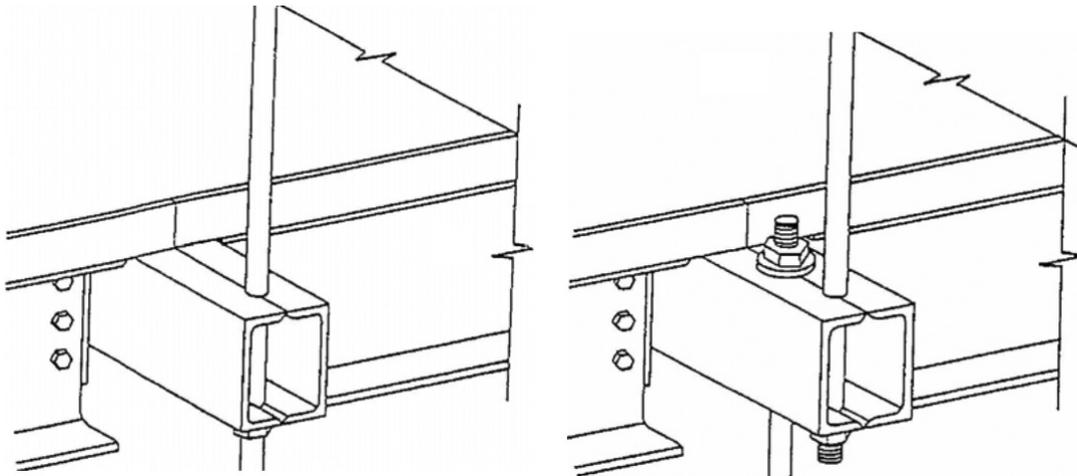
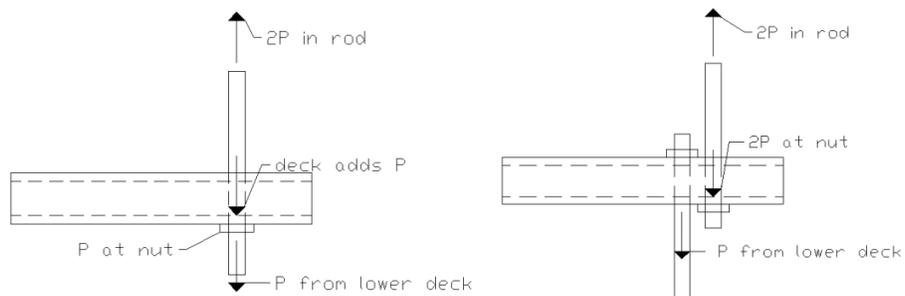


Fig. 4. Load path diagrams (Adapted from Delatte 1997).



and qualities in graduates entering civil engineering practice, and many of them relate to higher cognitive abilities. Whilst the educational outcomes may be clear, the routes towards effective learning and teaching are less obvious (Aktan et al.

2005). Given the extensive body of aspirations that continue to develop for university undergraduate teaching, significant additional pressures can build in already congested timetables. Therefore only those teaching methods that are robustly

validated and easily incorporated will lead to the necessary changes in curricula and pedagogies that will achieve the ambitions of the industry.

In the early 1990s, Professor Alan Davenport was intrigued by a debate that unfolded in his home between his daughter and a number of her peers. These students were enrolled in the Ivey Business School at the University of Western Ontario and they were discussing aspects of a 'case study' that formed part of their course. Fascinated by the process and the enthusiasm that he witnessed, Professor Davenport pursued the idea of teaching civil engineering using this methodology and this eventually led to the development of a full one-semester final year undergraduate course in '*Case Studies in Civil Engineering*' at the University of Western Ontario. This course has been further developed over the last two decades and now forms a significant part of the preparation of students for their professional careers. The course is currently taught by the first author and a number of guest lecturers following the Harvard Business School case study method (e.g., McNair and Hersum 1954). The evolution of the course has spawned a large number of cases that have originated from Professor Davenport and other participants involved with the course. An overview of a selection of these pioneering civil engineering teaching cases is shown in Appendix A (Table A1).

Other courses and case studies have also been developed elsewhere for the teaching of civil engineering (e.g., Bosela 1993; Rendon-Herrero, 1993a, 1993b; Baer 1996; Delatte 1997; Rens and Knott 1997; Pietroforte 1998; Carper 2000; Delatte 2000; Jennings and Mackinnon 2000; Rens et al. 2000; Delatte and Rens 2002) and a considerable database of case studies is now available for the teacher to utilize (see Appendix B). Whilst full courses such as that taught at the University of Western Ontario are still rare, dissemination of individual cases through other courses is becoming more common (Delatte and Rens 2002). Two distinct forms of case-based teaching method are employed in the majority of these courses: the classical Harvard Business School 'case study' and the 'case history'. Both approaches can address the higher levels of Bloom's revised taxonomy of learning domains (e.g., Bloom 1956; Anderson and Krathwohl 2001) and promote student-centred teaching that develops deeper and more meaningful engineering learning outcomes. The purpose of this paper is to discuss inductive engineering teaching methods and educational theories, to describe best practice for case-based teaching in civil engineering, to provide an example of a well-known civil engineering event in both case 'history' and 'study' formats, and to make suggestions for optimal usage of these methods in the classroom.

2. Inductive teaching and learning theories

Historically, engineering courses have been taught in a *deductive* manner, utilizing a highly structured framework for the presentation of the material (Russell and McCullough 1990; Elshorbagy and Schönwetter 2002; Mills and Treagust 2003). The instructor will often begin with a statement of the general principles involved and will use these principles, with any necessary simplifications or assumptions, to derive mathematical models. The next stage is the application of the models to simple scenarios and numerical examples, followed

by practice of similar derivations and further applications in assignments and tutorials. The final stage is preparation and performance of more formal assessments, such as written mid-term and final examinations. There is often little emphasis provided for the rationale of completing these tasks and the practicalities involved in their application (Prince and Felder 2006). Hence this is very much an *instructor-centered* model of teaching that is predominantly content driven.

