Design Codes in Structural Engineering Practice and Education

Matthew S. Barner, A.M.ASCE[1]; and Shane A. Brown, Ph.D., P.E., F.ASCE[2]

Abstract: Codes and standards are important tools in civil and structural engineering, but how they are applied in the workplace in comparison to how they are taught in undergraduate engineering education has been understudied. The purpose of this research is to explore the social and material contexts wherein codes are applied in a structural engineering workplace and in undergraduate structural engineering courses to better understand the alignment of these two environments. The researchers employed an ethnographic approach to participate in and observe the social and material contexts wherein engineers and students apply codes. Both students and engineers were observed applying codes prescriptively; however, engineers also had to apply codes with a more evaluative approach in certain scenarios. Students were never exposed to similar scenarios in their courses. Based on these findings, the authors provide some recommendations for engineering education to provide students with an improved evaluative understanding of codes that is less reliant on a limited prescriptive understanding of code procedures. Implementation of the evaluative use of codes presents challenges to an already full curriculum; therefore, the authors provide examples and descriptions for integrating codes into the existing curriculum to prepare students for the engineering judgment required when applying the concepts they learn in school in practice. **DOI: 10.1061/(ASCE)EI.2643-9115.0000026.** *© 2020 American Society of Civil Engineers.*

Introduction

The civil engineering curriculum has been considered insufficient in providing undergraduates what they need to know to be successful in the workplace (Aparicio and Ruiz-Teran 2007; Balogh and Criswell 2013; Solnosky et al. 2017). Common areas of insufficiency cited in engineering education are communication, teamwork and leadership, and proficiency with advancing technologies (Brunhaver et al. 2017; Johri and Olds 2011; Kelly 2008; Litzinger et al. 2011; Trevelyan 2007, 2010). Communication, teamwork, and leadership are broader skillsets that apply to all engineering disciplines, whereas technologies vary from discipline to discipline. Within civil engineering and more specifically structural engineering, technologies have been defined as problem-solving tools (ASCE 2008; SEI 2013).

In structural engineering, the word technologies might bring to mind software programs for structural analysis, but underlying these programs are a bevy of text-based technologies, such as building codes and standards. Building codes and standards—hereto simply referred to as codes for brevity—are tools (Batik 1992) that are constantly advancing and require proficiency from structural engineers for their appropriate use in practice (Solnosky et al. 2017). Proficiency with codes requires the comprehension of the structural engineering concepts represented within them (Rumsey et al. 2010; Solnosky et al. 2017). However, these same concepts are often taught in isolation from codes—if the codes are taught at all—in undergraduate structural engineering education (Kelly 2008; Koch et al. 2010; Solnosky et al. 2017). This isolated teaching is at least partially due to a commonly perceived educational notion that fundamental conceptual understanding must be established before teaching students how to use technologies; otherwise, students will have a "black box" understanding of the technologies (Center for Global Standards Analysis 2004; Rumsey et al. 2010; SEI 2013).

Although a valid educational concern, situated cognition theory posits that conceptual understanding is bounded within the social and material (sociomaterial) contexts wherein people learn and apply said concepts (Johri and Olds 2011). Therefore, teaching concepts in isolation from the sociomaterial contexts of codes may be contributing to students' deficiencies with the technologies of codes when entering the workplace, thereby limiting the application of their fundamental conceptual understanding. An improved understanding of the use of codes in academic and workplace settings would facilitate improving undergraduate education. Thus, the purpose of this research is to answer the following research question:

> How are structural engineering concepts represented through the sociomaterial contexts of code applications in academic and workplace environments?

Background

Building codes and standards are constantly evolving tools that provide requirements and/or guidance for structural engineers in designing safe structures (SEI 2013; Solnosky et al. 2017). The terms codes and standards are frequently used interchangeably and colloquially by instructors and engineers (Kelly 2008). The following sections aim to briefly define codes and standards, demonstrate how these tools contain conceptual representations important to structural engineering and what this means in terms of situated

[1]School of Civil and Construction Engineering, Oregon State Univ., 101 Kearney Hall, 1491 SW Campus Way, Corvallis, OR 97331 (corresponding author). ORCID: https://orcid.org/0000-0002-8581-6708. Email: barnerma@oregonstate.edu

[2]Professor, School of Civil and Construction Engineering, Oregon State Univ., 101 Kearney Hall, 1491 SW Campus Way, Corvallis, OR 97331. ORCID: https://orcid.org/0000-0003-3669-8407

Note. This manuscript was submitted on September 9, 2019; approved on May 27, 2020; published online on November 17, 2020. Discussion period open until April 17, 2021; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Civil Engineering Education***, © ASCE, ISSN 2643-9107.

cognition, present various opinions on the roles of these tools in engineering education, and then present studies with similar methodologies before outlining the research methods.

Codes and Standards

When discussing codes and standards in engineering, there are important differences in their meaning and application across different engineering disciplines (Kelly 2008). Within civil engineering, standards mostly pertain to design requirements or considerations for public welfare and are frequently referenced by code regulations. This often results in engineers frequently referring to both standards and codes as simply "codes" even though they are different (Kelly 2008; Quinn and Albano 2008).

In the United States, most building codes are modeled off one or more of the International Code Council's (ICC) 15 international codes, such as the International Building Code (IBC), and are administered at the state or local jurisdictional levels (Kelly 2008). In structural engineering, these codes reference and delegate certain design requirements to the standards for all major structural materials and analysis procedures (Kelly 2008). For example, "most building codes, which are mandatory regulations in their jurisdiction, reference ASCE's standard for minimum design loads" [i.e., ASCE 7 (ASCE 2013)] (Kelly 2008, p. 61). Building codes have been described as parent-codes to the standards they reference, and these standards are then referred to as child-codes (Solnosky et al. 2017). For clarity and consistency, throughout the rest of this paper, the authors refer to building codes and standards as codes.

Situated Cognition and Conceptual Representations in Codes

Codes are written by committees of experts from various fields who, during the last century, drafted and published ever-expanding codes that evolved with engineers' knowledge of how structures behave (Kelly 2008) by establishing newer heuristics and prescriptive requirements (SEI 2013; Quinn and Albano 2008). Thus, these tools drastically changed the profession of structural engineering and how engineers represent fundamental concepts during design activities (SEI 2013). Concepts are considered units of knowledge that function as hierarchical organizers for a discipline's knowledge domain (Perkins 2006; Rittle-Johnson 2006; Streveler et al. 2008). For example, the concept of local buckling is one that is hierarchically organized within the concept of buckling and encompasses the concept of lateral torsional buckling.

Although some might think of concepts as residing within the individual's mental schema; people represent concepts in the real-world and, thereby, demonstrate their conceptual knowledge through the social and material contexts of language, text, diagrams, symbols, equations, and others (Lemke 1997; McCracken and Newstetter 2001). For example, the concept of wind loads acting on a structure is represented in ASCE 7 through the material context of diagrams, equations, and tables, and within the social contexts of the environment in which ASCE 7 is applied and the evolution of this code's development by committees over time. Situated cognition is a learning theory that then argues if sociomaterial contexts mediate conceptual knowledge; they also shape and are inextricably connected to it (Johri et al. 2014; Lemke 1998). An implication of this theory then is that knowledge transfer to novel contexts is limited (Bransford et al. 2000; Carraher and Schliemann 2002; Lave and Wenger 1991). Therefore, the structural engineering profession's use of codes in design is a sociomaterial context wherein structural engineering concepts are represented, and when these sociomaterial contexts differ across academic and workplace environments, engineering education is hindered in its applicability to practice (Johri and Olds 2011). That said, a variety of opinions exist on how, if at all, codes should be taught in engineering education.

Codes in Structural Engineering Education

Within structural engineering, certain codes have become commonplace in the curriculum and others less so. For example, for material-specific design courses to introduce students to the design codes relevant to that material is fairly common (e.g., most reinforced concrete design courses expose students to using ACI 318) (Kelly 2008; Rumsey et al. 2010; Solnosky et al. 2017). However, jurisdictional codes and ASCE 7 often receive little or no attention in undergraduate structural engineering education, causing parent–child code relationships to go unnoticed by students (Koch et al. 2010; Solnosky et al. 2017).

Previous research and changes to both Accreditation Board for Engineering and Technology (ABET) criteria and ASCE's Body of Knowledge (BOK) demonstrate a myriad of opinions on whether codes should receive more or less attention in an undergraduate engineering education. For example, Shealy et al. (2015) found in a survey of more than 120 civil engineering faculty and AEC industry professionals that these two groups generally believe that codes are an important topic to teach in undergraduate education. Conversely, a separate Delphi survey of 32 structural engineers noted that codes should be primarily taught at the master's level and within the first five years of practice (Balogh and Criswell 2013).

ABET criterion five has relegated the incorporation of codes into an engineering education "curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework" (i.e., a capstone course) (ABET 2018). ASCE's commentary on ABET criteria for civil engineering programs noted that codes must be integrated into the design component of the curriculum (ASCE 2019b; Kelly 2008), and ASCE's second edition of the BOK (BOK2) defined a specific technical outcome (technical outcome 8) that notes that students should be able to apply engineering tools, such as codes, to engineering problem solving before entering the profession (ASCE 2008). However, ASCE's third edition on the BOK (BOK3) removes this technical outcome and uses less explicit language in its more broadly defined outcome of "Design," which simply notes that students "must consider" codes at various stages of the design process (ASCE 2019a). The Structural Engineering Institute (SEI) noted in their *Vision for the Future of Structural Engineering and Structural Engineers: A Case for Change* (SEI 2013) an overreliance on prescriptive codes in the profession and a lack of fundamental conceptual knowledge on the behavior of materials in structural engineering education as factors contributing to reducing the role of the profession in society from engineers to technicians. This report distinguished performance-based codes as a better tool than prescriptive codes for the future of the profession (SEI 2013). Some codes, such as ASCE 7, have been moving toward performance-based procedures, and the SEI report strongly encouraged other codes to do so (SEI 2013).

