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Structural Engineering Education and Accreditation: Perspectives, Developmental Paradigms, and Recommendations

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Introduction

It is a time of turmoil and transition in the structural engineering professional community. In its recently published "Vision for the Future of Structural Engineering and Structural Engineers," the Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE) has outlined a series of broad and troubling trends in structural engineering education and practice, including the following:[1]

- Many of the routine tasks traditionally performed by U.S. structural engineers are now performed by computers or by low-cost engineers overseas. Thus, the practice of structural engineering in the U.S. is described as a "shrinking space."
- The remaining non-routine structural engineering work is becoming increasingly complex, as a result of advances in building codes and standards, design aids and tools, project delivery methods, and construction materials.
- To an increasing degree, the graduates of today's typical baccalaureate civil engineering programs are inadequately prepared for professional practice in structural engineering.

In response to these challenges, there is a growing sense that the structural engineering discipline must transform itself in order to preserve its viability as a professional entity. As evidenced by articles in recent publications and initiatives, this need for transformation is being manifested in:

- calls for substantial increases in the technical structural engineering coursework offered by university engineering programs;[2,3]
- a growing consensus that a master's degree is required for structural engineering practice in all but the smallest firms;[1]
- and strong advocacy for structural engineering licensure.[4,5,6]

Although these various calls for change reflect a broad and growing consensus that professional standards for structural engineering practice must be raised, their advocates often disagree, not only on *how* standards should be raised, but also—more fundamentally—on the very nature of the structural engineering discipline. This fundamental disagreement can be characterized by a simple question: *Is structural engineering an advanced specialty sub-discipline of civil engineering, or it is an engineering discipline in its own right?*

The answer to this question is critically important to the future transformation of structural engineering, because it will dictate—to a large degree—the appropriate paradigms for (1) academic preparation of structural engineering professionals, (2) accreditation of structural engineering programs, and (3) professional licensure of engineers performing structural engineering work.

Purpose and Methodology

This paper addresses three closely related research questions:

(1) From the perspective of the engineering profession, what is the appropriate relationship between the civil engineering and structural engineering disciplines?

(2) What is the appropriate developmental paradigm for acquiring the professional body of knowledge in structural engineering?

(3) Should structural engineering programs be ABET-accredited; and, if so, at what level?

In addressing these questions, we define the two predominant perspectives on the nature of the structural engineering discipline, as follows:

- ***Perspective #1:*** Structural engineering is an advanced specialty sub-discipline of civil engineering. The most common educational paradigm that supports this perspective is an ABET EAC-accredited baccalaureate degree in civil engineering (typically with structural engineering emphasis) and—to an increasing extent—a master's degree in structural engineering.

- ***Perspective #2:*** Structural engineering is a stand-alone engineering discipline, comparable to other major engineering disciplines, such as civil, mechanical, and electrical engineering. The educational paradigm that most directly supports this perspective is an ABET EAC-accredited baccalaureate degree in structural engineering.

These two perspectives form the basis for our analysis of:

- *What is?*—the current status of the structural engineering discipline, as reflected in the existing education, accreditation, testing, and licensure systems; and
- *What should be?*—visions for the future, as articulated in formal published vision statements, future-oriented policy statements, and ongoing strategic initiatives.

Based on this analysis, we formulate recommendations with respect to the research questions listed above.

What Is? Current Status of the Structural Engineering Discipline

The current system for educating future structural engineering professionals in the U.S. is strongly aligned with Perspective #1. Only one institution of higher learning—the University of California at San Diego (UCSD)—offers an ABET EAC-accredited baccalaureate degree program named "Structural Engineering."[7] All other institutions that offer undergraduate structural engineering coursework do so within the context of EAC-accredited baccalaureate degree programs in Civil Engineering or (in a small number of cases) in Architectural Engineering.

This latter paradigm is fully consistent with ASCE's *Civil Engineering Body of Knowledge for the 21st Century* (CE BOK), which articulates the knowledge, skills, and attitudes necessary for entry into the professional practice of civil engineering.[8] The CE BOK specifies "civil engineering breadth" as one of the 24 outcomes constituting the professional body of knowledge;

and it identifies structural engineering as one of the seven traditional sub-disciplines constituting civil engineering breadth. These CE BOK provisions reflect ASCE's longstanding contention that professional practice, even if it is restricted to a single specialty sub-discipline, still requires a broad foundation of knowledge drawn from across the civil engineering discipline.

