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CIVIL ENGINEERING GRAPHICS

COURSE NOTES FOR CIV 235S

UNIVERSITY OF TORONTO

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Both pdf files are formatted for printing on letter-sized paper (8.5 by 11 inches), landscape orientation, two-sided printing, short-edge binding.

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First printing, January 2020

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Part I

Conduct of the Course

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About This Document

This document contains the course notes for CIV 235S *Civil Engineering Graphics* at the University of Toronto. This chapter gives a brief description of the content of these notes and how to work with them.

1.1 Reading this Document

This document is available in pdf format. The full version (approximately 360 MB) has maximum resolution for all images. It will enable maximum zooming of the images when viewed on-screen. It is available at the link provided ▷ . The reduced version (approximately 10 MB) has images with less than maximum resolution. It is suitable for printing and for viewing at 100% zoom. It is available at the link provided ▷ .

Click this text to download the full version of the course notes.

Click this text to download the reduced version of the course notes.

When either version is viewed on a computer screen using most of the common pdf viewers, the hyperlinks will be active.

Both pdf files can be printed out on letter-sized paper, landscape format. If you are printing double-sided, make sure you select the option that will enable you to bind it on the short (vertical) edge and turn the pages normally. Your printer driver will generally have an option such as “short edge binding” or “flip on short edge” that will need to be selected.

It can also be read on-screen, which enables the use of a rich set of hyperlinks. *Internal links* have been provided for all references to chapters, sections, figures, and tables. These references are shown in blue. Clicking on these references will take you to that location in the document provided this functionality has been enabled by your pdf viewer. *External references* have been provided to material located on external websites. These references are given in green.

1.2 Main Elements of Content

This document contains the following types of material:

1. Administrative information on the course, including relevant course requirements ▷

   This material can be found in Part I.

2. Explanatory material on the *principles* underlying drawing in engineering practice, the *methods* of drawing that will be used in the course, and *applications* of these methods to the practice of civil engineering ▷

   This material can be found in Parts II, III, IV, and V.

3. Descriptions of all the drawing exercises to be completed by students during class ▷

   This material can be found in Parts VI, VII, and VIII.

4. Useful reference material ▷ . Many of the objects that will be drawn in this course are real engineering objects, including bridges and bridge components. It is recognized that most students who take this course will have had little or no formal exposure to complete works of engineering. The reference material thus includes brief descriptions of the engineering objects that will be drawn in the course.

   This material can be found in Part IX.

5. The course Drafting Standards ▷ . These standards prescribe requirements that must be followed in all drawings done with CAD in this course.

   This material can be found in Appendix A.

1.3 Getting Started with these Course Notes

It is not necessary for students in CIV 235S to read all of the material in this document in order, cover to cover. The following items will be most helpful for students in the initial stages of the course:

1. Chapter 2 contains material normally contained in a course syllabus, including a general description of course content and how the course will be delivered, as well as the composition of final mark.

   This chapter also contains Table 2.2 ▷, which gives, for a given date, a reference to the chapter in which the class activities for that date are described. For class on a given date, just find the chapter number in the corresponding location in the table. Before class, read this chapter and complete all the tasks under the heading *Preparation*.

   See Section 2.4.

2. Chapters 3 and 4 give general requirements regarding the conduct of class periods for freehand drawing and computer-aided drawing (CAD) respectively. The conduct of these class periods differs significantly from tutorials and labs students have had thus far in other courses. This means that a good understanding of the material in these two chapters prior to the first drawing classes will help to maximize the chances of success.

3. Chapter 5 gives a brief introduction into how drawings are used in the engineering design process. Reading this chapter will help students to understand how the material they will learn in this course is related to their future engineering practice.

1.4 Revisions

Although all best efforts were made in the preparation of these course notes, they may contain errors that will make it necessary to revise them during the academic term. Any revisions made during the academic term will be made for the sole purpose of correcting errors. The class will be informed of all significant revisions.

2
General Course Information and Requirements

2.1 Overall Description

This course has the following two primary objectives:

1 Teach students fundamental skills in freehand drawing and computer-aided drawing that are relevant to civil engineering practice, and

2 Introduce students to the effective use of drawing as a tool within the design process

Students who successfully complete this course will have a good foundation of skill and knowledge that will enable them to maximize the opportunities for learning to draw effectively provided by future engineering study and practice. Because the time available for this course is limited, however, there is no expectation that students who complete this course will be able to demonstrate the level of skill and understanding of drawing that would be expected of experienced draftsmen and draftswomen.

The course covers three different drawing media: freehand drawing, drawing by computer using AutoCAD, and drawing by computer using SketchUp. Each medium accounts approximately for one third of the total class time and the total final mark.

Freehand drawing is used as a tool for creative thinking in the early stages of the design process. AutoCAD is used to create precise formal two-dimensional engineering drawings. SketchUp is used to create three-dimensional drawings with a good balance between speed and freedom on the one hand, and geometric precision on the other.

The content of this course differs significantly from the content of most courses in the curriculum. It is concerned primarily with the acquision of *skills* rather than learning elements of *knowledge*. As a result, the delivery of this course also differs in many regards from most courses in the curriculum. It is therefore important for students to understand all aspects of how the course will be delivered, what is expected of them, and how marks will be awarded. This chapter will help students gain an understanding of these important matters.

2.2 Unique Features of the Course

This course is distinguished from most other courses in the Civil Engineering curriculum by the following attributes:

1. There are no lectures. All of the classes are practical periods in which students will be engaged in the creation of one or more drawings, by hand or using the computer.

Drawing is a practical activity and as such, is best learned by doing.

2. All of the work that students will hand in for marking will be done in class. There are no assignments to be handed in for marking that must be done outside of class.
3. There is no team work in this course. All of the drawings a given student will hand into course staff for review or marking must be done entirely by their own hand.
4. Students are expected to come to class prepared. The amount of work that students will be required to complete in a given class and the standard by which student work will be marked will be based on the assumption that students have prepared conscientiously before class. A complete description of the work to be done in a given class, as well as background material that will help students to understand the techniques that will be used, will be available to students before class.

5 Although the class periods are devoted to practical activities, a quiet atmosphere must be maintained at all times. Students are permitted to engage in brief discussions with classmates regarding the work at hand, provided the sound level is kept to a whisper. Except when they need to leave the classroom to go to the bathroom, students are expected to remain seated during class. Walking over to talk to a classmate is not permitted.

Drawing well requires concentration, which is difficult to achieve while talking. For this reason, drawing is done best in silence.

2.3 Course Staff

2.3.1 Instructor

The instructor for this course is David Hubbell. David is a Senior Engineer at Entuitive, a structural engineering consulting firm. He holds a PhD from the University of Toronto, a Masters of Science in Engineering from Princeton University and a Bachelor of Applied Science in Engineering Science from the University of Toronto. He has worked on the design and rehabilitation of pedestrian, highway, and light-rail bridges. He is currently working on the construction engineering for the Gardiner Expressway rehabilitation between Cherry St and Jarvis St.

David can be reached by e-mail at `david.hubbell@mail.utoronto.ca`.

All marking of students' work in the course will be done by David. Any questions regarding marks should be directed to David, not the Teaching Assistants. Because there will generally be no time in class for review of previously marked work, students must arrange to meet the course instructor outside of class to deal with this type of matter.

A time for weekly office hours will be determined in the first week of classes.

2.3.2 Teaching Assistants

There are six Teaching Assistants for the course. The employment of teaching assistants at the University of Toronto is governed by a collective agreement between the trade union representing them and the university. One of the aspects of this agreement is that the number of hours they have been assigned for a given course is determined in advance of the course and cannot be exceeded. The available hours have been allocated primarily to classroom duty, with only limited time available for consultation outside of class. If your TA tells you they are not available to discuss a matter related to the course outside of class, it is for this reason.

Teaching assistants will not be involved with the marking of any course work or exams. Any questions about marking, or requests for review of a given mark must be addressed to the course instructor. Because there will generally be no time in class for review of previously marked work, students must arrange to meet the course instructor outside of class to deal with this type of matter.

2.4 Class Schedule

Students must attend class in the section to which they have been assigned. The weekly schedule for a given section consists of three periods of two hours each. The class periods assigned to a given section are shown in Table 2.1 to the right.

Table 2.2 gives a more detailed description of each class. For a given class, the following information is given: date, the medium that will be used for drawing, and the number of the chapter of these notes that contains material pertaining to the class, including activities that must be completed to prepare for the class. When reading these notes using a computer or tablet, clicking on a chapter number in the table will take you directly to that chapter.

Table 2.1: Class Period Assignments for Sections for 2020

	Drawing Medium		
Section	CAD 1	CAD 2	Freehand
Room	MB 400	MB 400	GB 304
PRA0101	Mondays 5-7	Wednesdays 12-2	Fridays 10-12
PRA0102	Mondays 3-5	Wednesdays 10-12	Fridays 12-2

2.5 Course Notes

Students are responsible for having read and understood the following material contained in the Course Notes:

1. All of the chapters listed in Table 2.2, and

2. All of the material that is referred to from chapters listed in Table 2.2.

For example, Chapter 30 refers to Chapters 2, 4, 7, 9, and 16, which implies that students are responsible for having read and understood the material contained in these chapters.

Table 2.2: Schedule of Classes for 2020

	Monday			Wednesday			Friday		
Week	Date	Medium	Chapter	Date	Medium	Chapter	Date	Medium	Chapter
1	January 6	SketchUp 1	30	January 8	SketchUp 2	31	January 10	Introductory Lecture	19
2	January 13	SketchUp 3	32	January 15	SketchUp 4	33	January 17	Freehand 1	20
3	January 20	SketchUp 5	34	January 22	SketchUp 6	35	January 24	Freehand 2	21
4	January 27	SketchUp 7	36	January 29	SketchUp 8	37	January 31	Freehand 3	22
5	February 3	SketchUp 9	38	February 5	SketchUp 10	39	February 7	Freehand 4	23
6	February 10	SketchUp 11	40	February 12	SketchUp 12	41	February 14	Freehand 5	24
7	Reading Week: no classes								
8	February 24	SketchUp (Exam)	—	February 26	AutoCAD 1	42	February 28	Freehand 6	25
9	March 2	AutoCAD 2	43	March 4	AutoCAD 3	44	March 6	Freehand 7	26
10	March 9	AutoCAD 4	45	March 11	AutoCAD 5	46	March 13	Freehand 8	27
11	March 16	AutoCAD 6	47	March 18	AutoCAD 7	48	March 20	Freehand 9	28
12	March 23	AutoCAD 8	49	March 25	AutoCAD 9	50	March 27	Freehand 10	—
13	March 30	AutoCAD 10	51	April 1	AutoCAD 11	52	April 3	Freehand 11	29
14	April 6	AutoCAD 12	53	April 8	AutoCAD (Exam)	—	April 10	Good Friday	—

2.6 Class Activities

Each class period will consist of one or more activities. These activities will be exactly as described in the corresponding chapter of these course notes ▷ .

See Table 2.2 in Section 2.4.

A given activity will consist of a drawing to be prepared by students during an assigned period of time. After the time allocated for a given activity has elapased, the drawings will be collected by course staff for marking.

When a class period consists of several activities, students will work on a given activity within a specific block of time that has been specified in advance. After this time has elapsed, students must hand their work. After this point, no further work is possible on that specific activity. Students who arrive late and miss one or more of the activities required of that class will therefore receive a mark of zero for those specific activities.

There will be three types of activity: Basic Exercises, Special Exercises, and Exams.

The purpose of the Basic Exercises is to *learn* relevant skills and techniques. The marking standard has been purposely relaxed for this type of exercise, to enable students to focus on the technique rather than the mark. The purpose of the Special Exercises and Exams is to *demonstrate proficiency* in the skills and techniques learned in the Basic Exercises. For these activities, the marking standard will be consistent with that expected of students in other courses in the curriculum.

The remainder of this section describes each type of activity in greater detail.

2.6.1 Basic Exercises

Most of the available class time will be devoted to Basic Exercises, the primary features of which are as follows:

1 CONDUCT. Students may communicate with each other during Basic Exercises, provided they remain seated and a quiet atmosphere is maintained at all times. ▷ There will generally be no limitations on the materials or implements students may use in completing this type of exercise.

See Section 2.2.

2 AVAILABLE ASSISTANCE. Course staff will be available to provide assistance to students as required.

3 MARKING STANDARD. Basic Exercises will be given a mark of 10/10 if they have been completed in a conscientious manner and 0/10 otherwise. Work with the following attributes will be deemed not to have been done conscientiously:

(a) Insufficient quantity of work or other evidence that work was done with a lack of diligence

(b) Sloppiness or other evidence that work was done with a lack of care

(c) Evidence that the student did not take the work seriously, including evidence that the specified procedure for completing the exercise was not followed

(d) Evidence that the student did not prepare adequately for the exercise

Work for which none of these attributes are present will be deemed to have been completed conscientiously and will be awarded a mark of 10/10.

Marking of Basic Exercises will not involve a detailed assessment of the quality of the work. It is emphasized that course staff will be looking for gross faults that demonstrate a significant lack of seriousness. It is thus expected that the vast majority of work handed in will be deemed to have been completed conscientiously.

2.6.2 Special Exercises

In each of the three drawing media, there will be three Special Exercises that will be completed in class and handed in for marking. These exercises will be spaced at relatively even intervals during the term.

1 CONDUCT. Students may communicate with each other during Special Exercises, provided they remain seated and a quiet atmosphere is maintained at all times. ▷ Restrictions on materials and implements that may be used during Special Exercises may apply. ▷

See Section 2.2.
See Sections 3.2 and 4.4.

2 AVAILABLE ASSISTANCE. Course staff will be available to provide assistance to students as required.

3 MARKING STANDARD. Special Exercises will be marked in detail by course staff, according to criteria that will be made available to students before the exercise. A mark in the range of 0 to 10 out of 10 will be assigned on this basis.

The marking standard for Special Exercises will be significantly higher than the marking standard for Basic Exercises. *Students must not assume that consistently earning 10 out of 10 in previous Basic Exercises will guarantee high marks in related Special Exercises.*

2.6.3 Exams

There will be one exam in each of the three drawing media covered in the course. The SketchUp and AutoCad exams will be held during class periods. The freehand drawing exam will be held during the final exam period after the last day of classes for the term.

1 CONDUCT. Exams will be conducted in full accordance with the Exam Regulations of the U of T and the Faculty of Applied Science and Engineering. In particular, students shall not communicate with each other during the exam. Restrictions on materials and implements that may be used during Special Exercises shall apply. ▷

See Sections 3.2 and 4.4.

2 AVAILABLE ASSISTANCE. Course staff will not provide assistance to students.

3 MARKING STANDARD. Exams will be marked in detail by course staff.

2.7 Composition of Final Mark

The final mark for this course is made up of several components, as decribed in Table 2.3 to the right. For each drawing medium, marks will be allocated in three categories: Basic Exercises, Special Exercises, and Exams, each of which is described below.

Table 2.3: Composition of Final Mark

	Drawing Medium			
Item	Freehand	AutoCAD	SketchUp	Total
Basic Exercises	5	5	5	15
Special Exercises	15	15	15	45
Exams	15	15	10	40
Total	35	35	30	100

2.7.1 Basic Exercises

As given in Table 2.3, the component of final mark corresponding to the Basic Exercises in a given medium has a maximum value of 5 marks. All Basic Exercises within a given drawing medium have equal weight and all will be marked out of a total of 10. The component of final mark C_m corresponding to the Basic Exercises in medium m will be calculated as follows:

$$C_m = \frac{A_m}{N_m \times 10} \times 5 \tag{2.1}$$

where A_m is the total of marks obtained for all Basic Exercises in medium m and N_m is the total number of exercises in medium m.

For example, assume there is a total of 50 Basic Exercises in freehand drawing, 25 in AutoCAD, and 25 in SketchUp. A mark out of 10 is awarded for each exercise. A student receives a total of 400 marks for the Basic Exercises in freehand drawing, 210 in AutoCAD, and 170 in SketchUp. The components of that student's final mark for each of the three types of Basic Exercise will therefore be as follows:

Freehand drawing: $(400/(50 \times 10)) \times 5 = 4.0$ marks out of 5
AutoCAD: $(210/(25 \times 10)) \times 5 = 4.2$ marks out of 5
SketchUp: $(170/(25 \times 10)) \times 5 = 3.4$ marks out of 5

2.7.2 *Special Exercises*

There will be three Special Exercises in each of the three drawing media covered in the course. The component of final mark corresponding to the Special Exercises in a given medium has a maximum value of 15 marks. All Special Exercises will carry equal weight and all will be marked out of a total of 10. The component of final mark C_m corresponding to the Special Exercises in medium m will be calculated as follows:

$$C_m = \frac{A_m}{30} \times 15 \tag{2.2}$$

where Am is the total of marks obtained for all Special Exercises in medium m.

2.7.3 *Exams*

There is only one exam for each of the three media, so calculation of the portion of the final mark corresponding to a given exam will be done by converting the mark awarded for the exam to a percentage and then multiplying this percentage by the maximum possible mark given in Table 2.3

2.8 *Tips for Success*

Achieving success in this course requires strategies that are different from the strategies students have used thus far in other courses. With this in mind, the following suggestions are made to students. These are based on observations of what has worked well for students who have taken the course in previous years:

1 READ EVERYTHING WE ASK YOU TO READ. This applies not only to material that has been identified as required preparation for a given exercise, but also instructions provided in class or an exam.

2 PREPARE CONSCIENTIOUSLY FOR EVERY EXERCISE. This is an integral part of the learning process in this course, and the standard of marking has been based on the premise that students have come to class well prepared. Students who have done well in this course in previous years always came to class well prepared.

3 UNDERSTAND WHAT IT IS YOU ARE ABOUT TO DRAW BEFORE YOU BEGIN DRAWING. You will be able to draw more quickly and more accurately if you understand the basic geometrical and functional characteristics of the object you are about to draw. This can include identifying axes of symmetry, parallel lines and surfaces, and bounding polygons that can be used as references for constructing the figure.

4 PLAN YOUR DRAWING BEFORE YOU BEGIN TO PUT LINES ON THE PAGE. There are efficient ways to draw and inefficient ways to draw. A little time invested in defining the steps you will follow to create the drawing before you begin to draw always results in a more efficient process and a better drawing.

5 REMAIN SILENT WHEN YOU DRAW. The part of the brain that controls our awareness of spatial geometry and creativity is different from the part that controls language. When we talk, we make it difficult for our brain to command our hands to draw well. Students who did well in this course always concentrated on their drawings and appeared to have little need to converse with their classmates.

6 PRACTICE OFTEN. People do well at the tasks they do often. If you draw a lot, you will get good at it. As engineering students, you have many opportunities to practice drawing skills in every course you take. All engineering courses require graphs, sketches, and diagrams of various types. Instead of scratching these out as a high school

student, use the opportunity to apply the techniques you will learn in this course.

3
Freehand Drawing Classes: General Information and Requirements

The course includes on freehand drawing class in each week of term, for a total of twelve freehand drawing classes. An exam in freehand drawing will be conducted during the final exam period. From week to week, the structure and conduct of the classes will be highly similar. The primary difference between two given classes will be the actual content of the drawing exercises. This chapter describes the common elements of the weekly freehand drawing classes, including general regulations that must be followed by all students.

3.1 General Information

A typical freehand drawing class period will consist of several Basic Exercises ▷ . Three class periods will also include Special Exercises ▷ .

See Section 2.6.1.
See Section 2.6.2.

Each exercise will be drawn on a separate sheet of paper (provided by course staff) and all students will work on the same exercise at any given time. Each exercise will have a specified time limit. The exercises will be designed to ensure that students are engaged in drawing until time is called for a given exercise. After time is called, the exercises will be handed in to course staff and there will be a short break before the next exercise begins. In most weeks, the first exercise will consist of a warm-up based on material introduced in previous weeks. Subsequent exercises will generally introduce new material.

A complete description of the exercises for a given class has been provided ▷ . Students are expected to be use this material to come to class adequately prepared. The description of a given exercise will generally include:

See Chapters 19 through 29

1 A general statement of the primary focus of the exercise and an explanation of how this relates to the overall objectives of the freehand drawing sequence for this course.

2 Links to chapters in these course notes and/or videos that explain general principles of drawing or aspects of drawing technique necessary for successful completion of the exercise.

3 A description of each exercise to be completed in class for the given week. Links will be provided to download the blank exercise sheets in pdf format.

The blank exercise sheets and completed exercises have been formatted for printing on 11 by 17 paper, landscape orientation, 100% scaling.

4 Worked examples of each exercise. These provide students with an indication of the quantity of and quality of work that is expected.

3.2 Materials and Implements

1 The computers in MB 400 shall not be used during freehand drawing classes.

2 Course staff will provide students with one copy of every exercise paper. No other material on paper will be provided by course staff.

Students who request a second copy of an exercise paper generally do so because they have made a mistake from which it is difficult to recover. Arriving to class prepared, understanding the requirements of the given exercise, and planning ahead before drawing should prevent this type of mistake.

3 All drawing exercises shall be done in pencil.

The recommended pencil for this course is *Blackwing 602* by Palomino (`http://palominobrands.com/blackwing/`). This is a high-quality wood/graphite pencil that can make excellent light and heavy lines with relatively little pressure.

4 For Basic Exercises, there are no specific regulations on the materials and implements that can be present on the desk and used during the exercise other than the two previous points and the general requirement that the work must be done in accordance with the specified procedure ▷ .

See Point 3c in Section 2.6.1.

The purpose of the Basic Exercises is to develop relevant skills and techniques. Proficiency in these skills and techniques must be demonstrated on the Special Exercises and the Exam, both of which have strict requirements regarding materials and implements that can be used. *Students are strongly advised to complete the Basic Exercises using nothing more than the materials and implements permitted for the Special Exercises.*

5 For Special Exercises, the only items that may be used by students and that may be readily accessible to students are the exercise paper and one wood/graphite pencil with no eraser. Course staff will provide pencil sharpeners for use during the exercise. The use of any device that can capture or display an image (e.g. any smartphone) is prohibited.

6 The Exam will be conducted in full accordance with the relevant regulations of the University and the Faculty of Applied Science and Engineering, including those regulations relating to prohibited materials and implements. In particular, the only items that may be used by students and that may be readily accessible to students are the exercise paper and one wood/graphite pencil with no eraser. Course staff will provide pencil sharpeners for use during the exam. The use of any device that can capture or display an image (e.g. any smartphone) is prohibited.

3.3 Description of Freehand Drawing Classes

Chapters 19 through 29 give, for each freehand drawing class, the following information:

1 A table with activities scheduled for the class period. Table 3.1 provides an example of the information contained in this table for a given class.

2 Background material with which students are expected to be familiar.

3 Required preparation activities specific to this class.

Table 3.1: Schedule of Class Activities (SAMPLE ONLY)

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	19	Straight lines	Blank	Completed
Break	2	—	—	—
Basic	19	Extending lines	Blank	Completed
Break	2	—	—	—
Basic	19	Light and heavy lines	Blank	Completed
Break	2	—	—	—
Basic	19	Subdividing lines into halves	Blank	Completed
Break	2	—	—	—
Basic	19	Parallel lines	Blank	Completed

4 Other information as required.

The table provides the following information ▷ :

See the example in Table 3.1.

1 *Type of Activity*. "Basic" refers to *Basic Exercises* and "Special", if present, refers to *Special Exercises* ▷ . "Break" is a short period of time in which completed exercise papers will be collected by course staff and new papers will be distributed.

See Section 2.6.

2 *Allotted Time*. It may be necessary to shorten the time alloted for a given exercise. If this is the case, an announcement will be made to students before the exercise begins.

3 *Links to Drawing Files for Downloading*. For a given exercise, clicking on the entry `Blank` directs you to a pdf file of the blank drawing for the exercise. Instructions for the exercise will also be provided on this drawing. Clicking on `Completed` directs you to a pdf file of the exercise completed by a member of course staff. Print out the blank drawing on 11 by 17 paper, 100% scaling, and use it to practice before the exercise. The completed drawing provides an indication of the quality (precision and total number of figures) expected.

4
CAD Classes: General Information and Requirements

The course includes the following classes in computer-aided drawing (CAD) ▷ :

For the timing of these classes, see Table 2.2 in Section 2.4

1. Twelve classes consisting of Basic and Special Exercises that involve drawing with SketchUp and LayOut
2. One exam, conducted during a class period, involving drawing with SketchUp and LayOut
3. Twelve classes consisting of Basic and Special Exercises that involve drawing with AutoCad
4. One exam, conducted during a class period, involving drawing with AutoCad

This chapter describes the common elements of the CAD classes, including general regulations that must be followed by all students.

4.1 General Information

A typical CAD class period (other than an exam) will consist of one exercise, either Basic or Special ▷ .

For a description of Basic and Special Exercises, see Sections 2.6.1 and 2.6.2.

4.2 Secure Network Environment

All exercises and both exams will be conducted in a secure network environment, that has been set up to ensure that all work submitted by a given student was actually performed by that student, and that students have access only to material that is specifically authorized by course staff.

4.2.1 Access

To use the secure environment, students must log in using a special ID and password combination, and not their regular ECF account. The special ID will be of the form `235civXXXX`, where `XXXX` is a one to four digit number. The special log-in credentials will be provided to students by course staff on a sheet of paper at the beginning of class. Regular ECF accounts shall not be used to complete exercises in class or to submit work.

Students are not allowed to share their log-in credentials with other students. Doing so constitutes a significant breach of academic integrity and will be dealt with accordingly.

The sheet containing the log-in credentials will also contain information required for submitting files to receive credit for the exercise.

4.2.2 General Description of the Secure Environment

Generally speaking, while in the secure environment, students will have access to everything they will reasonably need to complete the exercise that is to be completed in a given class period, but nothing more. This includes both software, data files, and other items of information.

In particular, students will not have access to the World Wide Web.

While in the secure environment, students will have access to the following directories:

1. The `C:\` directory. This directory will be empty when students log in. This is local storage only, i.e., files written to the `C:\` directory are not stored on a server, but rather only on the computer to which a given student is currently logged. These files disappear when a student logs out or when the computer crashes. For these reasons, the use of the `C:\` directory is *not recommended*.

2. The `W:\` directory. This directory is unique to each student who is logged in. It will be empty when students log in. Files written to the `W:\` directory are stored on the ECF server and will remain available for the entire class period, regardless of which computer a given student uses. In particular, students who are required to relocate to another computer due to hardware problems ▷ will have access to all of the files they have stored on the `W:\` directory. This directory is intended only for temporary storage of files during class, e.g. regular backups of work in progress. Course staff do not have access to this directory. It is therefore impossible for credit to be given for work that has been saved only to the `W:\` directory.

See Section 4.2.3.

3. The `S:\Courses\civ235\Source\` directory. Students can open and copy files that reside in this directory, but cannot write to it. Course staff will put all files required to complete a given exercise on this directory. In particular, a copy of these Course Notes in pdf format will generally be available in this directory. Because the World Wide Web is not accessible from the secure environment, the external hyperlinks in the Course Notes will not work.

4. The `S:\Courses\civ235\Submit\235civXXXX\` directory. This directory resides on the ECF server. The `235civXXXX` portion of the directory name is the special login ID used by the student ▷ . This ID does not have to be entered; the directory is automatically created for each student as part of the secure network environment.

See Section 4.2.1.

This directory will be empty when students log in. Students will use this directory to submit their work for marking. This is the only way work can be submitted to obtain credit. The use of this directory is straightforward, provided the following instructions are *strictly followed*:

(a) Work to be submitted to the `S:\Courses\civ235\Submit\235civXXXX\` directory *must be copied from the* `W:\` *directory*.

Do not save a file from SketchUp, LayOut, or AutoCad directly to the `S:\Courses\civ235\Submit\235civXXXX\` directory. If you do, it will appear as if a file has been created, but this file will be corrupted and course staff will not be able to open it. These files thus cannot be marked and will receive a zero.

This instruction will be stated once again for emphasis: *to submit files for marking, copy them from the* `W:\` *directory to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory*.

This is extremely important. Every year, several students make the mistake of saving files directly to `S:\Courses\civ235\Submit\235civXXXX\` rather than copying files from the `W:\` directory to the `S:\Courses\civ235\Submit\235civXXXX\` directory. Do not be one of these students.

(b) Name the files you submit according to the naming convention that will be given on the page that contains your log-in information ▷ .

See Section 4.2.1.

(c) Once a file has been written to the `S:\Courses\civ235\Submit\235civXXXX\` directory, it cannot be deleted. If you find that you need to make a correction or revision to work that has already been written to this directory, submit a new file. The page that contains your long-in information will give instructions on how to name these revision files. Course staff will mark the last file submitted by a given student. Course staff will not look at previously submitted files for any reason.

4.2.3 Problems

Problems with the computer hardware or software can and do occur. To minimize the negative consequences of such problems, the following procedures will be implemented:

1 If a student encounters a problem that they believe is due to hardware or software, they must inform a member of the course staff immediately.

2 Course staff will relocate the student to another computer.

3 Course staff will also record the time lost by the student, from the time they were informed until the time the student is up and running again with problem-free hardware and software. A credit for the lost time, plus an allowance of five minutes, will be applied in marking the exercise.

The special log-in credentials used in the secure environment ▷ enable a given student to log into the system from a computer other than the one from which they began working. Work in progress that students have saved to the secure environment will therefore be accessible from another computer. *It is therefore important that students save their work in progress to the secure environment often during the course of the exercise.*

See Section 4.2.1.

The additional allowance of five minutes that will be given by course staff in marking the work of students who experience hardware or software problems accounts for the expectation that students will be saving their intermediate work no less frequently than every five minutes. Course staff will not give credit for any additional time required to re-create work that was lost because a student did not save their intermediate work.

4.2.4 Submission of Work

All work will be submitted in digital form through the secure environment ▷ . *Files must be submitted in the specified format or they will not be marked.* In most cases, students will create their work in SketchUp and LayOut, or in AutoCad. They will then export their

See Section 4.2.2.

In this course, the final product of the drawing process is an image on paper. This is consistent with current practice in most sectors of civil engineering.

work to a pdf file for submission. In such cases, any submissions in native SketchUp, LayOut, or AutoCad format will not be marked by course staff. Students are therefore strongly urged to prepare at least an interim pdf file well in advance of the deadline for submission. An incomplete pdf submission may receive partial credit. Complete submissions in any of the native drawing formats will receive no credit.

4.3 Description of Exercises

A complete description of the exercises for a given class has been provided ▷ . Students are expected to be use this material to come to class adequately prepared. The description of a given exercise will generally include:

See Chapters 30 through 41 for SketchUp/LayOut and Chapters 42 through 53 for AutoCad.

1. An identification of the exercise as Basic or Special ▷ .

See Sections 2.6.1 and 2.6.2.

2. A short description of the drawing to be produced.
3. A description of the primary focus of the exercise and an explanation of how this relates to the overall objectives of the course.
4. Links to chapters in these course notes and/or external websites that explain general principles of drawing or aspects of drawing technique necessary for successful completion of the exercise.
5. Links to the files required to complete the work.
6. A recommended workflow that, when followed, will enable the exercise to be completed efficiently and the learning objectives to be achieved.
7. A description of activities required to prepare for completing this exercise in class.
8. A file with the completed exercise. This has been provided to give students an indication of the quality of work that is expected.

4.4 Materials and Implements

1 For Basic Exercises and Special Exercises, no additional electronic devices other than the computer provided to students and an approved calculator may be used. The use of any device that can capture or display an image (e.g. any smartphone) is prohibited. There are no restrictions on the materials printed or written on paper that can be present on the desk and used during the exercise other than the requirement that the work must be done in accordance with the specified procedure ▷ .

See Point 3c in Section 2.6.1.

A printer linked to all the computers will be provided in the classroom. Students are encouraged to use this computer to print out their work and check it before submitting it.

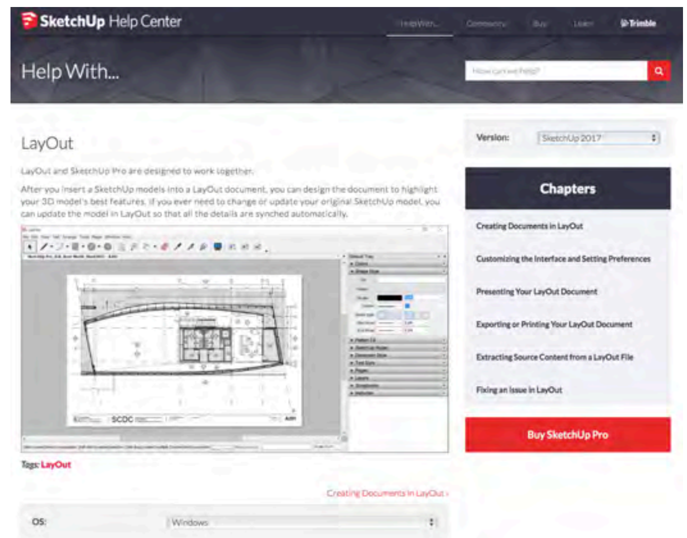


Figure 4.1: Online learning materials for SketchUp and LayOut showing pull-down menus for setting software version (upper right-hand portion of the view) and operating system (lower portion of the view).

2 The Exam will be conducted in full accordance with the relevant regulations of the University and the Faculty of Applied Science and Engineering, including those regulations relating to prohibited materials and implements. In particular, no additional electronic devices other than the computer provided to students and an approved calculator may be used. The use of any device that can capture or display an image (e.g. any smartphone) is prohibited. There are no restrictions on the materials printed or written on paper that can be present on the desk and used during the exercise.

4.5 Resources Available on the SketchUp/LayOut and AutoCad Websites

To complete this course, students are required to learn a set of commands specific to the SketchUp, LayOut, and AutoCad applications. To accomplish this, they will need to refer to training materials provided by the developers of these software products. These materials are available on the websites of the developers ▷ . Links to material on new commands that are required to complete specific exercises

For SketchUp, material can be found at `help.sketchup.com/en/sketchup/sketchup`.
For LayOut, material can be found at `help.sketchup.com/en/layout/layout`.
For AutoCad, material can be found at `knowledge.autodesk.com/support/autocad`.

will be given in the description of these exercises as required.

When using the training materials provided by the developers of SketchUp and LayOut, make sure the version and operating system have been correctly selected. As shown in Figure 4.1, the version can be set using a pull-down menu in the upper right portion of the window, and the operation system in the lower portion of the window.

Part II

Principles of Engineering Drawing

5
Drawing in the Engineering Design Process

Engineers learn to draw because drawing is the most important design tool at their disposal. Regardless of whether they use a pencil or the computer, it is by drawing that they make visible the ideas which they have imagined, and demonstrate that these ideas work.

Drawing and design are intimately related. It is not a coincidence that the English word *design* and the French word *dessiner* (which means to draw) share a common linguistic root. To design something is, in some fundamental sense, to draw it. It is by drawing that we stimulate our imagination to create new ideas, bring these ideas out of our imagination and into reality, demonstrate that the works built as described by our design will perform as intended, and communicate our design to the people who will build them.

This chapter describes the use of drawing as the primary tool within the engineering design process. It covers the following primary topics:

1 To understand the role played by drawing in the design process, we must first understand the design process itself. The chapter therefore begins with a suitable definition of *design*.

2 This is followed by a definition of *engineering design*, i.e., design as practiced by engineers. The use of the principles of science will

be shown to be the primary factor that distinguishes engineering design from design as practiced by other professions.

3 The primary elements of the *engineering design process* are then defined and described.

4 The understanding of engineering design thus gained is then used as a basis for describing how drawing is used in the design process.

5.1 What is Design?

Design is a creative activity, the outcome of which is the description of a useful thing. The description must be sufficiently complete to enable the useful thing to be built without further significant intervention from the designer.

To gain a better understanding of the nature of design, it is helpful to consider the significance of each element of this definition.

1 Design deals with useful things, i.e., things that perform a *practical function.* This distinguishes design from other creative activities such as poetry, sculpture, and musical composition. A description of the required practical function is usually a necessary precursor to design. We thus undertake a design process in response to the need for objects that can perform a given practical function.

This distinction is reflected in the way we use the word *design*: we design bridges, buildings, automobiles, computers, and furniture, but we do not design poems, sculptures, or symphonies.

2 The outcome of design is a *description* of the useful thing, not the useful thing itself. This distinguishes design from construction and manufacturing. Although it is possible for designer and builder to be one and the same person or organization, it is rare indeed that a builder will commit significant resources to a construction project without a prior valid and detailed description of what it is that needs to be built.

3 The description of the useful thing must be sufficiently *complete* to be *buildable* without further significant intervention from the designer. This distinguishes design from planning, which produces

descriptions that are not sufficiently complete or detailed to be built.

4 Design is a *creative* activity. We almost always have the opportunity to enable the works we design to perform the required practical function *better* than it had been done previously. In fact, the marketplace will generally demand this of designers, since objects that perform their function better than current alternatives are likely to create economic value for both companies and consumers. To accomplish this, we need to work with *new ideas*, since it is obvious that simply doing what has been done before will accomplish the practical function no better than what had been done previously. There is thus a clear incentive for designers to think creatively.

It is taken as an axiom that the human spirit is capable of responding well to this incentive, i.e., it is generally possible for designers to create works that do indeed improve on what had been done previously. The immense progress in all areas of technology since the Industrial Revolution, which has only increased in pace in recent decades, is compelling evidence of this proposition.

A public agency, for example, could produce a plan for a new highway which would locate the alignment of the route and identify the bridges required and their general characteristics. This plan could be used for budgeting purposes, to gain environmental approvals, or to gain political assent, but it could not be given to a contractor to build the highway or the bridges. The process of planning can thus be regarded as a precursor to design.

5.2 What is Engineering Design?

The definition of design given in the preceding section applies generally to a wide variety of disciplines, including engineering. The only thing that distinguishes design as practiced by engineers (which will be referred to here as *engineering design*) from design as practiced in other disciplines is that *engineers use the principles of science to demonstrate, prior to construction, that their designs will perform the required practical function as intended.*

The principles of science can predict, with great accuracy, the behaviour of physical systems. The systems need not be real, provided they can be described clearly and precisely in mathematical terms. The equations students learn in engineering courses are all intended to be used to predict how designs will perform their intended function. In structural engineering, for example, one of the most important aspects of practical function is for a given structure to be able to carry specified loads without collapse. To determine if a given bridge or building we have designed can perform this function, we create mathematical models of these works, which incorporate complete descriptions of relevant geometrical and material properties. The specified loads are likewise expressed in mathematical terms. We then use relevant scientific principles (such as Newton's laws and Hooke's law) to calculate the stresses produced in the structure by the given loads. By comparing the computed stresses to limiting values of the strength of the materials that will be used, we can determine whether or not the structure can perform this aspect of its intended function.

If we did not have the principles of science, the only way to determine whether or not the work we designed could perform its intended function would be to build it and test it. (Alternatively, one could also imagine just building it and then hoping for the best.) Figure 5.1 gives a lighthearted impression of this way of doing things. The problem with this approach is that if the work turned out not to perform as intended (i.e. the bridge collapsed at a load less than the minimum specified load), there would be severe economic consequences. Bridges are expensive works, and paying for a given bridge twice is not a sensible use of public funds. It is conceivable that there would also be severe human consequences, due to injury or loss of life sustained as a result of the collapse.

For this reason, society and industry usually entrust to engineers the responsibility of designing *new* works for which the risks, either human or economic, of committing to construction without adequate assurance that they will perform their function as intended are high. These are usually works for which the consequences of not performing as intended could include loss of human life and/or significant economic loss. Because engineers are the only designers

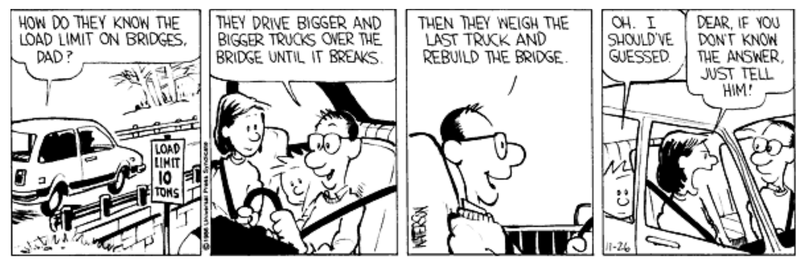


Figure 5.1: Calvin and Hobbes cartoon by Bill Watterson, United Press Syndicate

The qualifier "new" is significant here. If we are simply building something that has been built before and has performed well in the past, then it can often be considered validated on the basis of its prior performance. No additional validation using scientific principles would then be necessary. In such a case, it would not be necessary to have engineers design them.

who have mastered the principles of science and adopted them as primary tools in the design process, only engineers are capable of providing this assurance. They do so by predicting the response of the works they design to expected conditions *while these works are still "on paper"*.

5.3 The Engineering Design Process

Design is a process that takes place in time. The process begins with a *description of the useful function* to be performed by the object to be built from the design. This description is often referred to as "design criteria" or "design requirements". The process ends with the production of a *description of the useful object* that is sufficiently clear and complete to enable the object to be built by others solely on the basis of this description ▷ . When the design is produced by engineers, it is generally expected that the risk that the object built from the design will not perform as intended will be less than than an acceptable threshold ▷ .

Design criteria typically include requirements relating to margins of safety and other measures of acceptable performance in service, maximum construction cost, minimum service life, and other characteristics relevant to the practical function of a given work.

See Section 5.1.

See Section 5.2.

Between the establishment of design criteria and the delivery of the final description of the useful object, the design process can be regarded as a *series of decisions* made by the designer. For example, the decisions required in the design of the freeway overpass shown in Figure 5.2 would have included decisions such as how many spans (one or two), what materials to use (steel, precast concrete, or cast-in-place concrete), and what structural system to use (simply supported or rigid frame). The process would also have included decisions relating to the size, spacing, and details of all of the reinforcing steel bars used in the bridge.

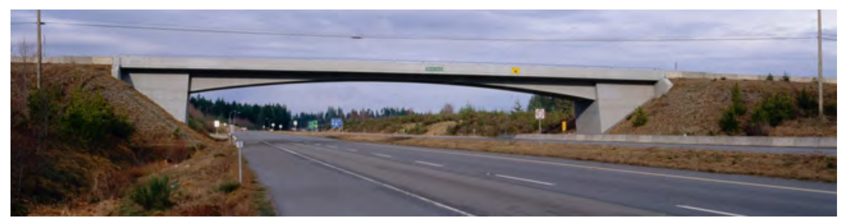


Figure 5.2: Royston Road Underpass, British Columbia. Design: Paul Gauvreau

Each decision contributes an *increment of definition* of the final product, contributing increasing clarity and precision to the description of the design. To a passive observer, therefore, witnessing a design process would likely be similar to approaching an object through a dense fog, with the image of the object becoming increasingly clear and complete as they got closer.

Engineering designs need to be carefully *validated*, in the sense that by the time we arrive at the end of the design process, we must have taken the necessary steps to determine that the object that will be built according to our design will indeed perform its function as intended. As discussed in Section 5.2, this will generally involve a suitable application of scientific principles. Although it is theoretically possible to perform the entire validation on the completed design at the end of the process, this is usually not done. Designers must generally do their work in accordance with good business principles, giving due consideration to schedules and budgets. To reach the end of the design process only to have to redo it from scratch because the design is found to have a major flaw will usually result in a financial loss for the designer and the inability to deliver the completed design on schedule.

The only way to eliminate all backtracking from the design process is never to design anything new. The likelihood of major backtracking, however, can be minimized. It is common practice to make many design decisions that contain high increments of definition early in the design process. In this way, it is possible to create quickly a description of the object that, although incomplete, provides a good indication of many of the important characteristics of the object. An example of such a description is the drawing shown in Figure 5.3, which was created as part of the design process of the bridge shown in Figure 5.2.

This drawing is not a complete description of the bridge to be built. It contains no information, for example, on the reinforcing and prestressing steel required. Both of these systems are, of course, of crucial importance to the function of the bridge. The drawing does, however, give a clear indication of the structural system and overall geometry of the structure. On this basis, it is possible to estimate the total quantity of concrete required, to infer the most likely method of construction, and hence to estimate the expected

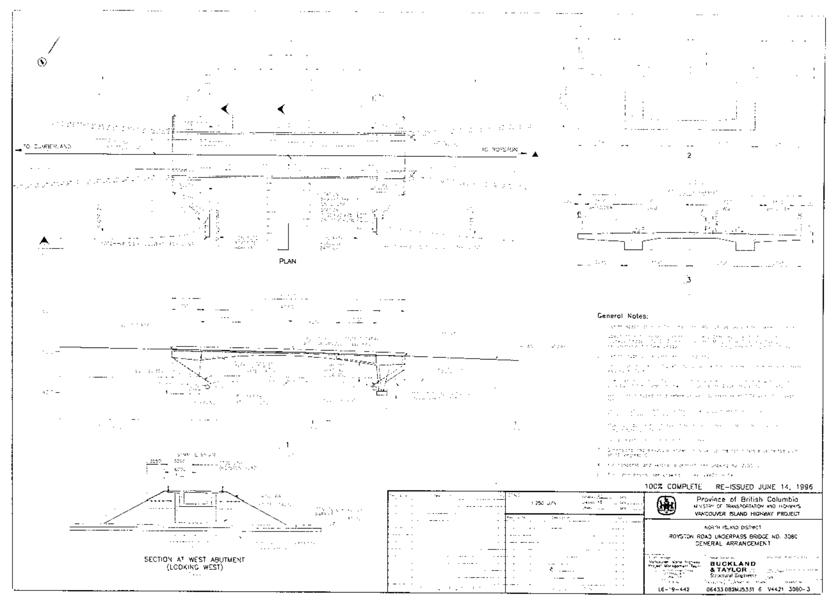


Figure 5.3: Royston Road Underpass, British Columbia: Design Concept

cost and duration of construction. It is also possible to verify that the functional requirements relating to the bridge as a component in a larger highway system have been satisfied, and to get a pretty good idea of the visual impression that will be created by the bridge. Although the basis for a definitive validation of the design remains the final description produced at the outcome of the design process, this single drawing provides an effective means to obtain an approximate validation of many important design decisions. The stage of the design process represented by the drawing of Figure 5.3 is commonly referred to as the *design concept*.

Many important design decisions remain to be made after the drawing of Figure 5.3 has been produced. As mentioned previously, all of the reinforcing and prestressing steel remain to be dimensioned. Although it is possible that the process of validating this steel could result in the need to backtrack and change the features of the design as depicted in this drawing, it is usually possible for competent and experienced designers to determine, on the basis of this drawing, that proceeding with the remainder of the design process on the basis of this drawing is unlikely to result in any major backtracking.

The primary features of the engineering design process can therefore be summarized as follows:

1 The process begins with the establishment of design criteria, which define the requirements that must be satisfied to ensure that the object to be built based on the design will function as intended.

2 The outcome of the design process is a description of the object to be built that is sufficiently clear and complete to enable the object to be built by people other than the designer.

3 Engineering designs must be validated, i.e., the designer must demonstrate that the design is indeed in accordance with the applicable design criteria.

4 The process consists of a series of design decisions, each of which contributes an increment of definition to the final description of the object.

5 To minimize the likelihood of major backtracking during the design process, validation is performed throughout the design process, not only at the very end.

6 It is common to proceed quickly to a *design concept* in the early stages of the design process. Although incomplete, the description of the design at the concept stage provides an effective basis for at least the approximate validation of most of the design decisions made up to that point, and for establishing that the subsequent design decisions are likely to be valid.

5.4 The Use of Drawing in the Engineering Design Process

Drawing has two primary roles in the design process:

1 It is a means of communicating information among participants in the design process

2 It is a tool for the designer, used in the creation of ideas and the validation of design decisions.

In engineering, a given drawing is thus a means to an end. The drawings we create serve in support of the design process, which in turn enables the construction of useful things. In this regard, engineering drawings differ significantly from drawings created by artists, which serve no process and are intended to be appreciated by virtue of their visible qualities alone.

5.4.1 *Drawing to Communicate the Outcome of the Design Process*

As stated in Section 5.1, designers usually do not build their own designs. The works of civil engineering, for example, are usually built by contractors who are independent of designers. This implies the need to *communicate* to builders a suitable description of what exactly has to be built. Because the works of civil engineering are usually large, three-dimensional objects that need to be built to precise geometrical specifications, it makes sense for designers communicate this information to builders using drawings.