Although the aforementioned surveys, learning outcomes, and reports espouse various beliefs about the roles of codes in education and practice, they all noted that codes are prevalent tools used in design and generally should have some role in the curriculum. However, the current undergraduate education on codes is believed to be limited due to the time made available to cover code related material, codes being taught in isolation from other course/curriculum content, variability in faculty knowledge of codes, limited resources to help faculty teach codes, and codes being taught using passive, ad hoc techniques (Center for Global Standards and Analysis 2004; Kelly 2008; Moon 2010; Solnosky et al. 2017). That said, little to no research has been conducted exploring the sociomaterial contexts wherein codes are applied in the workplace and education environments to gain a better understanding of how these contexts can be aligned across environments to better prepare students for the proficiency they need with codes when entering the workplace. Exploring these contexts in both environments is well suited for ethnographic methods.

Ethnographic Studies

Ethnographic methods situate a researcher or team of researchers within a specific environment in which they can gain access to a rich, descriptive understanding of the sociomaterial contexts in which participants operate through participation and/or observations of these contexts (Emerson et al. 2011). This method has been identified as a way to study situated cognition in engineering education (Case and Light 2011; Johri et al. 2014) but has been seldom used. Furthermore, most ethnographic studies in engineering education focused on broader engineering education within either a workplace or academic environment using purely observation techniques and no participation.

For example, Vinson et al. (2017) conducted an ethnography wherein they observed 20 early career engineers from nine different disciplines in five distinct workplace environments. Vinson et al. (2017) observed that as early career engineers become more exposed to codes and other text-based tools in the workplace, they become more likely to use these resources in problem solving. Fewer examples exist of ethnographic studies in academic environments. However, one that was conducted by Stevens, O'Connor et al. (2008) observed four engineering students in different disciplines throughout their four-year undergraduate experience and noted that lower-level courses generally had students use prescriptive approaches to reach singular right answers, whereas upper-level courses exposed them to more open-ended problems.

One example of an ethnographic study that focused specifically on structural engineering observed 19 structural engineers in three different workplace environments (Gainsburg et al. 2010). Gainsburg et al. (2010) observed codes being used as repositories of historically established knowledge to meet project time constraints, suggesting that they were used in a prescriptive manner. The authors know of only one discipline-specific ethnography wherein the researchers participated in the environment in which they observed. Bornasal et al. (2018) conducted a participant-observation ethnography of a transportation engineering firm wherein they observed engineers referencing codes to quickly make design decisions. Participation-observation ethnographies allowed the researchers gain a richer understanding of the participants and environments they study because the addition of the participation dimension can provide the researcher(s) with additional data for challenging or confirming observations and, thus, adds credibility to the ethnography (Emerson et al. 2011; Walther et al. 2013).

All of the previous ethnographic studies mentioned explored only workplace or academic environments. Very few engineering education studies employed any methodology that directly compared workplace and academic environments within a single study (Johri et al. 2014). The authors believe that it is worthwhile to do this to expand the engineering education community's understanding of differences in knowledge application across these environments and to offer more meaningful recommendations for the application of codes in an engineering curriculum. Therefore, the authors revisit their research question:

> How are structural engineering concepts represented through the sociomaterial contexts of code applications in academic and workplace environments?

Methods

A participant-observation ethnographic methodology was adopted to answer the research question via observational access to and experience with code applications in authentic academic and workplace environments. The decision to focus on a specific engineering discipline was to gain a more nuanced understanding of code application in education and practice than what has already been documented in the literature. The decision to focus on structural engineering was because the researcher conducting the ethnography—the ethnographer—has an educational background in this discipline and was able to participate more meaningfully in both environments. Furthermore, codes have been identified as a critical tool in structural engineering practice (Balogh and Criswell 2013; Gainsburg et al. 2010; Koch et al. 2010; SEI 2013; Rumsey et al. 2010); therefore, this discipline offers significant opportunities to explore the sociomaterial contexts within only a handful of environments.

Site Selection and Transferability

The academic and workplace environments selected for this study were a private architecture and engineering (A&E) firm and four undergraduate structural engineering courses, respectively. Both sites are in Oregon, which was geographically accessible to the ethnographer. The selection of these sites was based on the firm's willingness to participate and employ the ethnographer as a part-time intern, and receiving instructors' permission to participate in and observe their courses. As previously mentioned, ethnography situates the researcher(s) in a specific environment to explore and provide in-depth descriptions of the sociomaterial contexts of the environment. Therefore, the goal of ethnographic research is not to find generalizable results, but to provide rich, detailed descriptions of the environment that is meaningful to the research and education community to transfer within their own contexts (Lincoln and Guba 1985; Walther et al. 2013).

Tables 1 and 2 provide demographic information for additional context on the instructors and their courses, and the structural engineers in the workplace environment. All of the instructors that taught a course using a code had sound knowledge of their respective codes and historical development. All of the codes in the academic environment were observed being used in the workplace environment, albeit the workplace environment more frequently used previous editions. For example, all of the engineers in the workplace environment were observed using ASCE 7-10 over the most recent edition published in 2016. Most engineers were using the 14th edition of AISC's *Steel Construction Manual (SCM)*, whereas some others were using the 13th edition. One engineer used their copy of ACI 318-14 when the remaining engineers were using ACI 318-11.

Data Collection, Analysis, and Credibility

Data collection in an ethnography consists of three simultaneous sources: field notes from participant-observations, interviews, and artifact documentation (i.e., code excerpts) (Johri 2014; Emerson et al. 2011). During an ethnography, data analysis is occurring simultaneously such that the data collected from these three methods can be used to guide future data collection and triangulate

J. Civ. Eng. Educ., 2021, 147(2): 04020013

Table 1. Demographic info for structural engineering courses studied

Course	No. of students	Lecture (recitation) hours/week[a]	Code(s) used	Instructor teaching (industry) experience in years[b]	Female/male instructor
Structural analysis I	60	3 (2)	Oregon structural specialty code and abridged portions of ASCE 7-16 in textbook	30 (12)	Male
Structural analysis II	50	3 (2)	None	36 (29)	Male
Steel Design	67	3 (2)	AISC steel construction manual (15th ed.) and printout sections of ASCE 7-16	1 (2)	Female
Reinforced concrete cesign	60	4 (0)	ACI 318-14	22 (24)	Male

[a]All courses were on a quarter system, meeting 4–5 h per week for 10 weeks.
[b]Some instructors' industry and teaching experience overlap at various stages in their careers.

the existing data (Stevens et al. 2008; Walther et al. 2013). Furthermore, the ethnographer consulted two other engineering education researchers who were familiar with ethnographic methods before, during, and after exiting each environment to improve the credibility of the data being collected and analyzed.

Field notes from participation-observations consisted of the ethnographer initially handwriting notes of observations during his own use and when others were using or discussing codes. These handwritten notes were immediately typed up following the observation, and the ethnographer developed interview questions for pertinent participants and took pictures of pertinent code excerpts for artifact collection. These pictures were copied and pasted into relevant portions of the field notes to create an annotated description of the episodes wherein codes were discussed and/or applied. Interview questions were asked in formal and informal interviews based on participant availability. Interview data were used to fill in missing information in the ethnographer's field notes, check members, and access participants' interpretations of events wherein codes were applied (Emerson et al. 2011; Walther et al. 2013).

Following informal interviews, the ethnographer revised any relevant field notes. Formal interviews were audio-recorded and transcribed by a third party. Following transcription, the ethnographer reviewed the transcription and deductively coded excerpts based on specific conceptual representations that participants mentioned pertaining to codes. Following this initial round of coding, the ethnographer then inductively coded transcripts in tandem with field notes and the documented artifacts to create a holistic description of the episodes wherein codes were being discussed and/or applied. At this point, the episodes were descriptive case studies that were then analyzed and compared with one another to identify common themes across each episode (Yin 2003). Case studies are considered a valuable method for studying and presenting complex phenomena that are indistinguishable from their contexts (Baxter and Jack 2008; Yin 2003).

Table 2. Demographic info for structural engineers at the workplace environment

Parameter	Value
No. of structural engineers	20[a]
Industry experience in years	0–46 (10.3)
No. of licensed PEs (SEs)	12 (5)
No. of female/male engineers	7 (13)
No. of M.S./M.Eng. degree holders	7

Note: PE = professional engineer; SE = structural engineer; M.S = master of science; and M.Eng = master of engineering.
[a]The firm employs 24 structural engineers across three offices; however, only 20 were observed in-depth at the office in which the ethnographer was participating. Eight of the 20 engineers observed were graduates from the undergraduate program studied, with the other 12 graduating from eight different programs across the country.