The paradigm of nesting undergraduate-level structural engineering education within civil engineering degree programs is also reflected in the current ABET EAC Criteria for Accrediting Engineering Programs.[9] The EAC Criteria include baccalaureate-level program criteria for "Civil and Similarly Named Engineering Programs" but none for structural engineering programs. Purposefully formulated for consistency with the CE BOK, the EAC Civil Engineering Program Criteria (CEPC) specify that graduates of baccalaureate-level civil engineering programs must be prepared to "analyze and solve problems in at least four technical areas appropriate to civil engineering;" and, in ASCE's Commentary to the CEPC, structural engineering is explicitly identified as one of these specialty technical areas.[10]

Broad implementation of this educational paradigm does not imply that the civil engineering coursework offered in typical baccalaureate civil engineering programs provides adequate educational preparation for the professional practice of structural engineering. Indeed, the inadequacy of baccalaureate civil engineering programs in fully addressing the structural engineering body of knowledge is well documented. The National Council of Structural Engineers Associations (NCSEA) publishes a recommended twelve-course structural engineering curriculum, accompanied by a detailed list of topics for each course.[2] And every three years, NCSEA conducts a survey of accredited civil and structural engineering programs to determine which of these recommended courses are offered in each program. The results of the most recent (2016) edition of this survey indicate that only 16% of programs offer all twelve courses in the recommended curriculum. Furthermore, the NCSEA survey does not distinguish between required and elective courses, nor between undergraduate and graduate-level courses. Thus, there is no guarantee that undergraduates of the few programs that offer all twelve courses can actually attain the full NCSEA curriculum.

It is worth noting that the EAC-accredited baccalaureate structural engineering program at the University of California at San Diego—the sole U.S. institution representing Perspective #2—does offer the twelve courses specified in the NCSEA curriculum. To some extent, the program achieves this level of technical depth at the cost of breadth. By virtue of its degree title, the UCSD structural engineering program is not required to comply with the ABET EAC Civil Engineering Program Criteria and thus does not provide coverage of "at least four technical areas appropriate to civil engineering." It is also noteworthy that, because there are no EAC program criteria for structural engineering, the UCSD program is accredited *only* under the EAC General Criteria.[*] Thus, while UCSD offers the twelve courses specified in the NCSEA curriculum, the program is not subject to any explicit accreditation standards for its structural engineering content.

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[*]The relevant ABET policy is stated in paragraph I.C.4.c.(2) of the *ABET Policy and Procedure Manual*, as follows: "If a program name implies specialization(s) for which Program Criteria have been developed, the program must satisfy all applicable Program Criteria."[11]

Given the inability of most baccalaureate civil engineering programs to provide all required coursework for structural engineering practice, structural engineering firms with more than ten employees now hire primarily at the master's level. For this reason, in our definition of Perspective #1 above, we have characterized structural engineering as an *advanced* specialty sub-discipline of civil engineering.

Consistent with this hiring trend—and with Perspective #1—master's degree programs in structural engineering have become increasingly common, as have master's programs in civil engineering with an explicit structural focus. (For typical examples, see references 12, 13, and 14.)

None of these master's programs are ABET-accredited. Although the EAC of ABET does offer master's-level accreditation under the General Criteria for Master's Level Programs, there is currently no compelling reason for programs to seek master's-level accreditation, because the current standards for professional licensure require only an accredited baccalaureate degree.

The issue of structural engineering licensure is both complex and controversial, for two reasons. First, because engineering licensure in the U.S. is governed by the individual states and administered by state-level licensing boards, standards and processes vary widely. Second, many constituencies have strongly conflicting interests with regard to structural engineering licensure. Thus, for example, NCSEA strongly advocates separate licensure for structural engineers, while the National Society of Professional Engineers (NSPE) staunchly opposes it.[15]

For the purposes of this paper, it is neither necessary nor useful for us to advocate for or against structural engineering licensure; thus, we have chosen not to enter the fray. Nonetheless, certain aspects of the issue are quite relevant to this paper, in that they provide broader insights about perceptions of the structural engineering discipline within the professional community. These relevant aspects are as follows:

- Most of the 55 U.S. licensing jurisdictions only grant Professional Engineer (PE) licenses. However, eight states have implemented structural engineering *practice acts*, which require a separate structural engineering (SE) license, either to design *any* structure (Illinois and Hawaii) or to design structures in specified categories (Alaska, California, Nevada, Oregon, Utah, and Washington).[16]

- Of these seven states, five (Alaska, California, Oregon, Utah, and Washington) require registration as a PE prior to seeking SE licensure. These states' licensure systems reflect consistency with Perspective #1, in that they treat structural engineering as an advanced specialty sub-discipline and because the relevant PE examination—the Principles and Practice of Engineering exam in Civil Engineering (described below) incorporates a four-hour module addressing the full breadth of the civil engineering discipline.