For example, a contractor who undertook to build the bridge shown in Figure 5.4 would need a complete description of the shape of this structure in order to build it to the geometry defined by the designer. Although it is theoretically possible to convey this information using other means, drawings remain the preferred method to do so. They are geometric objects themselves, and thus have a close affinity to the work to be constructed.

Drawings such as the one shown in Figure 5.5 are a convenient and compact way of representing complex three-dimensional geometrical information.

Drawings intended to communicate information can be prepared at practically any stage in the design process. Perhaps most importantly, though, they are issued at the end of the process. At this stage, they provide a complete description of the object to be built and are generally incorporated into the contract that will be signed by owner and contractor to build the bridge. Essentially, the contract will state that the contractor has agreed to build the bridge as described in the drawings for a fixed sum of money. When they form part of legal documents such as this, drawings intended to communicate information must have a specific degree of formality. They must present information correctly, completely, and clearly. Any problems with this type of drawing are likely to lead to loss of time on the construction site and additional fees to be paid by the

Figure 5.4: Royston Road Underpass, British Columbia. Design: Paul Gauvreau

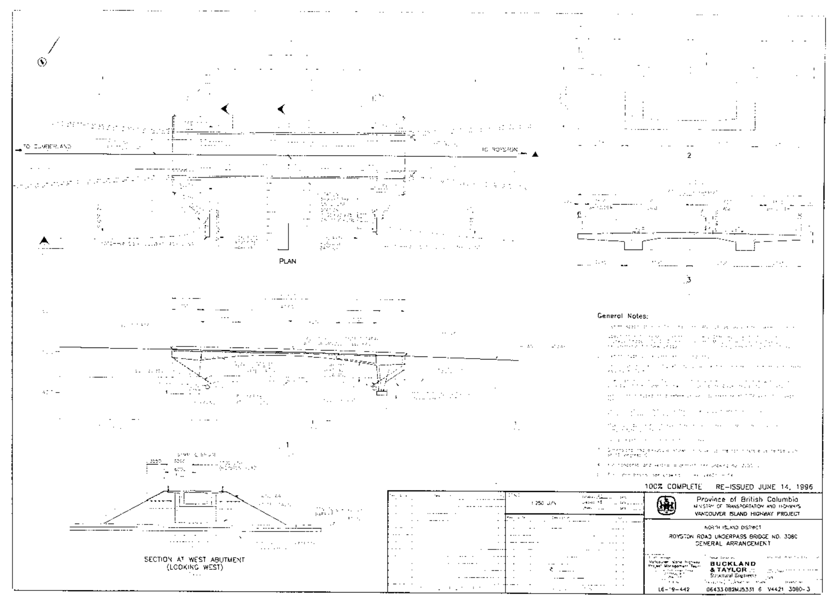


Figure 5.5: Royston Road Underpass, British Columbia: Design Concept

owner to the contractor.

Drawings can also be used to communicate internally within a design organization, for example from one designer to another or from designer to drafting staff. An example of such a drawing is shown in Figure 5.6. Because communication is within the same organization, the level of formality is less than what was used in the drawing of Figure 5.3. There is still, however, a significant expectation that the drawing will be clear and correct, since the quality of the work of others within the organization will depend on this.

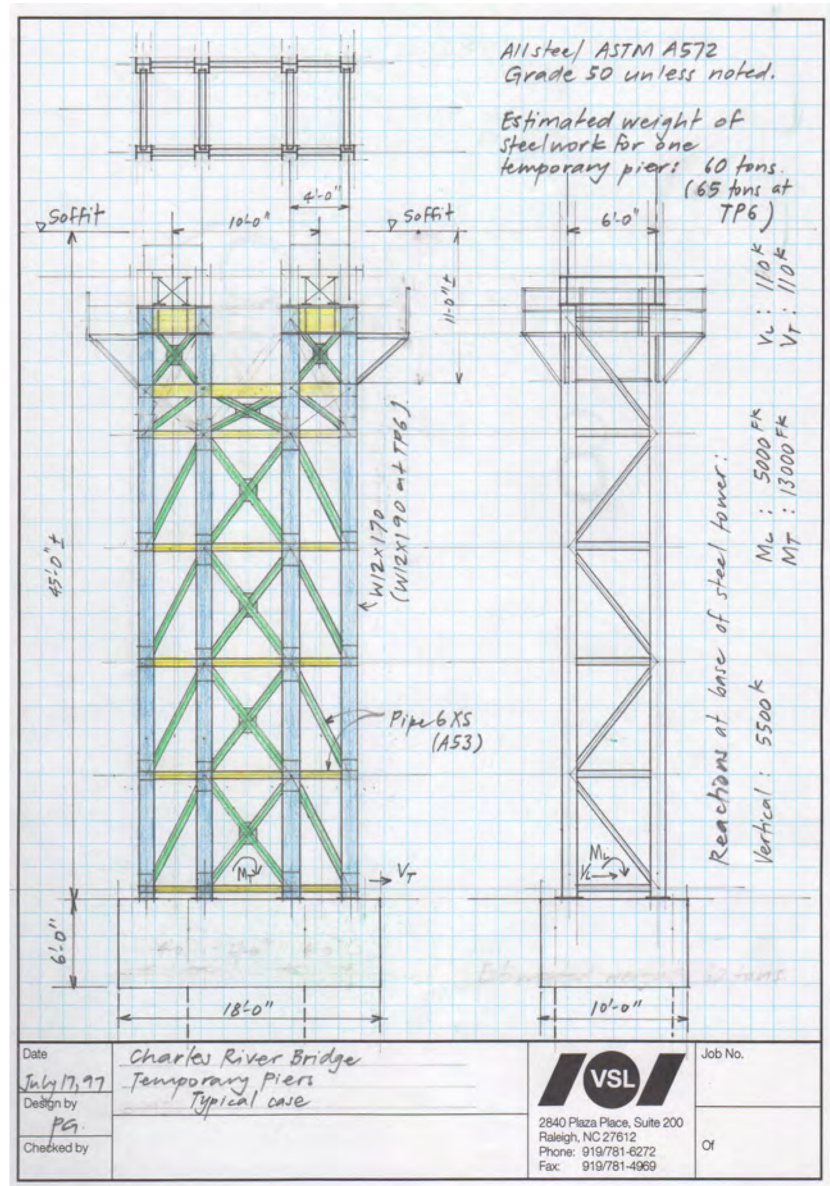


Figure 5.6: Sketch of Temporary Tower, Study for the Construction of the Charles River Bridge

5.4.2 *Drawing as a Tool for Designers*

When we make the drawings described in the previous section, we already know what to draw, i.e., the drawings communicate ideas that already exist. In the initial stages of the design process, though, these ideas have not been formed; we need first to imagine them. The process of creating new ideas where none exist also relies on drawing. The drawings produced to assist in this task can be regarded as *tools* that designers use to generate, improve, and validate ideas.

The use of drawing as a tool in the creative process is illustrated in the following set of sketches, all of which related to the task of developing a concept for a bridge to cross a valley. For this bridge, the following information has been given: the profile of the valley, the profile of the roadway, the location of a small river, in which no supports can be located, and three additional locations where supports for the bridge are not permitted. This information generally forms part of the *design criteria* ▷ .

See Section 5.3.

The first step is simply to *draw what you already know*. The outcome of this step is the sketch shown in Figure 5.7, which shows all the given information: the profiles of valley and roadway, the river, and three zones, called "A", "B", and "C" that represent the areas where supports for the bridge are not allowed. This drawing is of fundamental importance to the subsequent stages of the design process, and for this reason we will refer to it using a special term, the *base drawing*. It is the canvas upon which the ideas that emerge from the subsequent stages of the design process will be drawn. For this reason, the base drawing needs to be drawn with considerable care and precision (and, for obvious reasons, to scale). If it has been drawn precisely, then the sketches we draw on it later in the design process, even if done freehand, will themselves have a measure of realism that will greatly improve their value to the designer.

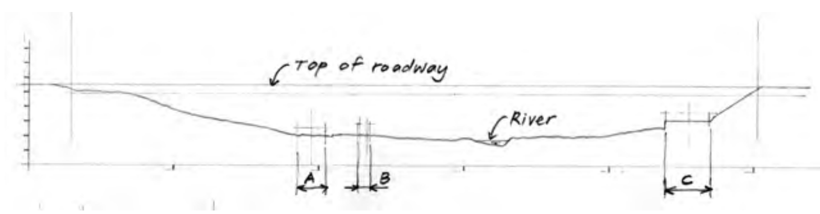


Figure 5.7: Base drawing of valley to be crossed by a bridge, with roadway profile and constraints

It may seem strange that the creative process should begin with the seemingly un-creative task of simply drawing up existing information. Although the outcome of this task, the base drawing, indeed contains no new information, the process of creating it can help to awaken the creative faculties of the brain. This relation between drawing and creativity was described by Edwards[1], whose work was based on Nobel laureate Roger Sperry's research into the bicameral mind[2]. Edwards identified the right side of the brain as the location of our ability to visualize objects in three dimensions as well as our ability to imagine new ideas. (The left side of the brain, in contrast, is the centre for language and logical thought.) She proposed that if we give the mind a task that can only be handled by the right side of the brain (e.g. making a drawing), then the right side becomes more active and the left side less active. As a result of the hightened state of activity of the right side of the brain, we make it more apt to perform all of the functions to which it is suited, including imagining new ideas.

[1] Betty Edwards. *Drawing on the Artist Within.* New York: Simon & Schuster, Fireside Books, 1987

[2] Roger W. Sperry. "Hemisphere deconnection and unity in conscious awareness." In: *The American Psychologist* 23.10 (1968), pp. 723–733

What is required is to draw with concentration and focus, paying close attention to the geometrical relationships linking the objects in our drawing. This not only gives the mind a task that only the right brain can handle, it calms the left side of the brain since we are really not relying on logic or language. This, of course, is only true if we remain silent while we draw. If we are engaged in conversation while we are trying to draw, then the left side of the brain will be maintained in an active mode and will tend to prevent the right side of the brain from assuming the dominant state required for creative thought.

Once we have completed the base drawing, we can use it as the canvas upon which we draw our new ideas. In this case, we will begin by drawing in the locations of the supports for the bridge. At this stage in the process, we probably do not know where these supports should be. We will find out, though, by drawing them at what we consider to be the "most likely" locations, and then examining what we have drawn. Figures 5.8 and 5.9 show two possible arrangements of supports that might emerge from this process. In both cases, they have been drawn freehand with vertical lines representing the centrelines of the piers. With these sketches, we now have a five-span option and a three-span option for the bridge.

We observe from these sketches that, even though the lines were drawn freehand and without measurement of any kind, they convey a reasonably convincing degree of realism. This is thanks to the base drawing, which was drawn with care and precision, and thus helps to maintain a considerable degree of precision to the drawings made on the basis of the base drawing, even if the subsequent lines were drawn freehand. We can thus use these sketches to verify that both options satisfy the constraints relating to areas where no supports can be located.

We also observe that, even though no more than six lines were drawn, we can visualize a bridge emerging from the sketches. This is because we chose to draw lines that embodied high *increments of definition* ▷ .

With the sketches of Figures 5.8 and 5.9, we effectively have two options that can be evaluated. The outcome of this evaluation will be to choose either the five-span option or the three-span option for further development. This decision might be made on the basis of the sketches as shown in Figures 5.8 and 5.9, or might be made based on the outcome of subsequent stages of development of the two options. One way or another, the decision cannot be made on a purely visual basis, but requires knowledge of bridges.

We will assume that we have decided to proceed further with the three-span option, and on this basis we use the sketch of Figure 5.9 as our base drawing for the sketches of Figures 5.10, a cable-supported bridge, and 5.11, a truss bridge.

Although both sketches were drawn freehand, and rather roughly, the impression of the two options thus created is sufficient realistic to serve as a basis for further evaluation and development of the design concepts. For example, on the basis of the sketch shown in Figure 5.11, the three-span truss concept can be further refined into

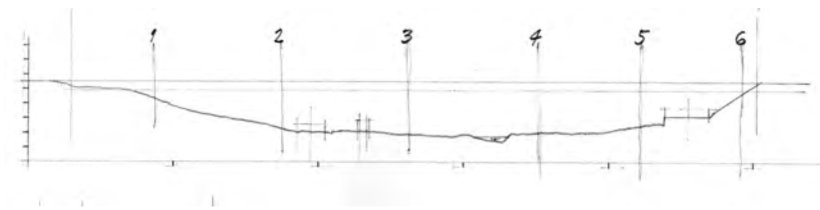


Figure 5.8: Bridge over a valley: possible locations for supports, five-span option

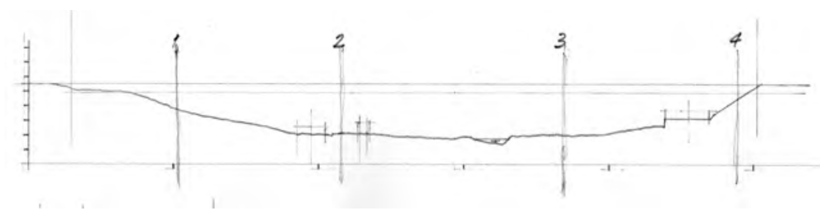


Figure 5.9: Bridge over a valley: possible locations for supports, three-span option

See Section 5.3

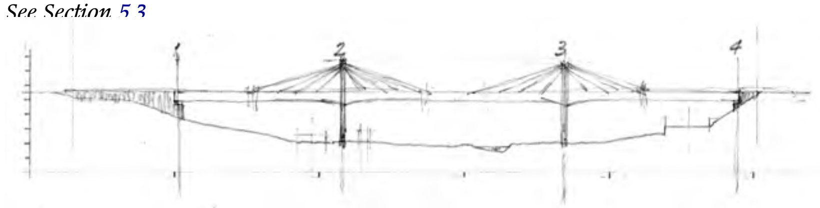


Figure 5.10: Bridge over a valley: cable-supported concept

Figure 5.11: Bridge over a valley: truss concept

the concept depicted in Figure 5.12. Although this is another view of essentially the same concept, it has been drawn with additional detail and precision. The precision is sufficient to enable the spans to be dimensioned.

Drawings made as tools in the creative process must balance *speed* and *geometric precision*. We need to draw as fast as our mind imagines new ideas, to ensure that no new ideas are lost while we are busy drawing up previously imagined ideas. This speed, however, must not be gained at the expense of precision, since insufficiently precise drawings will be of little help in subsequent stages of the design process.

Figure 5.13, for example, is an alternate sketch of the same concept shown in Figure 5.14 (which was shown previously as Figure 5.11). The sketch in Figure 5.13 was drawn more quickly, and without the use of a good base drawing. Both sketches show a three-span truss bridge, but the sketch of Figure 5.13 is less useful, since it does not allow us to verify whether or not the constraints regarding location of supports have been satisfied.

Computer-aided drawing systems are becoming easier and hence faster to use. Some individuals who are very proficient in CAD can draw at a speed rivaling that of freehand drawing. It is possible that, in the future, CAD will become the medium of choice for drawings used as tools in the creative process. There are still, however, significant benefits to be gained from acquiring the skills necessary to produce freehand drawings with sufficient speed and precision. These include the following:

1 Freehand drawing can be done anywhere and anytime, since it needs only a scrap of paper and a pencil. This is especially important when an idea occurs to us when we are away from a computer.

2 In the modern world, computers are often a source of distraction, with e-mail, instant messaging, and the world wide web constantly vying for our attention. Freehand drawing gives us a means of drawing away from the computer, and thus a means of concentrating

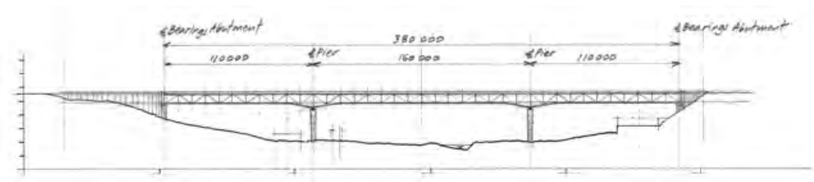


Figure 5.12: Bridge over a valley: refinement of the truss concept

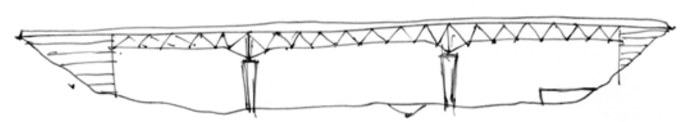


Figure 5.13: A very rough, quickly drawn sketch of the truss concept

Figure 5.14: A more precise sketch of the truss concept (reproduced from Figure 5.11)

completely on the design task at hand.

3 Current CAD systems require that lines and other drawing elements be positioned on the basis of dimensions and/or coordinates, i.e., on the basis of numerical information. When we draw freehand, we position these elements on the basis of known geometrical relationships, such as straightness, relative proportions, and familiar angular relations such as parallel lines and perpendicular lines. Because there is no need to be concerned with numerical relations when producing freehand drawings, it is usually easier for us to make the right side of the brain more active, and thus to maximize its potential for creative thought.

5.4.3 Discussion

To use drawing effectively in the design process, therefore, we need to be able to produce two different types of drawing. We need to make relatively formal drawings intended to convey information to others. These drawings need to be clear, complete, and correct, since they are often incorporated into formal contracts valued at many millions of dollars. We also need to make relatively informal drawings to serve as tools within our own creative process. These drawings not only provide a means of getting ideas from our imagination onto paper, but also can help the imagination in the process of creating new ideas.

6
The Process of Engineering Drawing

It is important for engineers to create drawings *efficiently*, i.e., to produce drawings that perform their required function within the design process with minimum time and effort. The task of producing drawings efficiently is made easier when a suitable *process* is followed.

This chapter defines a separate drawing process for each of the two primary types of drawing encountered in engineering design practice: drawings that are used as tools in the creative design process, and drawings that communicate the outcome of the design process ▷ . Both processes, however, essentially involve acquiring a clear understanding of the purpose of the drawing and the relevant characteristics of the object to be drawn, using this information to plan a sequence of drawing steps that is efficient, and then creating the drawing according to this plan. The two processes will be described in greater detail in the following sections.

See Section 5.4.

6.1 *Drawings that Communicate the Outcome of a Design Process*

Drawings created to communicate the outcome of a design process generally embody a high degree of *geometric precision*, i.e., fidelity the object it represents. The more precise a drawing, the more it "looks like" the object.

In addition, drawings created to communicate the outcome of a design process usually project a relatively high degree of *formality*. In this context, formality refers to the extent to which a given drawing adheres to accepted conventions that enable others to work with the drawings we have created. Drawings that will be used as a basis for a construction contract, for example, must generally include (1) a title block giving information on the project, designer, and owner, (2) a drawing number, (3) complete dimensions of the objects represented in the drawing, (4) *standard two-dimensional views* of the objects depicted ▷, and (5) centrelines and section cut symbols drawn according to an accepted standard ▷.

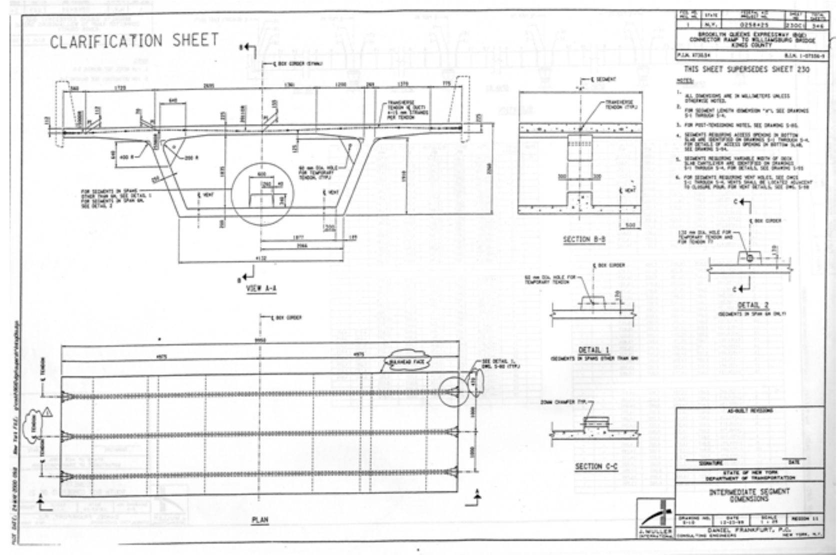


Figure 6.1: Drawing of a precast concrete bridge segment

See Chapter 7.

See Appendix A.

The drawing shown in Figure 6.1 embodies a high degree of geometric precision and projects a high degree of formality. We recognize the relatively high level of formality in this drawing by the items mentioned previously: the title block, dimensions, centrelines, section cut marks, and standard views. The high level of geometric precision is implied by the good agreement of the geometric features of the precast concrete bridge segment ▷ shown in the photograph of Figure 6.2 and the drawing of Figure 6.1. This agreement could be definitively confirmed by comparison of dimensions shown on the drawing and those obtained from on-site measurement of the segment.

For additional information on precast concrete bridge segments, see Chapter 54.

In this course and in most cases in current engineering practice, drawings created to communicate the outcome of the design process are drawn using CAD.

Figure 6.2: Photograph of the precast concrete bridge segment depicted in Figure 6.1

The primary steps of the process to be followed in creating drawings intended to communicate the outcome of a design process are as follows:

1. Define the function to be performed by the drawing
2. Confirm that the drawing can perform the function as intended
3. Organize all relevant information pertaining to the object to be drawn
4. Plan the steps to be followed in the actual production of the drawing
5. Produce the drawing according to the plan

Steps 1 through 4 are essentially planning tasks performed before the actual production of the drawing is undertaken. Step 5 is the actual production of the drawing. These steps will be discussed in greater detail in the following subsections.

6.1.1 Define the Function to Be Performed by the Drawing

This task essentially involves establishing *what exactly needs to be communicated* by a given drawing. We need to ensure that drawings are complete, i.e., that they convey all the information they are expected to. It is just as important, however, to ensure that a given drawing contains no more information than is necessary to perform its function. This minimizes the time required to create the drawing, which increases efficiency, and maximizes clarity.

The drawing shown in Figure 6.1, for example, was created to describe the precast concrete bridge segment shown in Figure 6.2. The drawing gives a complete description of the dimensions of the formwork required to produce the three-dimensional visible shape of the segment. It also defines the type and geometry of three post-tensioning tendons that extend across the top slab. This is not, however, a complete description of the segment. Absent, for example, is any information regarding the reinforcing steel that must be provided. These bars, shown in the photograph of Figure 6.3, are important and their arrangement is relatively complex. The engineer in charge of the design of this bridge decided that providing information on formwork dimensions, post-tensioning steel, and reinforcing steel was too much for one drawing, i.e., putting a complete description of the segment on one drawing could not be accomplished without sacrificing the required degree of clarity. In fact, two additional drawings were provided to describe the reinforcing steel, one of which is shown in Figure 6.4.

Based on these considerations, the function of the drawing shown in Figure 6.1 could thus be described as follows: *provide a complete description of (1) the dimensions for the formwork required to construct an intermediate segment and (2) the post-tensioning tendons required in the top slab.*

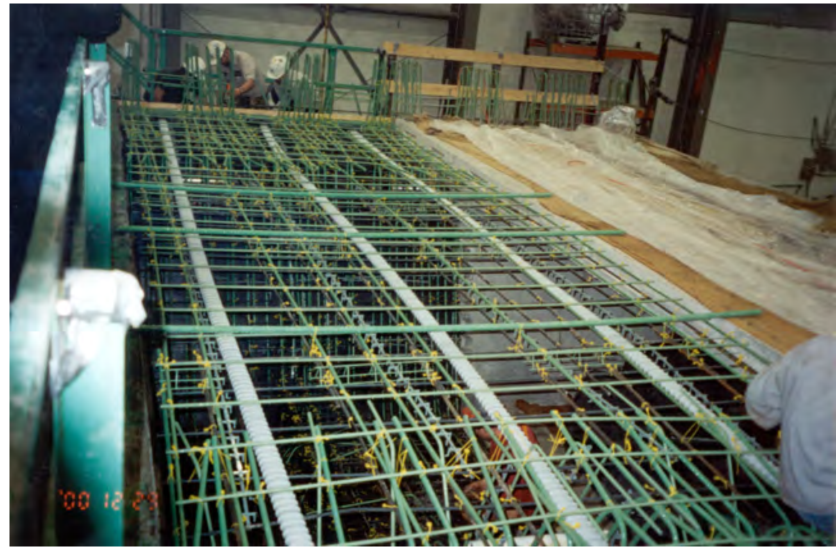


Figure 6.3: Photograph of reinforcing steel for the precast concrete bridge segment depicted in Figure 6.1

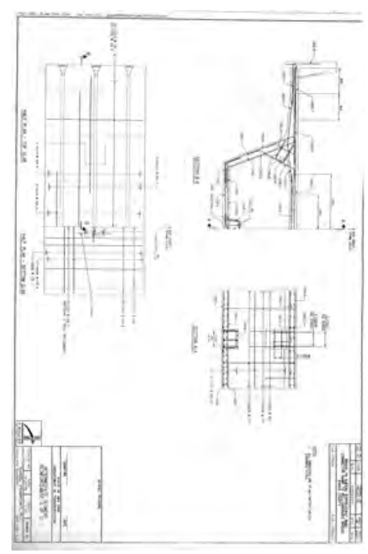


Figure 6.4: Drawing of reinforcing steel for the precast concrete bridge segment depicted in Figure 6.1

6.1.2 *Confirm that the Drawing Can Perform the Function as Intended*

It is important to confirm, before significant effort has been invested in producing it, that a given drawing will be capable of performing its intended function. This generally involves demonstrating that the drawing will be capable of describing, clearly and completely, all of the features of the given object that it is expected to describe.

This task is usually best accomplished using *mock-ups*. In this context, a mock-up is a rough sketch of the primary elements to be provided in a given drawing. All known elements that could limit the space available for views, such as borders and title blocks, are measured and drawn appoximately to scale. Scales are estimated for the views and space is blocked out accordingly. These blocks of space are then arranged within the border and the resulting arrangement is carefully reviewed, to ensure that everything that needs to be on the drawing can be provided in the available space with a suitable degree of clarity.

Figure 6.6 shows a mock-up for the drawing shown in Figure 6.5. The border and title blocks have been blocked out, approximately to scale, to ensure that views are not located in these areas. Based on this mock-up, it can be confirmed that the three primary views required to define the geometry of the formwork and the arrangement of the post-tensioning tendons can be accommodated within the available space at a scale of 1:25. Space has also been blocked out for notes.

The designer has also anticipated the need for additional details describing the block provided at the middle of the bottom slab. These details are required due to the presence of a pipe in the block. The location, diameter, and details of this pipe will need to be specified. The designer thought that providing this information in View A-A and Section B-B would result in an unacceptable reduction in clarity, and for this reason made provision for including these additional details.

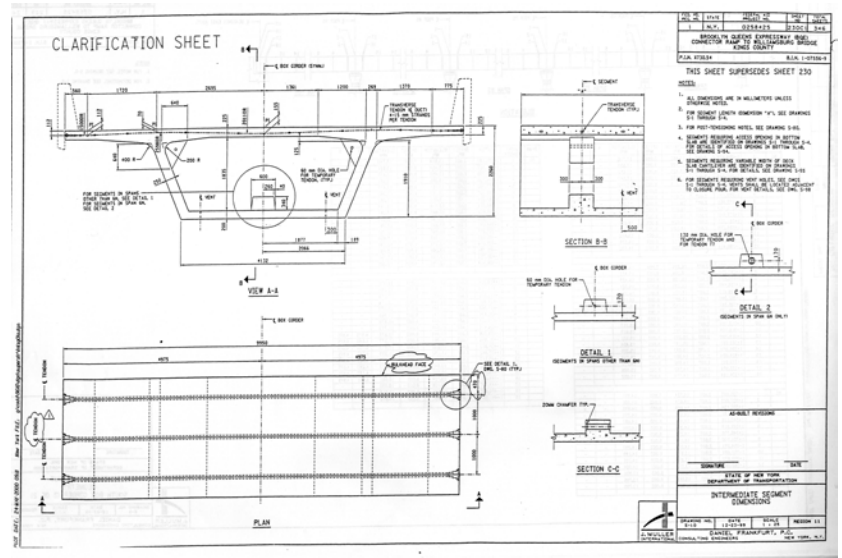


Figure 6.5: Drawing of a precast concrete bridge segment

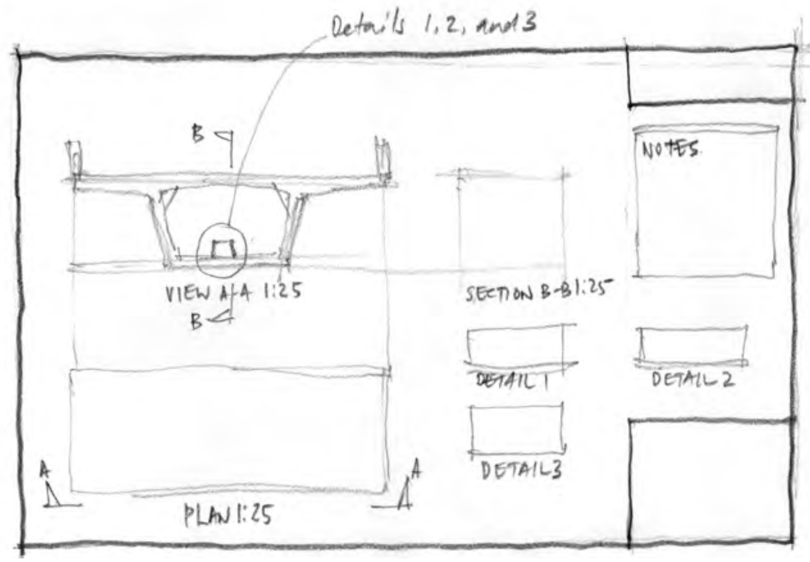


Figure 6.6: Mock-up of the drawing shown in Figure 6.5

When blocking out space for views, always make a reasonable allowance for accommodating dimensions, section symbols, titles, and leaders. Over half of the total height of the bridge elevation shown in Figure 6.7, for example, is taken up by dimensions. In such a case, blocking out space only on the basis of the view of the object without consideration of the space required for dimensions would have resulted in a significant under-estimation of the actual space required.

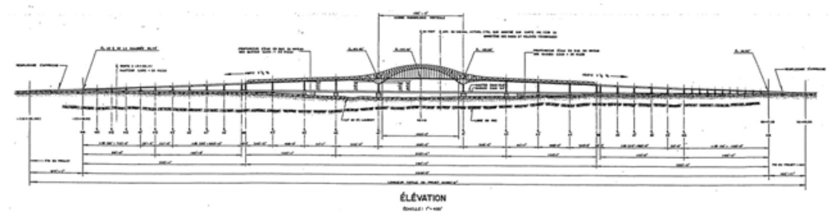


Figure 6.7: Elevation of the Laviolette Bridge across the St. Lawrence River near Trois-Rivières, Québec. For a photograph of this bridge, see Figure 7.28.

6.1.3 *Organize Information Pertaining to the Object to be Drawn*

When we create drawings to communicate the outcome of a design process, all of the information required to create a given drawing is by definition available before we begin drawing. This information, however, is not always presented in a way that makes possible an efficient drawing process. Before beginning to create a given drawing, therefore, it is always worthwhile to organize the available information into a format that enables the drawing process to proceed with maximum efficiency.

One of the primary considerations in this regard is defining the geometry of the object so that the object can be drawn as quickly as possible. When we draw with CAD, this often means drawing with minimal use of the keyboard and maximum use of the mouse. This can be accomplished by locating the key points of a given component (usually intersections of straight line segments) as the intersection of *construction lines* and then drawing the view by snapping to these intersections.

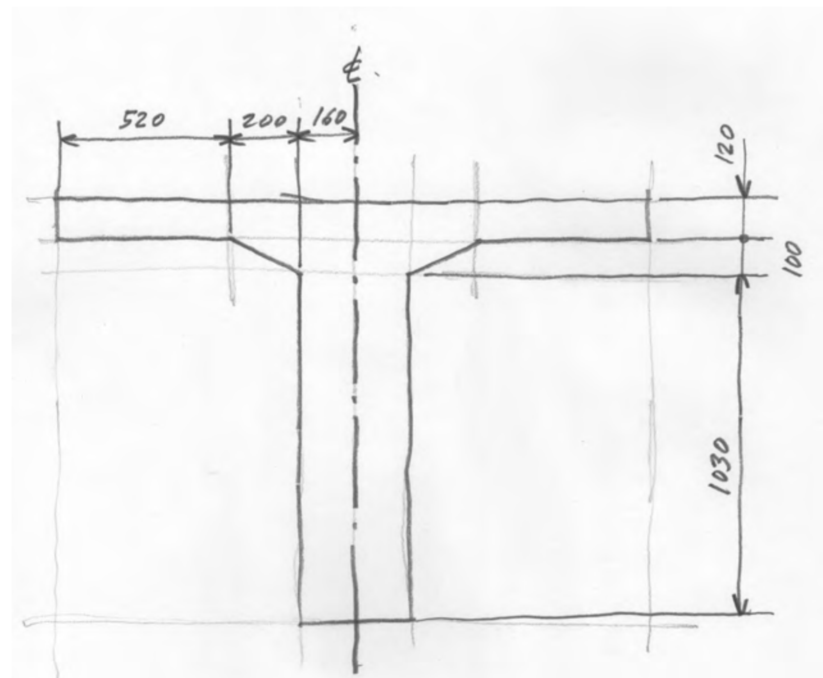


Figure 6.8: Sketch with geometrical information required to draw the T-section shown in Figure 6.9

The best way to organize relevant information on the object to draw in this way is to create simple sketches (these can generally be freehand) of the object to be drawn. These sketches should identify key points and give horizontal and vertical offsets of these points from established datum lines. The resulting set of dimensions does not have to conform to the drafting standard ▷ that applies to the formal drawing that will be created. In many cases, these working

See Appendix A.

dimensions will be quite different from the final formal dimensions.

The sketch shown in Figure 6.8 is used, for example, as a basis for drawing the T-section shown in Figure 6.9. The sketch, which consists of the outline of the cross-section, dimensions, and axis of symmetry, gives enough information to place intersecting horizontal and vertical lines at all key points on the T-section. These can then be quickly connected with a line that is snapped to the intersection points.

As we prepare sketches such as the one shown in Figure 6.8, we also acquire an understanding of important geometric relationships embodied in the object we intend to draw. These relations will play an important role in developing the plan to be followed in creating the drawing, which will be discussed in the following section. The most important geometric relationships include:

1. Any kind of symmetry, including bilateral and rotational symmetry
2. Parallel and perpendicular lines and planes
3. Major components
4. Regular geometrical figures such as squares, rectangles, circles, ellipses, and parabolas
5. Simple proportions (halves, quarters, etc.)
6. Identical figures and geometrically similar figures

For example, precast concrete bridge segments generally have four major components (Item 3 in the preceding list): a top slab, two inclined webs, and a bottom slab. They usually have a vertical axis of symmetry (Item 1 in the preceding list) and two important horizontal parallel planes (Item 2 in the preceding list), i.e., the top and bottom surfaces. The cantilevering portions of the top slab are approximately one quarter of the overall width of the top slab (Item 5 in the preceding list). The thickness of the slabs is generally small

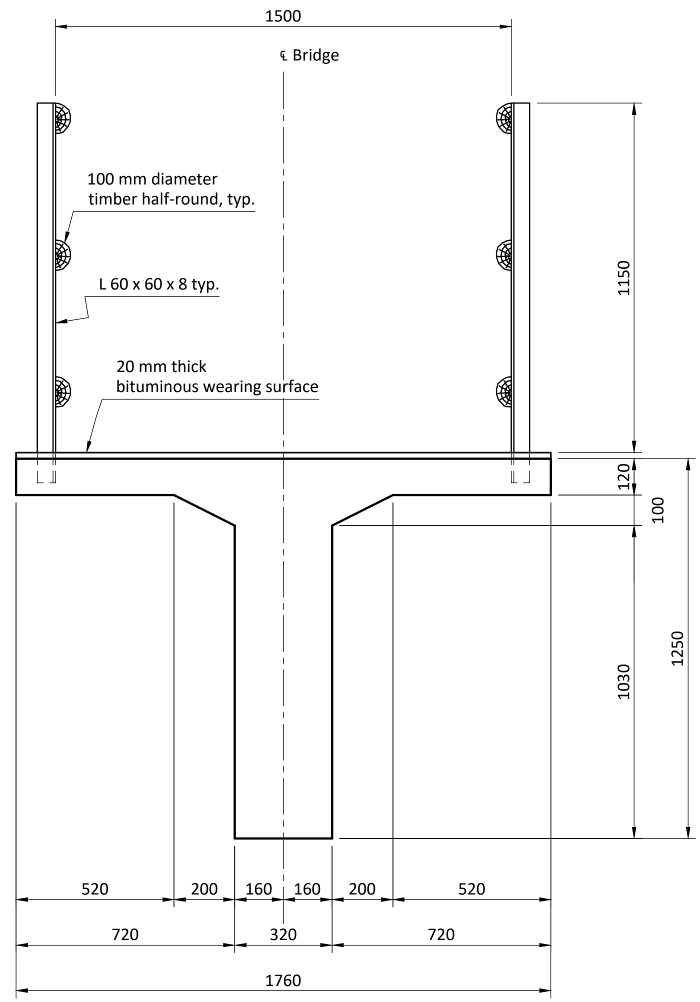


Figure 6.9: Pedestrian bridge cross-section drawn in part using the information provided in the sketch of Figure 6.8

relative to the overall width of the segment. These relationships are illustrated in the sketch shown in Figure 6.10.

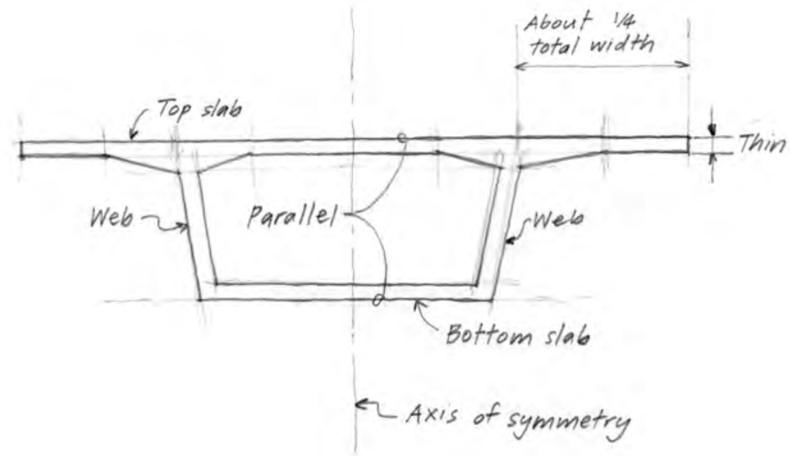


Figure 6.10: Sketch of precast concrete bridge segment

6.1.4 Plan the Steps to Be Followed in Producing the Drawing

There are two main tasks in producing drawings intended to communicate the outcome of a design process. The first is to *draw the object itself*, i.e., to define its geometry using lines and other drawing elements. The second is to *create and arrange the views* that will be required. This task includes adding all the elements required of formal engineering drawings, including dimensions, titles, section symbols, and annotations. Both of these tasks need to be considered in the development of an effective plan for producing a given drawing efficiently.

1 *Drawing the object itself*

In this course, drawings intended to communicate the outcome of a design process will be created using CAD, which offers several advantages over drawing by hand. With regard to efficiency, CAD's greatest advantage is that *it enables previously drawn work to be duplicated and transformed.* All CAD software products contain a rich set of commands that enable drawing elements to be translated, rotated, reflected about a given mirror line. Some products, such as SketchUp, contain advanced tools that enable two-dimensional objects to be transformed into three-dimensional objects by extrusion. These functions enable the process of creating a given drawing to progress much more quickly than if every drawing element was created from scratch. The process of creating a given drawing must be planned to take full advantage of this important property of CAD.

The basis for drawing by transforming what has already been drawn is *knowledge of the primary geometrical relationships embodied in the object to be drawn* ▷ . If we know that a given object has a vertical axis of symmetry, for example, we need draw only one half of the object, and then reflect it in the axis. If we know that two lines

See Section 6.1.3.

are parallel, we need draw only one of them from scratch and then create the second line by creating a copy of the first at a specified perpendicular distance from the first, a function called *offsetting*.

The following steps associated with creating a three-dimensional drawing of a simple bridge segment illustrate some aspects of the use of CAD functions for transforming previously drawn elements together with knowledge of the primary geometric relationships.

Figure 6.11 shows horizontal and vertical lines placed such that their intersections correspond to key points on the half cross-section. (The image has been produced in perspective view, so the lines do not appear perfectly horizontal and vertical).

Figure 6.12 shows diagonal lines corresponding to the inner and outer faces of the web. When working with parallel diagonal lines, it is sometimes more efficient to define one line using the intersection of horizontal and vertical lines, and to create the other one by offsetting from this line.

Figure 6.13 shows the half-section completely delineated. This was accomplished simply by "connecting the dots", i.e., by snapping to the intersection points of the horizontal and vertical lines defined previously.

Figure 6.14 shows the complete cross-section, created by reflecting the half-section about its axis of symmetry.

Figure 6.11: Establish the location of key points on the edge of the half cross-section as the intersection of horizontal and vertical lines

Figure 6.12: Establish the two sloped faces of the web

Figure 6.13: Draw the outline of the half cross-section

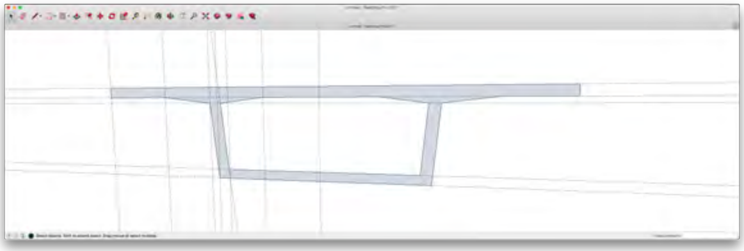


Figure 6.14: Mirror the half cross-section to produce the full cross-

Figure 6.15 shows the completed segment, created by extruding the cross-section.

The preceding steps obviously illustrate a drawing process that takes place after the plan has been developed. Planning the primary steps of this process, which must happen before beginning to draw, will require that these steps be imagined. Being aware of what you are doing when you are actually drawing, and whether or not you are working efficiently, will help in the process of imagining the process of drawing before you actually begin.

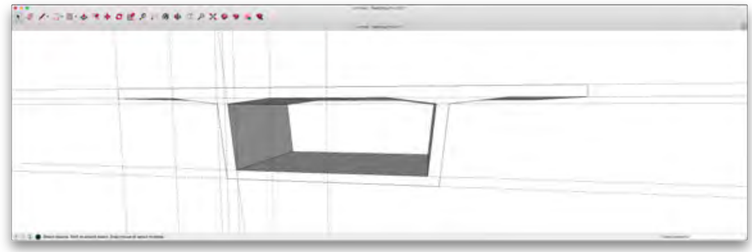


Figure 6.15: Extrude the cross-section to create the three-dimensional segment

2 *Creating and arranging the views*

Once the object has been drawn, it is necessary to create and arrange views as they will appear on paper. Many people underestimate the time required for this activity as well as its importance to the overall correctness, completeness, and clarity of the drawing. This usually results in either wasted time and effort, or drawings of inferior quality.

The challenge arising from this task is generally associated with develping an arrangement of dimensions, annotations, titles, and section marks that is clear and professional-looking, and then planning out a sequence of steps that will enable this arrangement to be created with minimum effort. It is usually helpful to work with a mock-up of the drawing, upon which all of the dimensions, annotations, titles, and section marks have been roughed with pencil. It must then be confirmed that the mock-up thus produced contains all of the necessary information and that the information is displayed clearly and correctly. Following this, the elements should be added to the drawing in layers, beginning with those closest to the object and moving outward away from the object. This will ensure not only that everything needed is drawn, but also that everything fits well.

Figure 6.16 illustrates these concepts. It is a plan of a bridge foundation supported by circular piles. A mock-up would reveal that it is necessary to locate the centreline labels between two lines of dimensions, so sufficient room must be provided. The recommended procedure is thus to draw the inner line of dimensions, add the centreline labels, and then add the outer line of dimensions. This creates the best conditions for providing adequate space to accommodate the dimensions and the labels. Drawing both lines of dimensions first could result in insufficient space for the centreline labels.

6.1.5 Produce the Drawing According to the Plan

Assuming the previous steps in the process have been performed well, the process of actually producing the drawing should be relatively straightforward.

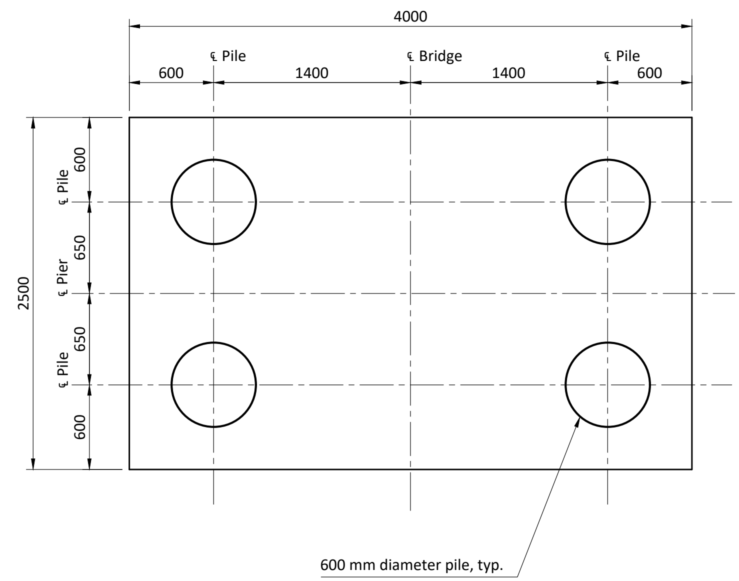


Figure 6.16: Plan of bridge foundation

6.2 Drawings Created to Serve as Tools in the Creative Design Process

To be effective as tools in the design process, drawings must be executed quickly and thus will be relatively informal. They are very often done freehand. It therefore follows that this type of drawing can and should proceed with less advance planning than would be expected for drawings created to communicate the outcome of a design process ▷ .

See Section 6.1.

Drawings created for use as tools in the design process will only be of value, however, if they embody a minimum degree of geometric precision. Although the drawing shown in Figure 6.17 is not as precise as a CAD drawing, it will be precise enough to be used effectively as a tool in many tasks in the design process. The drawing of Figure 6.18, is unlikely ever to be of significant value because its degree of geometric precision is insufficient.

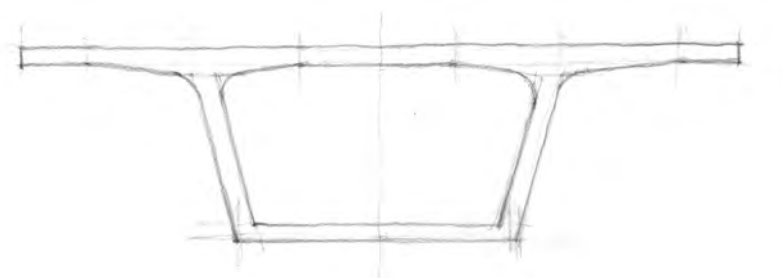


Figure 6.17: Informal drawing of the precast concrete bridge segment shown in Figure 6.2. It embodies a degree of geometric precision that will generally be sufficient for use as a tool in the design process.

This implies that the drawings we create to serve as tools in the creative process must bear some minimum degree of geometric fidelity to the objects they depict. To produce these drawings efficiently, therefore, we will need to have access to a suitably organized body of knowledge related to the objects we intend to draw. This implies the need for a drawing process that incorporates advance planning.

