# AC 2009-1242: INCORPORATING ASSIGNMENTS TO DEVELOP HAND-SKETCHING SKILLS IN THE CIVIL ENGINEERING TECHNOLOGY CURRICULUM

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# Incorporating Assignments to Develop Hand Sketching Skills in the Civil Engineering Technology Curriculum


## Abstract
Even with today's technological advances, hand sketching is still an important communication skill in civil engineering practice. To communicate effectively, civil engineers may need to quickly prepare hand-drawn sketches to document a given problem, communicate ideas during a meeting or to convey important information to colleagues. Unfortunately, at many schools, the emphasis on drawing skills has focused on computer aided drafting and design (CADD), at the expense of hand sketching. The result is unsatisfactory and sloppy sketching by civil engineering and civil engineering technology students and graduates. Although many engineering drawing courses no longer emphasize hand sketching, engineering educators can still provide opportunities for students to develop and practice hand sketching skills. This paper presents suggestions for incorporating hand sketching assignments in the undergraduate civil engineering technology curriculum and provides assessment results for several sketching exercises used by the author.


## Introduction
Hand-drawn sketches have traditionally been an important part of professional engineering practice. Sketching site conditions and layout during field reconnaissance, drawing free body diagrams for structural analysis, and preparing cross-sections and details from structural design calculations are common activities performed by civil engineers. Unfortunately, today's students are often not given adequate opportunities to develop hand sketching skills. In addition, the technologically savvy students of today are more comfortable using computer technology and digital cameras in the preparation of drawings and reports. While proficiency with CAD drawing software, MS Powerpoint,™ and digital cameras are important in engineering practice, hand sketching skills are still an appropriate and important communication tool. The American Society of Civil Engineers (ASCE) recognizes that the ability to communicate effectively is a required outcome for civil engineering education, noting that in addition to written and oral communication skills, graphical communication is also important when interacting with technical and non-technical individuals.[1]

## Importance and Use of Hand-Drawn Sketches
Kivett[2] notes free-hand sketching can quickly convey technical information to diverse audiences. At public meetings for proposed projects, clients often prefer free-hand architectural sketches rather than CAD drawings since hand-drawn sketches imply the design is not set in stone, whereas the public may perceive the project as unalterable when CAD drawings are used.[2]

According to Carrato and Kellogg,[3] although CAD drawings are used extensively in structural engineering, free-hand sketches are still used as part of the structural design process and are essential in communicating with drafting and construction personnel. Many new structural engineering graduates lack skill in preparing hand-drawn sketches and require guidance from senior engineers to develop good graphical communication skills.[3]

In geotechnical engineering practice, field sketches and cross-sections are a common step in the design process. It has been noted however, that the quantity and quality of geotechnical cross-sections have declined, as a result of recent graduates' lack of experience in graphical communication and an increased reliance on computers for drafting, analysis and design.[4-5] Hamel[4] states that sketching to scale the geotechnical site conditions with pencil and eraser allows time for critical thinking about the geotechnical conditions relative to proposed site development.

Even in education itself, use of technology by faculty has resulted in fewer opportunities for students to practice hand sketching. Classroom note-taking has traditionally helped students develop their hand sketching skills.[6] Transferring instructor drawn sketches from the chalkboard to their notes helps students develop their own graphical communication skills. Some instructors may not take full advantage of this, opting to use photocopied sketches or textbook drawings or MS Powerpoint™ handouts in class to save time and cover more material. Preparing a sketch on the chalkboard requires patience and skill; however, it provides students an opportunity to practice their drawing skills while thinking about the geometry of the problem as they learn.[6]

Rose[7] discusses the importance of graphical communication skills in engineering practice. Hand-drawn sketches are used in the engineering problem solving and the design process. Before an engineer can apply engineering principles to a design problem, they must first visualize the problem to be solved and the variables involved. Preparing sketches at various stages of the design provides a quick way to visualize the problem, consider design options and identify questions and uncertainties where more information is needed. Figure 1 shows a sketch by a structural engineer considering a repair option for a damaged load bearing wall in a parking garage structure. Before the proposed repair option could be analyzed and designed, the engineer needed to envision how the load transfer would occur. In other cases engineers are called on to graphically communicate ideas to clients or the public in a more formal but less planned way. Engineers may need to quickly explain a concept or address a question for a client or construction representatives. This could be during a meeting or in a field situation. Here the engineer may need to sketch on paper, a chalkboard or white board, a visual image that helps the recipient of the information better understand the concept or response to a question. Figure 2 shows a sketch prepared shortly before meeting with a client to illustrate how vibration isolation is provided by an existing drainage ditch between a proposed building site and an active railroad. Figure 3 shows a sketch prepared by a diver describing water currents in the area downstream of a dam. Details of a rock anchor installation sketched for a contractor performing a load test on a retaining wall are shown in Figure 4.

In addition to recent articles discussing the importance of hand-drawn sketches in civil engineering practice,[2-7] the engineering profession has also addressed the need for improved hand sketching skills. In January 2007, the Pittsburgh Section of ASCE held a one-day seminar on *Success with Sketching: Hand Drawing and Sketching in Civil Engineering*.[8] A number of engineering and geologic professionals with various levels of professional experience spent a Saturday in January 2007 attending this hands-on seminar and learning more about the importance of hand-drawn sketches and various techniques to prepare sketches used in engineering practice.