The credibility of the themes derived from the cases was enhanced through participation in *and* observation of both environments for an extended period to encounter diverse sociomaterial contexts wherein codes were used (Case and Light 2011; Johri 2011). The ethnographer has B.S. and M.S. degrees in civil engineering with a course emphasis in structures for both degrees. The ethnographer took the courses that were studied in his respective undergraduate program at a different institution. The ethnographer's previous practical experience was limited to broader civil engineering internships, with little exposure to structural engineering practice. The ethnographer spent three months in the workplace environment, arriving at the firm's office each weekday between 7–8 a.m. and leaving between 5–6 p.m. The ethnographer worked as an intern for approximately 16 h per week and conducted observations and interviews, collected artifacts, and analyzed data during the remainder of the work week. As an intern, the ethnographer assisted in 18 different structural engineering projects and observed engineers working on several others within the industrial, commercial, and public sectors.

The ethnographer spent six months in the academic environment over two 10-week terms, enrolling in two classes each term. The ethnographer participated in each class as a normal student would, attending lectures and labs, taking notes, completing homework assignments, and taking exams. Participating in these activities allowed the ethnographer to gain access to how codes were presented in a lecture and to how students were applying codes in homework, lab assignments, projects, and exams.

Findings

In general, codes contained several conceptual representations that were used in both environments to prescriptively determine the demand on and/or capacity of various structures. By *prescriptive* the authors mean that the engineers, students, or instructors utilized a portion of a code to the letter, with little to no explicit interpretation of the concepts being represented in their prescriptive approach. Engineering problems encountered in academic environments typically required students to use a code or codes to find relevant information and apply applicable equations with little or no ambiguity, thus justifying their prescriptive approach. More ambiguous cases that addressed the limitations and/or assumptions built into codes were typically only discussed in the lecture. Occasionally, students had to assess when more nuanced prescriptive methods in codes needed to be used and then apply them to gain greater capacity in their design or to reduce their demands. These "sharpening your pencil" calculations, as one instructor frequently put it for using a code's methods for more precise calculations, were also observed in the workplace. However, engineers were more likely to also use evaluative approaches in their application of codes to reduce their demand, increase their capacity, or be more conservative than a code's recommendations/requirements. By *evaluative* the authors mean that the engineers had to rely on sound engineering judgment, skepticism of code provisions, and/or fundamental conceptual knowledge when applying or deciding not to apply aspects of certain codes.

The following subsections present cases from first the academic environment and then the workplace environment. The cases presented herein are from field notes of participation-observations in each environment, interview excerpts with engineers and instructors, and artifact documentation of relevant excerpts from codes and design problems for additional context. Not all codes observed in the workplace environment were observed in academic environments; however, all codes used in the academic environment were present in the workplace environment. This is to be expected because a substantial amount of codes are used in practice, and not all of them could be realistically covered in engineering education. Therefore, the cases presented are meant to convey broader themes for how codes were applied and interpreted in both environments rather than make direct comparisons of how a specific code was used in either environment. The cases presented in this section are not meant to be encompassing of all codes or academic and workplace settings; rather, they are meant to convey themes that can supplement and/or refute existing ideas on the use of codes in engineering education to provide the reader with transferable findings to their own specific contexts.

Academic Environments

In three of the four courses observed, at least one code was utilized by students to some extent when solving structural engineering problems on their homework, recitation assignments, projects, and/or exams. The course that did not use any codes—Structural Theory II (ST-II)—had the primary objective of teaching students how to analyze indeterminate structures using the concepts of equilibrium, compatibility, and constitutive laws. Because this course was not focused on design or determining external loads, it could be argued that there is little to no need for using a code as part of its curriculum. Therefore, the following subsections present cases from the other three courses wherein a code or codes were presented in the lectures and used by students.

Academic Case 1: Strength Reduction Factor and Shear in ACI 318-14

Whereas the ST-II course primarily focused on concepts of equilibrium, compatibility, and constitutive relations, these fundamental concepts are prevalent in any structural engineering course and are embedded in many codes. For example, the Reinforced Concrete (RC) Design instructor mention in the lecture that "ACI 318-14 permits us to use equilibrium, compatibility, and constitutive relationships to circumvent the code." This evaluative approach to ACI 318-14 is further demonstrated within the code itself per section R1.3.2: "The minimum requirements in this Code do not replace sound professional judgment" [ACI 318-14 (ACI 2014, p. 10)]. However, no design problems given to the students in this course dealt with a scenario that warranted anything other than a prescriptive application of ACI 318-14. However, the instructor for this course emphasized limitations in ACI 318-14 to provide students with some idea of the assumptions built into this code. For example, in a lecture on the shear design of RC beams, the instructor

22.5.5 V_c *for nonprestressed members without axial force*

22.5.5.1 For nonprestressed members without axial force, V_c shall be calculated by:

$$V_c = 2\lambda\sqrt{f_c'}b_w d \qquad (22.5.5.1)$$

unless a more detailed calculation is made in accordance with Table 22.5.5.1.

Table 22.5.5.1—Detailed method for calculating V_c

V_c		
Least of (a), (b), and (c):	$\left(1.9\lambda\sqrt{f_c'} + 2500\rho_w \dfrac{V_u d}{M_u}\right)b_w d$ [1]	(a)
	$(1.9\lambda\sqrt{f_c'} + 2500\rho_w)b_w d$	(b)
	$3.5\lambda\sqrt{f_c'}b_w d$	(c)

[1] M_u occurs simultaneously with V_u at the section considered.

Fig. 1. Prescribed equations for calculating V_c for nonprestressed members without axial force. (Reprinted with permission from ACI 2014.)

mentioned that shear failure is non-ductile and, thus, difficult to predict. The instructor then stated that ACI 318-14 conservatively accounts for this feature by reducing the strength reduction factor, Φ, to 0.75 when determining the shear strength of a member. The instructor then mentioned that the AASHTO LRFD Bridge Design Specifications has a better model for equating shear failure than ACI 318-14 does and, thus, uses a strength reduction factor of $\Phi =$ 0.9 for normal weight concrete (AASHTO 2012, section 5.5.4.2.1). The instructor then presented the class with the equations that ACI 318-14 prescribes to calculate the nominal shear strength provided by just the concrete in a RC member, V_c. The instructor noted that the easiest and most common way to calculate V_c is by using equation 22.5.5.1 in ACI 318-14 (Fig. 1). The instructor then presented the class with Table 22.5.5.1 in ACI 318-14 (also in Fig. 1) and stated that if engineers want to "sharpen our pencil" for a more detailed calculation and gain more shear capacity, then they can use the least of the equations presented in Table 22.5.5.1. Students were never presented with a design scenario that required them to "sharpen their pencil" and always used equation 22.5.5.1 to determine V_c on their homework and exam problems.

This case from the RC Design course demonstrates how the instructor clearly identifies a limitation of ACI 318-14 and compares this limitation to a different code (the AASHTO LRFD Bridge Design Specification) to present students with an evaluative understanding of a conservative feature in ACI 318-14. The subsequent presentation on how to prescriptively calculate V_c with the sole emphasis on the more conservative equation—22.5.5.1—for homework and exam problems demonstrates how students primarily apply a code's prescribed conservative approach with little to no exposure to scenarios that might require a more evaluative approach to justify a less conservative, albeit permitted, solution.

Academic Case 2: Lateral Torsional Buckling Modification Factor in AISC 360-16

Similar to the case previously presented, in the Steel Design course, the instructor derived the critical stress equation for the flexural limit state of the elastic lateral torsional buckling of wide flange

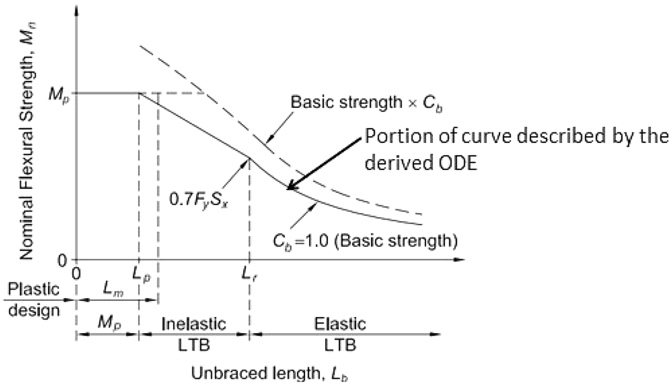


Fig. 2. Nominal flexural strength and buckling behavior based on unbraced length. (Adapted from AISC 2016.)

members to illustrate an assumption and factor built into the equation provided in the specification portion (AISC 360) of AISC's *Steel Construction Manual* (*SCM*). To illustrate this case, the following is an excerpt from an interview with the instructor wherein they were asked, "In what ways do you expose students to assumptions and/or handle limitations in either ASCE 7-16 or the *SCM*?" to which the instructor responded:

> Yeah, so this is one of the things that I feel like I didn't do that well on, but I think this is one of the big . . . this is the item. So I did a lot of assumptions, like maybe broken down in almost too much detail, but this is the reason the C_b thing for example, the reason you don't use C_b equals 1.0 is because the lateral torsional buckling equation is based off of the assumption that you have a uniform moment, so that's something built into the equation. [. . .] That is an assumption that's made before it even gets here [points to their SCM], and so I did a lot of that. I limited table use, but I think what I wish I would have done more was maybe that initial review of some strength of materials concepts, some structural analysis concepts, because I think it got to the point where they were just confused. There were too many assumptions floating around, and they didn't know which ones were important and which ones weren't. So, I think . . . you want to tell them that there are limitations, but you don't want to make them so confused that they don't know which direction to move in.