- These five "PE before SE" state licensing systems are also consistent with ASCE Policy Statement 524, which supports post-PE credentialing;[17] with SEI Policy Statement 101, which "encourages jurisdictions to license structural engineers as a post-PE credential;"[18] and with the position of the Structural Engineering Licensure Coalition (SELC). SELC is comprised of SEI, NCSEA, the Structural Engineering Certification Board (SECB), and the Council of American Structural Engineers (CASE) of the American Council of Engineering Companies (ACEC) and serves as "the united voice of these organizations dedicated to establishing and promoting a common position on structural engineering licensure and working towards implementation in all jurisdictions." SELC has formally advocated SE licensure as a post-PE credential.[5]

- The state licensure systems in Illinois, Hawaii, and Nevada, which do not require a PE as a prerequisite for SE licensure, reflect greater consistency with Perspective #2, in that they treat structural engineering as a stand-alone engineering discipline. No professional society has formally advocated stand-alone SE licensure, but individual advocates can be found in the literature.[19]

- As noted above, NSPE strongly opposes all forms of structural engineering licensure, on the grounds that it is preferable for individual professional engineers to self-regulate by providing engineering services only in their areas of competence. This position supports neither Perspective #1 nor Perspective #2.

These fundamental differences of perspective within the professional licensure community are also reflected in the licensing examinations developed and administered by the National Council of Examiners for Engineering and Surveying (NCEES). These include:

- The eight-hour Principles and Practice of Engineering (PE) Exam in civil engineering, which includes a four-hour section addressing the full breadth of the civil engineering discipline and a four-hour section addressing the examinee's choice of structural, construction, geotechnical, transportation, or water resources engineering. This exam design supports Perspective #1.[20]
- The 16-hour Structural Engineering (SE) exam, which is focused entirely on the structural engineering discipline. This exam design does not directly support either perspective; however, because it allows examinees to take the SE exam without having first passed the PE exam, it accommodates Perspective #2.[21]

Overall, the current status of the structural engineering discipline can be summarized as follows:

- The current U.S. education and accreditation systems are strongly aligned with Perspective #1. Most of today's structural engineers receive their educational preparation for professional practice through an ABET EAC-accredited baccalaureate degree in civil engineering and focused master's-level education in the structural engineering sub-discipline.

- In the current educational system, only a single program—the EAC-accredited baccalaureate structural engineering program at the University of California at San Diego—is aligned with Perspective #2.

- Within the professional licensure community, ASCE, SEI, and the SELC have published formal policy statements in support of SE licensure as a post-PE credential—consistent with Perspective #1—and four states have implemented SE practice acts that require prior registration as a PE. However, three states have implemented stand-alone SE licensure—a position more closely aligned with Perspective #2.

What Should Be? **Visions for the Future**

With the current status of the structural engineering discipline as a baseline, we now look to the future. The following recently published vision documents, policy statements, and strategic initiatives are highly relevant to the ongoing discussion about the future direction of structural engineering:

- In its landmark report, *The Engineer of 2020*, the National Academy of Engineering (NAE) suggests that, to meet the challenges of the future, engineers must be more broadly educated, while still achieving high levels of technical proficiency. According to this report, the engineer of 2020 will need broader understanding of contemporary issues like globalization, sustainability, and public policy, while also developing enhanced business, management, and leadership skills.[22]

- NAE's follow-up report, *Educating the Engineer of 2020*, recommends that the required increase in educational breadth be achieved by considering the baccalaureate degree to be an "engineer in training" degree and by establishing the master's degree as an educational prerequisite for engineering professional practice.[23]

- ASCE's "Raise the Bar" initiative—articulated in the Society's Policy Statement 465 and the *Civil Engineering Body of Knowledge for the 21st Century*—delivers a very similar message. This initiative asserts that the challenges of the future must be met by civil engineers with greater professional practice breadth and technical depth—outcomes that can best be achieved by establishing the master's degree (or equivalent) as an educational prerequisite for licensure.[8,24]

- Similarly, the "Report of the 5XME Workshop: Transforming Mechanical Engineering Education and Research in the USA" observes that mechanical engineers educated in the U.S. can only remain globally competitive "through the breadth of their intellectual capacity, their ability to innovate, and their leadership in addressing major societal challenges." The report concludes that the master's degree should become a requirement for professional practice.[25]

- Despite the American Society of Mechanical Engineers' (ASME) strong opposition to ASCE's "Raise the Bar" initiative, the ASME Vision 2030 incorporates many of the same themes—the need for mechanical engineering graduates to develop stronger professional skills, greater innovation and creativity, and enhanced "technical depth specialization." With regard to technical depth, the vision statement notes that "the growing availability of professional Master's degrees provides increased opportunity for graduates and practitioners to meet such a need."[26]