The difficulty is that, by definition, a complete body of knowledge of the objects we intend to draw is not available before we begin to draw, since the process of drawing the object is the process by which the geometric properties of the object will be defined. We therefore need to proceed by identifying geometric properties that would realistically be required to enable the object to perform its function, and/or on the basis of geometric properties embodied in objects that perform similar functions. When we draw a box girder bridge cross-section, for example, we might not know the exact dimensions of all the cross-section components as we begin to draw, but we will know

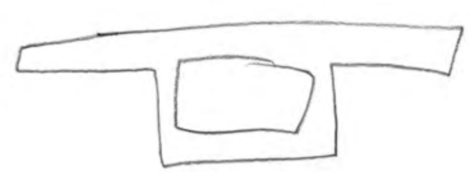


Figure 6.18: Informal drawing of the precast concrete bridge segment shown in Figure 6.2. Its degree of geometric precision is too low to enable this drawing to be of any value as a tool in the design process.

that this type of section is likely to embody the following geometric properties ▷ : (1) it will have four major components: a top slab, two inclined webs, and a bottom slab, it will most probably have a vertical axis of symmetry and two important horizontal parallel planes, i.e., the top and bottom surfaces, (3) the cantilevering portions of the top slab will be approximately one quarter of the overall width of the top slab, and (4) the thickness of the slabs will generally be small relative to the overall depth of the section. Once these relationships have been established, a reasonable freehand drawing of the cross-section can be created.

See Section 6.1.3 and Figure 6.10.

With this in mind, therefore, the steps defined previously for drawings created to communicate the outcome of a design process ▷ can be used as a template for developing steps for creating drawings to be used as tools in the design process:

See Section 6.1.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

For drawings created to communicate the outcome of a design process, this step was necessary to ensure that the drawing communicated exactly what the designer intended it to communicate. *This step will generally not be required for drawings created as tools in the design process.* Many of these drawings will be incomplete, and many will contain information that will turn out to be unnecessary. This does not detract from their value as tools in the design process.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

For drawings created to communicate the outcome of a design process, this step was necessary to ensure that the drawing would be capable of communicating the required information completely and clearly, given constraints on the physical dimensions of the printed drawing. *This step will generally not be required for drawings created as tools in the design process.* There will almost always be plenty of paper available for as many views as can be drawn by the designer. Useful drawings can even be created on small scraps of paper and by sketching overtop of existing drawings.

3 *Organize all relevant information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This step is important and is required for drawings created as tools in the design process. As stated previously, although a complete definition of the geometric properties of the object to be drawn will not be available when the drawing is started, a systematic compilation of all the information that is known on the object is possible and must be made. This includes known functional requirements that will have an effect on the geometric properties of the object. As discussed previously ▷ , this information is best compiled into a *base drawing*.

See Section 5.4.2.

It also includes knowledge of objects that have been built to perform similar functions in previous projects. If the objective, for example, was to design a single-cell box girder cross-section, we could benefit from knowledge of the geometric properties of previously built box girder cross-sections, even though we knew in advance that most of the dimensions of the previous sections would not be suitable. We could gain much useful information on geometric relationships that could be applied to the design problem at hand.

4 *Plan the steps to be followed in the actual production of the drawing* ▷ .

See Section 6.1.4.

Because of the intimate link between drawings created to serve as tools in the design process and the design process itself ▷ , it follows that the drawing process should proceed in parallel with the design process. In design, we strive to maximize the *increment of definition* contributed by each successive design decision. A drawing process that supports this design process must therefore proceed by maximizing the increment of geometric definition provided by each successive element added to the drawing.

See Section 5.4.2.

So the steps of the drawing process need to be planned to ensure that the object emerges as quickly as possible from the paper with the least number of lines. The process of drawing needs to be planned, at least informally, to ensure that this will be the case.

5 *Produce the drawing according to the plan* ▷ .

See Section 6.1.5.

Assuming the previous steps in the process have been performed well, the process of actually producing the drawing should be relatively straightforward.

So the process of creating drawings to serve as tools in the creative process has the following three steps:

1 Organize all relevant information pertaining to the object to be drawn

2 Plan the steps to be followed in the actual production of the drawing

3 Produce the drawing according to the plan

7
Standard Engineering Views

A basic task for drawing within the engineering design process is to represent three-dimensional objects with two-dimensional drawings, in such a way as to convey both qualitative and quantitative information. Qualitative information is important because it gives us a general overall impression of the visible characteristics of a given object (it enables us to visualize the object). Quantitative information is especially important for engineers because it enables us to extract numerical information on the object that is drawn (e.g. dimensions) and to verify that components fit together in the way they were intended to do.

One possible way to represent three-dimensional objects using two-dimensional drawings is the *contour map* ▷ , an example of which is given in Figure 7.1. Here a three-dimensional landform is represented by lines on the map joining points of equal elevation above sea level. These maps convey both qualitative and quantitative information.

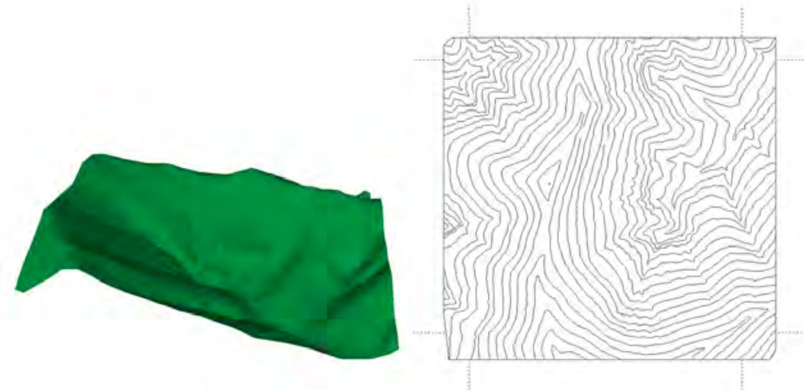


Figure 7.1: Three-dimensional landform (left) and corresponding contour map (right).

See Chapter 10.

Contour maps are not, however, suitable for all three-dimensional objects. Many three-dimensional objects cannot be depicted in a single two-dimensional view in a way that conveys quantitative information. For this reason, *most engineered objects are drawn using multiple views*. These views are generally drawn so that they are true to scale ▷ within the plane of the drawing (i.e., a dimension that is measured on the drawing is the true dimension of the physical object). The views are *linked* ▷ to ensure clarity of the representation and to maximize the information content. Figure 7.2 shows a drawing that depicts the primary features of a bridge using multiple views.

See Chapter 9.

See Section 7.5.

This chapter describes the geometrical basis for creating views that are dimensionally true within the plane of the drawing. It also describes a number of standard views of engineered objects and demonstrates how to link them on a given drawing to achieve greater clarity and enhance the effectiveness of drawings as tools in the design process.

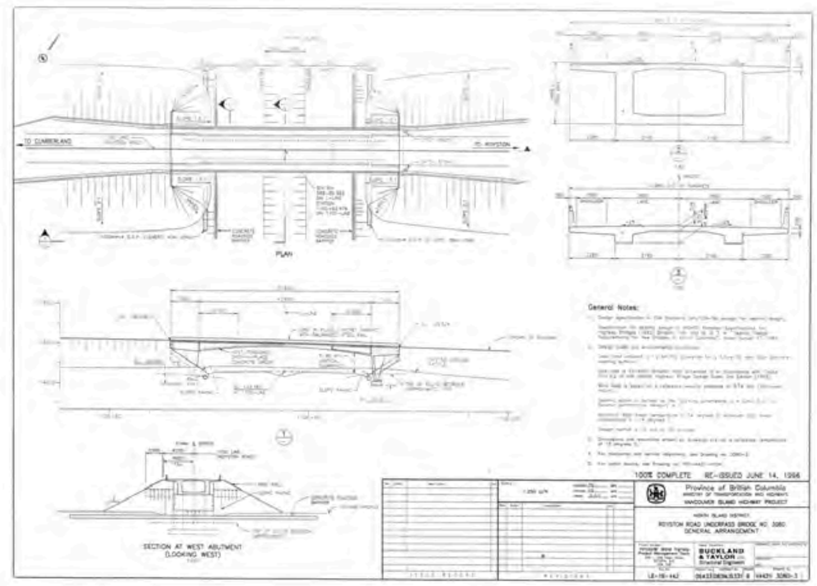


Figure 7.2: A drawing that uses multiple views: Royston Road Underpass, B.C.

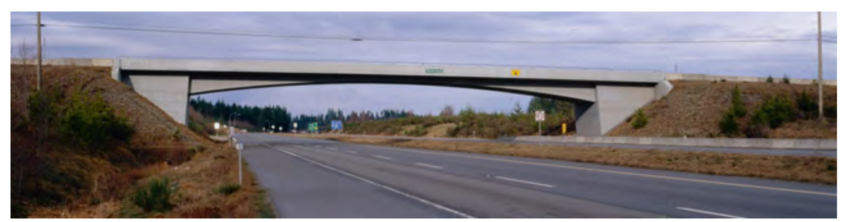


Figure 7.3: Royston Road Underpass, B.C. (A photograph of the bridge depicted in the drawing of Figure 7.2).

7.1 *Viewpoint and Projection Plane*

This section presents the logical basis that underlies the creation of drawings in standard engineering views. Once we understand this basis, we will find that the actual process of creating the drawings is actually quite familiar to anyone who has ever made a simple sketch of an object.

We can represent the act of looking at an object as *a ray extending from our eye to a given point on the object*. As we move our glance from point to point on the object, we can draw additional rays from the eye to each individual point. The location of the eye is called the *viewpoint*. Figure 7.4 depicts a viewer at Point A looking at a bridge segment. Rays from the viewer's eye to various points on the segment have been shown.

The act of creating a picture of the object can be represented by inserting a plane between the eye and the object. This plane will be referred to as the *viewing plane*. Each ray intersects the plane at a specific point (Fig. 7.5).

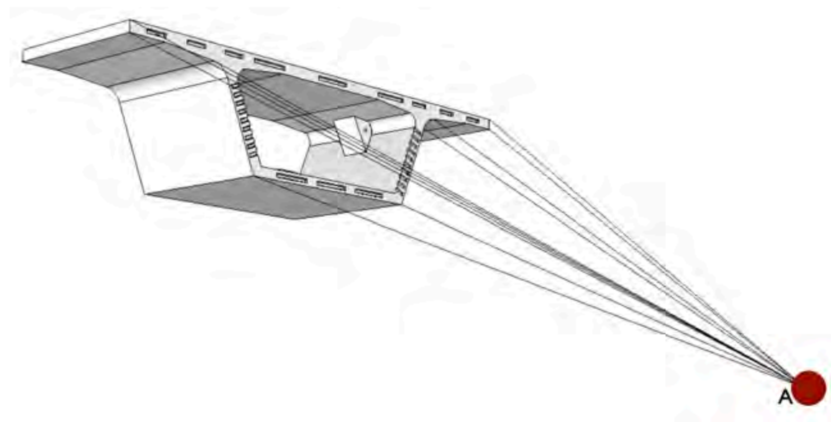


Figure 7.4: A viewer at Point A looking at a bridge segment

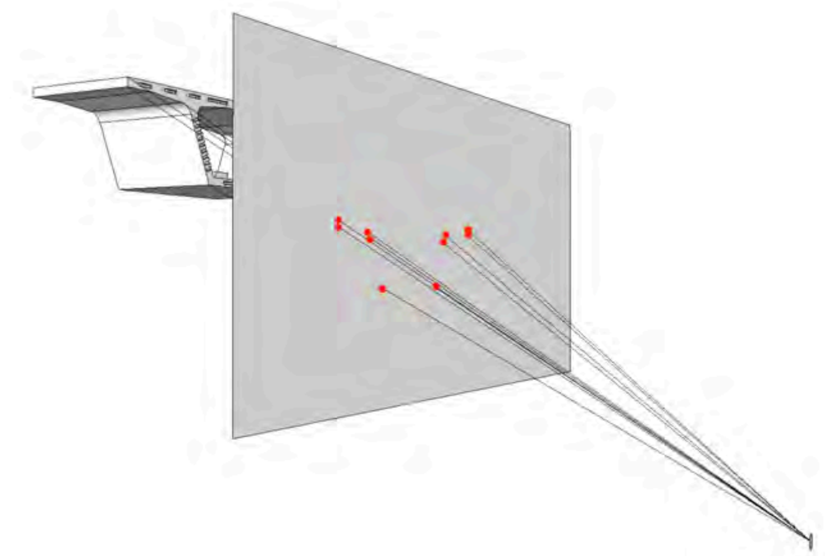


Figure 7.5: Intersection of the viewing plane and the rays between the eye and the object

By joining these points appropriately (Fig. 7.6), we can depict the edges of the object. This collection of points and line segments on the viewing plane thus becomes a two-dimensional representation of the three-dimensional object.

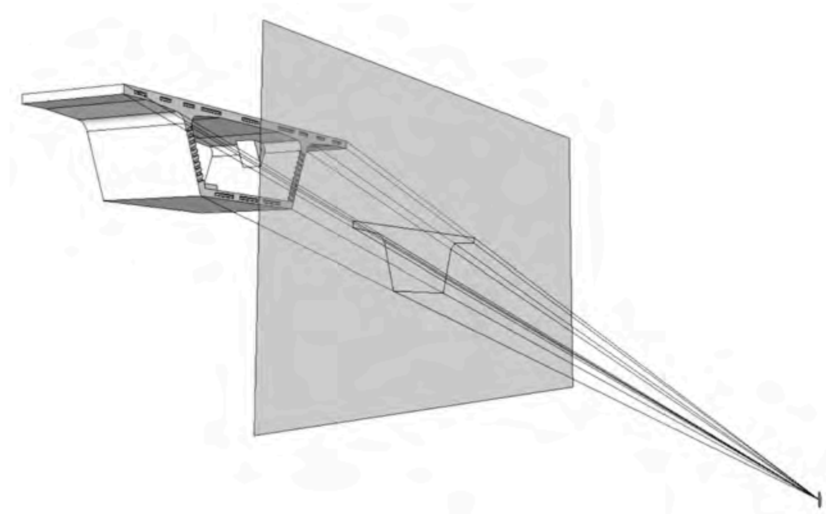


Figure 7.6: Two-dimensional image of the three-dimensional object formed by joining the points of intersection of the rays and the viewing plane

By moving the viewpoint and/or the viewing plane, we obtain a different image of the given object (Fig. 7.7). In fact, each different arrangement of viewpoint and viewing plane relative to the position of the given object produces a different picture.

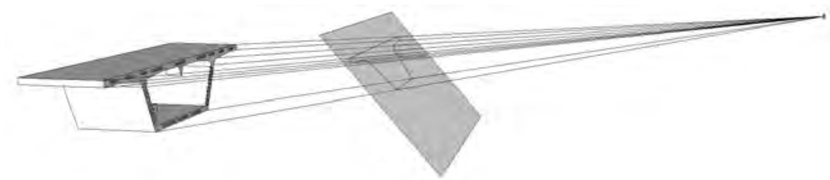
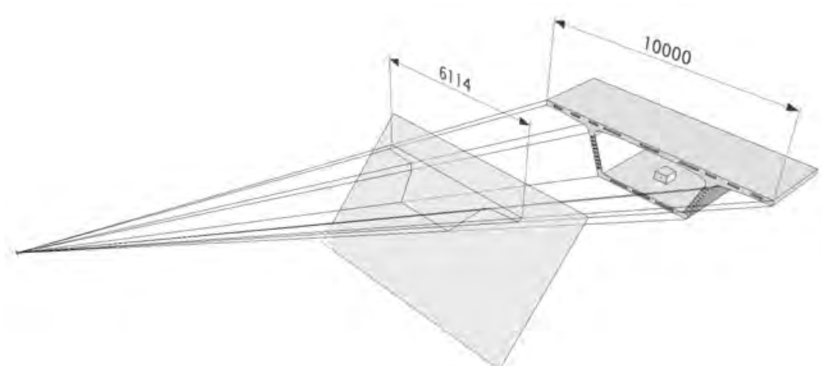


Figure 7.7: A different geometrical arrangement of viewpoint, viewing plane, and object produces a different two-dimensional image from the one shown in Figure 7.6.

We can measure the distance between two given points on the picture (Fig. 7.8). In general, the distance between two given points on the picture will not be equal to the distance between the corresponding points on the three-dimensional object. These types of picture thus do not convey accurate quantitative information.



7.2 Orthographic Views

For a given position of the three-dimensional object and the viewing plane, we observe that by moving the viewpoint farther and farther away from the object, the angle between two given rays becomes smaller and smaller. This phenomenon is depicted in Figure 7.9. As the distance from the viewpoint tends towards infinity, the angle between two given rays tends to zero, i.e., the rays become parallel.

Keeping the viewpoint at infinity, we can position it so that the rays are perpendicular to the front face of the segment. We can then position the viewing plane so that it is perpendicular to the rays. This situation is shown in Figure 7.10. We observe that the distance of any line segment on the object that is parallel to the viewing plane is equal to the distance between the corresponding endpoints as measured on the viewing plane.

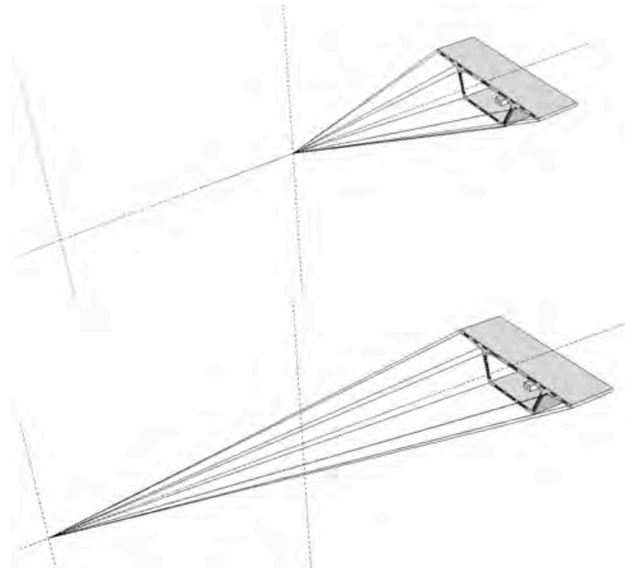


Figure 7.9: Angle between two given rays becomes smaller as viewpoint moves away from the object

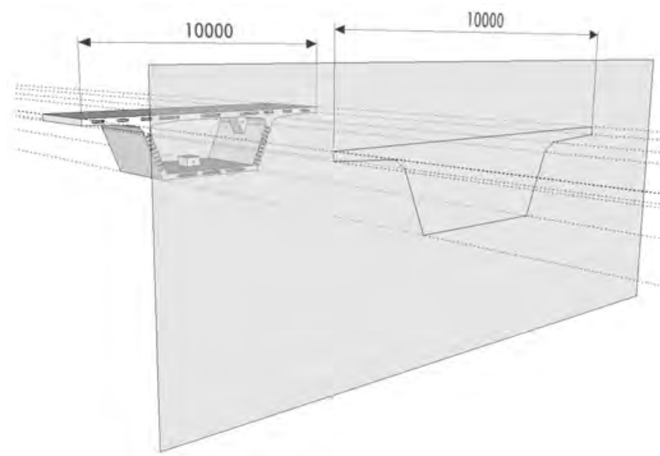


Figure 7.10: Rays are parallel to each other and perpendicular to the face of the segment. Viewing plane is perpendicular to the rays. Distances between two points on the viewing plane are equal to distances between the corresponding points on the face of the segment.

The geometrical arrangement depicted in Figure 7.10 is particularly useful in engineering because many engineered objects can be characterized by principal axes that are mutually orthogonal. It is thus usually possible to arrange a viewing plane parallel to one of the planes defined by two of the principal axes of the object, and to arrange the rays to be perpendicular to these two planes. The bridge girder shown in Figure 7.11, for example, has a clearly defined horizontal axis, which can be associated with the centreline of the roadway. The true vertical direction, which is orthogonal to the horizontal axis thus defined, likewise has meaning for the bridge, since it corresponds to the orientation of the piers and is also normal to the surface of the bridge deck. Having defined directions for the horizontal (longitudinal) axis and the vertical axis, and having convinced ourselves that these directions have meaning for the object under consideration, the third axis (which will be orthogonal to the other two) follows directly. The set of axes thus defined is orthogonal and has direct relevance to the specific characteristics of the object.

We can define viewing planes that are perpendicular to each of these three axes. When the viewpoint is located at infinity and the direction of view is perpendicular to the respective planes, the images thus created are particularly useful. Two such views corresponding to the bridge shown in Figure 7.11 are shown in Figure 7.12. Because the orientation of the viewing planes is perpendicular to the primary directions of the structure, the viewing planes tend to be parallel to a large number of relevant line segments and features within the structure. This enables the extraction of a relatively large amount of quantitative information, i.e., dimensions to be measured accurately on the two-dimensional view.

The relations linking viewpoint, viewing plane, and object represented by the geometrical arrangement depicted in Figure 7.10 can be summarized as follows:

1 Distance of the viewpoint from the object: *infinite*

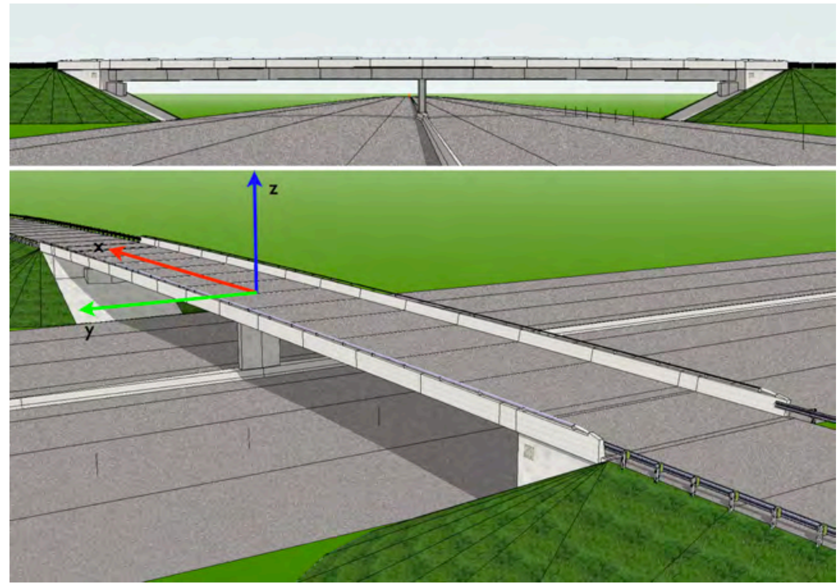


Figure 7.11: Orthogonal principal axes of a bridge girder

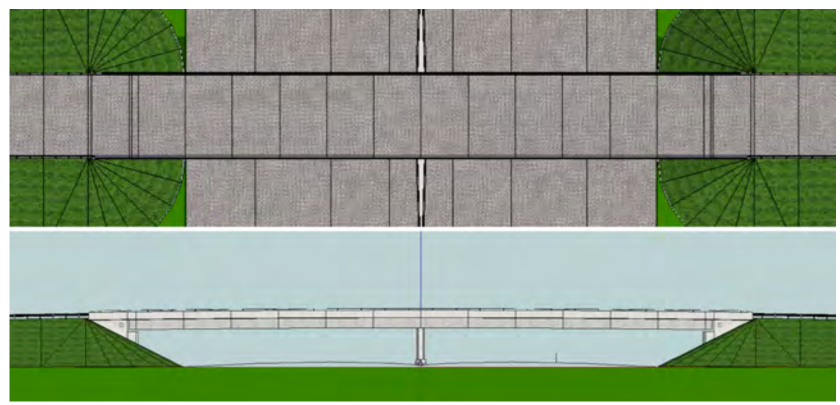


Figure 7.12: Two orthographic views of the bridge shown in Figure 7.11. Upper image: a view from above, called a *plan view or plan*. Lower image: an *elevation view or elevation*.

2 Direction of view relative to the object: *parallel to one of the primary coordinate axes of the object*

3 Orientation of the viewing plane relative to the direction of view: *perpendicular*

When these relationships are present, we call the geometric arrangement *orthographic projection* and the views thus producted *orthographic views*. The prefix ortho means perpendicular, and refers to the ninety degree angle between the rays and the primary axes of the object.

The preceding discussion is a relatively formal description of a type of drawing that is actually intuitively simple and familiar to everyone, and which is often the type of drawing adopted by people when they have to draw a picture. Figure 7.13 for example, shows an informal sketch of a house, drawn in a way that is familiar to most children. It is actually a crude orthographic view of the house.

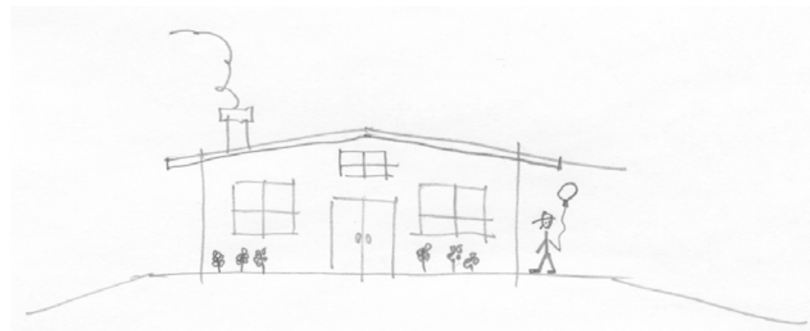


Figure 7.13: A simple drawing of a house, which is actually a crude orthographic view

7.3 Representing a Given Object with Multiple Views

Drawings that are intended to describe a given design so that it can be built on the basis of this description must be *correct* (they must contain no errors), *clear* (they must contain no ambiguities), and *complete* (they must contain all the information necessary to build the object described by the design). This implies that drawings must generally provide an accurate qualitative description of the visible features of a given object as well as a basis for extracting the necessary quantitative information associated with the object. The qualitative description enables us to visualize what the object will look like. The quantitative information enables us to build it exactly as was intended by the designer.

A single two-dimensional orthographic view of a given object can be correct and clear, but it will generally not constitute a complete description of the object. When viewed in orthographic projection from above (also called a *plan view*), the bridge segment shown in Figure 7.14 will appear as the rectangle shown in Figure 7.15. This view is correct and clear, but it is far from complete. If we had only the drawing of Figure 7.15, it would not be possible to build the bridge segment according to the designer's intent.

Even if we were to make the "hidden lines" visible in the top view, as shown in Figure 7.16, we would have no information regarding the height of the segment or its overall form.

The solution is not always to create "three dimensional" views such as the image in Figure 7.14, since these can be more difficult to produce than two-dimensional orthographic views, and do not always enable a clear presentation of information such as dimensions. It is often preferable to employ *multiple* orthographic views, sufficient number so as to define the relevant geometric characteristics of the object completely.

For example, if we use the plan view with hidden lines of Figure 7.16 together with the front elevation view of Figure 7.17, we have effectively created a complete description of the geometry of the segment, while maintaining the advantages provided by orthographic projection.

The two views, plan and elevation, go together. Figures 7.16 and 7.17 are thus not two independent drawings, but rather the two components of a drawing with two views.

The number of views required to draw a given object depends on the complexity of the object. Determining the number of views required and selecting suitable views is an important part of the drawing process. If we draw too few views or choose the wrong views to draw, we can end up with drawings that are incomplete. If we draw too many views, we waste time and can end up with drawings that are not clear.

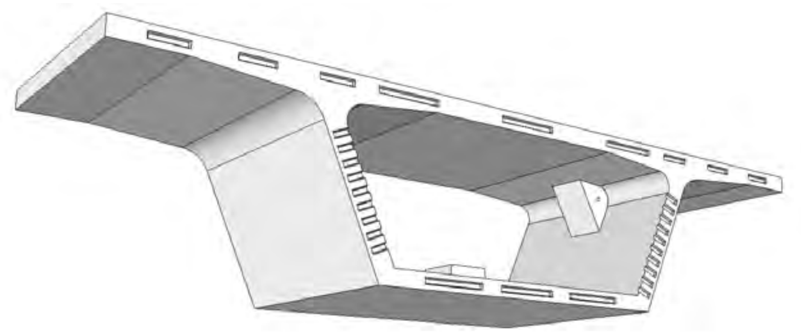


Figure 7.14: A precast concrete bridge segment

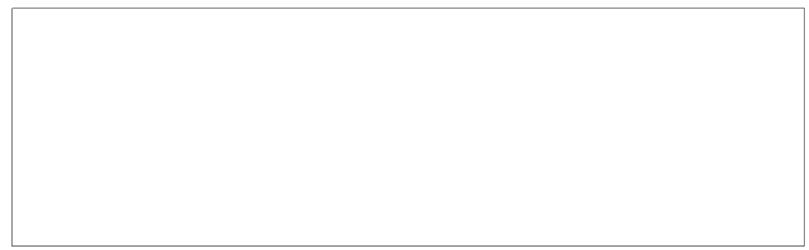


Figure 7.15: Plan view of the bridge segment shown in Figure 7.14

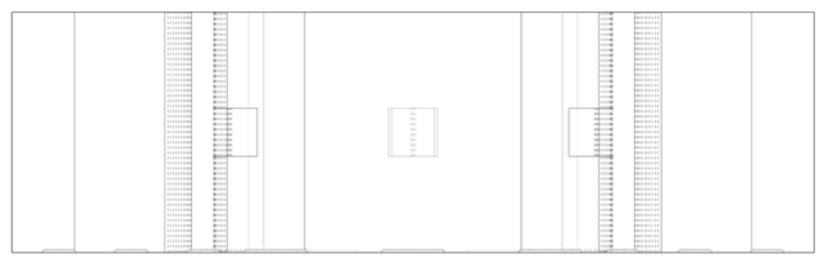
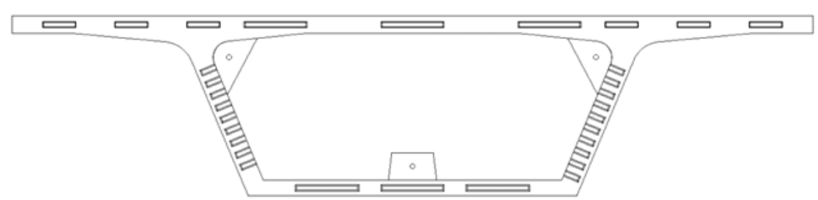


Figure 7.16: Plan view of the bridge segment shown in Figure 7.14, including "hidden" lines



7.4 Sections

In many cases, we create drawings based on the geometrical arrangement shown in Figure 7.18, i.e., with the viewing plane located outside the object, between the object and the viewpoint.

It is also possible to arrange the viewing plane so that it cuts through the object, as shown in Figure 7.19. This also defines a view, which is likewise defined by the points of intersection of the object and the plane. It is thus a view of the object after we have sliced away a part of it. This type of view is called a *section* or a *cross-section*. The origin of the English word *section* can be traced to the Latin word *secare* which means to cut. This is consistent with the creation of the view by cutting the object with a viewing plane. When we are working with sections, we usually refer to the viewing plane as the *section plane*. We often refer to drawing a section view as “cutting a section”.

Sections are important views and are used in practically all engineering drawings. They are particularly important when the object to be drawn has invisible detail on the inside, or when the object incorporates multiple overlapping layers of material. In such cases, sections are the most straightforward and effective means of depicting these aspects of the object.

Sections are always, however, artificial views, in the sense that it is generally not possible to see a section in reality with human eyes. This is because the viewing plane is inside the object we are looking at. Sections therefore usually require more detailed knowledge of the three-dimensional characteristics of the object, and are thus often more challenging to draw than views based on viewing planes that are outside the structure. This difficulty is usually more than made up for, however, by the value of the information provided by sections.

When we cut a given section, we create three types of lines:

1 Lines formed by the intersection of the object and the cutting plane.

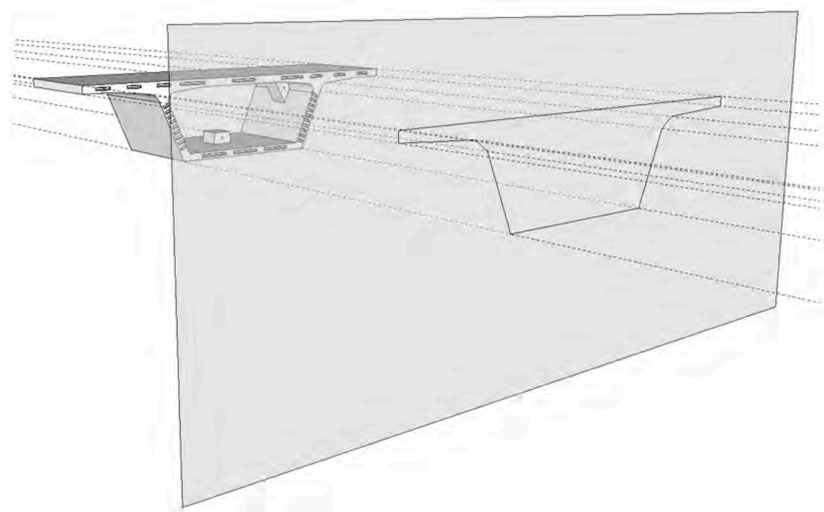


Figure 7.18: Viewing plane is outside the object

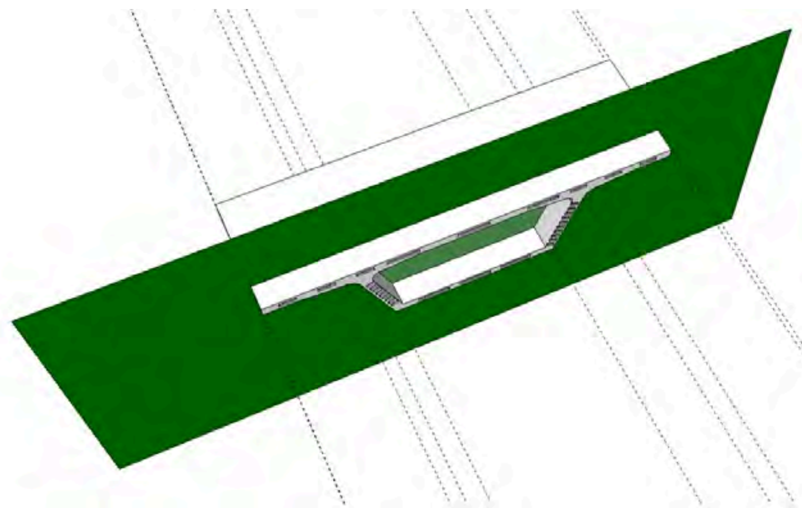


Figure 7.19: Viewing plane cuts through the object

These lines are usually rendered using relatively heavy solid lines.

2 Lines associated with features that are visible, but which are farther away from the viewpoint than the section plane. These are usually drawn using solid lines, but lighter than those present at the section plane.

3 Lines associated with features which are farther away from the viewpoint than the section plane beyond the section plane, and that are hidden by other features of the object. These are usually drawn using dashed lines.

All of the lines present at the section plane (Item 1 in the previous enumeration) must be drawn. The lines that lie beyond the section plane (Items 2 and 3) must be drawn unless their presence in the view results in a decrease in clarity.

When we cut sections, we must indicate on another view:

1 The location of the section plane

2 The direction in which the object is viewed at the cut

3 An identifying mark that relates the section view and its location in the object

This is accomplished using standard symbols, as shown in Figure 7.20. This is an elevation of a two-span overpass. In this image we see two L-shaped black lines, both ending in arrows, and two letters A. The vertical lines define the section plane, which always comes "out of the page" and contains the two vertical lines. The arrows define the direction of view. The letters A refer to the section view, which will be given the title "Section A-A". This allows us to refer the section view to its location in the object. Section A-A is depicted in Figure 7.21.

It is important to identify the sections properly, since a given drawing may include more than one section. This is the case in

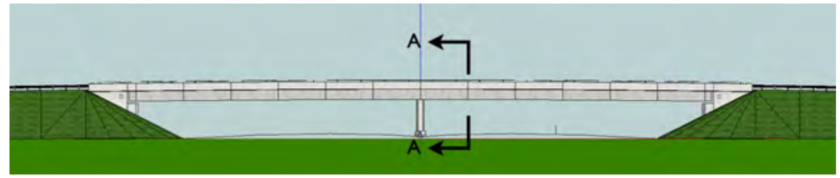


Figure 7.20: Elevation of bridge with standard section cut symbol identifying Section A-A

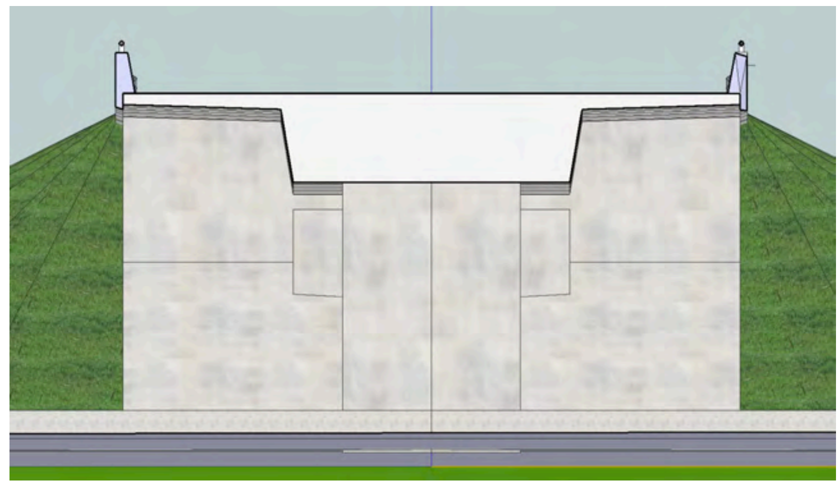


Figure 7.21: Section A-A, where location and direction of section are as defined in Figure 7.20

Figure 7.22, which contains four sections. In this case, three of the sections have been identified by numbers, and the fourth has been identified using words ("Section at West Abutment (looking west)").

The suitable use of sections may reduce the number of other views required to define the geometric characteristics of a given object.

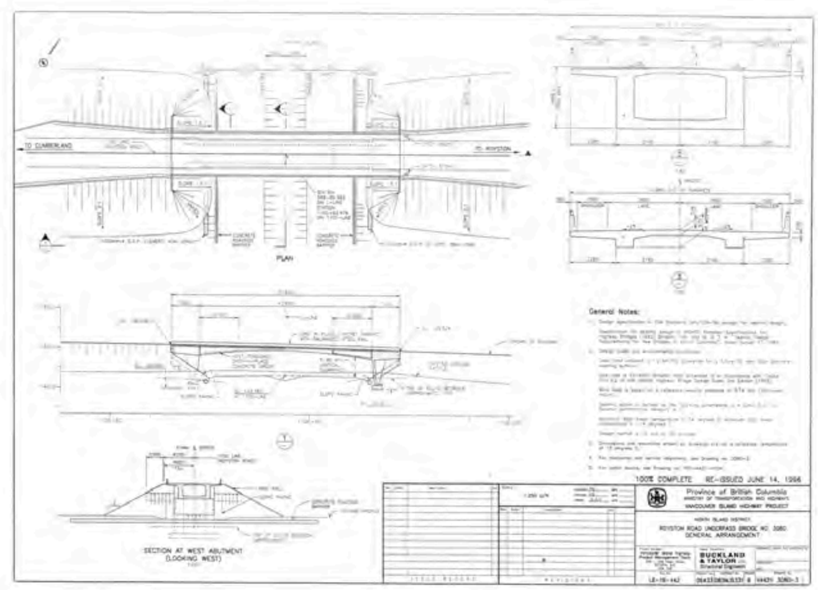


Figure 7.22: A drawing that includes four sections. (For a photographic view of this bridge, see Figure 7.3.)

7.5 Linked Views

As discussed previously ▷ , the use of sections requires establishing a relation between two views: the first is the section itself and the second is another view of the same object that shows the location and arrangement of the section plane and the direction of view. We use a standard section symbol for this purpose. This was done with the two views shown in Figures 7.20 and 7.21 respectively. We say that these two views are *linked*. In this case, the link is made through the standard section symbol in one view (identifying the where Section A-A was cut and the direction of view), and a suitable title of the other view (i.e., Section A-A).

See Section 7.4.

The linking of these two views is important. If we only had the section view, we would not know what part of the object it described. The two sections shown in the upper right-hand portion of the drawing in Figure 7.22, for example, have significant differences but both are cut from the same bridge girder. It is therefore important that we know the location along the span where these two sections were cut. If we only know where the section was cut, we would obviously not have a description of what was visible at that cut. The simple fact that two views are linked thus conveys more information than what is given by the two views independently of each other.

Another important way of linking views is by their arrangement on the page. By arranging views in such a way as to represent clearly the relations among features appearing in more than one view, the views can work together to describe the geometry of a given object with greater clarity and to maximize information content.

A common way of linking two views in this way is the pairing of a plan view and a side view of the same object. (In Canada, it is most common to draw a longitudinal elevation as the side view. In Europe, it is more common to use a longitudinal section.) The views are arranged such that the two views are arranged one above the other on the page and are adjusted horizontally with respect to each other so that identical features in both views line up vertically. This is illustrated in the two views shown in Figure 7.23, to which vertical red lines have been added to illustrate how identical features line up.

In the design process, linking views through a logical arrangement on the page is particularly important, because it allows designers to work on two distinct views simultaneously and to build up a geometrical definition of the object by transferring information from one view to another in a direct manner. In completed formal drawings, linking views through a logical arrangement on the page allows a more compact presentation of information. By lining up the plan and elevation views in Figure 7.23, for example, it is necessary only to give span lengths in one of the two views.

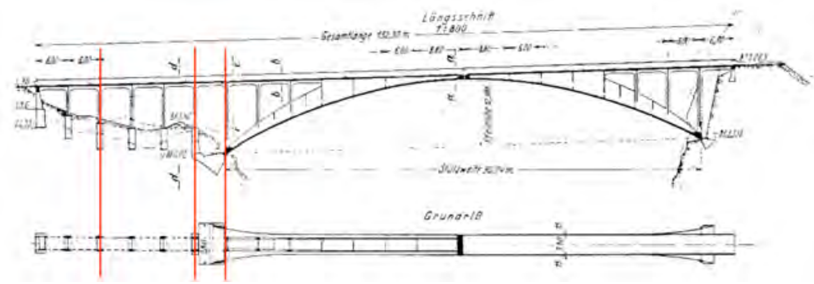


Figure 7.23: A pair of views linked by their arrangement on the page. Upper view: longitudinal section. Lower view: plan. Salginatobel Bridge, Switzerland. Design: Robert Maillart

Figure 7.24: A photograph of the bridge depicted in the drawing of Figure 7.23.

Linking views is sometimes best accomplished by orienting a view in a position other than “top side up”. An example of this type of arrangement is shown in Figure 7.25, in which Section C-C has been drawn “bottom to the right and top to the left”. This may seem counter-intuitive initially, but it enables a richer presentation of the links among more than two views. In this case, it enables all four of the views on the page to be mutually linked.

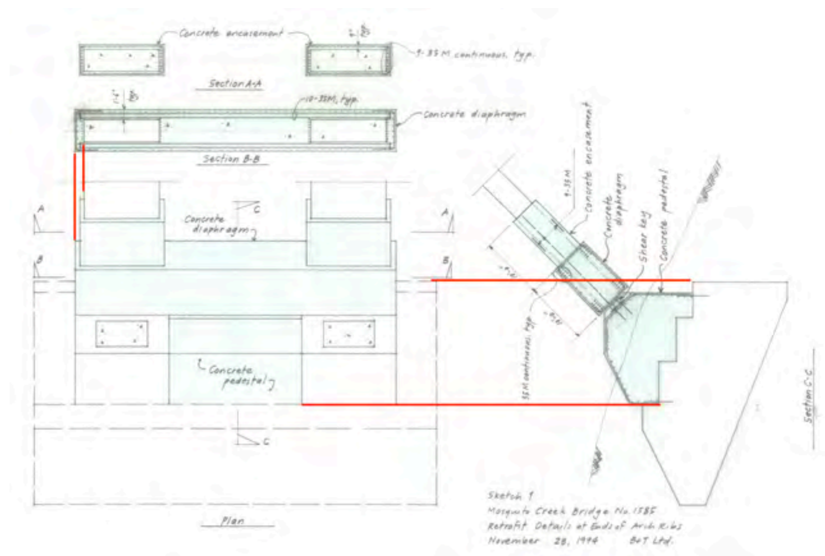


Figure 7.25: Linking views with view orientation other than “top side up”. The completed object depicted in these views is shown in the photo of Figure 7.26

Figure 7.26: Photograph of the completed object depicted in the drawing of Figure 7.25

7.6 Standard Orthographic Views

Civil engineers make frequent use of *standard orthographic views*. These views help to establish a common "vocabulary" of drawing and thus make it easier for engineers to work with drawings that they did not themselves create.

Two of the most important standard orthographic views are the *plan* and the *elevation*. As defined previously, the plan is a view from above, i.e., a bird's eye view. The elevation is a projection of a given object onto a vertical plane. Both views derive their utility from the fact that works of civil engineering are often rooted in a given landscape and thus have meaningful links to a vertical axis and a horizontal plane.

In bridge engineering, the longitudinal elevation is particularly important. It is a view projected onto a vertical plane that is parallel to the primary longitudinal axis of the bridge. (In Europe, it is common to draw longitudinal sections rather than elevation views of bridges.) As discussed previously ▷ , plan and elevation are often linked in bridge engineering. Figure 7.27 shows a linked plan and elevation pair for a major bridge.

In the design of buildings, it is common to draw elevations of the individual primary faces of the structure, such as north elevation, west elevation, etc.

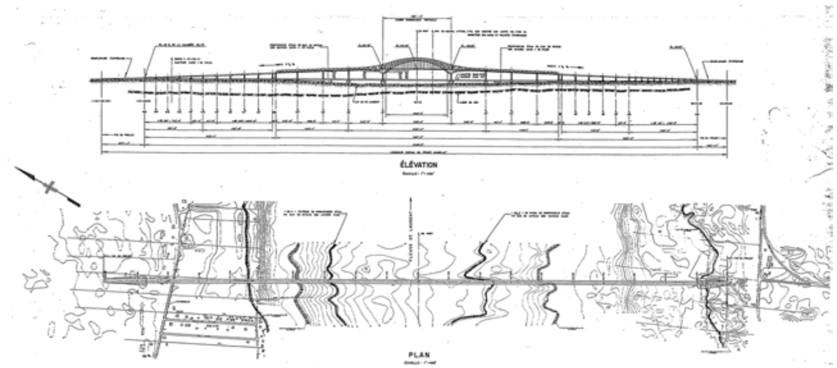


Figure 7.27: Elevation and Plan of the Laviolette Bridge across the St. Lawrence River near Trois-Rivières, Québec

See Section 7.5.

Figure 7.28: Photograph of the bridge depicted in the drawing of Figure 7.27

For bridges that are curved in plan, the longitudinal elevation view is often a *developed elevation*. In such cases, the bridge is projected onto a curved surface that is generated by a vertical line that follows the curved centreline of the bridge rather than onto a vertical plane. The advantage of the developed elevation is that it depicts the spans in their true arc length. The disadvantage is that it is more difficult to provide a clear link between plan and elevation views, since the centrelines of the piers no longer line up. An example of a developed longitudinal section is shown in Figure 7.29.

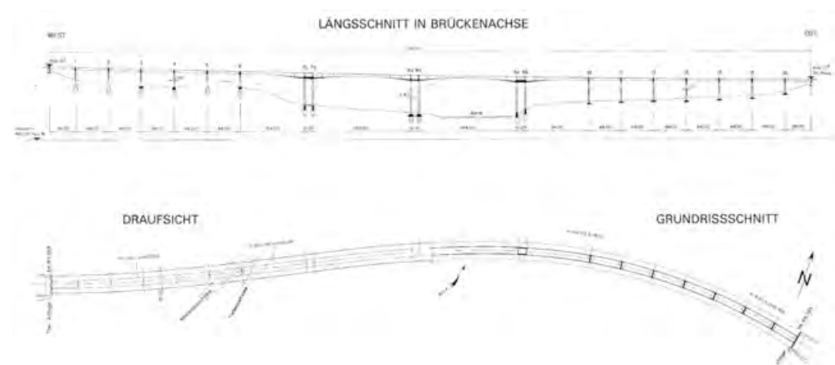


Figure 7.29: Longitudinal Section and Plan of the Felsenau Bridge, Switzerland. Design: Christian Menn

Figure 7.30: Photograph of the bridge depicted in the drawing of Figure 7.29. Photo: Ralph Feiner

In bridge engineering, a common standard drawing consists of overall plan, longitudinal elevation or section, and one or more typical cross-sections, where the cutting plane is vertical and perpendicular to the primary longitudinal axis of the bridge. In Canada, this type of drawing is often referred to as a *General Arrangement* drawing. A well drawn General Arrangement drawing contains a high density of information and thus can describe most of the important features of the bridge on a single sheet. Figure 7.31 shows an example of a General Arrangement drawing.