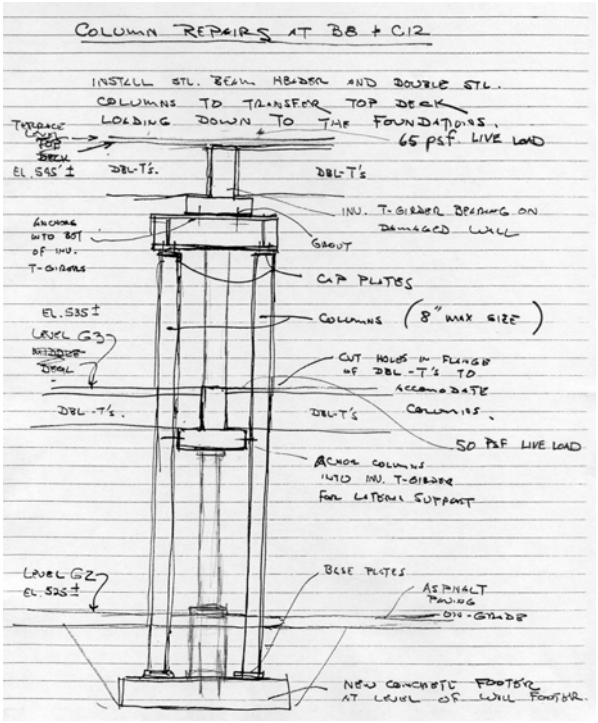


Figure 1. Sketch of structural repair option[7] (With permission from ASCE)

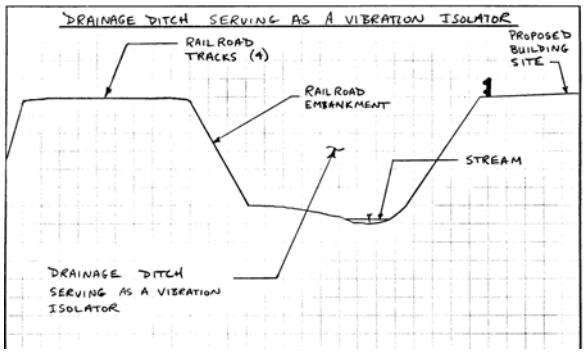


Figure 2. Sketch prepared prior to meeting to address client's concern[7] (With permission from ASCE)

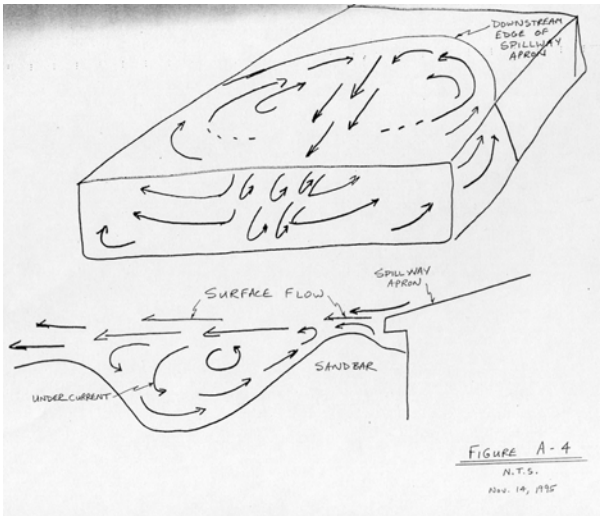


Figure 3. Hand-drawn sketch of water currents below a dam[7] (With permission from ASCE)

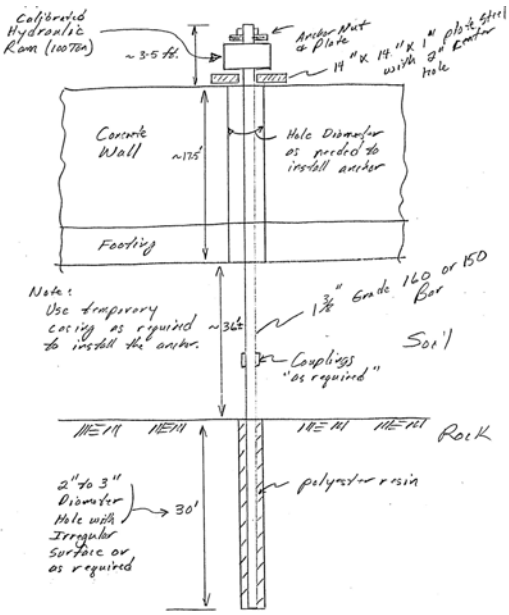


Figure 4. Sketch prepared for contractor showing rock anchor installation through retaining wall[7] (With permission from ASCE)

**Incorporation of Hand-Sketching Exercises in the CET Curriculum**

Since hand-drawn sketching skills are useful in engineering practice and students generally do not receive enough formal instruction in hand sketching, engineering educators can help students develop and improve their hand sketching skills by incorporating appropriate exercises or assignments throughout the curriculum. Some of the exercises and assignments used by the author will now be discussed.

