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Does an ABET EAC Civil Engineering Degree Prepare Structural Engineers for Practice?

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Abstract

Civil engineering is one of the oldest and broadest fields of engineering. There are numerous subdisciplines that undergraduate civil engineering programs (referred to as programs) cover including transportation, geotechnical, water resources, environmental, construction, and structural. Accreditation agencies and engineering societies do not have a consensus on how many subdisciplines must be taught to undergraduate students, instead they provide flexibility in curriculum development. Because of this lack of definition, content varies among programs even though practicing engineering in many subdisciplines requires significant educational depth in their respective area of the profession.

Structural engineering requires both educational breadth and depth to be proficient according to practicing engineers. In fact, some jurisdictions require a structural engineering (SE) license beyond a professional engineering (PE) license. This demonstrates the move to further define a distinct body of knowledge to practice structural engineering. Past studies of program content have focused on surveys of practitioners and academicians to determine which topics are necessary for entry-level structural engineers. This study aimed to synthesize what structural engineering courses are offered by civil engineering undergraduate programs in the United States. The civil engineering curricula at a representative sample of undergraduate programs accredited by the ABET Engineering Accreditation Commission (EAC) were reviewed to determine what structural engineering courses are required, offered as undergraduate elective courses, or offered as graduate elective courses. Data were collected from 101 programs in 25 course categories. The results were analyzed based on required courses, elective courses, and courses only available to graduate students. In addition, differences in the typical curriculum at programs in different regions of the country and programs with or without graduate education were reviewed.

The data indicated that there are standard core courses that over 80% of programs require students to complete including statics, mechanics of materials, soil mechanics with a laboratory, civil engineering materials, and introductory structural analysis. Furthermore, over 70% of programs offer the following topics in a required or elective undergraduate course: dynamics, steel I, reinforced concrete I, and foundations. While many programs offer a robust list of graduate course offerings in their catalogs, none of the programs require the following courses and fewer than 40% of universities made them available to students in undergraduate programs: seismic, wind, finite element methods, structural dynamics, steel II, concrete II, masonry design, prestressed concrete, and bridge design. The data showed that universities conferring graduate degrees offered more courses, but only some courses were directly available to undergraduate students. This demonstrates the need for structural engineers to learn a significant amount of material on the job or pursue an advanced degree after graduation from an ABET-accredited undergraduate program.

Introduction

Civil engineering is one of the oldest and broadest fields in engineering. The profession covers a range of topics through an array of subdisciplines, and each subdiscipline significantly impacts society and the environment. As the profession has evolved, so has the coverage of these areas in university-level civil engineering program curricula. The number of credit hours required for an average degree has declined during a time when knowledge and breadth in the profession have continued to increase. This has resulted in many changes to civil engineering undergraduate programs accredited by the ABET Engineering Accreditation Commission (EAC).

One of the historical subdisciplines of civil engineering is structural engineering. At a university, this area commonly includes most of the introductory engineering mechanics coursework along with structural analysis and structural design courses. Many have noted that the field of structural engineering has continued to become more complex and requires more advanced coursework, possibly even a graduate degree [1]-[2]; this sentiment aligns with other professions that are vital to public welfare, such as medicine and law, where graduate education is the entry level [3]. Due to the flexibility in course requirements and offerings in civil engineering programs, the typical undergraduate structural engineering content is not easy to identify, even among ABET-accredited programs. There is no documented requirement for a certain number or type of structural engineering courses.

Background

As knowledge continues to advance in structural engineering, university programs are challenged to offer relevant material that aligns with current societal needs. Typically, civil engineers attain a breadth of knowledge through completing an undergraduate degree and professional mentorship. However, many acknowledge that depth in a civil engineering subdiscipline (e.g., structures) is required to successfully practice civil engineering [4]-[7]. Depth in a civil engineering subdiscipline can be attained through a combination of undergraduate education, graduate education, and professional mentorship [4], [8]. Furthermore, depth is inherently required in the field of structural engineering by some jurisdictions that require a structural engineering (SE) license to practice, beyond a professional engineering (PE) license.

Several studies have been conducted by the National Council of Structural Engineers Associations (NCSEA) to investigate the level of depth achieved and needed in the field of structural engineering. The NCSEA seeks to improve the standard level of practice of the structural engineering profession, and within that organization, the goal of the Basic Education Committee (BEC) is to "promote the knowledge and skills the [structural] engineering community views as necessary when *entering* the profession." To determine what skills are necessary, the BEC conducted surveys in 2016, 2019, and 2020; in each year, two different surveys were distributed, one to universities to determine which structural engineering courses were deemed important from an educational standpoint ("curriculum survey") and a second to practicing structural engineers to gather similar data but with a focus on describing the skills and educational requirements that structural engineering firms value in *new* hires ("practitioner survey"). Thus, the two surveys addressed both the supply and demand side of the equation [7]. Most of the survey questions were related to 12 structural engineering courses/topics that were identified by the NCSEA BEC [9] to be the core of a structural engineering curriculum:

1. Structural analysis I: determinate analysis
2. Structural analysis II: indeterminate analysis
3. Structural analysis III: matrix analysis
4. Steel design I
5. Steel design II
6. Concrete design I: reinforced concrete
7. Concrete design II:
    a. Advanced reinforced concrete or
    b. Prestressed concrete
8. Wood design
9. Masonry design
10. Foundation design/soil mechanics
11. Structural dynamics
12. Technical communication

<u>BEC Practitioner Surveys</u>

The BEC practitioner surveys broadly addressed the question, "What type of education do engineering firms desire and require of their *new* employees?" Results from the surveys were reported by Hopkins and Dong [10] and Kam-Biron et al. [7] and are synthesized here, in the context of preparing students for a career in structural engineering.