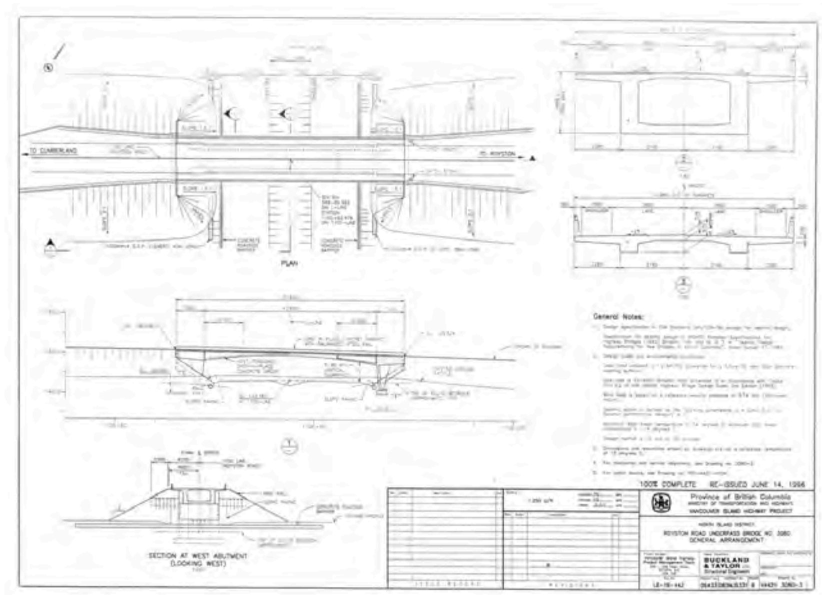


Figure 7.31: A General Arrangement Drawing (for a photograph of the bridge depicted in this drawing, see Figure 7.3)

8
Isometric Projection

In the previous chapter ▷ , we learned that drawings can be regarded as *projections* of a given object onto a *viewing plane*. A drawing of a given object will be determined by the following three factors:

See Chapter 7.

1 The distance of the viewpoint from the object

2 The direction of view relative to the object, i.e., the orientation of the vector from the viewpoint to the centre of the object

3 The orientation of the viewing plane relative to the direction of view

For the standard engineering views in what was referred to as *orthographic projection*, these factors are as follows:

1 The distance of the viewpoint from the object: *infinite*

2 The direction of view relative to the object: *parallel to one of the primary coordinate axes of the object*

3 The orientation of the viewing plane relative to the direction of view: *perpendicular*

Orthographic projection is very useful, in particular because it produces views that are dimensionally true, but it usually does not convey a strong sense of the three-dimensional qualities of a given object. Through a suitable re-orientation of the direction of view relative to the object, however, it is possible to convey much more realistic representation of three-dimensional qualities while maintaining a reasonable degree of dimensional fidelity. The direction of view we will choose is along the diagonal of a cube that has its edges oriented along the primary Cartesian coordinate axes. This is segment OA in Figure 8.1, i.e., the primary diagonal of the cube.

The view in Figure 8.1 is not isometric projection. It was drawn in this way just to identify the primary diagonal. We can now rotate the direction of view to align it with the direction defined by segment OA. Figure 8.2 shows a view that is more closely aligned with the direction defined by OA, and Figure 8.3 shows a view in which the direction of view is parallel with primary diagonal OA. In this view, the points O and A are coincident, and the diagonal is thus transformed into a point.

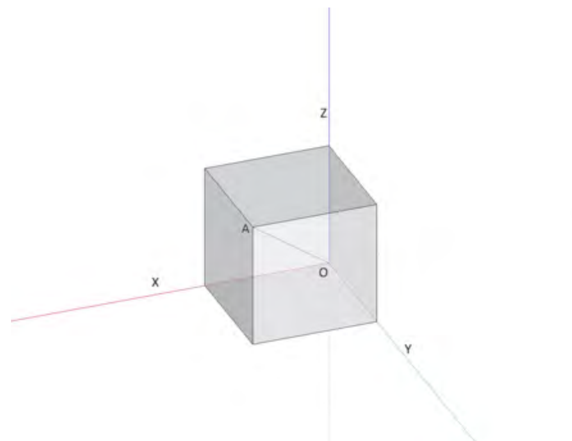


Figure 8.1: Cube with edges along coordinate axes and primary diagonal OA

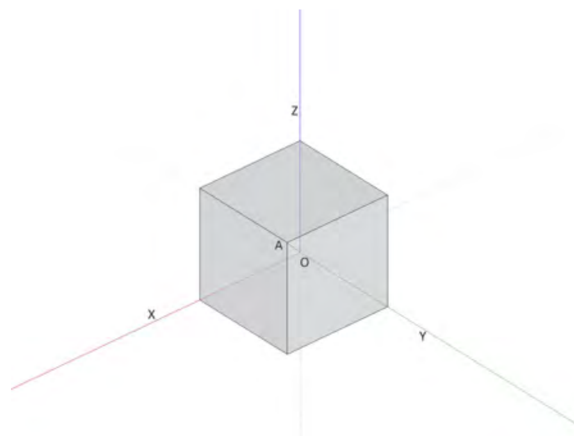


Figure 8.2: Direction of view moved closer to primary diagonal OA

The view shown in Figure 8.3 is *isometric projection*. When we measure the projected lengths of the edges of the cube (such as AB, AC, and AD), we find that they are all equal. This observation can be generalized. In isometric projection, the ratio of the real length of any line that is parallel to one of the original coordinate axes to the real length of any other line that is parallel to one of the original coordinate axes will remain unchanged when the lengths of these lines are measured in the isometric drawing. In addition, lines that are parallel in reality are rendered as parallel lines in isometric projection. These properties make isometric drawings relatively easy to create, especially when drawing freehand.

The defining factors of isometric projection are therefore as follows:

1 The distance of the viewpoint from the object: *infinite*

2 The direction of view relative to the object: *along the primary diagonal of a cube with edges oriented along the primary cartesian coordinate axes*

3 The orientation of the viewing plane relative to the direction of view: *perpendicular*

The cube in Figure 8.3 was drawn in a semi-transparent way, so that the principal diagonal OA would be visible in a variety of views. If we draw the cube as a solid object (Fig. 8.4), we see that the drawing does indeed convey a relatively strong impression of its three-dimensional character.

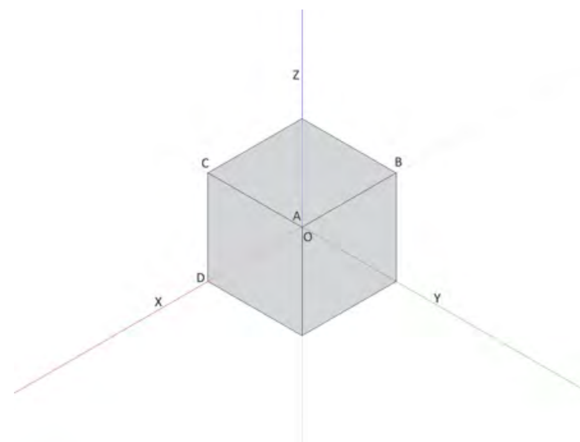


Figure 8.3: Direction of view aligned with primary diagonal OA: isometric projection

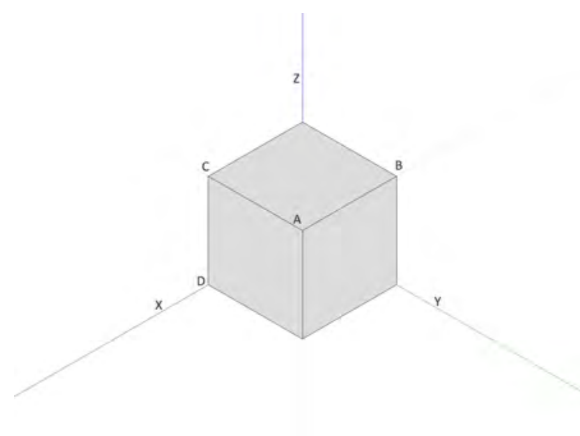


Figure 8.4: Isometric projection of a solid cube

The three-dimensional impression conveyed by isometric projection is generally stronger for more complex objects, such as the bridge segment shown in Figure 8.5.

As shown in Figure 8.6, the angle between lines parallel to the x and y axes in reality and the z (vertical) axis is rendered as 60 degrees in isometric projection. This provides a good starting point for drawing, and particularly for freehand drawing since the 60 degree angle is relatively easy to reproduce with reasonable accuracy.

As shown in Figure 8.7, even though the angle between the projected x and y axes and the vertical axis differ from 60 degrees, the three-dimensional effect is still significant. Length of segments along the coordinate axes will no longer be maintained, however, as in true isometric projection.

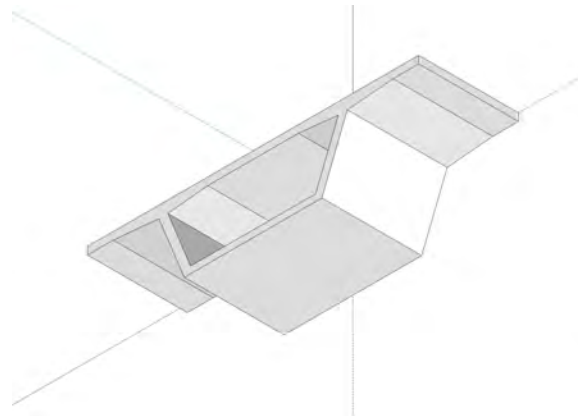


Figure 8.5: Isometric projection of a precast concrete bridge segment

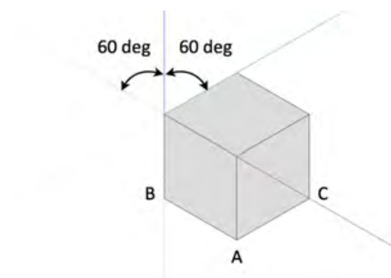


Figure 8.6: Basic angles in isometric projection

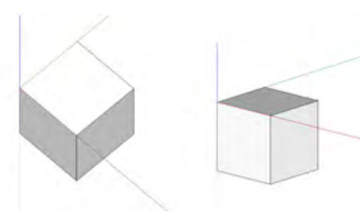


Figure 8.7: Effect of changing the angle between projected x and y axes and the vertical axis

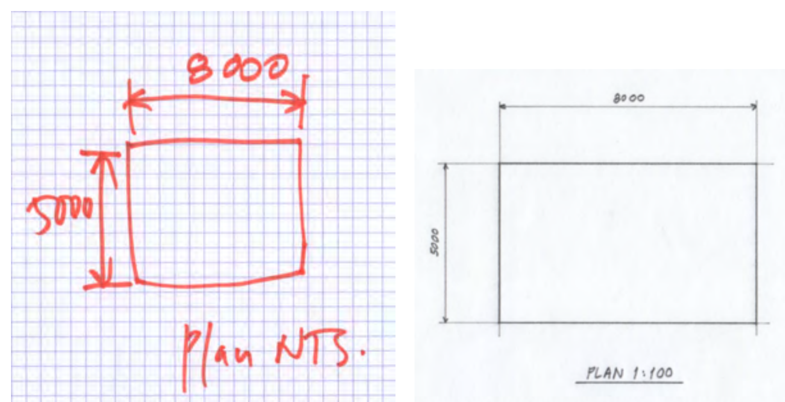
9
Scale

9.1 The Importance of Drawing to Scale

When engineers say that a given drawing is “to scale”, they mean that the image on paper is geometrically similar to the real object (either existing or to be built) that it depicts. This implies that the drawing has a high degree of *geometric precision*.

Strictly speaking, it is possible to create drawings that are not to scale and are still of some use. This is illustrated by the drawings shown in Figure 9.1. Both images depict a rectangular component. It could be a plan view of a bridge foundation. The right-hand image has been drawn to scale, in the sense that the angles are indeed right angles, the lines are straight, and the ratio of the drawn length of the long side to the drawn length of the short side is indeed 8:5 as the dimensions would indicate. In the left-hand image is not to scale. None of the properties just described (angles, straightness, lengths) are present in this drawing. The notation “NTS” is an abbreviation that means *not to scale*, which is indeed true in this case.

The image in Figure 9.1(a) is not, however, completely useless. In most engineering contexts, it would probably be understood that a figure like the one in this image was not intended to be built as an irregular shape with curved sides, but rather as a rectangle. If this is



(a) Not to scale (b) To scale

Figure 9.1: Plan view of a foundation for a bridge pier: two versions

the case, then the dimensions given provide all of the information contained in Figure 9.1(b).

Notwithstanding this, drawing to scale, i.e., producing drawings with a relatively high degree of geometric precision, is highly desirable in engineering. This is because engineers make and validate design decisions not only on the basis of the numbers they calculate, but also on the basis of how the things they design actually look. The basis for this action is not merely a subjective matter of liking or not liking a specific decision. The objects that are built based on our designs are three-dimensional solid objects. Their geometric properties, which are described in the drawings we make, thus play an important role in enabling these objects to perform their practical function. In other words, the visible qualities of the objects we design have direct bearing on the capacity of these objects to do what they were intended to do.

If we do not draw to scale, then the way our drawings look will differ from the objects they represent. They will thus generally be an invalid basis for making and validating design decisions. This is illustrated in the drawings of Figures 9.2 and 9.3. The former image shows the cross-section of a single-cell concrete box girder which has been drawn to scale using CAD. In a subsequent stage of the design process, the designer has used a pencil to sketch, freehand, the pier. Because the cross-section has been drawn to scale, it constitutes a valid basis for establishing whether or not the pier as sketched will work well with the pier. Had the girder cross-section been drawn as shown in Figure 9.3, i.e., not to scale, it would have been of little use as a basis for developing concepts for the piers.

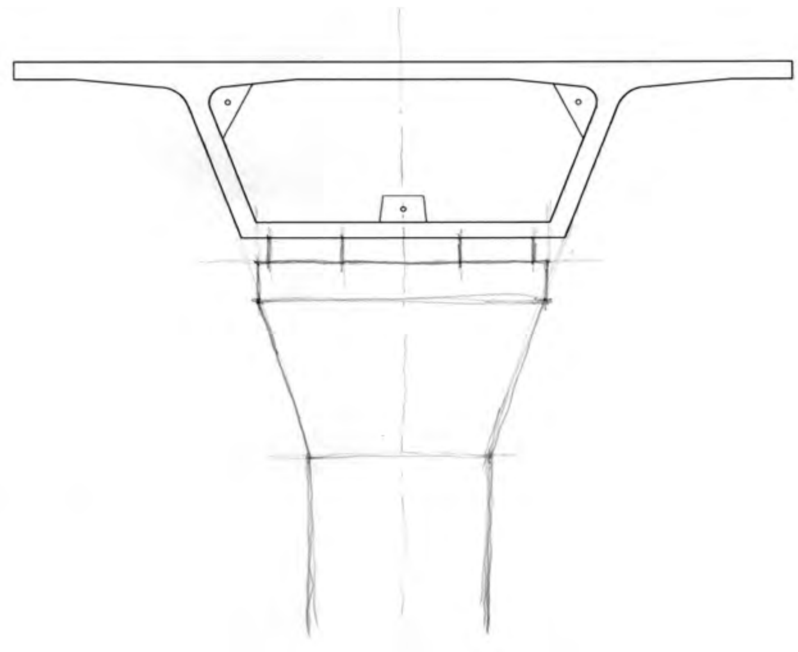


Figure 9.2: Cross-section of bridge girder with pier. Girder cross-section has been drawn to scale

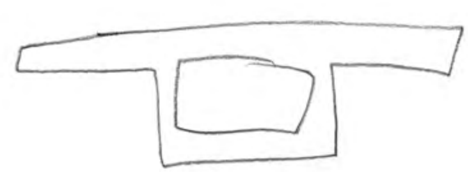


Figure 9.3: Girder cross-section not drawn to scale

Determining whether or not the things we design are satisfy applicable geometric constraints (i.e., determining whether or not they “fit”) is an extremely important aspect of the validation of design concepts that is best accomplished visually, and which can only be done when we draw to scale. This is illustrated by Figure 9.4, which shows three *linked views* ▷ of a bridge foundation: a plan in the upper left portion of the drawing, a front elevation immediately below, and a side elevation to the right. The plan has been drawn onto a *base drawing* ▷ of the site. The relevant features, drawn to scale, include the bank of a river and a line drawn inland from the river bank, defining an area that cannot be encroached on by any construction. This kind of constraint is common when building near bodies of water.

See Section 7.5.

See Section 5.4.2.

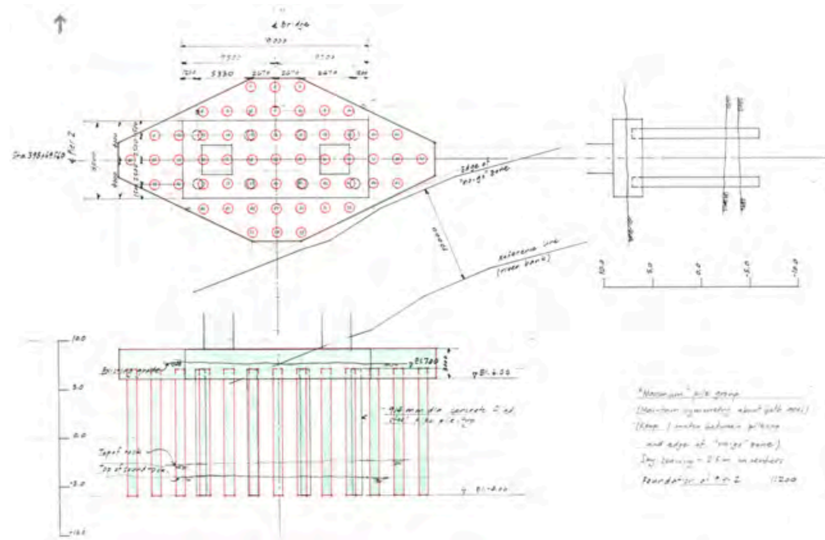


Figure 9.4: Plan and elevations of a bridge foundation, with geometric constraints (Edge of “no-go” line) indicated on the plan

The task at hand was to design a foundation that did not encroach into the No-Go zone present at the site. Since the No-Go zone and the foundation are essentially geometrical objects, and encroaching is a geometrical relationship (one object occupies the same space as the other), it makes sense to demonstrate that a given design satisfies the constraint by means of a drawing such as the one shown in Figure 9.4. Because we can see in this drawing that the foundation does indeed not intrude on the No-Go zone, we have effectively validated that the design satisfies this constraint. Validating the design on the basis of a drawing is only possible, however, if both constraint and design are drawn to scale.

Drawing to scale also imposes a discipline on one’s thinking that generally leads to a more efficient design process. Although it might appear more time consuming to draw to scale, it is actually easily learned and soon becomes second nature. Any additional time that might be spent in drawing to scale is almost always far less than the additional time required to correct errors that inevitably arise when we make design decisions based on drawings that are not to scale.

Finally, when we draw to scale, our work projects an impression of professionalism. The care and attention required to produce drawings to scale is usually reflected in the quality of the drawing, which in turn gives an impression that the engineer who created it was indeed competent.

9.2 *Scale as Ratio*

The basic definition of drawing to scale proposed in the previous section, i.e., producing a drawing that is geometrically similar to the object it depicts, implies that the ratio of the distance between two points on the drawing to the corresponding two points in the object is constant for that drawing. This ratio is called the *scale* of the drawing. When metric units are used (as they will be exclusively in this course), scale is usually expressed as a ratio "1:A", which means that one unit measured on the drawing is equal to A units in the real object depicted by the drawing. So a scale of 1:200 means that 1 cm measured on the drawing corresponds to 200 cm in reality. A distance of 5.5 cm measured on the drawing would thus correspond to $5.5 \text{ cm} \times 200 = 1100 \text{ cm}$ in reality.

This ratio is usually not relevant when we draw freehand. Although the degree of geometric precision that is possible in freehand drawing can be sufficient to create drawings that really do look like the objects they represent, attempts to produce drawings in which all dimensions are in a constant ratio to corresponding dimensions in the object would be extremely difficult even for engineers who were reasonably proficient in freehand drawing. For the small number of engineers who could create such drawings, the slow pace required of the drawing process would negate most of the benefits normally arising from the process of freehand drawing ▷ .

See Section 11.5.1.

The scale of a given drawing (i.e., the ratio of length measured in the drawing to length in reality) is particularly important when precise drawings need to be created by hand with instruments. When a precise drawing must be created by hand, it is necessary to determine the scale in advance, since this will determine the size of the image on the page. Starting out a drawing to be made by hand without proper advance consideration of scale can easily result in drawings that are too small (and thus do not show sufficient detail) or too large (and thus do not fit on the page).

Once the scale (1:A) of a given drawing has been established it is necessary to draw the lines accordingly. So if we wanted to draw a line that was 0.5 m long in reality and the scale of the drawing was 1:20, we would have to draw a line that was $0.5 \text{ m}/20 = 0.025 \text{ m}$ long, or 25 mm on the paper. This results in a tedious process by which each dimension in reality has to be divided by the scale to determine the length to be drawn on paper. This task is greatly simplified by the use of special rulers (also called *scales*) for which standard ratios of dimensions on the drawing to dimensions in the object (i.e. standard scales) have been established. Figure 9.5 shows the use of a scale. The scale of the drawing is imprinted on the end of the ruler ("1:20"). The engineer is measuring a distance of "0.5". The actual distance measured on paper is 25 mm, as previously calculated. So the use of the scale (ruler) and standard scales (ratios) enables engineers to work always in real world units rather than always convert using ratios to paper units.

Figure 9.5: Creating a drawing using a *metric scale*. Note the ratio 1:20 imprinted on the scale. The distance measured is a power of 10 times 0.5 m.

In this course, all of the precise drawings we create will be made using CAD, so it will not be necessary to learn the use of the scale (ruler). Most CAD systems use a different way of drawing to scale. We proceed as follows:

This includes the two systems we will use in this course, SketchUp and AutoCad.

1 Draw the object at a scale of 1:1, i.e., in real world units. It is usually easier to regard this process as one of creating a *model* of the object at a scale of 1:1 rather than a drawing, since we create the model without any regard of how it will be displayed on paper.

2 Create one of more *views* of the model at specific scales and arrange these views so that they can be printed on paper. The scales will be determined on the basis of the size of the object, the level of detail required, and the size of physical paper that will be used to display the images.

When we work with SketchUp, we use SketchUp to create the 1:1 model of the object. We then use a related application, called LayOut, to create the scaled views ▷ . When we work with AutoCad, we create the 1:1 model within a function called “Model Space” and then create the scaled views within a function called “Paper Space”. Both functions reside within the AutoCad application ▷ .

For a more extensive description of how to work with SketchUp and LayOut, see Chapter 16.

For a more extensive description of how to work with Model Space and Paper Space in AutoCad, see Chapter 17.

Working in this way, we do not need to determine the scale at which the views will be displayed before we begin the process of creating the model. We can use the same model to display views at several different scales.

9.3 Standard Scales

Although the ratio 1:A is valid for any positive real number A, engineers normally work with a set of *standard scales*. When we work with metric units, the following series of scales are standard:

1 The scales $1 : 1 \times 10^n$, where n is a non-negative integer. This series of scales thus includes 1:1, 1:10, 1:100, and 1:1000.

2 The scales $1 : 2 \times 10^n$, where n is a non-negative integer. This series of scales thus includes 1:2, 1:20, 1:200, and 1:2000.

3 The scales $1 : 5 \times 10^n$, where n is a non-negative integer. This series of scales thus includes 1:5, 1:50, 1:500, and 1:5000.

These series should accommodate the vast majority of cases in engineering drawing, and should thus be regarded as the *first preference* for scales. It can occur, however, that views cannot be properly displayed on paper using any scale in these three series. In such cases, the following *second preference* series of scales can be used:

1 The scales $1 : 1.25 \times 10^n$, where n is a non-negative integer. This series of scales thus includes 1:1.25, 1:12.5, 1:125, and 1:1250.

2 The scales $1 : 2.5 \times 10^n$, where n is a non-negative integer. This series of scales thus includes 1:2.5, 1:25, 1:250, and 1:2500.

3 The scales $1 : 7.5 \times 10^n$, where n is a non-negative integer. This series of scales thus includes 1:7.5, 1:75, 1:750, and 1:7500.

When imperial units are used, these scales do not apply. There are two series of imperial scales, called *Architect's scales* (see Table 9.1) and *Engineer's scales* (see Table 9.2). In this course, we will not create drawings in imperial units.

Table 9.1: Architect's Scales ("in" = inches, "ft" = feet)

Architect's scale	Non-dimensional equivalent
1/16 in = 1 ft 0 in	1 : 192
3/32 in = 1 ft 0 in	1 : 128
1/8 in = 1 ft 0 in	1 : 96
3/16 in = 1 ft 0 in	1 : 64
1/4 in = 1 ft 0 in	1 : 48
3/8 in = 1 ft 0 in	1 : 32
1/2 in = 1 ft 0 in	1 : 24
3/4 in = 1 ft 0 in	1 : 16
1 in = 1 ft 0 in	1 : 12
1 − 1/2 in = 1 ft 0 in	1 : 8

Table 9.2: Engineer's Scales ("in" = inches, "ft" = feet)

Engineer's scale	Non-dimensional equivalent
1 in = 10 ft 0 in	1 : 120
1 in = 20 ft 0 in	1 : 240
1 in = 30 ft 0 in	1 : 360
1 in = 40 ft 0 in	1 : 480
1 in = 50 ft 0 in	1 : 600
1 in = 60 ft 0 in	1 : 720

9.4 *Using Scale in Engineering Drawings*

The use of scale in engineering drawing involves both the practice of drawing to scale as well as the practice of working with drawings that have been made to scale. In this regard, the following recommendations should always be followed:

1 Except when drawing freehand, *always draw to scale*. One you have developed the habit of drawing to scale, it becomes second nature and really does not require any significant increase in time. The value of scaled drawings to the design process is infinitely greater than the value of drawings that are not to scale. When drawing freehand, always maintain a suitable balance between geometric precision and speed.

2 When preparing views for printing on paper, *always use standard scales*. Although it is theoretically possible to use any scale of the form $1 : A$, the use of standard scales conveys a greater sense of professionalism and increases the effectiveness of drawings as tools within the design process.

3 Even though a given drawing is made to scale and has been plotted to paper at a standard scale, *always provide a complete set of dimensions*. Do not force others who will use your drawings to measure

your paper drawing to extract the information they require. The dimensions provided should be sufficient to provide a complete geometric description of the object drawn.

4 When working with drawings prepared by others, *never measure them to extract geometrical information*. If the dimensions given are insufficient, ask the person who prepared the drawing to provide the necessary information. Although it is normal to indicate the scale of a given view in a prominent position, it is common to photocopy or print a given drawing in such a way as to make the ratio stated on the drawing incorrect. Always rely on dimensions and never measure drawings prepared by others.

Part III

Applications of Engineering Drawing

10
Contour Mapping

This chapter describes the contour map, a common type of drawing in civil engineering. It is an ideal means of representing a three-dimensional surface using a single two-dimensional view. Contour maps not only convey a qualitative impression of the features of the surface but also enable, using a single view, complete quantitative information to be extracted from the drawing. They are often used for topographic maps and for other applications that will be briefly mentioned in the article.

10.1 What Is a Contour Map

Contour maps will be described using a simple example, which involves representing a three-dimensional landform using only two dimensions.

A three-dimensional surface is given. For example, we can consider a the landform shown in Figure 10.1. The perspective view shown is obviously a two-dimensional representation of a three-dimensional object. This conveys a reasonable qualitative impression of the overall characteristics of the landform, but it does have the following shortcomings:

Figure 10.1: Perspective view of a three-dimensional landform

1 Depending on the point from which the view is taken, we may miss

valuable information. For example, when the landform is viewed to obtain the upper of the two views shown in Figure 10.2, we have no information on what lies beyond the red line. We need to rotate to a different viewpoint to obtain this information.

2 There is no reliable way of extracting quantitative information from this image. For example, we may wish to know the elevation of a specific point on this landform or the difference in elevation between two given points. Not only is it difficult to locate a given point exactly in a horizontal plane, it is also difficult to gain more than a general impression of its elevation.

We can solve the first problem to some extent by using multiple views of the same landform. This is shown in the lower image in Figure 10.2, where the original viewpoint has been rotated by approximately 90 degrees to obtain a second view. With the help of the second view, we can see what lies beyond the ridge highlighted in red. By selecting a sufficient number of views, we can generally provide a correct qualitative impression of the entire landform. The problem with this approach is that it is not compact, in the sense that one view is generally not enough. Furthermore, to be of value as a basis for extracting quantitative information, this approach also requires a means of relating one view to another. This is not a straightforward task.

Figure 10.2: Perspective views of the landform of Figure 10.1 from two different viewpoints

We can solve the second problem to some extent by identifying specific points and writing in the elevation of these points on the drawing. This has been done for two points in the drawing of Figure 10.3. Elevations are given in metres above sea level. This increases the quantitative content of the drawing. If a sufficiently large number of such elevations were given, it would be possible to estimate, at least approximately, elevations of other points by interpolation. There is still no reliable quantitative basis, however, for locating points in the horizontal plane. It is practically impossible, for example, to know the distance and bearing of the point with elevation 1019 relative to the point with elevation 1178. Reliable answers to questions relating to the elevation of a point of known coordinates relative to a given point thus remain difficult to obtain.

Neither providing multiple perspective views nor providing elevation values for given points thus allows us to represent the three dimensional surface using a single two-dimensional drawing that enables quantitative information to be extracted (i.e., the z coordinate of a point given its x and y coordinates).

To accomplish this objective, we need a more suitable two dimensional representation of the three dimensional surface. We begin by imagining that the landform has been sliced by a horizontal plane, i.e., a plane of constant elevation. In this case, its elevation is taken to be 1000 m. The landform and the plane are shown in Figure 10.4. Where this plane cuts the landform defines one or more curves in a horizontal plane. We can erase the plane itself but leave the line created by the intersection of the plane and the landform. This curve joints points of equal elevation. It is shown in Figure 10.5. We define any curve joining points of equal elevation a *contour line*, or simply a *contour*.

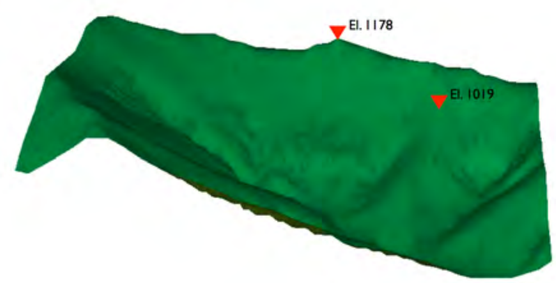


Figure 10.3: Perspective view of the landform of Figure 10.1 (elevations are given in metres above sea level)

Figure 10.4: Landform of Figure 10.1 sliced by a plane at Elevation 1000

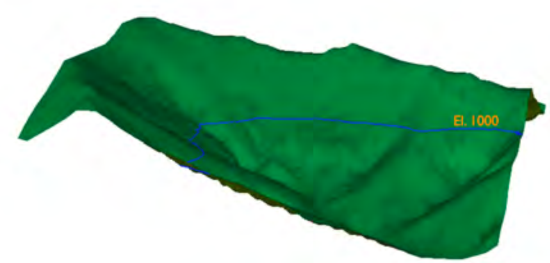


Figure 10.5: Contour formed by intersection of plane and landform. All points along contour are at Elevation 1000.

We can repeat this construction for planes at other elevations. For example, we can do so for planes with elevation 1100 m and 900 m, as shown in Figure 10.6.

Greater detail can be provided by showing more contour lines. In Figure 10.7, contours have been procied at vertical increments of 20 m. We say that the *contour interval* in this drawing is 20 m. This contour interval appears to cover the landform reasonably well and capture the changes in topography.

Although the drawing of Figure 10.7 conveys significantly more information than the original perspective view of Figure 10.1, it is in itself is not particularly useful, since it still has most of the short-comings of the drawings developed initially. It can be transformed into highly useful drawing, however, by representing this information on a horizontal plane.

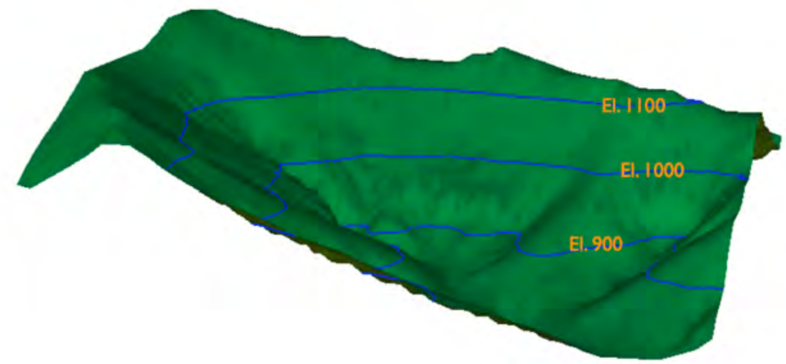


Figure 10.6: Landform of Figure 10.1 with three contours

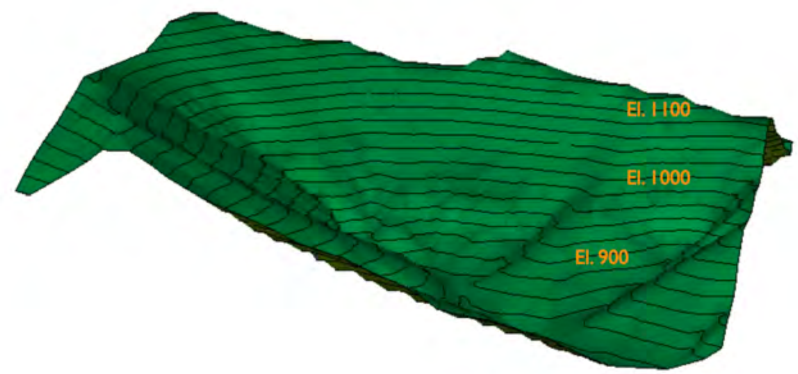


Figure 10.7: Landform of Figure 10.1 with contours at 20 m intervals

We do this by viewing the landform, with the contour lines, looking directly down from a point above it ▷ . This view is shown in Figure 10.8. By choosing this projection, we gain a dimensionally true representation of the horizontal plane, which permits us to use true $x - y$ coordinates to locate points. The vertical dimension disappears visually but is now represented in a more abstract way through the contour lines, which now appear to be drawn on a horizontal plane.

This is an orthographic view, and because it is from above, it is called a plan. *See Section 7.3.*

A given point can now be located and measured in $x - y$ coordinates from any other point on the map. Its elevation can be read directly from the contour that intersects the point or, for points located in between contours, by interpolation. For example, a point 500 m to the east and 500 m to the north of the origin in the lower left portion of the drawing (shown with the red dot) is found to have an elevation of approximately 1008 m.

It is important that contour maps always incorporate a constant contour interval. By doing this, we can get a visual sense of the three-dimensional properties of the surface, even when the shading of the original landform has been removed, by considering the patterns formed by the contours.

The closest path from one contour line to an adjacent contour gives the steepest path. This follows directly from the definition of slope, which is equal to rise over run. For a constant rise (fixed contour interval), the greatest slope corresponds to the smallest value of run (closest distance between contours). It therefore follows that closely spaced contours denote regions that are steep and widely spaced contours are regions that are relatively flat.

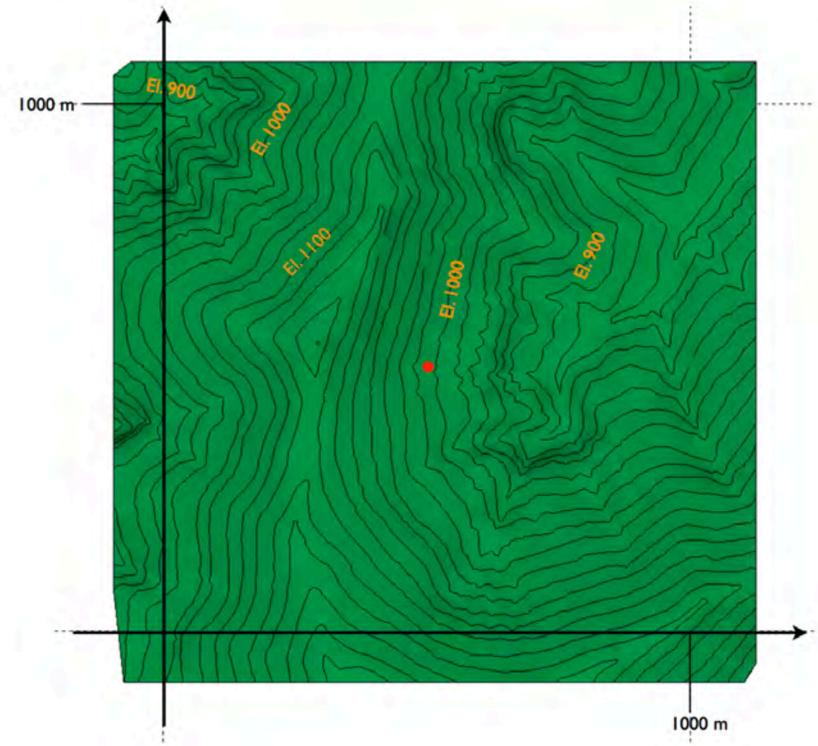


Figure 10.8: Plan view of landform of Figure 10.1 with contours at 20 m intervals

Closed curves denote either "hills" or "depressions". We distinguish between the two by considering whether the contours are increasing or decreasing. In the case of the map shown in Figure 10.9, the change of the contours indicates that the triangular figure enclosed by the green rectangle would be the top of a hill.

A series of adjacent contours that all "point" in the same direction often indicates the path of a river, since this corresponds to the landform created by the flow of water through the earth. The blue line drawn onto the map to the right indicates one possible river.

We can summarize the essence of contour maps as follows. Contour maps allow us to represent three-dimensional surfaces using a single two-dimensional drawing. They maintain the ability to locate points accurately in two horizontal dimensions. Everything in these two dimensions is drawn to scale. We lose a direct means of visualizing the third dimension, but are able to represent it accurately through lines joining points of equal elevation, called contour lines. These are equivalent to the curve formed by intersecting the surface of the given landform with planes of constant elevation. By working with a constant contour interval, we gain the ability to visualize indirectly the three-dimensional characteristics of the surface.

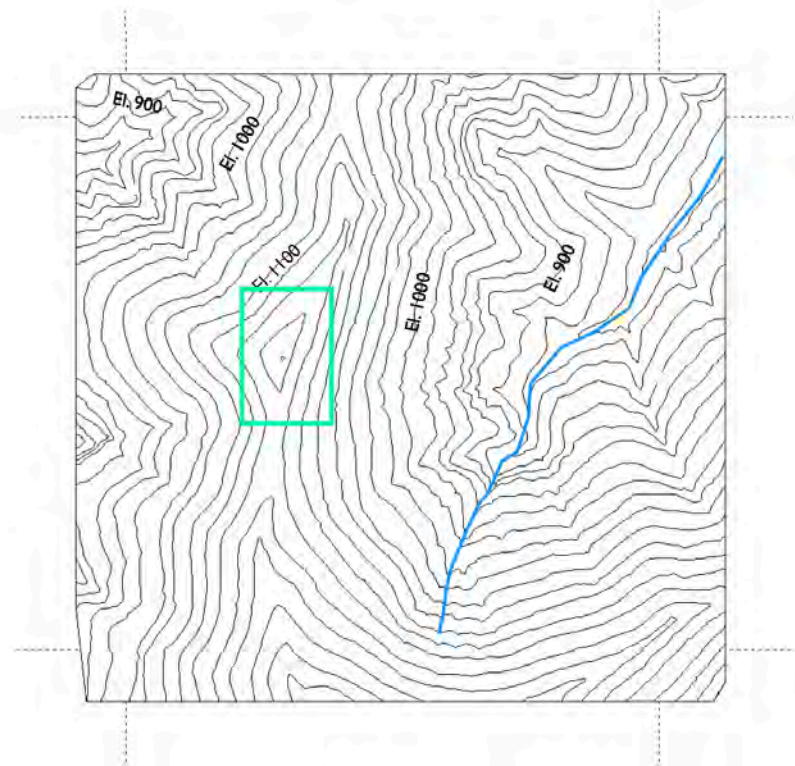


Figure 10.9: Plan view of landform of Figure 10.1 with contours at 20 m intervals

The data used to generate the landform considered in this example originate from the National Map of Switzerland. The corresponding section of this map is shown in Figure 10.10. The contour interval in this case is 10 m.

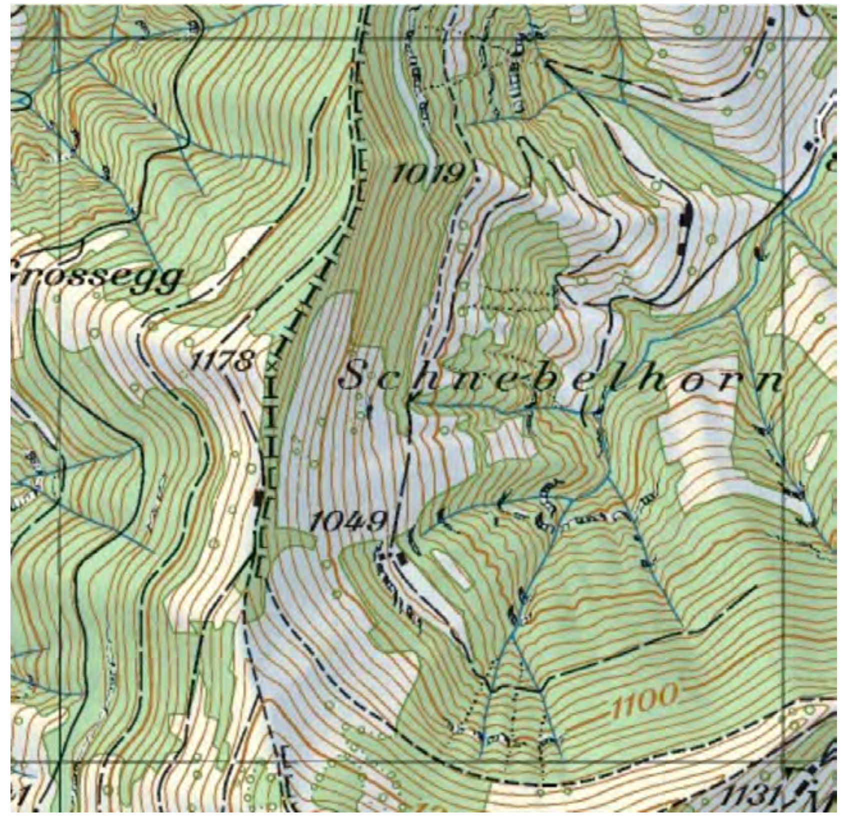


Figure 10.10: Excerpt from National Map of Switzerland used for creation of landform of Figure 10.1. The grid square represents 1 km.

10.2 Suitable Applications

Contour drawings are not the ideal way to represent all three-dimensional objects. They are best suited to representing objects that have a single surface, a significant and well defined reference plane, and a significant third coordinate perpendicular to the reference plane.

It follows from these conditions that contour drawings are well suited to the representation of landforms. They have a single surface (the surface of ground), a well defined reference plane (the horizontal plane) and a significant third coordinate perpendicular to the reference plane (the z coordinate represents elevation, which is of primary significance).

Contour drawings are not suitable for representing other types of three dimensional objects when at least one of these conditions is not satisfied. The bridge pictured in Figure 10.11, for example, does not have a single surface, but rather several including a near vertical surface, a far vertical surface, and an upper surface. A single contour diagram cannot adequately represent all of these surfaces. This type of object is best represented in other ways, such as with multiple views based on standard viewing planes as shown in Figure 10.12. In these drawings only two dimensions are depicted in each view. No quantitative (and often no qualitative) information regarding the third coordinate can be extracted from a given view. For this reason, more than one view is required to describe the object completely.

Figure 10.11: Royston Road Underpass, B.C.

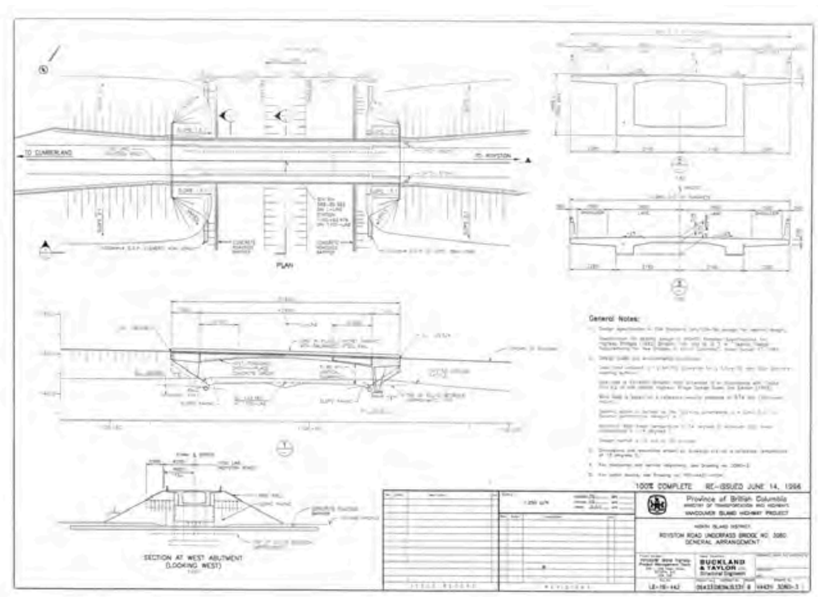


Figure 10.12: General arrangement drawing of the bridge shown in Figure 10.11. The drawing uses multiple orthographic views.

10.3 Examples from Practice

This section describes several types of contour drawing in common use in engineering.

10.3.1 Standard Topographic Maps

Topographic maps describe, with a high level of detail and accuracy, the topography (i.e., the shape) of a given geographical area. The standard way of representing the three dimensional features of landforms is contour lines.

Figure 10.13 shows an example from Canada's National Topographic System of maps. The most detailed scale available is 1:50 000.

Figure 10.14 shows an example from the National Map of Switzerland. This map is drawn to a scale of 1:50 000.

Figure 10.15 shows an example from the National Map of Switzerland, this time from their 1:25 000 series.

The Swiss maps are produced with much greater detail and with additional visual cues to help the user gain a qualitative impression of the three-dimensional landforms from the contours. This is accomplished by: (1) a relatively small contour interval (in this case 10 metres), (2) subtle shading that corresponds to the shadows that would be cast on the landforms when the sun shines from the north-west quadrant of the map, and (3) pictorial symbols such as the cliff symbol, which is used when the slope of the land is so steep as to cause excessive bunching of the contour lines.

Figure 10.13: Canadian National Topographic System 1:50 000 (to scale). Each square represents 1 km. Contour interval is 100 feet (about 30 m).

Figure 10.14: National Map of Switzerland (*Landeskarte der Schweiz*) 1:50 000 (to scale). Each square represents 1 km. Contour interval is 20 m.

Figure 10.15: National Map of Switzerland (Landeskarte der Schweiz)

10.3.2 Project-Specific Topographic Plans and Diagrams

When the level of detail given on standard topographic maps is insufficient, it is possible to produce topographic plans for a given site based on specific survey data. These plans are used, for example, for the layout of bridges. In Figure 10.16, for example, the contour interval is 5 m, which is considerably less than the contour interval used on standard topographic maps.

This type of map will generally be prepared by a specialist land survey firm.

Although contour diagrams are most often used to represent natural features such as topography, they are sometimes used to represent features of the facility to be built. Contour maps are sometimes made, for example, of bridge decks to validate that drainage will work properly.