**Chalkboard Sketches and Student Note-Taking**

The author uses the chalkboard extensively in teaching courses in soil mechanics, foundations, and structural analysis and design. In taking class notes, students are sketching free body diagrams, soil and foundation cross-sections, beam and column cross-sections, and sketches showing layout of reinforcing steel in concrete members, and structural floor plan layout and building cross-sections. When presenting material requiring complex sketches, handouts are entirely appropriate, but if the sketch is not too complex, a hand-drawn sketch on the chalkboard is used. This keeps students active in note-taking, sketch preparation, and the course content and discussion. Many times students will question the material, referring to the sketch, requiring further clarification on the board and in their notes.

**Student Homework Solutions at Chalkboard**

In structural steel design and reinforced concrete design courses, a recitation period is used for homework problem review and project work. As part of the course requirements students are required to present at least one homework problem at the board. This includes the drawing of a sketch related to the problem, including dimensions and important details. While these sketches are typically given in the textbook, the drawing of the sketch on the chalkboard gives students an opportunity to prepare a sketch at a larger scale and on a surface they may not use frequently. This may help prepare students for future conference room presentations where a quick sketch on a white board is needed. Figure 5 shows students presenting reinforced concrete design problems on a chalkboard.

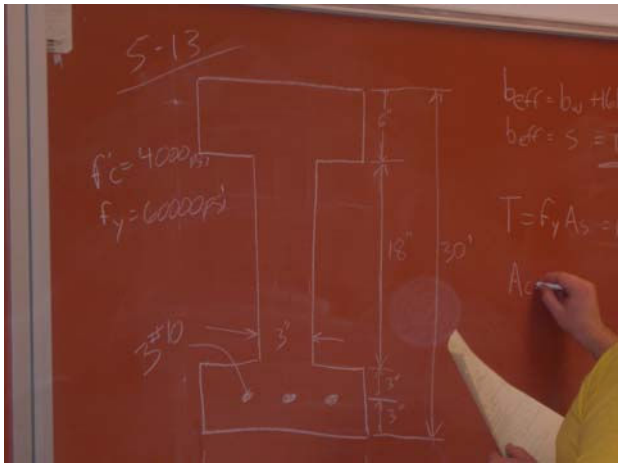


Figure 5. Student sketch on chalkboard used in problem solution

**Sketches of Laboratory Devices and Experimental Setups**

Another opportunity for students to practice hand sketching skills is in laboratory courses. In many cases, sketches may be too complex for hand sketching, and a digital photograph inserted in a report and labeled using editing software, may be more appropriate. However, simple sketches of laboratory setups, such as constant head and falling head hydraulic conductivity tests, can be prepared as part of the laboratory exercise. Sketch preparation requires attention to detail and measurement of various dimensions to properly define test variables.

**Homework or Exam Problems Requiring a Hand-Drawn Sketch**

Many times a textbook homework problem or an instructor prepared exam problem includes a sketch as part of the problem statement. It is possible to give problems which describe the problem (geometry, dimensions, properties, etc.) and require the student to prepare a sketch based on the information provided. This allows students to express their understanding of the terminology of the particular field and practice their hand sketching skills, as well. Figure 6 shows a student sketch of an angle tension member, based on a description of the problem given on an exam.

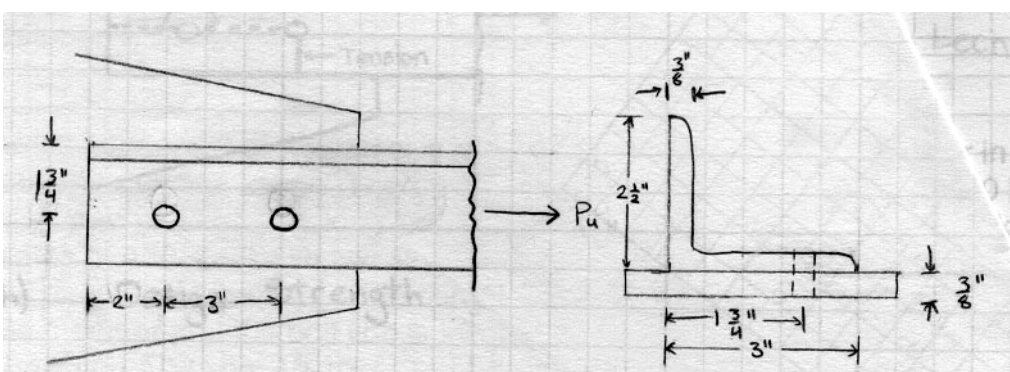


Figure 6. Student sketch of tension member connection based on written description of connection[7] (With permission from ASCE)

**Require and Give Credit for Well-Drawn Sketches**

Assignments in statics and structural analysis courses can require neatly drawn sketches for which points are assigned through a grading rubric as part of problem solution. It is difficult to analyze a truss or beam without sketching the structure and appropriate free-body diagram. Students should be required to include a sketch of the structure, showing unknown reactions. Some students carefully prepare problem sketches while others put little effort into sketch preparation. By assigning a portion of the assignment grade to the completeness and quality of the sketch, development of better hand sketching skills can be encouraged. Requiring students to use engineering paper will also allow free-hand sketching using the grid lines on the paper, rather than always depending on a straightedge. Figure 7 shows a student prepared sketch used in a virtual work problem to determine truss joint displacements.