Here, the instructor refers to a lecture wherein the ordinary differential equation (ODE) is derived for the critical stress due to elastic lateral torsional buckling (LTB) for the portion of the curve presented in Fig. 2, for which the unbraced length, L_b, is greater than the critical unbraced length corresponding to the development of the yield moment, L_r (i.e., $L_b > L_r$).

To derive this equation, the instructor mentioned during the lecture that we assumed uniform moment across the beam's unbraced length. However, beams do not always experience uniform moment across their unbraced length, and AISC 360 accounts for this by multiplying the derived ordinary differential equation with the factor C_b, where $C_b = 1.0$ for uniform moment and $C_b > 1.0$ for nonuniform moments across L_b. The instructor refers to this example in the interview when they broke down an assumption in an ODE derived from the theoretical strength of material concepts and how AISC 360 accounts for that assumption with the additional factor, C_b. Students were expected to calculate C_b on a couple of homework problems but were often told to make the conservative assumption of $C_b = 1.0$ in their calculations of a wide flange member's nominal moment strength. The instructor mentioned in the lecture that most engineers make this same assumption because it is conservative and saves time by not having to calculate $C_b > 1.0$. The instructor also mentioned in the lecture that one of the main reasons they actually taught the class how to calculate C_b was to give students additional practice creating moment diagrams.

This instructor finished their answer to the interview question by noting that they wanted to expose students to the limitations and assumptions built into codes, but they were worried that students would be confused if there were too many "assumptions floating around" and subsequently not know "which direction to move in" when applying a code. The instructor also mentioned in that interview excerpt that they want to focus initially on greater material strength and structural analysis concepts before addressing the assumptions and limitations in the codes such that students are less confused about the source of these assumptions and limitations.

Similar to the previous case, the instructor presented why certain factors exist in their respective codes and the assumptions off which they are built that typically lead to more conservative equations in the codes and how students can prescriptively use the codes to perform more detailed, less conservative calculations. However, students received little to no practice wherein they were exposed to a scenario that warrants a more detailed and less conservative calculation of $\underline{C}_b$ because their homework problems told them either when to calculate $C_b > 1.0$ or assume that $C_b = 1.0$ with no additional context for why the calculation or assumption should be made. These homework problems came from a single assignment and are portrayed in Fig. 3.

This and the previous case from the RC Design course demonstrate how these instructors lectured on limitations and assumptions in their respective codes, whereas students prescriptively applied their codes on homework assignments and exams with little to no evaluation of these limitations and assumptions. However, these cases provided students with some exposure to the importance of carefully reading their respective codes to ensure they are using the appropriate equation prescribed in their codes. The importance of reading codes carefully was emphasized by the instructor of the Structural Theory I (ST-I) course and demonstrated in the following case.

Academic Case 3: Live Load Reduction in ASCE 7 and OSSC 2014

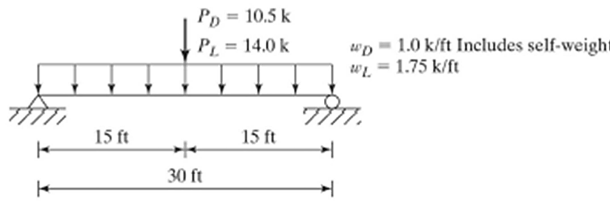
In the ST-I course, the instructor has some early homework and recitation assignments wherein students were required to navigate the 2014 edition of the Oregon Structural Specialty Code (OSSC) and portions of ASCE 7-16 provided in their textbook for determining live, dead, snow, wind, and earthquake loads. For example, in a recitation exercise, students were expected to use pertinent sections of the OSSC to determine the live load on the column and beam highlighted in Fig. 4 and whether any live load reduction could be applied. In an interview with the instructor, they stated that the intention for these assignments was to have students read the codes carefully:

> And mostly the point there, I guess it's just, it's easy to not read it correctly. I'm not necessarily teaching them in that class how to read ASCE 7, but just making the point that you better read it carefully. [. . .] And then you have to look not just in one place [. . .] So you can't just look in this page right here, there might be relevant information here, here, here, and here.

Here and in the recitation assignment, the instructor emphasizes to the students the importance of reading codes carefully and reading all of the relevant information before assuming whether or not

Problem 1

A W24 × 104 beam is used to support the loads shown in the figure below. Lateral bracing of the compression flange is supplied only at the ends. Determine C_b. If $F_y = 50$ ksi, determine if the W24 is adequate to support these loads. Use the equations in Chapter F of the manual to calculate L_p, L_r, and $\phi_b M_n$ and use the appropriate design tables (Table 3-2 and Table 3-10) to check your answers. Check for shear.



Problem 2

A W14×90 of A572 Grade 60 steel ($F_y = 60$ ksi) is used as a beam with lateral support at 10 foot intervals. Assume that $C_b = 1.0$ and compute the nominal flexural strength. (Hint: This is not a standard steel material for wide-flange members. Check local buckling to determine whether it affects M_p.)

Problem 3

Design the lightest W shape beam of 50 ksi steel to support the loads shown in the figure below. Neglect the beam self-weight. The beam has continuous lateral bracing between A and B, but is laterally unbraced between B and C. Determine C_b. Check for shear.

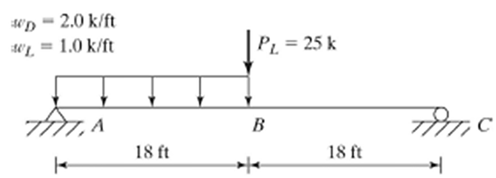


Fig. 3. Homework assignment for the Steel Design course wherein students calculated C_b or assume that equaled 1.0 in their subsequent calculations for nominal flexural strength (M_n). (Reproduced with permission.)

an equation is applicable. For the recitation assignment presented in Fig. 4, students had to carefully read sections of the OSSC to determine whether they could reduce the live load demand on the beam and column and then correctly apply Equation 16-23 in the OSSC (2014). This equation is the same one for live load reduction in ASCE 7-16.

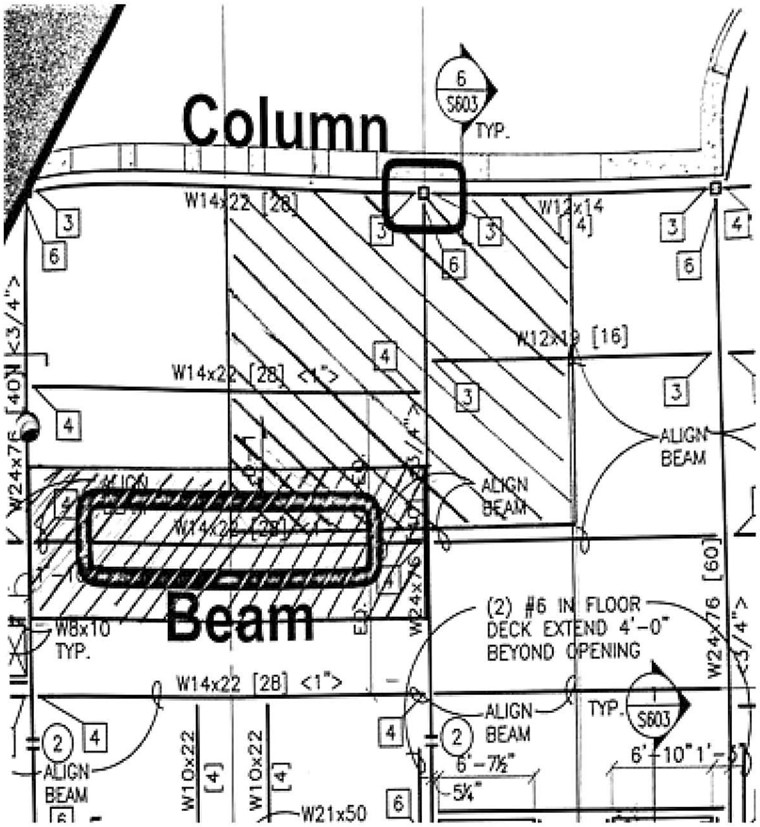
This case is another example of how students were exposed to prescriptively navigating and applying the code to use a more detailed, less conservative equation (in this case, live load reduction). Thus, in all three cases provided from the academic environments, students were shown equations in various codes and taught to some extent how they could use more detailed equations subsequently provided in their codes to increase their capacity or reduce their demand. Whereas these cases provided students with some exposure to the assumptions that went into the development of these code equations and their limitations, students were never provided with examples or practice with scenarios in which they have to use an evaluative approach to justify using more or less conservative equations from within or outside of their codes. Although many of the same codes and equations were observed being used in a similar manner in the workplace, occasional scenarios arose wherein engineers used an evaluative approach rather than a prescriptive one when applying certain provisions in a code.

Workplace Environment

Multiple codes were observed being used in the workplace environment, with engineers often simultaneously navigating more than one code in their design activities. In general, the engineers often used codes to prescriptively calculate loads/demands and check limit states for various structural elements. However, other scenarios emerged wherein the engineers had to go beyond prescriptively applying a code and, instead, had to negotiate an evaluative approach in how they chose to apply certain provisions in various codes. The following cases illustrate these scenarios to provide an overview of what the authors mean by this evaluative approach and how it differs from the prescriptive applications of codes.