- Considering both surveys, 90% of practitioners considered 9 of the 12 core courses as necessary for students to complete; courses on structural analysis III: matrix analysis (85%), prestressed concrete (70%), and masonry design (87%) were viewed as necessary by fewer than 90% of respondents.

- The three most important subjects identified by practitioners were structural analysis I, reinforced concrete I, and steel I. In addition to the top three, practitioners stated that the list of the top five most important topics included two additional entries: (1) foundation design and (2) loading and load paths. Practitioners in both surveys overwhelmingly stated that the most important technical skill/topic not listed in the 12 core topics was related to loading and load paths, which is described in syllabi for structural systems (ASCE 7) courses at some universities.

- Approximately 43% of respondents expressed the need for students to be able to complete classical structural analysis methods (e.g., hand calculations); 57% of respondents expressed a need for students to be exposed to computer programming, modeling, and software to complete their education (in addition to successfully understanding and checking results from the software).

- When answering the question "Are new graduates and rising professionals with an undergraduate degree adequately prepared when entering the [structural engineering] workforce?," 72% of practitioners replied no, which is related to both technical skills and "soft skills" (e.g., technical communication). A list of additional "soft skills" noted by practitioners in the 2021 survey [7] included communication, creativity, flexibility, leadership, public speaking, and engineering teamwork.

- In the 2021 survey [7], practitioners were also asked to rate the importance of the additional courses/topics shown below, which were identified and listed by the BEC. The five most important additional topics identified by practitioners are shown in bold.
    1. **Load paths/load flow**
    2. Cold-formed steel design
    3. Bridge design
    4. **Structural stability**
    5. **Material science**
    6. Earthquake engineering
    7. Sustainable design
    8. **Finite element analysis**
    9. **Wind engineering**
    10. Blast/progressive collapse
    11. Construction management
    12. Forensic engineering/engineering failures
    13. Performance-based design
    14. Introduction to architecture or architecture history
    15. Construction documentation/drafting
    16. Building information modelling

<u>BEC Curriculum Surveys</u>

The main objective of the BEC curriculum surveys presented to universities was to "validate the recommended curriculum, determine the importance of courses within the recommended curriculum, and to identify the number of institutions where it's possible to complete courses in the recommended curriculum" [11]. Results from the surveys were reported by Perkins [12] and Francis [8] and are synthesized here, in the context of preparing students for a career in structural engineering.

- From a logistics standpoint, "once students complete the necessary foundational (statics, dynamics, mechanics of materials) and breadth courses within their area of study, undergraduate students are often left with only 16 to 24 semester hours of technical courses required to complete their degree. Therefore, at the conclusion of the average student's undergraduate education, many have taken at most only 4-6 of the 12 BEC recommended courses" [8].
- Results indicated that 38% of responding universities offer all 12 core courses at the B.S. or M.S. level; 73% of schools offered 10 of the 12 core courses across both levels. Nearly every university offered the following courses:
    - Structural analysis I
    - Steel design I
    - Concrete design I
    - Foundation design/soil mechanics

  Design courses in materials other than steel and concrete were offered at less than 50% of schools. Masonry design was offered least frequently at the responding schools.
- Timber design and masonry design are not offered frequently; the primary reasons, among others, were a lack of student demand, no faculty member with the expertise, or

imposed unit restrictions. A course on the topic of cold formed steel was also deemed to be useful by practitioners but not frequently offered at universities.

- University faculty (and practitioners) noted the importance of exposing students to real-world applications, design projects, design of an entire building rather than individual components, and building codes.

Research Significance

The main objective of this study was to review the structural engineering coursework at universities with ABET-accredited civil engineering undergraduate programs (referred to as programs in this study). This study investigated coursework breadth and depth to determine what baseline level of structural engineering knowledge is typically required for undergraduate students. At universities that also had graduate programs, data was gathered on courses only available to graduate students. The data in this study were gathered using publicly available course catalogs or bulletins rather than survey responses. In addition, the course data were explicitly filtered to determine which courses were available to each subgroup of students (undergraduate, graduate, or both) and which undergraduate courses were required. The findings were compared to results in the literature that indicate what employers expect of undergraduates they hire and what structural engineering coursework electives are reportedly available to undergraduate and graduate students. The following research questions were specifically investigated:

- Which *required* structural engineering courses are typically offered in undergraduate accredited civil engineering programs?
- Which *elective* structural engineering courses are typically offered in accredited undergraduate civil engineering programs?
- Which structural engineering courses are offered in civil engineering graduate programs?
- Are there differences in course offerings among universities that do and do not have graduate programs and in different regions of the United States?

Research Methods

To accomplish this study, the structural engineering coursework listed at the undergraduate and graduate levels was reviewed at 101 ABET accredited undergraduate civil engineering programs. Approximately 260 ABET accredited undergraduate civil engineering programs existed when this study was performed, and the selected institutions were taken as a representative sample. A program was selected from every state and approximately 20% were private institutions. The type of degree offered at the reviewed institutions ranged from Bachelor of Science degree (B.S.) only, B.S and Master of Science (M.S.) only, and B.S. through Doctor of Philosophy (Ph.D.) degrees. Approximately 75% percent of the programs offered a doctoral degree in civil engineering and 91% offered some form of graduate degree.

