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Paradigm for Teaching Structural Technology

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Structural technology courses required in construction and architecture curricula must be taught differently from their parent structural engineering courses. Rather than focusing on the scientific details of the syllabus topics, structural technology courses should be concerned primarily with the structural engineering process itself – the continuity among the syllabus topics. To accomplish this, a paraphrasing of the theory of structures is presented in narrative fashion. In paraphrasing structural engineering, relative terms such as 'about' or 'may generally be taken as' are taken to be absolute values from which approximate results are developed and considered to be final solutions. This is sufficient for construction and architecture courses, because it is the role of the engineers to optimize problem solutions. Using this paradigm to teach structural technology, approximate but reasonable solutions to quite complex and broad-based engineering problems can be covered despite the reduced levels of math and science and the restricted number of courses dedicated to the study of structures in construction and architecture curricula.

Key Words: Structural Technology, Engineering Contents, Art of Engineering, Educational Paradigm

Introduction

Structural engineering is a broad field of study devoted to all aspects of designing, constructing, maintaining, and repairing structures. Most students preparing for professional careers in structural engineering are required to take extensive college coursework in mathematics, physics, and especially structural engineering. Likewise, most students pursuing degrees in construction and architecture are required to study structural engineering by taking several structural technology courses derived from engineering statics, mechanics of materials, timber/steel/concrete design, and perhaps, soils and foundations. These structural technology courses have lower level math and science prerequisites than do structural engineering courses.

The experience of twenty-five years of teaching structures to engineering students and especially teaching structural technology to construction and architecture majors makes it clear that there needs to be a much different approach taken in the study of structural technology compared with that of structural engineering. This view is certainly shared by others as well. In survey results of construction programs in the United States, "seventy eight percent of respondents believe that we should not be tied to the traditional engineering formats in teaching structures to our construction students. More diverse subjects should be covered with less depth" (Chini, 1995).

Most students of structural technology are not studying to become practicing structural engineers, so that a) their prerequisite courses differ from engineering course prerequisites, and,

b) their intended purpose for studying structures also differs. Though these different capabilities and needs of the structural technology students are obvious, they seem not to have any fundamental influence on the methods by which structures courses are presented to non-engineering majors. "Most professors that teach structures classes have an engineering background and tend to present structural concepts in the same way their professors presented the concepts to them" (Williams & Sattineni, 2002).

The objective of this paper is to draw the distinction between structural engineering and structural technology, and to suggest an appropriate paradigm for teaching structural technology for construction and architecture. This paradigm has significant implications concerning the style of presentation and expected learning outcomes of structural technology courses.

Paradigm for Teaching Structural Technology

To prepare engineering students for their professional careers, the typical engineering course syllabus is filled with rigorously detailed topics. For structural engineering, these courses include: statics, strength of materials, classical structural analysis (I and II), computer-based analysis, reinforced concrete structures (I and II), steel structures (I and II), timber structures, masonry structures, geotechnical engineering, foundation engineering, bridge engineering, structural dynamics, wind and earthquake engineering, and reliability of structures. With this enormous volume of detailed structures topics, there is little time available so that little effort is spent within a course focusing on the interrelationships and the continuity inherent to the subject matter.

Construction and architecture curricula also have a long list of required courses in their specific areas. Structural technology is, of necessity, only a relatively small part of these curricula, with perhaps from two to six structural technology courses required in the areas of statics and structural analysis, mechanics of materials, timber/steel/concrete design, and perhaps a course in soils and foundations. Especially in light of the many demands that ever-changing technology places on college curricula, construction and architecture departments must continually revisit a key question: "What is essential structural technology for construction and architecture and how should it be presented?" A detailed case study into the difficult planning issues raised when grappling with the question is presented in (Senior & Hauck, 2001).

A complete answer to this question constitutes an educational paradigm for teaching structural technology. From the dictionary, a paradigm is "a philosophical and theoretical framework of a scientific school or discipline within which theories, laws, and generalizations and the experiments performed in support of them are formulated" (Merriam-Webster, 2002). There are different paradigms commonly used to teach structural technology, and a brief discussion of the limitations of two such models follows.