In contrast, *inductive* teaching assumes that knowledge can be based on the experiences and interactions of the student with different phenomena (Lahti 1978; Stahovich and Bal 2002). The instructor will initially illustrate a concept through a tangible example, rather than through generic instances. Students then attempt to make appropriate generalizations from observations (often quickly recognizing the need for relevant particulars, skills and concepts), with the support of the instructor. This provides a more experiential, guided form of discovery learning. Inductive teaching is therefore more *learner-centered*, challenging students to take more responsibility for their own learning, when compared to deductive teaching methods. There are a wide range of inductive teaching methodologies available, such as inquiry learning, problem-based learning, experiential learning, case-based teaching and discovery learning, and these are described in greater detail elsewhere (e.g., Kirschner et al. 2006).

The effectiveness of inductive teaching methods has been investigated previously and has been found to encourage deep learning approaches (e.g., Coles 1985; Norman and Schmidt 1992; Ramsden 1992), enhance intellectual development (e.g., Felder and Brent 2004) and align with the findings of neurological and psychological studies (e.g., Bransford et al. 1999). In particular, workers in cognitive psychology have developed frameworks linking cognition, development and learning (e.g., Piaget 1972; Vygotsky 1977). They stress the importance that context and environment play for the learner, and argue that as humans we are already immersed in social and physical environments. These social interactions provide learners with established systems that can modify thought processes, present new values and introduce sets of obligations. Given the existence of strong professional engineering organizations and industries in many countries, this research suggests that we may benefit our teaching by further improvement of links between academia and industry, to provide the appropriate immersion and exposure within these engineering communities.

Certain forms of inductive teaching are described as *constructivist* methods (Piaget 1972; Steffe and Gale 1995), which adopt the principle that students will actively construct their own knowledge and versions of reality, rather than passively receiving information presented by their instructors and textbooks (Stage et al. 1998; Biggs 1999). The theory of constructivism proposes that students learn by incorporating new information into their existing cognitive structures and their learning will be less effective if information does not provide immediately apparent connections with their current knowledge and beliefs. Educational psychology suggests that people are most strongly motivated to learn when they can perceive the usefulness or need for the learning outcomes (Prince and Felder 2006). In addition, the probability that learnt knowledge and skills will transfer to industrial settings

has been found to relate to the similarity of the two environments.

Further development of the constructivist approach has involved collaborative learning and concepts of group work (Bruffee 1993). Collective construction of knowledge forms the basis of problem-based and case-based learning, where the instructor functions as the 'master' learner and resource, and group members function as a community to develop their own unique set of solutions to problems. One difficulty associated with constructivist approaches for instructors is that students are sometimes not compelled to develop suitable expertise prior to interacting with teaching sessions. However, they can still be encouraged to explore the presented problems and although they relate to them in a less intellectually robust manner, the aim of the learning outcomes will be the actual process of acquisition and retention of information. Therefore, learning 'content' for inductive methods is often a means to further knowledge, rather than an end in itself, and relates more to the development of unique and individual ways of understanding.

The scheme of intellectual development created by Perry (1970) describes the sequence of approaches adopted by students during learning and their progression to more complex forms of thought as they develop with time. Four of the nine stages have been emphasized by Thompson (1999) as representing the most significant milestones: dualism, multiplicity, contextual relativism and commitment to relativism. This progressive development involves learners altering the approach that they take to learning and content, from an acceptance of the certainty of knowledge and the influence of authorities (i.e., the instructor), to an acknowledgment of the uncertainty and contextual nature of knowledge, and recognition of their own analytical abilities. The use of this model in the context of engineering education has been discussed by various researchers (e.g., Culver and Hackos 1982; Pavelich and Moore 1996; Palmer and Marra 2004). Unfortunately, engineering students will often only reach the lower levels of the Perry scale (Wise et al. 2004), which is a reflection of the predominance of 'dualistic' forms of teaching in engineering (Wankat 2002). Baxter-Magolda (1992) extended the Perry model and defined four levels of intellectual development: absolute knowing, transitional knowing, independent knowing and contextual knowing. The actions and relationships between students, instructors, knowledge and assessment for this scheme are given in Table 2. Preferably students reach the level of *contextual relativism* or *contextual knowing*, where their thought processes begin to approach those of expert engineers. Since critical thinking and problem-solving skills are linked to these higher levels of intellectual development (Baxter-Magolda 1992), it is important to create appropriate learning opportunities to achieve this progression. With suitable engineering instruction, students eventually become aware of the pluralism of learning, and are able to understand and manage multiple frameworks with conflicting perspectives.

Most faculty are aware of the terms *surface* and *deep* in relation to the approaches that students adopt during their learning. The work of Marton and Säljö (1976) identified these learning styles from empirical research and further study suggested the need for another category of *strategic* learning (Entwistle and Ramsden 1983). Students using a

surface approach will use rote memorization to answer anticipated questions and will not attempt to understand the material, treating it as isolated and unlinked information. A *deep* approach will involve a critical analysis of ideas, linking them to known concepts and principles, and investigation of the implications and limitations of the information, and even the meaning of the learning itself (Tang 1994). This approach has been shown to improve learning outcomes, retention of concepts and enable problem solving in unfamiliar contexts. Other students utilize the *strategic* approach, which is essentially a well organized form of surface learning, where the learner does only the necessary work to achieve their grades, taking a surface approach if sufficient and a deep approach if necessary. It should be noted that all of these approaches are not necessarily personality traits or fixed styles, but rather reflect the student perceptions of the task provided. Thus the design of the learning opportunity and the assessment method will have a significant influence on the adoption of a particular approach. Since the major features of contextual relativism and deep learning have been found to be similar (Felder and Brent 2004), some of the conditions that will foster both approaches are: interest in the content, active and long-term engagement with the subject, assessments that emphasize concepts and understanding, student responsibility for learning and placing new knowledge in context with prior experience.

