Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Geotechnical-structural integration in US foundation engineering curricula

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ABSTRACT: The degree of integration between the structural and geotechnical aspects of foundation engineering, as taught in US undergraduate civil engineering programs, is explored. Faculty surveys, reviews of textbooks, and reviews of curricula indicate little integration. Structural design of spread footings is frequently taught in reinforced concrete design courses, but almost completely independent of any geotechnical considerations. About half of introductory geotechnical engineering courses do not include any coverage of foundation analysis or design. Coverage of structural topics in foundation engineering texts has significantly decreased over the past 30 years. Surveys of practitioners indicate a greater emphasis on integration of geotechnical and structural aspects of foundation engineering than that perceived by faculty. The increased emphasis on Load and Resistance Factor Design in geotechnical engineering further underlines the importance of an integrated approach. Greater emphasis on this integration would produces future geotechnical engineers and structural engineers who are better equipped to optimise their foundation designs.

1 BACKGROUND

Foundation engineering is a cross-disciplinary topic that transcends geotechnical engineering, structural engineering, and construction engineering, so practising professionals should have competency in all three aspects. Nevertheless, the authors have observed an artificial separation between geotechnical/construction engineering and structural engineering, and this separation appears to be present both among foundation engineering practitioners and in academia. This lack of sufficient integration between geotechnical and structural engineering often leads to poor foundation design decisions.

For example, the interaction between geotechnical and structural design of spread footings is too often reduced to little more than communicating an allowable bearing pressure, as if this single parameter was sufficient. Foundation types are sometimes selected without sufficient attention to the various soil-structure interaction considerations, which sometimes results in a foundation system that is unnecessarily expensive.

As a result of these observations, the authors created an undergraduate foundation engineering course which integrates both the geotechnical and structural aspects of design. This course focuses on spread footings, and the expected outcomes include the ability to start with structural loads and subsurface exploration and characterisation data, and produce a complete foundation design including all structural details. In the authors' opinion, this type of integrative course, particularly at the undergraduate level, helps develop stronger design skills among civil engineering students. However, there was little or no information on how other academics and practitioners viewed this matter.

Therefore, the goal of the research presented in this paper was to determine the current state of foundation engineering education in the US as it relates to the integration of geotechnical and structural aspects of analysis and design. To accomplish this, the authors conducted a survey of geotechnical and structural faculty to determine the degree to which these topics are integrated in foundation engineering courses. A survey of foundation engineering practitioners was also conducted with two objectives: to determine their perceptions of the importance of various aspects of foundation design and to determine their satisfaction with recent civil engineering graduates. Finally, a review of the available library of foundation engineering and structural engineering textbooks was conducted to determine how geotechnical and structural design topics are presented.

2 SURVEY INSTRUMENTS

2.1 *General characteristics*

Two surveys were conducted online using a commercial survey provider. The surveys were conducted from July to August, 2011. Respondents were solicited via online professional networks such as the United States Universities Council on Geotechnical Education and Research, professional organizations such as

Table 1. Demographics of practitioners completing the survey.

Characteristic	Number responding	Percent responding
Engineering discipline		
Geotechnical	39	57%
Structural	22	32%
Construction	4	6%
Other	3	6%
Affiliation		
Private firm	60	87%
Public agency	9	13%
Geographic scope of firm/agency		
Local	12	17%
Regional	22	32%
National (US)	15	22%
International	20	29%
Service provided by firm/agency		
Engineering design	51	74%
Consulting	50	72%
Design/build	31	45%
Construction services	21	30%
Construction management	23	33%

ADSC: The International Association of Foundation Drilling and US civil engineering department chairs email list. There were no individual invitations for survey participants so it is not possible to determine the return rate of the surveys.

2.2 *Characteristics of practitioner respondents*

A total of 69 practitioners responded to the survey. The demographics of the practitioners responding are shown in Table 1. One of the goals of the survey was to get data from those describing themselves as both geotechnical and structural engineers. As seen in Table 1, geotechnical engineers are slightly over represented compared to structural engineers (57% geotechnical, 32% structural) but there is significant representation among both groups.

