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Engineering and Construction Management: Leadership and Opportunity

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ABSTRACT: Construction engineering and management (CE&M) is a recent and successful academic area that continues to grow and evolve to meet the need for engineers who specialize in CE&M and design engineers who understand CE&M. The construction industry is constrained by many problems, and CE&M research removes constraints and advances the industry. Research is needed in describing construction processes; document form, quality, and packaging for construction; construction sequencing and documentation; construction worker training, safety, and ergonomics; controlling construction impacts; erection stresses, tolerances, and damages; and subcontractor problems. This research requires engineers who have strong backgrounds in CE&M, built on a solid understanding of engineering sciences and engineering design. CE&M engineers benefit from strong backgrounds in design engineering, just as design engineers benefit from CE&M knowledge. We must make sure the success of our CE&M programs does not damage the engineering base on which CE&M is built. As CE&M expands and grows, it must not be at the expense of strong preparation of students in engineering design.

Introduction

If this occasion consisted only of the presentation of the Peurifoy Construction Research Award, I would say a simple thank you, in appreciation to you, my colleagues, for the honor you have given me. But our purpose today is not to honor a person. It is to gather together on the annual occasion at which we most honor our profession. We ask one of our senior colleagues to direct his attention to the state of our profession in order to encourage a wisdom that we otherwise bury in our busy efforts to address the chaotic demands of our daily work. In that spirit I offer my remarks.

It is fitting that we do this within the American Society of Civil Engineers (ASCE), because here we have our common ground that differentiates us from others within our industry. That common ground is engineering. I have chosen to direct my remarks to the engineering base of construction engineering and management (CE&M), because it is engineering that establishes our position of professional responsibility and leadership in construction.

Basic Development of CE&M

My career happens to parallel the development and growth of CE&M programs in the United States, and I will describe some of these parallels to provide an early story line for comments that

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follow. I received my BS in architectural engineering from the University of Texas in Austin in 1961. I had not taken the only construction course offered, construction estimating, because it was taught only during the summer. As a junior and senior my plan was to join my father in residential and small commercial building construction in San Antonio after graduation.

Several of my undergraduate courses included elements of construction, as was typical of the time. I had two courses in building materials and methods and one course in specifications, all required of architects and architectural engineers and all taught by architecture faculty. The courses were primarily descriptive. I also took two architectural engineering courses that included construction, mixed with structural, mechanical, and electrical systems, and taught in engineering. Other core courses included six in structural engineering, two in geotechnical engineering and one design course in each of plumbing, heating and cooling, electrical, and lighting systems. All but two of these courses were required of all architectural engineers.

I became so interested in learning that I continued and completed an MS in architectural engineering in structural engineering at Texas. For this degree I took six structures courses, a mechanics course, a math course, and six hours of thesis on a structural materials topic, as my objective changed to becoming a consulting engineer. I took no graduate construction courses in CE&M. No courses in CE&M, much less a degree program, were available.

I was so excited by engineering teaching and research, that I accepted a Ford Foundation Fellowship to pursue a PhD. I was trying to choose between the structures programs at the University of California at Berkeley and the University of Illinois when someone told me there was a CE&M program at Stanford University. I had never considered studying construction, much less pursuing a career in teaching and research in construction, because I did not know it was available. So I was the third person, after Paul Teicholz and Jim Douglas, to study for a PhD in CE&M at Stanford. Stanford was still feeling its way in its CE&M PhD program.

So I just missed the launch of the first CE&M graduate programs in the mid 1950s—which along with Stanford included at least the University of Michigan, University of California at Berkeley, University of Illinois, and University of Missouri—and I arrived just as PhD study was becoming a reality.

In 1967 I returned to the University of Texas where I taught structures to undergraduates, taught the estimating course in the summer, and developed the first graduate courses in CE&M. At that time there were about six to 10 CE&M graduate programs at some stage of development. In 1973 I went to the University of Colorado in Boulder, to join Walt Meyer, who had become a contractor after getting his bachelor's in architectural engineering. He had later completed his MBA and joined the Colorado faculty. We established a master's program at Colorado. There were then perhaps 12 graduate CE&M programs.

