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Increasing the Preparedness of Masters- Level Structural Engineering Graduates during their First Five Years of Professional Practice

Dr. Zsuzsa Balogh, Metropolitan State University of Denver
Dr. Marvin E. Criswell P.E., Colorado State University

Dr. Marvin Criswell is professor emeritus in the Department of Civil and Environmental Engineering at Colorado State University.

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Introduction

Structural engineering practice combines engineering knowledge, as can be provided in the academic environment, and many professional practice skills and expertise, as practiced in the design and construction environments. Thus, it is generally accepted that a masters-level program in structural engineering, as configured in the U.S., does not fully prepare its graduates to immediately become an independent practicing structural engineer. Rather, the aspiring young structural engineer typically learns many or most of the professional practice skills in his or her initial time in professional practice as an employee.

This paper presents information from a Delphi-type survey on the additional competencies expected by the structural engineering community to be gotten by the entrance-level engineer during the first 5 years of experience following completion of a masters-level graduate program. It does this by defining the competencies as quantified using Bloom's taxonomy [1] expected by the structural engineering profession in 44 specific subtopics within the following 5 general areas: A-Basic Mechanics and Engineering Tools, B-General Structural Engineering Tools, C-Technology and Communication Tools, D-Structural Engineering Topics and Tools, E-Management and Professional Tools at both the time of completion of the Masters-level program and after the first five years of professional experience following the masters-level program [2]. The difference in the expectations at these two times defines the profession's expectations for the initial employment period. The organization and conduct of the survey and the results for the time of completion of the masters-level work is described in a companion paper.

The survey also evaluated the perceived importance of five general sources by which the young structural engineer can obtain the desired additional expertise, these being Added Courses, Short Courses, In-House Training, Self Learning, and Experience in Practice, for each of the 44 specific areas. To better define the opportunities present in the "Added Courses" area, the survey included an assessment of the competency levels that the survey participants generally expect to be available at the typical larger structural engineering program through additional courses that not all or most graduate students would take. These "Elective" courses serve special individual interests and needs, including needs of a PhD program, associated university research endeavors, and additional academic opportunities for those in the profession.

Background

Professional experience, along with self-study and continuing education sources, are very important means for the young engineer choosing the structural engineering field to achieve the competency levels expected by the profession. The authors have completed a recent Delphi-based survey of a sample of structural engineering professionals to define these expectations for each of 50 (44 initially and 6 additional subtopics requested by the expert panel participants in Round1) subtopics within six topic areas at the time of the completion of a masters-level program emphasizing structural engineering and after a subsequent initial five year period of employment in structural engineering. The results of this study [2] define a current Framework of Knowledge (FOK) for entrance into professional-level, often independent, activity as a structural engineer. This FOK can be considered to be the step subsequent to the ASCE statement of a Body of Knowledge (BOK) [3] for civil engineers. This FOK specializes the BOK to the structural engineering specialty area and to the present and near term future competencies needed by young engineers choosing this profession.

This paper addresses the additional levels of competencies expected to be provided after completion of a masters-level program and the importance of various sources for these additional levels of preparation.

A companion paper describes the formulation and conduct of this survey and the results for the competencies expected at the completion of the undergraduate and graduate programs using the achievement levels described by Bloom's taxonomy, the evaluation scale previously used in the ASCE Body of Knowledge study and subsequent report [3].

An overview of the FOK study and its conduct is next given, with more details available in Reference [2] and the companion paper.

Overview of the Overall Delphi Study on Expected Cognitive Achievement

The study used a survey-based adaptation of the Delphi method to define achievement levels expected by those in the structural engineering profession for each of the 50 subtopics or subjects grouped into six topic areas. The Delphi method entails gathering anonymous information from each of a group of experts and/or decision makers in a first round, then providing each respondent with a summary of the group's input and an opportunity for the respondent to change their input and adding comments (in a second round). Additional rounds are used until an adequate group consensus is reached. This study utilized a questionnaire developed considering the individual input from a group of twelve practicing structural engineers and several academics from the Denver and Front Range Colorado area for an e-mail based survey planned for a maximum of three rounds. The first two rounds of the survey were devoted to obtaining a distribution of respondee's expectation for achievement levels to be reached by the aspiring structural engineer both upon completion of a masters-level program in structural engineering and after five years of practice in the profession. If the results of Round 2 varied significantly from those of Round 1, the planned use of Round 3 was to conduct Round 3 in the same manner as Round 2 in order to achieve more stable basic information. If the Round 2 results showed little change from Round 1, then Round 3 was planned to be used to gather additional information on early career modes of professional preparation.