Structural technology should not be considered merely as "structures lite" – a field of study that parallels structural engineering but which mostly ignores theoretical developments in lieu of devoting attention to demonstrating how to use simplified design tables and graphs found in various building codes. This paradigm is intended to be superficial in nature, as it deals with only a small part of the design process, like “What is the deflection in a specific beam that spans X feet and supports Y load?” Alternatively, a more meaningful question would be “How will we know if there will be excessive roof deflection if the ridge beam depicted in the architects sketch is used?” The underlying interrelationships and continuity of the design process is barely apparent with “structures lite”.

Likewise, structural technology is not a disparate selection of “top 10” topics – a subset comprising the most interesting or most easily understood key topics chosen from the domain of all topics within the field of structural engineering. This teaching model is akin to a condensed review manual for a major standardized exam. One or two of the topics selected might focus on the derivation of key formulas like axial deformation and the flexure formula, for instance, but thereafter, other such formulas are presented with little or no background development. Also typical, having presented a key topic once, say the technique of tracking forces through a structure to determine member loads, thereafter its role in other key problems is ignored and, following this example, a later topic might be beam analysis that will begin with all loads given. As with “structures lite,” little attention is given to continuity, but also, the advantages of repetition are lost with the “top 10” approach.

In the previous two paradigms of teaching structural technology, with so little attention given to developing a sense of continuity among the topics, the dynamic process by which new concepts and problem solutions evolve from interrelating previous ones is unobserved, yet this is the essence of structural engineering. With these models of teaching, students miss out on an experience of the ingenuity of applying math and physics to derive practical design formulas. The posing of narrowly focused questions bypasses opportunities to see the whole engineering process at work.

The following paradigm suggests a better approach:

> Teaching structural technology for construction and architecture, the professor provides the curious student with an appreciation of the engineering process and prepares the student to competently discuss structures in the engineering language. This language includes technical terminology, code specifications, hand sketches and engineering drawings, experimental observations, and basic mathematical and physical relationships. Structural technology is presented as a paraphrase of structural engineering theory and practice that is expressed in prose and simple mathematical style. Various narrative stories are crafted that make use of the power of analogy to illustrate the ever-broadening development of structural analysis and design theory that flows by means of the continuities among interrelated structures concepts. It is this dynamic flow of the engineering process that is the primary focus of the study of structural technology.

Flow of Things

In structural engineering curricula, with so many courses and with each one filled with detailed scientific focus on every one of the numerous syllabus topics, the continuity from the first course in statics through foundations and even further on to the more specialized subjects is not usually at issue. The underpinning of advanced topics by the more elementary ones is simply taken for granted as the emphasis is on covering as many advanced topics as possible. With each of the numerous courses, there is intensive drill work employing numerous homework problems to reinforce the subject matter of one topic, all to be repeated with the next topic. Progressing through all of the structures courses in this manner, the engineering student must generally overlook the forest in order to study all the trees.

From Zen and the Art of Motorcycle Maintenance (Pirsig, 1974):

> "Science works with chunks and bits and pieces of things with the continuity presumed, and [an artist] works only with the continuities of things with the chunks and bits and pieces presumed? the lack of artistic continuity [is] something an engineer couldn't care less about."

This statement is a bit absolute in tone, but it is nonetheless quite profound. Of course artists must concern themselves with the bits and pieces from time to time, and engineers probably experience and appreciate the underlying continuity and flow of the engineering process. But generally speaking, what the artist most keenly understands and the engineer will occasionally experience is that, as the song says, "The rhythm is gonna get you." It is while immersed in the practice of engineering using all of the bits and pieces of the engineering language that the underlying continuity of things – the dynamic flow, or art – will be experienced by the engineer. In The Existential Pleasures of Engineering (Florman, 1976), it is said, "At the heart of engineering lies existential joy."

Constructors and architects are not licensed professional engineers, but this does not preclude them from an experience of the art of engineering practice. Because they will practice structural engineering in a very limited way, if at all, it is important that the art of engineering be a major focus throughout their structural technology coursework. With respect to the study of structures, constructors and architects do not share the same needs, abilities, and interests of the professional engineer. Their need is less filled with detailed explanations of specific topics (chunks and bits and pieces) and more with gaining a sense of the engineering process (continuities of things) – a broad view of the science and engineering of structures.

