Considerations of Diversity, Equity, and Inclusion in Advanced Structural Engineering Courses

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Abstract

This paper presents various techniques investigated by the authors to bring discussion of societal impact into two advanced structural engineering courses taught at Cal Poly – San Luis Obispo within the Architectural Engineering (ARCE) department during the 2020-21 academic year. The first was an undergraduate reinforced concrete design lecture/lab class where the instructor was able to convey the stories of the individuals and events that influence the ACI 318 code and ASTM standards used for concrete design. The second was a graduate nonlinear structural behavior lecture class that involves a weekly seminar by guest speakers who presented case studies with varying social impacts that students discussed in a post-seminar forum. One seminar from the graduate class was particularly applicable to the ideas of diversity, equity, and inclusion (DEI) and so more information was requested from the project engineers enabling the authors to develop a learning module – presentation and class activities – for undergraduate engineering students that addressed technical design concepts and DEI simultaneously. This paper is intended to provide some ideas to other educators (university instructors or industry mentors) on how to bring the discussion of diversity or social impact into technical conversations on structural design and retrofit.

Introduction

This paper demonstrates how structural engineering educators (university instructors or industry mentors) can communicate and have students (or young engineers) discuss societal impacts related to advanced structural engineering topics. The authors have investigated various techniques to bring these conversations into two courses in the ARCE program at Cal Poly – San Luis Obispo during the 2020-21 academic year: an undergraduate reinforced concrete design lecture/lab class and a graduate nonlinear structural behavior lecture class.

Within the reinforced concrete design course, this consisted of adding short anecdotes of international case studies that tell the history behind standard development like the ASTM splitting cylinder test, and failure scenarios the highlight the need for various ACI 318 code provisions such as minimum area of tensile flexural reinforcement. Furthermore, efforts were made to introduce the many diverse engineers that have contributed to the ACI 318 code provisions such as in the confirmation of existing equations for high strength steel and update of one-way shear provisions.

For the nonlinear analysis course, there were weekly industry and academic guest speakers that shared recent projects and research. Each talk was followed by an online student discussion forum with instructor-generated questions on technical aspects of the projects as well as how engineers communicated risk to their clients and were able to serve a help achieve positive societal outcomes. Some examples of topics included research on fire engineering of a steel-framed structure, seismic upgrades to a natural gas platform serving the West Coast, retrofit of an existing hospital, and blast design of the façade on a critical building, among others.

The paper also details one specific case study from the graduate course seminars – the seismic retrofit of the historic Hotel Churchill as it was transformed into transitional housing – and how it was developed into a learning module for

undergraduate structural engineering courses with a focus on the diversity, equity, and inclusion aspects.

As a collection, the examples presented in this paper can be used a model of how to select and construct anecdotes or more extensive case study presentations and activities that bring together technical structural engineering concepts with a discussion of social impact. The argument for the actively including in DEI curriculum is presented in depth by the authors in Leader et al. (2021); to summarize, the primary reasons are related to engagement and retention of engineering practitioners from underrepresented groups and in a more complete awareness of how engineering solutions impact diverse project stakeholders to better serve their needs.

Highlighting Diversity in Code-Based Instruction

In the Cal Poly undergraduate ARCE curriculum, students complete a design lecture and lab for masonry, steel, reinforced concrete, and timber. In these technical classes, they are exposed to the prevailing design codes and material testing procedures utilized in the United States. Taking the ARCE 444 Reinforced Concrete Design course as an example, these documents would be ACI 318-19 and various ASTM Standards. Given they are published by organizations referred to as the *American* Concrete Institute and the *American* Society for Testing and Materials, a reasonable student misconception may be that only domestic practitioners and researchers contribute. Additionally, student perception of industry-wide demographics for structural engineering leaders of male, White Caucasian, and advanced number of years in career (NCSEA SE3, 2020), may result in other assumptions about who participates in code development.

It is important that engineering educators in the classroom or professional setting communicate that a code like ACI 318 is a living document, typically updated on a three-year cycle by an international team of design, construction, and materials experts representing a range of demographics and career levels. They meet at biannual conference, and virtually on other occasions, with committees focused on topical expertise. They volunteer their time to share insights gained from participating on design and construction projects, experimental and computational research, as well as forensic analysis in their own communities to improve how concrete structures are designed and built. These individuals impact human safety globally since ACI 318 serves as the primary code or is referenced in more than 30 countries (Awad, 2017).