Workplace Case 1: Lateral Stability Factor in NDS 2012

This first case demonstrates a design task wherein the ethnographer had to apply provisions from American Wood Council's (AWC) National Design Specification (NDS) (AWC 2012) for lateral stability when designing wood members. For this design task, the ethnographer had to design a hip beam for a canopy structure. When determining the bending capacity of the wood beams, a stability factor (C_L) less than or equal to 1.0 must be multiplied to the referenced bending stress capacity of the member. This stability factor potentially reduces the design capacity of the member to account for the effects of LTB. The *NDS* permits $C_L = 1.0$ (no reduction) if



(a)

1607.10 Reduction in uniform live loads. Except for uniform live loads at roofs, all other minimum uniformly distributed live loads, L_o, in Table 1607.1 are permitted to be reduced in accordance with Section 1607.10.1 or 1607.10.2. Uniform live loads at roofs are permitted to be reduced in accordance with Section 1607.12.2.

1607.10.1 Basic uniform live load reduction. Subject to the limitations of Sections 1607.10.1.1 through 1607.10.1.3 and Table 1607.1, members for which a value of $K_{LL}A_T$ is 400 square feet (37.16 m²) or more are permitted to be designed for a reduced uniformly distributed live load, L, in accordance with the following equation:

$$L = L_o\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right) \quad \textbf{(Equation 16-23)}$$

For SI: $L = L_o\left(0.25 + \frac{4.57}{\sqrt{K_{LL}A_T}}\right)$

where:

L = Reduced design live load per square foot (m²) of area supported by the member.

L_o = Unreduced design live load per square foot (m²) of area supported by the member (see Table 1607.1).

K_{LL} = Live load element factor (see Table 1607.10.1).

A_T = Tributary area, in square feet (m²).

L shall not be less than $0.50L_o$ for members supporting one floor and L shall not be less than $0.40L_o$ for members supporting two or more floors.

TABLE 1607.10.1
LIVE LOAD ELEMENT FACTOR, K_{LL}

ELEMENT	K_{LL}
Interior columns Exterior columns without cantilever slabs	4 4
Edge columns with cantilever slabs	3
Corner columns with cantilever slabs Edge beams without cantilever slabs Interior beams	2 2 2
All other members not identified above including: Edge beams with cantilever slabs Cantilever beams One-way slabs Two-way slabs Members without provisions for continuous shear transfer normal to their span	1

(b)

Fig. 4. Recitation assignment in ST-I course wherein students had to (a) determine the live load acting on the highlighted beam and column; and (b) apply the live load reduction equation from OSSC (2014) if applicable. (Reprinted from OSSC 2014.)

the bending member has sufficient lateral support per section 3.3.3.3: "When the compression edge of a bending member is supported throughout its length to prevent lateral displacement, and the ends at points of bearing have lateral support to prevent rotation, $C_L = 1.0$" (AWC 2012, p. 15). The *NDS* then provides subsequent provisions to calculate C_L based on the geometry and material properties of the member. The ethnographer was not sure if he could safely assume the rafters framing into the hip (Fig. 5) provided sufficient lateral support to justify using $C_L = 1.0$ or if they should be conservative (but spend more time) following the subsequent provisions in the NDS to calculate $C_L < 1.0$.

The rafters framed into the hip every 0.61 m (24 in.), but the *NDS* does not explicitly address whether this spacing was sufficient lateral support, leaving the ethnographer uncertain. The ethnographer asked a senior engineer whether the rafters provided enough lateral support to merit $C_L = 1.0$. The senior engineer said that the rafters provided more than enough lateral support. In a subsequent interview with this same engineer, the ethnographer asked how the engineer was so certain that the rafters would provide enough lateral support. To answer the question, the engineer shared an anecdote from a field trip to a structures testing lab during a graduate course they had taken wherein they observed the amount of force required to prevent LTB in a slender steel beam:

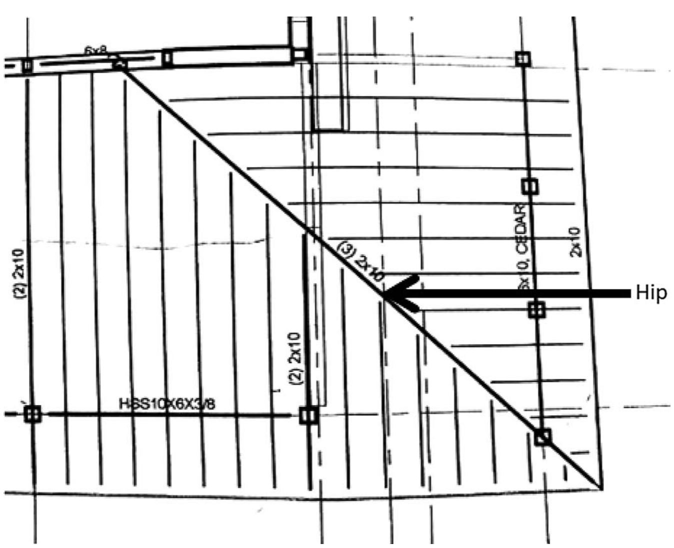


Fig. 5. Canopy framing plan illustrating rafters framing into the hip of the canopy.

> **Engineer:** . . . as the relatively slender beam started to try to laterally torsionally buckle, he [the instructor] said, "Okay, hand someone a yardstick," he said, "Just push on it." There's several thousand pounds being applied to this and you're just pushing on it with a yardstick, and now it's not laterally torsionally buckling. So that real simple connection of like, "Oh, this is what a brace force is and oh, doesn't actually take that much." It's just about restoring equilibrium to make sure that it yields in plane and doesn't buckle out of plane, and actually doesn't require that much force. [. . .]

Ethnographer: Yeah. And in my head, I was even thinking, I was just like, "I don't feel comfortable saying that these rafters provide lateral stability," just because I had no concept of . . .

Engineer: What it takes.

This episode demonstrates that because the ethnographer lacked a fundamental conceptual understanding of how much a brace force should be and how frequently one is needed throughout a span to provide lateral stability, they were unable to use an evaluative approach in interpreting the *NDS* for determining C_L.

Workplace Case 2: Risk Category in ASCE 7

The previous example demonstrates how fundamental conceptual knowledge allows an engineer to take an evaluative approach to a code and justify a less conservative design. Other cases in the workplace environment conversely demonstrated how engineers sometimes use an evaluative approach to applying codes based on their engineering judgment and/or skepticism of a code's minimum requirements to justify being more conservative than said code's minimum requirements. An example of this type of case comes from an observation of three engineers working on a project that had some uncertain site conditions pertaining to the foundation of a nearby existing structure. One of the engineers quipped after their meeting that their department head "drew the short straw and had to stamp this project," implying that the uncertain site conditions made it a liability for whoever had to stamp the project. The department head overhears this and says, "Wait a minute . . . " to which the same engineer who made the joke quickly replied that the project was risk category II as defined in ASCE 7. The department head retorts that just because ASCE 7 permits a structure to be risk category II does not mean that it should not be a higher risk category. Higher risk categories are designed for larger forces and, thus, more conservatively designed than lower risk category structures.

The ethnographer asked the department head what they meant by this in a subsequent interview, and the department head alluded to a specific excerpt from the commentary in ASCE 7-10 as an example of the code permitting structures containing toxic, highly toxic, or explosive substances being classified as risk category II. The excerpt from the interview is provided as follows for additional clarity:

. . . somebody wrote in the 7-10, some committee, somehow, that said, basically, if you can contain, if you've got chemicals, and you can contain them and they won't spill over to the neighbor after an earthquake, that you're fine. You can be level two. And I just think that is—and it used to be in the commentary that it kind of made that inference that—and it wasn't real super clear. But people would take that exception and go back to the commentary and say, "You know, this is really what it says." Well, now it's explicit in the code [ASCE 7-10 C1.5.3, presented in Fig. 6]. I mean, it just comes right out and says that, "Hey, if the neighbors aren't affected, you don't have to be a [category] three or four." And what I was saying is that, probably that's coming from the East coast some place. I'm just speculating now, and I don't know this. I doubt this would ever come out in California and if they ever had a big earthquake down in California, is what I was saying [. . .] you'll have chemical plants that will collapse, kill workers. [. . .] I don't think California would let people do this . . . and in most jurisdictions it would be no way. But let's say they did and some big chemical plant was only a group two, and it was just life safety. They didn't have to go the extra mile, and a bunch of stuff collapses, a bunch of pipes break, and yeah, it doesn't even spill over to the neighbors, but it does a bunch of environmental damage [. . .] and then everybody's going to be up in arms, asking, "What the hell? Why wasn't this designed as a group four?" Well we just did it to code. And that happened in North Ridge [. . .] and you know, there's a lot of stuff in our codes that have been developed since North Ridge and stuff we're even doing since North Ridge that probably won't do well. It won't perform well, and our codes will have to change.

Fig. 6 provides the portion of the ASCE 7-10 commentary to which the department head referred in this interview.

In the interview excerpt, the department head says that many jurisdictional codes would not permit risk category II for some structures even though ASCE 7-10 does. The regional codes take precedent over ASCE 7-10, but the department head used this as an example for when an engineer should use his or her better judgment to potentially assign a structure a higher risk category, resulting in a more conservative design even though a code might permit a less conservative design. The department head emphasized this point by noting how codes evolved after the Northridge earthquake in 1994 and how they were still skeptical of minimum design provisions in the code that they suspected needed to be further updated after another major earthquake event. Thus, this case demonstrated an engineer's overall evaluative approach to a code in the workplace environment wherein they used their judgment and skepticism of codes based on their limitations to be more conservative in their design.