With limited structures coursework, it is more important that the structural technology student gain a sense of the engineering process, than, say, a keen ability to solve equilibrium problems or construct shear and moment diagrams (of course they will also study these concepts). With limited time and prerequisite coursework, a condensed version, or paraphrase, of the field of structural engineering most effectively allow structural technology students to experience the process of structural engineering analysis and design.

Paraphrased Engineering

In paraphrasing structural engineering theory, terms such as 'about,' 'generally', 'may be approximated as,' etc., may be treated as absolutes, and the analysis and design approximations that result are treated as though they are the final solutions. In this manner, considerable time is freed-up that can be used to pursue topics in greater depth. By using less time and mathematical effort dealing with the detailed tasks necessary to work the 'bits and pieces' into the "exact" solution, the continuities of things gain more prominence.

For example, in foundation engineering the design of a footing typically requires using Terzaghi bearing capacity equations to determine the theoretical soil bearing stress. This involves a multi-step iterative procedure that requires determining equation constants from separate graphs based on soil properties. The result is that the whole process of determining just the allowable pressure under the footing constitutes a complete problem for an engineering student. However, generalizing from the formulas, we may develop rules-of-thumb that approximate the allowable pressure to be, for clayey soil, the unconfined compression strength, and for sandy soil, 250 times the Standard Penetration Test blowcount.

By using such rules-of-thumb in combinations with others (establishing typical design loads for various structure types, for instance) and employing basic engineering principles like tracing loads through structures and pressure equals load intensity, far more meaningful and yet still short answer questions can be posed. Instead of "Determine the allowable bearing pressure for a footing," we can pursue more meaningful inquiries like "Compare the required footing size for a three story steel office building with 30 ft. by 30 ft. bays if it is to be built a) on a medium density clay, and b) a dense sand." The answer to the latter question will be as brief as that of the former, but instead of a detailed footing analysis, the student completes an entire structural design – a process beginning with determining design loads and ending with grounding them into the soil through the footing.

Prose Narratives

Because the focus is on the flow of the structural engineering process, the paraphrased engineering language is presented in narrative fashion. Mathematical developments within the text seldom exceed the complexity of simple algebraic equations. Using everyday prose, brief narratives are employed to develop concepts and present a view of the engineering process, such as the following:

"Your neighbor Bill has come to you with a problem. The contractor that built his house has used 2 x 8 floor joists to span fourteen feet and placed sixteen inches on center. The joists have already sagged more than 1 inch, and seem to be continuing to deflect. Bill has purchased some fourteen foot 2 x 4's and plans to jack the floor joists back into their original position. After the 2 x 8 floor joists are raised to their original position he plans to screw a 2 x 4 to the joist as shown. He also plans to screw the sub floor to the joists so that the plywood will act in conjunction with the beam. Bill wants you to tell him which orientation is most efficient for the 2 x 4's, and how much all this work will improve the situation" (Williams & Sattineni, 2002).

When several concepts are to be combined in analysis and design situations, the narratives can be real or fictitious stories specifically chosen or fashioned to demonstrate how the various elements of the engineering language are interrelated to solve a problem-at-hand. The efficacy of stories for conveying ideas is a time-honored tradition, and we might note the impact that parables (brief stories) used in the Bible has had in delivering important themes throughout the ages.

A similar educational situation exists where students are required to take a few semester courses of a particular foreign language, say French. They are not expected to emerge from their studies as fluent speakers of the language; while some may go on to do so, most will emerge with an experience of the basics of the language, and a sense of things *franchise*. The students experience the language through basic skills exercises centered on recognizing words and forming sentences, then they are presented with stories that incorporate these elements in a context that helps to provide a feel for the language. The story might, for instance, recount a fictitious episode in which Louise and Jacques are taking a train trip from Paris to a small vineyard in the French countryside.