The respondents are heavily weighted to private firms (87%) compared to public agencies (12%) as shown in Table 1. Among the private firms there is a good diversity of geographic size of the firms as seen in Table 1. The data also show that firms/agencies represented by respondents most commonly provide design or consulting services (over 70%), but significant percentages of respondents report providing design/build or construction services (45% design/build, 30% construction). One third of respondents report providing construction management services.

The authors believe the sample group is sufficiently diverse and representative of the practicing foundation design community in the US, but no attempt was made to compare the demographics of the respondents to demographics of US engineering firms and agencies. The sample is significantly biased toward private firms versus public agencies and slightly biased toward geotechnical engineers versus structural engineers, but these biases in the data do not appear to significantly affect the conclusions reached in this paper.

Table 2. Demographics of institutions represented in the academic survey.

	All ABET Schools*		Survey sample	
Characteristic	number	percent	number	percent
Status				
Private	64	26%	23	24%
Public	185	74%	70	76%
Carnegie classification 2010†				
Bachelors	23	9%	9	10%
Masters	16	24%	22	23%
Doctorate	17	7%	4	4%
Research	149	60%	59	63%

*Data from ABET (2011).
†Data from Carnegie Foundation (2010).

Table 3. Demographics of faculty completing the survey.

Characteristic	Number responding	Percent responding
Engineering discipline		
Geotechnical	62	41%
Structural	74	49%
Multidisciplinary	16	11%
Academic area		
Geotechnical	75	49%
Structural	77	51%

2.3 *Characteristics of faculty respondents*

A total of 152 faculty members responded to the surveys. These respondents represented 99 institutions of which 94 were US institutions with 4-year ABET accredited civil engineering or civil engineering technology programs. The remaining 5 institutions were either outside the US or were 2-year community college programs and were excluded from the analysis presented in this paper. Including only US based ABET accredited 4-year programs reduced the total sample size to 147.

The demographics of the institutions included in the analysis compared to demographics of all US based ABET accredited 4-year civil engineering or civil engineering technology programs are shown in Table 2. In terms of public-private status, and Carnegie classification (Carnegie Foundation, 2010), the survey sample is representative of the total population.

The demographics of individuals responding are shown in Table 3. The balance between geotechnical and structural engineers in this survey was better than in the practitioner survey (41% geotechnical, 49% structural, 11% multidisciplinary) and the balance of academic areas in which the respondents reported teaching was nearly equal (51% structures, 49% geotechnics). No attempt was made to compare this data to the total population of all civil engineering faculty. The goal was to achieve a balance between faculty teaching structural courses versus geotechnical courses and this was achieved. The authors believe the survey sample is a satisfactory representation of the population.

3 UNDERGRADUATE FOUNDATION ENGINEERING CURRICULA

A brief review of the data from the faculty survey and a web-based review of BSCE curricula indicated nearly all institutions included design of spread footings in various places within their undergraduate curriculum, albeit often within elective courses. Deep foundations were always included in the graduate curricula and in some cases also in the undergraduate curricula. Since the design of spread footings is generally one of the first foundation systems covered in a design course and since it includes both geotechnical and structural engineering design aspects, the authors chose to focus on the design of spread footings to assess the coverage of geotechnical and structural aspects of foundation engineering in undergraduate curricula.

3.1 *Preparatory coursework for foundation engineering*

Important preparatory courses for foundation engineering include introductory geotechnical engineering (or soil mechanics), reinforced concrete design, and, to a lesser extent, structural steel design. Welker (2012) reports that 93% of US BSCE programs require an introductory geotechnical engineering course. A web-based review indicates all BSCE programs require at least one structural design course, but the students often have the option of selecting courses on certain materials (steel, concrete, etc). Informal discussions with civil engineering faculty at a number of US institutions indicate that all BSCE students who choose to focus on structural engineering and the vast majority of those who choose to focus on geotechnical engineering take both reinforced concrete design, and structural steel design courses.