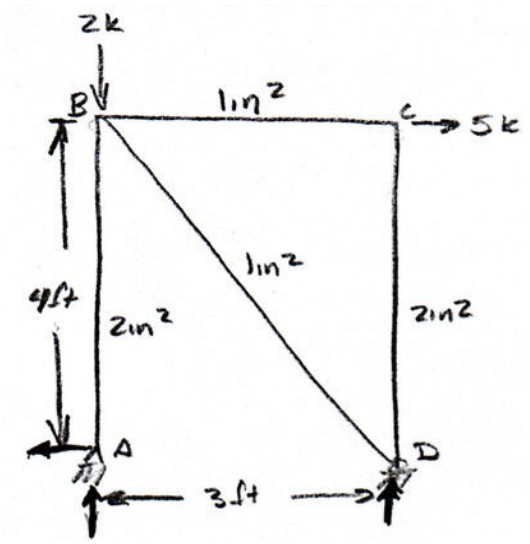


Figure 7. Student free-hand sketch of truss prepared as part of problem solution

**Structural Design Sketches**

Structural analysis and design often results in solutions which will be communicated from the design engineer to draftsperson through a hand-drawn sketch showing structural details of connections, building layout configurations, reinforced concrete dimensions and reinforcing layout and details. In structural engineering courses, instructors can use assignments which require not only a numerical solution, but also preparation of a sketch showing the results of the design process, as would be prepared for drafting. In the author's reinforced concrete design course, design problems often require preparation of design sketches showing dimensions and reinforcing details, as would be prepared for drafting purposes. Figure 8 shows a typical design sketch for a reinforced concrete beam design problem.

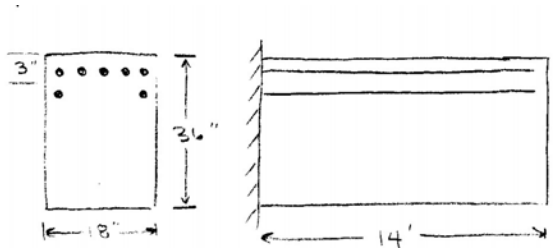


Figure 8. Student sketch for reinforced concrete beam design problem

**Geotechnical Cross-Sections**

Assignments can also be used to develop skills in geologic cross-section development and understanding of site geology.[7] Working in teams, students prepare a geotechnical exploration report for a proposed building to be constructed at a given site. From the author's consulting experience students are provided with a site plan for a proposed project and logs of soil borings. From this information, class discussion focuses on which cross-sections are most beneficial for characterizing the site geology, relative to the proposed development. Students often want to develop their cross-sections on the computer, especially those with considerable CAD experience. When this is allowed, students often interpret the assignment as an exercise to practice their CAD skills and focus too much on developing a perfect drawing, rather than a learning experience to appreciate the variability, uncertainty, and significance of the geologic conditions at the site.[7] Requiring cross-sections to be sketched by hand allows students to think about the variability of the geologic deposits at a site, as well as the characteristics of the soils present, relative to the proposed development. In another assignment, students sketch cross-sections for assessing the stability of a proposed cut slope. Figure 9 shows typical hand-drawn cross-sections for a building project and a proposed cut slope.

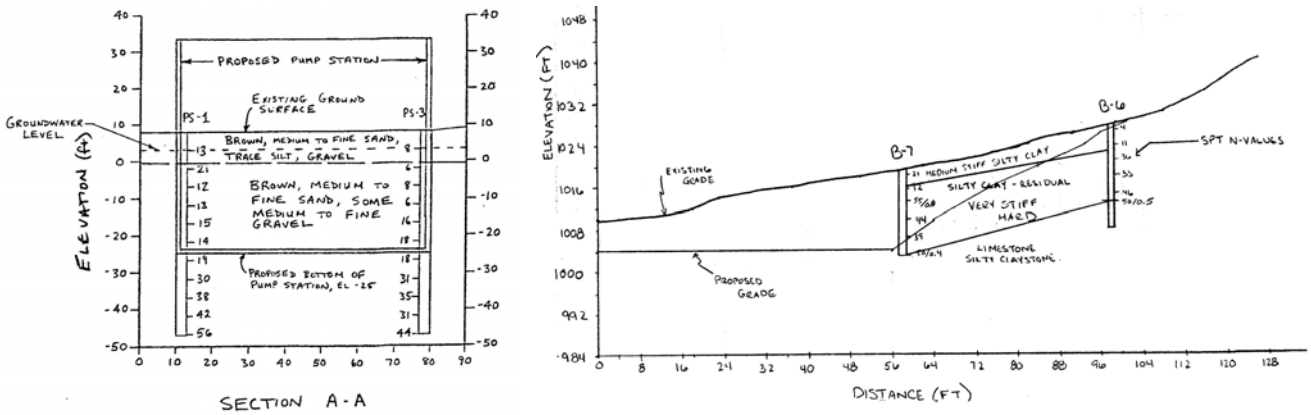


Figure 9. Hand-drawn geotechnical cross-sections[7] (With permission from ASCE)

Recommended guidelines for the preparation of geotechnical cross-sections are as follows:[4]

1. Geotechnical-cross sections should be sketched by hand using pencil and eraser on sheets of grid paper.
2. Cross-sections should be large enough to adequately show and describe significant geotechnical conditions. Equal horizontal and vertical scales are preferred to properly represent geometric relationships. If needed, sections with exaggerated vertical scales may be sketched subsequently.
3. Cross-section locations should be shown on plan drawings and both the plan and cross-section should show scales preferably in graphical form.
4. The cross-sections should extend sufficient distances to depict conditions of importance to the project and show any known existing and proposed structure locations and elevations through which the cross-section passes.