The list of 25 courses shown in Table 1 was compiled for use during data collection; this list included 10 of the 12 core structural engineering courses listed by the NCSEA. Structural analysis II: indeterminate and technical communication were not included. Most introductory structural analysis courses cover the analysis of both determinate and indeterminate structures (i.e., structural analysis I and structural analysis II in NCSEA); therefore, the structural analysis topics were divided into two groups in this study: structural analysis I and matrix structural analysis (structural analysis III in NCSEA). In addition, other studies have reported on technical communication in civil engineering undergraduate programs, so this topic was not specifically investigated. This study also specifically separated foundation design courses from soil mechanics courses. A reinforced concrete III course was included in this study to capture programs that provide an additional opportunity to study reinforced concrete topics in depth. The topic probability/risk/reliability included courses that specifically covered these engineering applications, but general statistics courses that did not specifically apply to engineering were not included; course descriptions were used for clarification. A few courses likely incorporated a separate laboratory component (e.g., mechanics of materials, soil mechanics/geotech I, and/or civil/construction materials), but this information was not differentiated; rather, it was included in the total number of credit hours for that specific topic.

Table 1—List of 25 structural engineering courses used during data collection.

Engineering Mechanics	Supplemental Courses	Analysis	Design
1. Statics 2. Dynamics 3. Mechanics	4. Civil / Construction Materials 5. Soil Mechanics / Geotech. I 6. Foundations 7. Probability/Risk/Reliability 8. Advanced Concrete Materials	9. Structural Analysis I 10. Matrix Structural Analysis 11. Seismic 12. Wind 13. Structural Systems (ASCE 7) 14. Finite Element Method 15. Stability 16. Structural Dynamics	17. Steel I 18. Reinforced Concrete I 19. Steel II 20. Reinforced Concrete II 21. Reinforced Concrete III 22. Wood 23. Masonry 24. Prestressed Concrete 25. Bridge

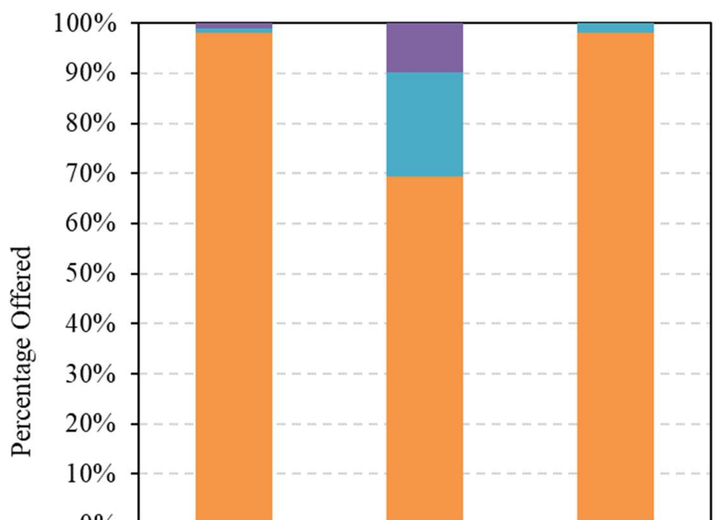
The list in Table 1 was subdivided into four categories consisting of engineering mechanics courses, supplemental courses that are closely related to the field of structural engineering, structural analysis courses, and structural design courses. The coursework data were collected during 2022 and 2023 from the most current published course catalogs (called bulletins at many universities). These are considered contracts with students during their incoming year and provide a written document that outlines courses that are currently offered and required to graduate. Many universities have separate course catalogues for undergraduate and graduate programs; therefore, every catalog applicable to the engineering programs selected for this study was reviewed. Some structural engineering coursework can be found in engineering mechanics and mechanical engineering curricula as well, so many of these programs were also reviewed.

When collecting data, a distinction was made among five categories of courses: not offered, required undergraduate (UG required) courses, undergraduate elective (UG elective) courses, graduate (GR) courses, and courses that were dual-listed or co-convened for undergraduate and graduate (UG/GR) students. In this study, dual-listed or co-convened meant that the course had the same subject designation but was offered with both 4xxx/5xxx course numbers (or similar, such as 4xx/5xx), where the 4xxx meant undergraduate and the 5xxx meant graduate. The number of credit hours was tabulated for all required courses; it was assumed that one credit hour was equal to one hour in the classroom. In the case when a program used a system other than semester-based credit hours (e.g., quarter system), the required credits were converted to a typical 130-credit semester-based system. Courses that offered additional structural engineering electives/topics beyond the 25 in Table 1 were noted.

Results

Engineering Mechanics Courses

The first category of courses reviewed were engineering mechanics courses as shown in Figure 1. Included in this category were statics, dynamics, and mechanics of materials, which can also be called solid mechanics, strength of materials, or deformable body mechanics (shortened to "mechanics" for ease in this paper). Statics and mechanics were required in 98% of programs, and both were typically offered as 3-credit courses; however, on average, statics was 2.9 credits and mechanics was 3.4 credits. The standard deviation and range of credit hours (i.e., difference between minimum and maximum) was higher for mechanics than statics or dynamics. Dynamics was required in 69% of the programs and was typically a 3-credit course, but it was not offered in 10% of the programs. All three courses were only offered to undergraduates in all programs (i.e., they were never offered as a graduate course).

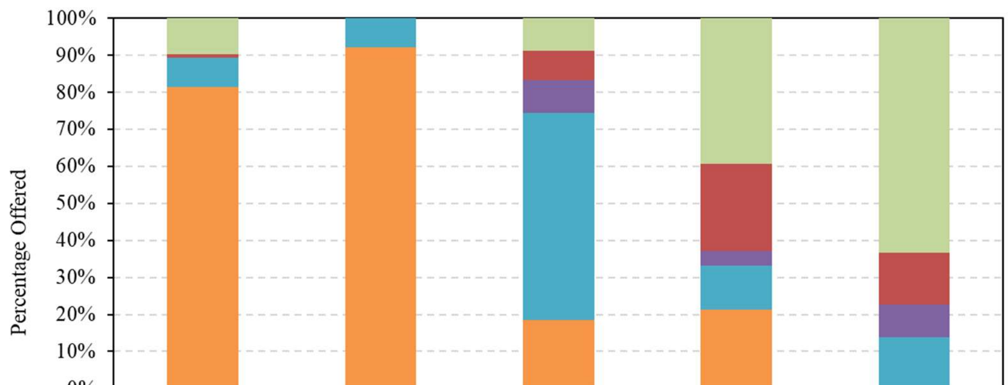


	Statics	Dynamics	Mechanics
Not Offered (%)	1	10	0
UG Elective (%)	1	21	2
UG Required (%)	98	69	98
Avg. Credits	2.9	3.0	3.4
Max. Credits	4.0	4.9	9.0
Min. Credits	1.0	1.9	2.0
St. Dev. Credits	0.48	0.45	0.80

Figure 1—Percentage of programs offering engineering mechanics courses.