Since introductory geotechnical engineering, reinforced concrete design, and structural steel design are taken by the vast major of students who are likely to become practicing foundation engineers, the faculty survey was used to determine what spread footing design topics were covered in these courses. Figure 1 shows those topics covered in introductory geotechnical engineering courses. Approximately half of the respondents report covering bearing capacity and/or settlement in this course. Equally important, nearly half of the respondents reported no coverage of footing design topics. A number of respondents reported in their comments that their introductory geotechnical engineering course covered geotechnical behaviour and analysis to the exclusion of design.

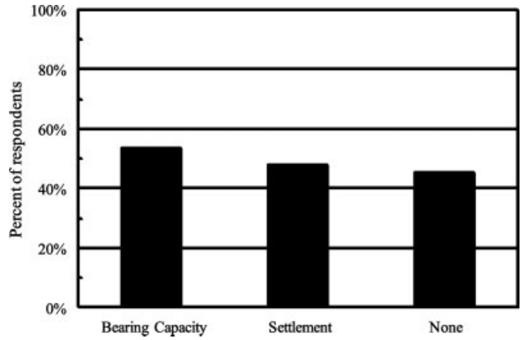

Figure 1. Footing design topics covered in introductory geo-technical engineering courses.

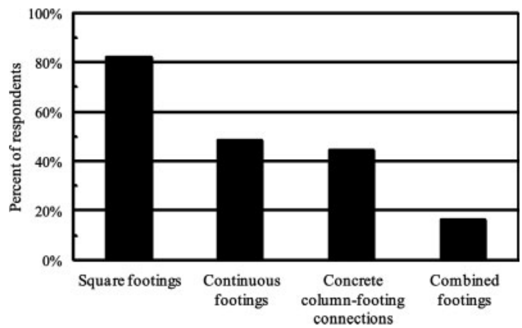

Figure 2. Footing design topics covered in reinforced concrete design courses.

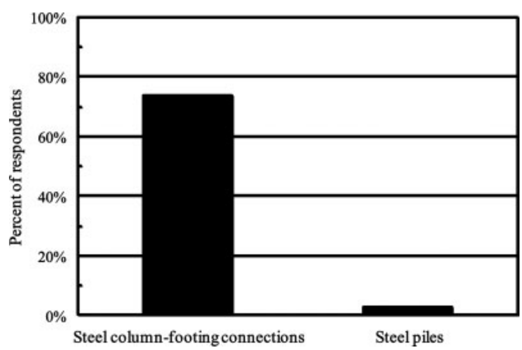

Figure 3. Footing design topics covered in structural steel courses.

Coverage of footing design topics in the structural engineering courses is shown in Figures 2 and 3. As shown in Figure 2, 82% of respondents report covering structural design of square footings. Significantly lower percentages report covering continuous footings, combined footings and column-footing connections. The data in Figure 3 indicate 74% cover steel column-footing connections, while only 3% cover the design of steel piles.

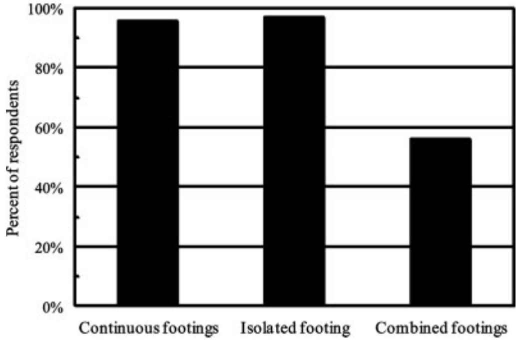

Figure 4. Footing foundation systems covered geotechnical engineering design courses.