As with any assignment of this nature, providing adequate guidelines and examples will help students prepare better quality submissions.

**Field Assignments: Observation, Gathering Information and Sketching**

Field sketching exercises for undergraduate students are another way to help students improve their sketching skills.[7] Field observations are noted as being very important in the practice of geotechnical and structural engineering.[9] What is observed in the field is not always documented well enough to be remembered later. Engineers may often return to the office thinking the field conditions are well understood, only to find that although what was being done in the field was observed, many details were forgotten and a return trip is needed to further observe and document the work.[9] Peck[9] emphasizes the importance of observation and preparing careful field notes and sketches, in order to fully observe and understand the field conditions.

Today digital cameras enable engineers to obtain an instant image and may save an engineer from making a return trip to a site. They do not, however, provide actual measurements, nor are they able to view every angle. Rose[7] discusses an experience as a junior engineer inspecting the condition of an unused steel smokestack and foundation at an old industrial facility as part of a property transfer. As is often the case, no drawings of the smokestack were available. Under the direction of a senior engineer, the junior engineer visited the site observing the plumbness of the smokestack and the condition of its foundation. Missing brick on the interior lining of the stack and cracking of mortar between brick on the outside of the foundation were noted. Photographs and measurements were taken and field sketches prepared. After returning to the office and reviewing the field sketches, photographs and measurements, the presence of some cracking prompted the senior engineer to ask if any soundings of the brick had been made to detect hollow sounds in the foundation. Since this was not done, a second trip to the site was needed to perform this task. When preparing the final letter report for the project, a "clean" sketch from the field notes and sketches was prepared, only to find that a key measurement was missing. A third trip to the site was necessary to obtain this missing piece of information. Through this example, Rose[7] conveys to the students the importance of preparing complete field notes with detailed sketches and obtaining adequate measurements and photographs. Figure 10 shows one of the field sketches of the smoke stack foundation and a final sketch that was presented to the client in the letter report.[7]

Sending students out to construction sites to observe construction activities may not be possible due the safety and liability concerns. Students can be assigned to observe engineering conditions in other ways. Masters and Engle[10] discuss the use of "around town" assignments to improve an undergraduate statics course. Students are to find an example of a course concept in the real world, take photographs or prepare sketches and provide a written discussion of how the concept is illustrated in their example. Examples included finding something that represented a vector and looking at support conditions for a structure and sketching an appropriate free body diagram. In a less formal way, the author has asked students to look for different structural elements in the local community. These included looking for a cantilever beam in the form of shopping center signs or electric transmission line poles and noting the base conditions used to resist moment, or looking for threaded tension rods often used with architectural awnings, and looking at connections and members in local truss bridges.

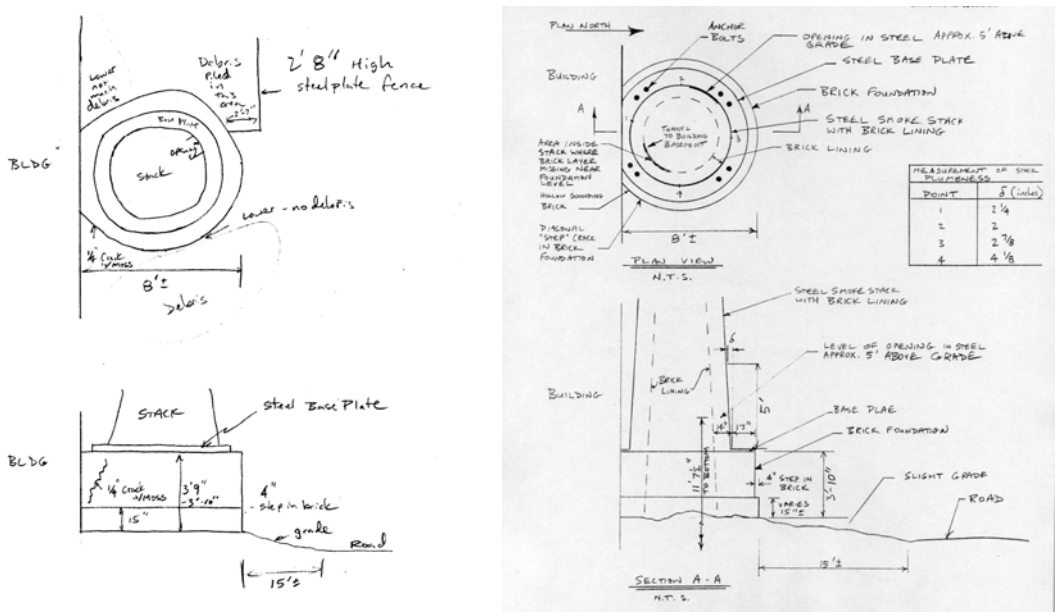


Figure 10. Field sketch and final sketch of smokestack foundation[7] (With permission of ASCE)

Assignments requiring field sketches and approximate measurements can be used to improve sketching skills and to help students develop approximation skills, as well.[7] In both engineering practice and student assignments, actual measurements may or may not be possible due to accessibility and safety concerns. Having students practice approximating distances and dimensions is a worthwhile activity that should be encouraged as part of such assignments.[7] Engineering students often lack a sense of proportion regarding the size of engineering structures.[9]

