Challenges in Civil and Environmental Engineering Education: Materials and Structural Systems

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Introduction

- As a society, we experience a time of dynamic change with economical growth, rapid technological development, issues of national security, and global economic competitiveness.
- In this process, engineers play an important role and these changes force the boundaries of engineering to expand.
- As educators, we need to respond to these changes and challenges.
In this context, the two initiatives on shaping the future engineering education:


The NAE identifies the trends and challenges that are likely to redefine the scope of engineering in the future. Among them are:

- Global population approaching 10 billion with a growing demand for diversity in the engineering work force
- The growing complexity, uncertainty, and interdisciplinary foundations of engineered systems
- The need for sustainability in view of population growth, industrialization, and environmental degradation
- Increased focus on public safety and security
- Rapid technological advances and concerns about their social and political implications
These complexities will certainly create enormous challenges to be faced by the society. As educators, we have additional and critical challenges to include the elements of such complexities in educating future engineers and to develop a well thought-out plan for creating a balanced and effective curriculum.
The Role of CEE

In view of these complexities some of the basic challenges faced by civil and environmental engineers may be categorized as follows:

- Expanding population and housing
- Deteriorating infrastructure
- Deteriorating environment
- National disasters and climate change
- Security of infrastructure and public
- Need for transporting more people and goods
Understanding these problems and designing sustainable solutions will require multidisciplinary and innovative approaches of applied science and engineering.

In this context the CEE curriculum will need to be transformed into one providing a fundamental understanding of the physical and social issues, and integrating knowledge from different disciplines for creative solutions.
Challenges in the area of Materials and Structural Systems will include to understand complex phenomena in multi-scale including levels of nano-, micro-, meso-, and macro-systems. Thus, in essence, a system’s approach will apply at several interconnecting levels.
Materials and Structures

Specific issues in the area of materials related to infrastructure:

- Multi-element systems
- Multi-material systems
- Material processing and design
- Smart materials
- Material durability
- Innovative and economical materials for repair and strengthening
From Nano to Macro

- Materials are made out of atoms
- Depending on the scale looked at materials, these atoms are “visible” or not
- Nevertheless, the atomic structure always plays an essential role in determining material properties (in particular under certain conditions)

- **Example:** Structure of a complex biological material (levels of hierarchies)

Example: Supersonic Fracture

Mother-daughter-granddaughter mechanism

Here: Elastic mismatch is $\Xi = 3$

$\Xi = k_0/k_1$

Potential energy field

Initial crack

Shear dominated loading

Buehler et al., 2005
A: Mother crack (primary)
B: Daughter crack (secondary)
C: Granddaughter crack (tertiary)

Multiple shock fronts are observed

Buehler et al., 2005

M.J. Buehler, Doctoral Thesis, 2004
Specific issues in the area of structures:

- Large-scale complex systems
- Mega-projects
- Earthquake resistant structures
- Strengthening and repair of structures
- Structural health monitoring
- Sensors and sensing systems
- Non-destructive testing (NDT)
- Adaptive structures
- Innovative tall buildings
- Life-cycles of structures
Far-field Airborne Radar NDT
Far-field Airborne Radar NDT

Far-field condition

Specimen
Styrofoam tower

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Far-field Airborne Radar NDT

Frequency-angle imagery
- Specimens Intact and CYLAD1
- X-band

Oblique incidence

Side without defect

CYLAD1, HH Pol., max = -5.09 dBsm

Side with defect

CYLAD1, HH Pol., max = -6.41 dBsm
Far-field Airborne Radar NDT

Range – Cross-range Imagery

- Intact and CYLAD1 specimens

Oblique incidence
New Fundamentals

Addressing and solving these challenging problems will require new knowledge and fundamentals, new technologies, and new kind of engineers.