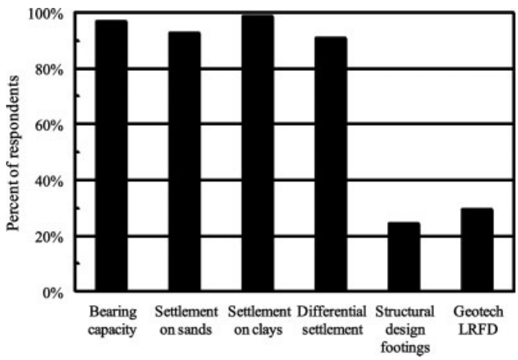

Figure 5. Topics covered in geotechnical engineering design courses.

3.2 *Foundation engineering design courses*

It is not surprising to find that a significant number of introductory geotechnical engineering courses focus exclusively on behaviour and analysis since this is the students' first course in geotechnics. In contrast the concrete and steel design courses follow one or two courses in structural analysis and are therefore able to focus directly on design.

Welker (2012) reports that 75% of programs offer a geotechnical engineering elective after the introductory course but only 37% of programs require a second geotechnical course. Data from this survey indicate that 6% of programs offer only an introductory geotechnical engineering course, 77% offer a second course, and 17% offer both a second and third geotechnical engineering course. Welker (2012) reports that in the majority of undergraduate programs, foundation engineering is the second geotechnical course offered. This survey indicates in 99% of the programs, the second course covers shallow foundation design. Figure 4 shows the shallow foundation systems covered in the second geotechnical engineering course and Figure 5 shows the topics covered in this course. Of particular note, Figure 5 shows that only 24% of programs cover structural design of shallow foundations in the geotechnical engineering elective course. By comparing responses of geotechnical and structural faculty at the same universities, the survey data indicate that 29% of programs which do not cover structural design of footings in their reinforced concrete class do cover it in their geotechnical design class.

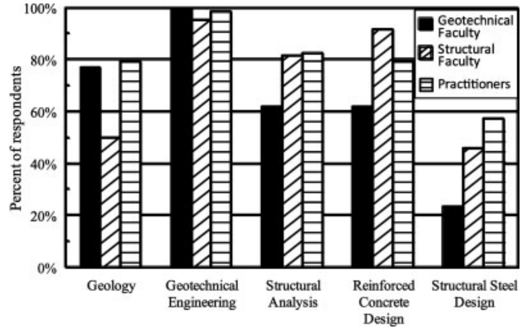

Figure 6. Importance of foundation engineering subjects as reported by geotechnical faculty, structural faculty, and practitioners.

Load and Resistance Factor Design (LRFD) is reportedly covered in 33% of programs (Fig. 5), but the survey did not distinguish between geotechnical and structural aspects of LRFD in this question. It is unlikely that the coverage of geotechnical LRFD design goes beyond a qualitative overview in those few courses which cover it, given the lack of textbook coverage of this subject as discussed later in this paper.

Two conclusions are apparent: First, most students are taught structural footing design either in their reinforced concrete or geotechnical design course. Second, the most common curriculum structure is to cover structural design of footings in the reinforced concrete course but not in the geotechnical design course.

4 FACULTY AND PRACTITIONERS' OPINIONS OF FOUNDATION ENGINEERING TOPICS

One objective of this study was to determine what, if any, differences existed between faculty and practitioners' opinions concerning the importance of certain subjects in foundation engineering. To accomplish this, respondents to both surveys were asked to rate the importance of several subjects potentially related to foundation engineering. The respondents were asked to rate the importance on a four point Likert scale (not very important, somewhat important, important, very important). In the following analyses the importance is reported as the percentage of respondents indicating a given topic was important or very important.