Workplace Case 3: K-Rating Speeds in FEMA 430

In a similar case, engineers in the workplace environment were observed discussing a project and whether they should apply a code's minimum criteria or use a more evaluative approach to justify a more conservative design. This case was observed during a design meeting for a project installing bollards at an airport to increase security against a potential terrorist attack from a truck being used as a battering ram. The project engineers were designing the bollard system and subsequent load path per the K4 certification outlined in FEMA 430 Section 4.2.2 Barrier Crash Test Standards (Fig. 7) based on their client's requirements. A couple of engineers mention considering using a higher certification class or adding a factor of safety due to the uncertainty in the impact load (e.g., vehicle weight, speed and angle at impact, explosives, simultaneous loading scenarios). The engineers working on the project ultimately settled on the original K4 criteria per the client's requests. The existing challenges that they were already facing with handling the large forces flowing from the bollards into existing structural elements as a result of a K4 rated impact also influenced their decision to apply the code as indicated. This case demonstrates how even when engineers in the workplace environment settle on applying a

Buildings and other structures containing toxic, highly toxic, or explosive substances may be classified as Risk Category II structures if it can be demonstrated that the risk to the public from a release of these materials is minimal. Companies that operate industrial facilities typically perform hazard and operability (HAZOP) studies, conduct quantitative risk assessments, and develop risk management and emergency response plans. Federal regulations and local laws mandate many of these studies and plans (EPA 1999a). Additionally, many industrial facilities are located in areas remote from the public and have restricted access, which further reduces the risk to the public.

Fig. 6. Excerpt from ASCE 7-10 section C1.5.3. (Reprinted from ASCE 7-10.)

Certification Class	Speed (mph)	Speed (kph)
K12	50 mph	80 kph
K8	40 mph	65 kph
K4	30 mph	48 kph

To become certified with a DOS "K" rating, the 15,000-lb. vehicle must achieve one of the K-rating speeds, and the bed of the truck must not penetrate the barrier by more than 36 inches. The test vehicle is a medium-duty truck such as those that any driver with a commercial license and a credit card can buy or rent. Note that the amount of intrusion is measured to the front of the cargo bed of the truck, where explosives would typically be located (Figure 4-8).

Fig. 7. FEMA 430 table illustrating differences in Department of State (DOS) K-rating certification classes. (Reprinted from FEMA 2007.)

minimal code requirement, there is still some evaluative negotiation based on their engineering judgment and fundamental conceptual understanding for uncertainty in predicting loads.

One of the engineers who suggested using a factor of safety on this design was subsequently interviewed and asked if they could provide an example in which they were not comfortable with the uncertainty in a code, particularly when the evaluation of the prescribed load led to the use of a more conservative load. The engineer responded with:

> We do it all the time up front if we're doing a schematic design because we know that variables will change [. . .] A lot of the times if we're designing a mezzanine or something, or just offices, we'll bump up the weights by 25%. Just because of the unknown and you don't want to have to go back and redesign things.

ASCE 7-10 prescribes a minimum live load of 50 PSF for typical office spaces and a variety of live loads depending on the occupancy or use of a mezzanine (ASCE 2013). The values of these minimum loads already have some conservative assumptions underpinning their quantification; however, even so, the uncertainty and dynamicity of real-world loads resulted in the engineers in the workplace environment taking an evaluative approach when applying the minimum loads provided in ASCE 7.

The three cases presented demonstrated how engineers in the workplace environment sometimes take an evaluative approach when applying and interpreting codes to either justify more or less conservative designs. These cases also demonstrate how the sociomaterial contexts of the code being applied and the nature of the project or design task being worked on influences whether or not the engineers used an evaluative or prescriptive approach.

Discussion

The findings presented in these cases demonstrate how the sociomaterial contexts of the workplace environment sometimes require an evaluative approach in applying codes. In the academic environments, such evaluative approaches were only alluded to in the lecture, and students practiced applying the codes in purely prescriptive ways. This resonates with some of what the existing literature noted as limitations in the way codes are taught in undergraduate education—most notably that information on limitations and assumptions in codes and the need to apply them in an evaluative fashion is mentioned ad hoc in lectures, minimizing students' opportunities to engage with this information (Kelly 2008; Solnosky et al. 2017). Furthermore, the courses observed were generally structured around initially presenting conceptual content in the lecture. Then, the students practiced applying codes prescriptively on their homework and/or lab/recitation assignments with a minimal explicit connection back to the relevant conceptual content.

Isolating codes from other course content was an additional limitation identified in the literature of the instruction of codes (Solnosky et al. 2017). In this case, the RC course was somewhat unique because "the core of ACI 318 is built around a subtle and elegant stipulation that all concrete cross-sections meet the requirements of strain compatibility and equilibrium" (Rumsey et al. 2010, p. 1); therefore, these concepts are constantly reinforced through the application of the equations in this code. Conversely, the Steel Design course utilized the *SCM*, which represents many concepts through tables that students can apply prescriptively without a considerable understanding of the conceptual information represented in them. The steel instructor even shared in an interview how they were initially taught to use these tables:

> When I learned steel design, I was like a table wizard. I could look up things instantly in tables, but I had no concept of what those tables actually meant. Which means if you got any sort of section that wasn't one of the standard ones, like a wide flange, and it wasn't in the textbook, you had no idea what to do with it. And you didn't know what any of its properties were. There was no intuitive sense of what the section was doing. [. . .]This issue I have with the code and I bet this is the same issue that [other instructors have] with it too . . . **it causes the students to not think critically.** They just like, it just gives them an answer.

Here, the instructor talked about how they were taught to prescriptively use the tables in the *SCM* without additional evaluation for what they were representing. The instructor also perceives the nature of codes as problematic because they can cause students to not think critically, which resonates with the concerns raised about prescriptive codes in the SEI (2013) report presented in the Background section. However, based on the workplace environment cases, there appears to be an opportunity to use the codes as a medium for teaching fundamental concepts and developing students' critical thinking around those concepts. For example, exposing students to design scenarios wherein they are required to take a more evaluative approach in using the codes, similar to the engineers in the workplace, gives students more explicit opportunities to think critically about code-based conceptual representations.

Although the SEI (2013) report raises concerns about how prescriptive codes limit engineering students' fundamental conceptual knowledge, it does not address the influence of how instructors teach such codes on that fundamental conceptual knowledge. According to one of the instructors: "We teach them [codes] as cookbooks, most definitely. We teach them [students] as, you go by the code. You follow these steps. You'll get to the answer." If students are only provided "cookbook" scenarios wherein they use prescriptive codes with prescriptive approaches, then the SEI (2013) report's concerns of prescriptive codes on early career professionals are warranted. For example, take this workplace department head's perspective of the codes on graduating:

> When I got out of school, I literally thought [. . .] it [the code] just had tons of research behind it, and just some really super smart people came up with the code, and it's gospel. And, boy, it didn't take long, and I figured, and I was like, "Wait a

minute, this isn't necessarily the gospel. There's some stuff kind of messed up in here."

These two quotes about the codes being cookbooks exemplify the concerns of SEI (2013) over students being purely taught prescriptive applications of codes and developing an overreliance on codes that limits the application of the fundamental conceptual knowledge instructors attempt to emphasize in school. However, when students are taught to apply codes with an evaluative approach, an opportunity exists for students to apply their fundamental knowledge of concepts within a sociomaterial context similar to workplace environments rather than to create a separate set of working knowledge that is purely code-based (Rumsey et al. 2010). Such an approach can also foster a healthy skepticism of codes "that attempt to define the design parameters of upwards of 95% of the structures being built today" (SEI 2013, p. 7).

As previously mentioned, codes are written by committee and, although the committees are large and full of experts from diverse fields (Kelly 2008), the codes are still subject to fallacies inherent in human-made objects "designed by committee." For example, take one of the workplace engineers' experience from attending the NCSEA 2018 conference that they shared in an interview with the ethnographer:

> One of the presenters walked through why certain tenets of the code are in there. Why are you only allowed to design a concrete shear wall building up to 155 (sic) feet? He's like, well it's based on shadow zonings from LA in the '50s. And oh, by the way, it's a typo. It was supposed to say 165, and it's been in every subsequent edition since then. There's no theoretical basis for it. It has to do with zoning and not creating too much shadow on adjacent properties. And then it got codified in engineering standards. So there's no good reason why you can't have a taller building from an engineering standpoint that performs just as well. **So his message to everyone was, challenge the code. Use your fundamentals. Use the skills and tools you were taught as an engineer to determine what is a good and prudent practice.**

To clarify, the engineer meant to say 48.8 m. (160 ft) instead of 47.2 m (155 ft) and is referring to ASCE 7 height limits on lateral force resisting systems prescribed in Tables 12.2.1 in the 2010 version of ASCE 7 (ASCE 2013). The ethnographer looked into this claim and confirmed that the 48.8-m (160-ft) value was "established by the first [Structural Engineers Association of California (SEAOC)] *Blue Book* to supplement an earlier Los Angeles code requirement for buildings taller than 13 stories. A height limit of 13 stories, approximately 45.7 or 48.8 m (150 or 160 ft), was imposed by Los Angeles zoning regulations since approximately the early 1900s. [. . .] Thus, the 48.8-m (160-ft) limit has its origins in this Los Angeles city planning rather than an explicit seismic design rationale (SEAOC Seismology Committee 2009).