Figure 10.16: Project-specific topographic map used for location of a bridge

10.3.3 Contour Graphs

It is also common to use contours to represent abstract surfaces, i.e., mathematical functions of two variables $z = f(x, y)$. In such cases, x and y need to be spatial coordinates in a well defined and meaningful plane. Function z then defines a three-dimensional surface, similar to a landform. The same principles used to draw contour maps of physical landforms can be used to draw contour graphs of such functions.

Figure 10.17 shows one such application. This diagram is called an influence surface for a slab free along the bottom, fixed in shear and bending along the top, and extending to infinity in the other two directions. It is based on the function $z = M_A(x, y)$, where A is a given fixed point and M_A is the bending moment at Point A due to a unit load applied at Point (x, y). It is the two-dimensional analog of the one-dimensional influence line.

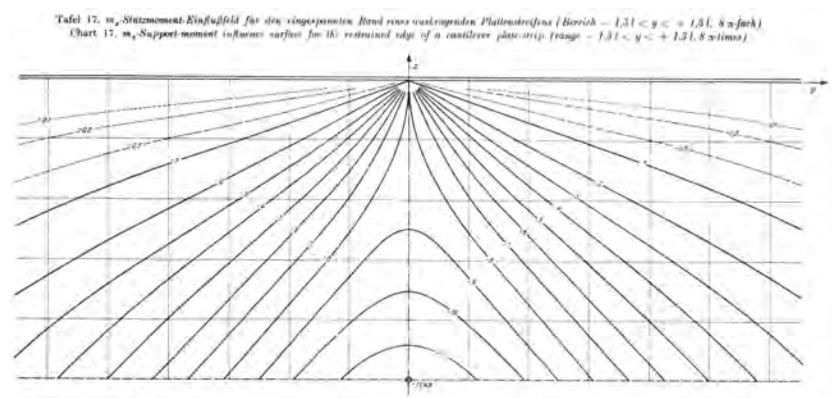


Figure 10.17: Influence surface for a cantilever slab. Fixed end is at the top. Contours give bending moment per metre of length for a unit load applied at that location (Pucher, Einflussfelder elastischer Platten)

This type of diagram can be used to calculate bending moments in bridge deck slabs due to loads applied by the wheels of a heavy truck. Its use is illustrated in Figure 10.18.

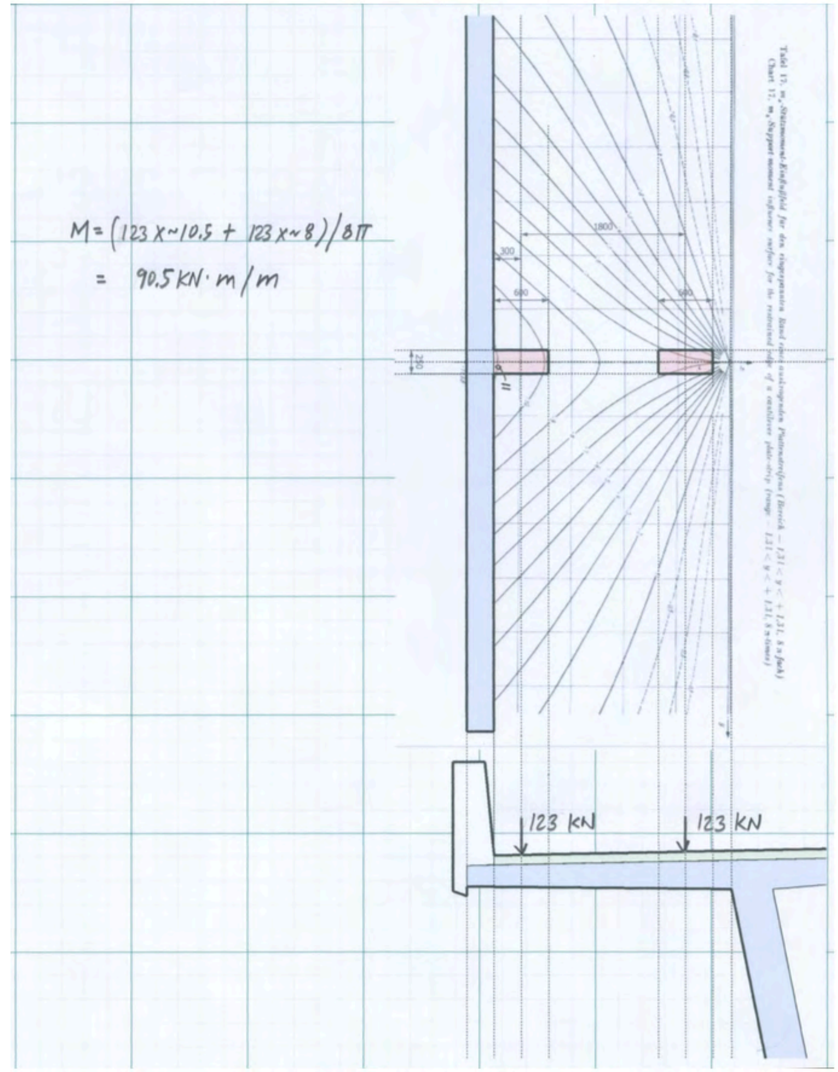


Figure 10.18: Use of the influence surface of Figure 10.17 in calculating bending moments in cantilever bridge deck slabs

10.4 Applications: Cutting Sections from Contour Maps

It is often useful to cut sections ▷ from contour maps. These sections can be visualized as the curve formed by the intersection of the given three dimensional surface and a vertical plane.

See Section 7.4.

A common application of sections cut from contour maps is drawing of the elevation of a valley to be crossed by a bridge. The procedure for cutting such a section is relatively straightforward. In SketchUp, it is handled automatically by the Section Tool. In two-dimensional AutoCad and when drawing by hand, the sections must be drawn explicitly. This procedure is described using a simple example.

We need to draw the cross-section described by Line A-A in Figure 10.19. We proceed as follows:

1 Draw a line parallel to Line A-A on a blank portion of the page. This will be the horizontal datum of the section to be cut.

2 Based on the maximum and minimum elevations intersected by Line A-A, draw a vertical scale of elevations to the left of, and perpendicular to, the horizontal datum. Provide suitable labels to this axis. Draw horizontal gridlines based on the labels given on the axis. This information is shown in the upper portion of Figure 10.19. The area just created is called the section diagram.

3 For each contour that intersects Line A-A, do the following:

(a) Identify the points of intersection of the contour and Line A-A. We will call one such point Point P_i.

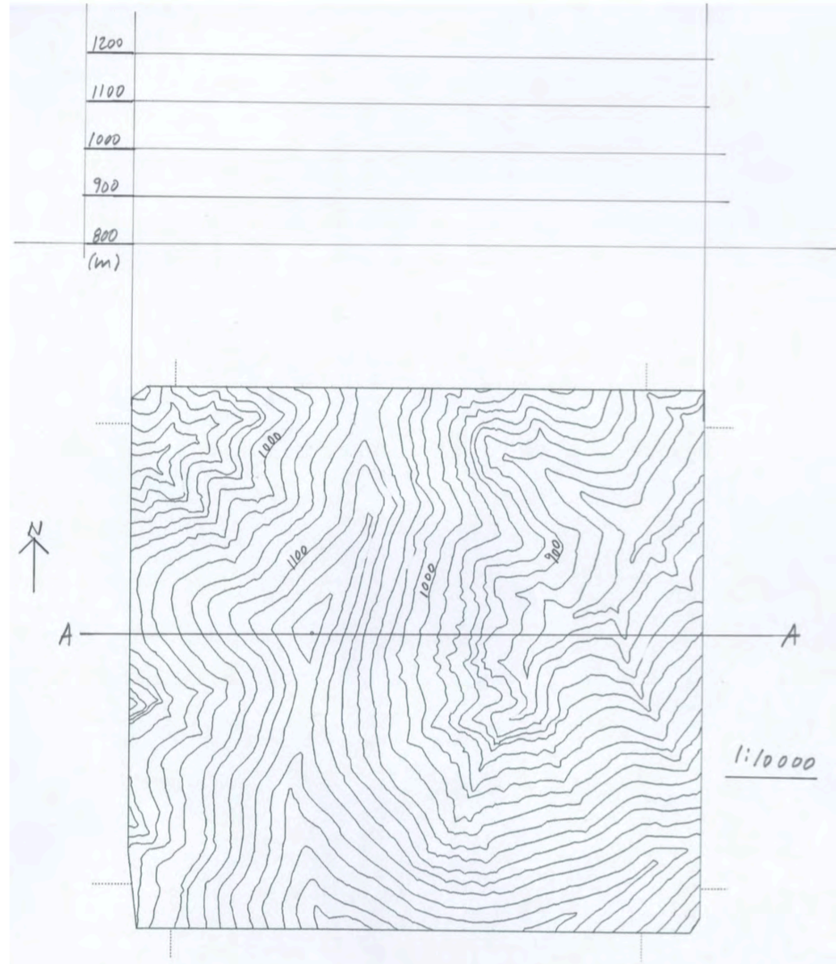


Figure 10.19: Setting up to cut section from contour map along Line A-A

(b) Draw lines perpendicular to Line A-A from Points P_i to the section diagram. The outcome of this step is shown in Figure 10.20.

(c) Draw horizontal lines in the section diagram corresponding to the contour elevations.

(d) Identify the points of intersection Q_i of the perpendicular line originating from P_i and the horizontal line corresponding to its contour.

4 Join the points Q_i to form a continuous curve. The resulting curve is the section cut along Line A-A.

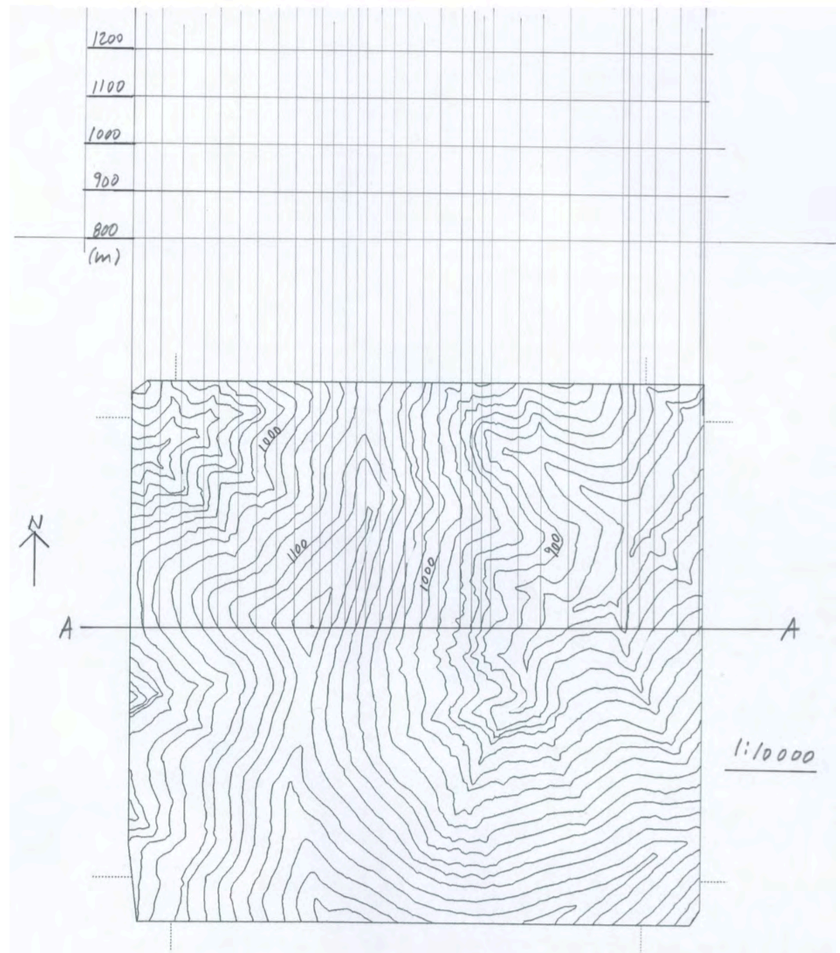


Figure 10.20: Perpendicular lines drawn from Points P_i to the section diagram.

Figure 10.21 shows the finished section cut along Line A-A. The location of one point of the profile is highlighted. It corresponds to the 1000 level contour.

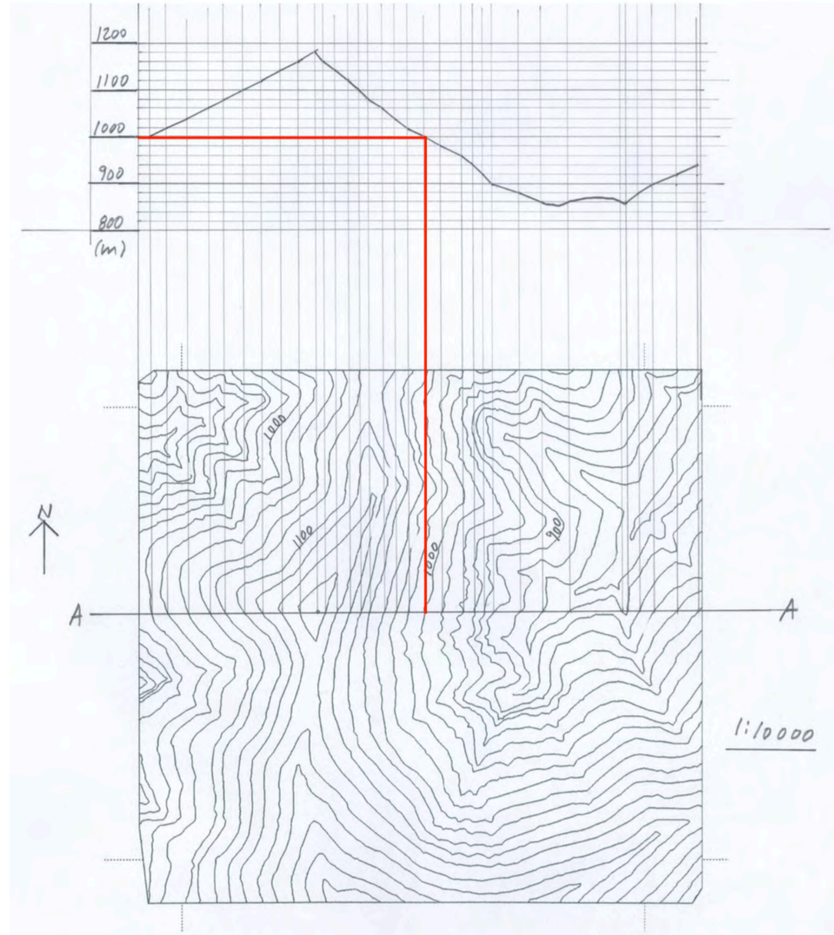


Figure 10.21: Finished section cut from the contours

Part IV

Technique: Freehand Drawing

11
General Principles of Freehand Drawing in Engineering

Notwithstanding the ease and speed with which precise drawings can be made using computers, freehand drawing remains an important tool in the engineering design process. Although it is impossible to predict the future, it is likely that engineers will continue to recognize the utility of freehand drawing in spite of inevitable further advances in CAD technology. Because it takes advantage of a very direct link between the mind and the image on the page, freehand drawing will always provide a rapid and effective means of enabling ideas to make their first and crucial step into reality. Figure 11.1 shows two freehand sketches as typically used in engineering. These sketches are made in the early stages of the design process, to assist the designer in making important decisions. In this case, the decision at hand is whether or not to use an arch or a girder for the longest span of a bridge that will cross a valley. These sketches were drawn quickly, and are therefore fairly rough, but they have sufficient realism to ensure that the pictures on paper are reasonably faithful representations of the designer's idea, because only in this way can they be useful to the designer.

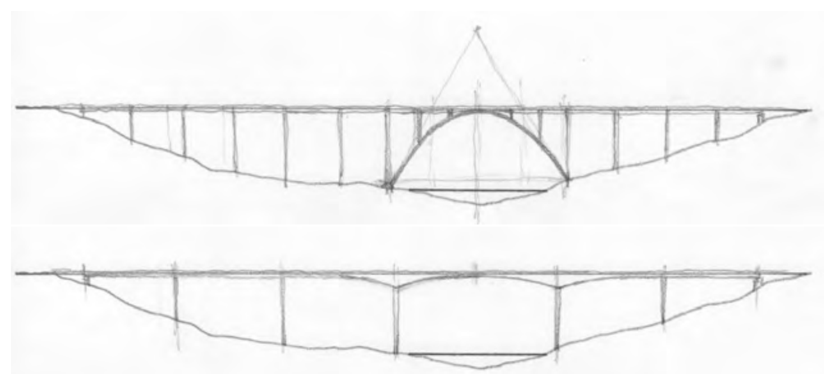


Figure 11.1: Freehand sketches of two alternative concepts for a bridge across a valley

Ability in freehand drawing seems to come naturally to a small number of people. For all others, freehand drawing is a skill that must be learned. Although this can appear daunting at first, just about everyone can learn to draw freehand to a level of competency that is adequate for use in the engineering design process. As with any skill, learning to draw freehand requires both an understanding of basic principles and lots of conscientious practice.

This chapter provides an introduction to the most important principles underlying the use of freehand drawing in engineering. It will be followed by chapters devoted to methods of drawing basic elements that are used to create freehand drawings ▷ .

See Chapters 12 (Basic Linework), 13 (Basic Two-Dimensional Figures), 14 (Basic Three-Dimensional Figures), and 15 (Drawing Engineering Objects).

11.1 What Is Freehand Drawing?

As the name implies, freehand drawing is a way of creating an image by which lines are drawn by a hand that is "free", i.e. unencumbered by implements such as straightedges or scales. In its simplest and most common form, freehand drawing involves only paper and a pencil or pen.

What makes freehand drawing different from other types of drawing, such as CAD, is not so much the means used to create the lines (pencil or computer), but rather the *basis that is used to establish the geometry of the image to be drawn.* The process of creating any representational drawing involves positioning lines and other basic drawing elements so that their geometry on the page produces a faithful representation of the geometry of the object to be depicted. When we draw with CAD, lines and other elements are positioned on the basis of numerical coordinates that are in one-to-one correspondence with the coordinates defining the geometry of the object to be depicted. This enables drawings to be created to a degree of geometric precision that is effectively perfect.

In fact, with most CAD systems, the coordinates used for drawing are identical to the coordinates that define the object.

In freehand drawing, it is not possible to use coordinates to position lines and other basic drawing elements on the page. Rather, we proceed on the basis of:

1 *Knowledge* of fundamental properties that define the primary geometric features of the object we wish to draw, and

2 The ability of the eye to recognize *fundamental visible relationships* between geometric objects on the page

Creating any type of engineering drawing requires prior relevant knowledge of the object to be drawn. Because the person who makes freehand drawings in the engineering design process is usually the designer, this knowledge will be available or will be determined as needed ▷ . Recognizing fundmental visual relationships, however, requires further discussion. This will be covered in the following section.

The use of knowledge of the object to be drawn in the drawing process is discussed in Chapter 6.

11.2 The Power of the Eye

In freehand drawing, the primary basis for ensuring that the geometry of the image on the page is a faithful representation of the geometry of the object to be drawn is the eye. Although this is less precise than drawing on the basis of coordinates, it is by no means lacking in rigor and is an effective means of creating drawings with a degree of realism that is sufficient for the purposes normally intended for freehand engineering drawings. This works because *the eye is very good at recognizing whether or not a given line or group of lines satifies certain fundamental geometric conditions.*

This proposition is illustrated using Figures 11.2, 11.3, and 11.4. The closed curve in Figure 11.2 is an attempt at drawing a circle freehand. Most people, including those who have had no training in freehand drawing, can immediately tell that this curve is a poor rendition of a circle. This is because all people are familiar with the fundamental visible properties of circles and can discern when these properties are not present in a given curve by simple visual inspection. They might not be able to explain these properties mathematically or in any other way, but they all somehow "know" what circles look like.

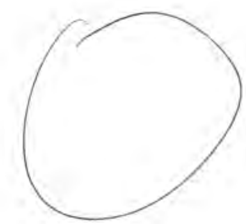


Figure 11.2: An initial (poor) attempt at drawing a circle

The story generally ends here, unless we are the ones who intended to draw the circle to begin with. In such a case, the eye's ability to discern that the curve is not a circle can also be used to determine how the curve can be corrected to transform it into a circle. Using our knowledge of what circles look like, we can keep as much of the original curve as possible and add curves inside and outside the original curve as required to make it conform to our known mental image of a circle. Figure 11.3 shows the original curve with these corrections applied.

Figure 11.3: The circle of Figure 11.2 with corrections drawn freehand

The corrected curve in Figure 11.3 does indeed look more like a circle. Comparing it to a true circle shows that it is actually a very good approximation of a circle. Figure 11.4 shows the corrected

Figure 11.4: The corrected freehand circle of Figure 11.3 with a "perfect" circle drawn using CAD

curve together with a slightly larger "perfect" circlar area drawn using CAD. The white space between the freehand curve and the circular shaded area is of relatively uniform thickness, thus confirming that the freehand curve is a relatively faithful representation of a circle.

The eye is therefore very good not only at judging whether certain important geometric conditions have been satisfied, but also at judging whether these same conditions have been satisfied "sufficiently well". This ability is the foundation of freehand drawing, as it provides a reliable means of ensuring that the geometry of the image on paper is a faithful representation of the geometry of the object to be drawn. The most important of these geometric properties and relationships that are used in freehand drawing are:

1 Whether or not a given line is *straight*

2 Whether or not a closed curve is a *circle*

3 Whether or not two lines are *parallel*

4 Whether or not two lines are *perpendicular*

5 Whether or not two line segments are *equal in length*

6 Whether or not two closed figures are geometrically *congruent*

These conditions are particularly useful in freehand drawing not only because they can be readily assessed by eye, but also because they correspond to the most significant visual properties that define the geometry of the object to be drawn. They thus provide an effective means of relating the image on the page to the object in our mind. These fundamental geometric properties and relationships will therefore be used as the foundation of the freehand drawing technique that will be described in the following section.

11.3 An Effective Freehand Drawing Method

The process of representational drawing involves positioning lines and other drawing elements on the page to create a faithful representation of a given object, real or imagined. The primary challenge of freehand representational drawing is to position lines and other drawing elements on the basis of visual relationships alone, without the help of coordinates. Fundamental geometrical properties and relationships that are readily recognizable by eye were identified previously ▷ . These will be used as the basis for an effective method of representational freehand drawing developed in this section.

See Section 11.2.

The method that is presented here has been used to good effect in the author's design practice and also by many engineers known personally to the author. It is, however, not the only method that can be used to create good freehand drawings. As you acquire experience in drawing and design, you may end up adapting the method presented here to suit your own circumstances. There is nothing wrong with this, since freehand drawing serves as a tool for designers, and whatever method produces the most useful drawings for a given designer is the method that is best for them. For now, though, students are strongly urged to devote serious effort to learning the method described here, since it is simple, it is based on sound principles, and it works.

11.3.1 Draw, Inspect, Correct

As with all effective methods of drawing, this method requires *prior knowledge of the most important geometrical relationships embodied in the object to be drawn* ▷ . Before drawing any lines, we need to identify in the object to be drawn the presence of axes of symmetry, parallel lines, and other primary geometric attributes, as well as estimate the most important proportions that define the relations between the lengths of important pairs of lines.

See Chapter 6.

This knowledge is first used to plan out a *suitable sequence for creating the drawing*. What is required is to draw lines in an order that enables the overall image of the object to emerge with the smallest possible number of lines. In more technical terms, the sequence is chosen to maximize the *increment of definition* of each line as it is drawn ▷ .

See Section 6.2.

Once this advance planning is complete, we can begin to draw. The production of each individual line follows a three-step process: *draw*, *inspect*, and *correct*. These steps are described as follows:

1 *Draw*. Draw the line or other drawing element using a suitable technique ▷ .

See Chapters 12 (Basic Linework), 13 (Basic Two-Dimensional Figures), 14 (Basic Three-Dimensional Figures), and 15 (Drawing Engineering Objects).

2 *Inspect*. Look at what you have drawn as an element on its own and also in relation to what you have already drawn. Use fundamental geometric properties and relationships such as the ones defined in the previous section ▷ to determine whether or not the position of the element you have drawn is correct.

See Section 11.2.

3 *Correct*. If it is not correct, re-draw it, using the previously drawn "incorrect" element to help in establishing the correct position.

In the early stages of learning to draw freehand, you may need to make several corrections before positioning a given drawing element correctly. In such cases, it is advisable to draw using relatively light lines. Otherwise, you will create a messy jumble of lines, out of which it will be difficult to discern the correct line.

After you have roughed out the image in this way, you can delineate the image by going over the correct lines again to make them heavier. In this way, they will stand out from the light lines that were drawn incorrectly.

11.3.2 An Example

This process is illustrated using the following example. The task is to draw a rectangle with horizontal and vertical sides, where the horizontal sides are twice the length of the vertical sides. The relevant knowledge of the object to be drawn includes: (1) opposing sides of the rectangle are parallel, (2) the corners of the rectangle form 90 degree angles, and (3) the horizontal sides are twice as long as the vertical sides. All of these properties of the object to be drawn correspond to visible relationships that will be present in the drawing.

With this knowledge in hand, the image is created following a process of drawing, inspection, and correction, using eye's ability to discern the fundamental geometric relations that must be present in the image. The primary steps are given below. Each step corresponds to one of the images in Figure 11.5:

1 Draw the lower horizontal side. Inspect it to ensure that it is straight, and if not, correct it.
2 Draw two lines of yet indeterminate length, both perpendicular to the first horizontal line. These will become the vertical sides. Inspect these lines to ensure that they are perpendicular to the horizontal line, and if not, correct them.
3 Locate the midpoint of the horizontal segment thus formed. Inspect and correct as required.
4 Locate the endpoint of one of the vertical sides of the rectangle. This will be equal in length to the distance from the end of the horizontal segment to its midpoint. Inspect and correct as required.
5 Draw the upper horizontal side, parallel to the lower side. Inspect and correct as required.

The presence of additional lines (left lighter than the lines delineating the final result), confirm that we did indeed make some "mistakes", but these were then used as the basis for making suitable corrections that allowed us to converge on a final image that is a sufficiently accurate rendition of the rectangle we set out to draw.

As our skills develop, we can move more directly to images that satisfy the required geometric conditions with a greatly reduced need for correction. Regardless of our level of skill, however, the

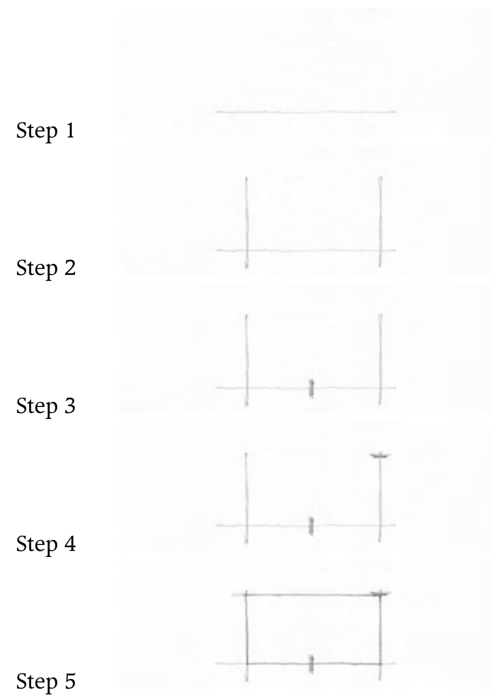


Figure 11.5: The process of freehand drawing: a rectangle with 2 to 1 aspect ratio

process of first identifying the fundamental geometric relationships that define the object to be drawn and that can be readily be verified by eye in the image on paper, and then proceeding by drawing, inspecting, and correcting, will always be a sound basis for representational freehand drawing in engineering.

11.4 The Role of Freehand Drawing in Engineering

Engineers need a means of making new ideas visible in the crucial early stages of the design process. To be effective, the means used by engineers to draw their ideas must be compatible with the creative process that gives rise to new ideas. What is required is thus a means of drawing that is fast and free, to ensure that the process of making a given drawing does not slow down the process of creating ideas. Just as important, though, the means of drawing must also provide a degree of geometric precision that ensures that the image on paper is indeed a faithful representation of the original idea. If our idea was a *precast concrete bridge segment* ▷ and we wished to draw it in cross-section, but our drawing turns out to be the image shown in Figure 11.6, then the drawing will be of only very limited use in the subsequent steps of the design process.

See Chapter 54.

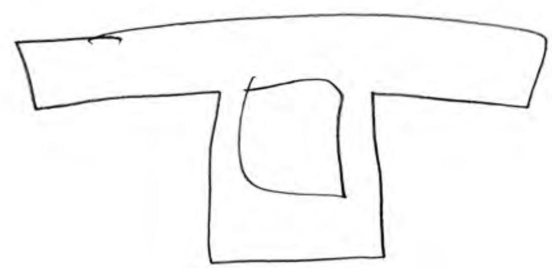


Figure 11.6: A more or less useless sketch of a precast concrete bridge segment

Engineers have historically relied on the freehand method to produce this kind of drawing. Engineers who have acquired a sufficient level of proficiency in freehand drawing find that this method enables them to produce images that faithfully depict the ideas in their imagination, at a speed that is fast enough to ensure that the drawing process does not slow down the creative process. At the present time, it is possible to create this type of drawing using the computer. Some engineers are sufficiently skilled in CAD to be able to draw with excellent precision and with a speed approaching that of a competent practitioner of freehand drawing. Notwithstanding this, freehand drawing remains useful and is likely to remain so for years to come. Freehand drawing can be done just about anywhere and at any time. All that is needed is to keep a pencil or pen and a slip or two of paper in your pocket. Drawing with CAD requires a computer and in most cases a printer. The roughness of freehand drawing is also consistent with the early stages of the design process, where ideas are not yet completely formed and nothing is cast in stone. The high precision provided by CAD can given the false impression that ideas have been defined and validated with a similar level of finality.

The use of drawing as a means of giving visible expression to ideas in the imagination is fairly easy to understand. We are simply drawing something that we can see with our mind rather than with our eyes. This use of drawing presupposes the existence of an idea in our mind that is ready to be drawn. The question of how to produce new ideas in our imagination is certainly legitimate and its answer is not at all straightforward. There is, however, strong evidence supporting the proposition that drawing has an important role to play, not only in giving visible expression to ideas already in the mind, but also in helping the mind to create these new ideas.

Nobel laureate Roger Sperry developed the theory of the *bicameral mind*, which holds that the left and right hemispheres of the brain play different roles[1]. The left side is best suited to handle tasks involving language and numbers, whereas the right half is adapted for problems involving spatial perception and creative thought. The link between spatial perception (central to drawing) and creativity was further studied by Betty Edwards, who proposed that the *act of drawing* was sufficient to bring the right side of the brain into a more active state than the left side, thus enabling the faculties of the right side to be more readily put to use in creative thought[2].

[1] Roger W. Sperry. "Hemisphere deconnection and unity in conscious awareness." In: *The American Psychologist* 23.10 (1968), pp. 723–733

[2] Betty Edwards. *Drawing on the Artist Within.* New York: Simon & Schuster, Fireside Books, 1987

If this is true, then it is certainly smart to draw when we need to think up new ideas, and it is best to do so freehand. Other types of drawing, such as CAD, involve the use of numbers (spatial coordinates) and language (typed commands), which keep the non-creative left side of the brain in action. Freehand drawing, which relies only on visual information, does not involve the left side of the brain and thus enables the right (creative) side to assume a dominant role relative to the left side.

Engineers should therefore learn freehand drawing because it is a very important tool for use in the crucial early stages of the design process. It enables ideas to be transformed into images that are truly representative of the designer's intent and is also a reliable way of stimulating the creation of new ideas.

11.5 Quality in Freehand Engineering Drawing

One of the main challenges encountered by engineers who are learning to draw freehand is to understand the appropriate standard of quality. It is certainly possible to create freehand drawings with very high levels of geometric precision and workmanship, as demonstrated by William Redver Stark's sketch of a Canadian soldier shown in Figure 11.7. Although this is a simple drawing, the artist's mastery of proportions, attention to detail, and use of shading come together to convey a level of realism that is almost photographic. Engineering students often assume that their freehand drawings must also embody a comparable level of quality. This is not true. For engineers, the effort required to produce a freehand drawing of this precision and workmanship is hardly ever justified by the value such a drawing can bring to the engineering design process.

Figure 11.7: William Redver Stark: Profile drawing of a soldier with his arm extended [Sketchbook 5, folio 5.16r], 1917
Source of image: William Redver Stark fonds, Library and Archives Canada, e008315328

Unlike the sketch of Figure 11.7, engineering drawings do not exist to be appreciated for the intrinsic beauty of the images they contain. Rather, they are created to perform specific functions within the design process ▷ . It follows that the only meaningful standard of quality in engineering drawing is *how well a given drawing performs its required functions*. To understand the standard of quality for freehand engineering drawings, therefore, we must first understand the these drawings play in the engineering design process.

The role of drawing in the engineering design process is discussed in Chapter 5.

11.5.1 Attributes of Good Freehand Drawings in Engineering

As discussed previously ▷ , the role of freehand drawings in engineering is to *stimulate the creation of new ideas and to transform these ideas into images on paper*. Freehand drawings are thus a means of bringing new ideas into reality, and as such can be regarded as essential tools for use in the creative process. To perform this important function, freehand drawings must have the following attributes:

See Section 11.4.

1 The drawings themselves must have a degree of *geometric precision* that is sufficient to ensure that they are a faithful visual representation of the ideas in the designer's mind. In other words, the drawings must *look like the idea in the designer's mind.*

2 The process of creating a given drawing must not impede the creative process of producing and validating new ideas. In other words, the focus of the designer's focus must not be on creating the drawing, but rather on creating the ideas depicted in the drawing.

These two attributes might appear contradictory. Attribute (2) implies that the process of producing freehand drawings in engineering must be relatively fast and free, to ensure that the act of drawing is responsive to the underlying creative process that it serves. Attribute (1), however, implies the need for a specific level of care in producing a given drawing, to ensure that its image can be useful to designers in assessing whether the idea depicted by the image has the potential for further development or should be abandoned in favour of other ideas. This usually implies a relatively slow pace of drawing, especially for a method of drawing that establishes the position of lines and other elements without resorting to numerical coordinates ▷ . The primary challenge of freehand drawing in engineering is therefore to find the proper speed, which needs to be fast enough to keep pace with our creative process, but not too fast to ensure that the images we produce are sufficiently precise to be useful. The problems associated with drawing too fast or too slowly are described in the following subsections.

See Section 11.2.

11.5.2 Drawing Too Quickly

Drawing too fast can produce images of insufficient geometric precision, which can reduce their usefulness to designers. This is illustrated by the images in Figure 11.8. Supppose that we are in the early stages of designing a bridge and wish to begin defining the primary attributes of the superstructure cross-section. We decide to consider a single-cell concrete box girder. We have an idea of how it should look: as the name implies, it will look sort of like a box, with a bottom, two sides, and a top, and a cavity in the middle. The top of the box needs to extend outward beyond the sides as two cantilevers. So we proceed to sketching our idea. Figure 11.8 shows two possible cross-sections that could be drawn.

The left-hand drawing was made quickly. It took less than ten seconds to draw. It does indeed contain all the information that was described using words in the previous paragraph. But the level of *geometric precision* is very low. It takes only a rudimentary knowledge of construction to realize that the irregular lines defining the outline of the cross-section will not be built according to the curves shown. This brings into doubt this drawing's capacity to convey any additional useful information about the cross-section as imagined by the designer.

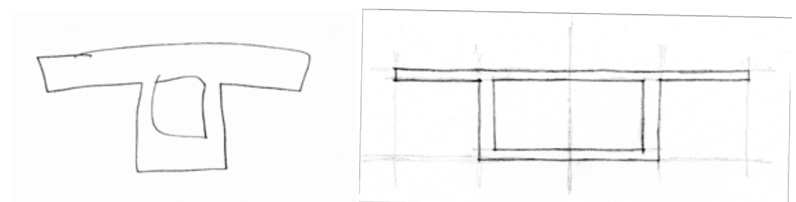


Figure 11.8: Two freehand sketches of a single-cell box girder bridge cross-section

The right-hand drawing was drawn more slowly. It took about one minute to draw. It also contains all the information that was given previously. It has, however, been drawn to a higher level of geometric precision than the left-hand drawing. Lines that are straight in the drawing correspond to lines that are intended to be straight in reality. The same relation between what we see in the drawing and what was intended for the final as-built product applies to parallel lines, proportions, and symmetry.

Which of the two drawings is better? In this case as in all cases, it is the one that is more *useful to the designer*. The left-hand drawing in Figure 11.8 conveys no more information than the description given previously in words, whereas the right-hand image gives useful information on the cross-section and its components including proportions and relative thickness of components. It can be used effectively in comparative studies of other cross-sections, such as the one shown in Figure 11.10. It can also be used as a basis for moving forward in the design process, for example as a basis for studies on how the superstructure can be connected to its supporting piers, as shown in Figure 11.11. The geometric precision of the left-hand drawing in Figure 11.8 is insufficient to enable it to be useful in these capacities. On this basis, we can therefore conclude that the right-hand image in Figure 11.8, reproduced in Figure 11.9, is better. The reduction in speed required to draw it appears to be justified.

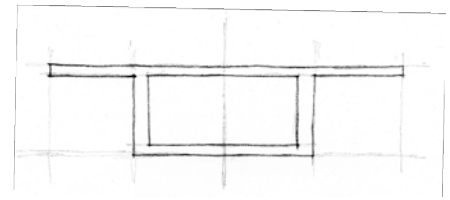


Figure 11.9: Freehand sketch of a single-cell box girder bridge cross-section

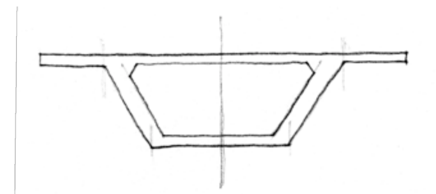


Figure 11.10: A variation on the original single-cell box girder bridge cross-section

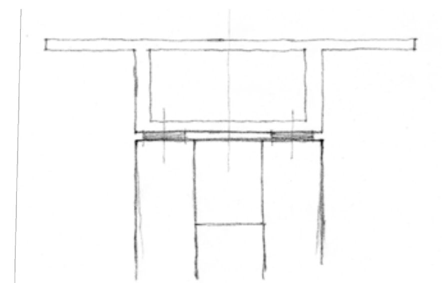


Figure 11.11: Connection of superstructure to pier

11.5.3 Drawing Too Slowly

Drawing too slowly can result in the loss of good ideas. When the mind is occupied for too long with drawing a given idea, especially when this process is fraught with stress brought on by concerns about geometrical precision and workmanship, it is difficult for the mind to respond to the spark of new ideas as they occur. Because this problem is associated with a process, it is difficult to illustrate it using static images such as figures Figures 11.8 through 11.11.

Engineers who draw too slowly generally do so because they are trying to achieve a standard of geometric precision and workmanship that is too high. The point is not to create perfect drawings, but rather to create drawings that are useful to the designer. This can be accomplished with drawings that are considerably less than perfect.

This proposition is illustrated using Figures 11.12 and 11.13. Both images depict the same view of the same design, namely, the front elevation of a hangar with an arched roof. The freehand sketch was drawn by the designer for the designer's own use during the early stages of the design of this structure. The CAD drawing was created in a subsequent stage of the design process and is an extract from one of the final contract drawings.

The freehand sketch is fairly rough and was clearly done quickly. Its worksmanship and precision are clearly inferior to the sketch of the soldier in Figure 11.7. It even shows some "mistakes", in the sense of lines that have been crossed out or superseded by other lines. It also depicts ideas that can be considered "false starts", such as the gables on the sloping faces of the arch that were not included in the final design. The overall impression, though, is a reasonably good representation of the final design shown in the CAD drawing. All of the primary features are present, and the overall geometry is reasonably close to the final product. From this perspective, therefore, in spite of geometric precision and workmanship that are considerably less than perfect, the freehand sketch did exactly what

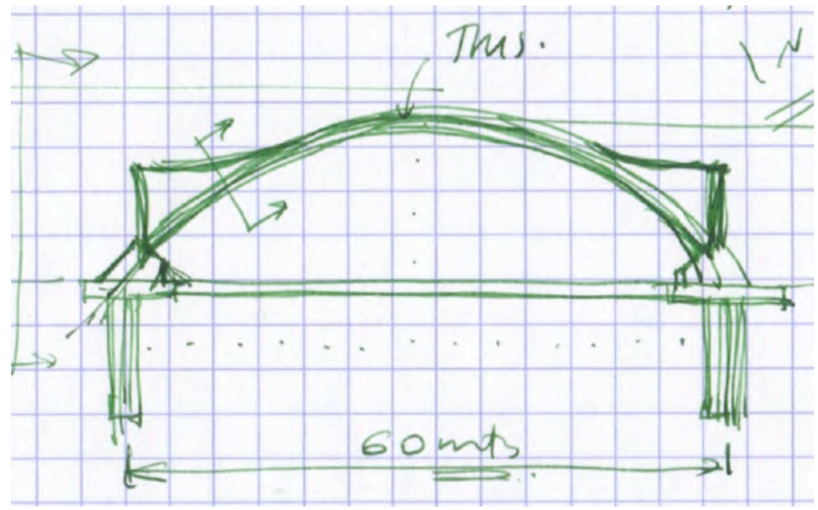


Figure 11.12: Hangar with arched roof: drawing created to bring the designer's idea into reality

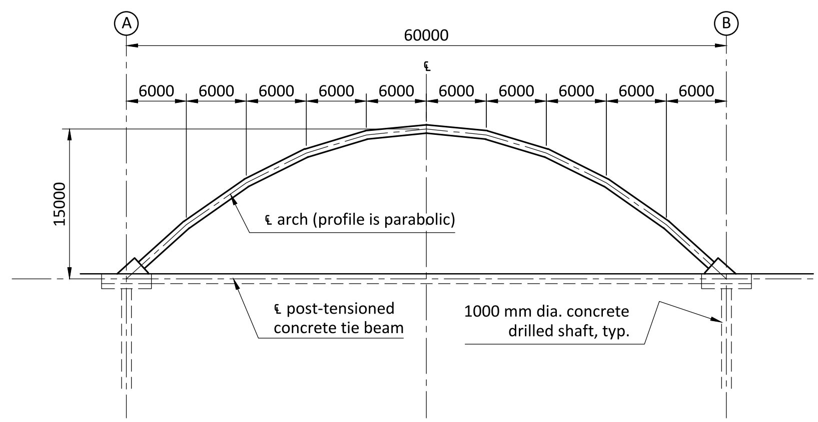


Figure 11.13: Hangar with arched roof: drawing created to describe a design to others

it was supposed to do within the design process. It gave the designer a reasonable visual impression of the overall proportions of the structural system and its primary components, which provided a valid basis for subsequent design decisions (such as removing the gables).

Producing a standard of geometric precision and workmanship in freehand drawing that approaches that of coordinate-based drawings such as CAD drawings is thus not necessary, since useful freehand drawings can be produced with a considerably lower standard of precision and workmanship. Moreover, producing freehand drawings to such a high standard is usually extremely difficult if not impossible.

The futility of trying to produce "perfect" freehand drawings is illustrated by Figures 11.14 and 11.15, which are two drawings of the same concrete bridge segment. Both were drawn by the same person, an experienced designer of bridges who is reasonably competent in engineering freehand drawing. The sketch in Figure 11.14 was drawn as quickly as possible while still correctly depicting the most important geometric relationships (parallel lines, relative proportions, etc.). It was completed in about two minutes. There are indeed some rough aspects to this drawing, such as lines that are less than perfectly straight, pairs of lines that are less than perfectly parallel, and construction lines that were left in place, including a few that needed to be corrected in the drawing process. The overall impression is still, however, relatively strong. The sketch is a very faithful depiction of the designer's idea and the execution is sufficiently precise to ensure that the drawing can be useful in subsequent stages of the design process.

The sketch in Figure 11.15 was drawn to maximize precision and workmanship without regard for time. It was completed in fifteen minutes. The precision an workmanship of this sketch are indeed higher than that of the sketch in Figure 11.14. The lines are straighter, parallel lines have been drawn with greater consistency, and the

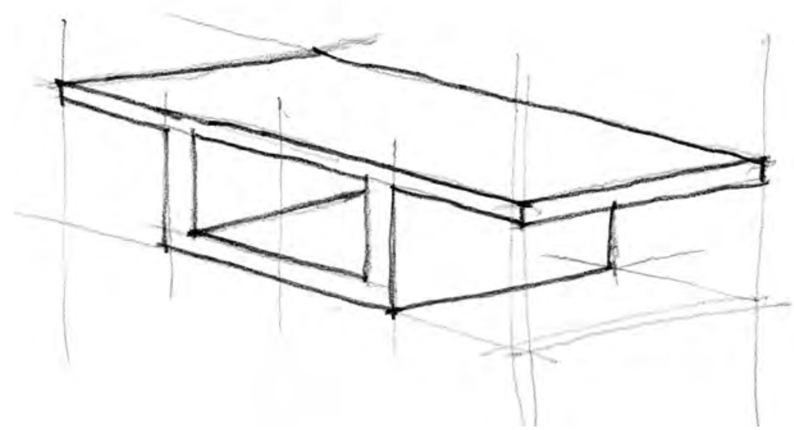


Figure 11.14: "Rough" freehand sketch of bridge segment that required two minutes to draw

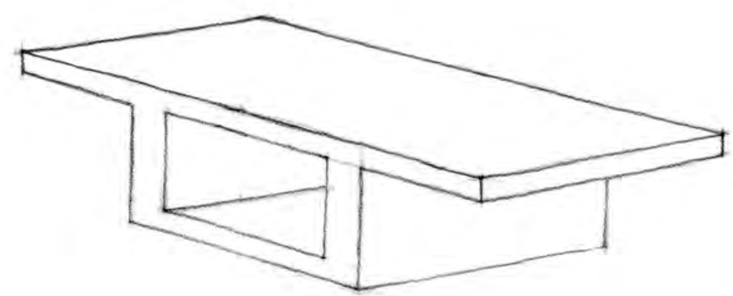


Figure 11.15: "More refined" freehand sketch of bridge segment that required fifteen minutes to draw

construction lines have been carefully erased. In spite of this, however, this sketch really does not convey any more information than its quickly drawn counterpart from Figure 11.14. The additional time required to produce the more precise sketch (over seven times longer) thus did not increase the value of the sketch to the design process.

When we draw too slowly, therefore, we reduce the effectiveness of the *process* of drawing as a tool within the creative process without significantly increasing the value of the *drawing itself* in the same process.

11.6 Learning Freehand Drawing in the Classroom

It is generally not possible to replicate a realistic design situation in the classroom. It is thus difficult for engineering students to experience the use of freehand drawing as a tool for use in the design process ▷ , and especially to assess their drawing skills according to the effectiveness of the images they create and the process of creating these images in helping them to create good designs ▷ .

See Section 11.4.

See Section 11.5.

Learning freehand drawing in an engineering academic setting will still involve drawing from the imagination (i.e., drawing what the mind sees), but the objects to be drawn will be defined in advance rather than developed within a creative process that occurs at the same time as the act of drawing. In the initial stages of learning, these objects will be basic drawing elements such as regular geometric shapes (Fig. 11.16). Following this, students will move on to draw objects that could actually be drawn by engineers in a real design process (Fig. 11.17).

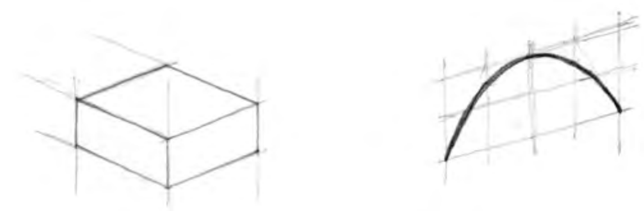


Figure 11.16: Simple geometric figures to be drawn in class: an isometric prism and a parabola

The same method will be applied for all objects ▷ :

See Section 11.3

1 *Understand* the geometric properties and relations that define the primary visible characteristics of the object to be drawn.

2 *Plan* the drawing process to enable the image to appear on the page

with the minimum number of lines.