It is an abstract idea to students – that any knowledgeable and dedicated structural engineer can aspire to and, in fact, influence the technical advancement of the field. To make this more tangible, educators should provide specific anecdotes of who and what has driven code updates that are technically relevant to their audience. The following list provides a few brief examples of the influences on ASTM and ACI 318 standards the faculty author has utilized in ARCE 444 drawing from her research knowledge and personal network:

- **Splitting tensile strength of cylindrical concrete specimens (ASTM C496/C496M-17):** Credit is given to Brazilian engineering professor Fernando Carneiro and Japanese doctoral candidate Tsunei Akazawa for independently developing the indirect tensile test procedure in late 1943 (Carneiro, 1943; Akazawa, 1943). Carneiro was motivated by wartime efforts to quantify the tensile strength of concrete airport pavements, having had little success with direct tensile tests. He conceived of the indirect test as a solution when tasked with relocating a Baroque church in Rio de Janeiro due to conflicts with roadway construction. Given the shortage of steel to fabricate rollers, he conducted experiments to use concrete cylinders (Fairbairn & Ulm, 2002). Discussion of Akazawa's efforts is not as readily available, which may have impacted the uptake of "Brazilian split-cylinder test" as a synonym to refer to the ASTM C496 method.

- **Minimum reinforcement ratio (ACI 318-19, R18.10.2.4):** It is possible to make analogies between the minimum wall reinforcement with similar provisions for other member types, like ACI 318-19, R9.6.1.1. These provisions all promote member ductility through the formation of distributed cracking in the plastic hinge zone and ensuring that flexural strength exceeds the cracking strength by a sufficient margin. Response of the 5-year-old Gallery Apartment in the 2010-11 Canterbury, New Zealand earthquakes illustrates poor performance of a wall with a low flexural reinforcement ratio of 0.16% leading to limited cracking in the plastic region and multiple fractured longitudinal bars (Sritharan, 2014). The personal connection to this example is that the faculty author's doctoral dissertation focused on the seismic behavior of RC walls (Behrouzi, 2016). At Cal Poly, she continues collaborations to examine specific issues and retrofit approaches for this type of lightly reinforced walls (Luong & Sevilla, 2020; Williams & Doan, 2020).

- **Maximum reinforcement spacing for one-way slabs and beams (ACI 318-19, R24.3.2.1):** Research by Dr. Aishwarya Puranam is cited in the commentary as verifying the appropriateness of the tensile reinforcement stress value, f_s, for Grade 100 steel. This is but one finding of her doctoral dissertation at Purdue University on the strength and serviceability of concrete members constructed with high-strength steel reinforcement (Puranam, 2018). Her investigations address many other critical concerns encountered by practitioners as they seek slabs, and walls for building applications in seismic areas.

The personal connection is that Dr. Puranam and the faculty author have worked and published together on post-earthquake investigations for the 2017 Mexico event (Alcocer et al., 2020) and on efforts of ACI 133: Disaster Reconnaissance committee (Laughery et al., 2020).

- **Concrete contribution to one-way shear strength of non-prestressed members (ACI 318-19, R22.5.5.1):** Work by Drs. Daniel Kuchma and Sihang Wei, among others, is cited in the commentary indicate that one-way shear provisions have been stagnant since 1963. To address this, databases of hundreds of non-prestressed beam tests from the last few decades have been compiled by multiple ACI technical committees with the assistance of the German Committee for Structural Concrete to support development of more reliable shear design approaches (Kuchma et al., 2019). In 2017, six teams submitted proposals for new shear provisions using these datasets. These were formulated by researchers in Canada, Germany, South Korea, Spain, Taiwan, and the United States. Further committee deliberation and investigation of the proposals resulted in shear equations now accounting for: tensile longitudinal reinforcement ratio, shear reinforcement area, axial load, and member size. The personal connection is that Dr. Kuchma was the faculty author's doctoral advisor and Dr. Wei was her research colleague at the University of Illinois.

The authors encourage educators to consider who are the contributors to standards like ASTM and ASCE 318. Beyond sharing the quantitative (formulas and procedures), they should highlight the human aspect and personal connections (credit the individuals; how they represent an array of technical backgrounds, nationalities, genders, age groups, and other types of diversity; and how the educator knows them, if applicable). Likewise, there are events – industry projects, research programs, innovations, and failures – occurring around the globe that are informative to our collective knowledge as structural engineers. These case studies should be examined and discussed as well. Highlighting diversity in codes and standards identifies the mutual global intellect and experiences that inform efforts to safely design, construct, retrofit, and repair the structures that form our communities.

Highlighting Socioeconomic Impact in Case Study Seminars

The Cal Poly graduate ARCE program includes classes that cover the theory and practical application of structural mechanics, nonlinear structural behavior, and finite element modelling. The flexibility of the graduate-level curriculum lends itself to instructors inviting engineers and research scientists that can speak to how course concepts directly translate to real case study projects. The value of the guest lecture can be extended by the instructor facilitating follow-up discussions of technical innovations and social impact of the projects. The remainder of this section provides details on weekly, 50-minute-long seminars in the Fall 2020 offering of the ARCE 502 Nonlinear Structural Behavior I taught by the faculty author. This model can be used beyond the university setting for professional organizations or firms hosting a speaker series.