Although it is impossible for engineering instructors to know all of the limitations and assumptions built into every code, the authors believe that teaching students an evaluative approach to applying codes develops a healthy skepticism in students of code provisions that they can take into their careers to prevent them from thinking of codes as cookbooks that can be followed without critical thinking. This is not to say that students should not be taught a prescriptive approach to codes. Indeed, these are powerful tools used in the industry that students should be taught how to use (Kelly 2008; Koch et al. 2010; Solnosky et al. 2017). The authors merely suggest that students receive some additional practice applying these codes that goes beyond prescriptive applications. Some may argue that an already full curriculum limits such extensive teaching of codes. The authors believe that these concerns can be adequately resolved by integrating code applications into existing curricula. Therefore, the authors developed the following recommendations for code education within single courses and across the engineering curriculum.

Recommendations

The first recommendation that the authors suggest is providing students with design scenarios in homework assignments that require them to consider a more evaluative approach when applying codes. The easiest way to implement this is through homework problems that require students to decide whether they should use a more conservative or detailed "sharpened pencil" calculation prescribed in a code. For example, in RC design, students could be provided with a scenario wherein a hypothetical architect has reduced their allowable beam depth due to desired floor heights. The problem could be set up such that the commonly used conservative equation used to calculate the shear capacity due to the concrete alone in their RC beam results in insufficient total shear capacity. To resolve this issue, the students need to understand the conservative assumptions built into that equation and apply the more detailed equations in Tables 22.5.5.1 in ACI 318-14 presented in Academic Case 1 to boost their shear capacity with the architecturally constrained geometry of their beam. A similar scenario could be used in a steel design course based on the more detailed calculation of C_b presented in Academic Case 2. Moreover, in contrast to the capacity versus demand equation, students could be presented with a scenario wherein they need to reduce the demand on an existing structure by using live load reductions rather than being prescriptively taught how to use the live load reduction equations. These scenarios provide students with experience in making the code work for their design rather than the other way around. These scenarios also give students a better conceptual understanding of what and how sociomaterial contexts affect the variability of determining capacity versus demand, as demonstrated in Workplace Case 3. These types of problems may require more time from students—and instructors for grading. However, the authors believe that simply adding one of these types of problems on a handful of assignments across multiple courses could expose students to more evaluative code applications and develop their engineering judgment without significantly burdening the existing curriculum. For example, an existing homework problem that asks students to apply a code prescriptively to obtain a design value could be expanded to also ask students to consider a more evaluative procedure that results in a slightly different, but still valid, answer requiring the use of engineering judgment to justify. That said, future research could also explore including practicing engineers in the development of the curriculum to aid instructors in making decisions on the curriculum that could be reduced to make time for adding the curriculum that is more authentic to practice.

Another recommendation is to integrate field trips and/or lab visits wherein students are exposed to how structural materials are put together and behave in the real-world such that their only conception of these things is not solely pictures, diagrams, and equations in codes and textbooks. Observations of construction sites and lab tests allow students to see how constructability and other real-world conditions affect the performance of structures (Koch et al. 2010). When possible, the instructor can connect how the code does or does not handle these conditions. This recommendation resonates with Workplace Case 1, wherein the engineer mentoring the ethnographer shared their lessons learned from a field trip visit to a structures lab testing beams. Field trips and/or lab visits may not always be feasible, but several online videos exist that demonstrate lab tests of structures and case studies of prominent structural failures that can be presented in the classroom to emphasize constructability issues and how codes have evolved over time as a result of testing and lessons learned.

The authors are aware that the curriculum in nearly all engineering disciplines is considerably full, and adopting these recommendations may be considered unfeasible (Solnosky et al. 2017) without sacrificing the breadth of other code-related topics or by focusing on more fundamental conceptual knowledge. Regarding the desire to cover fundamental conceptual knowledge in the abstract before learning about codes, the authors believe that fundamental conceptual knowledge can be enhanced and made more engaging when taught through scenario-based cases using codes to organize "bigger ideas" about engineering practice and fundamental design principles (Rumsey et al. 2010; Walther et al. 2011). Regarding concerns about sacrificing breadth, one recommended practice for mitigating this concern is assigning students or groups of students sections of code(s) to research and present to the class. This practice allows students to dissect and investigate the underlying tenets and conceptual knowledge in their assigned section of the code and more efficiently expose them to the breadth and depth of codes (Rumsey et al. 2010). Furthermore, when each upper-level course in an engineering curriculum provides students with at least one in-depth scenario-based exploration of codes that requires an evaluative approach, then the entire onus of teaching the complexities of codes does not fall on a capstone course, and students are better prepared for the challenges they encounter with applying codes in the capstone.

Conclusion

The purpose of this research was to explore how structural engineering concepts were represented within the sociomaterial contexts of code application in workplace and academic environments. This research is more broadly valuable to the structural engineering community and engineering education community because of the variety of opinions on the role that codes should or should not play within the curriculum. Through the use of ethnographic methods, the researchers were able to capture detailed descriptions of how the sociomaterial contexts of the workplace require structural engineers to take an evaluative approach when applying codes and how this contrasts with the sociomaterial contexts of structural engineering courses that instill a primarily prescriptive approach to applying codes. An in-depth exploration of these environments offered greater insights into potential avenues for improving code education in structural engineering at the undergraduate level. The authors believe that this insight is likely applicable to other civil engineering disciplines and, potentially, engineering disciplines outside of civil engineering and encourage similar research that investigates the sociomaterial contexts of code application in other fields.

As previously mentioned, the dilemma with the suggested approaches is how to make curricular decisions within an already packed curriculum. Two endpoints exist—either require more coursework in Bachelor of Science and Master of Science programs or very carefully consider the efficacy of the existing curricular requirements, with infinite solutions considering both endpoints. Codes are an important consideration in this dilemma because they are often considered "workplace" knowledge, and evaluative approaches to codes are even more likely in this category. However, the base assumption of the current curriculum—that students learn the fundamental concepts first and then how to apply them—can be revisited. Evaluative approaches to codes are an example of the interplay of codes and concepts in that the evaluation process normally requires some understanding of the base concepts. Assumptions of learning concepts are widely challenged, both theoretically through theories of contextual learning and situated cognition, and in practice through project- and design-oriented curriculum, such as that at Olin College of Engineering (2020). Therefore, perhaps it would be healthy and productive to view education more holistically as enculturation into the civil engineering practice, in which the base ideas of what it means to be a practicing civil engineer are better understood, and curriculum is designed around the essence of civil engineering practice. This approach is well documented in learning theory through descriptions of cognitive apprenticeship (Lave 1988), where education intends to expose students to "...the whole rich web of practice-explicit and implicit-allowing the learner to call upon aspects of practice, latent in the periphery, as they are needed" (Brown and Duguid 1993, p. 13). Cognitive apprentice approaches advocate for providing learning opportunities to students around evaluative code approaches that occur throughout the curriculum rather than at the expense of conceptual content. It may even be suitable to have a course on codes, including how they are developed and how they can be evaluated.

The addition of our recommended approaches may require greater involvement of active practicing engineers in the curriculum. They are much more likely to have contemporary understandings of the code, including limitations and exceptions. It is relatively common to involve practicing civil engineers in capstone courses; however, perhaps there are feasible ways of incorporating them into curricular practices, such as homework problem development, including rubrics and evaluation criteria. The knowledge of civil engineering faculty related to codes and design will likely always be inherently limited based on hiring processes and job responsibilities; however, it is almost certain that additional ways exist to incorporate authentic practice throughout the curriculum by increasing the use of and participation with active practicing engineers. Lastly, the authors began this paper by identifying common areas of insufficiency cited in engineering education literature before specifically focusing on technological proficiency with codes. However, technological proficiency and the other areas of communication, teamwork, and leadership do not exist in isolation from one another. Therefore, when education can improve students' technological proficiency—such as through evaluative approaches to code application—students are provided with opportunities to also demonstrate their proficiency in communication, teamwork, and leadership in the workplace through their technological proficiency.

Data Availability Statement

Some or all of the data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions (e.g., anonymized data) including, but not limited to, field notes, images of artifacts, and interview transcripts.

References

AASHTO. 2012. *AASHTO LRFD bridge design specifications*. Washington, DC: AASHTO.

ABET. 2018. "Criteria for accrediting engineering programs." Accessed August 20, 2019. https://www.abet.org/wp-content/uploads/2018/11/E001-19-20-EAC-Criteria-11-24-18.pdf.

ACI (American Concrete Institute). 2014. *Building code requirements for structural concrete*. ACI 318-14. Farmington Hills, MI: ACI.

AISC. 2016. *Specification for structural steel buildings*. ANSI/AISC 360. Chicago: AISC.

Aparicio, A. C., and A. M. Ruiz-Teran. 2007. "Tradition and innovation in teaching structural design in civil engineering." *J. Civ. Eng. Educ.* 133 (4): 340–349. https://doi.org/10.1061/(ASCE)1052-3928(2007)133:4(340).

ASCE. 2008. *Civil engineering body of knowledge for the 21st century*. Reston, VA: ASCE.

ASCE. 2013. *Minimum design loads for buildings and other structures*. ASCE/SEI 7-10. Reston, VA: ASCE.

ASCE. 2019a. "Civil engineering body of knowledge: Preparing the future civil engineer." 3rd ed. Accessed August 20, 2019. https://www.asce.org/uploadedFiles/Education_and_Careers/Body_of_Knowledge/Content_Pieces/ce-bok-third-edition-asce-draft-bod.pdf.