In recent years, there has been a shift of pedagogical emphasis in engineering away from the laboratory and small-group sessions, to lecture-based and web-based education (Abdulwahed and Nagy 2009). This is thought to be due to a number of reasons, including larger class sizes, cost of maintenance and upgrading laboratories, and poor alignment of laboratory and lecture outcomes. However, recently there has been a rethink of this type of teaching (Feisel and Peterson 2002; Hofstein and Lunetta 2004) as the appeal of constructivist approaches has increased. The philosophical and research basis for this type of 'experiential' learning is encapsulated in the cyclical learning model of Kolb (1984), see Fig. 1. This model assumes that there is a sequence of learning activities that are involved in effective learning, where there is a cycle of experiencing, reflecting, thinking and acting. Learners belong to one of four types: divergers, assimilators, convergers and accommodators, being most comfortable with the activities in one quadrant of the learning cycle. This approach is useful because it enables understanding of different learning styles and simultaneously explains experiential learning. The model has been updated recently (e.g., Jarvis 1995), but still remains as an important model in learning theory. Other, similar learning inventories also exist (describing different types of preferred learning style), such as those of Gardner (1983), Honey and Mumford (1986), and Felder and Silverman (1988). Ideally instructors create an environment that allows students to learn by exposure to all parts of the cycle, giving them an opportunity to learn in their preferred manner and also to experience other approaches; the engagement point within the cycle has been found to be relatively unimportant. Problem-based and case-based learning has been found to match this type of teaching experience well (Kuri 1998; Harb et al. 1993).

Most faculty will recognise teaching approaches within their own curricula that already follow a number of the con-

cepts within this literature review, e.g., group teaching, laboratory sessions and applied problem solving. However, only a narrow selection of teaching styles are often employed in the engineering classroom, with a majority of auditory, abstract, deductive, passive and sequential forms. Unfortunately, engineering students are typically visual, sensory, inductive, active and global learners (Felder and Silverman 1988). Hence it is understandable how frustrations occur for both the instructor and student due to these mismatches. Inductive teaching approaches are obviously not a universal panacea, but educational and cognitive research strongly supports their use within engineering learning (Felder et al. 2000). Whilst the practicalities of teaching will ensure that deductive teaching will predominate, optimal civil engineering teaching methods and curricula will enable students to learn and develop using both deductive and inductive approaches.

3. Case-based teaching methods

3.1. Overview

In recent years, case-based methods have become more popular for engineering teaching and have taken an important role in developing professional skills and knowledge. Case-based teaching methods are defined in various ways in the literature, e.g., ‘*stories with a message*’ (Herreid 1994), ‘*analysis of historical or hypothetical situations that involve solving problems and (or) making decisions*’ (Prince and Felder 2006), ‘*an account of an engineering activity, event or problem containing some of the background and complexities actually encountered by an engineer*’ (Kardos and Smith 1979), ‘*a complex example to give insight into the context of a problem, as well as illustrating a main point*’ (Fry et al. 1999) and ‘*a student-centered activity based on topics that demonstrate theoretical concepts in an applied setting*’ (Davis and Wilcock 2003). The breadth of these descriptions gives some insight into the range of case-based teaching methods currently employed in universities and of the expected learning outcomes of the instructors. Although the origin of the case method may be traced to medicine, it is generally accepted that its first modern application occurred with the Harvard Law School in about 1870 (Weaver 1991) and it was further developed by the Harvard Business School in the 1920s (Copeland 1958), before expanding into other fields.

In comparison with traditional deductive teaching methods, case-based approaches have been shown by educational researchers to improve different aspects of teaching and learning (Prince and Felder 2006), such as retention (Fasko 2003), reasoning and problem-solving skills (Levin 1997; Fasko 2003), higher-order skills on Bloom’s taxonomy (Gabel 1999), the ability to make objective judgments (Dinan 2002), the ability to identify relevant issues and recognize multiple perspectives (Lundeberg et al. 1999), motivation and interest in the subject (Mustoe and Croft 1999), cooperative and active learning (Bonwell and Eison 1991) and awareness of ethical issues (Lundeberg et al. 2002).

3.2. Case teaching styles

As methods have developed, researchers have attempted to categorize case-based teaching in many ways, for example, Herreid (1994) identified the following forms: lectures, dis-

ussions, debates, public hearings, trials, problem-based, individual assignment, scientific research teams and team learning. The role of the students and instructor can vary significantly between these different teaching modes and depending on how they are implemented, some of them may not be considered to be purely inductive methods (Prince and Felder 2007). However, many of them lead to similar learning outcomes and skills development, providing emphasis on life-long learning, experience of coping with ill-defined problems, improving analytical skills, exposing students to important non-technical issues in professional practice, introducing the history of the civil engineering profession and encouraging learning in authentic contextual environments (Hagerty et al. 2005). Two of the most often utilized case forms are the *lecture* (case-history) and the *discussion* (case-study), which will be described in more depth below and are used with a teaching example in the next section.