The first stage of planning the seminars involved preparing a list of potential speakers, or intermediaries, to contact. This included young Cal Poly alumni (with the knowledge that some would not have in-depth nonlinear analysis experience yet, but could recommend peers and mentors that did), colleagues from the instructor's graduate studies or service in professional organizations, and speakers who had given relevant talks at recent conferences. The shared characteristic that was sought among the speakers was that they all have a developed expertise in nonlinear analysis and that they committed to the goal of introducing new graduate students to this complex topic in a clear and engaging manner with a specific and practical case study. Deliberate efforts were made to build a line-up of guests that received their academic training at different institutions; worked in a range of engineering firms, national labs, and universities; had distinct areas of structural engineering expertise; were at various stages in their careers; as well as representing diverse demographic backgrounds. All the while, also ensuring the speakers would be sharing projects that had unique function, and thus, served different stakeholders. Around twenty-five individuals were contacted nearly two months before the date intended for the first presentation to ultimately secure eight lectures which are summarized in Table 1.

Once the speakers had been identified, each were asked to provide a short biography, portrait photograph, presentation title, and abstract summarizing the case study which was formatted into a flyer. Additionally, since the students were unfamiliar to some of the design loads that trigger nonlinear response such as fire or blast, background video and reading materials were requested that would orient the class to the guest lecturer's topic. Each presenter's flyer and informational resources were distributed to students via email and on the course webpage prior to the visit. These enabled students, who were in the early stages of job hunting and determining a career path, to investigate new work organizations and types of projects, while exposing them to the diversity of the presenters and their backgrounds. Prior to the talk, a document was also sent to the speakers reminding them the students were new to nonlinear analysis and consider this as they determined what technical details and terminology to include. It also included a list of nine questions that identified the topics that should be discussed for a given case study project. This document was a

Table 1. ARCE 502 Graduate Seminars

Lecture	Degree	Institution	Career Level	Gender	Organization	Size	Location	Project Type	Structure
1	PhD	Purdue Univ	Asst Professor	F	University	Large	Corvallis, OR	Fire	Steel multi-story
2	MS	San Diego State	Principal	M	Firm	Large	San Diego, CA	Seismic retrofit	Historic hotel
	MS	UC-San Diego	Associate	M					
3	MS	UC-Berkeley	Principal	M	Firm	Small	San Francisco, CA	Seismic retrofit	Gas Platform
4	MS	Univ of Illinois	Engineer	F	Firm	Large	Alburqurque, NM	Blast	Façade
5	PhD	Purdue Univ	Associate	M	Firm	Medium	Northbrook, IL	Forensic	Water tank
6	PhD	UC-Berkeley	Engineer	F	Firm	Medium	Los Angeles, CA	Seismic retrofit	Hospital
7	PhD	UC-Los Angeles	Engineer	M	National Lab	Large	Gaithersburg, MD	Uncertainty	Bridge columns
8	MS	Cal Poly - SLO	Associate	F	Firm	Large	Los Angeles, CA	Seismic design	Stadium

Size: Small <100 , Medium 100-999, Large >999 employees

method of coaching the speakers, many of whom are early-career professionals, to be aware of and successfully help achieve the seminar series' learning objectives within the course. A sample of this document is in Appendix A.

The 50-minute virtual seminars consisted of 30 to 40 minutes of technical discussion of the project followed by a 10-to-15-minute Q&A session. During this the instructor took detailed notes and encouraged the students to do the same. Shortly after the presentation, a discussion forum commenced on the course webpage with 5+ unique questions that responsive to the specific case study. Within the week, the students were required to provide at least one substantive comment to a question that initiated the conversation for a particular question or was responsive to a classmate's comment. The following list provides a brief synopsis of the items related to societal impact that arose during the various speaker's presentations and/or during student reflection through responding to the discussion forum. Lecture #2 was the case study with the most direct tie in with diversity, equity, and inclusion, it is covered in depth in the subsequent section of this paper titled "Detailed Diversity, Equity, and Inclusion Case Study".

- **Lecture #1:** The lecture identified the limitations of prescriptive code design and the value of performance-based fire engineering for capturing the time-dependent, nonlinear effects of fire on a steel prototype building. A number of students expressed strong connections to this topic recounting personal experiences with wildfire in their communities near their hometowns (including Camp Fire, CA and Southern Oregon Fires). In one case the student pointed out that thousands of small businesses as well as light-frame timber and manufactured homes were disproportionately destroyed. They reflected on the combustible nature of these classes of structures and their future role as engineer to implement designs that would protect their communities. While this did not come up in the discussion forum, it is relevant to note that the Butte County region effected by the Camp Fire had higher poverty rates than the national average (US Census, 2019a-b). A financially vulnerable populace like this would likely have barriers to implementing defensive measures, and after a catastrophic fire, to recover.