Supplemental Courses

Data on supplemental courses that are closely related to the field of structural engineering are shown in Figure 2. The first two courses, civil engineering materials and soil mechanics plus laboratory, were required in most programs (approximately 81-92%). Soil mechanics was offered in every program and civil engineering materials was offered in 90% of programs. Soil mechanics courses averaged 4.0 credits, which indicated that most three-credit lecture courses were accompanied by a one-credit soils laboratory course. Foundations, advanced concrete materials, and probability/risk/reliability courses were all required in less than 21% of programs. However, a foundations course was offered as some type of elective in 91% of programs, which indicates that it is deemed important by educators; this notion aligns with the NCSEA practitioner survey results [7], [10]. A course on probability/risk/reliability or advanced concrete materials was not offered in a significant number of programs and, when offered, was often a graduate course.

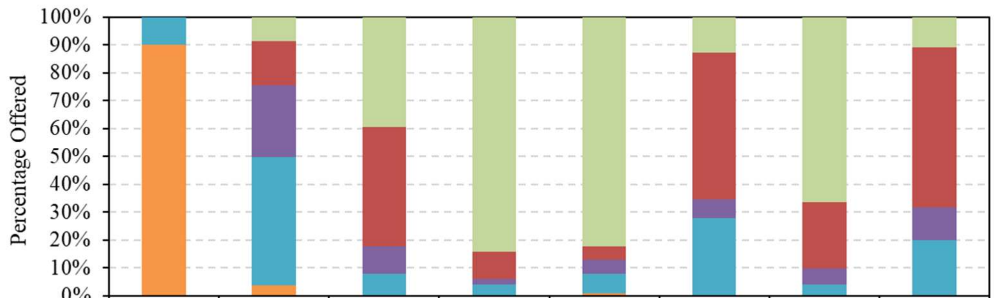


	CE Matls	Soils + Lab	Foundations	Prob/Risk/Reliab	Adv Conc Matls
Not Offered (%)	10	0	9	40	63
GR Elective (%)	1	0	8	24	14
UG/GR Dual-listed Elective (%)	0	0	9	4	9
UG Elective (%)	8	8	56	12	14
UG Required (%)	81	92	18	21	0
Avg. Credits	3.0	4.0	3.0	3.0	0
Max. Credits	6.0	5.0	4.0	5.0	0
Min. Credits	1.0	2.0	1.0	2.0	0
St. Dev. Credits	0.87	0.60	0.69	0.65	0.00

Figure 2—Percentage of programs offering supplemental courses.

<u>Structural Engineering Analysis Courses</u>

Data on structural engineering analysis courses are shown in Figure 3. Undergraduate students are required to complete an introductory structural analysis course at 90% of programs, which was 3.3 credits on average. Only 3% of undergraduate programs required a matrix structural analysis course, but a matrix analysis course was offered in over 75% of the undergraduate programs. A finite element method course was offered in 35% of undergraduate programs. Most graduate programs offered courses in structural dynamics and seismic, but they were far less common in undergraduate programs. Courses in wind, ASCE 7 (structural systems), and stability were not offered in most programs at either the undergraduate or graduate level. All three of these topics may be covered in other classes, but this study only focused on courses that were dedicated to each topic.



	Struc Analysis	Matrix	Seismic	Wind	ASCE 7	FEM	Stability	Struc Dynamics
Not Offered (%)	0	9	40	84	82	13	66	11
GR Elective (%)	0	16	43	10	5	52	24	57
UG/GR Dual-listed Elective (%)	0	26	10	2	5	7	6	12
UG Elective (%)	10	47	8	4	7	28	4	20
UG Required (%)	90	3	0	0	1	0	0	0
Avg. Credits	3.3	3.2	0	0	0	0	0	0
Max. Credits	8.0	4.0	0	0	0	0	0	0
Min. Credits	1.5	2.5	0	0	0	0	0	0
St. Dev. Credits	0.75	0.76	0.00	0.00	0.00	0.00	0.00	0.00

Figure 3—Percentage of programs offering structural engineering analysis courses.

The structural engineering analysis course offerings were also analyzed considering U.S. regions (Figure 4), as defined by the U.S. Department of Commerce [13]. The data in Figure 4 are grouped together regardless of whether a course was offered as UG required, UG elective, GR, or UG/GR. At least 78% of programs offered matrix analysis, finite element methods, and structural dynamics courses regardless of region, with only one exception. Courses on wind and ASCE 7 were not typically offered in programs regardless of region, except for an ASCE 7 course being offered at the two schools investigated in the Pacific region. Seismic courses were more frequently offered in the Pacific West, Mountain West, and East Midwest. Stability is most frequently offered in the West Midwest. In general, there were no major differences in course offerings by region.