The new kind of engineers will have to be knowledgeable of emerging new fields for a synergistic and productive multidisciplinary activity that will lead to innovation.
Emerging New Fields

- New materials and manufacturing processes
- Nanotechnology
- Advanced information technology
- Biotechnology
- Energy technologies (MIT Energy Initiative)

These fields will influence the future civil and environmental engineering and education of engineers. For example, understanding of materials and structural systems from nature will have a direct impact on creating new and efficient materials and structures through structure mimicking and novel designs.
Educating New Kind of Engineers

The challenges to the creation in an effective education system for the future engineers will include the following elements:

- Strong background in classical and new fundamentals
- Ability for synthesis and design
- Hands-on experience and active learning
- Integration of science and engineering
- Multidisciplinary perspective and knowledge
- Understanding of societal, economic, and environmental impacts of engineering
- Communication and team skills
- Appreciation of ethical context
Civil engineers have been known to build mostly buildings, bridges, tunnels, railroads, and dams. Today, we see an expanded mission for civil and environmental engineers to ensure that human environment we create is compatible with nature, and is sustainable.

Thus, materials and structural engineering education should be integrated with other dimensions, such as ecology, management and social and political processes.
Educating New Kind of Engineers (cont’d)

Structural engineers are faced on one side with the safety of the systems they design and build. They must also understand societal, economic, and environmental impacts of their creation. Thus, they have an expanded responsibility to society.

This aspect is well recognized by the following quotations from Herbert Hoover (1954) and Norman R. Augustine (1994).
“The great liability of the engineer compared to men of other professions is that his works are out in the open where all can see them. His acts, step by step, are in hard substance. He cannot bury his mistakes in the grave like the doctors. He cannot argue them into thin air or blame the judge like the lawyers. He cannot, like the architects, cover his failures with trees and vines. He cannot, like the politicians, screen his shortcomings by blaming his opponents and hope that the people will forget. The engineer simply cannot deny that he did it. If his works do not work, he is damned.”

– Herbert Hoover (1954)
“The Tacoma Narrows Bridge did collapse. So did the walkways in the Kansas City Hyatt Hotel. The Challenger’s explosion still reminds us that our skills, while extraordinary, are in the end subject to human errors.”

“…as engineers, our achievements are largely taken for granted and our occasional failures draw intense public criticism.”

– Norman R. Augustine (1994)
“Socioengineering...combines the elements of a traditional engineering education with far broader skills needed to prosper in the 21\textsuperscript{st} century, ranging from written and oral communications to political science and from economics to international relations.”

– Norman R. Augustine (1994)
MIT Academic Program

- Student comes to MIT
- 1st year: Core courses (General Institute Requirements, GIR)
  - Science, math, humanities, arts, social sciences chosen from a wide variety of courses
- 2nd year: Student chooses a major
  - Continue study to meet GIR
  - Begin departmental program
  - UROP (Undergraduate Research Opportunity Program)
- 3rd and 4th years:
  - Departmental program
  - Elective courses
  - Preparation for studying medicine, law
  - Minor program
  - Double degree program
  - UROP
GIR requirements: Total 17 courses

- Science
- Laboratory
- Restricted Electives in Science and Technology
- Humanities, Arts, and Social Sciences
Communication requirement:

4 courses as an integral part of undergraduate program

- 2 from humanities, arts and sciences (CI)
- 2 from major program (CI-M)
- Student must complete at least one course per year
- CI and CI-M courses are given in great details
MIT Academic Program (cont’d)

• Departmental program and unrestricted electives

• Program is scheduled each year with a normal load of 8 or 8½ courses. Degree requirements are completed within the equivalent of 32-34 courses.

