# AC 2007-986: CONSTRUCTION AS THE INTEGRATING ELEMENT OF A COMPREHENSIVE CIVIL ENGINEERING CURRICULUM

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# Construction as the Integrating Element of a Comprehensive Civil Engineering Curriculum

**Abstract**
This paper demonstrates how construction can effectively function as the integrating element of a comprehensive civil and environmental engineering curriculum. The United States Air Force Academy offers ABET-accredited undergraduate programs in civil and environmental engineering. Throughout these programs, construction is used to provide realistic experience, to teach project management, and to provide opportunities for multi-disciplinary capstone experiences.

As in many other engineering programs, students at the Air Force Academy spend the first two years of study taking many required courses. Before beginning their junior year, students majoring in civil and environmental engineering take a five-week summer course. The first two weeks familiarizes the students with civil engineering at an Air Force installation, followed by three weeks of intensive hands-on construction activities ranging from operating heavy equipment to building a wood frame house. This course provides a common construction experience similar to cooperative work or intern opportunities in other programs. The timing is important because it precedes the beginning of the junior year and therefore most of the engineering majors' courses.

During the remaining two years of study, which emphasize traditional engineering design, the summer field course serves as a common point of reference for learning the design theory behind the construction practices. In the senior year, students have the opportunity to take two design option courses in which they can add depth in one or two of four disciplines; construction, environmental, geotechnical, or structures. One or both of these design options will serve as a "feeder course" to the spring capstone course, forming a two-course capstone experience.

The final capstone course in the spring of the senior year is "Project Management and Contract Administration". In this course, students working in multi-disciplinary teams combine their expertise to function as the owner's team on a design-build project. They must define the project scope, perform conceptual design, estimate the cost, schedule the construction, and other tasks in creating a full request for proposals. Each project team must interact with a faculty member playing the role of the owner.

The last week of the course concludes with an intense and fun competitive event in which students can apply what they have learned. This event is loosely based on the Associated Schools of Construction student competition. The project teams are reshuffled and students must shift their perspective to playing the role of a design-build team competing for a contract. This new project is based on an actual, recently-completed Air Force construction project. With limited time, student teams respond to a project solicitation and then a request for proposal. They must present their project team, explain their project approach, complete a preliminary design, and provide a cost proposal and a detailed schedule. They must also make an oral presentation.

A variety of assessment tools have validated the learning in this curriculum and specifically in the final student competition. Throughout this comprehensive curriculum, construction provides the common context for integrating learning.

**Background**

The mission of the U.S. Air Force Academy Department of Civil and Environmental Engineering (the department) is to,

> *"Build and maintain nationally accredited undergraduate civil and environmental engineering programs with a clear linkage to the operational Air Force as we produce Air Force leaders of character."*[1]

As at many other universities across America, students at the U.S. Air Force Academy spend a majority of their first two years taking required fundamental courses to prepare them for engineering and to round out their curriculum. The Academy Bachelor of Science degree requires 146 semester hours as compared to the national average of 130.4 credits in undergraduate civil engineering programs.[2] This ensures that everyone, including engineering students, has a strong background in the basic sciences, engineering, humanities, socials sciences and leadership. This gives Academy graduates a head start in these areas of the American Society of Civil Engineers' (ASCE) proposed "body of knowledge" which will eventually be required to sit for the professional engineer licensing exam[3]. These first two years include some engineering courses, including a new "Introduction to Air Force Engineering" course currently in development.

**Summer Field Engineering Course**

At the end of the second year, all students majoring in civil and environmental engineering take a unique five-week course consisting of two parts. In the first part, "flights" of 15-20 students each spend two weeks at an Air Force base learning about both the operational and the civil engineering missions of the installation. In recent years, students have had the opportunity to experience aircraft operations as well as planning, engineering design, construction, facility maintenance, environmental restoration and preserving natural and cultural resources at installations such as Kadena Air Base, Japan, Hurlburt Air Force Base, Florida, and Elmendorf Air Force Base, Alaska. Once they return, the student flights move into a small tent city in the Academy's field training area. This simulates living and working in field conditions such as they will experience during future military deployments. During this three-week portion of the course, the students spend their days engaged in 21 different hands-on construction activities. The activities, ranging from placing concrete and paving roads to surveying and testing water quality, are each designed to tie directly to one of more of the traditional engineering design courses in their civil or environmental engineering major.[4]

For example, in the concrete beam activity students spend approximately an hour in a classroom setting reviewing what they learned in their first statics course about point

loads and shear and moment diagrams for a simply-supported beam. Then the students are given a limited amount of steel reinforcing and concrete forms and tasked to design the strongest beam they can to span a given length with a limited amount of concrete. Within a couple hours they must complete the design and build the forms, prior to the delivery of one-and-a-half yards of concrete. A week later, the students test their beams to failure to see how the actual strength compares to what they predicted.