In 1978 I joined the thriving CE&M master's program at the University of Michigan with Bob Harris. By then probably 20 schools offered a master's in CE&M, and several had awarded at least one PhD, as had Michigan. Within a few years we established a sound PhD program that complemented our master's program.

We now offer two master's degrees at Michigan. The Master of Science in CE&M that originated in 1954 now contains a research component, and it is recommended for those who have a PhD interest. Most of our master's students now take a Master of Engineering in CE&M,

which we created three years ago. It includes a Professional Practice Seminar in which student teams consult on a problem or project for an industry client. We also have a 75 semester-hour dual Master of Architecture and Master of Engineering in CE&M program and a 69 semester-hour dual MBA and Master of Engineering in CE&M program. We produce about two PhD graduates per year. In parallel 40 to 50 American universities now award master's degrees in CE&M within civil engineering, among whom at least 20 have awarded several PhDs.

Current Status of CE&M

There are several things to note in this evolution and growth we have witnessed for CE&M:

1. CE&M is still reasonably early in its evolution. It was pioneered primarily by master's programs starting about 40 years ago. Master's degrees became reasonably widespread starting 30 years ago. PhD programs started about 35 years ago and have spread primarily within the last 20 years. Undergraduate courses in CE&M have developed in conjunction with master's programs, over the past 40 years.

2. By default CE&M study was pioneered by faculty and practitioners who had strong backgrounds in engineering but no academic backgrounds in CE&M, for there were no CE&M courses and programs before them. For example, Clark Oglesby and Bob Harris taught engineering for many years before they became involved in CE&M: Clark in transportation engineering at Stanford and Bob in structural engineering at Michigan. Many of these professors taught a variety of courses before they began teaching CE&M. For example, Bob Harris has taught all typical undergraduate civil engineering courses except transportation and sanitary engineering. In addition to all structures courses, this included geotechnical engineering, materials, fluid mechanics, and hydraulic engineering. I expect Clark Oglesby had similar teaching breadth. Other engineers became CE&M faculty after significant careers in construction that followed graduate work in engineering other than CE&M. These people brought strong engineering backgrounds to CE&M, and they developed CE&M on that engineering base.

3. Each CE&M program went through birth pains that included convincing engineering faculty and administrators that CE&M is a vital part of civil engineering. Construction industry interest was a major factor in establishing CE&M education. Industry attention was primarily at the undergraduate level, but the research and graduate studies' nature of civil engineering faculties built the real foundation for each program on the master's level. This was in contrast with nonengineering construction programs, which focused on building undergraduate programs. Many nonengineering construction programs have recently launched master's and even PhD programs, to create an acceptable academic stature for their programs and faculty and to perform research in parallel with CE&M programs.

4. Growth of programs, once launched, was built very significantly on student interest and enrollment. Many civil engineering students have always been interested in construction. They welcomed the opportunity to study CE&M on their way to realizing their professional aspirations. Therefore, more and more engineers in construction have CE&M backgrounds and understand CE&M education and research. However, outside

financial support of students and research has not been of a magnitude warranted by the size and importance of our industry.

5. CE&M has become not just an accepted academic area within civil engineering, it is now a necessary area for any full service civil engineering program. Even a couple of years ago, there were still a few strong civil engineering departments without CE&M. But over just the last couple of years we have seen recruitment to establish CE&M programs at such schools as Northwestern University, Renssalaer Polytechnic Institute, Michigan State University, and Cornell University.

6. CE&M is now an accepted area for research. The National Science Foundation supports CE&M research, and such government laboratories as the Construction Engineering Research Laboratory and the National Institute of Standards and Technology perform CE&M research. Federal and state departments of transportation, safety, natural resources, and the environment increasingly support CE&M research. The National Cooperative Highway Research Program supports CE&M research, and CE&M is an activity within the Transportation Research Board.

7. The CE&M publishing horizon is unlimited. The ASCE *Journal of Construction Engineering and Management* is one of the most recognized and stable civil engineering journals, thanks largely to Bob Harris, and now our colleagues at Iowa State. Other journals, including several other ASCE journals, offer alternative opportunities. Publishers will publish any book we write.