3 To produce a given line, proceed by *drawing*, *inspecting*, and *correcting*.

Because drawing cannot be used in a classroom setting as a tool in the design process, the quality of a given drawing cannot be assessed according to way the images themselves and the process of creating them creates value for the design. Instead, the quality of a given drawing will be assessed according to the two primary attributes of engineering freehand drawing defined previously ▷ :

See Section 11.5.1

1 *Realism*. It must be possible to discern the intended image on the page and this image must look like the object it purports to depict. This involves both geometric precision and workmanship. The quality that is possible with CAD is not possible nor expected. Attempting to reach this level of quality with freehand will lead to frustration and will waste time. Rather, students need to become familiar with the "look" of good freehand drawings, which, although somewhat rough, is still sufficiently realistic to suit the needs of the design process.

2 *Speed*. Students need to produce drawings with a level of realism described under Point (1) at a speed that will ensure that, when they are in a real design situation, the process of drawing does not impede the creative design process.

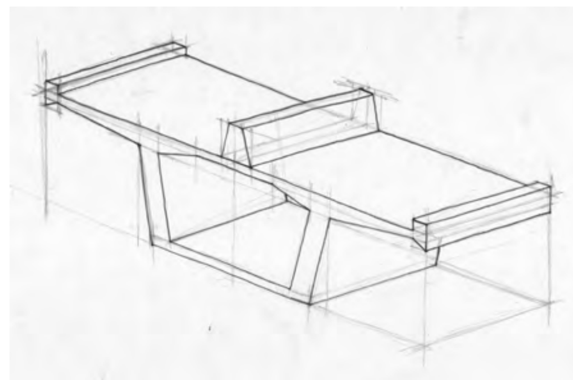


Figure 11.17: Simple engineering object to be drawn in class: a precast concrete bridge segment

11.7 Opportunities for Practice

As with any skill, acquiring proficiency in freehand drawing requires regular and frequent practice. Fortunately, the day to day activities of engineering students provide ample opportunities to do so. These include:

1 *Taking notes*. Engineering students attend lectures for several hours a day and take copious notes. These usually include graphs, di-

agrams, and charts of various kinds. Each one of these provides an excellent opportunity to practice freehand drawing skills. While taking notes, students should challenge themselves to recognize the basic geometric figures already learned within the images to be drawn, and apply the technique of draw, inspect, and correct to the task of drawing these diagrams freehand ▷ . Figure 11.18 shows an example of diagrams commonly encountered in civil engineering courses that can and should be drawn freehand.

See Section 11.3.

2 *Doing assignments.* In a similar way, regular engineering assignments usually involve drawing diagrams, often in response to a formal request made in the problem statement. If the course instructor who has set the assignment has not specified the medium to be used for the drawing, take advantage of this opportunity to draw the diagram freehand.

3 *Idle time.* Many students commute back and forth to campus every day. It is easy to keep a notebook and pen or pencil handy for making simple sketches while on the subway or bus. This is an excellent opportunity in particular for practicing the simple geometric figures that form the building blocks for more complex sketches.

Students who take advantage of as many opportunities as possible to practice their newly acquired freehand drawing skills will find that they will gain proficiency more quickly than their classmates who do not draw as frequently.

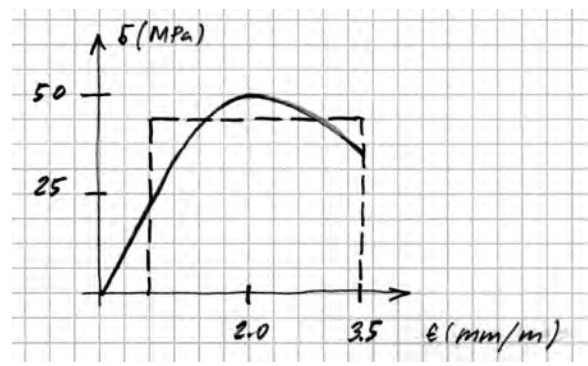


Figure 11.18: Diagram from class notes

11.8 Implements

The implements that will be used in the course for freehand drawing are simple and few. We will use:

1 *A pencil.* Strictly speaking, any pencil will do ▷ . An engineer who has mastered the technique of freehand drawing will be able to use

There are, however, formal requirements for the type of pencil that can be used in Special Exercises and Exams. These requirements are specified in Section 3.2.

freehand drawing as an effective tool in the design process regardless of the implement used. Conversely, a person who is struggling to apply the technique will not do much better or worse simply by changing the type of implement. Having said this, though, a suitable pencil can make it easier for most people to apply the techniques presented in this course.

The recommended pencil for this course is *Blackwing 602* by Palomino Brands ▷ . This is a high-quality wood/graphite pencil that can make excellent light and heavy lines with relatively little pressure. This makes it ideal for the work we will do in this course.

More information on Blackwing pencils can be found at the following link: http://palominobrands.com/blackwing/.

2 *Plain white paper.* As with pencils, just about any piece of paper will do. One of the great advantages of freehand drawing over other media is that it can be done on practically whatever is at hand, including the back of envelopes.

When you are learning to draw freehand, it is important that the paper have no lines or other markings other than the ones you make. Plain bond paper (the kind that is used in printers or photocopy machines) works well. It is plentiful and relatively inexpensive. The recommended pencil for this course (see the previous point) can produce a good range of light and heavy lines on this paper.

All of the drawings done in class (exercises and exam) will be done on paper provided by course staff. This will in all cases be plain bond paper.

11.9 The Question of Erasing

Many students are tempted to erase their false starts when drawing freehand. The desire to erase is easy to understand. Students usually consider drawn lines incorrectly to be "mistakes" that reduce the quality of their drawings. This perspective betrays a lack of understanding of freehand drawing and its role in the engineering design process. Engineers are strongly urged not to erase when drawing freehand, for the following reasons:

1 *There is simply no need to erase.* The presence of incorrectly drawn lines and other extraneous lines is certainly not welcome in many

types of formal drawings ▷ . This, however, is not at all the case with informal drawings such as freehand drawings. In engineering, freehand drawings are tools used by the person who makes the drawing and are generally not intended to communicate information to other people. Because they are the personal tools of the designer, and they can be of great value to the creative process even though they are not "perfect". Construction lines that are drawn lightly, even if they are in the wrong place, need not prevent designers from discerning the image that was intended. If the presence of too many construction lines makes it difficult to discern the image, it is either because the designer is exploring too many ideas within the same image, in which case additional images should be drawn, or the designer is making too many mistakes, in which case their skills need to be sharpened.

See Section 6.1.

2 *Erasing wastes time.* The importance of speed in the freehand drawing process has already been established ▷ . When designers erase, it reduces speed, thus reducing the value of the drawing process to the underlying creative process.

See Section 11.5.1

3 *Erasing removes useful visual references that actually help in achieving better geometrical precision.* In freehand drawing, we must locate lines and other drawing elements on the page based on purely visual means. Detecting an incorrectly drawn line implies that we have a good idea of where the correct line should be relative to the incorrect one. Leaving the incorrect line in place thus gives us a visual reference that can be used as a basis for drawing the corrected line. When we erase the incorrect line before drawing the correct one, we deprive ourselves of this useful reference.

4 *Erasing detracts from the "look" of freehand drawing.* Freehand drawings are associated with speed and exploration of ideas. There is thus an expectation that they will reflect imperfection in the design process (false starts, changes of mind, and other evidence that we did not find the best idea on the first try), as well as imperfection in

the drawing process, since we need to draw quickly to support an effective creative process. It is thus always acceptable for freehand drawings to look a little "rough".

Engineering students who are learning to draw freehand are therefore strongly urged *not* to erase.

11.10 Summary

1 *Freehand drawing is a tool in the creative design process, rather than a means of formally describing a completed design.* The standard of quality for freehand drawings must be consistent with this fundamental nature of freehand drawing in engineering.

2 *Freehand drawings must be sufficiently precise to be of use in the design process.* As a minimum, drawings must look like the ideas that were in the designer's mind. The level of precision and refinement must be sufficient to enable the drawing to be used as a basis for making design decisions.

3 *Freehand drawings must be drawn relatively quickly.* The speed of drawing must be sufficient to ensure that the process of drawing does not impede the underlying creative process. When drawing, the focus must always be on the object that being drawn rather than on the drawing itself.

4 *A certain degree of roughness is always acceptable in engineering freehand drawings.* This is part of the "look" of freehand drawing. Straight lines to not have to be as straight as those drawn by CAD, provided the drawing represents faithfully the overall proportions of the object it depicts. Provided the features of the object are clearly recognizable, there is no need to erase construction lines, even those that were drawn incorrectly. Erasing wastes time and is inconsistent with the nature of freehand drawing as a tool in a dynamic design process.

5 *Freehand drawing must not be used where it is not appropriate.* Drawings that must provide perfect geometric precision are best done with CAD.

12 Basic Linework

This chapter presents freehand techniques for drawing a fundamental set of primary drawing elements. All of the figures that will be drawn in this course will be based on these elements.

Once mastered, these techniques will help you to achieve minimum acceptable levels of speed and geometric precision which are the two primary attributes of good freehand drawing ▷ .

We need enough precision to ensure that what appears on the page is a reasonable representation of what was in our mind. We need enough speed to ensure that the process of producing the drawing does not slow down our creative design process. For more on this subject, see Section 11.5.1.

The techniques presented here are not the only way to draw these figures, but they will work well if properly learned through conscienctious practice. As you acquire proficiency in drawing, you may find that other techniques work better. This is normal. For now, though, especially if you have little or not experience in freehand drawing, you should strive to master these techniques as described here.

Success in drawing these primary elements requires both good position and control of the hand, and also proper use of the eye to guide the pencil. Especially important in this regard is not to fixate on the pencil point. In most cases, mastery of the technique requires focusing attention on other parts of the drawing.

As with every aspect of freehand drawing, mastery of these fundamental figures requires lots of careful and conscientious practice. At first, concentrate on getting a good feel for the pencil on paper and a good fluid motion of the fingers. In the initial stages of learning a technique, do not worry about accuracy. That will come with practice. It is especially important not to draw too slowly in the pursuit of accuracy that is not attainable in freehand drawing.

All of these techniques should be practiced and applied using the implements described previously ▷ .

See Section 11.8.

12.1 Straight Line Segments

This section presents a technique for drawing relatively short straight line segments. Straight lines are the basic building block that will be used extensively in every freehand figure we draw, and upon which all other drawing elements we learn will be based.

In engineering drawing, straight lines are everywhere. This is because the things we design usually perform their function better when they have a straight axis or straight edges. For example, gravity acts vertically, so it is most efficient for building columns and bridge piers to have a straight vertical axis. In buildings, straight floors, walls, and ceilings usually provide the most efficient use of available space. Straight components are usually easier and more economical to transport and erect, and components with straight edges often fit together more easily than with edges that follow other shapes.

The basic technique is presented in a short video ▷ . Any technique in freehand drawing involves both the eye and the hand. The technique presented in the video emphasizes the hand. It involves keeping the forearm and wrist firmly resting on the table, and moving only the fingers to draw the line. This is very important. To draw a straight line from a biomechanical point of view, we need to work with more than one joint. If we held the pencil rigidly with our fingers and moved only our wrist, we would get an arc. The same is true if both fingers and wrist were locked, and we moved our elbow. By locking our elbow and wrist, we mobilize the joints of the fingers,

Video: Freehand Technique for Drawing Straight Line Segments `https://youtu.be/14PbFkLEXMQ`.

each of which has three joints, and thus is mechanically capable of drawing a straight line segment.

This technique requires that, prior to drawing a given line segment, the page be rotated into position so that the line can be drawn vertically, i.e., towards one's chest. This is very important. The technique will not work effectively for lines drawn in any other direction. It is very important, therefore, that *the page be rotated into position before drawing any line segment*. This might appear time consuming, but it will soon become second nature and will produce lines of much better quality than would otherwise have been possible.

Students are strongly urged to use this technique until they have acquired a level of proficiency with which they are satisfied.

Because this technique involves drawing with the hand and arm completely stationary, it can only be used for line segments of maximum length 5 or 6 cm (depending on the length of your fingers). The following section describes a technique for drawing longer segments.

12.2 Extending Straight Line Segments

The basic technique for *straight line segments* described previously ▷ requires the forearm and wrist to remain stationary, so the maximum length of segment we can draw with this technique is about 5 or 6 cm. If we want to draw longer lines, we need to do so in more than one increment. We will do so by drawing the first segment, shifting the paper into a different position, and drawing the second segment. Each segment will be drawn using the technique described previously.

See Section 12.1.

The technique is presented in a short video ▷ .

Video: Freehand Technique for Extending Straight Line Segments `https://youtu.be/6QCHgYjFXbI`.

The primary challenge is to align the successive segments so that they come together to form a straight line. This technique thus relies more on the eye than the technique of drawing a single short line segment, since it requires sighting the previously drawn segment to ensure that the new segment being drawn is aligned with the previous segment. The eye is actually very good at judging if a given line is straight, and you will soon find that you are getting very good results.

12.3 Line Weight

For the previous techniques described in this chapter, relatively light lines were drawn. This remains the basic technique for most of the freehand drawing we will do. A light touch enables us to maintain maximum control over the motion of the pencil. Freehand drawing involves inspecting what we have drawn and correcting our mistakes, if required ▷ . Correcting is done simply by drawing a new light line without erasing. We also generally draw lines beyond where they will actually end up in the finished image. This is for convenience and speed.

See Section 11.3.1.

This is illustrated by the images in Figure 12.1. The image on the left shows a rectangle that has been roughed out using light lines. We can see several instances were corrections have been made on the basis of inspection. The top horizontal line was determined to be too far from the bottom horizontal line, so another one was drawn in. We also see that the line segments that define the rectangle also extend beyond its corners.

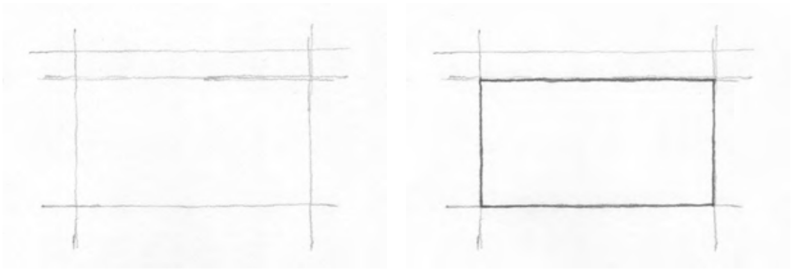


Figure 12.1: Freehand drawing of a rectangle. Left: figure roughed out with light lines. Right: rectangle delineated with heavy lines

Following this, it would be possible to erase all the unwanted lines, but this slows down the drawing process. It is more efficient just to make the lines that define the figure we had intended to draw heavier. Erasing tends to get us focusing on an unattainable and unnecessary level of precision, when what we need to be focusing on is speed ▷ . We call the process of defining the desired figure with heavy lines *delineating* the figure. The image on the right in Figure 12.1 shows the outcome of the delineation of the rectangle that had been roughed out in the image on the left. This makes the intent of the drawing clear.

See Section 11.9.

This technique will be used extensively when we draw more complex objects. For this, we will follow a process that involves roughing out the primary shape with simple figures such as rectangles and prisms, and then "carving out" the object we had intended to draw from these simple figures. We then use heavy lines to delineate the object. Figure 12.2 shows the drawing of a bridge cross-section that has been roughed out with light lines. Figure 12.3 shows the same segment after it has been carved out of from the arrangement of light lines using heavy lines.

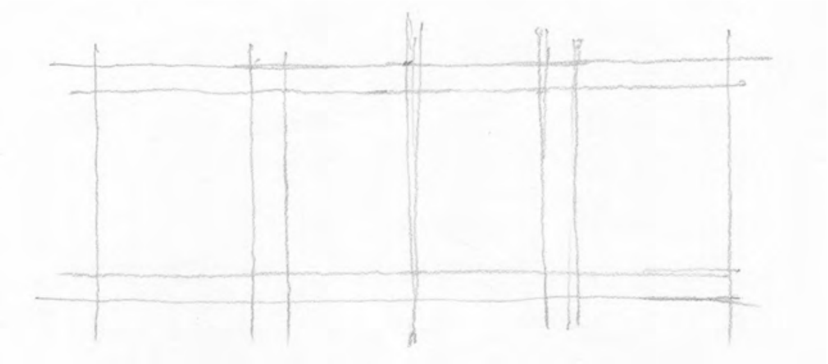


Figure 12.2: Simple geometric figures to be drawn in class: an isometric prism and a parabola

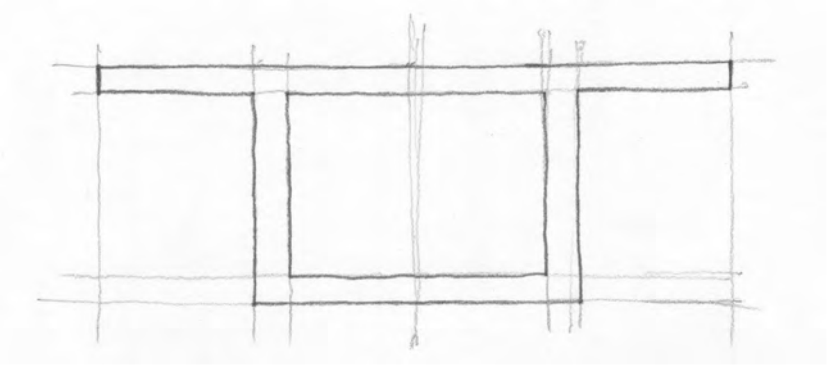


Figure 12.3: Simple geometric figures to be drawn in class: an isometric prism and a parabola

The technique is presented in a short video ▷ . It involves keeping very light pressure on the pencil at all times, to maintain control over the motion of the pencil point. Making lines heavier thus involves going over the lines we want to delineate more than once. This will be easier when a suitable pencil is used ▷ . If the original lines are sufficiently light, and if the lead is sufficiently soft, it will only be necessary to make one or two additional passes over a given line to make a visible distinction in weight.

Video: Freehand Technique for Light and Heavy Lines
`https://youtu.be/rvGEoIzoAlY`.

See Section 11.8.

12.4 Straight Line Segments Through Two Given Points

The techniques described previously required that the line segments we drew be straight. The technique presented in this section involves an additional challenge: making the line pass through a predetermined "target" point. So we must not only make the line straight, we must set its initial direction correctly.

This is not too difficult when the lines we wish to draw are sufficiently short, i.e., short enough to be drawn without moving the page relative to the hand. It becomes more challenging when we need to re-position the page relative to the hand ▷ .

See Section 12.2.

The technique presented in this section involves relatively short lines only. It is described in a short video ▷ . It involves *sighting* the target point, i.e., keeping the eyes focused on the point where the line segment will terminate, and not on the point of the pencil.

Video: Freehand Technique for Drawing a Straight Line Between Two Given Points `https://youtu.be/sW_-hTvThgg`.

A technique for drawing long straight line segments between two given points is described elsewhere ▷ .

See Section 13.4.

12.5 Parallel Lines

Parallel lines are also ubiquitous in engineering drawing, for two primary reasons. Components that have parallel lines and/or surfaces are easier to produce, transport, and connect to other components. Parallel lines also form the basis for drawing squares, rectangles, and prisms, which are the basic building blocks from which we will create freehand drawings of just about everything ▷ .

See Chapters 13 and 14.

The technique for drawing parallel lines is presented in a short video ▷ . It involves sighting the space between the previously drawn line segment and the segment currently being drawn, and ensuring that this is maintained constant throughout the drawing process. This is more convenient to do when the line currently being drawn is between the hand and the previously drawn line. For right-handed people, this means drawing parallel lines from left to

Video: Freehand Technique for Drawing Parallel Lines `https://youtu.be/nn5eaSJMEwo`.

right. For left-handed people, parallel lines should be drawn from right to left (Fig. 12.4).

After the lines are drawn, it is necessary to inspect the lines and to make a suitable correction if necessary. The eye is a very good judge of whether or not two lines are parallel. Rotating the page and looking at the lines for several different angles can help in this regard.

The challenge of drawing parallel lines becomes greater as the distance between the lines increases. In such cases, drawing the lines longer than is required for the image can sometimes help increase the geometric precision.

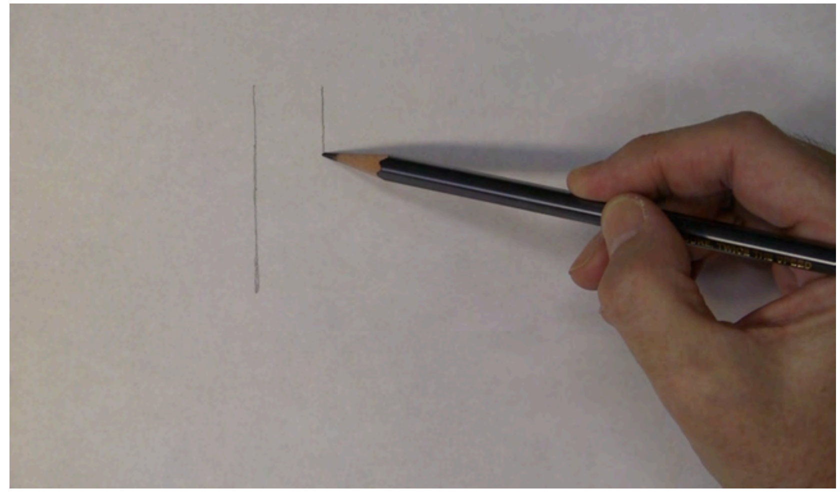


Figure 12.4: When drawing parallel lines, make sure the line you are drawing is between the previously drawn line and your hand. For a right-handed person, this means drawing lines from left to right.

12.6 Perpendicular Lines

Perpendicular lines are also encountered often in engineering drawing. As with parallel lines, they are not only common in the components designed by engineers, but they also are a useful construction applied to the task of drawing many types of figures.

The technique for drawing parallel lines is presented in a short video ▷ . It involves rotating the page so the the line segment defining the first leg of the angle is horizontal, and then drawing the second leg of the angle. It is generally easier to draw a cross rather than to draw an angle, since this provides a better basis for inspecting the angle thus drawn.

Video: Freehand Technique for Drawing Perpendicular Lines
https://youtu.be/ikAQ17Zy3DE.

After the lines are drawn, it is necessary to inspect the angle and to make a suitable correction if necessary. The eye is a very good judge of whether or not two lines are perpendicular. Rotating the page and looking at the lines for several different angles can help in this regard.

12.7 Subdividing a Line Segment into Segments of Equal Length

Freehand drawing does not rely on any numerical basis for geometric precision. We do not measure nor do we use coordinates. Instead, freehand drawing relies to a large extent on mastery of the relative *proportions* of drawing elements.

As an initial step to mastering the technique of proportions, we will first develop the technique of subdividing a given line into a given number of segments of equal length. This technique is presented in a short video ▷ . The technique is based on the principle that the eye is very good at determining whether or not two related drawing elements are of equal length. We thus begin by moving the pencil to our best estimate of the dividing point, making a short perpendicular line, and the inspecting the result.

Video: Freehand Technique for Subdividing a Given Straight Line into Segments of Equal Length
https://youtu.be/gftS6sfh3VA.

We should take advantage of multiples of two, since it is easiest for the eye to assess the equality of two related components. So if we wish to subdivide a line into six equal components, we can first divide the line into three equal components and then subdivide each of the segments thus produced into two equal components.

13
Basic Two-Dimensional Figures

The techniques described in the previous chapter for creating elementary drawing objects will now be applied to creating more complex two-dimensional figures. These figures will be the basic building blocks for all of the objects you will draw.

13.1 Parallelograms

Parallelograms are the most important of the basic two-dimensional figures, since they will be used as the basis for drawing every other basic two-dimensional figure and every three-dimensional figure. The technique for drawing them is relatively simple. It requires proficiency in drawing straight lines and parallel lines.

The procedure is as follows:

1 Draw two light parallel lines (Fig. 13.1) ▷ . Inspect and correct them if necessary.

See Section 12.5.

2 Rotate the page and draw two more light parallel lines in any direction other than the direction of the previous two lines (Fig. 13.2). Inspect and correct them if necessary.

3 Delineate the parallelogram with heavy lines (Fig. 13.3) ▷

See Section 12.3.

When drawing the first pair of parallel lines (Step 1), try to anticipate the shape of the parallelogram you intend to draw by offsetting the lines. This has been done in Figure 13.1, where the line on the right has been drawn lower than the line on the left, anticipating the downward arrangement of the final parallelogram shape.

There is a practically infinite variety of possible shapes for parallelograms: short, tall, fat, thin, large, small, etc. This technique can be used to draw the full range of possible shapes. When you practice this technique, it is recommended that you cover as much of this range as possible.

Figure 13.1: Drawing a parallelogram: Step 1

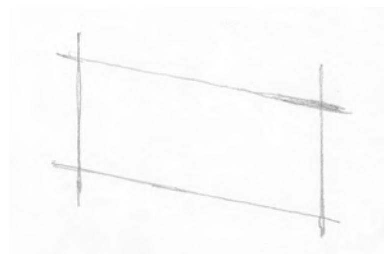


Figure 13.2: Drawing a parallelogram: Step 2

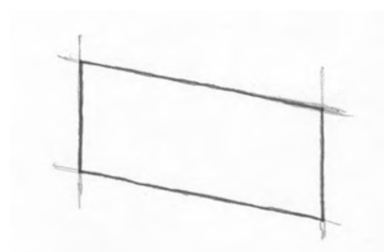


Figure 13.3: Drawing a parallelogram: Step 3

13.2 Rectangles

Rectangles are simply parallelograms in which the angles defined by adjacent sides are all 90 degrees. The technique for drawing them is therefore a relatively simple adaptation of the technique for drawing parallelograms:

1 Draw two light parallel lines (Fig. 13.4). Inspect and correct if necessary.

2 Rotate the page and draw a light line perpendicular to the two parallel lines (Fig. 13.5) ▷ . Inspect and correct if necessary.

3 Draw the fourth line of the rectangle parallel to the previously drawn line (Fig. 13.6). Inspect and correct if necessary.

4 Delineate the parallelogram with heavy lines (Fig. 13.7).

It is important to execute Step 2 deliberately, and to inspect the third line drawn to ensure it is perpendicular to the first two lines, before proceeding to drawing the fourth line. Always try to detect and correct your mistakes as early as possible in the drawing process.

Figure 13.4: Drawing a rectangle: Step 1

See Section 12.6.

Figure 13.5: Drawing a rectangle: Step 2

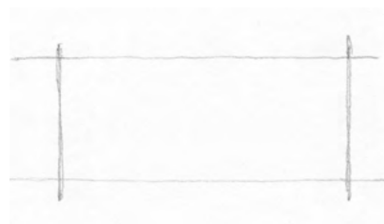


Figure 13.6: Drawing a rectangle: Step 3

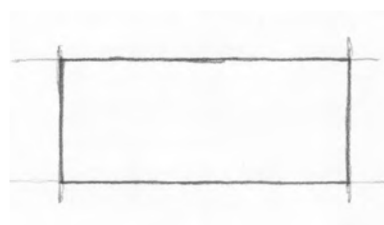


Figure 13.7: Drawing a rectangle: Step 4

13.3 Squares

Squares are rectangles with four equal sides which the angles defined by adjacent sides are all 90 degrees. The technique for drawing squares is therefore a relatively simple adaptation of the technique for drawing rectangles:

1 Complete Steps 1 and 2 of the procedure for drawing rectangles (Fig. 13.8) ▷ .

2 Mark a point on one of the two parallel lines to define a segment that is equal to the length between the two parallel lines (Fig. 13.9) ▷ . Inspect and correct if necessary.

3 Draw the fourth line of the square through the point thus identified and parallel to the previously drawn line (Fig. 13.10). Inspect and correct if necessary.

4 Delineate the square with heavy lines (Fig. 13.7).

It is important to execute Step 2 deliberately, and to inspect the point thus defined to ensure it defines a line segment of equal length to the distance between the two parallel lines, before proceeding to drawing the fourth line. Always try to detect and correct your mistakes as early as possible in the drawing process. Figure 13.9 shows an initial attempt at defining the point and a subsequent correction.

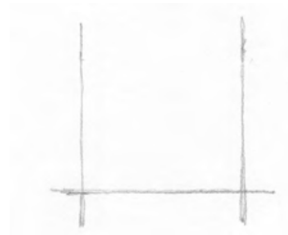


Figure 13.8: Drawing a square: Step 1

See Section 13.2.

See Section 12.7.

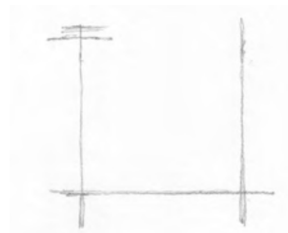


Figure 13.9: Drawing a square: Step 2

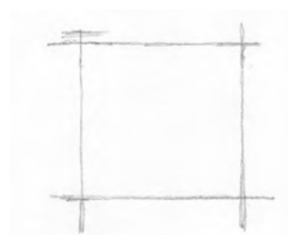


Figure 13.10: Drawing a square: Step 3

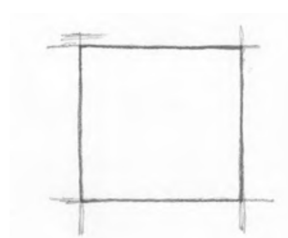


Figure 13.11: Drawing a square: Step 4

13.4 Long Straight Line Segments Through Two Given Points

This technique is not used very often, but can be of help from time to time. Because it is relatively time consuming, we should generally try to keep our freehand sketches small enough so that we do not have to use it.

The task at hand is to draw a line segment through two given points A and B. The two points are farther apart than can be drawn by maintaining the hand in one position ▷ . The steps are as follows:

See Section 12.4.

1 Draw a straight line starting from Point A. Aim for an imaginary point *away from* Point B (Fig. 13.12). Concentrate on drawing a line that is straight, using the techniques described previously ▷ .

See Section 12.2.

Figure 13.12: Drawing a long straight line between two given points: Step 1

2 Draw another straight line starting at Point B parallel to the first line, going back close to Point A (Fig. 13.13).

Figure 13.13: Drawing a long straight line between two given points: Step 2

3 Draw a rectangle incorporating the two parallel lines and the two given points (Fig. 13.14) ▷ .

See Section 13.2.

Figure 13.14: Drawing a long straight line between two given points: Step 3

4 Subdivide the rectangle into two or more equal parts ▷ . These should be no larger than what can be drawn without moving the hand.

See Section 12.7.

5 Place tick marks at the halfway and, where the rectangle has been divided into four parts, quarter points of the subdividing lines (Fig. 13.15).

Figure 13.15: Drawing a long straight line between two given points: Step 6

6 Draw the required line through the tick marks (Fig. 13.16) ▷ .

See Section 12.4.

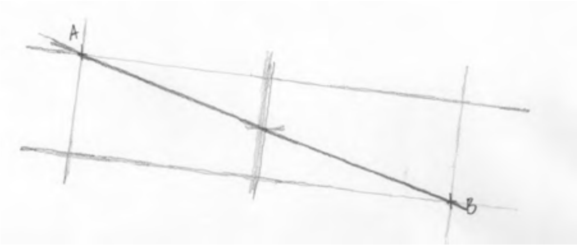


Figure 13.16: Drawing a long straight line between two given points: Step **??**

13.5 Skew Ellipses

Although there are relatively few objects designed by civil engineers that are actually elliptical in shape, the ellipse is one of the most important shapes to be learned in the process of acquiring proficiency in freehand drawing.

This is because of the geometric relation that exists between ellipses and circles. Many objects designed by civil engineers are circular in shape. When they are drawn in three dimensions according to the conventions of *isometric projection* ▷ , circles are transformed into ellipses.

See Chapter 8.

This is illustrated in the images to the right. Figure 13.17 shows a circle viewed from directly above, i.e., the line from the eye to the circle is perpendicular to the plane of the circle. A square that is tangent to the circle at four points has also been drawn. We say that the circle is *bounded* by the square.

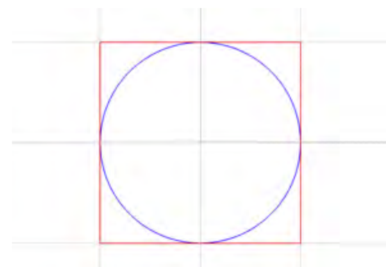


Figure 13.17: Circle viewed from directly above

When we change the viewpoint so that the line from the eye to the circle is at an angle of less than 90 degrees to the plane of the circle, the circle is transformed into an ellipse. In Figure 13.18, the eye remains in one of the coordinate planes. The bounding square of Figure 13.17 has become a bounding rectangle. This special case of an ellipse, in which the bounding figure is a rectangle, will be called an *orthogonal ellipse*.

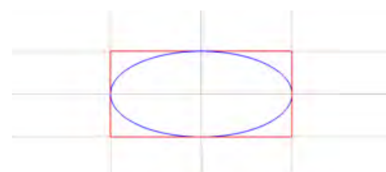


Figure 13.18: Circle viewed from an angle to its plane. Its projection is transformed into an ellipse.

In Figure 13.19, the eye has now moved away from the coordinate planes. The ellipse remains an ellipse, but the bounding rectangle has been transformed into a parallelogram. We call this type of ellipse a *skew ellipse*.

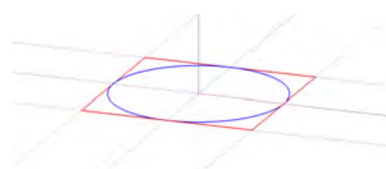


Figure 13.19: Circle viewed from another angle to its plane. Its projection is transformed into a skew ellipse.

Just as the square can be regarded as a special case of a rectangle, and the rectangle can be regarded as a special case of parallelogram, so can the circle be regarded as a special case of an orthogonal ellipse and the orthogonal ellipse can be regarded as a special case of the skew ellipse. So our techniques for drawing circles and ellipses will all be based on the general technique of drawing skew ellipses.

The procedure is as follows:

1 Using light lines, draw a parallelogram (Fig. 13.20) ▷ . (You do not have to add the letters to the vertices.)

See Section 13.1.

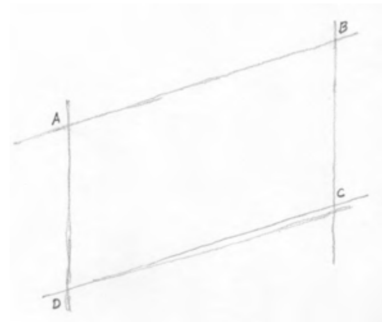


Figure 13.20: Drawing a skewed ellipse. Step 1.

2 Divide it into equal quarters (Fig. 13.21) ▷ .

See Section 12.7.

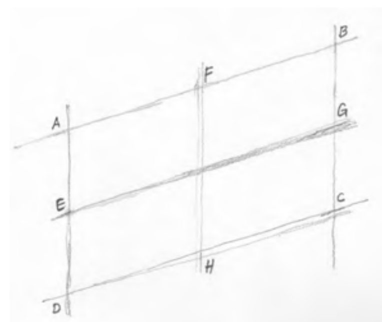


Figure 13.21: Drawing a skewed ellipse. Step 2.

3 In one of the quarters, draw the curve of the ellipse (Fig. 13.22). For example, in quarter EDH, begin at point E and begin by lightly drawing a tangent that begins to deviate away from ED. Do the same for the tangent at H. Switch back and forth between both tangents, slowly bringing the two arcs together somewhere in the middle.

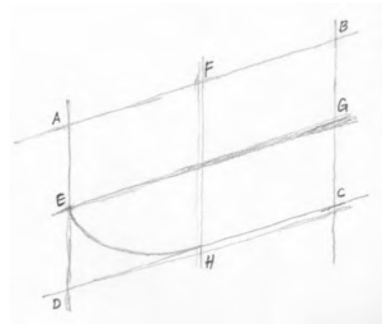


Figure 13.22: Drawing a skewed ellipse. Step 3.

4 Do the same for the opposite quarter (Fig. 13.23). It should be symmetrical with the curve you have just drawn.

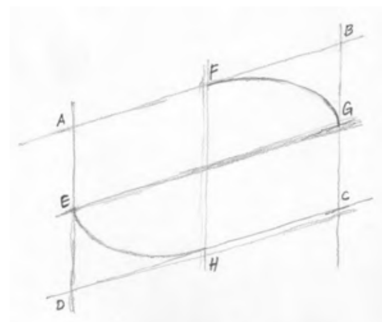


Figure 13.23: Drawing a skewed ellipse. Step 4.

5 Draw the curves in the other two quarters (Fig. 13.24). Delineate the ellipse with a heavy line if required.

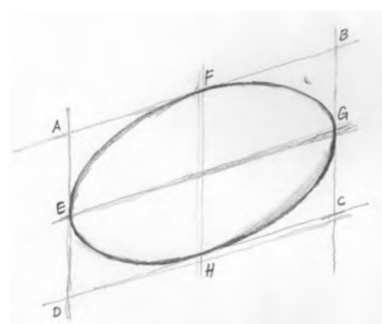


Figure 13.24: Drawing a skewed ellipse. Step 5.

To draw an orthogonal ellipse, simply change the parallelogram to a rectangle in the preciding process. To draw a circle, change the parallelogram to a square.

13.6 Parabolas

Parabolas are a common shape for arch bridges and suspension cables. The technique for drawing parabolas freehand is based on the mathematical properties of this function. These are illustrated in Figure 13.25 for the parabola $y = x^2$. The slope of the tangent at for any given value of x is $2x$. For a given value x_0, therefore, the function is equal to x_0^2 and the slope is $2x_0$. If we draw the tangent to the curve passing through (x_0, x_0^2), it will therefore cross the x-axis at $x = x_0^2/(2x_0) = x_0/2$, i.e., halfway from the origin to the given value x_0. This gives us a simple way of drawing the tangent to a parabola at a given point.

The procedure is as follows:

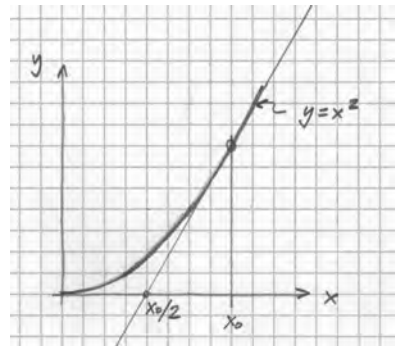


Figure 13.25: Intersection of tangent to parabola with x-axis

1 Using light lines, draw a parallelogram (Fig. 13.26) ▷ . Note: the parallelogram can also be a rectangle or a square. A parallelogram is shown here to represent the general case.

See Section 13.1.

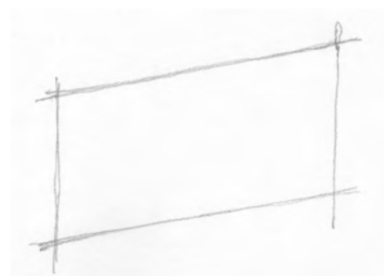


Figure 13.26: Drawing a parabola. Step 1.

2 Divide the parallelogram into eight equal parts as shown in Figure 13.27. Add tic marks (E and F) at the quarterpoints of the second and fourth vertical lines as shown.

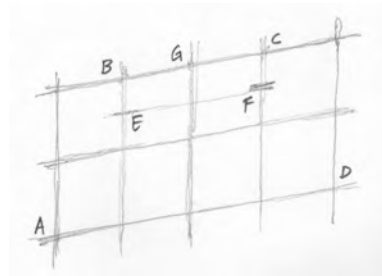


Figure 13.27: Drawing a parabola. Step 2.

3 Draw the tangents AB and CD as shown in Figure 13.28.

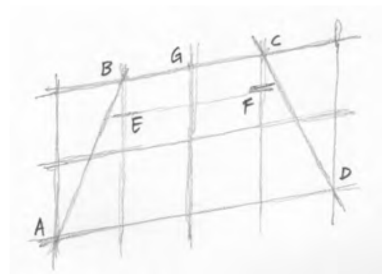


Figure 13.28: Drawing a parabola. Step 3.

4 Draw the parabola as shown in Figure 13.29. It passes through Points A, E, G, F, and D, and is tangent to AB, BC, and CD.

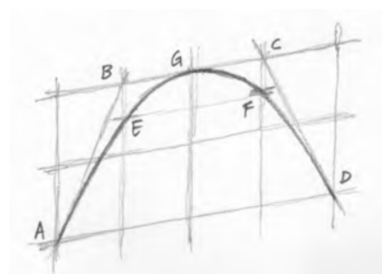


Figure 13.29: Drawing a parabola. Step 4.

14
Basic Three-Dimensional Figures

This chapter describes two elementary figures that will be used as the basis for drawing objects that depict three-dimensional characteristics: the isometric prism and the isometric cylinder. Both make use of the principles of isometric project described previously ▷ . All of the three-dimensional objects that we will draw freehand will be based on these two elementary figures.

See Chapter 8.

It is also possible to draw three-dimensional objects in *perspective projection.* This can provide a more realistic rendering of the object, but is more difficult to execute than isometric projection. For most situations encountered in engineering design, isometric projection provides a suitable balance between difficulty and realism.

14.1 Isometric Prisms

The isometric prism is relatively simple to draw, since it is a relatively straightforward application of the basic linework techniques and the basic two-dimensional figures presented previously ▷ . There are many ways to draw an isometric prism, but the following procedure is recommended because it provides a good balance between efficiency (minimizing the different set-ups of the page) and providing the best conditions for precision (providing the best visual cues for keeping the lines going in the proper direction).

See Chapters 12 and 13.

The end product will look similar to the images in Figure 14.1. *A given prism will always have three vertical edges.* This is not the only orientation of isometric prisms, but it will be the only one that will be used in this course. For prisms with three vertical edges as

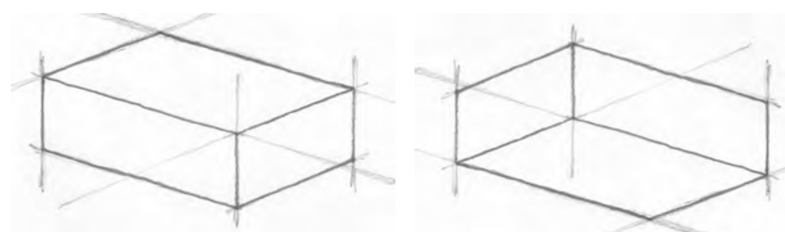


Figure 14.1: Isometric prisms. Left: prism viewed from above. Right: prism viewed from below

shown, the other edges can be drawn so as to give the impression of viewing the prism from above (one the left in Figure 14.1) or from below (one the right in Figure 14.1).

Strictly speaking, the angle between the vertical edges and the inclined edges must be 60 degrees ▷ . When we draw freehand, this angle does not have to be exactly 60 degrees. The basic "look" of isometric projection is not compromised when the inclined edges are a few degrees away from this value.

See Chapter 8.

The flexibility that is available in the inclination of the inclined edges in freehand isometric drawing stands in contrast to perpendicular lines (See Section 12.6), for which there is relatively little flexibility in the angle. The eye is very good at determining whether or not a given angle is 90 degrees, so when two lines are intended to be perpendicular, we must make sure we draw them as such.

The procedure for drawing the basic isometric prism is based primarily on the technique for drawing parallelograms described previously ▷ . Its steps are as follows:

See Section 13.1.

1 Draw the three vertical segments (Fig. 14.2).

Figure 14.2: Drawing an isometric prism. Step 1.

2 Draw two parallelograms to form the front faces of the prism, as shown in Figure 14.3.

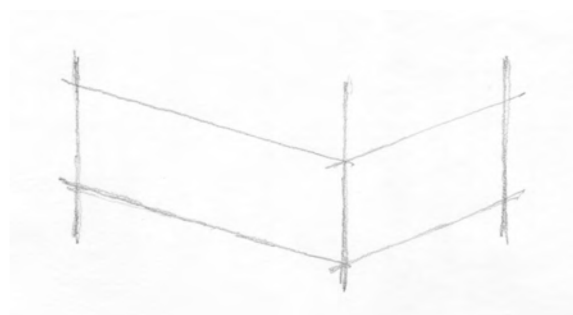


Figure 14.3: Drawing an isometric prism. Step 2.

3 Extend the previously drawn forward top edges as shown in Figure 14.4. This will provide a more reliable basis for ensuring that the back edges of the prism are parallel to existing edges. Draw the back edges of the prism.

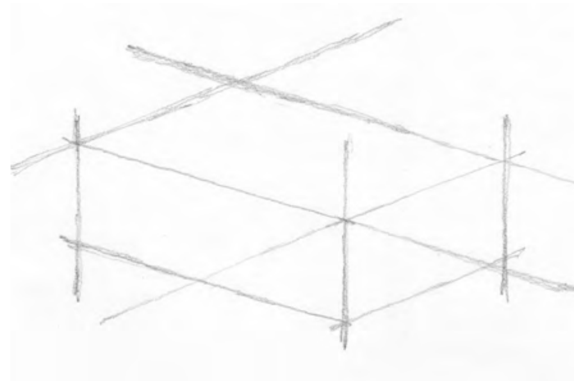


Figure 14.4: Drawing an isometric prism. Step 3.

4 Delineate the visible edges of the prism (Fig. 14.5).

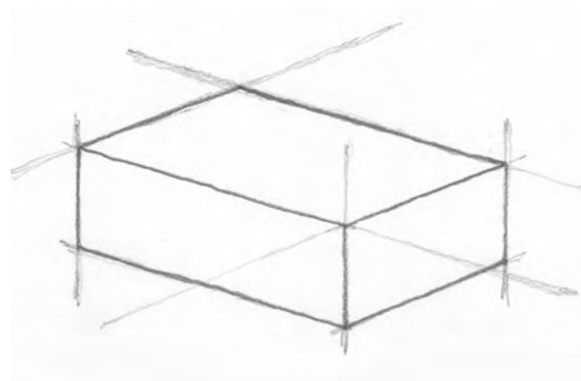


Figure 14.5: Drawing an isometric prism. Step 4.

The same technique can be used to draw a cube. In such a case, the parallelograms that form the faces of the prism must be rhombi, i.e., parellelograms with all edges of equal length. In the previous procedure, make sure that the gap between the left and middle vertical lines is equal to the gap between the middle and right lines (Step 1). Figure 14.6 shows an example of an isometric cube.

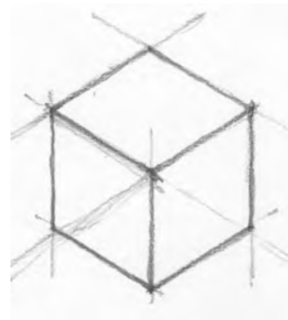


Figure 14.6: An isometric cube.

Although all edges of the isometric cube must be of equal length ▷ , it is difficult to ensure this is the case when drawing freehand. Instead, become familiar with the "look" of the isometric prism (draw them on SketchUp and study them, for example), and concentrate on reproducing this look when you draw.

This is a property of isometric projection: edges parallel to the coordinate axes that are equal in length in reality will also be equal in length when drawn in isometric projection. See Section 8.

14.2 *Isometric Prism with Hidden Edges Drawn*

The procedure given in the previous section was developed for drawing prisms as we would see them, i.e., only the visible edges were drawn. In some cases, it is useful to draw the hidden edges also. The procedure is a straightforward extension of the procedure developed in the previous section.

1 Draw Steps 1 through 3 of the procedure for isometric prisms (Fig. 14.7) ▷ .

See Section 14.1.

Figure 14.7: Drawing an isometric prism with hidden edges. Step 1.

2 Draw the three additional line segments defining the hidden edges of the prism (Fig. 14.8).

Figure 14.8: Drawing an isometric prism with hidden edges. Step 2.

We normally draw hidden edges to help us in the construction of other figures, so it is normally not necessary to delineate the edges. This has, however been done in Figure 14.9 for clarity. The visible edges have been drawn with solid lines and the hidden edges have been drawn with dashed lines.

Figure 14.9: Isometric prism showing both visible and hidden edges.

14.3 Isometric Cylinders

The technique for drawing isometric prisms with hidden edges will now be applied to the task of drawing cylinders. A cylinder will be "carved" it out of a prism. The procedure is as follows:

1 Draw an isometric prism with hidden lines (Fig. 14.10) ▷ . If the task is to draw a circular cylinder, then the prism must be a square prism, i.e., the top and bottom faces must be drawn as rhombi. For elliptical cylinders, the top and bottom faces can be any shape of parallelogram.