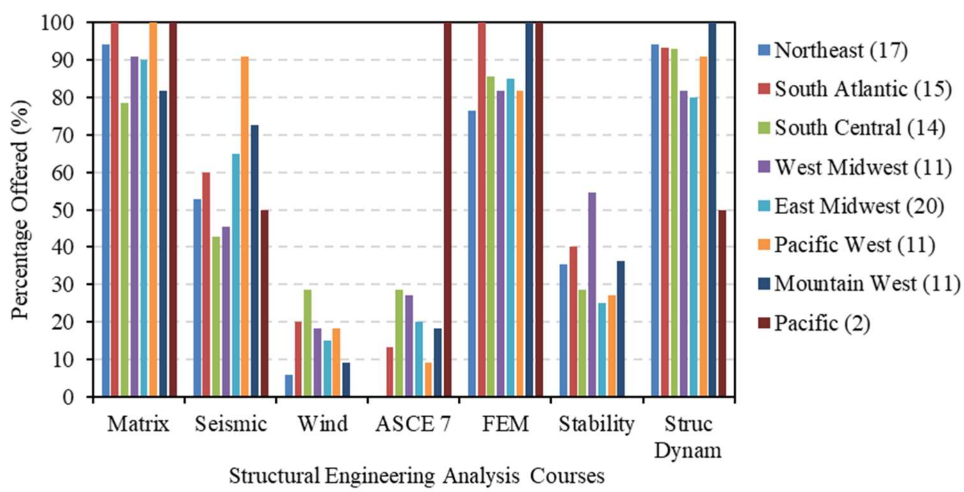


Figure 4—Percentage of programs offering structural engineering analysis courses by region. The legend parentheses indicate the number of schools investigated in the region.

The percentage of programs offering structural analysis courses varied the most when considering if the university had a graduate program in civil engineering (Figure 5). No undergraduate program offered wind, ASCE 7, or stability courses. Additionally, these courses were typically offered in less than 40% of the graduate programs. Seismic courses were also not offered in undergraduate programs, but they were offered in about 66% of graduate programs. While matrix analysis, finite element method, and structural dynamics courses were offered in some undergraduate programs, they were offered in at least 90% of the universities with Ph.D. programs.

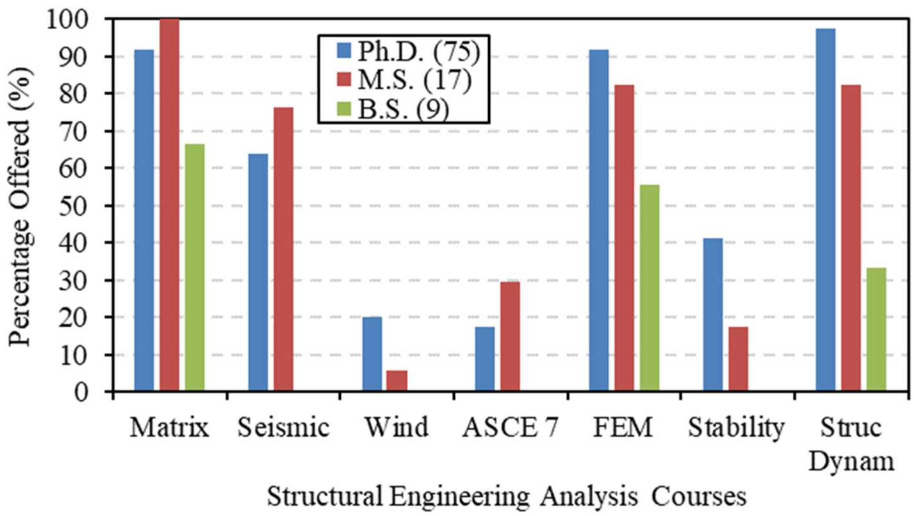
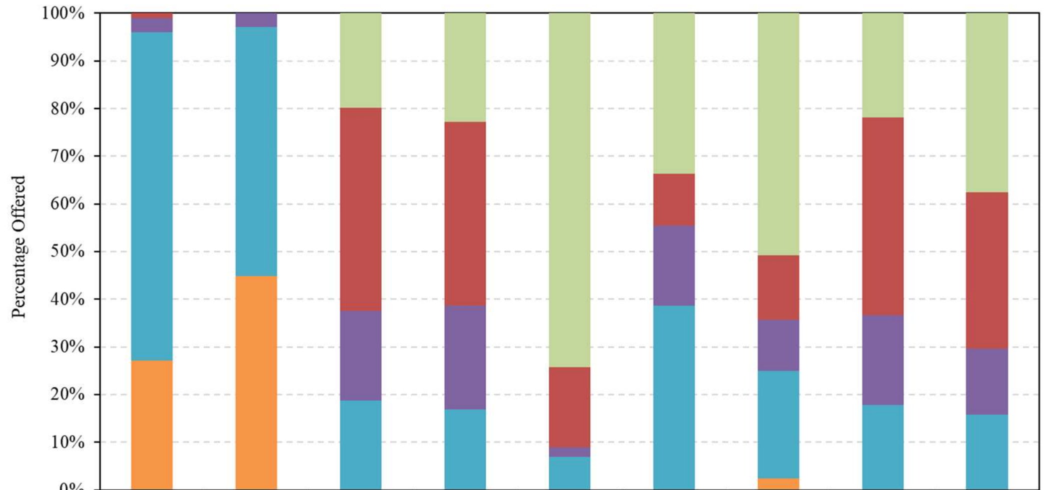


Figure 5—Percentage of programs offering structural engineering analysis courses based on highest degree awarded. The legend parentheses indicate the number of schools investigated.