Participants were instructed in Round 1 and Round 2 to describe expected achievement levels using Bloom's taxonomy using Key Set #1 as follows: 1 = Knowledge, 2 = Comprehension, 3 = Application, 4 = Analysis, 5 = Synthesis, 6 = Evaluation. These key set numbers were considered to be ordinal variables. Participants were provided the Bloom's taxonomy definitions as part of the survey questionnaire instructions.

Quantitative Analysis

The data from the Round 1 and Round 2 of the Delphi questionnaire were analyzed by non-parametric methods using the Statistical Package for Social Sciences (SPSS) version 20.0 for Windows [4]. The strong correlation that resulted between Round 1 and Round 2 from this analysis, along with a subjective examination of these results, suggested that the use of a Round 3 with the same general format of Round 2 would produce only minor or no changes. Therefore, Round 3 did not continue with the format of Rounds 1 and 2; rather it was restructured to address the importance level of the five primary educational modes identified to be relevant in obtaining higher achievement levels after completion of the masters-level degree.

In Round 3, the participant responses and subsequent analyses were based on the Key Set #2 values for importance levels as follows: 1 = Not important, 2 = Somewhat important, 3 = Important, 4 = Extremely important, values defined as cardinal variables. Mean values were used in the data analysis of the Round 3 responses.

Round 3 was thus used to describe the expectations on how the young structural engineers would supplement their capabilities achieved at the completion of the masters-level program to reach the levels expected by the profession after their initial five years in practice, the time chosen by the researcher at which the young engineer has reached the experience level typically required to apply for professional registration. In Round 3, the expert panel participants were asked to give input on the perceived importance and usefulness of five sources for this additional preparation. The five primary modes identified for use in Round 3 were: Added Academic Courses, Short Courses, In-House Training, Experience in Practice, Self Learning.

Round 3 and Associated Round 2 Results

As noted in the Introduction, the increase in the profession's expectations for competencies of the young engineer during the first five years of initial professional employment following completion of the masters-level program may be used as a measure of the importance of the early career period for the young engineer's preparation in the area of interest. Table 1 displays the expected competencies for Round 2 for subtopics in Topic Group A, and Topic Group E at three conditions, namely, completion of the masters-level program, after five years of experience, and available through commonly offered elective academic classes. The other (B, C, D, F) Topic Groups and the subtopics they contained are given in Table 2. This table has also been given in the companion paper emphasizing the masters-level program without the assessment of the electives. Again, results from Group A, the group traditionally most assigned to the academic community, and Group E, the group traditionally most assigned to practice, are emphasized. The ≥3 (top four achievement levels) and ≥5 (top to achievement levels) measures were chosen, as they were found to provide more useful information on typical expected achievement levels and increases with experience than did other possible "at or above" levels. More information of the other Topic Groups is given in Reference [2].

Table 1: Expected Competency Summary for Round 2, Topic Groups A and E

Question	At Graduation		After 5 Years		Elective Offerings	
	≥ 5 Level	≥ 3 Level	≥ 5 Level	≥ 3 Level	≥ 5 Level	≥ 3 Level
A. Basic Mechanics and Engineering Tools						
A1. Advanced Mechanics of Materials	9	75	31	97	16	84
A2. Structural Analysis – Framed Structures	28	97	84	100	45	97
A3. Finite Element Analysis/Modeling	6	75	50	100	22	88
A4. Elastic Stability	3	66	38	100	16	84
A5. Structural Dynamics	3	75	41	97	23	84
A6. Analysis of Plates and Shells	3	31	16	78	13	66
A7. Properties & Behavior of CE Materials	6	66	47	97	23	81
A8. Numerical Methods	3	44	13	56	9	66
E. Management and Professional Tools						
E1. Design Office Organization/Management/Office Ethics	0	19	34	94	0	48
E2. Business Development and Practices	0	10	22	81	0	25
E3. Design/Build & Other Project Methods	0	13	23	87	3	23
E4. Leadership Skills/Adaptation to Changes	0	32	25	91	3	40
E5. Working with Architects, Contractors, etc.	0	27	34	100	3	33
E6. LEED, Green Buildings, Energy Use	0	23	19	84	3	40
E7. International Design and Construction Practices	0	7	3	48	3	14