- NCEES Position Statement 35 observes that “future demands for increasing technical and professional skills have resulted in the need for additional education beyond the bachelor’s degree for those entering the engineering profession” and advocates four alternative educational pathways to attain this expanding engineering body of knowledge.[27]

- In its “Vision for the Future of Structural Engineering and Structural Engineers,” SEI observes that future structural engineers will need enhanced technical expertise, soft skills, professional abilities, and creativity—and concludes that “the entry level of education for a structural engineer may rest more comfortably in the neighborhood of six years rather than four.” The vision statement includes a bold recommendation to reform structural engineering education by creating graduate-level professional schools of structural engineering—modeled on the professional schools of law and medicine—thus allowing for substantially broader “pre-engineering” undergraduate degrees.[1]

- In parallel with the development of its strategic vision, the SEI Board of Governors also established a Task Committee on ABET Accreditation of Structural Engineering Programs in 2011. The Task Committee considered a range of options for implementing ABET EAC Program Criteria for structural engineering and submitted its preliminary report in August 2012. The Board of Governors responded with definitive guidance: (1) that the master’s degree should be considered the entry-level degree for structural engineering; (2) that structural engineering programs should *not* be accredited at the baccalaureate level; (3) that master’s-level program criteria for structural engineering should be developed; and (4) that SEI will partner with ASCE’s Committee on Education to move the development process forward. In response, the Task Committee formulated a set of draft Master’s Level Structural Engineering Program Criteria and submitted its final report in November 2012. There has been no substantive progress on this initiative since then.

All of these visions, policies, and initiatives directly or indirectly support Perspective #1, in that they emphasize increased breadth at the baccalaureate level and technical specialization at the master’s level. The SEI Board of Governors’ response to the Task Committee on ABET Accreditation of Structural Engineering Programs *explicitly* rejects Perspective #2; and all of the remaining visions, policies, and initiatives *implicitly* reject it by *not* advocating increased technical specialization at the baccalaureate level.

Only one aspect these future-oriented documents is supportive of Perspective #2. SEI’s “Vision for the Future” proposes to decouple structural engineering education from civil engineering undergraduate education by providing all specialized engineering coursework in graduate-level professional schools, such that “pre-engineering” baccalaureate degree programs would only need to provide prerequisite courses in math, science, and mechanics. Through this provision, the SEI Vision evidently seeks to establish structural engineering as a stand-alone professional entity, independent from civil engineering.

This ambitious proposal notwithstanding, all of these published vision documents, policy statements, and strategic initiatives are strikingly consistent in their support of an educational paradigm that provides baccalaureate-level breadth and master's-level technical specialization.

Conclusions and Recommendation

As the above analyses demonstrate, all recent authoritative published vision statements and policies relevant to the future of structural engineering are primarily aligned with Perspective #1. These documents consistently envision engineers who are better prepared to meet future challenges through broader baccalaureate-level education combined with master's level technical specialization. And our current education and accreditation systems are already appropriately organized to support this perspective.

In the realm of licensure, the situation is more complex; nonetheless, with ASCE, SEI, and SELC fully aligned in support of SE licensure as a post-PE credential, we conclude that the long-term trend in licensure is most likely to be toward Perspective #1.

Consistent with these conclusions, we offer four recommendations:

(1) Ongoing efforts to reform structural engineering education, licensing, and professional practice should be guided by an underlying assumption that structural engineering is an advanced specialty sub-discipline of civil engineering (Perspective #1).

(2) Consistent with this assumption, the educational paradigm for the preparation of future structural engineers should be institutionalized as a broad baccalaureate degree—ideally in civil engineering—plus a master's degree (or equivalent) focused in the structural engineering technical specialty.

(3) This educational model can and should be operationalized through the development and implementation of ABET EAC Master's Level Structural Engineering Program Criteria. As such, we strongly support the resumption of the joint SEI-ASCE initiative to implement these criteria.

(4) ASCE should develop a formal policy statement that: (a) explicitly recognizes structural, geotechnical, water resources, environmental, transportation, and construction engineering as advanced specialty sub-disciplines of civil engineering; (b) articulates the preferred educational paradigm for professional practice in these sub-disciplines as noted in (2) above; and (c) advocates the development and implementation of ABET EAC Master's Level programs criteria in these sub-disciplines as appropriate.

Finally, we suggest that this analysis is broadly applicable, not only to the specific case of structural engineering and the other traditional civil engineering specialty sub-disciplines, but also to the many emerging specialty curricular areas in other disciplines (e.g., mechatronics, robotics, and energy systems engineering).

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