8. We have a home in ASCE, particularly in its Construction Research Council. We no longer have to fight to be a part of ASCE or its committees. For a long time now, CE&M researchers have been a foundation of many ASCE committees, including several outside the Construction Division.

9. So, we can say CE&M education, research, and practice are a success. Of course, there will always be skirmishes and battles to fight but we have won the war.

Parallel CE&M Initiatives

We see these other major industry activities in parallel with the growth of academic CE&M programs and research:

1. A variety of national initiatives, most of which include strong university involvement and research or education elements, have improved the construction industry. These include the Business Roundtable Construction Industry Cost Effectiveness project, Construction Industry Institute, Center for Integrated Facilities Engineering, Construction Innovation Forum (CIF), Civil Engineering Research Foundation (CERF), National Center for Construction Education and Research (NCCER), and the regional Construction Users Councils.

2. An academic and professional structure in construction outside engineering has developed in parallel with CE&M, including

   - University academic programs called construction technology, building construction, construction science, or construction management

- Associated Schools of Construction in parallel with perhaps the ASCE Construction Research Council and American Society for Engineering Education
- American Institute of Constructors in parallel with ASCE
- American Council for Construction Education in parallel with the American Board for Engineering and Technology

Construction needs these programs, because it needs good people and leadership from all sources. To the extent nonengineering programs add engineering to construction management, they create stronger graduates.

3. There is a strong national need for skilled crafts in construction, shared by both union and open-shop contractors. This need created the NCCER, supported in common by the Associated General Contractors (AGC) and the Associated Builders and Contractors (ABC). In response to this need, community colleges provide civil engineering technology and construction technology programs for construction crafts. Building trades and contractors increasingly recruit minorities and women into apprenticeship programs. Building trades provide training to update capabilities of experienced journey workers. Still the need for skilled crafts continues to grow.
4. The industry is establishing programs that train and educate all management levels. This includes the AGC emphasis on supervisor training programs. The AGC, ABC, and subcontractor organizations organize professional seminars and management training programs for their members. Construction is a professional practice area in the National Society of Professional Engineers and its state affiliates. Continuing construction education has never been stronger.
5. More and more engineering graduates use their engineering education as a basic foundation from which they go on to MBA or law degrees, many in preparation to enter construction.
6. Many local initiatives are improving and advancing construction on a broad front. For example, in southeastern Michigan we have several interrelated initiatives that include the Construction Unity Board; Management and Unions Striving Together; and the Labor, Owners, and Contractors Summit; all working together to make southeastern Michigan the best place in the United States to perform construction. From the vibrations I receive in the industry, similar efforts are being made all over the United States.

Role of CE&M

From all this we can safely say that we in CE&M are a significant part of the overall game. But what do we in particular have to contribute? What makes us different? What makes us particularly important?

Yes, we and our graduates, on the average, are smarter than most. But that hardly establishes a beachhead, much less a position of leadership in advancing construction. Are we going to out-administer the MBAs? Are we going to out-motivate those scrapping for a place at the table? Are we going to out-politic or out-promote the many politicians or promoters in the industry? Are we going to out-compete in this most competitive industry? I think not. What we bring to construction is our engineering capability, which stands us above the other players. On this we either build our leadership, or we have no leadership.

For what is engineering but problem solving? It is problem solving that distinguishes engineers from others. Upon occasion we are asked how one can tell if they would like engineering or be a good engineer. The closest I can come to explaining engineering to nonengineers is to relate it to “word problems.” Everyone has faced word problems, at least in algebra. Some of us even seek out brainteasers and the like. To me engineering is word problems. A person who likes word problems will probably like engineering, and a person good at word problems will probably be a good engineer.

We are also sometimes asked if CE&M is engineering and if CE&M research is really engineering research. In fact, what is engineering? My simple answer is that engineering is whatever engineers do in which they use their engineering capability. My family and nonengineer friends say I think just like an engineer. Of course I do. I am an engineer and a good one.