<u>Structural Engineering Design Courses</u>

The largest category of course offerings was in the subcategory of structural engineering design (Figure 6). No course was required in over 50% of the programs and steel I and concrete I were only required in 27% and 45% of undergraduate programs, respectively. However, both courses were offered in every undergraduate program but one. Of the remaining seven design courses, wood design and masonry design were most often offered in the undergraduate curricula as an UG elective. Steel II, concrete II, and prestressed concrete courses were frequently available to students but were typically offered as GR or UG/GR dual-listed courses. A reinforced concrete design III course was rarely offered by any program. Bridge design courses were offered in approximately 60% of the programs, but were often only available as graduate courses. The 60% availability of a bridge design course contrasts with the topic not being listed in the NCSEA's core list of structural engineering courses [9].



	Steel I	Conc I	Steel II	Conc II	Conc III	Wood	Masonry	Prestressed	Bridge
Not Offered (%)	0	0	20	23	74	34	51	22	38
GR Elective (%)	1	0	43	39	17	11	14	42	33
UG/GR Dual-listed Elective (%)	3	3	19	22	2	17	11	19	14
UG Elective (%)	69	52	19	17	7	39	23	18	16
UG Required (%)	27	45	0	0	0	0	1	0	0
Avg. Credits	2.7	3.0	0	0	0	0	0.5	0	0
Max. Credits	3.0	4.0	0	0	0	0	0.5	0	0
Min. Credits	1.0	1.0	0	0	0	0	0.5	0	0
St. Dev. Credits	0.61	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 6—Percentage of programs offering structural engineering design courses.

The structural engineering design course offerings across the U.S. regions are shown in Figure 7. Masonry design courses are more frequently offered in the Pacific West and Mountain West. Bridge design courses are more often available in the Northeast and South Atlantic, but less often in the Pacific West. Wood design is predominant in the Mountain West and West Midwest. In general, there were no major differences in course offerings by region.

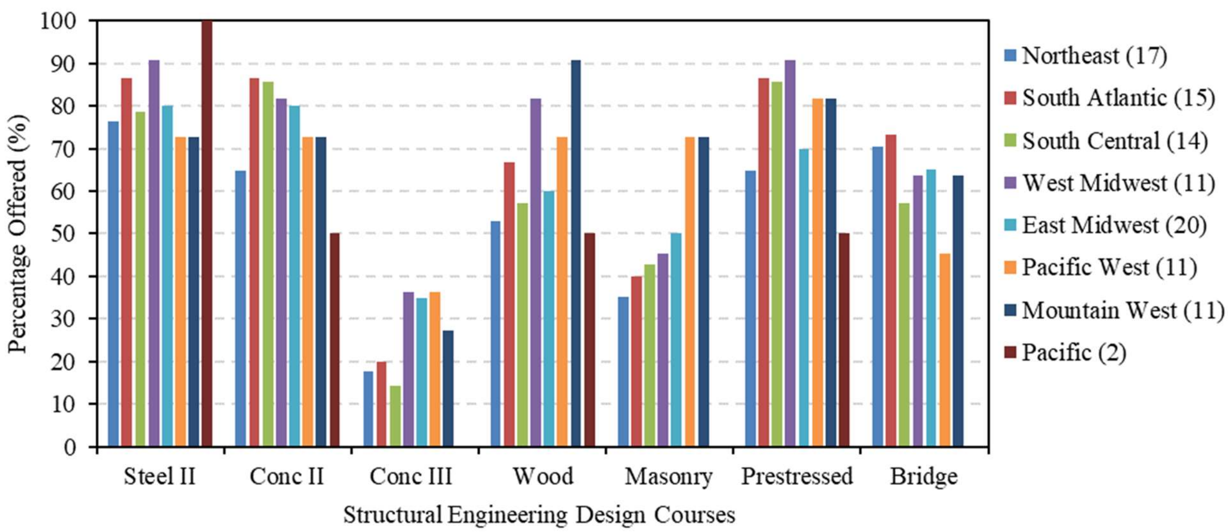


Figure 7—Percentage of programs offering structural engineering design courses by region. The legend parentheses indicate the number of schools investigated in the region.

The percentage of programs offering structural engineering design courses based on highest degree awarded are shown in Figure 8. None of the courses are offered in more than 45% of the undergraduate-only programs. However, wood design and masonry design courses were the most common electives offered in these institutions. Over 80% of universities with a Ph.D. program offered steel II, concrete II, and prestressed concrete courses. Bridge design and wood design courses were offered in over 60% of the programs with graduate programs.

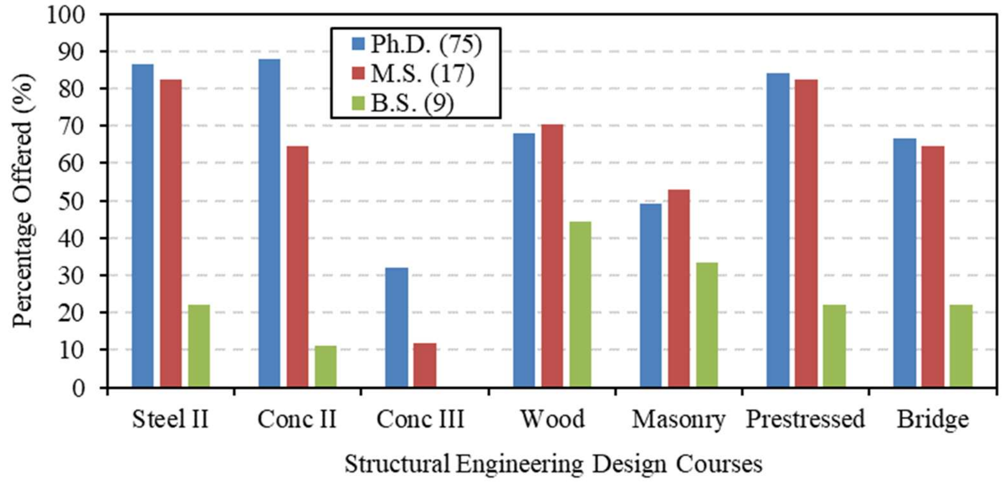


Figure 8—Percentage of programs offering structural engineering design courses based on highest degree awarded. The legend parentheses indicate the number of schools investigated.