4.1 *Importance of component subjects*

Figure 6 compares the importance reported by geotechnical faculty, structural faculty and practitioners related to geotechnical and structural subjects. With the exception of geology, the opinions of structural faculty are more congruent with practitioners' opinions than are the opinions of geotechnical faculty. Another

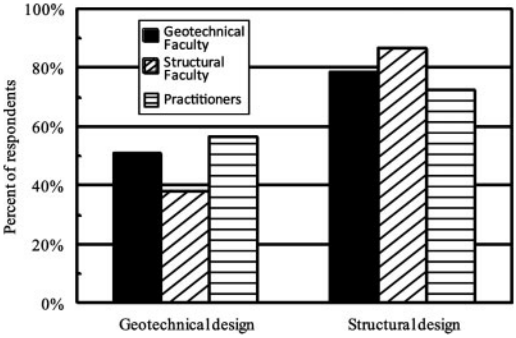

Figure 7. Importance of geotechnical and structural LRFD in foundation design as reported by geotechnical faculty, structural faculty, and practitioners.

possible interpretation of these data is that both academic disciplines undervalue the importance of the other disciplines, whereas practitioners place value on both.

4.2 *Importance of load and resistance factor design*

The importance LRFD in foundation design is increasing due to newer regulatory guidance such as Eurocode 7 and US Federal Highway Administration design criteria for transportation structures. One objective of this study was to compare how faculty and practitioners perceive the importance of LRFD given its increasing importance.

Figure 7 compares the importance of LRFD to foundation design reported by geotechnical faculty, structural faculty and practitioners. As shown in this figure, all three agree that LRFD in structural design is significantly more important than LRFD in geotechnical design. The structural engineering faculty attach significantly less importance to LRFD in geotechnical design compared to both geotechnical faculty and practitioners. Practitioners were asked the additional questions "For your firm or agency, how do you see the importance of LRFD methods, as applied to geotechnical foundation design, changing in the future?" Over 70% of practitioners responded that expected LRFD importance to significantly increase over the next ten years.

Practitioners' identification of the increasing importance of geotechnical LRFD methods and the faculty's underestimation of their importance are significant findings of the surveys. LRFD methods clearly separate strength limits from serviceability limits. This increases the importance of understanding soil-structure interaction which will, in turn, increase the need for interaction between structural and geotechnical disciplines.

5 EVALUATION OF TEXTBOOKS AND REFERENCE BOOKS

Foundation engineering and reinforced concrete design textbooks currently used in the United States were reviewed to evaluate their coverage of structural design of foundations. A similar review also was conducted on English language foundation engineering reference books and out-of-print textbooks.

5.1 *Reinforced concrete design textbooks*

Major US publishers currently offer nine reinforced concrete design books suitable for use as textbooks in civil engineering courses (Brzev and Pao, 2010; Fanella, 2011: Hassoun and Al-Manaseer, 2008; Limbrunner and Aghayere, 2010; McCormac and Brown, 2008; Nawy, 2009; Nilson, et al., 2009; Wang, et al., 2007; and Wight and MacGregor, 2012). All nine include an entire chapter on the structural design of foundations. In all cases the structural design of spread footings is covered in some detail. The structural design of deep foundations, mat foundations, pile caps, and other structural members is either not covered or only briefly mentioned. None discuss the geotechnical aspects in any detail, other than using an allowable bearing pressure to size the footings.

5.2 *Foundation engineering textbooks*

Major US publishers currently offer nine foundation engineering books suitable for use as textbooks in civil engineering courses (Bowles, 1996; Budhu, 2008; Cernica, 1995; Coduto, 2001; Das, 2011; Murthy, 2003; Rao, 2011; Reese, et al., 2006; and Salgado, 2008), and one additional book is self-published by the author (Candogan, 2009). All focus primarily on the geotechnical aspects, and cover them in detail. Only three of these books (Bowles, 1996; Coduto, 2001; Cernica, 1995) cover the structural design of spread footings, and each does in some detail. These three and Candogan, 2009 also include some coverage of the structural design of deep foundations, although to a lesser degree than for shallow foundations. The remaining books have no substantive discussion of the structural design aspects of foundation engineering.