The *case-history* is quite common in engineering and is often utilized for the teaching of famous cases in forensics courses (e.g., Russell and McCullough 1990). This format of case presents a complete description and chronology of an engineering event, who the individuals and organizations were (and their relationships), what happened and how the stakeholders and shareholders behaved, and what the outcomes were (Lynn 1999). Indeed, many faculty already employ this approach in a shortened form when they use anecdotes in their lecturing to emphasize points (Herreid 1994). In the longer format, it is helpful for students to study the case before the teaching session and prepare for discussion in the class. Additional aspects that a case-history can address were described by Rens et al. (2000): to analyze the impacts of engineering decisions on society, to appreciate the importance of ethical considerations on engineering decision making, to provide understanding of how engineering science changes over time (as performance and lessons are learned), to inform students of classic failures and successes, and to enable students to grasp difficult technical concepts and develop intuitive ‘feel’ for structural behaviour, load paths, construction sequences, etc. Often with this form of case, the analysis, actions and outcomes are given to the students as part of the narrative, hence this does not address the teaching of critical thinking and decision-making, and its use cannot be considered to be truly inductive (Lynn 1999).

The majority of teaching guides for the *case-study* method suggest that the cases presented should be authentic and represent an actual situation confronted by real organizations and individuals within professional practice (Erskine et al. 1981; Keenan and Gilmore 2010). A classical approach will often involve decisions or challenges of various kinds, e.g., diagnosing technical problems, resolving conflicts, formulating solution strategies or making management decisions, whilst making allowance for a range of competing technical, economic, social, ethical, political, temporal and psychological elements (Russell and McCullough 1990; Chinowsky and Robinson 1997; Raju and Sanker 1999). The task of the instructor is to effectively place the student in the position of the decision-maker and allow them to evaluate the information provided (often incomplete and irrelevant) within the available time (Keenan and Gilmore 2010). Many good cases will not have one obvious or clear solution (Stanford University Newsletter of Teaching 1994). The processing, presenta-

tion and defence of their positions and decisions to a group of their peers has been found to be an extremely effective training method for decision making (Erskine et al. 1981). Since students can often be challenged by cases to explore their preconceptions, beliefs and knowledge, potentially modifying them to accommodate the realities of the case, this method falls within the framework of constructivism (Prince and Felder 2006). It has also been found that the cases that engage students most effectively will involve a thought provoking issue and promote empathy with the central characters (Stanford University Newsletter of Teaching 1994).

Following the case description, if the decisions made by the central characters are withheld (so that the students can do their own analysis and decision-making), then the instruction can be described as inductive (Lynn 1999). Thus the most important feature of this approach is the *progressive revelation* of the particulars of the case. Typically cases will involve several steps (Kardos 1978; Prince and Felder 2006): (1) review of the case content, (2) statement of the problem, (3) collection or presentation of relevant information, (4) development and evaluation of alternatives, (5) selection of a course of action, and (6) evaluation of solutions. Of particular benefit is a final review of the actual decisions and outcomes that occurred in the case. With additional use of group activities, this approach can encourage active learning, provide opportunities for the development of key skills (e.g., communication, group dynamics and problem solving), increase student enjoyment and the desire to learn, develop individual study skills (such as information gathering and analysis), and teach time management, presentation and practical skills.

3.3. Integration into the curriculum

A number of issues have been found to affect the implementation of case methods into the curriculum and classroom. Foremost of the factors for the instructor is to have a very clear idea of the learning objectives that will define the outcomes when teaching is completed. The alignment of these objectives with the problem focus, learning activities and assessments is very important, and recent educational theories of *constructive alignment* provide guidance (Biggs 1996). In addition, approaches for addressing professional engineering accreditation bodies (e.g., ABET and CEAB) with learning objectives are provided in the literature (Felder and Brent 2003). Another important choice for the instructor is the appropriate selection of the inductive or case-based method. Part of the process should include an assessment of the experience of the instructor and the students, the time and resources available, and access to suitable information or cases. A considered decision of whether the learning objectives will encompass higher levels of cognitive abilities is necessary, since inductive teaching methods may not be appropriate or desired.

According to Davis and Wilcock (2003), social inertia within the faculty body may be problematic during implementation of global changes in the emphasis of the curriculum and understandably, experienced instructors may be reluctant to modify their teaching styles. They also suggest that for significant changes, extra time must be allocated in the timetable for background reading and that cases must be added gradually to correctly identify the resources, time and

support needed. Formulating good cases can be a very difficult and time-consuming task, and before instructors take steps to write their own cases, they should first check the libraries of engineering cases that exist (see Appendix B). Routes to developing cases have been suggested by Davis and Wilcock (2003): (i) develop case studies based on research interests of faculty; (ii) get students to develop cases based on their interests; (iii) develop cases from scratch; (iv) invite external lecturers to give or develop cases (this also has the advantage of creating formal or informal links between students and practicing engineers), and (v) develop cases to replace parts of traditional teaching. The ability to teach a *series* of cases has also been found to be useful, creating the possibilities for additional depth of learning and ensuring progression of intellectual development.

Experience has shown that many students have only limited exposure to inductive teaching and therefore clear guidance for students is paramount to ensure effective teaching and avoid resistance from the students (Stanford University Newsletter of Teaching 1994). Good instructions on their responsibilities for preparing and engaging with the class discussion are important. Informing them of whether they need to do additional research beyond the case notes, giving them pre-arranged questions or getting them to produce a brief group report are useful methods to ensure successful case sessions. It is also important that the instructor has carefully planned the session and is able to guide the discussion in the appropriate way (i.e., identifying the major concepts for learning). There will inevitably be situations in class when the instructor needs to intercede in the discussion, to change the direction, or to keep the discussion going, and open ended questions, exploratory or relational questions can be useful to continue the flow of ideas. The instructor is also encouraged to moderate the discussion by checking that the class is satisfied that each action has been discussed fully, making lists of key aspects, paraphrasing where necessary and allowing sufficient time for reflection. The summary at end of the session is very important, and should cover both the content and the process of evaluation and analysis. Providing research tasks for further investigation can also be useful for continuity and learning between sessions.