- **Lecture #3:** This seminar discussed the seismic evaluation and retrofit for an existing steel platform, previously used for extraction, now repurposed for storage of natural gas. The capacity is approximately six months of supply for 10 million customers in the West Coast region. The students were exposed to the strategic analysis process leveraging preliminary linear investigations to inform further nonlinear modeling of the seismically-isolated platform structures supporting critical wells, pumps, and pipelines. The students noted that damage to the structure and pipeline rupture could trigger service interruptions to significant portions of California which would have a cascading effect as the state is the fifth largest economy worldwide. Additionally, there could be negative environmental impacts due to gas emission, and in extreme cases, fire or explosion risk endangering workers and the facility. The detriment to small nearby communities and far-reaching cities the platform serves highlights the socioeconomic impact structural engineers have by resolving seismic vulnerabilities in non-traditional structures.

- **Lecture #4:** The presentation focused on the use of computational fluid dynamics with finite element analysis to understand the blast effects on a window-mullion façade system. The students learned about the many design parameters that have a critical role when considering this loading and noted connections between this case study to high casualty blast events like the 1994 Alfred P. Murrah Building (Delatte, 2009), U.S.; the 1998 U.S. Embassy in Nairobi, Kenya (US DOS, 1999); and the 2020 Beirut Warehouse, Lebanon (Rigby et al., 2020).

Referencing technical reports about these events, the students described the vulnerabilities from a structural engineering and site planning perspective as well as urban risk assessment and emergency response management. They underscored the importance of these lessons being translated to codes of practice and public policy to ensure human safety, particularly around critical governmental facilities and in densely populated urban areas worldwide.

- **Lecture #6:** The seminar discussed the seismic evaluation and upgrade of an existing hospital with steel moment frame and scattered concrete shear walls. Students expressed concerns of acute care facilities ability to acquire funding and retrofit to meet even the most cost-effective option of Structural Performance Category (SPC)-4D, particularly in rural Northern California where they noted that change of classification restricting operational abilities would only magnify the region's health and economic disparities. They also noted poor performance of hospital structures in past earthquakes: 1971 San Fernando, CA where the Veteran's Association hospital collapse led to 44 deaths and 1994 Northridge, CA where several hospitals had to be evacuated for structural and non-structural damage, requiring transportation of patients to neighboring facilities (AAMC, 2019). The discussion highlighted the need for hospitals to remain in service while working towards seismic retrofit requirements and after earthquakes to continue to provide medical care to local communities.

- **Lecture #8:** The final presentation covered the design of a new multi-billion-dollar stadium facility incorporating seismic isolation. A number of students identified that these structures serve as architectural icons and the host of important sports and cultural events in communities, and as such serve as economic drivers for the nearby businesses and tax revenue. They also noted that this scale of projects enables engineers to innovate and provides significant job opportunities within the design and construction fields. In contrast to these positive comments, students referenced instances – like the historic Maracanã Stadium in Rio de Janiero, Brazil – where significant public funds were directed towards the stadium rehabilitation for the 2016 Olympics at the cost of investing in other social services, with the stadium already falling back into disrepair only given a few years (Winterbottom, 2014). Another situation that was mentioned was preparations for the 2022 World Cup in Qatar stadiums with reports of mistreatment of migrant construction workers with respect to pay and adequate living accommodations (Amnesty Intl, 2016). This discussion emphasizes balancing use of private versus public funds and social impact when seeking to create the modern icon.

As a note, the responses summarized in the list above often came through a discussion forum question that encouraged students to consider the social impact of the project, like for the stadium project in Lecture #8 (given below). These open-ended questions allowed students to investigate and share case studies located in the personal to the international contexts and introduce beneficial to detrimental socioeconomic outcomes, as it related to the guest lecturer's topic.

> *Stadium Cost and Benefits to Communities: Stadiums have an interesting role in community. While costly (** Stadium estimated at $** billion) they can serve as iconic host structures for national and global sporting/cultural events. Comment on case studies of other iconic stadiums around the world to understand both the public value and cost.*
>
> *If you are referring to other external resources in your answer, please provide a link that your classmates can access.*

While this section has focused on a graduate course with weekly seminars, the inspection of the social impact of case study projects can be translated to professional organization or internal company presentation. The audience should be given the time for discussion whether immediately afterwards, in a following meeting, or via an interactive virtual environment. It is likely that attendees already contemplate, debate, and celebrate the technical lessons learned from the project; however, there should be a deliberate space to examine the social impact from similar historical situations to understand real outcomes or to reflect on the hypothetical. It is critical for structural engineers to understand how our work fits into the context of society. The reader will hopefully come to appreciate this more in the next section of the paper where in Lecture #2, on a seismic retrofit of a hotel, the engineers described the leadership role they assumed in the design decision-making that was not triggered by code, but rather serving project stakeholders.