Table 2: Topic Groups and Subtopics besides Topic Group A and Topic Group E

B. General Structural Engineering Tools
B1. Behavior of Structural Systems. Load-Path.
B2. Building Codes & General Requirements
B3. Architectural/Aesthetics Considerations
B4. Conceptual & Preliminary Planning
B5. Design Loads, Including Evaluation
B6. Foundations & Geotechnical Topics
C. Technology and Communication Tools
C1. Project Plans & Specifications
C2. Communication Software & Tools
C3. Computer Graphics
C4. Structural Engineering Design Software
C5. Building Information Management (BIM) Systems
C6. Programming Skills
D. Structural Engineering Topics and Tools
D1. Structural Steel Design – Basics
D2. Structural Steel – More Advanced Topics
D3. Reinforced Concrete Design Basics
D4. Prestressed Concrete Design
D5. Reinforced Concrete – Advanced Topics
D6. Masonry Design
D7. Timber Design
D8. Design with Structural Aluminum
D9. Bridge Design – Short/Mid Span
D10. Bridge Design – Long Span Systems
D11. Earthquake Engineering – Basics
D12. Earthquake – High Risk Areas
D13. Design to Resist Unusual Loads/Blast
D14. Special Concerns for High Rise Systems
D15. Condition of Structures/Repair, Renovation, Reuse
D16. Special Requirements – Residential
D17. Special Requirement – Light Commercial
F. Additional Topics
F1. Communication Skills (Oral, Written, Graphical)
F2. Effective Speaking
F3. Financial Assessment
F4. Working as a Team
F5. Total Building Design Project
F6. Bridge Design Codes (as an addition to B2)

An alternate presentation of the increase in achievement level expected during the first five years in practice is presented in Table 3, which gives a compilation of the distribution of the increases or decreases in achievement levels assigned by each respondent. For example, for subtopic A1, Advanced Mechanics of Materials, one of the 32 respondees assigned an expected achievement after five years which was one level lower than at completion of the masters-level program, 11 assigned the same achievement level at both two levels and in one case, the upward movement was four levels. One approximate but useful way to quantify the expected increase in achievement is to average the number of steps moved up or down. For subtopic A1, the average of the 32 cases described above is +0.938 (((-1)(1)+1(11)+2(8)+4(1))/32=0.938).

Table 3: Achievement Level Movement between Graduation and after 5 Yrs of Experience

Question Achievement Level Difference Round 2	-2	-1	0	+1	+2	+3	+4	+5	∑
A. Basic Mechanics and Engineering Tools									
A1. Advanced Mechanics of Materials	0	1	11	11	8	0	1	0	32
A2. Structural Analysis – Framed Structures	0	0	2	16	12	2	0	0	32
A3. Finite Element Analysis/Modeling	0	0	3	13	12	4	0	0	32
A4. Elastic Stability	0	0	4	14	13	1	0	0	32
A5. Structural Dynamics	0	0	6	10	15	1	0	0	32
A6. Analysis of Plates and Shells	0	1	6	12	11	2	0	0	32
A7. Properties & Behavior of CE Materials	0	0	4	14	12	2	0	0	32
A8. Numerical Methods	1	1	15	11	4	0	0	0	32
E. Management and Professional Tools									
E1. Design Office Organization/Management/Office Ethics	0	0	1	6	11	11	2	0	31
E2. Business Development and Practices	0	0	0	10	10	8	1	0	29
E3. Design/Build & Other Project Methods	0	0	1	8	9	12	0	0	30
E4. Leadership Skills/Adaptation to Changes	0	0	2	10	11	8	0	0	31
E5. Working with Architects, Contractors, etc.	0	0	1	5	13	8	2	1	30
E6. LEED, Green Buildings, Energy Use	0	0	1	12	12	5	0	0	30
E7. International Design and Construction Practices	0	0	5	15	9	1	0	0	30

As could be predicted, the expectations for the various sources for additional expertise varied widely among the structural engineering areas. For example, expectations for In-House Training and Experience in Practice were assigned much less importance for the General topic A, Basic Mechanics and Engineering Tools, than for General topic E, Management and Professional Tools as shown in Table 4.

Table 4 gives this expected change (increases) in the achievement level for the Topic Group A and E subtopics, including all the average importance level assigned by the Round 3 respondees for each of the five primary additional preparation modes.