An engineer approaches construction problems as an engineer, with capabilities only engineers have. Therefore, an engineer doing CE&M, including research and teaching, is doing engineering. An accountant approaches construction as an accountant, a carpenter as a carpenter, and a lawyer, I am afraid, approaches it as a lawyer. Each practices its own profession or trade, even when working on the same problem.

We in CE&M attack a problem as both construction engineers and construction managers. We must formulate and solve the word problem in a way that leads to a good solution from both perspectives. We must practice engineering to define and satisfy its technical aspects, and we must practice management to define and satisfy its business and implementation aspects.

Engineering in CE&M Innovation

As many of you know, I was a founder of the Construction Innovation Forum, and I led the development and chair the NOVA Awards for construction innovation. These are presented each year to innovations that have been proven to improve quality and cost effectiveness of construction. I was also heavily involved in developing the CERF Charles Pankow Innovation Award program, and I am one of its judges. I have reviewed several hundred construction nominations for these awards from around the world. In preparing these remarks I looked back over these nominations, to determine the impact of engineering on construction innovation.

The CIF presents the NOVA Award for innovation in any area of construction—it is not limited to engineering. However, in my quick review of more than 230 NOVA Award nominations, about 90% have engineering aspects. Of the 23 NOVA Awards given over the seven years of its existence, all but one involve engineering. The Pankow Award can be considered an engineering innovation award, so its nominations naturally include engineering. All of these successful innovations also include significant management aspects. Innovation is not complete without successful implementation, and successful implementation always requires good management. So construction innovation is typically a successful combination of engineering and management.

Engineering in CE&M Research

I have also looked back in some depth to determine the various parts engineering played in my past research. I recommend the same exercise to you. I found a few of my projects were primarily engineering, but most of my work combines construction engineering and management. And in most of my work, particularly in my primary research streams, engineering and management are inseparable. How does one separate engineering from management in research on construction project and process simulation? In competitive bidding and market analysis? In project controls?

By definition all of us in CE&M depend on both engineering and management. But it is the engineering that sets us apart from construction managers without it. Look at your own work. Could you have done it without your engineering base? And had you tried would the results have been as good, the professional and research contributions as strong?

CE&M Research Needs

For this talk I have identified several things I believe we have yet to do through research. As I describe these research needs in the following, please consider, Do they not all require an engineering understanding of the processes and materials and equipment that are the basic elements of construction? Though some problems at first may seem to lie outside engineering, who but those with strengths in both engineering and construction management can develop useful solutions?

1. Describing processes. We have no methods with which to describe a construction process. And there is a large variety of construction processes, each of which differs from project to project. For example, try to describe in a simple manner exactly how to frame a window, lay brick around a window (including interesting brick patterns), place rebar in a column or erect formwork or place concrete for a column or a wall or a beam and supported slab. Instead, we use a combination of drawings and words that leaves much to a combination of skill, craftsmanship, and imagination. This severely limits our capabilities to design, estimate, evaluate, control, and document construction processes.

2. Constructing the design. We construct from working drawings much as people did when we were born. Except now working drawings are generally not as good as they were then. What an amazing jump of faith, or is it of ignorance, we take across the gap between the output of architectural and engineering design and its realization on a site. We give craftsmen, some of whom have difficulty reading, two dimensional drawings that provide limited information of what it should look like when completed, and these craftsmen figure out how to do it, we hope. Of course, there is often the intermediate step to produce shop drawings for the fabrication shop, or more occasionally, erection drawings for use on site. However, this still leaves it to shop or site workers to figure out how to perform the work shown.

3. Document quality. We know different plans and specifications vary in their adequacy and accuracy for construction. How do we evaluate their quality? How can an architect, an engineer, an owner, or a contractor measure the quality of drawings, specifications, and other contract documents and instructions? Should we not have simple measures by

which we can judge performance in order to evaluate and control basic contract document quality?

4. Packaging documents for site work. In more cases than not we scatter information on each work item through various working drawings, specifications, test results, instructions, shop drawings, erection drawings, notes, consultant reports, architect and engineer approvals, product samples, and change orders. Rarely do those who determine how to perform work or who inspect work have easy, friendly access to all useful information. Should we not bring together all information useful to placing reinforcing steel at column lines B, D, 4, and 6 or for setting air handling units on the roof or for placing wire trays through the mechanical room or driving piles for the northeast corner? Should we not separate pertinent information from information extraneous to the task?