Stories are powerful because they can be crafted to emphasize key lessons at hand while also providing a sense of how the inherent language is used. Stories help to invoke the imagination and so more mental effort is at work to grasp the nature of the dynamic flow of things. In the case of the foreign language story, the imagination can help to give the student a sense of what it feels like to be a French patriot, just as it can give a constructor or architect a sense of what it is to be practicing the art of engineering.

Accentuating Continuities

It is important to draw attention to the continuity of things and the power of analogy whenever possible. Consider the following narrative describing relationships among structural members and systems:

> "? we see how the simple beam moment to the arch rise/cable sag ratio, M/s, is used to determine the force, H, which acts along the axis between the supports of arch and cable members. We will see later in the book that for a beam of length, L, and stiffness, EI, the ratio of simple beam moment, M, to corresponding deflection, D, (deflection is the slight amount of sag caused by transverse load) is a constant given by $M/D = 10EI/L^2$

We will also discover later that the critical buckling load, which is the largest axial force that a straight column can support without failing by buckling, is given as $F_{CR} = 10EI/L^2$, the same as the ratio of M/D of a beam. Thus, all of the common structural elements, beams, cables, arches, and columns, may be studied by means of beam analysis. Don't be surprised if the same isn't true of entire structural assemblies" (Dishongh, 2001).

The importance of continuity is that it facilitates the dynamic flow that leads to the creation of new insights about structures and/or novel problem solutions. As it turned out, while working with the beam/cable/arch interrelationships above, the author discovered a new and elegantly simple approach for presenting the topic of slender column analysis and design called the Universal Column Formula (Dishongh, 2002). This presentation of slender column behavior seamlessly interrelates classical theoretical column analysis formulas with the practical design formulas found in current code specifications, offering educators and practitioners alike a new way to look at columns.

Stylistic Facets of the Paradigm

Determining the topical contents of a series of courses in structural technology is a straightforward task. There are many textbooks available in this area including (Shaeffer, 2002), (Dishongh, 2001), (Ambrose & Parker, 2000), and (Engels, 1984) to name a few. These works contain some or all of the important topics – the chunks and bits and pieces – comprising the language of structural technology. These topics need not be listed here, as the reader is probably familiar with the tables of contents of these texts.

The specific goals of different curricula will lead to an emphasis of some engineering topics over others. For instance, architects will tend to be less concerned with bridge engineering than construction managers and programs that focus on commercial and industrial construction will likely emphasize steel and concrete structures, while timber and masonry are more important in residential construction programs. This is no problem as there is more than enough information to meet the needs of everyone with more being developed every day, so like a popular snack chip advertisement says, "Don't worry, we'll make more."

How the bits and pieces are to be presented so as to bring forth the underlying dynamic flow – the art – of the engineering process is not so simple a matter. It matters less *what* is presented than *how* it is presented. The degree of care of the professor and the students, the style of the textbook, and the relevance of the intended learning outcomes have the most important influence on the quality experience of the art of engineering.

Professors and Students

Careful attention towards the subject matter on the parts of professor and students is of such primary importance that, without it, there can be no envisioning the art, let alone any appreciation for it. The professor of structural technology courses will usually have an academic and practical background in the fields of civil or structural engineering. The professor may be a member of the construction or architecture department with full-time duties teaching structural technology courses, but it is more common for the professor to be a member of an engineering department and have only part-time duties teaching structures "service courses" to non-majors. While volumes may be written comparing the merits of one of these situations over another, the quality of instruction is simply a matter of the care that the professor brings to the course material.

Equally as important as the care on the professor's part is the curiosity (careful observation) that the students must bring to the subject matter. To facilitate student interest, the professor will want to demonstrate the art of structural engineering as the natural course of things. Explanations of problem solutions should include lots of references to analogous situations already covered and numerous questions about the fundamentals being used. Students tend to worry over the bits and pieces and chunks – the formulas and the shortcut procedures and the categorizing of problem types – in order to develop sure-fire recipes for solving each category of problem. The professor must resist their desire for the material to be presented in a cookbook fashion, and take every opportunity to accentuate the continuities inherent to the flow of the engineering process.