In a structural analysis course, groups of students are assigned to observe and sketch a structural element of a local structure.[7] At the local grocery store, students observe the roof support system and main girder. The roof is supported by bar joists bearing on a cantilever (Gerber) girder.[11] Students estimate the column spacing, the spacing of the bar joists applying load to the girder, the location of the splices in the girder, and the type of connections between the girder sections. The grocery store is contacted before students are given the assignment, and all dimensions are to be estimated based on pacing on the grocery store floor. Later in the course, assignments address the advantages of this girder system vs. simply supported spans from column to column.[7]

Similarly, an assignment requires students to observe and sketch the main girder of a nearby three-span continuous bridge.[7] They discuss the differences in the connections between the girder sections for the continuous bridge and those used in the cantilever girders of the grocery store. After the assignment, class discussions address the difference in moment transfer capabilities of the two different connections, as well as the fact that the splices in the continuous girder are located near points of minimum moment. Students also estimate the span lengths but pacing or measuring is not allowed due to safety concerns. Span estimates are based on their knowledge from their transportation course on typical traffic lane and shoulder widths and how many lanes and shoulders pass under the bridge. Figure 11 shows student sketches of the cantilever girder and the continuous girder.[7]

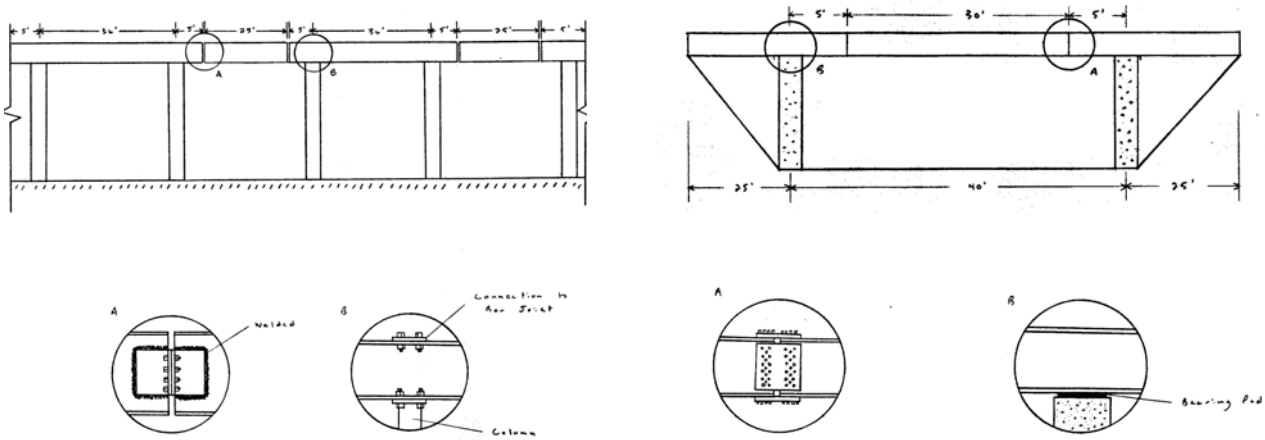

Figure 11. Student sketches of cantilever girder and continuous girder with connection details[7] (With permission from ASCE)

For assignments involving the preparation of field sketches, Rose[7] notes that providing some general guidelines promotes quality sketches and helps students understand what is expected. Appropriate guidelines for field sketching assignments are as follows:[7]

1. Students should use field books to record notes and sketches. These can usually be those purchased for surveying courses.
2. Like surveying, the location, date and time, those present and the weather conditions should be recorded.
3. Sketches should be made neatly, with a straight edge if appropriate and notes should be clear and easy to read.
4. Measured or estimated dimensions should be shown with appropriate units indicated.
5. Sketches can be redrawn on engineering paper from field notes, but a copy of the field book pages should be submitted with the final sketch.
6. Student discussions related to observations should typically be typed and could be in memorandum format with the sketch attached.

**Senior Capstone Design Courses**

Senior capstone design courses provide an opportunity for instructors to include exercises for students to further develop their hand sketching skills. At the author's institution, the senior capstone design course sequence is split over two semesters and includes a 1-credit senior project proposal course and a 3-credit senior project course. Most projects involve local sites where field reconnaissance, surveying, and soil sampling are possible. Field sketches can be required showing prominent features, surveying instrument locations, and approximate locations where soil samples were obtained.

One potential hand sketching exercise is related to landscape architecture and site development and layout. Using a USGS or other topographic map of a site, students can study the site topography, site access, and other nearby features. Then, using a sheet of tracing paper over the map, they can sketch a preliminary layout for the site, including site boundaries, points of access

and traffic flow on the site, undesirable areas such as steep slopes or wetlands, and focal points for the property. Figure 12 shows an example of using hand sketches on tracing paper as part of developing a conceptual plan for a site.