A summary of the mean importance levels assigned to each of the five post-graduate/early employment modes for each of the six Topic Groups is presented both in Table 5, and these same data are shown visually in Figure 1. This graphic representation also illustrates the high level of importance given to the experience-in-practice source for the increased achievement levels expected during the first five years of practice. Key Set #2 (1 = Not important, 2 = Somewhat important, 3 = Important, 4 = Extremely important) was used in both Table 4 and Table 5. The detailed results are found in Reference [2].

Table 4: Source Importance in Achieving Expected Change

Question	Expected Change	Added Courses	Short Courses	In-House Training	Exper. in Practice	Self Learning
A. Basic Mechanics and Engineering Tools						
A1. Advanced Mechanics of Materials	0.938	2.200	2.000	1.680	2.600	3.042
A2. Structural Analysis – Framed Structures	1.438	1.960	1.880	2.360	3.560	3.292
A3. Finite Element Analysis/Modeling	1.531	2.200	2.200	2.360	2.960	3.042
A4. Elastic Stability	1.344	1.880	2.080	2.080	2.960	2.917
A5. Structural Dynamics	1.344	2.440	2.160	2.160	2.920	2.833
A6. Analysis of Plates and Shells	1.219	2.200	2.040	1.880	2.680	2.875
A7. Properties & Behavior of CE Materials	1.375	1.960	2.200	2.160	3.080	3.000
A8. Numerical Methods	0.500	2.120	1.840	1.720	2.320	2.583
E. Management and Professional Tools						
E1. Design Office Organization/Management/ Ethics	2.281	1.320	1.680	3.160	3.640	2.458
E2. Business Development and Practices	1.935	1.560	2.040	3.120	3.640	2.583
E3. Design/Build & Other Project Methods	2.012	1.400	2.040	2.720	3.560	2.458
E4. Leadership Skills/Adaptation to Changes	1.716	1.560	1.960	2.840	3.600	2.958
E5. Working with Architects, Contractors, etc.	2.190	1.240	1.520	2.600	3.760	2.708
E6. LEED, Green Buildings, Energy Use	1.649	1.760	2.840	2.600	3.120	3.208
E7. International Design and Construction Practices	1.149	1.440	1.880	2.360	3.280	2.875

Table 5: Mean Importance Levels

Topic Group Mean	Added Courses	Short Courses	In-House Training	Experience in Practice	Self Learning
A	2.120	2.050	2.050	2.885	2.948
B	1.735	2.093	2.740	3.667	2.935
C	1.540	2.066	2.587	3.240	3.069
D	2.002	2.381	2.351	3.351	2.998
E	1.469	1.994	2.771	3.514	2.750
F	1.776	2.036	2.718	3.594	2.826
Overall	1.777	2.103	2.536	3.375	2.921

Added Courses were considered to have the lowest importance of the five sources to bridge the gap between achievement levels at graduation and after five years of experience for five of the six topic groups, the exception being Group A. Using assessments for all five modes, the average importance for Added Courses was 1.777 (given in Table 5), with the highest average values for Group A (2.120), just above the 2.050 value for both "Short Courses" and "In-House Training", with the lowest for Group E (1.469). The highest importance (2.440, between somewhat important and important) assigned to additional coursework from among the Group A and E subtopics for Structural Dynamics with D2, Structural Steel –More Advanced Topics (2.400), and D6, Masonry Design (2.400), also among the higher ranked topics.