Assessment of case-based teaching can follow typical methods with both formative (improving student learning and performance, skills testing and feedback) and summative (evaluation against a set of predetermined standards) approaches (Herreid 2001). An additional requirement for case-based teaching can be assessing the class discussions, which is somewhat subjective, but can be effective using a class seating chart and the aid of teaching assistants to rank substantive inputs and note class absences. The inclusion of case studies in examinations can also produce good alignment between the course assessment and teaching activities. Group work can form an important part of case-based teaching and it is worth ensuring that students have some training in group dynamics, functioning and meeting protocols. Peer evaluation of group coursework submissions has been found to be an effective way of ensuring all group members contribute equally (Kaufman et al. 1999). Researchers are also investigating new, web-based approaches for the teaching and assessment of cases in distance learning modes, using multimedia and multi-user object oriented environments (e.g., Lin-

deman et al. 1995; Kinzie et al. 1998; Cannings and Talley 2002).

A few authors have suggested some caveats for teaching case methods in engineering (e.g., Herreid 1998). Case teaching is not well suited to situations with single solutions and if the formulation of generalizations is sought from students, this may require them to be exposed to many individual decisions (which can take time and patience). Cases require a certain period of time to mature (as the contributing factors are uncovered by the industry), but can also become outdated and may require updating regularly. Ensure that the students are familiar with each other and comfortable talking in front of each other, and the instructor should listen carefully to the students; a classroom with 'U'-shaped seating encourages more interaction compared with more traditional lecture style rows of seating. Practice should be encouraged of 'framing' and determining the pertinent aspects of problems, and not just of solving and analyzing problems. Kirschner et al. (2006) also cautioned that the learning experiences from inductive teaching should effectively reproduce the processes and methods of civil engineering practice. Considerable experience of teaching using case-based methods has been accumulated and further expert help for instructors can be found in the extensive literature that exists (e.g., Boehrer and Linsky 1990; Christensen and Hansen 1987; Christensen et al. 1991).

4. Case-based teaching example: the Kansas City Hyatt Regency walkway collapse

4.1. Overview

This section presents a single case given in the two case-based formats already described (i.e., the case-study and case-history). This includes a comparison of the learning objectives, activities, expected outcomes and assessment styles. The chosen case is the Kansas City Hyatt Regency walkway collapse, which is widely used in engineering education in general and civil engineering education in particular. A quick internet search finds a number of Web sites hosted by various universities that already discuss the case (e.g., <http://matdl.org/failurecases/>).

The case, at first glance, appears to be straightforward. The building was completed in July 1980, but had a serious structural flaw. On the evening of 17 July 1981, this undetected flaw led to the collapse of one walkway located on the 4th floor on to the top of another one on the 2nd floor. This caused 114 deaths on and under the two walkways. Both walkways were suspended by rods from the roof (see Fig. 2). The case is often presented as a structural engineering error. The original connection for the walkway showed a continuous rod from the lower walkway, up through the upper walkway to the roof, with a nut halfway up the rod supporting the upper walkway. Clearly, this would not be easy to build without some modification. The steel fabricator noted this and suggested a change to two rods, one from the roof to the upper walkway, and another from the upper walkway to the lower walkway (see Fig. 3). The structural engineer approved the change without calculating the revised forces, but the change doubled the bearing force between the nut and the cross beam of the upper level walkway. This connection failed, with the nut punching through the beam. Techni-

cal discussions of this failure may be found from several sources (e.g., Roddis 1993; Delatte 1997; Moncarz and Taylor 2000).

This was a devastating tragedy for Kansas City, Missouri, and there were strong demands for action. Criminal charges were considered, but in the end were not brought. The Missouri board for professional engineering licensure held hearings and eventually revoked the licenses for David Duncan, the engineer for the project, and Jack Gillum, the owner of the engineering firm. These engineers were also licensed in other states, and nearly all of those states also revoked their licenses. The American Society of Civil Engineers (ASCE) also held hearings and suspended both from the Society (Pfatteicher 2000).

The technical issues are pertinent to a number of engineering courses. In a 'Statics' course, or perhaps even a 'Physics' course, a load path diagram may be used to show the doubling of the force on the nut at the critical connection (see Fig. 4). It can be described, simply, as the aesthetic difference between two men hanging off a rope versus one man hanging off a rope and a second man hanging from the first man's ankles. In the latter case, the first man has to support the weight of two people. The connection can be analyzed in more detail in a 'Mechanics of Materials' or 'Structural Steel Design' course.

Presenting this case study in a simplified manner, however, is a disservice to the engineering profession, and obscures some of the major lessons that can be learned. At first glance, it appears to be sloppy or careless engineering, compounded by a failure to check the work on at least two occasions. Even to an undergraduate student encountering the case for the first time, this would appear to be an obvious blunder that would be easy to avoid. The story is, however, a good deal more nuanced. A series of four papers published in May 2000 in the ASCE Journal of Performance of Constructed Facilities provided many more details, nearly two decades after the disaster. Shorter versions of the papers were presented at the ASCE 2nd Forensic Engineering Congress in San Juan, Puerto Rico, May 2000. The paper by Moncarz and Taylor (2000) provides a detailed structural analysis of the failed connection. Pfatteicher (2000) discusses the tragedy and the actions taken by the Missouri board and ASCE in the context of the evolution of the ASCE Code of Ethics.