ASCE. 2019b. "Commentary on the ABET program criteria for civil and similarly named programs." Accessed August 20, 2019. https://www.asce.org/uploadedFiles/Education_and_Careers/University_Curriculum_Development/Content_Pieces/CEPC%20Commentary%202019-2020.pdf.

AWC (American Wood Council). 2012. *National design specification (NDS) for wood construction*. Leesburg, VA: AWC.

Balogh, Z. E., and M. E. Criswell. 2013. "Framework of knowledge for master's-level structural engineering education." *J. Civ. Eng. Educ.* 140 (1): 04013007. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000176.

Batik, A. L. 1992. *The engineering standard: A most useful tool*. Ashland, OH: Book Master/El Rancho.

Baxter, P., and S. Jack. 2008. "Qualitative case study methodology: Study design and implementation for novice researchers." *Qual. Rep.* 13 (4): 544–559.

Bornasal, F., S. Brown, N. Perova-Mello, and K. Beddoes. 2018. "Conceptual growth in engineering practice." *J. Eng. Educ.* 107 (2): 318–348. https://doi.org/10.1002/jee.20196.

Bransford, J. D., A. L. Brown, and R. R. Cocking. 2000. *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Brown, J. S., and P. Duguid. 1993. "Stolen knowledge." *Educ. Technol.* 33 (3): 10–15.

Brunhaver, S. R., R. F. Korte, S. R. Barley, and S. D. Sheppard. 2017. "Bridging the gaps between engineering education and practice." In *US engineering in the global economy*. Chicago: University of Chicago Press.

Carraher, D. W., and A. D. Schliemann. 2002. "Is everyday mathematics truly relevant to mathematics education?" Chap. 8 in *Everyday and academic mathematics in the classroom. Monographs of the journal for research in mathematics education*, edited by J. Moshkovich and M. Brenner. Reston, VA: National Council of Teachers of Mathematics.

Case, J. M., and G. Light. 2011. "Engineering methodologies in engineering education research." *J. Eng. Educ.* 100 (1): 186–210. https://doi.org/10.1002/j.2168-9830.2011.tb00008.x.

Center for Global Standards Analysis. 2004. "Report on a survey of schools of engineering in the United States concerning standards education." Accessed August 20, 2019. http://engineering.cua.edu/StandardsCenter/Research/SurveyII.doc.

Emerson, R. M., R. I. Fretz, and L. L. Shaw. 2011. *Writing ethnographic fieldnotes*. Chicago: University of Chicago Press.

FEMA. 2007. "Site and urban design for security: Guidance against potential terrorist attacks." Accessed August 20, 2019. https://www.fema.gov/media-library-data/20130726-1624-20490-9648/fema430.pdf.

Gainsburg, J., C. Rodriguez-Lluesma, and D. E. Bailey. 2010. "A 'knowledge profile' of an engineering occupation: Temporal patterns in the use of engineering knowledge." *Eng. Stud.* 2 (3): 197–219. https://doi.org/10.1080/19378629.2010.519773.

Johri, A. 2011. "Sociomaterial bricolage: The creation of location-spanning work practices by global software developers." *Inf. Software Technol.* 53: 955–968.

Johri, A. 2014. "Conducting interpretive research in engineering education using qualitative and ethnographic methods." In *Cambridge handbook of engineering education research*, 551–570. Cambridge, UK: Cambridge University Press.

Johri, A., and B. M. Olds. 2011. "Situated engineering learning: Bridging engineering education research and the learning sciences." *J. Eng. Educ.* 100 (1): 151–185. https://doi.org/10.1002/j.2168-9830.2011.tb00007.x.

Johri, A., B. M. Olds, and K. O'Connor. 2014. "Situative frameworks for engineering learning research." In *Cambridge handbook of engineering education research*, 47–66. Cambridge, UK: Cambridge University Press.

Kelly, W. E. 2008. "Standards in civil engineering design education." *J. Civ. Eng. Educ.* 134 (1): 59–66. https://doi.org/10.1061/(ASCE)1052-3928(2008)134:1(59).

Koch, L., R. Goff, and J. Terpenny. 2010. "Introducing undergraduate to load calculations: A course designed around ASCE 7." In *Proc., ASEE South East Section Annual Conf.* Washington, DC: American Society of Engineering Education.

Lave, J. 1988. *Cognition in practice*. Cambridge, MA: Cambridge University Press.

Lave, J., and E. Wenger. 1991. *Situated learning: Legitimate peripheral participation.* Cambridge, MA: Cambridge University Press.

Lemke, J. L. 1997. "Cognition, context, and learning: A social semiotic perspective." In *Situated cognition: Social, semiotic, and psychological perspectives*, edited by D. Kirshner and J. A. Whitson, 37–56. Mahwah, NJ: Erlbaum.

Lemke, J. L. 1998. "Metamedia literacy: Transforming meanings and media." In *Handbook of literacy and technology: Transformations in a post-typographic world*, 283–301. Mahwah, NJ: Erlbaum Publishing.

Lincoln, Y. S., and E. G. Guba. 1985. Vol. 75 of *Naturalistic inquiry.* London: Sage.

Litzinger, T., L. R. Lattuca, R. Hadgraft, and W. Newstetter. 2011. "Engineering education and the development of expertise." *J. Eng. Educ.* 100 (1): 123–150. https://doi.org/10.1002/j.2168-9830.2011.tb00006.x.

McCracken, W. M., and W. C. Newstetter. 2001. "Text to diagram to symbol: Representational transformations in problem-solving." In *Proc., 31st Annual Frontiers in Education Conf. on Impact on Engineering and Science Education*. NewYork: IEEE.

Moon, K. S. 2010. "Design-oriented structural engineering education." In *Proc., 19th Analysis and Computation Specialty Conf. on Structures Congress 2010*. Reston, VA: ASCE.

Olin College of Engineering. 2020. "At Olin the culture is the curriculum." Accessed March 20, 2020. http://www.olin.edu/academics/curriculum/.

OSSC (Oregon Structural Specialty Code). 2014. "Oregon structural specialty code." Accessed August 19, 2020. http://ecodes.biz/ecodes_support/free_resources/Oregon/14_Structural/14_ORStructural_main.html.

Perkins, D. 2006. "Constructivism and troublesome knowledge." In *Overcoming barriers to student understanding*, 57–71. London: Routledge.

Quinn, K. A., and L. D. Albano. 2008. "Problem-based learning in structural engineering education." *J. Civ. Eng. Educ.* 134 (4): 329–334. https://doi.org/10.1061/(ASCE)1052-3928(2008)134:4(329).

Rittle-Johnson, B. 2006. "Promoting transfer: Effects of self-explanation and direct instruction." *Child Dev.* 77 (1): 1–15.

Rumsey, N., J. Russell, and K. Tarhini. 2010. "Innovative approach to teaching undergraduate reinforced concrete design." In *Proc., 2010 IEEE Frontiers in Education Conf. (FIE)*. NewYork: IEEE.

SEAOC (Structural Engineers Association of California) Seismology Committee. 2009. "Seismic force-resisting systems." *Structure Magazine*, January 2009.

SEI (Structural Engineering Institute). 2013. *A vision for the future of structural engineering and structural engineers: A case for change*. A Board of Governors Task Committee Paper. London: Structural Engineering Institute.

Shealy, T., A. A. Kiesling, and T. R. Smail. 2015. "An online course and teacher resource for residential building codes and above code construction methods." In *Proc., ASEE Annual Conf.* Washington, DC: American Society of Engineering Education.

Solnosky, R. L., W. Schneider, A. Kottmeyer, and S. Zappe. 2017. "Building code educational modules for professional exposure in AE Curriculums." In *Proc., AEI 2017*, 10–23. Reston, VA: Architectural Engineering Institute.

Stevens, R., K. O'connor, L. Garrison, A. Jocuns, and D. M. Amos. 2008. "Becoming an engineer: Toward a three dimensional view of engineering learning." *J. Eng. Educ.* 97 (3): 355–368. https://doi.org/10.1002/j.2168-9830.2008.tb00984.x.

Streveler, R. A., T. A. Litzinger, R. L. Miller, and P. S. Steif. 2008. "Learning conceptual knowledge in the engineering sciences: Overview and future research directions." *J. Eng. Educ.* 97 (3): 279–294. https://doi.org/10.1002/j.2168-9830.2008.tb00979.x.

Trevelyan, J. 2007. "Technical coordination in engineering practice." *J. Eng. Educ.* 96 (3): 191–204. https://doi.org/10.1002/j.2168-9830.2007.tb00929.x.

Trevelyan, J. 2010. "Mind the gaps: Engineering education and practice." In *Proc., 21st Annual Conf. for the Australasian Association for Engineering Education*. Barton, Australia: Australasian Association for Engineering Education.

Vinson, A., P. Davis, and R. Stevens. 2017. "Problem solving in engineering education and professional engineering work." In *Proc., ASEE*. Barton, Australia: Australasian Association for Engineering Education.

Walther, J., N. Kellam, N. Sochacka, and D. Radcliffe. 2011. "Engineering competence? An interpretive investigation of engineering students' professional formation." *J. Eng. Educ.* 100 (4): 703–740. https://doi.org/10.1002/j.2168-9830.2011.tb00033.x.

Walther, J., N. W. Sochacka, and N. N. Kellam. 2013. "Quality in interpretive engineering education research: Reflections on an example study." *J. Eng. Educ.* 102 (4): 626–659. https://doi.org/10.1002/jee.20029.

Yin, R. 2003. *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.