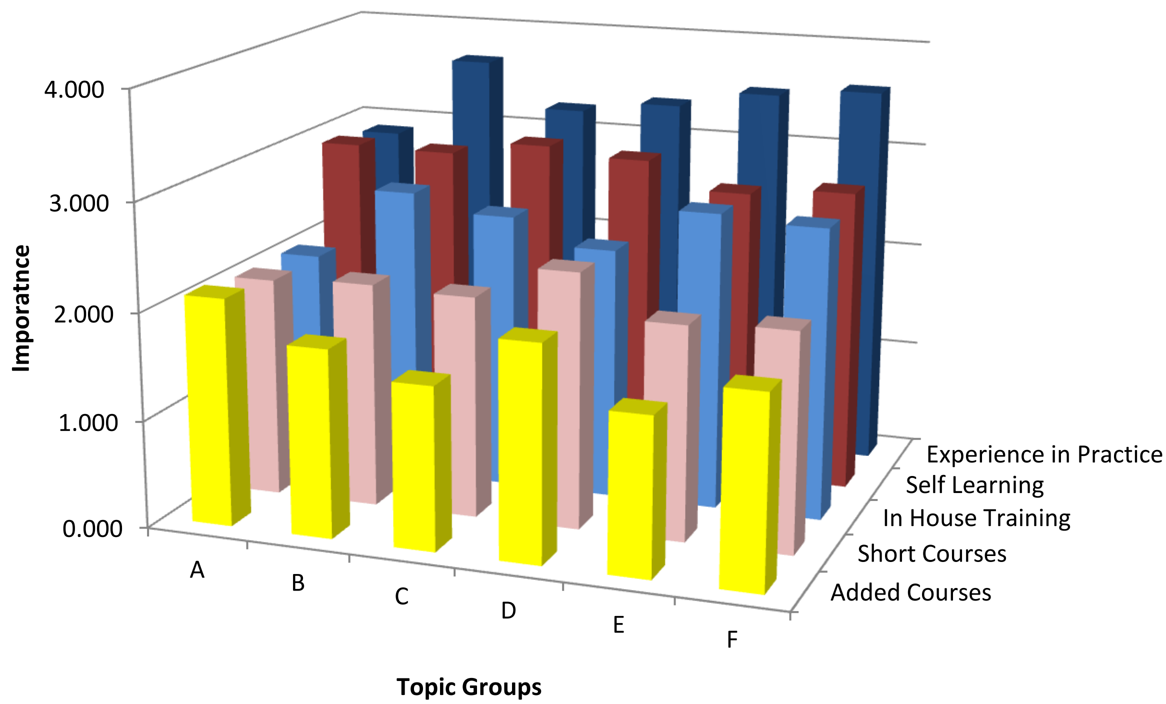

Figure 1: Mean Importance Levels by Topic Group and Source

Additional coursework was assigned the least expected importance for C1, Project Plans and Specifications, and E5, Working with Architects, Contractors and Others, both of these topics having an importance value of 1.240. Some of the desired additional subjects might be offered as electives. The mode assigned the highest overall importance is Experience in Practice, a mode which was ranked highest for all Topic Groups except for Group A. The Self-Learning mode was assigned quite high importance levels, being highest for Group A and second highest for Groups B, C, and F. The In-House Training mode was assigned the second highest importance level for Group E, Management and Professional Topics, just above the Group E value for the Self-Learning mode. The two highest importance levels assigned to a subtopic are both within the Topic Group B, General Structural Engineering Tools, and for the Experience in Practice mode. Many more details on the importance levels are in Reference [2].

Availability of the Additional Academic Course Mode

Just as the differences between the competency expected at completion of the masters-level program and that after five years indicates the importance of the early professional years in Table 3, the differences between the expected competency at the completion of the masters-level program and the level expected to be available through electives is a measure of the potential for the use of additional electives in the early professional years.

Academic subjects which are typically considered to be specialized topics and/or PhD-level subjects were found to offer the largest potential. Included in this group are A5, Structural Dynamics; A6, Analysis of Plates and Shells; D9, Bridge Design-Short/Mid Span; D13, Design to Resist Unusual Loads including Blast, and D12, Earthquake-High Risk areas. Those with the lowest potential for continuing professional development include A2, Structural Analysis-Framed Structures; F3, Financial Assessment, and E3, Design Buildings and Other Project Methods.

Differences in Expectations Based on Participant Affiliation

A question of interest in defining the Framework of Knowledge (FOK) is whether the academic, professional society and structural engineers in design firms have similar expectations for the young engineer's preparation. The study results show that the expectations of the academic and structural design in practice groups were generally quite similar, with some significant differences. At the time of masters-level completion, the expectation of those in academics is significantly higher, especially in Task Groups B and C. Those in practice often have higher expectations for the young engineer completing his or her first five years in practice. Table 6 gives the distribution of the survey participants by affiliation, and Reference [2] gives more details on survey responses based on participant affiliation.