See Section 14.2.

Figure 14.10: Drawing an isometric cylinder. Step 1.

2 Draw the left and right quarter arcs of the ellipse on the upper face (Fig. 14.11) ▷ .

See Section 13.5.

Figure 14.11: Drawing an isometric cylinder. Step 2.

3 Draw vertical tangents to the two arcs just drawn (Fig. 14.12). These will be the visible vertical edges of the cylinder.

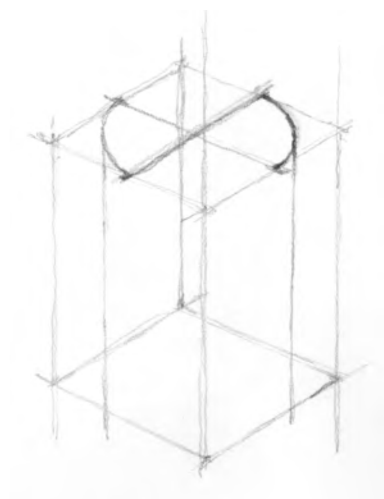


Figure 14.12: Drawing an isometric cylinder. Step 3.

4 Draw the front, left, and right quarter arcs of the bottom ellipse (Fig. 14.13). Make sure that the left and right arcs are tangent to the vertical lines drawn in the previous step.

Figure 14.13: Drawing an isometric cylinder. Step 4.

5 Complete the ellipse on the top face. Delineate the visible edges of the cylinder (Fig. 14.13).

Figure 14.14: Drawing an isometric cylinder. Step 5.

15
Drawing Engineering Objects

The technique described previously for drawing cylinders ▷ involved "carving out" the object from a prism. This technique of carving, i.e., first drawing a bounding prism and then removing material from it to define the object, will be the primary technique used in drawing three-dimensional engineering objects. The technique will be illustrated in the following section.

See Section 14.3.

15.1 *Isometric Drawing of a Simple Precast Concrete Bridge Segment*

The task is to draw a simple precast concrete bridge segment ▷ , viewed from below. The procedure is as follows:

See Section 54.2.

1 Draw the bounding prism, including hidden lines, in the proper orientation (Fig. 15.1) ▷ .

See Section 14.2.

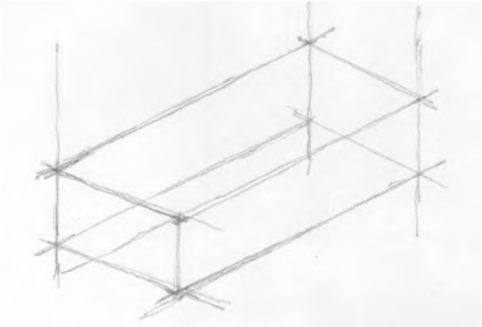


Figure 15.1: Drawing a simple bridge segment. Step 1.

2 Mark out the axis of symmetry and the quarterpoints on the front face (Fig. 15.2).

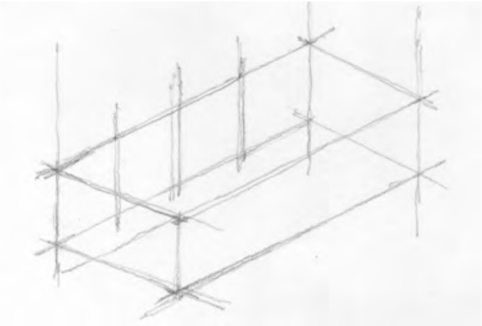


Figure 15.2: Drawing a simple bridge segment. Step 2.

3 Draw the primary features on the front face (Fig. 15.3).

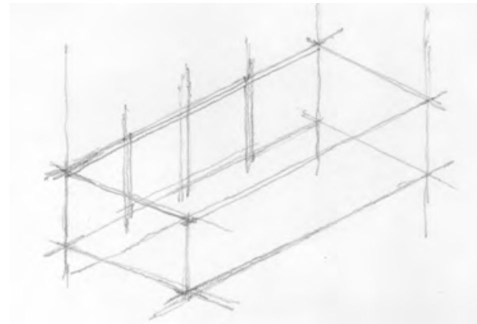


Figure 15.3: Drawing a simple bridge segment. Step 3.

4 Draw lines back from the primary features on the front face towards the back face (Fig. 15.4).

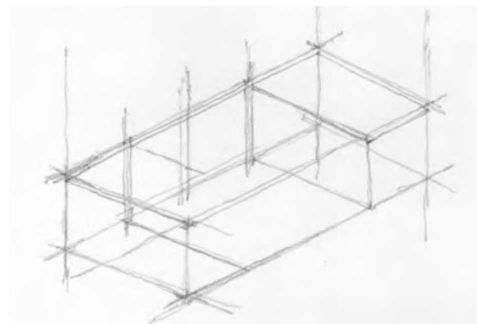


Figure 15.4: Drawing a simple bridge segment. Step 4.

5 Delineate the visible edges of the segment (Fig. 15.5).

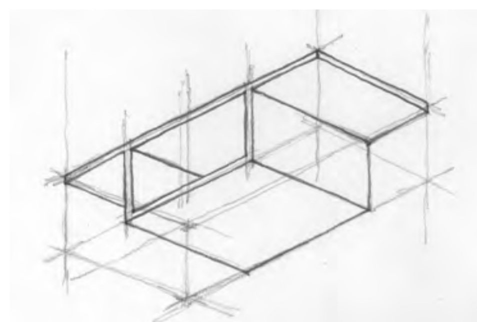


Figure 15.5: Drawing a simple bridge segment. Step 5.

Part V

Technique: Drawing with CAD

16
SketchUp

The primary resource for information on how to work with SketchUp and LayOut are the online Help Centres provided by the developers of this software ▷ . This chapter is therefore not intended to be a comprehensive treatment of how to work with SketchUp and LayOut. Rather, its intent is to provide additional insight into several important and particularly useful tools and constructs in the two applications.

Click this text for the SketchUp Help Centre.
Click this text for the LayOut Help Centre.

16.1 Intersect Faces with Model

This is an extremely useful feature of SketchUp.

In SketchUp, when we move a two- or three-dimensional object to intersect with another, the objects overlap while maintaining their geometry, but no objects are created at the intersection. Figure 16.1 shows two distinct objects. In Figure 16.2, they have been moved such that the two objects overlap.

In many cases, we would like to delete the portion of one object that protrudes from the other after we have moved the two objects together, but this is not possible in the situation depicted in Figure 16.2 since there are no edges (lines) at the intersection. SketchUp does not create them automatically. For example, if we delete the

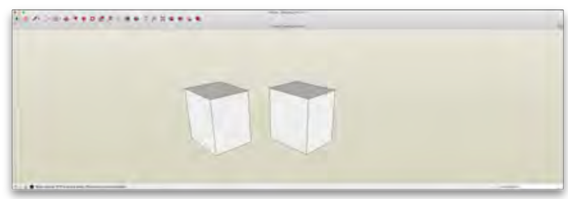


Figure 16.1: Two distinct objects

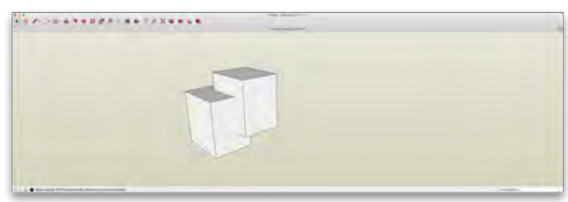


Figure 16.2: The two objects from Figure 16.1 have been moved to overlap with each other

vertical edge of the upper box that enters the lower box, we simply change the upper box without affecting the lower box. This is shown in Figure 16.3. There is thus no interaction between the two objects.

We can, however, create edges, which will enable us to delete portions of one object that protrude from the other. This is accomplished by selecting both objects, right-clicking in the selected portion, and invoking the command `Intersect Faces → With Model` from the pop-up menu (Fig. 16.4). You will see that edges have been created at the interface between the two objects (Fig. 16.5). It is now possible to delete portions of one object that project from the other, as shown in Figure 16.6.

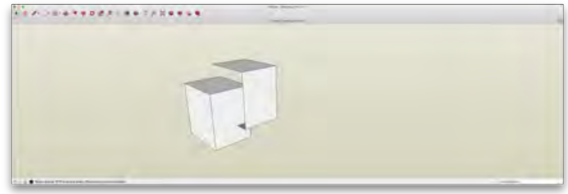


Figure 16.3: Deleting an edge affects only the object that originally contained the edge

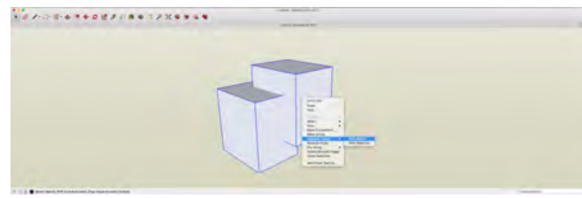


Figure 16.4: `Intersect Faces → With Model`

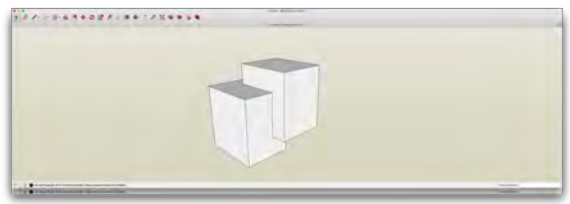


Figure 16.5: Edges have been created where the two objects intersect

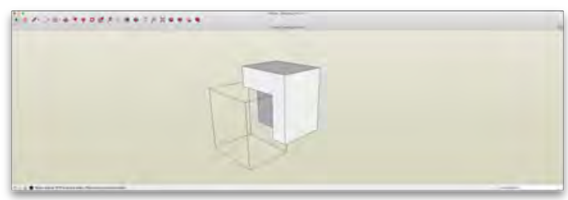


Figure 16.6: Entities can now be deleted up to the intersection, thus making it possible to "trim" one object with the other

Additional information on the `Intersect Faces → With Model` feature is available at the links provided ▷ .

See the section Subtracting one solid from another (or use Intersect Faces with Model) *in the article* `Modeling Complex 3D Shapes with the Solid Tools` *at the SketchUp Help Centre. Another useful link is the article* `The Basics of Intersection in SketchUp` *at the SketchUcation website.*

16.2 Groups and Components

In SketchUp, individual objects can be transformed into *groups*. Selecting a group selects all the entities within the group, which allows them to be moved as a unit. In this course, groups can be particularly useful in organizing complex models. Groups can be placed onto layers, which can then easily be hidden or made visible.

Components are similar to groups in that they create a higher-level object from a collection of individual entities. The primary difference between components and groups is that when we make a copy of a group, the two groups are completely independent. If we make changes to one group, those changes will not be made to the other group. If we make a copy of a component, however, all changes made to one of the copies will be automatically made to the other.

If we wish to make changes to one instance of a component without affecting other instances of the same component, we need to right-click the component we with to change and select `Make Unique` from the pop-up menu. A new component is then created from the one we will change.

Additional information on groups and components is available at the links provided ▷ .

See the articles `Grouping Geometry` *and* `Creating a Basic Component` *at the SketchUp Help Centre.*

16.3 Layers

In SketchUp, *layers* are a way of hiding or making visible specific objects. The basic process is to create a layer and then assign objects to the layer. The layer can then be turned on or off, thus controlling the visibility of the objects in that layer. A model can have any number of layers. This feature is particularly useful when cutting sections for which only the edges that intersect with the section plane are to be drawn. We can assign the objects that are behind the section plane to another layer and then turn that layer off.

Whether or not a given layer is on or off is a property that is embedded in a given *scene* ▷ .

See Section 16.5.

Every new SketchUp file contains a special layer called *Layer 0*. All objects should be drawn on Layer 0 and then assigned to another layer. Always keep Layer 0 visible. If it contains objects that you want to hide, assign them to another layer.

Objects are assigned to a given layer using the `Entity Info` window. Just select one or more objects to be assigned to another layer, and then select the layer from the pull-down menu in the window. Check to make sure the assignment was made correctly by turning the layer off and back on again.

Additional information on layers is available at the link provided ▷ .

See the article `Controlling Visibility with Layers` *at the SketchUp Help Centre.*

16.4 Styles

Styles in SketchUp are similar to styles in word-processing software: a given style contains specific settings that control how objects look. Additional information on styles is available at the link provided ▷ .

See the article `Creating and Editing a Style` *at the SketchUp Help Centre.*

The course SketchUp template has several styles that will generally cover all of the work to be done in the course. The link gives additional information on the styles contained in the course template ▷ .

See Section A.16.

The choice of style is a property that is embedded in a given *scene* ▷ . It is important to select a style immediately before creating a new scene. Otherwise, SketchUp may prompt you to save changes to the current style, which is usually not our intent. Unless we have knowingly made changes and do indeed want to save them, it is usually better not to accept the changes if we receive this prompt.

See Section 16.5.

16.5 Scenes

Scenes are the best way to create views to be included in LayOut. To ensure that a given scene displays your model exactly as you wish it to be displayed, it is usually better to follow a standard procedure in setting up the scene. Proceed as follows:

1 Select the layers you wish to be visible in the scene.

2 If the scene is to display a section, then the specific section must be activated. From the `View` menu, select `Section Planes`. All of the section planes in the model are then displayed. Right-click on the plane you want to have active in the scene and make sure `Active Cut` is checked.

3 From the `Camera` menu, set the camera to parallel or perspective projection. For orthographic views, always select parallel projection.

4 Orient the view. For orthographic views, it is common to select one of the standard views from the `Camera` menu. For perspective views, you can use the `Orbit` tool to select a suitable view.

5 Apply the desired style.

6 Create a new scene, give it a name, and save it.

16.6 Sections

This section provides only a brief overview of some aspects of the use of sections in SketchUp, and recommendations for the effective use of this function. A more complete description of the use of sections in SketchUp can be found in SketchUp's online documentation ▷ .

See the article `Slicing a Model to Peer Inside` *at the SketchUp Help Centre.*

1 Sections in SketchUp are planes that can be positioned and oriented as required. A given section plane has arrows corresponding to the direction of view.

2 A given section plane is associated with a *context*. A context can be (1) the entire SketchUp model (i.e., all entities contained in the SketchUp file), (2) a group, or (3) a component ▷ . The user chooses which context is associated with a given section plane.

See Section 16.2.

3 A given section plane cuts through all objects within the context to which it is associated. Everything in the associated context that is on the opposite side of the section plane to the arrows is thus made invisible. A given section plane has no effect on other contexts, unless they are completely contained within the context to which it is associated.

4 To create a section plane that is associated with the entire model, simply use the section tool.

   To create a section plane that is associated with a given group or component, first open the context by double-clicking on it. The apply the section tool to the given group or component.

5 Within a given context, there can be several section planes, but only one can be active at a given time. Each context can therefore have one active section plane. Only active section planes actually cut through objects. The others remain in place but do nothing.

   A given section plane can be activated by right-clicking the plane and selecting `Active Cut` from the pop-up menu.

6 Section planes can be made visible or hidden using the menu command `View` → `Section Planes`.

These concepts are illustrated in the figures to the right. Figure 16.7 shows six objects: three red bridge segments, all of which are instances of the same component, a neutral-coloured segment, which is a component unrelated to the red segments, a blue rectangle which is a group, and a neutral-coloured rectangle which is neither in a group nor in a component.

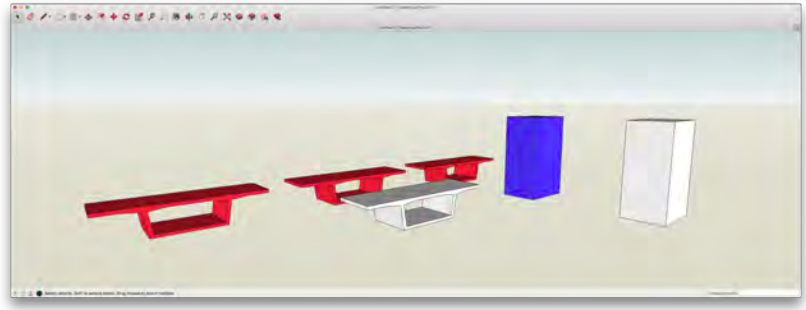


Figure 16.7: Some objects in SketchUp. Red segments are three instances of the same component. The neutral segment is another component unrelated to the red components. The blue rectangle is a group. The neutral rectangle is neither in a group nor a component.

Figure 16.8 shows the situation after a horizontal section plane has been applied to the context of the entire SketchUp model. *Because the context is the entire model*, all objects in the model have been cut by the plane and everything on the side of the plane opposite the plane has been hidden.

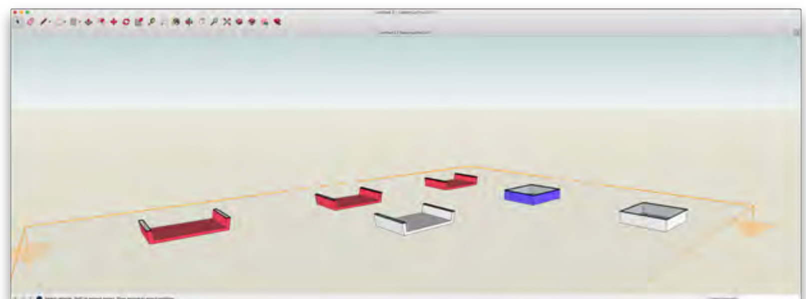


Figure 16.8: Horizontal section plane. Context is the entire SketchUp model.

Figure 16.9 shows the situation after the section plane shown in Figure 16.8 has been removed and a horizontal section plane has been applied to the context of the red segment component. *Because the context is the red segment*, the section plane is applied to all instances of this component, but has no effect on anything else. All other objects remain uncut. Although all three instances have been cut, it is only necessary to apply the section plane to one of these three instances. Whatever is done to one instance is applied to all three.

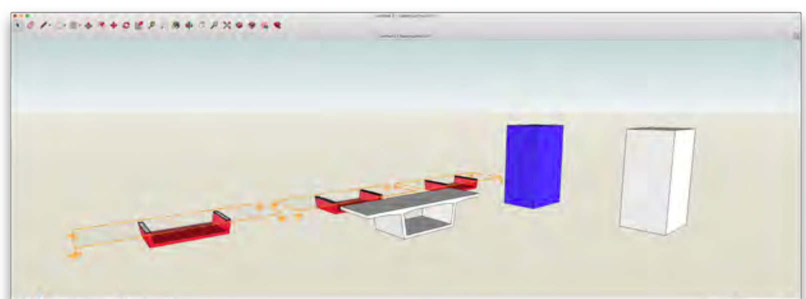


Figure 16.9: Horizontal section plane. Context is the red segment component.

Figure 16.10 shows the situation after the section plane shown in Figure 16.9 has been removed and three new horizontal section planes have been introduced. The lowest of the three is applied to the red segment context. Slightly above this is a plane that has been applied to the neutral coloured segment (a component independent of the red segment). The highest of the three has been applied to the blue prism (a group). All three planes act only on the context to which they have been associated.

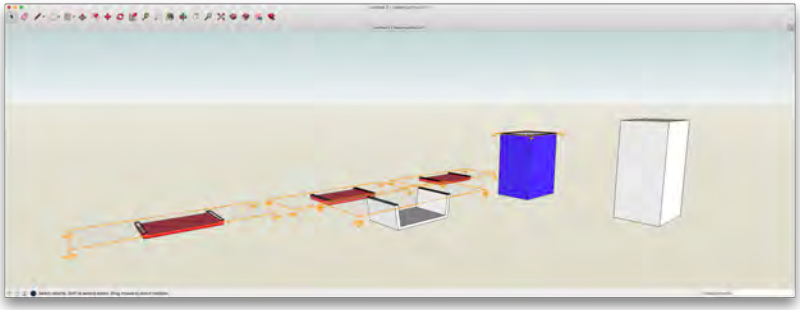


Figure 16.10: Three horizontal section planes applied to three different contexts.

Figure 16.11 shows the situation after another plane has been added to the planes depicted in Figure 16.10. The new plane is a vertical plane, and its context is the entire SketchUp model. All of the cuts shown in Figure 16.10 remain active, since they are applied to specific contexts. The objects that are behind by the new plane are hidden, regardless of whether or not they belong to a component or group, since the context of the new plane is the entire model. Although the red segment is a component with three instances, only the instances that is intersected with the plane or behind the plane are hidden.

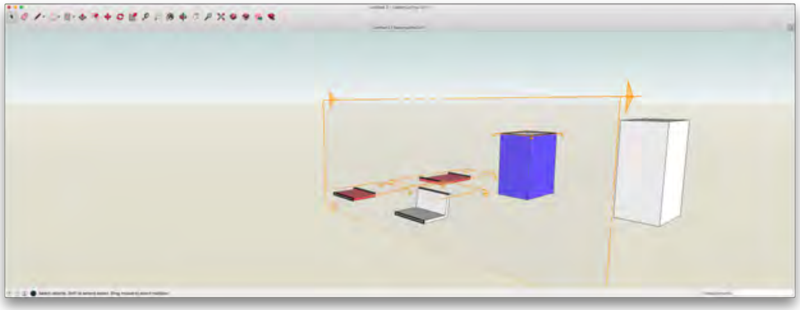


Figure 16.11: Three horizontal section planes applied to three different contexts, plus a vertical section plane applied to the entire model.

16.7 *Summary of Commands and Keyboard Shortcuts*

Quick Reference Cards are available for SketchUp and LayOut ▷ . They are reproduced in smaller format in Figures 16.12 and 16.13

Note that many common commands have single-key shortcuts. Using these keyboard shortcuts will usually be faster than selecting tools from menus or toolbars. This of course requires that the keyboard shortcuts are committed to memory.

Click this text to download the SketchUp Quick Reference Card
Click this text to download the LayOut Quick Reference Card

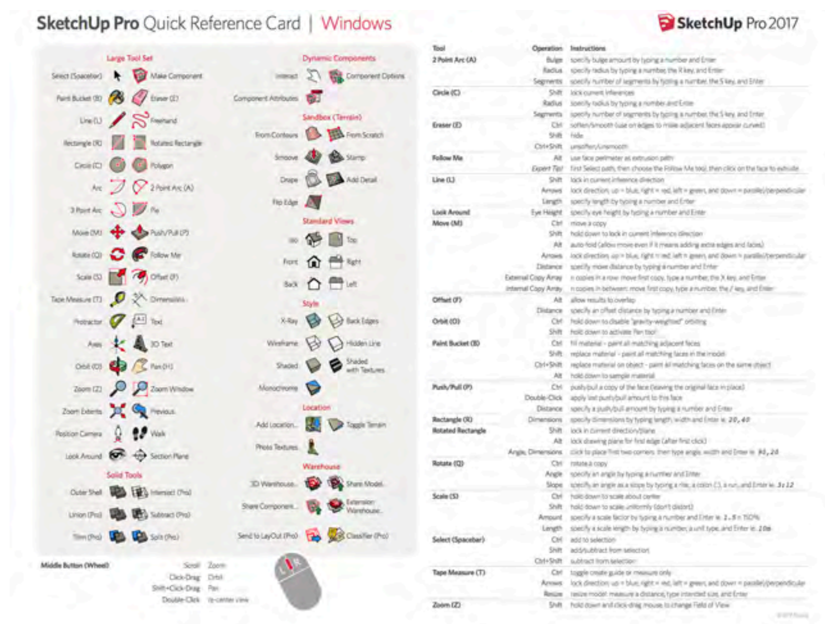


Figure 16.12: SketchUp Quick Reference Card

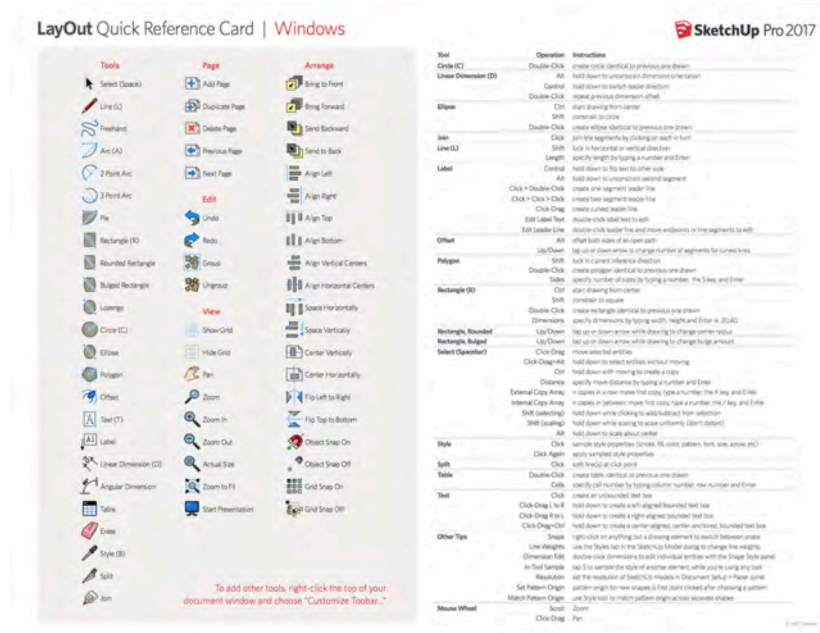


Figure 16.13: LayOut Quick Reference Card

17
AutoCad

The intent of this chapter is to highlight some of the more important tools and constructs that will be useful in this course. This chapter is not intended to provide a comprehensive reference for AutoCad.

17.1 Basic References

The online document *The Hitchhiker's Guide to AutoCAD Basics* provides a good introduction to most of the fundamental aspects of working with AutoCad ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

17.2 User Interface

An annotated AutoCAD window is shown in Figure 17.1. This diagram can be used to help identify the different menu buttons and their locations. The figure was produced using a screenshot of AutoCAD 2011 for Windows, which may differ slightly from the version that is provided in the classroom.

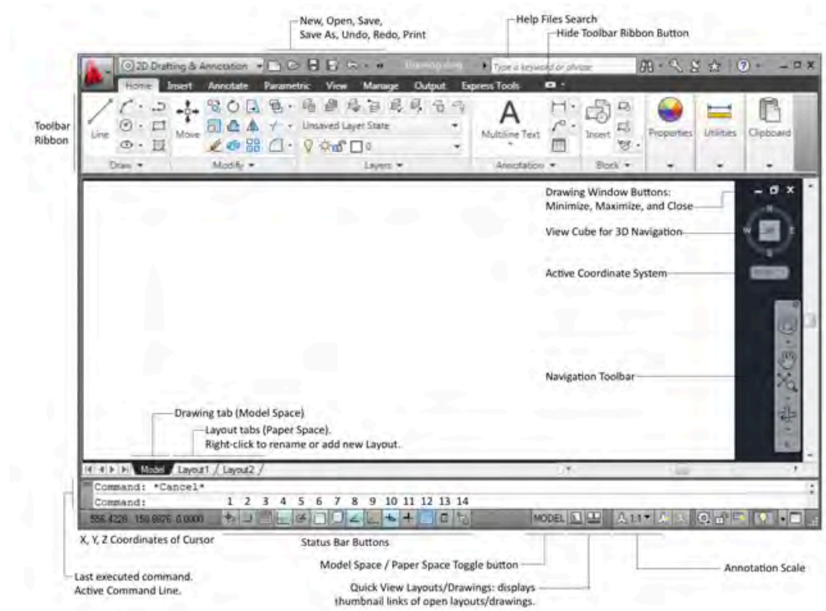


Figure 17.1: AutoCad window

17.2.1 Command Line Entry

AutoCAD commands can be invoked in several ways, including drop-down menus from the main menu bar, toolbar buttons, and a command-line interface. It is generally more efficient to use the command line interface along with keyboard shortcuts than to use any of the other methods. The commands and keyboard shortcuts have remained more or less the same from one version of AutoCAD to the next. Because of its efficiency and constancy, command line entry will be the preferred method of entry for this course. To achieve this efficiency, however, it is necessary to memorize the keyboard shortcuts of the most common commands. If ever you forget a keyboard shortcut, it is always possible to invoke commands from the menus or toolbars.

To enter a command, move the cursor so that it is within the drawing window, then type the command and press `Enter`. While commands are in progress, helpful instructions and options pertaining to the active command will appear on the command line. To cancel a command, press `Esc`. To repeat the last command, press `Enter`.

A summary of common keyboard shortcuts has been provided ▷
.

See Section 17.4.

17.2.2 Status Bar

The Status Bar is typically positioned along the bottom of the AutoCAD window. The current x, y, z coordinates of the cursor appear on the left side of the bar. Toward the middle, Status Bar buttons used for toggling different drawing modes are shown. For 2D drawing, the most frequently used Status Bar buttons are 4, 6, 8, and 10 (these numbers are given for convenience in this text, but do not appear in the operation of the software). The effects and shortcuts for these drawing modes are described as follows:

1. Button 4: Orthogonal Mode `F8`. When activated, lines are constrained to be orthogonal to the current coordinate axes. This also applies to pick points that are used to define drawing objects other than lines.
2. Button 6: Object Snap `F3`. When activated, the cursor snaps to the endpoints, midpoints, centres, etc. of previously drawn objects. Right-click on the Status Bar button to configure which snaps are active.
3. Button 8: Object Snap Tracking `F11`. When activated, a tracking extension line will appear after pausing over object snap points.
4. Button 10: Dynamic Input `F12`. When activated, coordinate information, relevant measurements, and command prompt information are displayed dynamically beside the cursor.
5. Button 14: Selection Cycling. When activated, an object selection dialog box will appear when two or more objects are layered on top of one another at the cursor location.

The right side of the Status Bar has buttons related to switching between drawing and layouts, and to Annotation Scale:

1. The Model/Paper toggle button switches between Model Space for drawing and Paper Space for layouts.
2. The Quick View buttons allow you to navigate between all the different drawings and layouts that you have open. These buttons serve the same function as the drawing and layout tabs.

3 The Annotation Scale button displays the current annotation scale being used ▷ .

See Section 17.3.

17.2.3 Toolbar Ribbon

Toolbars in AutoCAD have changed significantly from version to version. The icons in the toolbars invoke specific commands, and are thus redundant for users who are familiar with using the command line. One important exception is the Layers menu ▷ . Layers organize objects in a drawing into groups. Because users tend to switch between Layers frequently, it is recommended that the Layers menu is kept open and accessible while drawing. All toolbar icons can be hidden from view to maximize the visible drawing space.

See the article `Layers` *in the AutoCad Help Centre.*

17.2.4 Navigation

Navigating within AutoCAD is done primarily with a mouse. By default, the scroll wheel is used to zoom in and out of a drawing or layout. View panning is assigned to the third mouse button, which is typically activated by pressing and holding down the scroll wheel. Icons in the Navigation Toolbar activate the same zoom and pan functions, and are thus redundant. The View Cube controls 3D navigation. Since only 2D drawing in AutoCAD will be done in this course, the View Cube need not be used and can be hidden from view.

17.3 Scaling of Annotations

Whenever we draw in Model Space, we are drawing in real-world coordinates, i.e. at a scale of 1 to 1 ▷ . The objects thus drawn are represented in Paper Space using viewports to which we have assigned a scale, such as 1:50, that will permit the object to be completely contained by the viewport and the viewport to fit as required onto the paper that we will use to print the drawing.

See Chapter 9.

Text that is associated with a given view, e.g. dimensions, leaders, and other annotations such as "CL Bridge" looks best on the printed page when it has a size that is uniform across all views. For example, the course CAD template provides two text styles, one with height 2.5 mm on the printed page and the other with height 1.5 mm on the printed page. In most cases, therefore, it makes sense to create text associated with a given view in Paper Space.

Problems arise because the text that is associated with a given view often has to be linked with the object in Model Space in a more complex manner. Dimensions, for example, need to be linked to specific points on the object in Model Space. This allows the dimension text to be generated automatically, which is one of the significant conveniences of CAD. The approach ensure that text is displayed at the correct size differs for dimensions, leaders, and labels. These are described in the following subsections.

17.3.1 Dimensions

AutoCad allows some commands to be used "trans-spatially", i.e., to be invoked in one space but to be linked to the other space. The dimension command, for example, can be invoked in Paper Space but can snap to the object in Model Space and produce true real-world dimensions. The advantage is that the dimension text will always be the correct size on the physical printed page.

The normal procedure for creating dimensions is therefore first to draw the object in Model Space and then to draw the dimensions in Paper Space. This has the advantage that the scale of the viewport can be established and the viewport positioned before dimensions have been drawn. The final appearance of the dimensions on paper, including their proximity to other views, can be seen at the time the dimensions are created. Dimensions thus created will move with the object as the viewport is displaced or as the view is panned within the viewport.

This approach should be used wherever possible. It only works well, however, if dimensions either (1) remain as they have been drawn by AutoCad, or (2) have been modified in the `Properties` window of AutoCad. In some cases, it will be necessary to modify a dimension as drawn by AutoCad to make it in accordance with the course drafting standard ▷ . In such a case, right-click the dimension to be modified and then select `Properties` from the pop-up menu. Any changes you make within the `Propeties` window will enable the modified dimensions to move along with the viewport.

See Section A.10.

17.3.2 Leaders and Labels

Leaders and labels drawn in Paper Space will not move consistently and properly with the object when the viewport is displaced. It is therefore recommended that these objects be drawn in Model Space.

To ensure that text created in Model Space appears at the same consistent physical size on paper as the size of text created in Paper Space, the scale of the viewport in which this text will appear must be known before the text is created in model space. The procedure is as follows:

1 Determine the scale of the viewport that will be used to display the object in Paper Space. Ideally, create the viewport, set the scale, and create all dimensions in Paper Space before proceeding.

2 In Model Space, set the *annotation scale* to the same scale as the viewport in which the object and the annotations to be created will be viewed. The setting can be made using a button in the lower right-hand portion of the drawing frame (Fig. 17.2). It is important that this scale be set before any annotations are created in Model Space.

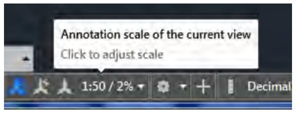


Figure 17.2: Button used to change annotation scale

3 Draw leaders and labels. The annotation scale that was set at the time the leaders and labels were created will remain with these annotations, even though the annotation scale is changed at some sub-

sequent time. A given Model Space can therefore contain annotations associated with different scales.

4 Enter Paper Space and confirm that the annotations are in a suitable position. If not, return to Model Space and make the necessary changes.

17.3.3 Annotations and Multiple Viewports

In some cases, it is worthwhile to have two different views of the some object at two different scales. For example, some objects may require excessively complex dimensioning if only one view is used. This will not be a problem if all dimensions are drawn in Paper Space. If some dimensions are drawn in Model Space (and if leaders or labels are also drawn in Model Space), they may show up at an incorrect size in one or the other of the multiple views.

To prevent this problem, proceed as follows:

1 Draw the dimensions and annotations required for a given view in Model Space.

2 Create a new layer ▷ , which will be a copy of the `Dimension` layer. Call this layer "Annotations xxx" where "xxx" is a description of the view in which these annotations will be displayed (for example, "Annotations Section A-A").

See the article `About Layers` *in the AutoCad Help Centre.*

3 Transfer the dimensions and annotations created in Model Space to this layer ▷ .

See the article `To Change the Layer of Selected Objects` *in the AutoCad Help Centre.*

You may need to create multiple layers for annotations depending on the extent to which objects in Model Space need to be displayed in multiple views.

As you work, you can turn off these new layers as required to ensure clarity and ease of drawing.

When it comes time to plot your drawing, proceed as follows:

1 Turn on all layers.

2 In Paper Space, for each viewport, freeze all the "Annotation" layers you have created except the one that needs to be visible in that viewport ▷ .

See the article `To Freeze or Thaw Layers in the Current Layout Viewport` *in the AutoCad Help Centre.*

17.4 Common AutoCad Commands and Shortcuts

In AutoCad, although most commands are available from menus and buttons on the screen, it is generally faster to use keyboard shortcuts. This keeps the cursor in the drawing area rather than moving about to click on menus and buttons. This might not appear significant to someone who does not have extensive experience with AutoCad, but the fractions of seconds required to find and click menus and buttons add up in the course of a large drawing.

Keyboard shortcuts must be learned, but the speed gained through their use makes this effort worthwhile. Several collections of keyboard shortcuts are available. AutoCad's *Shortcuts Guide* ▷ is a comprehensive collection of all the keyboard shortcuts available. Also useful is AutoCad's *One Key Shortcuts* summary ▷ is particularly useful, since it is a subset of the most common commands. A smaller version of this summary has been reproduced in Figure 17.3.

Click here to download the AutoCad Shortcuts Guide

Click here to view AutoCad's One Key Shortcuts summary

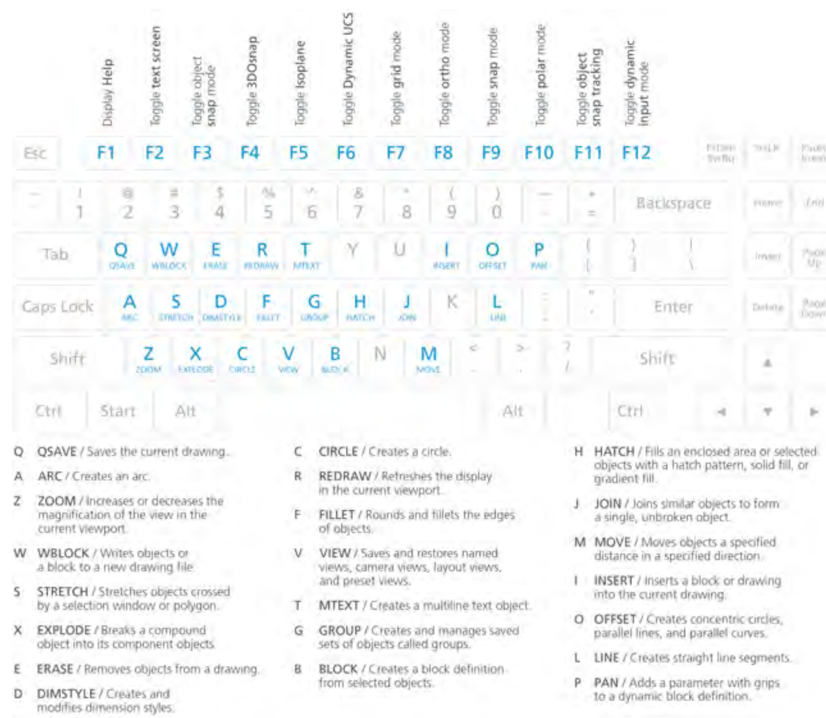


Figure 17.3: AutoCad One Key Shortcuts

18
Differences Between AutoCad and SketchUp/Layout

Because this course requires students to use both AutoCad and the SketchUp/Layout combination, it is important for students to understand the primary differences between these two software packages. This is particularly important since both packages use some important terms, such as "layer" in different ways. To avoid confusion and to make the best use of the features of each package, students should be aware of the following differences:

1 *2-D versus 3-D.*

AutoCad was initially developed as a purely two-dimensional CAD package. Although a rich set of features for three-dimensional modeling has been added to AutoCad, learning these features requires an investment of time that goes beyond what is available in this course. Many engineers use only the two-dimensional features of AutoCad in their practice.

When we use only the two-dimensional features of AutoCad, views such as cross-sections must be created "by hand", since they cannot be cut from a three-dimensional model.

In this course, we will use AutoCad only for two-dimensional drawing.

SketchUp was originally designed as a fully functional, easy to learn and use three-dimensional package. It accomplished this reasonably well. When it first appeared, though, LayOut did not exist. It was thus almost impossible to produce suitable two-dimensional views of any kind with SketchUp on its own. (This remains true to this day if LayOut is not used.) LayOut first appeared several years after SketchUp. The two applications remain "separate but linked" to this day.

Although we will use the SketchUp/LayOut combination in this course to produce two-dimensional views, this option does not provide the same richness of features provided by AutoCad for precise and professional formatting, dimensioning, and annotating of views.

2 *Layers.*

In SketchUp, layers have only one function: to control visibility of objects ▷ . We assign objects to layers and then can switch the layers on and off to make them visible or hidden.

See Section 16.3.

In AutoCad, layers can also be hidden or made visible. Layers also, however, contain *style settings*, which can be set as required to control the appearance of lines, dimensions, and text in the final plotted document. The course AutoCad template, for example, contains the layers "Thin", "Thick", and "Thicker", each of which corresponds to a different line weight in the plotted document.

In AutoCad, specific colours can be assigned to individual layers to enable users to distinguish between them on the screen. The appearance of layers on the screen will be different from the way they appear in the plotted document. In SketchUp, different layers do not have a distinct visual appearance unless the objects in a given layer have been explicitly assigned to different styles.

3 *Guide lines and points.*

In SketchUp, there is a separate construct for guide lines and points. They can be easily created by offsetting from other objects. They can be positioned precisely through entry of a precise offset dimension.

In AutoCad, there is no separate construct. Guide lines need to be created as any other type of line. In the course AutoCad template, the layer `Nonprint` can be used for guide lines, since it is never included in the final plotted document.

4 *Model Space and Paper Space.*

In AutoCad, Model Space and Paper Space are present in the same software application. In SketchUp/Layout, two linked applications need to be used: the model space is in SketchUp and the paper space is in Layout.

5 *Annotation Scaling.*

In SketchUp/LayOut, there is no annotation scaling. For this reason, all dimensions and annotations are best made in LayOut.

Part VI

Description of Classes: Freehand Drawing

19
Freehand Drawing Class 1

This class will take place on the date indicated in Table 2.2 for "Freehand 1" ▷ .

See Section 2.4.

19.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 19.1.

Table 19.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	19	Straight lines	Blank	Completed
Break	2	—	—	—
Basic	19	Extending lines	Blank	Completed
Break	2	—	—	—
Basic	19	Light and heavy lines	Blank	Completed
Break	2	—	—	—
Basic	19	Subdividing lines into halves	Blank	Completed
Break	2	—	—	—
Basic	19	Parallel lines	Blank	Completed

19.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 19.1.)

2 Chapters 5 and 6.

19.3 Preparation

Before class, students must prepare as follows:

1 Read Chapter 11.

2 Read Sections 12.1, 12.2, 12.3, 12.5, and 12.7.

3 Download the blank and completed drawings for each exercise listed in Table 19.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

20
Freehand Drawing Class 2

This class will take place on the date indicated in Table 2.2 for "Freehand 2" ▷ .

See Section 2.4.

20.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 20.1.

Table 20.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	19	Straight lines	`Blank`	`Completed`
Break	2	—	—	—
Basic	19	Light and heavy lines	`Blank`	`Completed`
Break	2	—	—	—
Basic	19	Subdividing lines into quarters	`Blank`	`Completed`
Break	2	—	—	—
Basic	19	Parallel lines	`Blank`	`Completed`
Break	2	—	—	—
Basic	19	Perpendicular lines	`Blank`	`Completed`

20.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 20.1.)

2 Chapters 5, 6, and 11.

3 Sections 12.1, 12.2, 12.3, 12.5, and 12.7

20.3 Preparation

Before class, students must prepare as follows:

1 Read Section 12.6.

2 Download the blank and completed drawings for each exercise listed in Table 20.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

21 Freehand Drawing Class 3

This class will take place on the date indicated in Table 2.2 for "Freehand 3" ▷ .

See Section 2.4.

21.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 21.1.

Table 21.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	19	Straight lines	Blank	Completed
Break	2	—	—	—
Basic	19	Extending lines	Blank	Completed
Break	2	—	—	—
Basic	19	Subdividing lines into quarters	Blank	Completed
Break	2	—	—	—
Basic	19	Subdividing lines into thirds	Blank	Completed
Break	2	—	—	—
Basic	19	Lines between two points	Blank	Completed

21.2 Background

Students are expected to be familiar with the following material:

1. Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 21.1.)
2. Chapters 5, 6, and 11.
3. Sections 12.1, 12.2, 12.3, 12.5, 12.6, and 12.7

21.3 Preparation

Before class, students must prepare as follows:

1 Read Section 12.4.

2 Download the blank and completed drawings for each exercise listed in Table 21.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

22
Freehand Drawing Class 4

This class will take place on the date indicated in Table 2.2 for "Freehand 4" ▷ .

See Section 2.4.

22.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 22.1.

Table 22.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	19	Subdividing lines into thirds	Blank	Completed
Break	2	—	—	—
Basic	19	Parallel lines	Blank	Completed
Break	2	—	—	—
Basic	19	Perpendicular lines	Blank	Completed
Break	2	—	—	—
Basic	19	Parallelograms	Blank	Completed
Break	2	—	—	—
Basic	19	Rectangles	Blank	Completed

22.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 22.1.)

2 Chapters 5, 6, 11, and 12.

22.3 Preparation

Before class, students must prepare as follows:

1 Read Sections 13.1 and 13.2.

2 Download the blank and completed drawings for each exercise listed in Table 22.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

23
Freehand Drawing Class 5

This class will take place on the date indicated in Table 2.2 for "Freehand 5" ▷ .

See Section 2.4.

23.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 23.1.

Table 23.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	19	Lines between two points	Blank	Completed
Break	2	—	—	—
Basic	19	Parallelograms	Blank	Completed
Break	2	—	—	—
Basic	19	Rectangles	Blank	Completed
Break	2	—	—	—
Basic	19	Squares	Blank	Completed
Break	2	—	—	—
Basic	19	Subdividing parallelograms into quarters	Blank	Completed

23.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 23.1.)

2 Chapters 5, 6, 11, and 12.

3 Sections 13.1 and 13.2.

23.3 Preparation

Before class, students must prepare as follows:

1 Read Section 13.3.

2 Download the blank and completed drawings for each exercise listed in Table 23.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

24
Freehand Drawing Class 6

This class will take place on the date indicated in Table 2.2 for "Freehand 6" ▷ .

See Section 2.4.

There are two Special Exercises ▷ in this class. Students must be familiar with all applicable requirements for this type of exercise before coming to class.

See Section 2.6.2.

Table 24.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	15	Subdividing parallelograms into quarters	Blank	Completed
Break	2	—	—	—
Basic	15	Subdividing parallelograms into ninths	Blank	Completed
Break	2	—	—	—
Basic	15	Long lines between two points	Blank	Completed
Break	5	—	—	—
Special	20	Parallelograms	Blank	Completed
Break	5	—	—	—
Special	20	Rectangles	Blank	Completed

24.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 24.1.

24.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 24.1.)

2 Chapters 5, 6, 11, and 12.

3 Sections 13.1, 13.2, and 13.3.

24.3 Preparation

Before class, students must prepare as follows:

1. Read Section 13.4.
2. Download the blank and completed drawings for each exercise listed in Table 24.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

24.4 Marking of Special Exercises

Each Special Exercise will be awarded a maximum of ten marks. In these exercises, students will be expected to demonstrate both speed of drawing and quality of the images drawn.

The following attributes of a given drawing will be considered in marking:

1. *Number of figures drawn.* The standard will be the number of figures in the "Completed" drawings linked to in Table 24.1.
2. *Quality of shape.* Within the limitations of freehand drawing, lines that are supposed to be straight should look straight, lines that are supposed to be parallel should look parallel, angles that are supposed to be equal should look equal, and angles that are supposed to be right angles should look light right angles.
3. *Quality of linework.* There should be a clear distinction between light lines intended for construction and heavy lines intended to delineate the final figure. Light lines used for construction must be visible in all the figures. *Incorrectly drawn light lines that are suitably corrected will not be penalized.*
4. *Range of sizes.* Students are expected to draw small and large figures, as in the "Completed" drawings linked to in Table 24.1.

5 *Overall professionalism.* This relates to whether or not the instructions for the exercise were correctly followed and evidence that the work was done conscientiously.

For each of these attributes, the standard is defined by the "Completed" drawings linked to in Table 24.1. These drawings do not demonstrate a level of geometric precision that is possible when drawing by hand with instruments or with CAD. This level of precision is not expected. Students should strive to achieve a degree of geometric precision that is consistent with freehand drawing, i.e., that enables good speed to be achieved.

25
Freehand Drawing Class 7

This class will take place on the date indicated in Table 2.2 for "Freehand 7" ▷ .

See Section 2.4.

25.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 25.1.