<u>Additional Structural Engineering Electives/Topics</u>

While this study focused on the list of 25 common engineering courses identified for structural engineers, other graduate electives that appeared in multiple programs were noted. Some of the most common courses included:

- composite materials
- advanced mechanics of materials
- plates and shells
- forensics and experimental testing
- cold-formed steel
- elasticity
- nonlinear analysis
- fracture mechanics

These courses demonstrate both the breadth of structural engineering curricula and future trends in curriculum design. Future structural engineering curricula research studies should consider investigating the availability of these additional courses as they become more commonplace.

Synthesis and Discussion

There is an expectation that a student graduating from an undergraduate civil engineering program has mastered key topics. Employers or graduate programs consider this when deciding who to hire and what training to provide. In this study, the courses shown in Table 2 were most commonly required for undergraduate students (≥80% of programs). Additionally, the courses that may not be required, but are typically offered as an elective in more than 70% of programs are shown in Table 2. The lists in Table 2 indicate what coursework a student interested in structural engineering will likely take in an undergraduate civil engineering program. Based on the comprehensive results from this study, students have more structural engineering courses available to them. Part of the challenge is ensuring students know which courses to take and in what order; this issue can be solved through good undergraduate advising.

Table 2—Courses required or offered as electives in an undergraduate civil engineering program.

Required Course (≥80% of Programs)	*Elective* Course (≥70% of Programs)
Statics	Dynamics
Mechanics	Foundations
Civil Engineering Materials	Steel I
Soil Mechanics and Lab	Concrete I
Structural Analysis	

The NCSEA BEC listed 12 core courses in a structural engineering curriculum needed for an entry level practitioner [9]. In this study, 10 of those courses were directly reviewed. Synthesized results in Table 2 show that only 1 of 10 courses (structural analysis) is required in over 80% of undergraduate programs and most of the time this includes material from structural analysis I and II. Foundation design, steel I, and concrete I are almost always offered as electives (≥70% of programs). The six additional courses listed by the BEC are not offered in over half of the investigated undergraduate programs.

Figure 9 compares the results of this study to those from the 2019 NCSEA curriculum survey [8]. The 2019 NCSEA curriculum survey contacted 175 civil engineering programs. The results from the NCSEA curriculum survey course offerings should be similar to the summation of course offerings investigated in this study (UG required + UG elective + UG/GR dual-listed elective + GR elective). Data in Figure 9 show that the differences in course offerings between this study and the NCSEA survey were less than 10% in every category except matrix structural analysis which was 15% different; the difference between NCSEA results and the GR elective category in this study is shown in Figure 9 as an example. These small differences indicate that this study confirmed the coursework offerings. However, the availability of a course to undergraduate versus graduate students varied greatly. Many courses are only offered in graduate programs.

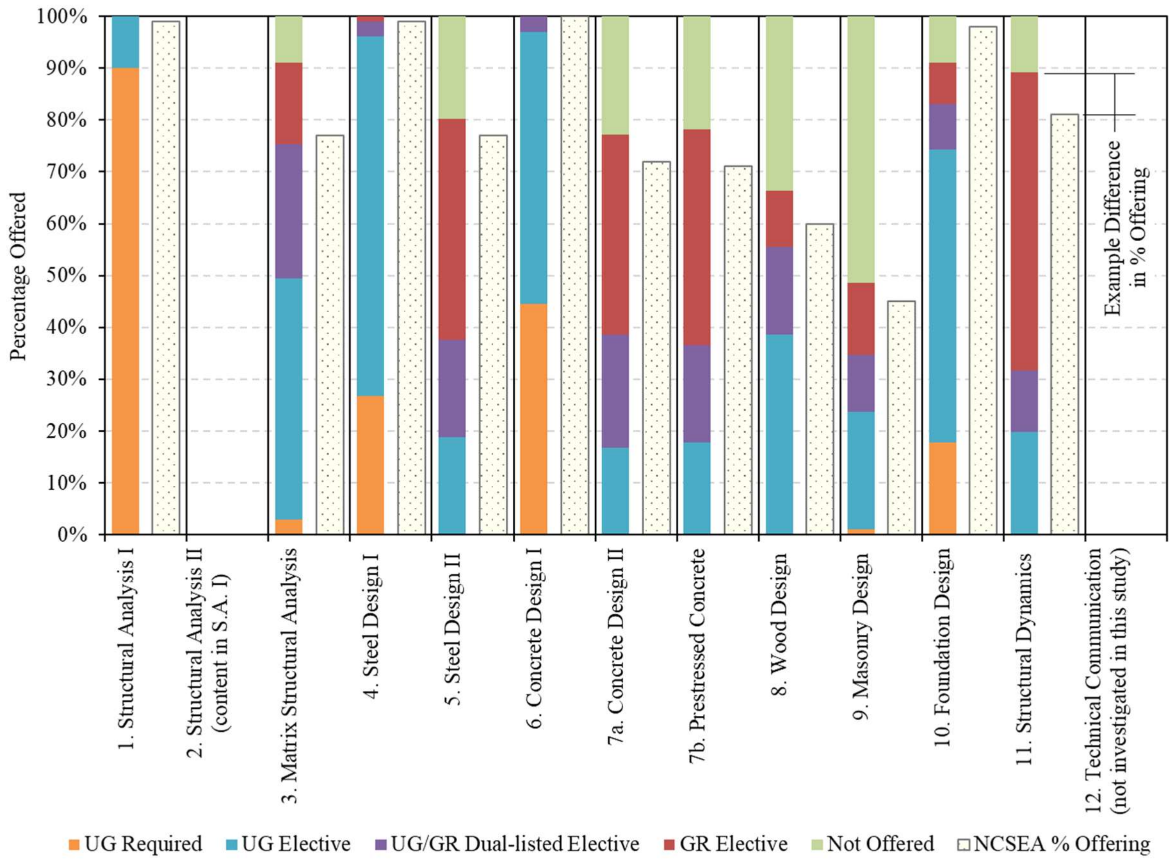


Figure 9—Percentage of programs offering courses investigated in this study versus those reported as offered in the 2019 NCSEA curriculum survey [8].