Detailed Diversity, Equity, and Inclusion Case Study

As part of the graduate-level ARCE 502 course mentioned previously, Lecture #2 was given by Shaun Walters, S.E. and Erik Lehmkuhl, S.E. of KPFF Consulting Engineers who presented on the seismic retrofit of Hotel Churchill located in San Diego, CA (Walters & Lehmkuhl, 2020). Along with the technical discussion of nonlinear analysis for this project, they also directly addressed ideas related to diversity, equity, and inclusion as the historic hotel was transformed into transitional

housing to serve San Diego's citizens at risk of homelessness. After their Fall 2020 talk, the KPFF engineering team generously provided the authors with many additional resources that would enable the creation of learning modules to integrate the discussion of social impact into undergraduate courses on structural systems, material design, and/or earthquake engineering (these relevant courses are listed in Appendix B). The resources included historic literature and drawings; site, architectural, and structural design materials for the retrofit; as well as conference papers, media articles, funding agency videos, and much more.

The student authors synthesized all the content provided by KPFF to create a presentation that could be given by a faculty member in a single class meeting and created a number of follow-up technical activities for the students to complete to reinforce technical concepts learned during the presentation. The remainder of this section of the paper provides the structure for the Hotel Churchill presentation including historical background, seismic retrofit, design team communications, and impact on the project stakeholders. The objective in providing these details is to encourage other educators to use this as a model to present other case study projects that have a notable diversity, equity, and inclusion component so concepts related to structural engineering and social impact are taught simultaneously.

Note that terms that appear with an asterisk (*) in the following section are defined in Appendix C.

Historical & Social Perspective

Understanding the historical and social context of a structure is key to intentional design. This includes, but is not limited to, details about initial construction, associated entities, project fund sources and budget, as well as the community stakeholders.

In the related course module, the Hotel Churchill case study was introduced as follows:

> *San Diego's Hotel Churchill was built in 1914 to prepare for an influx of tourism from the 1915 Panama-California Exposition (Hotel Churchill, 2020). The six-story hotel was primarily constructed with reinforced concrete as well as hollow infill clay tile walls. In the mid 1920's, a seventh floor was added with unreinforced masonry brick walls around the perimeter (Showley, 2016).*

Before delving into technical aspects of the building, additional information about the project's path to rehabilitation and consequent social impact on the community was provided.

Hotel Churchill had been vacant in disrepair since 2005 before being acquired by the San Diego Housing Commission (SDHC) in a 2011 court settlement as part of the historic* building's foreclosure proceedings (Hotel Churchill, 2021). With funding from organizations like the U.S. Department of Housing and Urban Development (HUD), the SDHC's non-profit affiliate - Housing Development Partners (HDP)- facilitated the rehabilitation of the hotel into affordable housing. The hotel required a near-complete redesign to house 72 studio units for San Diego residents who are veterans, have aged out of foster care, or exited the corrections system (Lehmkuhl et al., 2017). HDP collaborated with the following design partners to complete the rehabilitation: StudioE Architects, KPFF Consulting Engineers, and Heritage Architecture and Planning.

The SDHC is a branch of HUD's Moving to Work Demonstration Program which seeks to maximize resources that support those actively seeking work opportunities by providing project-based housing vouchers* for rental assistance. Monthly rent at Hotel Churchill is $942 and residents are expected to pay no more than 30% of their income towards housing expenses (SDHC, 2021). Additionally, residents receive support from social services and case management on-site (Housing First, 2017).

It is important to share stories of the stakeholders that are directly impacted by the project. In Figure 1(a) we meet a U.S. Navy Veteran and Hotel Churchill resident, Luis, who served for 18 years as an electronic warfare technician on submarines. After finding residence at Hotel Churchill, Luis had the time and resources and support to study contemporary computer applications and prepare for job interviews. In Figure 1(b) we meet former deli manager, Natalie, who experienced homelessness before living at Hotel Churchill and enrolling in hospitality and marketing courses at a local college. Luis and Natalie's stories continue to inspire intentional design and planning that invigorates communities (Hotel Churchill Grand Reopening, 2016).

Vulnerabilities & Retrofit Approaches

After providing historical and social context, the next portion of the presentation should identify factors that drive engineering decisions. While none of the structural deficiencies in Hotel Churchill triggered a code-mandated structural retrofit, the team from KPFF Consulting Engineers was effective in expressing the urgency of upgrading the structure to ensure the safety of residents and contribute to the resiliency of the surrounding community (Lehmkuhl and Walters, 2017). This section summarizes vulnerabilities and retrofit approaches utilized by KPFF. When possible, each vulnerability in the course module includes relevant damage images from earthquakes from around the world to illustrate

Figure 1. Hotel Churchill Residents: (Left) Luis, (Right) Natalie (Hotel Churchill Grand Reopening, 2016)

consequence of poor design; likewise, for each retrofit there are images from in-field or research implementation to highlight innovative methods to upgrade structures. Images of the retrofitted Hotel Churchill are shown in Figure 2 and 3.