**Figure 1 – Cadets Forming Concrete Beams during the Summer Field Engineering Course**

This is the essence of the summer field course, applying engineering through construction. Since this course comes before most of their engineering design courses, the engineering tends to be intuitive. But the students begin to understand the results of changing variables in their designs. They also recognize the impact of their designs on constructability since they must execute their own design. In other activities, such as the wood-frame house they build, the design has already been provided and the learning emphasis is on aspects such as integrating systems, safety, reading construction drawings and updating the project schedule. Together, these activities are the first construction experience for most students and form a literal foundation for the engineering courses to come.

**Design Options**

The Accreditation Board for Engineering and Technology (ABET) requires civil engineering programs to provide depth in at least four disciplines. At the Air Force Academy these four disciplines are construction, environmental, geotechnical, and structures. The summer field course provides an introduction to each of these disciplines, not just construction. In the junior and senior years, students take the design courses required for their civil or environmental engineering majors. These design courses are

very similar to comparable courses at other ABET-accredited programs across the country. In their senior year, students have the opportunity to add more depth to their major by taking two design options among the following:

Architectural Design*
Construction Project Management*
Foundation Engineering*
Earth Structures: Embankments/Slopes/Buried Structures
Solid and Hazardous Waste Facilities Design*
Design of Air Pollution Controls
Structural Design of a Multi-Story Building
Wastewater Treatment Plant Design
Water Treatment Principles and Design

Each of the courses with an asterisk, as well as Concrete Design (required of all civil engineering majors) can count as the first course in a two-course capstone sequence. Therefore, the course in Concrete Design, and the four other design options, serve as engineering design feeder courses for our multi-disciplinary final capstone course.

For those students who choose it, "Construction Project Management" provides a strong basis in materials, methods and project management from a builder's perspective.[5] This design option course covers construction materials, quantity take-off, construction methods, cost estimating, scheduling, bidding risk, site layout, constructability, safety, and environmental requirements during construction. The course also includes two field trips to construction sites. In a semester project, student teams use drawings and specifications from an actual project to estimate, schedule and plan the facility construction as if the students were competing for the contract. These students will become the construction "experts" in the final capstone course.

**Capstone Course**

In the last semester of their senior year, all civil and environmental engineering majors take "Project Management and Contract Administration". This course covers project scope definition, budgeting and planning, scheduling and design, engineering economics and construction administration, and is taught from an owner's point of view.

This course also includes a comprehensive semester-long project to prepare the students as future military officers to manage and administer government contracts with civilian contractors. Students are assigned to teams of four or five so that each group has students with as many different disciplinary backgrounds as possible. Each group will include at least one student that has taken a design option course in architectural design, concrete design, and construction project management. Many project teams will also include students that have taken foundation design, or that are majoring in environmental engineering or systems engineering management.

The student teams are paired with a faculty member playing the role of the project owner in a design/build scenario. The students must interview the owner and research the

project requirements to complete a scope definition. After each project submittal, the students meet with their owner to receive feedback and guidance. Next, they produce a conceptual project design including a site plan, building elevations, floor plans, and a parametric cost estimate. This submittal also includes a design narrative describing the foundation, structure, other major systems, environmental issues, constructability issues and sustainable construction practices. For the project work plan submittal, the student teams submit a detailed work breakdown structure and schedule. Finally, they correct and combine their previous work into a request for proposals (RFP), adding a summary of contractor responsibilities, submission instructions and conditions, and proposal evaluation criteria

**Culminating Competition**

During the final two weeks of the course, the students form their own new teams for a culminating competition and academic event. Four team leaders draft members based on their academic background and previous performance. Each team portrays a real design/build firm competing for a contract based on an actual project requirement. The students receive a solicitation for the project and begin learning about that project type and its site. To respond to a request for qualifications the teams must each research their firm and come up with a management approach and organizing structure. After a week of preparation in the classroom, the competition itself begins when the four "firms" submit their qualifications packages.