Three other books (Teng, 1962: Leonards, 1962; and Peck, et al., 1974) were commonly used in the US as textbooks, but are now out of print. All three focused primarily on the geotechnical aspects, but two included significant coverage of the structural design of spread footings, one included a detailed discussion of the structural design of deep foundations, and one included a brief discussion of the structural design of deep foundations.

Bowles' textbook was originally published in 1968 and in use at the same time as the three out-of-print texts. Thus, during the 1970s and 1980s three of the four available foundation engineering texts (75%) included significant structural design content. Currently, only three of the nine available texts from publishers (33%) include significant structural design content and one of these three is the 1996 edition of Bowles' text. One could make the case that the coverage of structural foundation design foundation engineering texts has dramatically decreased in the past three decades. This increased specialisation at the sacrifice of topical breadth is not unusual in engineering education, but is nevertheless a troubling trend.

5.3 *Foundation engineering professional reference books*

All of the foundation engineering textbooks also are useful references for practicing engineers. In addition, eight other English language professional reference books, both in print and out of print (Brown, 2001; Curtin, et al, 2006; Das, 2009; Day, 2006; Fang, 1991; Gunaratne, 2006; Ng, et al, 2004; and Wyllie, 1999) were reviewed. Of these, only two included substantive coverage of the structural design of spread footings and only three included substantive coverage of the structural design of deep foundations.

5.4 *LRFD coverage in textbooks*

All of the reinforced concrete foundation design textbooks cover LRFD design extensively as that is the current design standard in the US. Only one of the textbooks reviewed (Coduto, 2001) has any cover of geotechnical LRFD design and the coverage in the text is limited to an overview of the approach. No geotechnical guidance suitable for design is provided.

There are four important observations from this review. Structural design of spread footings is a major topic in all of the major American reinforced concrete design textbooks, but the coverage is completely independent of any geotechnical considerations, other than the allowable bearing pressure. Only 33% of currently published American foundation engineering textbooks cover structural design of spread footings. Substantive coverage of structural design of deep foundations is available only in one foundation engineering textbook. Finally, only one foundation engineering text covers geotechnical LRFD, and even that coverage is in broad conceptual terms.

6 PRACTITIONERS' SATISFACTION WITH GRADUATES

In order to reach some understanding of how well academic curriculums are meeting the expectations of practitioners, the survey included questions related to practitioners' satisfaction with BSCE graduates hired within the last five years. Only firms or agencies reporting having hired a recent BSCE graduate during the past five years were asked to respond. The survey asked the practitioner both about the importance of certain foundation engineering topics (using the same four point scale described above) and their satisfaction with the performance of recent graduates. Satisfaction was rated on a four point Likert-like scale (very dissatisfied, dissatisfied, satisfied, very satisfied). The practitioners' ratings of importance and satisfaction were combined into a single measure by computing

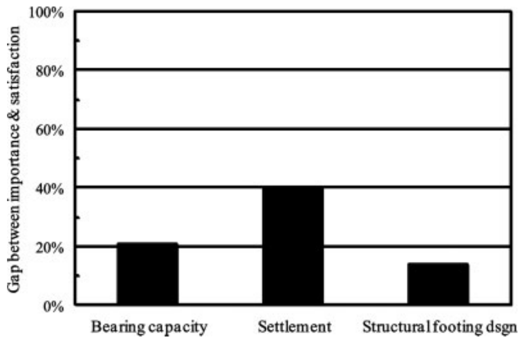

Figure 8. Gap analysis comparing practitioners' importance and satisfaction with footing design abilities of BSCE graduates hired within the past 5 years.

the gap between reported importance and reported satisfaction. The gap was computed by subtracting the satisfaction rating from the importance rating, since the importance rating always exceeded the satisfaction rating.

Figure 8 presents the gap analysis comparing practitioners' rated importance and satisfaction with recent BSCE graduates employed in the last five years. The data indicate practitioners are most satisfied with graduates' abilities in structural design of footings and significantly less satisfied with their abilities in bearing capacity and settlement computations.