5. Sequencing construction. We sequence major activities using the critical path method (CPM). Upon occasion we go further. But we largely leave it to the site workers to actually sequence the work tasks done second by second, minute by minute, hour by hour, day by day. Upon occasion we check for interferences, most often only interferences in final location. But we pay little attention from an engineering or management standpoint to efficient, effective, functional sequencing.

6. Documenting construction. We document construction with photographs and videos, daily project reports, invoices, payment requests, time sheets, letters, etc. Sometimes we produce as-built schedules and as-built drawings. These provide valuable information, but even together they do not tell in detail what was done. Therefore, it is difficult to carry experience from one project to another or to analyze what happened on one project so we can improve it on another. We can determine cost or schedule variances, but we have little data with which to analyze what went wrong (or right) to help us fix the process or carry good methods to other projects. In other words, individuals may learn by experience, but we lack adequate methods to capture experience and transfer it from one person or project to another.

7. Construction worker knowledge. What should workers regularly carry in their toolbox of knowledge, and what should they learn for a specific project or task? In general, we leave craft and supervisor training to the crafts and industry. What makes a good craftsman? How can they be recruited, instructed, evaluated, and advanced? If it is they who select methods to perform work in a productive, safe, quality manner, what background and training should they have? Should it not include training in work planning, sequencing, inspecting, evaluating, documenting, and control?

8. Construction safety: The industry is comfortable with the objective of no lost-time accidents on a project, though most construction projects still only pay it lip service. Remember, an accident is an interruption of an orderly process, and only a few of the many accidents actually cause injury. Therefore, we accept many accidents on projects, hoping that none causes a significant injury. I suggest the proper objective is a zero-injury career and a zero-accident project. That is, no injuries during a worker’s career and no disruptions on a project that could cause an injury. My suggestion of a zero-injury career has met a positive response, though usually with an expression of, “Gee, I never thought

of that." It is an order-of-magnitude step beyond what we now do. Should it not be a primary objective against which construction processes should be judged?

9. Construction ergonomics. What do we really know about what workers do with their bodies and to their bodies? What are the short-term and long-term impacts of different crafts and methods? Which are good, which are bad, and how do we determine the difference? What kind and how much variety or mix of work is good, and how do we determine it? What impact does ergonomics have on short-term and long-term productivity? On recruitment and retention of good (or bad) workers? How do we design work so it can be performed in a cost-effective, quality manner and in a manner that protects construction workers?

10. Construction impact control. Construction, by its nature, is disruptive. It can be considered the ultimate in change. We tear out whatever was there and replace it with something foreign to the environment. With effort and luck, the finished product is an enhancement. However, the weeks, months, or years of construction exact their own toll that we understand and control all too little. Though we have ordinances, standards, codes, and reviews to satisfy, we have little base research to develop methods to estimate the impact or to select an acceptable level of disruption. Therefore, we either constrain projects too tightly or, more commonly still, cause too great an impact on the public and our environment.

11. Erection stresses, tolerances, measurements, and damages. Contract documents show or specify centerline or overall or nominal dimensions of the completed facility. Less often they also show capacity or output or function expected at completion. Construction must consider the process by which completion is achieved, which is itself not usually specified. What conditions during construction are reasonable, expected, and acceptable; and which cannot be expected to produce the specified or acceptable quality in the completed facility?

12. Subcontractor problems. We most often research general contractors and their relations with owners, but subcontractors perform most construction. What are the core problems and solutions of subcontracting and its various specialties?

Certainly, research has attacked parts of many of these areas, but there is still so much to do.

Engineering and CE&M

We have looked at the general state of CE&M education and some construction research needs. I now will address more specifically, with some concern, the roles of engineering and CE&M.

First, any intelligent person can learn business administration. That obviously requires no engineering. But an intelligent person must first learn engineering to understand facility design and construction fully. And only those who fully understand design and construction can provide the strongest project engineering and management leadership.