Greg Luth was a recent engineering graduate working in Gillum's firm at the time of the collapse. He provides some critical background to the case that is often overlooked (Luth 2000). For example, the original detail is usually referred to as a designed detail, but that is not true. It was, instead, a *conceptual* sketch with the notation of a 22 kip (98 kN) load to indicate that the connection still needed to be designed by the detailer. A 1 3/4 inch (44 mm) diameter rod was also shown, and the connection was made directly to the walkway's longitudinal beams without a transverse box beam, using eccentric angles instead. The architect requested a thinner rod for appearance, and so the detail was revised to a 1 1/4 inch (32 mm) high strength (60 ksi [410 MPa] yield strength) rod, now shown continuous through the box beam. In the end, the use of a thinner rod made no difference, since it had to be encased in fireproofing. When the detail was transcribed by the draftsman, however, the designations for the load and for the high strength steel were left off. When the drawings were sent to the fabricator, the fabricator requested

a change to the two rods. Duncan gave approval by telephone, but asked for the paperwork to be sent; however, the corresponding paperwork was never issued. Duncan was also asked about the 1 1/4 inch (32 mm) rod, which the detailer said would not work. Duncan replied, from memory, that it was a high strength rod.

The project went through a number of changes of critical personnel. Both the project engineer and the senior design engineer left Gillum's firm midway through the project. The steel fabricator landed a larger contract and handed off the shop drawings to an outside engineering firm. The testing firm was also fired midway through the project for poor performance, and the project was completed without a testing firm. As the project was nearing completion, a small structural failure caused part of the atrium roof to collapse, in the vicinity of the walkways. A complete design check was performed at this point, but somehow that missed the critical connection. In fact, the so-called "revised design" was never drawn before the collapse; the shop drawings, which the structural engineer had little time to review, only showed the box beam with two holes for the rods (Luth 2000).

Jack Gillum had asked several times for his firm to be retained to perform structural inspections for the project, but it was not. It is possible, although not certain, that a knowledgeable structural engineer would have observed and questioned the detail, or seen some evidence of deformation. For example, the separate 3rd story walkway, across the atrium, showed plastic deformation of the nuts bearing against the box beam even though only that single walkway was attached. Gillum (2000) describes receiving a telephone call immediately after the collapse, and being asked for an approximate weight of the walkways for rescue operations. He immediately flew to the site and saw the connection for the first time. His paper is a poignant account of his interactions with the Missouri board and ASCE, and his recommendations as to how this sort of disaster could be avoided in the future. He has continued to practice engineering and has spoken on many occasions to ASCE groups, engineering students, and workshops about the case.

Some cases lend themselves very well to presentation at various levels, in a variety of different courses, as students mature and progress through the curriculum. The Hyatt case is certainly one of these. It may be used in a statics course for beginning students (deductively in a case history type of presentation to a large lecture course). The students can then become familiar with the technical aspects of the case at this point. Later, in a capstone seminar course (smaller group) it is possible to revisit the case using a more inductive format as a case study. The students are now more familiar with the roles and responsibilities of various parties, the ethical dimensions, etc., and, as more mature students, they are able to articulate their thoughts on these "non-technical" aspects of the case. They should still remember some of the basic story from the earlier presentation and assigned readings. At the University of Louisville, students participate in a "mock trial" in which they take the roles of the different players in the Hyatt Case (engineering, contractor, testing lab, etc.) and defend the respective positions.

Students often have strong reactions to this case, as well they should. It is a case that reveals more, the more one digs into it. The various accounts available in the literature are

often at odds. Investigators hired by different parties, such as the steel fabricator or Kansas City, have published their views. Rubin and Banick (1987), for example, present the view from the legal profession that the system worked and the parties at fault were justly and harshly penalized. It is a fairly straightforward matter to present a short version of the story and there are certainly engineering lessons to be learned even from this approach. However, with careful planning the case can provide a much richer learning experience. In the next section, the case-study and case-history methodologies for the Hyatt collapse case are described and discussed, with further commentaries on the expected learning outcomes and assessments.

4.2. Case-history versus case-study

For both styles of teaching, it is necessary for the instructor to decide how much of the story to tell, since it is a complex and multi-faceted tale. Thus the learning outcomes from the teaching session must be clearly identified, and the composition and delivery style prepared accordingly. One approach in the US is to use the Accreditation Board for Engineering and Technology (ABET 2007) outcomes or the ASCE Body of Knowledge (ASCE 2004, 2008) outcomes (Delatte et al. 2009). The advantage of using the ABET outcomes is that the course materials can be used as documentation for the next accreditation visit. This documentation may be in the form of the summative assessments used to grade the students. For a well known case such as this, search engines can find a lot of information and opinions of varying reliability. This offers an opportunity for students to access many sources and to learn to resolve the tensions between the competing arguments, but can also present some problems due to familiarity with the content.

For a *case-history* approach to the Hyatt Regency walkway collapse, the following sequence of steps could be adopted:

- a. *Brief overview of the case.*
- b. *Major characters, organizations and their relationships (including conditions of contract):* owner — Crown Centre Redevelopment Corporation; Construction Management — Concordia Project Management; Architect & Planner — PBNMML; General Contractor — Eldrige Construction Company; Steel Fabricator (sub-contractor) — Havens Structural Steel; Consulting Structural Engineers — GCE International/Gillum Colaco Associates; Operator — Hyatt Hotels Corporation; City of Kansas. Individuals: Jack Gillum (GCE), Daniel Duncan (GCE), Donald Hull (CCRC), and Wayne Lischka (structural engineer hired by The Kansas City Star newspaper).
- c. *Chronology of the events:* From 1976 to 1985 — design, construction, failure, post-investigation, regulatory response. A very detailed chronology is given by Luth (2000).
- d. *Detailed description of the failure and technical causes:* engineering design of the suspended walkways; original design of box beam and how it relates to the building codes; the flaws in the actual built structure.
- e. *Potential non-technical causes and contributing factors:* poor management communications; misunderstandings in design modifications; inadequate attempts to review facilities; ineffective local and state regulatory system.
- f. *Outcomes for the individuals and organizations:* Duncan and Gillum lost their professional engineering licenses

and were suspended from the ASCE; CCRC settled more than 90% of the plaintiffs claims (which exceeded \$140M).