High Seismic Mass

The building has considerable dead load as the structural system is comprised of concrete beams and columns supporting concrete joists and slabs (Lehmkuhl et al., 2017). The seventh floor contributes significantly to the building's mass with unreinforced masonry (URM) interior partitions, concrete and hollow clay tile architectural finishes, as well as structural masonry walls at the perimeter. The earthquake forces are magnified by the significant mass at the uppermost floor, which would result in higher demands on the lateral force resisting system (LFRS) and foundation. To remedy this issue, KPFF elected to remove the interior URM partitions at all floors. Additionally, the entire seventh floor was demolished and replaced with a much lighter structural steel system.

Soft Story Condition at Lobby Level

The first story of Hotel Churchill is almost twice as tall as the floors above to accommodate the lobby with large window. However, the desire to maintain these openings does not allow vertical continuity of concrete shear walls from the basement level to mitigate soft story effects. To address this soft story condition, four fluid viscous dampers (FVD) were placed at each face of the building at the lobby level. This option was deemed preferable to braced frames or shear walls, since these more traditional approaches would increase building stiffness and therefore reduce the building period to a region of the response spectra with higher accelerations (Walters and Lehmkuhl, 2020). At this stage in the course module there is an opportunity to introduce students to companies that develop and manufacture products used in the case study example to improve structural performance of the building, which in the case of Hotel Churchill the dampers by Taylor Devices.

Unreinforced Concrete Columns

The original structural drawings of this historic hotel called out unreinforced concrete columns (plain concrete) at the corners of the building which would be expected to fail in a brittle manner with little warning. Other columns in the structure had inadequate reinforcement and would also experience a non-ductile failure. Where existing slabs and columns were had inadequate reinforcement, fiber-reinforced polymer (FRP) was utilized. While FRP design is not typically covered in undergraduate education, this is an increasingly popular and valuable retrofit approach and allows the instructor to introduce a number of experimental column retrofit studies that effectively increase column strength and/or ductility using FRP.

Communication of Risk & Solutions

Aside from presenting technical information about the structural analysis performed by KPFF, Walters and Lehmkuhl emphasized the importance of communicating with clients and other members of a design team. As structural engineers they recognized the importance of conducting a retrofit for Hotel Churchill given the vulnerabilities discussed previously, even though it was not required by the code. The KPFF engineering team created graphics that were tailored to

Figure 2. Exposed Fluid Viscous Damper (Hotel Churchill, 2021)

Figure 3. Hotel Churchill Reopening Images (SDHC President, 2017)

the architect and clients to demonstrate the effects of seismic loads on the building when comparing the existing condition to various retrofit solutions. By communicating effectively with graphics and explanations, the engineers successfully advocated for moving forward with design of a structural retrofit. Specifically, they were able to make use of their team's nonlinear analysis expertise to conduct a detailed performance-based seismic retrofit that resulted in a relatively simple and cost-effective solution. This engineering decision will yield long-term benefits in terms of resilience of these affordable housing units that will serve the community and its many residents for years to come.

In the entirety of the course module, the instructor can lead by example by focusing on their own clear verbal communication and thoughtful creation or selection of graphics to help students and peers understand the technical aspects of the given case study project and how those design decisions impact the stakeholders. These will serve as examples for the types of effective graphics and presentation so their audience can use this as a model to be effective advocates for design strategies when interacting with clients and their design team.

Activities

The technical activity that would follow the Hotel Churchill presentation varies is course dependent, the student co-authors created a load take-offs assignment for the introductory design lab (ARCE 371) and seismic analysis of Hotel Churchill to compare the pre-existing construction with the retrofit design for the earthquake engineering course (ARCE 483). This encourages further course-related interaction with the case study at hand.

Recommendations for Educators

With respect to highlighting diversity in code-based design instruction:

- Use the opportunity after each code cycle to divide engineers into smaller teams to present to one another the changes and to update existing in-house design tools. Also, communicate any significant international events that instigated these changes (experimental research tests or damage seen in recent earthquakes, for example) and the diverse individuals who are credited with these advancements. For university students, instructors should take the lead on this for the code provisions relevant to the course curriculum since students often do not have access to both the current and prior versions of the code.
- As an alternative or to complement the prior point, invite diverse leaders from these code-writing bodies to present to your firm or class to get their personal perspective on the thought process and discussions to arrive at the code provisions. This could provide insight on the limitations or items being investigated for a future code cycle.
- Support students and younger engineers to attend professional organization conferences to expand their network, present on their projects or research, and to contribute their growing expertise to code and educational committees. Connect first time attendees with a more senior student, faculty member, or engineer to introduce them to leaders in the organization and accompany them to technical committees so they understand how to navigate and develop a sense of community in this new environment.