As CE&M faculty we have two primary objectives: (1) we provide in-depth CE&M teaching and research to engineers who are preparing for a CE&M career; and (2) we provide basic

CE&M to engineers in the design areas of civil engineering and engineers in other engineering disciplines who have an interest in constructed facilities.

When we add CE&M to a strong engineering education we add another dimension of professional leadership and opportunity. We must be careful, however, to build CE&M on a strong base of engineering courses and not to replace engineering courses with CE&M. Otherwise we destroy the basic foundation of engineering design and understanding on which CE&M leadership and opportunities must be built.

Undergraduate engineering programs are generally expected to provide breadth in math, science, engineering science, and engineering design. They may allow a few courses in an area to provide students a sense of depth, but breadth is considered more important in an undergraduate program than specialization. Those who wish to specialize further should pursue graduate study. Courses in CE&M displace other engineering courses. A required CE&M course provides breadth for all civil engineers. Two or three additional CE&M courses give appropriate depth for those interested in CE&M practice, and still allow for sufficient engineering outside CE&M. The same is reasonable for other specialty areas. More specialization in a bachelor's degree significantly limits engineering breadth and understanding.

Graduate programs have their own constraints. Many CE&M master's programs, including ours at Michigan, require no engineering outside CE&M. Some students take all their non-CE&M courses in business or architecture. Thus, if excess CE&M specialization occurs in a bachelor's program, we might grant CE&M master's degrees to students who have no more than one course in any engineering design area.

I have the same concerns for CE&M faculty. Some new PhD graduates from strong CE&M programs may have too little engineering outside CE&M and much less design engineering than earlier CE&M faculty who had fewer CE&M courses.

Master's and PhD students from foreign countries often have a stronger design engineering base than many United States CE&M students, because CE&M courses are not as available in foreign universities. Of course, as foreign universities establish CE&M programs, they will gain the same benefits and disbenefits as we.

So, we are increasing CE&M knowledge and capability in our industry, but often at the expense of other engineering knowledge and capability. Therefore, our CE&M graduates have basic math, science, and engineering capability beyond nonengineers, but they may not be as capable as engineers outside CE&M to analyze and understand the engineering side of construction. For example, an engineer who takes structures courses instead of CE&M courses can understand structural applications in construction, including materials and geotechnical aspects, better than an engineer who took CE&M courses instead.

This is also true for CE&M teaching and research. For example, I am much better prepared than most CE&M faculty to teach and research in CE&M related to structures because of my structures background. Mechanics and materials in my structures study also prepared me better for CE&M teaching and research in geotechnical and materials engineering.

Somewhat equal but opposite actions and reactions occur in design engineering teaching and research. Design engineering courses and research have always given too little attention to contracts, specifications, working drawings, engineering and project management, safety, and ethics. As CE&M programs develop, other faculty increasingly expect these topics to be covered in CE&M, and they neglect them in their own teaching and research even more than before. These are important losses because the products of design engineers are engineering contract documents, and design engineers have significant responsibilities to review shop drawings and changes, design temporary works, and perform on-site inspection.

Summary and Conclusion

Construction engineering and management is successful, and it continues to grow and evolve. The industry is working hard to improve and CE&M is a leader in that effort. There is much still to do. And those who can do it best have strong backgrounds in CE&M built on a solid understanding of engineering sciences and engineering design. But we must still raise an important question. As we expand and grow in CE&M, are we actually putting less engineering capability in the classroom and on the job site?

The industry needs design engineers who understand CE&M and engineers who specialize in CE&M. We have developed strong CE&M courses and programs to meet those needs. The industry is constrained by its many problems, and our CE&M research removes those constraints and helps the industry advance.

But let us not give so much attention to CE&M that we lose our perspective on the breadth of our industry and its overall needs. Just as design engineers benefit from CE&M knowledge, CE&M engineers equally benefit from strong backgrounds in design engineering. Let us make sure the success of our CE&M programs does not damage the engineering base on which CE&M is built.

I want to thank all of you for being here this morning. I am greatly honored to accept the Peurifoy Construction Research Award, because it comes from those whose good opinion I value the most, my colleagues in construction engineering and management.