Depending on the chosen emphasis of the case, the whole of this list can be presented as a narrative, or it can be curtailed at (e), omitting the non-technical issues. The lecturing style of the instructor will determine the interaction of the students with this story, ranging from a monologue to a purely Socratic style. Convenient points for class discussions are located at (d) and (e), addressing many professional aspects and issues for the industry. Often there is less preparation required for a case history teaching session (compared to case study) and the primary aspects of the case can be provided for the students with prepared handouts or they can take their own notes during the lesson. The complete sequence can be covered in a single 45–50 min lecture. Learning objectives could include (but are not limited to): structures and materials knowledge, project management, communication and record keeping, legal and professional responsibilities, civil engineering regulatory systems and the ASCE code of ethics. Assessment can be standard examinations, homework assignments or short research papers.

A *case-study* approach to the Hyatt Regency walkway collapse, could use a similar sequence of steps and activities:

- a. *Brief overview of the case.*
- b. *Major characters, organizations and their relationships (including conditions of contract).*
- c. *Chronology of the events.*
- d. *Discussion of the failure and technical causes:* (i) Have the students suggest the possible causes of failure. Discuss how each cause affected the system and its significance. These may include: poor structural materials (steel), poor construction (welds or bolted connections), unexpected loads (people, floor finishes or harmonic motions) or fundamental design flaws. (ii) Discuss the effects of dynamics on the failure. Have the students suggest methods for testing the effects of dancing with respect to vibrations or the dynamic excitation caused by it. (iii) Distortions of the 3rd level walkway were found and represent long-term ductile failure. Have the students suggest the cause of these distortions and what changes should have been made with respect to the design code. The collapse occurred suddenly and without warning, suggesting brittle failure. However, these distortions show ductile failure. Have the students comment on the possible connection between these two failure mechanisms. (iv) The building code for steel construction states that bearing stiffeners are to be provided at the points of concentrated loads and that loads are to be applied in the plane of the web. Have the students suggest an alternative design in which both these of factors would have been accounted for.
- e. *Non-technical causes through role-play or discussion:* A number of different scenarios can be presented to the students, where they adopt the viewpoints or stances of different characters in the case, providing discussion or role-play situations. Examples may be: (i) A member of the ASCE disciplinary hearing board. This enables discussion of aspects such as: Which parts of the ASCE code of ethics were violated? Was the suspension of Gillum for three years appropriate? Should the ASCE police or promote the industry? What can the ASCE and other professional bodies do to ensure this type of failure does not

occur again? Did the previous judgement by the Missouri board for professional licensure to revoke the licences of Gillum and Duncan, and the press affect the outcomes?

(ii) A hypothetical junior engineer in GCE or Havens Steel who discovered the flaw in the design independently. This will enable discussion of the ASCE code of ethics, the correct procedures to be followed, the implications of whistleblowing in the event of negative responses and the protection afforded by (and the limitations of) the whistleblower protection laws. Excellent summaries on whistleblowing are provided by Chertow et al. (1993) and Oliver (2003). (iii) The administrative hearing commission judge (James Deutsch). This enables discussions of the legal responsibility of the engineer of record, the professional and legal responsibilities between the engineer of record and an engineer working for a steel detailer or fabricator, the development and sealing of shop drawings, fee basis and bidding, communication between parties and record keeping. The papers by Rubin and Banick (1987), Thornton (1986), and Pfatteicher (2000) may be used to help prepare the students for this discussion.

- f. *Discussion of the % of blame that could have been legally apportioned to the characters and organizations:* taken from straw poll of students.
- g. *Outcomes for the individuals and organizations.*

This approach works most effectively using progressive revealment of the particulars of the case and utilizing a Socratic style (i.e., questioning students to develop the narrative and outcomes). It involves breaks in the session, for group discussions and critical thinking, followed by peer presentation and defence of their positions and findings. Coupled with problem-solving and structural analysis, this provides a very active form of learning and engagement with the content of the case. Prior reading of the case is very helpful and can take the form of case notes and web-based sources, augmented by preparation of a short overview or questions in the form of a report. Given the number of activities, this is better broken up into a series of separate teaching sessions or ideally conducted over a 2–3 h session with breaks. Learning objectives could include (but are not limited to): technical structures and materials knowledge, project management, communication and record keeping, legal and professional responsibilities, civil engineering regulatory systems, ASCE code of ethics, critical thinking, problem-solving and analysis, group work and forensic engineering methods. Students can make their own notes during the sessions and it is helpful to pause occasionally, to summarize points on the blackboard, to help note taking and reflection to occur. Assessment can be examinations, peer discussion contributions, group or individual submissions (before or after the session) and research papers.

Further issues that may be discussed by the students using both approaches:

- Describe the design process failure that occurred with the Hyatt Regency collapse, discuss how the project team was structured and suggest ways that it could have been better structured. To what extent has the US solved the problems with project delivery revealed by the case? How do the design and regulatory processes differ in Canada?
- What changes to the building codes and the Kansas City Building Department could have changed the outcome?

- Does the fast-track process inherently compromise public safety?
- Is divided responsibility inevitable for large projects? If so, how do we ensure that critical concepts are communicated? How do we ensure 'organizational' memory exists when people leave companies?

The two formats for the Hyatt case (described above) present distinctly different approaches for the teaching and learning outcomes. The essential difference between the two styles is that the 'case study' attempts to place the student in the position of one of the players involved, rather than purely recounting the story from the position of a third party (i.e., the 'case history'). The deductive 'case-history' approach is certainly neater and more time efficient, and students will be more comfortable with the style due to familiarity. The inductive 'case-study' approach leads to a less structured teaching session, but may produce more flexible and better outcomes. Some additional preparation and practice is required for case-study teaching, but once the students have become comfortable with the different demands of this style, the benefits become apparent. Some ideas may not be wholly suited to inductive teaching, but using progressive revelation techniques and having students being intimately involved with analyses and problem-solving can be very beneficial for both teaching approaches.