With respect to highlighting diversity in case study seminars:

- Reach out to diverse experts as engineering firms, national labs, non-profits, and academic institutions. Draw from past and current colleagues, authors or presenters whose publications or conference talks have been of interest, university alumni, or solicit recommendations for presenters from others within the organization.
- Once speakers have been identified, coordinate with them to curate a seminar series consisting of distinct project types so the audience can learn about social impact to varying stakeholder groups.
- Build off case studies to develop a discrete task related to the course curriculum (in-class activity, homework assignment or a mini-project). In the firm the case study project could form the basis for a sample design solution of a method or provisions that the younger engineers may not have been exposed to in their academic career but is necessary for their current or upcoming projects.

At the heart of all these recommendations is the common thread that as humans we connect with people and stories, so celebrate the work of structural engineering heroes and friends whenever possible. The next generation will be inspired to join in if they can see the who, what, and why of the passion of their predecessors and are supported in bringing their diversity, originality, and enthusiasm to the table.

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References

ACI 318-19, *Building Code Requirements for Structural Concrete*, American Concrete Institute, 2019.

Akazawa, T., "New Testing Method to Find the Tensile Strength of Concrete," *Journal of Japan Society of Civil Engineers*, Japan Society of Civil Engineers, 1943.

Alcocer, S. et al., "Observations About the Seismic Response of RC Buildings in Mexico City," *Earthquake Spectra*, SAGE Journals, 2020.

ASTM C496/C496M-17, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens,* ASTM International, 2017.

Awad, Khaled W. "News Detail: ACI and the World." American Concrete Institute, 2017.

Behrouzi, A., "Impact of Cross Section, Web Reinforcement and Load History on the Seismic Performance of Slender Concrete Walls," *PhD Dissertation,* University of Illinois at Urbana-Champaign, 2016.

Carniero, F., "A New Method to Determine the Tensile Strength of Concrete," *Brazilian Association for Technical Rules Proceedings*, Brazilian Association for Technical Rules, 1943.

Delatte, Norbert J. "Beyond Failure Forensic Case Studies for Civil Engineers," *American Society of Civil Engineers Press*, 2009.

Fairbairn, E. and Ulm, F., "A Tribute to Fernando L. L. B. Carniero," *RILEM Publications*, International Union of Laboratories and Experts in Construction Materials, Systems and Structures, 2002.

"Homelessness Solutions," *San Diego Housing Commission*, 2017.

"Hotel Churchill," *Heritage Architecture & Planning*, 2020.

"Hotel Churchill," *Housing Development Partners*, 2021.

"Hotel Churchill Grand Reopening," *YouTube*, SDHousingComission, 2016.

"Housing First – San Diego SDHC's Homelessness Action Plan," *San Diego Housing Commission*, 2017.

Jaret,P. "Hospitals on shaky ground: Meeting the challenge of seismic safety," *American Association of Medical Colleges*, 2019.

Kuchma, D. et al., "The Development of One-Way Shear Design Provisions of ACI 318-19," *ACI Structural Journal*, American Concrete Institute, 2019.

Laughery, L. et al., "The Institute's Team for Damage Investigations," *Concrete International*, American Concrete Institute, 2020.

Leader, C. et al., "Student-Led Summer Diversity Workshops for Built-Environment Majors," *Proceedings of the American Society for Engineering Education Annual Conference*, 2021.

Lehmkuhl, E., Pebley, A., and Walters, S., "Hotel Churchill: Using Dampers Strategically," *SEAOC Convention Proceedings*, Structural Engineers Association of California, 2017.

Lehmkuhl, E. and Walters, S., "Hotel Churchill Case Study," *Presentation*, California Polytechnic State University, 2020.

Luong, J. and de Sevilla, R., "Experimental Testing of a Lightly Reinforced Concrete Shear Wall," *MS Project Report*, California Polytechnic State University, 2020.

"NCSEA SE3 2020 Survey Topic Brief," *National Council of Structural Engineers Associations,* 2020.

Puranam, A., "Strength and Serviceability of Concrete Elements Reinforced with High-Strength Steel," *PhD Dissertation*, Purdue University, 2018.

"Report of the Accountability Review Boards: Bombings of the US Embassies in Nairobi, Kenya and Dar es Salaam, Tanzania on August 7, 1998," *U.S. Department of State*, 1999.

Rigby, S.E. et al., "Preliminary yield estimation of the 2020 Beirut explosion using video footage from social media." *Shock Waves* 30, 2020.

"San Diego Housing Commission," *U.S. Department of Housing and Urban Development*, 2021.

"SDHC President and CEO Richard Gentry," *SOHO San Diego*, Save Our Heritage Organization, 2017.

Showley, R. "Churchill Reopens with 72 Rentals for Homeless," San Diego Union-Tribune, September 2016.

Sritharan, S. et al., "Understanding Poor Seismic Performance of Concrete Walls and Design Implications," *Earthquake Spectra 30*, SAGE Journals, 2014.

"State Historical Building Code (SHBC)," *Office of Historic Preservation*, California State Parks.