The overall satisfaction with BSCE graduates' abilities in foundation engineering is quite low. However, this should be tempered by most practitioners' belief that an advanced degree is important for foundation engineers. When asked about the required level of academic training for foundations engineers, 83% replied that a master's degree was either advisable or essential. Still it is clear that there is plenty of room for improvement in the academic preparation of foundations engineers.

7 SUMMARY OF FINDINGS

7.1 *Undergraduate curricula*

Significant foundation engineering instruction is available to students interested in the subject. However, it is most commonly delivered in a stovepipe fashion with structural topics relegated to structural design courses and geotechnical topics relegated to geotechnical courses. Over 80% of the reinforced concrete design courses have significant coverage of the design of footings. Nearly half of the commonly required introductory geotechnical engineering courses cover some foundation engineering topics. Essentially all geotechnical design courses cover shallow foundation design, but less than 25% of these courses include structural foundation design. Both reinforced concrete design and geotechnical engineering design are most commonly elective courses, but are likely taken by students interested in foundation engineering.

This stovepipe mentality is also apparent in the importance geotechnical and structural faculty attach to the foundation design aspects of one another's disciplines. Geotechnical engineering faculty, in particular, attribute less importance to structural aspects of foundation design than do practitioners.

Structural aspects of LRFD are clearly covered in structural engineering courses. However, geotechnical LRFD subject are covered in less than one third of the geotechnical design courses and then most likely only as an overview without significant design content.

7.2 *Textbooks*

All current reinforced concrete textbooks thoroughly cover structural LRFD and devote an entire chapter to the structural design of foundations, but this is done in nearly complete isolation to geotechnical aspects of design. The coverage of structural design in foundation engineering textbooks has significantly decreased in the past two decades as older texts which frequently covered these topics are replaced by new texts which most often do not. None of the foundation engineering texts contain sufficient coverage of geotechnical LRFD topics.

7.3 *Practitioners satisfaction with graduates*

Foundation engineering practitioners are moderately satisfied with BSCE graduates hired in the past 5 years. They are significantly more satisfied with the graduates' abilities in structural design of foundations compared to their abilities in geotechnical design of foundations. The area with the least satisfaction is in settlement of footings. These finding are tempered by the fact that the vast majority of practitioners believe a master's degree is advisable or essential to foundation engineers.

8 CONCLUSIONS AND RECOMMENDATIONS

The geotechnical, structural, and construction aspects of foundation engineering practice are clearly intertwined, and the best foundation designs are achieved when all three aspects are fully considered. Most foundation engineering textbooks used in the United States 30 years ago included both the geotechnical and structural aspects, and presumably the corresponding courses also did so. However, most of today's textbooks focus almost exclusively on the geotechnical aspects, with only some attention to construction, and virtually none to structural aspects. The vast majority of undergraduate foundation engineering courses taught in the US today reflect this topical coverage.

The authors have observed that this artificial separation also carries over into practice, with insufficient communication and interaction between structural and geotechnical engineers. This often leads to less-than-optimal foundation designs.

This lack of integration will become more problematic as geotechnical LRFD methods become more widely used in practice. These methods force a clearer separation between strength requirements and serviceability requirements, which necessitates better interaction between the disciplines. The transfer of a single allowable bearing stress between the geotechnical and structural engineer has always represented an insufficient interaction. The adoption of geotechnical LRFD methods will make this blatantly apparent.

The authors believe the impending adoption of geotechnical LRFD methods in the US presents an opportunity to improve the quality of foundation engineering practice by forcing more effective interaction between geotechnical and structural engineering. The authors recommend implementing a greater integration between the structural and geotechnical aspects of foundation design, especially in undergraduate foundation engineering courses. This stronger emphasis should lead to better qualified graduates, who will then go on to implement stronger interactions among practitioners.

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