Students at the University of Western Ontario who have experienced the Hyatt case study and others on the 'Case Studies in Civil Engineering' undergraduate course are very enthusiastic about the experience. Typical responses from the end of year student feedback surveys are: 'Best course we've had this year'; 'Good context, valuable lessons'; 'I like how it encourages independent learning'; 'Course is unique and I feel a necessary part the curriculum'; 'Excellent course, great subject matter'; 'Better way to learn about industry and client-based relationships'. It may be argued that these two teaching approaches described herein represent opposite ends of a spectrum of case teaching methodologies and unfortunately as a teaching profession, we are currently biased towards one end of this spectrum.

5. Conclusions

Despite significant changes occurring in teaching and learning theories, civil engineering education still relies heavily on deductive instructional methodologies. Inductive approaches are commonly used in other fields and have considerable support in the literature. Case-based teaching is one of the most widespread forms of inductive learning and this paper has described the shared elements and differences for two of the most familiar types: 'case-histories' and 'case-studies', and presented these methods using the classic Kansas City Hyatt Regency walkway collapse as an exemplar. Preferred learning styles by students affect the efficiency of teaching and use of a combination of deductive and inductive methodologies may be the route to higher level and broader learning outcomes.

The case teaching method has been found to be extremely effective, particularly for senior students and is good preparation for life-long learning skills. The benefits of using this approach are improved retention of knowledge, better reasoning and analytical skills, development of higher-order skills

on Bloom's taxonomy, greater ability to identify relevant issues and recognize multiple perspectives, higher motivation and interest in subjects and further awareness of non-technical issues. Many of these outcomes are part of the expected attributes of civil engineers outlined by professional accrediting bodies (e.g., ABET 2007). The quality of the teaching and learning experience is important in the completion of these outcomes and best practice must be sought from the extensive literature on case methods to ensure that this is achieved. Indeed, many exemplars of best practice can be found in the selection of cases from Dr Davenport's writings given in Appendix A and the case studies bibliography in Appendix B. Also contained in Appendix A are suggested objectives from the ASCE Body of Knowledge (Table 1) that these cases could help to address in the classroom.

Professor Alan Davenport pioneered the usage of the case-study method in civil engineering education at the University of Western Ontario and this approach has been a great success over last 20 years. The course that he developed is often cited by undergraduate students as the most enjoyable and effective in their final year. Given the emphasis that is now placed upon critical thinking and problem-solving skills, it is surprising that this type of course is not more commonly used in civil engineering curricula across North America. The authors hope that this situation will change and that civil engineering educators will embrace this teaching approach in their efforts to educate and mentor the next generation of practicing civil engineers.

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Appendix A

Table A1 appears on the following page.

Appendix B. Case studies bibliography

This appendix provides a short bibliography of books

about civil engineering cases and failures. A more up to date summary of cases in periodicals, papers and other media can be found at <http://matdl.org/failurecases/bibliography.htm>.

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Table A1. Case studies authored or co-authored by Professor Alan Davenport.

Title and date	Content	Major ABET Educational outcomes (see Table 1)
Forintek Western Research Facility (1994)	Discussion of the development of a new research institute's building design and construction. The primary objective of the building was to demonstrate the usage of wood in commercial and industrial buildings. Insight into the forest products industry and differences between wood and steel construction.	3, 12, 13
Hot In-Place Recycling (1994)	Recycling of pavement waste products and introduction of new technology into the civil engineering industry. Rehabilitation and repair of aging infrastructure. Environmental concerns in civil engineering. Cost of traffic disruptions in planning road works. Difference in attitudes between countries.	8, 10, 12
Kansas City Hyatt Regency walkways collapse (1994)	Summarizes the events surrounding the collapse of the Kansas City Hyatt Regency walkways in 1981. Discusses chronology, causes (technical and non-technical), outcomes and repercussions for the civil engineering industry.	1, 5, 7
Note on the Canadian Construction Industry (1993)	Overview of the Canadian construction industry in the early 1990s. Links the state of the industry to socio-economics, research and development, and discusses the stakeholders and future directions.	8, 10, 14
PCL Constructors Eastern Inc: The Ottawa Palladium (1996)	Addresses project management from the perspective of interpersonal relationships and concerns of the stakeholders. Completion of construction projects on time and on budget. Driving forces behind projects.	7, 13, 15
Stills Associates Ltd (1993)	Describes a highway paving project where the young engineer is forced to make a decision which has financial and legal consequences. Covers the background for paving operations and hierarchy on a construction site. Discusses potential conflicts between inspector and (or) engineer and contractor, and standards and regulations.	7, 13, 15
The Listowel Memorial Arena Collapse (1994)	History of the Listowel Memorial Arena and the collapse in 1959. Contributing factors for the arena collapse. Discussion of changes made to the National Building Code of Canada for snow loading and methods used to check the structural adequacy of arenas. Computer based numerical methods.	1, 5, 11
The Tottering Skyscraper: The Citycorp Centre, NY (1996)	Discussion of the repairs to the Citycorp Centre, New York. The potential flaws in the design when the building was subjected to 'quartering winds'. Engineering ethics and the code of practice; responsibility to society. Whistleblowing and the civil engineering industry. Wind loading on structures.	1, 5, 6
The Victoria Hospital Energy from Waste Facility (1996)	Describes the technical and economic issues for creating energy from waste. Health risks from processing waste. Political difficulties and public consultations. Role of engineers in politics and society.	10, 12, 14

Note: Copies of these cases can be acquired by contacting the first author.