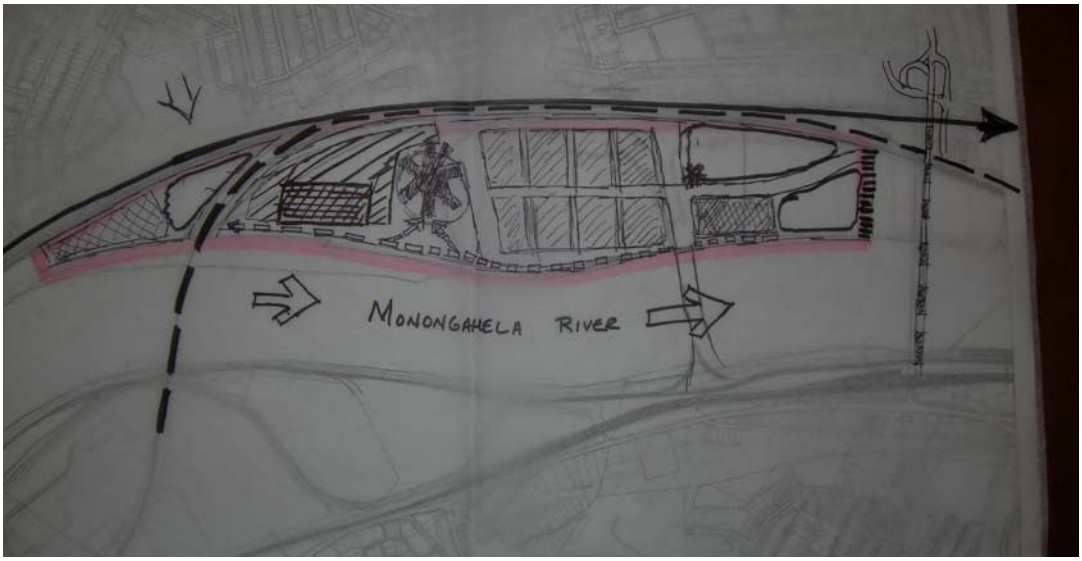


Figure 12. Tracing paper sketch of conceptual site development plan[8]

Another possibility is for student teams to maintain a journal to document team meetings, design discussions and decisions regarding the project. This is common in senior design projects in mechanical engineering technology (MET).[7] Figure 13 shows some MET student design sketches for senior project.[7]

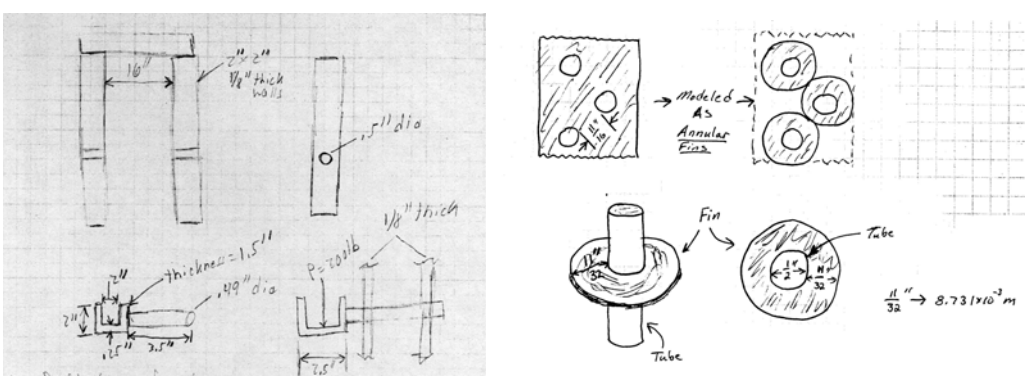


Figure 13. Design notebook sketches of mechanical engineering senior design students[7] (With permission from ASCE)

Meetings of senior project teams, during both the proposal course and the project itself, can allow experiences for students to show their hand-sketching skills. Meeting in a conference room, faculty can ask student teams to explain or clarify design concepts or details using white boards or chalkboards. During the current semester, one senior project group is designing a campus baseball stadium and the author observed the student team vigorously discussing the

conceptual design in a student lounge. One of the team members used the chalkboard in the lounge to illustrate his concept for the stadium layout to his colleagues. On another occasion, the same team used the chalkboard to illustrate the structural support system for the stadium roof. Both chalkboard sketches are shown in Figure 14.