• Graduation requires GIR courses plus 180-198 units beyond the GIR’s.
Science requirements: 6 courses

- Chemistry (3.091 or 5.111 or 5.112)
- Physics (8.01 or 8.011 or 8.012 or 8.01L, and 8.02 or 8.022)
- Calculus (18.01 or 18.01A or 18.014 and 18.02 or 18.02A or 18.022 or 18.023 or 18.024)
- Biology (7.012 or 7.013 or 7.014)
Humanities, Arts and Social Sciences-HASS requirements: Minimum 8 courses

• Distribution
• Concentration
• Wide variety of courses
MIT Academic Program (cont’d)

• Restricted Electives In Science and Technology (REST) req’t. 2 courses
• Laboratory requirements 1 course (12 units, or 2 courses 6 units each)
• Physical education requirement
  – 4 physical courses
  – Pass swimming test
• Independent Activity Period (IAP)
  – 4 weeks in January, between semesters
  – Variety of short courses are offered for credit or for knowledge
Rethinking the program:

- Undergraduate education is a key driver of change in the profession.
- Do new societal needs and realities require a reassessment of the CEE profession? There are new opportunities as well as new challenges.
- Could a change in emphasis increase the influence, visibility, and enrollment of CEE undergraduate programs?
- Should Civil and Environmental Engineering really be separate undergraduate programs within a single department? Or should they be variants on a common theme?
New CEE Academic Program (cont’d)  MIT

Program design constraints:

- Department should offer accredited degrees in both civil and environmental engineering (ABET requirements are different)
- Common sophomore year (students don’t decide specialty until end of sophomore year): Why?
  All students will appreciate connection between technology and environment.
- Program begins and ends with a shared design experience: Why?
  CEE students can learn how to work together to meet human needs in a sustainable way.
- Students appreciate context and need for “fundamentals”.

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A change in culture:

- Broader faculty participation in undergraduate education
- Less distinction between Civil and Environmental Engineering, more emphasis on sustainable use of technology, broader interpretation of career options and professional identity.
- More student-centered, hands-on design activities.
- Increased emphasis on design will require additional space, equipment, and staff. New resources must be found and existing resources reallocated.
## New CEE Academic Program (cont’d)  MIT

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**New subject**

- Behavior of Structural & Geotechnical Systems (18)
- Project Evaluation (9)
- **Structural & Geotechnical Design (12)**
- Unrestricted Elective (12)
- 3 HASS (36)

### Capping/Design (12)

1E total = 180 beyond GIR

1C total = 183 beyond GIR

(Thanks to D. McLaughlin for providing information on this section)
New CEE Academic Program

1.101 Introduction to Civil and Environmental Engineering Design     (1-3-2.5)
Project-oriented introduction to the principles and practice of engineering design. Development of hands-on skills, teamwork, and testing.

1.050 Engineering Mechanics I    (3-2-7)
Basic principles of mechanic to describe the behavior of materials, structures, and fluids. Open-ended structural and geotechnical engineering studio exercises and experiments with natural and man-made physical systems.

1.060 Engineering Mechanics II    (3-2-7)
Mechanics principles for incompressible fluids and their interactions with solid materials. Application and principles through open-ended studio exercises and experimentation.

1.018 Ecology I: The Earth System    (3-1-8)
Fundamentals of ecology, considering Earth as an integrated dynamic system.

1.020 Ecology II: Engineering for Sustainability    (3-2-7)
Ecological and thermodynamic principles to examine interaction between humans and the natural environment.
Forces Pushing the CEE Boundaries

- Developments in science and engineering within the discipline (new materials, new concepts and innovative designs, extensive software capabilities and computational tools)
- Increased complexities of infrastructure (multi-element, multi-material, large-scale systems) and increased responsibility of engineers for safety, security, environment and sustainability
- Requirement of multidisciplinarity and new developments in other fields (material science, electrical engineering and computer science, chemical engineering, biological engineering, etc.)
- Emerging fields
Some Thoughts

- 8 years to produce a medical doctor
- 7 (or 8) years to produce a lawyer
- ? years to produce an engineer
- “Four-year” program:
  - Paralegal
  - Paramedic
  - Paraengineer ?

“The four-year engineering degree must join the slide rule as an artifact of the past.”

– Norman R. Augustine (1994)
The entire curriculum and educational system should be revamped to center around a longer, more comprehensive program to bring the Civil and Environmental Engineering into the 21st Century.
MIT Campus

Dept. of Civil & Envir. Eng.