"The Resiliency Advantage." *YouTube*, US Resiliency Council, 2021.

"The Ugly Side of the Beautiful Game: Exploitation of migrant workers on a Qatar 2022 World Cup site," *Amnesty International*, 2016.

US Census, "QuickFacts: Butte County, California," *United States Census Bureau*, 2019a.

US Census, "Income and Poverty in the United States: 2019," *United States Census Bureau*, 2019b.

Williams, J. and Doan, T., "Investigation of Modeling Strategies for Slender Lightly Reinforced Concrete Shear Walls," *MS Project Report*, California Polytechnic State University, 2020.

Winterbottom, T. "The Tragedy of the Maracanã Stadium," *RioOnWatch*, 2014.

Appendix A

Document for graduate course seminar speakers (some details redacted).

Speaker Series

Name____________________________

Nonlinear Structural Behavior I
ARCE 502 – Fall 2020
Cal Poly – San Luis Obispo

Thank you again for agreeing to speak to Cal Poly graduate students in ARCE 502 about your projects and/or research.

I. Speaker Schedule

The speaker schedule is below (Fridays 10:10-11:00am Pacific, Zoom link to be provided in a later email). In terms of length, I would recommend planning for ~30 minutes of presentation and 10-15 minutes of Q & A. Please be aware that students are new to nonlinear analysis as you consider what technical details and terminology to include in your talk.

Date	Speaker Name	Speaker Affiliation	General Topic Area
9/25/20			Fire Engineering
10/2/20			Historic Hotel Retrofit
10/9/20			Steel Gas Platform Retrofit
10/16/20			
10/23/20			Blast Engineering
10/30/20	Reserved for Course Midterm		
11/6/20			Evaluating Hospitals & PBE
11/13/20			Uncertainty in Seismic Assessment
11/20/20			Advanced Seismic Systems

II. Recommended Items to Discuss

1. What is the structure being analyzed? What are the imposed loads and boundary conditions?
2. What types of analyses were conducted? What prompted these specific types of analyses?
   - 2-D or 3-D
   - Elastic or non-linear (geometric and/or material non-linearity)
   - Static pushover or dynamic (modal, time history)
3. What codes or guide documents were used as a point of reference for the analyses?
   - Existing Buildings: ASCE 41, International Existing Building Code (IEBC), FEMA P-58
   - New Construction: L.A. Tall Building Council Framework, ATC/NIST guidelines, ASCE 7, FEMA P-58
4. Were any material or structural member tests conducted for the project to help you develop inputs for your analyses? If not, was a literature review conducted to acquire test data from other projects?
5. What software (commercial, research, or in-house) were utilized to support the analyses? If various software were used, what was the specific analysis task completed with each software?
   - SAP2000, ETABS, Perform-3D, Opensees, etc.
6. What metrics were assessed (important outputs) from the analyses?
   - Drifts, loads in structural members, deformations in structural members (elongation or rotations), overall building stiffness/damping
   - Impact of structural member loads/deformations on non-structural members
7. In the case of performance-based design, what were the intended performance objectives of the client? How did this relate to the metrics from the previous question?
8. What were the major challenges or uncertainties in the analysis process?
9. What are the important lessons from these analyses related to nonlinear structural behavior that graduate students studying structural engineering should take note of as they enter their careers?

Appendix B

Relevant courses for Hotel Churchill learning module.

Course	Course Title	Course Description
ARCE 371	Structural Systems Lab	Introduction to structural systems and exposure to ASCE 7. Basic load flow and introduction to seismic affects.
ARCE 444	Reinforced Concrete Design	Theory and design of basic reinforced concrete elements: beams, one-way slabs and non-slender .
ARCE 452	Concrete Structures Design & Constructability Lab	Cast in place concrete framed project; structural system configuration and selection, structural analysis, and construction drawings and specifications.
ARCE 483	Seismic Analysis and Design	Earthquake analysis and introduction to ASCE 41 as well as ETABS.
ARCE 502	Nonlinear Structural Behavior I	Study of nonlinear behavior and systems-level modelling.
ARCE 503	Nonlinear Structural Behavior II	Application of nonlinear behavior and systems-level modelling.
ARCE 511	Structural Systems Behavior	Exploration of relationship between structural systems and architectural form.
ARCE 548	Seismic Rehabilitation	Introduction to seismic rehabilitation process and philosophy.

Appendix C

This appendix contains definitions of key words as indicated by an asterisk (*), in order of appearance:

Historic:
A historic building, defined by state historic building codes, is safeguarded from being demolished; thus, Hotel Churchill would still be in its previous condition without the retrofit (State Historical Building Code).

Project based housing voucher:
Project-Based Housing Vouchers are awarded to specific affordable housing developments to provide rental assistance linked to their units. When a tenant moves on, the rental housing voucher remains with the affordable housing unit to help another San Diegan experiencing homelessness to move off the streets (Homelessness Solutions).