Additional structural engineering courses are offered at most universities as shown in Figure 3 and Figure 6. However, more than 40% of the undergraduate programs offer only wood design and matrix analysis. Results in Figure 5 and Figure 8 indicated that many courses are more often available to students if they are at a university with a graduate program (e.g., structural dynamics, steel II, concrete II, prestressed, and bridge). However, results in Figure 3 and Figure 6 demonstrate that these courses are not typically offered to undergraduate students; the graduate course catalogs use language such as graduate standing, graduate status, or only graduate students. While there may be exceptions for students who are dual-enrolled, take dual-listed electives, or receive instructor consent, these students are atypical. In essence, the breadth of electives at universities with graduate programs is not widely available in a typical undergraduate civil engineering curriculum.

Based on the average number of courses required and available in an undergraduate program, a student would graduate with the following NCSEA core structural engineering courses:

1. structural analysis I
2. steel I
3. reinforced concrete I
4. foundations

However, in most cases, the first structural analysis course covers topics from both structural analysis I and II. Furthermore, previous research has shown that technical communication courses are required in approximately 50% of civil engineering undergraduate programs and as an elective in others [14]. Therefore, a reasonable assumption is that students will have taken 6 of 12 recommended core courses:

1. structural analysis I
2. structural analysis II
3. steel I
4. reinforced concrete I
5. foundations
6. technical communication

Thus, most entry-level practitioners need to acquire knowledge depth in structural engineering (i.e., the remaining six NCSEA core courses/topics) through a combination of graduate education and/or professional mentorship. Therefore, the remaining six courses are essentially the core curriculum for an M.S. degree in the subdiscipline of structural engineering. If each course is assumed to be three credit hours (i.e., three multiplied by six is the approximately 18 credits associated with the coursework component of a thesis-based M.S. degree). These courses include:

7. structural analysis III (matrix analysis)
8. steel II
9. reinforced concrete II/prestressed concrete
10. wood design
11. masonry design
12. structural dynamics

Even the most advanced undergraduate students would only be able to take some of the 12 core structural engineering courses based on course availability, time limitations, and undergraduate elective opportunities. A master's degree would be the minimum educational requirement to obtain all the knowledge suggested by the NCSEA BEC.

Conclusions

The main objective of this study was to review the structural engineering coursework at universities with ABET-accredited civil engineering undergraduate programs. This study investigated coursework breadth and depth to determine what baseline level structural engineering knowledge is typically required and available for undergraduate students. The following conclusions were drawn:

1) The data indicated that there are standard core courses that over 80% of programs require students to complete, which include statics, mechanics of materials, civil engineering materials, soil mechanics with a laboratory, and introductory structural analysis.
2) Over 70% of undergraduate programs offer the following topics in a required or elective course: dynamics, foundations, steel I, and reinforced concrete I.
3) Course offerings were mostly uniform among the different regions of the country. A few minor differences occurred for regional offerings of wood design, bridge design, stability, and seismic design courses.
4) While many programs offer a robust list of graduate course offerings in their catalogs, fewer than 40% of universities made the following courses available to undergraduate

students: seismic, wind, ASCE 7, finite element method, stability, structural dynamics, steel II, concrete II, concrete III, masonry design, prestressed concrete, advanced concrete materials, probability/risk/reliability, and bridge design. None of these courses are required of undergraduate students and five of them are offered in less than 10% of undergraduate programs.

5) The course offering data gathered in this study were typically within 10% of the 2019 NCSEA BEC course offering survey results. However, this study revealed that most course offerings were only available to graduate students rather than undergraduates.
6) An undergraduate student can reasonably expect to complete six of the NCSEA core structural engineering courses by the end of their undergraduate curriculum: structural analysis I and II, steel I, concrete I, foundations, and technical communication.
7) While a student may cover one or two additional topics, most of the remaining NCSEA core topics must be learned in graduate school or on the job, including matrix structural analysis, steel II, concrete II, prestressed concrete, wood design, masonry design, and structural dynamics. These courses could make a core curriculum for a M.S. degree in structural engineering.
8) Results from the NCSEA BEC practitioner surveys indicated that students should be able to complete classical structural analysis methods by hand, which is being satisfied by courses typically required at universities. However, university curricula should try to implement computer programming, modeling, and/or structural engineering software in structural analysis, reinforced concrete I, or steel I courses to ensure students meet the needs of practitioners.
9) Results from the NCSEA BEC practitioner surveys indicated that one of the most important topics for students to be exposed to during their education is loading/load paths/load flow. These topics are frequently covered in depth in a structural systems (ASCE 7) course, but results in this study indicated that an ASCE 7 course was offered at fewer than 20% of universities and rarely at the undergraduate level.

Historically, entry-level engineers often learned many structural engineering topics while working, as needed. The data clearly showed that universities with graduate programs had more courses, most of which were not directly available to undergraduate students. This demonstrates the need for structural engineers to learn a significant amount of material on the job or pursue an advanced degree after graduation from ABET accredited civil engineering undergraduate program. From a technical knowledge point of view, employers hiring entry-level structural engineers should review transcripts and/or program curricula to know what courses their candidates completed; their assumptions may be incorrect.

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