The competition, based loosely on the Associated Schools of Construction student design/build competition, kicks off at the same training location where the students began their summer field engineering course two years before.[6] This results in a kind of symmetry to the curriculum, beginning and culminating in the same location, with the bulk of the majors courses in between. The owner of the real project used for the competition briefs the firms on its scope and requirements and issues a request for proposal.

The student teams spend two hours the first evening and five hours the next day preparing a response to the owner's request. The proposals will include a narrative, structural design calculations, foundation design calculations, environmental design calculations, site and architectural conceptual design drawings, a design and construction schedule, a cost estimate and other supplemental information. The teams organize themselves into specialized sub-teams by discipline, but also work together to integrate their solutions into a complete design. During the competition, each team has the advice of one or two representatives from local design and construction industry who serve as sounding boards for the students' ideas. The teams can also use allocated time and funds to buy advice from faculty members playing the role of design consultants. After submitting their proposals, each team gives a half-hour presentation to an evaluation team that serves as an additional criterion for winning the contract.

While the proposals are being evaluated the students enjoy a barbeque before an award ceremony. Awards are presented for several categories such as best cost estimate and

best schedule before the overall winning team is announced. The owner also gives a briefing on the actual project's design and construction.


**Figure 2 – A Student Works with Industry Advisors during the Culminating Competition**

This culminating competition helps bring the curriculum to a close on a high note as the cadets look forward to graduation and commissioning.

**Curriculum Assessment**

The Department of Civil and Environmental Engineering uses a variety of tools to assess the success of its curriculum. These tools include traditional end-of-course critiques, student focus groups, a Cadet Advisory Council, an outside Academic Degree Committee and surveys of our graduates and their supervisors.

End-of-course critiques are required for all courses and instructors. They include questions about the course and instructor and the option to write in comments. Results are provided to the instructors and to course directors who check trends through longitudinal analysis.

The Academy's Center for Educational Excellence conducts focus groups of cadets as they near graduation to find out what aspects of our curriculum they have found to be the biggest positive and negative impacts. Students have listed both the summer field engineering course and the culminating competition as major positive events. Sophomores, juniors and seniors who volunteer to serve on the Cadet Advisory Council meet monthly during the academic year with the department head and other senior faculty members to give input, ideas and to ask questions about improving their academic experience and the curriculum.

The Academic Degree Committee visits the department annually to review the curriculum, to offer ideas and to ask questions. It is comprised of representatives from the Air Force Institute of Technology, former department faculty members, the Air Force Civil Engineering community that receives our graduates, and outside members of industry and/or academia.

We also conduct surveys of our graduates and their supervisors two years after graduation to learn how well prepared for their careers they were and how the supervisors rate their skills and knowledge.

The department uses input from all these assessment tools to continuously adjust and improve our courses, faculty and facilities. This way the curriculum is not static, but continuously being updated. All in all, these assessment instruments show a high degree of success in meeting our curriculum objectives. We also receive anecdotal evidence of the curriculum's effectiveness, such as the following excerpt from a graduate's email:

> *I just wanted to contact you to let you know that I have been using much of the material that you taught us in* (Construction Project Management) *and* (Project Management and Contract Administration). *I am working in the Engineering Flight at Hurlburt Field* (Florida) *and have already been involved with several types of contract arrangements. Your class gave me the foundation and preparation to be able to deal with the dynamics of each type of contract, whether it was design/build or CM. … I remember your emphasis on the high cost associated with late changes in the scope of a project and have unfortunately seen that play out. Anyway, I just wanted to let you that I have applied many of the lessons you taught us.*[7]

## Conclusion

The civil and environmental engineering curricula at the Air Force Academy provide high quality, ABET-accredited programs, as do many other engineering schools. One unique aspect at the Air Force Academy is that the construction discipline serves as the introduction and conclusion to the curriculum. In fact, the construction context is a constant thread woven through much of the curriculum. This approach not only works well academically, but it serves the students well in preparing them for the roles they will have as civil engineering officers managing projects for the Air Force, and for their engineering futures beyond military service.

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