Teaching Materials

The narratives that form the basis of teaching structural technology are not likely to make it to the New York Times' bestseller list, but they can be interesting and somewhat motivating for students, especially if accompanied with a physical model to help explain things. See (Arumala, 2002) for an interesting discussion of hands-on "student-centered activities to enhance the study of structures." The reader has no-doubt noticed the interest levels associated with coursework-related television programs that show from time to time on The Learning Channel or public television. The narrative-style of these programs is just about what the paradigms for teaching structural technology should be like, and videos about structures from these sources would certainly make fine teaching materials.

This also suggests the style of structural technology textbooks. Their authors should envision the textbook as a sort of transcript (with accompanying illustrations and/or photos) of a television series on structural engineering complete with additional exercises for the reader to practice some of the things discussed. The text should be self-contained, existing as a single volume to be used throughout all of the structures courses to facilitate the continuity from the beginning fundamentals to the last subjects covered in the curriculum. So when discussing the load on one of a cluster of piles beneath a tall bridge pier, the professor should encourage the student to flip back to eccentric loads and combined stresses to see how the loads combine to affect the critical piles.

There are certainly other instructional media available. The use of internet-based instructional materials to augment classroom lectures has been growing; for instance, see (Burt, 2002) for a report on preliminary results of one such attempt to enhance students in their structural analysis studies. The use of software to facilitate students' abilities in conceptualizing basic elements of the engineering language, such as moments of inertia, is reported in (Williams & Sattineni, 2002). And in the course of conducting a survey of structures courses offered by ASC construction educators (Chini, 1995), the following prophetic comment was noted:

> "There seems to be a need for better discipline-specific textbooks and more context based problems/solutions. A recommendation to develop a library of digital images of construction sites, problems, examples, etc., between ASC schools seems interesting and the Committee of Undergraduate Education should look into that "

Expected Learning Outcomes

Of course there are expected learning outcomes that serve to guide and to provide a goal for students. The questions and problems posed to students through homework exercises and course exams are the traditional means of directing and evaluating students. Emphasis on the continuities of things and using paraphrased structural engineering has implications regarding the amount of assigned work and the nature of the questions and problems that are covered.

If each new topic is developed in context with others that have already been covered, then the number of exercise problems required at various steps along the way need not be as large as for engineering courses where topics are usually presented as stand alone bits and pieces. In this way, upcoming narrative concept developments and stories build on previous lessons and so they will incorporate all of the elements just covered, and with emphasis on the continuity of things, the stories are crafted so that the most fundamental relationships keep recurring. The most fundamental of the elements of structures language – those that come first in structural technology courses – will receive the most repetition, ensuring that the traditional repetition role of homework drills is not bypassed.

For example, the concept of tributary areas and load paths should be introduced early in the first course of structural technology. Thereafter, all of the problems described in narratives can be presented in their fullest context by starting each narrative with the most basic engineering task – that of determining the loads on a structural element – as was exemplified in the footing example mentioned previously. Thus, in the course of things, the student will have applied the tributary load and load path concepts many times, just as students of foreign language apply new concepts to develop ever more complex sentences, which must still include the fundamental elements of subject and verb.

With a style of presentation that emphasizes continuities of things, exercise and test questions will tend to be quite broad in scope and usually quite interesting, especially compared to the focused homework and test questions typically posed to engineering students that require mathematically rigorous solutions. The significance of each newly introduced element of the structures language is better appreciated when placed in context to other related elements in a complete story. Because the engineering language elements have been paraphrased in structural technology, they require less time and effort to employ, and so many elements can be interrelated in a single question, with the result of fewer but more engaging questions required to demonstrate the flow of the structural engineering process.

Conclusion

The paradigm for teaching structural technology for construction and architecture presented herein is to some degree already employed in most structural technology courses – this is inevitable and well it should be. The attempt here has been to elucidate the benefits of maintaining a focus on the process of structural engineering when presenting the technology to students, and to establish this dynamic, this art, as the key point of focus. Department chairpersons and even departmental accrediting agencies of construction and architecture programs may wish to take note of issues raised here to perhaps give guidance for curriculum development that ensures optimal benefits from the limited time spent in the study of structural technology.

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