Table 6: Distribution of Participants by Affiliation

	Affiliation			
	Structural Engineering Firm	Professional Society	Academia	TOTAL
Initial (Target) Panel				
Participants	68	10	20	98
% of 98	69	10	20	100
Panel Returning R1				
Participants	25	5	10	40
% of 40	63	13	25	100
Panel Returning R2				
Participants	24	5	10	39
% of 39	62	13	26	100
Panel Returning R3				
Participants	18	5	9	32
% of 32	56	16	28	100

Use of the Survey Results to Various Stakeholders in Structural Engineering

The results of this research can contribute to the structural engineering profession on several levels and in several different ways for the various stakeholder groups in the structural engineering areas. These many stakeholder groups include academic institutions, providers of structural engineering services, the taxpayers, and a wide variety of general interest groups. Six stakeholder communities most directly involved in structural engineering are listed below. The two stakeholder communities most involved in the young engineer's preparation during the first five years of professional practice are the first two groups listed; the employer and the young engineer. The potential uses of the survey results addressing the initial employment period by these two groups are specifically noted.

- Employers Hiring masters-level Graduates in Structural Engineering – addressed earlier in the paper and in the following points.

- Young Structural Engineers Planning their Professional Growth

  The individual's professional development becomes a joint responsibility of the young engineer and of the employer, acting both as a structural engineering provider and as a representative of the overall profession. Especially during the initial years, but continuing on, the developing structural engineer is advised to take an active role in the planning and carrying out of their own professional development. The young professional needs to invite additional assistance and career development opportunities from the employer to help him or her reach personal professional goals.

  The survey findings on the importance of major information/learning sources beyond the masters-level work can inform the young professional in his/her own planning of overall career development. Notable for this young structural engineer is the importance assigned to the Self Learning mode, found to be second only to experience-in-practice as a source. These finding clearly communicate to the young aspiring structural engineer that life- long learning, perhaps especially during the first several years, is an inherent component of this professional career and thus it needs to be included in his or her expectations, be carefully planned, and then diligently carried out.
- Academic Institutions offering masters-level Structural Engineering Programs
- Institution/Firms/Organizations Involved in Post Masters Degrees Education
- Licensing Boards and Professional Exam Providers
- ASCE and Other Professional Societies Addressing Structural Engineering

Some General Observations, Conclusions, and Recommendations

The output of this Delphi study analysis, the literature, and other inputs from professionals lead to the major findings, conclusions and recommendations of the study. These results are the main elements supporting a proposed Framework of Knowledge directed toward the masters-level structural engineering programs and the initial professional experience for the changing structural engineering professional field.

Reviews of current practices and the survey's findings, as well as the review of literature, suggest that structural engineering education should include additional information than it does at present, including more basic coverage of the professional, technical tools, and management topics which are all also very dependent on the early professional experience of the young engineer in order to be further developed to the level needed for effective independent professional practice.

A practicum/internship as a part of the core graduate curriculum would both assist the student progress in the professional areas not emphasized in the academic courses and, perhaps at least as importantly, can give this student a better understanding of what is involved in structural engineering professional practice so that this student can better discern how well this profession fits with his/her interests, priorities, and abilities and so they can have a better perspective on how best to plan their formal and informal preparation for this profession. However, such programs are not often considered to be practical or possible at the graduate level. Formal co-operative programs are generally at the undergraduate engineering level and are only available at some schools. Some graduate students obtain some attributes of an internship through a combination of employment and often part-time graduate studies. A requirement for an internship within the graduate-level structural engineering program would require the academic institution to both assist the student in finding an appropriate position and to work with the employer on the expectations for this experience so that it can a have a strong role in the overall preparation of the young aspiring professional.

It is generally accepted that a significant portion of the young structural engineer's preparation needs to be provided by the profession, especially by the initial employer. Although the scope of this research did not include a complete review of this phase of the structural engineer's preparation for practice, the results presented in this paper provide information on both the areas perceived by the profession to be of most need in this initial employment period and the perceived importance of five primary modes for obtaining additional capabilities beyond those expected from the formal graduate programs.

For the structural engineering profession to have the capabilities, recognition, and respect needed both to more effectively provide structural/physical infrastructure to society and to obtain a larger role in the planning and managing these facilities, the general call of the civil engineering profession is that we have to "Raise the Bar" as described in References [3], [5], and [6]. Two of the key steps in reaching this goal are to increase the formal post-undergraduate academic requirements and to correspondingly increase the professional licensure requirements. Structural engineering groups (e.g. NCSEA, SEI) and structural engineers active in engineering groups (e.g. ASCE, NCEES [7]) are currently very involved in these efforts and can help make these changes a reality.

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