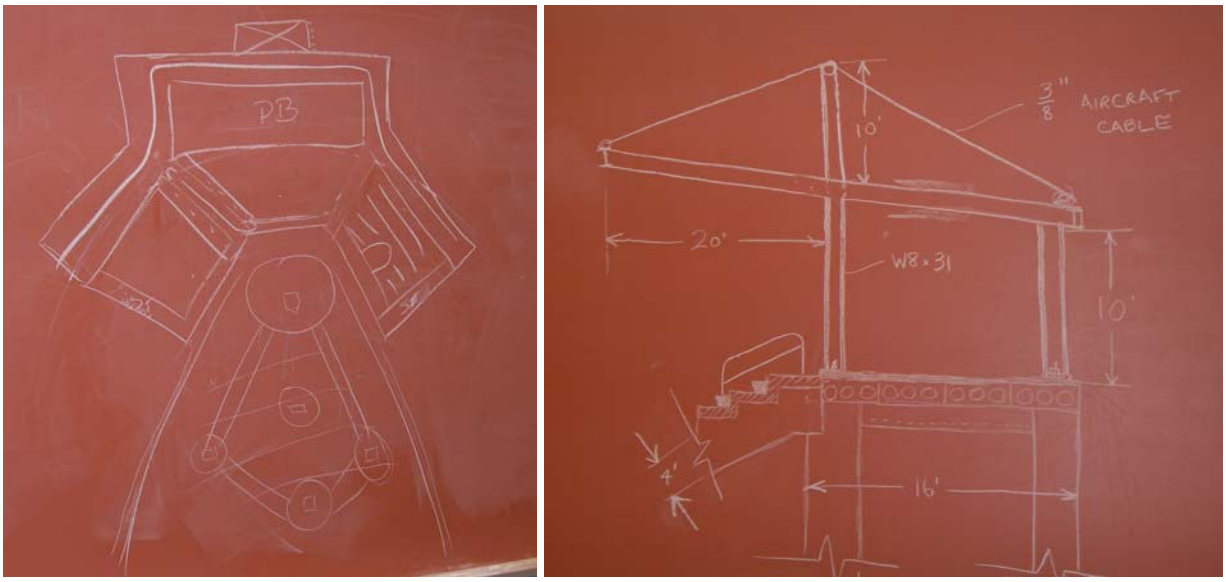


Figure 14. Senior project sketches prepared during project discussion in student lounge

**Assessment and Evaluation**

Classes or assignments involving hand-drawn sketches have been assessed for their effectiveness. In an undergraduate course in Soil Engineering, where hand-drawn sketches and geotechnical cross-sections are used, students were surveyed pre- and post-course to determine if their hand-sketching skills were improved by the course assignments. Table 1 summarizes the results.

**Table 1. Student Assessment of Learning for CET 1131 – Soil Engineering**

0 = I have no understanding or have never heard of the concept listed.
5 = I fully understand and have mastered this concept completely.

| Course Outcome | Course Entrance | Course Exit | Change |
|---|---|---|---|
| Communicate effectively using sketches | 2.94 | 4.67 | 1.73 |

Evaluation of the results suggests students perceived their abilities to communicate effectively using sketches to have improved as a result of the course exercises.

In a structural steel design course, the quality of structural design sketches has been assessed as part of a steel design assignment. Table 2 summarizes the results.

**Table 2. Assessment of Structural Steel Design Sketches**

| | Quality of Cross Sections Sketched | Dimensions Provided | Sketch of Column Orientation | Overall Presentation |
|---|---|---|---|---|
| | 0 = poor or missing | 0 = not provided | 0 = missing | 0 = Basic |
| | 3 = average | 3 = average | 3 = average | 1 = Average |
| | 5 = very good | 5 = very good | 5 = very good | 2 = Outstanding |
| Average Value | 4.3 | 3.6 | 3.2 | 0.9 |
| Percentage | 86% | 71% | 64% | |
| Standard Dev. | 0.99 | 1.79 | 1.25 | 0.62 |
| High Score | 5 (100%) | 5 (100%) | 5 (100%) | 2 |
| Low Score | 3 (60%) | 0 (0%) | 0 (0%) | 0 |

For Assessment of Overall Presentation: Basic (3 submissions or 21.4%)
Average (9 submissions or 64.3%)
Outstanding (2 submissions or 14.3%)

Evaluation of the assessment results shows that average student scores of 86 and 71 were above 70% for *quality of cross sections* and *dimensions provided*. For the *sketch of the column orientation*, the average score was 64%, which is below 70% suggesting that students may have difficulty understanding the importance of the column orientation on the behavior of the structure.

In a reinforced concrete design course, a footing design assignment included preparation of a sketch showing footing dimensions and reinforcing layout. Assessment of student sketches is presented in Table 3.

**Table 3. Assessment Summary for Sketch Associated with Footing Design Assignment**

| | **Assessment of Footing Design Sketch (10 points)** |
|---|---|
| **Average** | 7.21 (72.1%) |
| **Standard Deviation** | 1.89 |
| **High Score** | 10 (100%) |
| **Low Score** | 4 (40%) |

Evaluation of the data shows that average student scores for the footing sketch were above 70%. However, low scores were 40%, indicating that some students prepared sketches that were well below expectations and further exercises, examples and reinforcement is needed to improve student skills in preparing hand-drawn sketches.

In the author's experience, the quality of student sketches increases if students know points are associated with sketch preparation and quality. Many students will take pride in their work and make an effort to prepare quality sketches. A few students will consistently put minimal effort into their course work and their sketches will usually be poor, reflecting their poor attitude toward their studies. The author also believes that providing examples of good (and maybe bad) sketches helps students understand assignment requirements and instructor expectations.

## Conclusions and Recommendations

For many practicing civil engineers, hand-drawn sketches are still an important part of the engineering analysis and design process. Today's engineering and engineering technology students often lack adequate experiences and skills in hand sketching. Assignments and exercises can be incorporated into the undergraduate engineering and engineering technology curriculum to provide training and development of hand sketching skills. Improved student performance on assignments stressing hand-drawn sketches will result if a portion of the assignment grade is earned for sketch quality. In addition, educators should provide clear guidelines or expectations for hand-drawn sketching assignments. Providing examples and discussing what makes a sketch good or bad may also lead to improved student sketches. Engineering educators have a number of options for incorporating hand sketching exercises into the curriculum. Planned properly, these exercises can help students develop and improve their skill at preparing sketches and communicating information graphically, to better meet the needs of industry.

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