Table 25.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	15	Subdividing parallelograms into quarters	Blank	Completed
Break	2	—	—	—
Basic	19	Skew ellipses	Blank	Completed
Break	2	—	—	—
Basic	19	Circles	Blank	Completed
Break	2	—	—	—
Basic	19	Simple bridge segments in 2-D	Blank	Completed
Break	2	—	—	—
Basic	19	Isometric prisms	Blank	Completed

25.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 25.1.)

2 Chapters 5, 6, 11, and 12.

3 Sections 13.1, 13.2, 13.3, 13.4, and 13.5.

25.3 Preparation

Before class, students must prepare as follows:

1 Read Chapter 8.

2 Read Sections 14.1 and 14.2.

3 Read Chapter 54.

4 Download the blank and completed drawings for each exercise listed in Table 25.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

26
Freehand Drawing Class 8

This class will take place on the date indicated in Table 2.2 for "Freehand 8" ▷ .

See Section 2.4.

There are two Special Exercises ▷ in this class. Students must be familiar with all applicable requirements for this type of exercise before coming to class.

See Section 2.6.2.

26.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 26.1.

Table 26.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	15	Circles	`Blank`	`Completed`
Break	2	—	—	—
Basic	15	Parabolas	`Blank`	`Completed`
Break	5	—	—	—
Basic	15	Subdividing prisms	`Blank`	`Completed`
Break	2	—	—	—
Special	20	Skew ellipses	`Blank`	`Completed`
Break	5	—	—	—
Special	20	Simple bridge segments in 2-D	`Blank`	`Completed`

26.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 26.1.)

2 Chapters 5, 6, 8, 11, and 12.

3 Sections 13.1, 13.2, 13.3, 13.4, and 13.5.

4 Sections 14.1 and 14.2.

5 Chapter 54.

26.3 Preparation

Before class, students must prepare as follows:

1. Read Section 13.6.
2. Download the blank and completed drawings for each exercise listed in Table 26.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

26.4 Marking of Special Exercises

Each Special Exercise will be awarded a maximum of ten marks. In these exercises, students will be expected to demonstrate both speed of drawing and quality of the images drawn.

The following attributes of a given drawing will be considered in marking:

1. *Number of figures drawn.* The standard will be the number of figures in the "Completed" drawings linked to in Table 26.1.
2. *Quality of shape.* Within the limitations of freehand drawing, lines that are supposed to be straight should look straight, lines that are supposed to be parallel should look parallel, angles that are supposed to be equal should look equal, angles that are supposed to be right angles should look light right angles, and ellipses should look like ellipses.
3. *Quality of linework.* There should be a clear distinction between light lines intended for construction and heavy lines intended to delineate the final figure. Light lines used for construction must be visible in all the figures. *Incorrectly drawn light lines that are suitably corrected will not be penalized.*
4. *Range of sizes.* Students are expected to draw small and large figures, as in the "Completed" drawings linked to in Table 26.1.

5 *Overall professionalism.* This relates to whether or not the instructions for the exercise were correctly followed and evidence that the work was done conscientiously.

For each of these attributes, the standard is defined by the "Completed" drawings linked to in Table 26.1. These drawings do not demonstrate a level of geometric precision that is possible when drawing by hand with instruments or with CAD. This level of precision is not expected. Students should strive to achieve a degree of geometric precision that is consistent with freehand drawing, i.e., that enables good speed to be achieved.

27
Freehand Drawing Class 9

This class will take place on the date indicated in Table 2.2 for "Freehand 9" ▷ .

See Section 2.4.

27.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 27.1.

Table 27.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	15	Long lines between two points	Blank	Completed
Break	2	—	—	—
Basic	19	Complex bridge segments in 2-D	Blank	Completed
Break	2	—	—	—
Basic	19	Arch bridge elevations	Blank	Completed
Break	2	—	—	—
Basic	19	Isometric prisms	Blank	Completed
Break	2	—	—	—
Basic	19	Isometric cubes	Blank	Completed

27.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 27.1.)

2 Chapters 5, 6, 8, 11 ,12, and 13.

3 Sections 14.1 and 14.2.

4 Chapter 54.

27.3 Preparation

Before class, students must prepare as follows:

1 Read Chapter 55.

2 Become familiar with the geometry of the Intermediate Segment and the Deviation Segment Type 2 as shown in Figures 27.1 and 27.2. Larger size versions of these drawings can be downloaded by clicking on the figure captions. These segments are to be drawn in class under the entry "Complex bridge segments in 2-D" in Table 28.1. Only the primary concrete components must be drawn. Holes and post-tensioning tendons need not be drawn. In the intermediate segment, the three build-outs (at the intersection of webs and top slab, and in the middle of the bottom slab) need not be drawn. *Students will not have access to these drawings in class.*

3 Download the blank and completed drawings for each exercise listed in Table 27.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

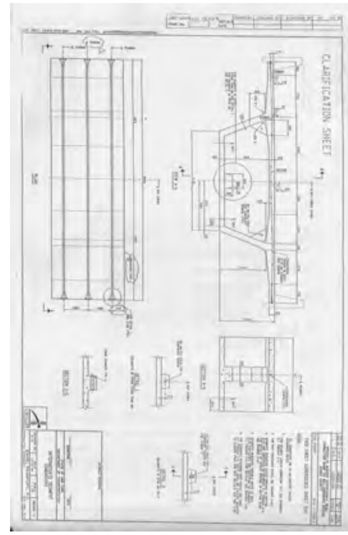


Figure 27.1: Intermediate segment

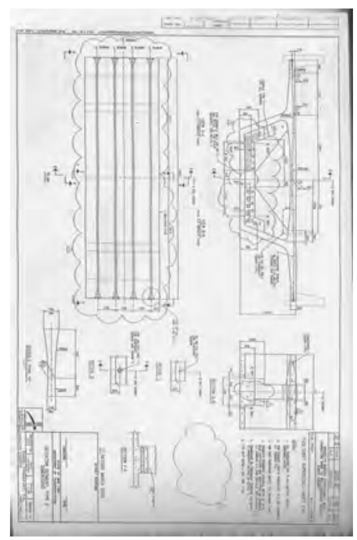


Figure 27.2: Deviation segment

28
Freehand Drawing Class 10

This class will take place on the date indicated in Table 2.2 for "Freehand 10" ▷ .

See Section 2.4.

28.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 28.1.

Table 28.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	15	Parabolas	Blank	Completed
Break	2	—	—	—
Basic	19	Complex bridge segments in 2-D	Blank	Completed
Break	2	—	—	—
Basic	19	Arch bridge elevations	Blank	Completed
Break	2	—	—	—
Basic	19	Simple bridge segments in 3-D	Blank	Completed
Break	2	—	—	—
Basic	19	Isometric cylinders	Blank	Completed

28.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 28.1.)

2 Chapters 5, 6, 8, 11 ,12, and 13.

3 Sections 14.1 and 14.2.

4 Chapters 54 and 55.

28.3 Preparation

Before class, students must prepare as follows:

1 Read Section 14.3.

2 Become familiar with the geometry of the Intermediate Segment and the Deviation Segment Type 2 as shown in Figures 28.1 and 28.2. Larger size versions of these drawings can be downloaded by clicking on the figure captions. These segments are to be drawn in class under the entry "Complex bridge segments in 2-D" in Table 28.1. Only the primary concrete components must be drawn. Holes and post-tensioning tendons need not be drawn. In the intermediate segment, the three build-outs (at the intersection of webs and top slab, and in the middle of the bottom slab) need not be drawn. *Students will not have access to these drawings in class.*

3 Download the blank and completed drawings for each exercise listed in Table 28.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

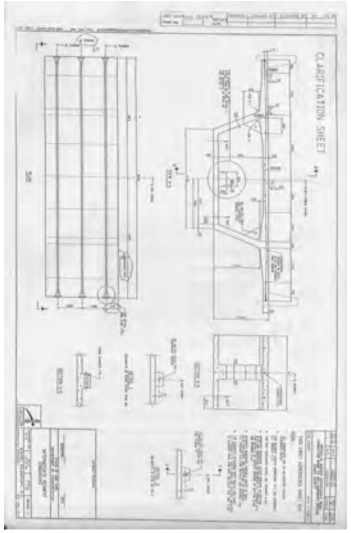


Figure 28.1: `Intermediate segment`

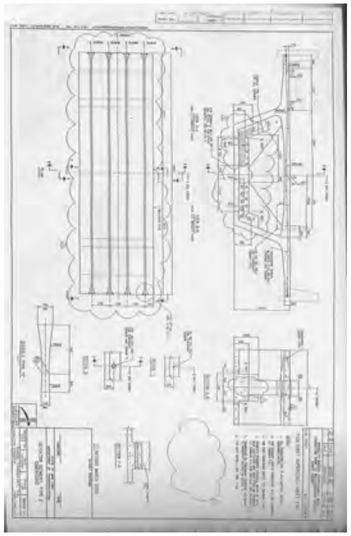


Figure 28.2: `Deviation segment`

29
Freehand Drawing Class 11

This class will take place on the date indicated in Table 2.2 for "Freehand 11" ▷ .

See Section 2.4.

There are two Special Exercises ▷ in this class. Students must be familiar with all applicable requirements for this type of exercise before coming to class.

See Section 2.6.2.

Table 29.1: Schedule of Class Activities

Type of Activity	Allotted Time (minutes)	Topic	Links to Drawing Files for Downloading	
Basic	15	Subdividing prisms	Blank	Completed
Break	2	—	—	—
Basic	15	Complex bridge segments in 3-D	Blank	Completed
Break	2	—	—	—
Basic	15	Isometric cylinders	Blank	Completed
Break	2	—	—	—
Special	20	Complex bridge segments in 2-D	Blank	Completed
Break	5	—	—	—
Special	20	Simple bridge segments in 3-D	Blank	Completed

29.1 Activities Scheduled for this Class Period

This class will consist of the activities as described in Table 29.1.

29.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 3. (Section 3.3 provides a general explanation of the items in Table 29.1.)

2 Chapters 5, 6, 8, 11 ,12, 13, and 14.1 and 14.

3 Chapters 54 and 55.

29.3 Preparation

Before class, students must prepare as follows:

1 Become familiar with the geometry of the Intermediate Segment and the Deviation Segment Type 2 as shown in Figures 29.1 and 29.2. Larger size versions of these drawings can be downloaded by clicking on the figure captions. These segments are to be drawn in class under the entry "Complex bridge segments in 2-D" and "Complex bridge segments in 3-D" in Table 29.1. Only the primary concrete components must be drawn. Holes and post-tensioning tendons need not be drawn. In the intermediate segment, the three build-outs (at the intersection of webs and top slab, and in the middle of the bottom slab) need not be drawn. *Students will not have access to these drawings in class.*

2 Download the blank and completed drawings for each exercise listed in Table 29.1. Print out these drawings on 11 by 17 paper, scaled at 100%. Practice each exercise and compare your work to the corresponding completed exercises.

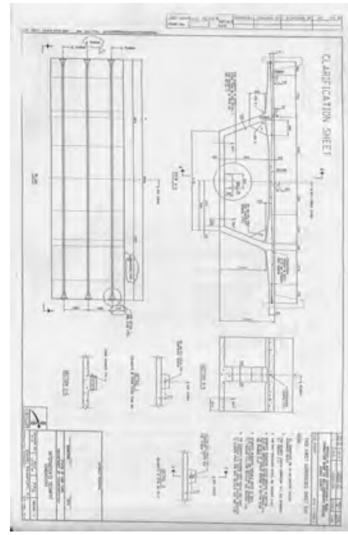


Figure 29.1: Intermediate segment

29.4 Marking of Special Exercises

Each Special Exercise will be awarded a maximum of ten marks. In these exercises, students will be expected to demonstrate both speed of drawing and quality of the images drawn.

The following attributes of a given drawing will be considered in marking:

1 *Number of figures drawn.* The standard will be the number of figures in the "Completed" drawings linked to in Table 29.1.

2 *Quality of shape.* Within the limitations of freehand drawing, lines that are supposed to be straight should look straight, lines that are

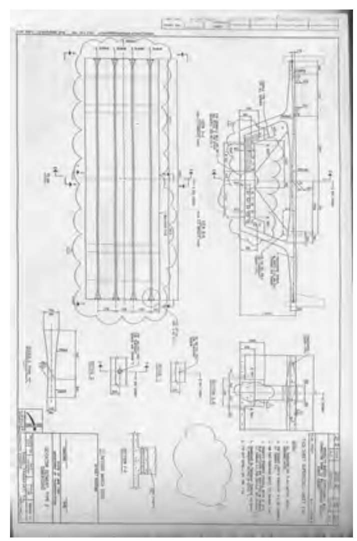


Figure 29.2: Deviation segment

supposed to be parallel should look parallel, angles that are supposed to be equal should look equal, angles that are supposed to be right angles should look light right angles, and ellipses should look like ellipses.

3 *Quality of linework.* There should be a clear distinction between light lines intended for construction and heavy lines intended to delineate the final figure. Light lines used for construction must be visible in all the figures. *Incorrectly drawn light lines that are suitably corrected will not be penalized.*

4 *Range of sizes.* Students are expected to draw small and large figures, as in the "Completed" drawings linked to in Table 29.1.

5 *Overall professionalism.* This relates to whether or not the instructions for the exercise were correctly followed and evidence that the work was done conscientiously.

For each of these attributes, the standard is defined by the "Completed" drawings linked to in Table 29.1. These drawings do not demonstrate a level of geometric precision that is possible when drawing by hand with instruments or with CAD. This level of precision is not expected. Students should strive to achieve a degree of geometric precision that is consistent with freehand drawing, i.e., that enables good speed to be achieved.

Part VII

Description of Classes: SketchUp

30
SketchUp Class 1

This class will take place on the date indicated in Table 2.2 for "SketchUp 1" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

30.1 Brief Description of Exercise

This exercise consists of producing, in the course LayOut template, a drawing that consists of three linked orthographic views and one perspective view of the precast concrete bridge segment contained in the SketchUp template. The completed drawing is shown in Figure 30.1.

This exercise requires no drawing per se in SketchUp, i.e., no creation or modification of objects. The intent of this exercise is to provide an introduction to basic tasks in SketchUp and LayOut that include:

1 Working with the course LayOut template

2 Creating scenes, working with styles, and cutting sections in SketchUp

3 Linking a SketchUp file to a LayOut file

4 Adding basic dimensions and annotations

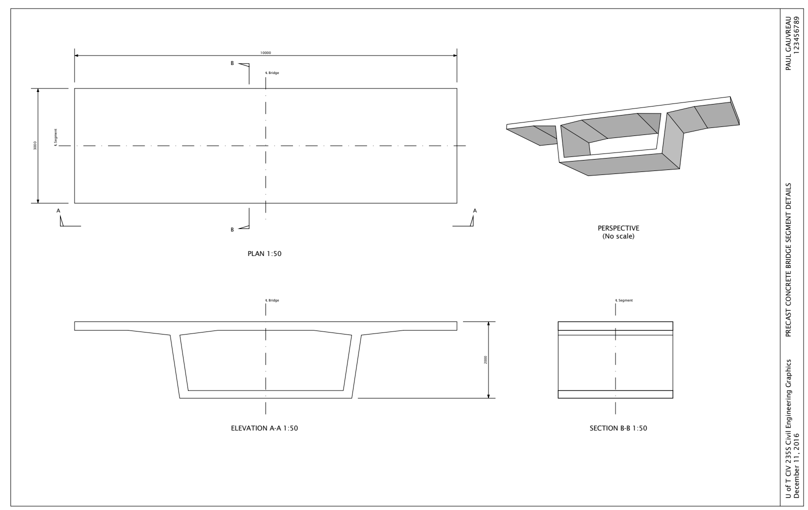


Figure 30.1: SketchUp Class 1: Completed drawing.

5 Submitting a pdf of the completed drawing to the secure network environment

Students are expected to produce a drawing that projects a high degree of professionalism.

30.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Applicable sections of the course Drafting Standards (Appendix A).

30.3 Preparation

Before class, students shall prepare as follows:

1 Read Section 6.1.

2 Read Chapters 7, *9*, and 16.

3 Complete the exercise before class. This will involve reading and understanding the material available at the links to the SketchUp and LayOut Help Centres provided in the Recommended Workflow.

30.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course SketchUp template, identical to the file available at this link ▷ .

Click this text to download the course SketchUp template.

3 The course LayOut template, identical to the file available at this link ▷ .

Click this text to download the course LayOut template.

30.5 Recommended Workflow

Steps 1 through 4 of this workflow correspond to the first four steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ . Steps 5 through 12 implement the fifth step of the general drawing process ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4.

See Section 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 30.1) have been defined in advance by course staff.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 30.1) have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Set up the LayOut file.*

(a) Download and open the course LayOut template ▷ .

Click this text to download the course LayOut template.

(b) Enter the required changes to the title block ▷ .

See Section A.4 for requirements. The title of the drawing shall be taken from Figure 30.1.

6 *Create the model in SketchUp.*

(a) Open the course template in SketchUp ▷ .

Click this text to download the course SketchUp template.

In this exercise, the model does not have to be created. We will use the bridge segment model that has been provided in the template.

7 *In SketchUp, create the scenes that correspond to the views to be produced in LayOut.*

A total of four scenes will be required. For a given scene, proceed as follows:

(a) If required, insert a section plane and make it active ▷ . A section plane will be required for only one of the scenes.

See Section 16.6 and the article Slicing a Model to Peer Inside *in the SketchUp Help Centre.*

(b) Set the *camera* to parallel or perspective projection as required for the scene to be created ▷ .

See the article Viewing a Model *in the SketchUp Help Centre.*

Parallel projection will be used for the three orthographic views (plan, elevation, and section). Perspective projection will (obviously) be used for the perspective view.

(c) Set the viewpoint using the orbit tool or by selecting one of the standard views ▷ .

See the article Viewing a Model *in the SketchUp Help Centre.*

(d) Select the style that is required for the scene ▷ .

See Sections 16.4 and A.16, and the article Choosing a Style *in the SketchUp Help Centre.*

(e) Create and save a scene corresponding to the depiction of the model thus produced ▷ .

See Section 16.5 and the article Creating Scenes *in the SketchUp Help Centre.*

When saving a scene, if you are prompted by SketchUp to save changes to the style, do not save the changes. If you do, one of the standard styles in the template will be changed and you will have to change it back by hand.

8 *Save your work in SketchUp.*

This is important, since the process of importing into LayOut works with the most recently saved SketchUp file rather than what currently appears in the SketchUp window.

9 *In LayOut, import the SketchUp file you just saved* ▷ .

See the article `Inserting a SketchUp Model into Your Document` *in the LayOut Help Centre.*

A window with a view of the SketchUp model is created.

10 *In LayOut, make required adjustments to the window.*

Proceed as follows:

(a) Set the SketchUp scene and scale of the window ▷ .

See the article `Editing a SketchUp Model's View and Style Settings in LayOut` *in the LayOut Help Centre.*

For two-dimensional orthographic views that do not show texture and shading, make sure the Rendering Mode has been set to `Vector`. For perspective views that show texture and shading, make sure the Rendering Mode had been set to `Raster`.

(b) If necessary, resize the window so that the entire model is visible ▷ .

See the article `Editing a SketchUp Model's View and Style Settings in LayOut` *in the LayOut Help Centre.*

Make sure the box `Preserve Scale on Resize` is checked before you resize the window.

(c) Move the window into position on the page.

11 *For the remaining three windows, proceed as follows*:

(a) Copy the previously created window ▷ .

See the article `Copying, Pasting, Erasing, and Other Editing Tasks` *in the LayOut Help Centre.*

The recommended procedure is to hold down `Control` and `Shift` as you left-click and drag the window. This will automatically create a copy and will also contrain the motion to vertical or horizontal. This will ensure that the views are properly aligned or *linked* ▷ .

See Section 7.5.

(b) Set the SketchUp scene and scale of the window.

(c) If necessary, resize the window so that the entire model is visible.

12 *Add centrelines, dimensions, section symbols and view titles.*

These items shall be in accordance with the course Drafting Standard ▷.

See Appendix A.

Dimensions shall be made using the dimension tool in LayOut ▷. If the appearance of dimensions (text and/or line style) differs from the sample provided in the template, use the sample tool ▷ to copy the style of the sample and apply it to the dimensions drawn.

See the article `Marking Dimensions` *in the LayOut Help Centre.*

See Section A.1.4.

Draw centrelines using the line tool in LayOut. Snap to a suitable point (often a midpoint of a line segment) in the SketchUp model ▷ and draw the line. Holding the `Shift` key will constrain the line to be horizontal or vertical. If the appearance of a given centrline differs from the sample provided in the template, use the sample tool to copy the style of the sample and apply it to the centreline drawn.

See the article `Arranging, Moving, Rotating, and Scaling Entities` *in the LayOut Help Centre.*

For other items, make maximum use of the samples provided to the left of the drawing area in the template by copying, pasting, and modifying as required.

The drawing should look like the completed drawing in Figure 30.1.

13 *Create a pdf of the drawing you created in LayOut* ▷. Store the pdf file on the `W:\` directory ▷.

See the article `Exporting or Printing Your LayOut Document` *in the LayOut Help Centre.*

See Section 4.2.2.

14 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

15 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

16 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

30.6 *Completed Drawing*

The drawing to be produced in this exercise, shown in Figure 30.1, is available for download at the link provided ▷ .

Click this text to download the completed exercise.

31
SketchUp Class 2

This class will take place on the date indicated in Table 2.2 for “SketchUp 2” ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

31.1 Brief Description of Exercise

This exercise consists of creating a three-dimensional SketchUp model of a precast concrete bridge segment and producing, in course LayOut template, a drawing that consists of three linked orthographic views and one perspective view. This drawing must contain a minimal set of dimensions and annotations. The completed drawing is shown in Figure 31.1.

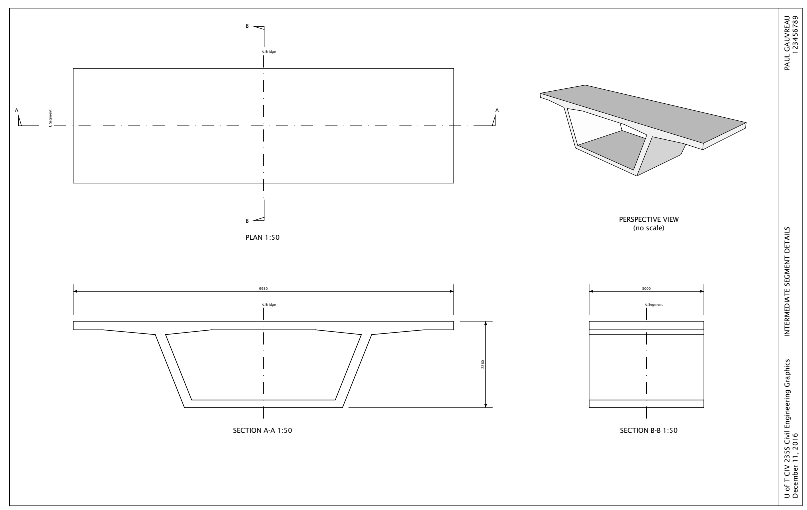


Figure 31.1: SketchUp Class 2: Completed drawing.

The end product of this exercise is very similar to that of SketchUp Class 1. The primary difference between the two exercises is that the segment model must be created in SketchUp.

The intent of this exercise is to provide an introduction to basic tasks in SketchUp and LayOut that include:

1 All of the items covered in previous SketchUp classes

2 Creating three-dimensional models in SketchUp

Students are expected to produce a drawing that projects a high degree of professionalism.

31.2 *Background*

Students are expected to be familiar with the following material:

1. Chapters 1, 2, and 4.
2. Section 6.1.
3. Chapters 7, 9, and 16.
4. Applicable sections of the course Drafting Standards (Appendix A).
5. All of the SketchUp and LayOut techniques covered in previous classes.

31.3 *Preparation*

Before class, students shall prepare as follows:

1. Read Chapter 54.
2. Become familiar with the precast concrete bridge segment to be drawn in this exercise. It is shown in Figure 31.2. A higher resolution version of this image is available at the link provided ▷ . Note the annotations made on this drawing and the instructions given in Point 1 of Section 31.5.
3. Complete the exercise before class. This will involve reading and understanding the material available at the links to the SketchUp and LayOut Help Centres provided in the Recommended Workflow.

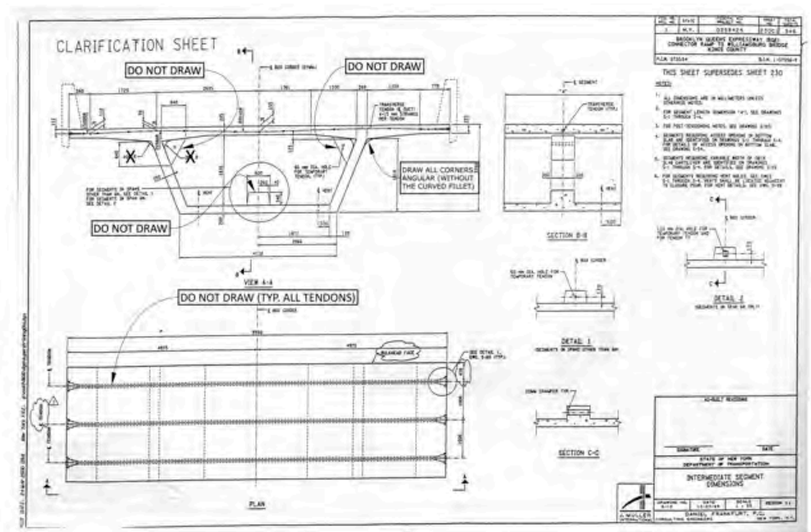


Figure 31.2: Drawing of the precast concrete bridge segment to be drawn.

Click this text to download the drawing of the segment.

31.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The drawing of the precast concrete bridge segment to be drawn, identical to the file available at this link ▷ .

`Click this text to download the drawing of the segment.`

3 The course SketchUp template, identical to the file available at this link ▷ .

`Click this text to download the course SketchUp template.`

4 The course LayOut template, identical to the file available at this link ▷ .

`Click this text to download the course LayOut template.`

31.5 Recommended Workflow

Steps 1 through 4 of this workflow correspond to the first four steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ . Steps 5 through 9 implement the fifth step of the general drawing process ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4.

See Section 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The drawing to be produced in this exercise shall be as shown in Figure 31.1. The purpose of this drawing is to describe the dimensions required to construct the formwork for building this segment.

The rounded fillets at the corners between the webs and the top slab shall not be drawn. Instead, these corners shall be drawn angular by prolonging the tangents on either side of the corner to their point of intersection.

The post-tensioning tendons shall not be drawn. The holes in the three blocks in the interior of the box section shall not be drawn.

Only a minimal set of dimensions and annotations is required. Basically, the information given on the completed drawing shown in Figure 31.1 shall be provided.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 31.1) have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the drawing shown in Figure 31.2. Dimension "A" on this drawing shall be taken to be 3000 mm.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Set up the LayOut file.*

(a) Download and open the course LayOut template ▷ .

`Click this text to download the course LayOut template.`

(b) Enter the required changes to the title block ▷ .

See Section A.4 for requirements. The title of the drawing shall be taken from Figure 31.1.

6 *Create the model in SketchUp.*

(a) Open the course template in SketchUp ▷ .

Click this text to download the course SketchUp template.

(b) Delete the model that is provided in the template. It will not be used.

(c) Draw the basic cross-section ▷ . Make extensive use of the Tape Measure tool to create guide lines. These are used to locate key points as the intersection of two guide lines. Lines can then be drawn accurately by snapping to these intersection points. You will need to activate the guide lines by making sure `Guides` is checked in the `View` menu.

See the articles Introducing Drawing Basics and Concepts, Selecting Geometry, Erasing and Undoing, *and* Measuring Angles and Distances to Model Precisely *in the SketchUp Help Centre.*

(d) Extrude the basic cross-section to create a three-dimensional segment ▷ .

See the article Pushing and Pulling Shapes into 3D *in the SketchUp Help Centre.*

7 *In SketchUp, create the scenes that correspond to the views to be produced in LayOut.*

A total of four scenes will be required. Proceed according to the steps given previously for SketchUp Class 1 ▷ .

See Step 7 in Section 30.5.

8 *Save your work in SketchUp.*

This is important, since the process of importing into LayOut works with the most recently saved SketchUp file rather than what currently appears in the SketchUp window.

9 *Import the SketchUp file into LayOut, create the views, and add dimensions and annotations.*

Proceed according to the steps given previously for SketchUp Class 1 ▷ .

See Steps 9 through 12 in Section 30.5.

The drawing should look like the completed drawing in Figure 31.1.

10 *Create a pdf of the drawing you created in LayOut* ▷ . Store the pdf file on the `W:\` directory ▷ .

See the article Exporting or Printing Your LayOut Document *in the LayOut Help Centre.*

See Section 4.2.2.

11 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

12 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

13 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

31.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 31.1, is available for download at the link provided ▷ .

`Click this text to download the completed exercise.`

32
SketchUp Class 3

This class will take place on the date indicated in Table 2.2 for "SketchUp 3" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

32.1 Brief Description of Exercise

This exercise consists of creating a three-dimensional SketchUp model of a precast concrete bridge segment and producing, in course LayOut template, a drawing that consists of three linked orthographic views and one perspective view. This drawing must contain a minimal set of dimensions and annotations. The completed drawing is shown in Figure 32.1.

The end product of this exercise is very similar to that of SketchUp Class 2. In SketchUp Class 2, the geometry of the segment had been simplified. In this exercise, the segment shall be drawn without these simplifications, namely: (1) the three blocks in the interior cavity of the box girder shall be drawn, and (2) the rounded corners (fillets) at the joint between the webs and the top slab shall be drawn.

The intent of this exercise is to provide an introduction to tasks in SketchUp and LayOut that include:

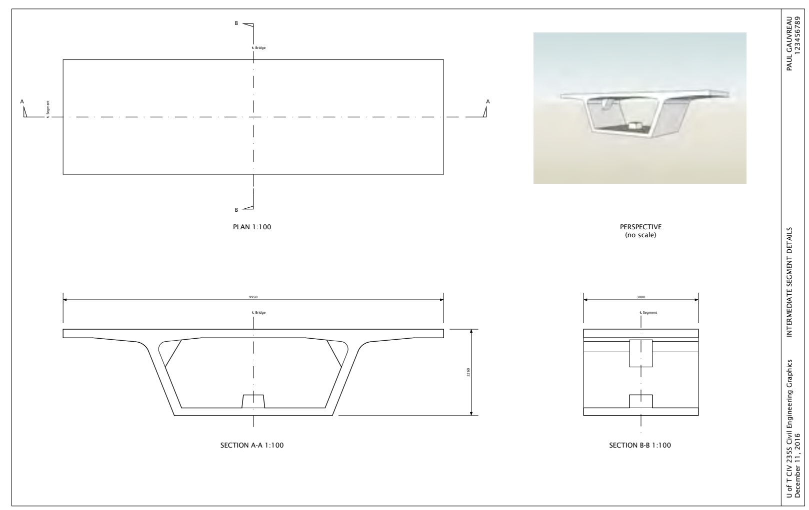


Figure 32.1: SketchUp Class 3: Completed drawing.

1 All of the items covered in previous SketchUp classes

2 SketchUp modeling techniques of greater complexity including groups, solid tools, and arcs.

Students are expected to produce a drawing that projects a high degree of professionalism.

32.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, 16, and 54.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes.

32.3 Preparation

Before class, students shall prepare as follows:

1 Become familiar with the precast concrete bridge segment to be drawn in this exercise. It is shown in Figure 32.2. A higher resolution version of this image is available at the link provided ▷

2 Complete the exercise before class. This will involve reading and understanding the material available at the links to the SketchUp and LayOut Help Centres provided in the Recommended Workflow.

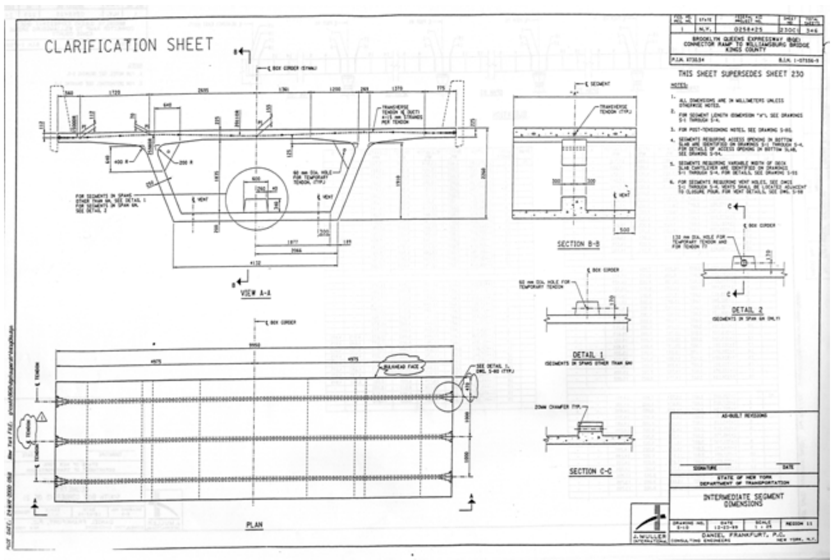


Figure 32.2: Drawing of the precast concrete bridge segment to be drawn.

Click this text to download the drawing of the segment.

32.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The drawing of the precast concrete bridge segment to be drawn, identical to the file available at this link ▷ .

`Click this text to download the drawing of the segment.`

3 The course SketchUp template, identical to the file available at this link ▷ .

`Click this text to download the course SketchUp template.`

4 The course LayOut template, identical to the file available at this link ▷ .

`Click this text to download the course LayOut template.`

32.5 Recommended Workflow

Steps 1 through 4 of this workflow correspond to the first four steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ . Steps 5 through 9 implement the fifth step of the general drawing process ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4.

See Section 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The drawing to be produced in this exercise shall be as shown in Figure 32.1. The purpose of this drawing is to describe the dimensions required to construct the formwork for building this segment. Information related to the post-tensioning tendons thus need not be considered. The holes in the three blocks in the interior of the box section need not be drawn.

Only a minimal set of dimensions and annotations is required. Basically, the information given on the completed drawing shown in Figure 32.1 shall be provided.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 32.1) have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the drawing shown in Figure 32.2. Dimension "A" on this drawing shall be taken to be 3000 mm.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Set up the LayOut file.*

(a) Download and open the course LayOut template ▷ .

`Click this text to download the course LayOut template.`

(b) Enter the required changes to the title block ▷ .

See Section A.4 for requirements. The title of the drawing shall be taken from Figure 30.1.

6 *Create the model in SketchUp.*

(a) Open the course template in SketchUp ▷ .

`Click this text to download the course SketchUp template.`

(b) Delete the model that is provided in the template. It will not be used.

(c) Draw the basic cross-section (this is the cross-section consisting of the top slab, bottom slab, and webs, without the three blocks in the cavity of the box girder) ▷ . Make extensive use of the Tape Measure tool to create guide lines. These are used to locate key points as the intersection of two guide lines. Lines can then be drawn accurately by snapping to these intersection points. You will need to activate the guide lines by making sure `Guides` is checked in the `View` menu.

Guide lines will be particularly useful in locating the centre of the arcs at the corners between top slab and webs.

See the articles `Introducing Drawing Basics and Concepts`*,* `Selecting Geometry`*,* `Drawing Arcs`*,* `Erasing and Undoing`*, and* `Measuring Angles and Distances to Model Precisely` *in the SketchUp Help Centre.*

(d) Extrude the basic cross-section to create a three-dimensional segment ▷ .

See the article `Pushing and Pulling Shapes into 3D` *in the SketchUp Help Centre.*

(e) Make a group from the partially completed segment thus drawn ▷ .

See the article `Grouping Geometry` *in the SketchUp Help Centre.*

(f) Add the corner blocks.

There are many ways of doing this. Perhaps the easiest is to draw the blocks outside the segment and move them in ▷ . Figure 32.3 shows the corner block outside the segment. Note the extensive use of guide lines to ensure that the completed block can be moved precisely to its required location in the segment. Also note that there is no need to draw the curved portion of the block, since SketchUp will hide the interior corner inside the segment.

See the article `Moving Entities Around` *in the SketchUp Help Centre.*

Before moving the block into position in the segment, make it into a group.

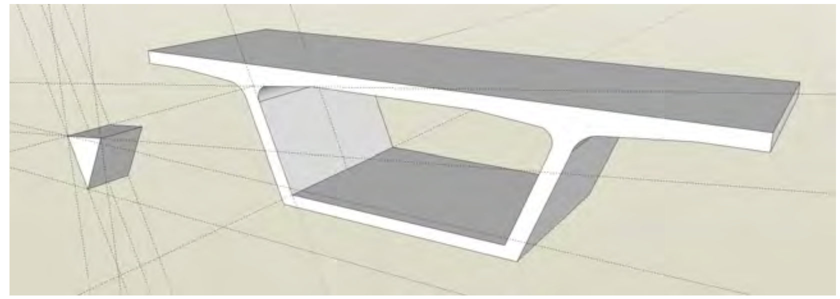


Figure 32.3: Drawing the corner block outside the segment

(g) Draw the central block.

Again, there are several ways of doing this.

(h) Remove any lines that are "inside" the concrete ▷ . The tool required is the `Outer Shell` tool. If you have made groups of each corner block and of the partially completed segment, then the tool will work. You may with to turn on transparency to see the tool in action. Just activate `X-ray` from the `View` → `Face Style` menu.

See the article `Modeling Complex 3D Shapes with the Solid Tools` *in the SketchUp Help Centre.*

7 *In SketchUp, create the scenes that correspond to the views to be produced in LayOut.*

A total of four scenes will be required. Proceed according to the steps given previously for SketchUp Class 1 ▷ .

See Step 7 in Section 30.5.

8 *Save your work in SketchUp.*

This is important, since the process of importing into LayOut works with the most recently saved SketchUp file rather than what currently appears in the SketchUp window.

9 *Import the SketchUp file into LayOut, create the views, and add dimensions and annotations.*

Proceed according to the steps given previously for SketchUp Class 1 ▷ .

See Steps 9 through 12 in Section 30.5.

The drawing should look like the completed drawing in Figure 32.1.

10 *Create a pdf of the drawing you created in LayOut* ▷ . Store the pdf file on the `W:\` directory ▷ .

See the article `Exporting or Printing Your LayOut Document` *in the LayOut Help Centre.*

See Section 4.2.2.

11 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

12 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

13 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

32.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 32.1, is available for download at the link provided ▷ .

`Click this text to download the completed exercise.`

33
SketchUp Class 4

This class will take place on the date indicated in Table 2.2 for "SketchUp 4" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

33.1 Brief Description of Exercise

This exercise consists of drawing a complete set of dimensions for the bridge segment drawn in SketchUp Class 3 ▷ . The SketchUp model will be provided and does not need to be drawn. The completed drawing is shown in Figure 33.1. All of the dimensions have been provided. Students must understand why these dimensions have been provided and reproduce them on their own drawings.

See Chapter 32.

This exercise has the following objectives:

1. Gain proficiency in the use of the dimension tool in LayOut
2. Learn how to develop an efficient sequence of operations for drawing dimensions
3. Understand the significance of a complete set of dimensions for a given object

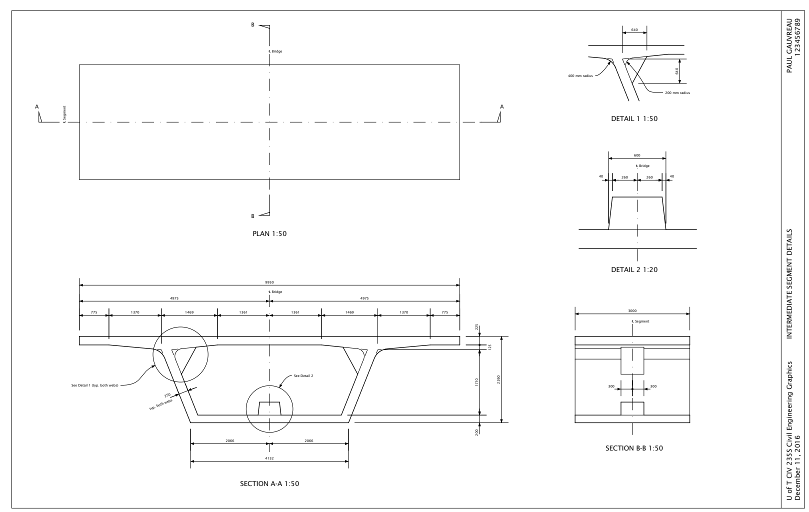


Figure 33.1: SketchUp Class 4: Completed drawing.

4 Gain proficiency in laying out a set of dimensions and annotations that projects a high degree of professionalism

Although the use of the dimension tool in LayOut is fairly straightforward, it does not always produce dimensions that are in accordance with the course drafting standard ▷ . It is thus generally the case (and will certainly be the case in this exercise) that some of these dimensions will need to be modified. This can be accomplished as follows:

See Section A.10.

1 Draw a given dimension normally using the dimension tool

2 If the dimension is not in accordance with the course drafting standard, right-click the dimension and select `Explode` from the pop-up menu. This enables the individual components of a given dimension (dimension quantity, dimension line, and extension lines) to be modified or deleted.

3 Modify the dimension to bring it into accordance with the course drafting standard

Additional lines corresponding to the extension of the tangents to the faces of the webs and the underside of the top slab need to be drawn *in LayOut*. These are shown in Figure 33.2. These must be snapped to the SketchUp model and drawn carefully to ensure that they are collinear with the faces of the model. If they are not properly snapped, then the dimensions drawn to these points will not be accurate.

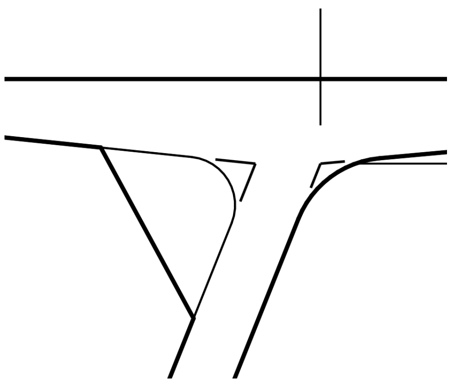


Figure 33.2: Additional lines to be drawn in LayOut

33.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, 16, and 54.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes.

33.3 Preparation

Before class, students shall prepare as follows:

1 Become familiar with the SketchUp model of the segment to be drawn and dimensioned in LayOut. It is shown in Figure 33.3. The SketchUp file available at the link provided ▷

Click this text to download the SketchUp file.

2 Complete the exercise before class. This will involve reading and understanding the material available at the links to the SketchUp and LayOut Help Centres provided in the Recommended Workflow.

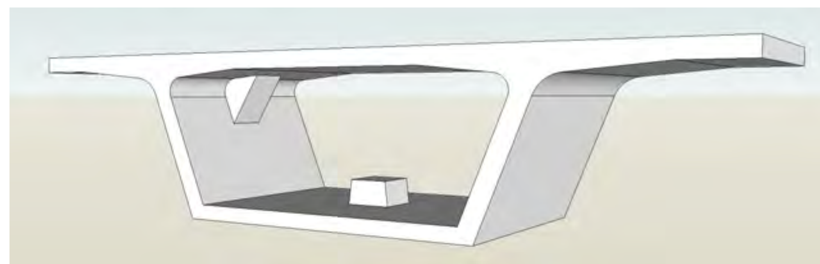


Figure 33.3: Drawing of the precast concrete bridge segment to be dimensioned

33.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The SketchUp file with the model of the segment from which the views in LayOut will be created, identical to the file available at this link ▷ .

Click this text to download the SketchUp file.

3 The course LayOut template, identical to the file available at this link ▷ .

Click this text to download the course LayOut template.

33.5 Recommended Workflow

Steps 1 through 4 of this workflow correspond to the first four steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ . Steps 5 through 9 implement the fifth step of the general drawing process ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4.

See Section 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The drawing to be produced in this exercise shall be as shown in Figure 33.1. The purpose of this drawing is to describe the dimensions required to construct the formwork for building this segment. Information related to the post-tensioning tendons thus need not be considered. The holes in the three blocks in the interior of the box section need not be drawn.

A complete set of dimensions and annotations is required. The information given on the completed drawing shown in Figure 33.1 shall be provided.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 33.1) have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve planning the required scenes in SketchUp and views in Layout, and going through the completed drawing (Fig.

33.1) to verify that a complete set of dimensions in accordance with the course drafting standard has indeed been provided.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ . This will involve planning an efficient sequence of steps for drawing the dimensions. This includes identifying dimensions that will need to be modified ▷ .

See Section 6.1.4.

See Section 33.1.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Set up the LayOut file.*

(a) Download and open the course LayOut template ▷ .

(b) Enter the required changes to the title block ▷ .

`Click this text to download the course LayOut template.`

See Section A.4 for requirements. The title of the drawing shall be taken from Figure 30.1.

6 *Create the model in SketchUp.*

The model has already been created and must be downloaded from the link provided ▷ .

`Click this text to download the SketchUp file.`

7 *In SketchUp, create the scenes that correspond to the views to be produced in LayOut.*

A total of three scenes will be required. Proceed according to the steps given previously for SketchUp Class 1 ▷ .

See Step 7 in Section 30.5.

8 *Save your work in SketchUp.*

This is important, since the process of importing into LayOut works with the most recently saved SketchUp file rather than what currently appears in the SketchUp window.

9 *Import the SketchUp file into LayOut, create the views, and add dimensions and annotations.*

Proceed according to the steps given previously for SketchUp Class 1 ▷.

See Steps 9 through 12 in Section 30.5.

Details 1 and 2 can be copies of the `Section A-A` window, re-sized and, if required, re-scaled.

The drawing should look like the completed drawing in Figure 33.1.

10 *Create a pdf of the drawing you created in LayOut* ▷. Store the pdf file on the `W:\` directory ▷.

See the article `Exporting or Printing Your LayOut Document` *in the LayOut Help Centre.*

See Section 4.2.2.

11 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

12 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

13 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

33.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 33.1, is available for download at the link provided ▷.

`Click this text to download the completed exercise.`

34
SketchUp Class 5

This class will take place on the date indicated in Table 2.2 for "SketchUp 5" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

34.1 Brief Description of Exercise

This exercise consists of creating a SketchUp model of a precast concrete bridge segment, creating views in LayOut, and drawing a complete set of dimensions. The completed drawing is shown in Figure 34.1. This exercise has no new work. It combines the work performed in SketchUp Classes 3 and 4.

This exercise has as its objectives to improve proficiency and speed in creating SketchUp models, creating views in LayOut, and producing a complete set of dimensions.

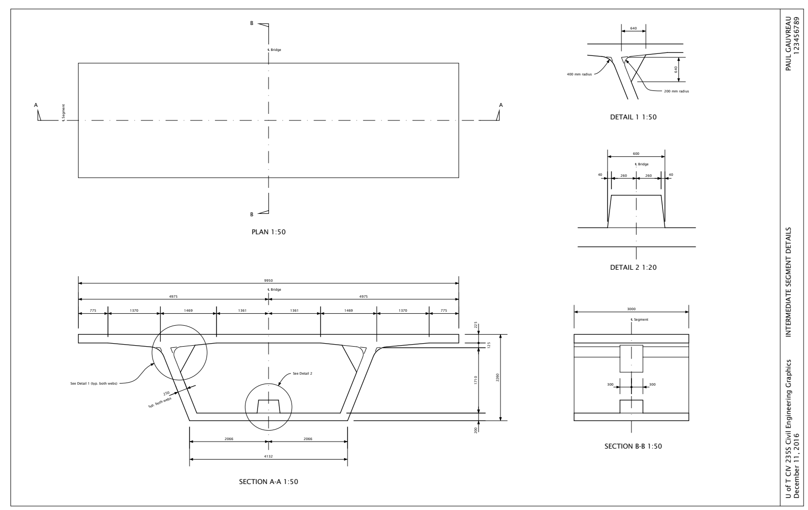


Figure 34.1: SketchUp Class 5: Completed drawing.

34.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, 16, and 54.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes.

34.3 *Preparation*

Before class, students shall prepare as follows:

1 Become familiar with the precast concrete bridge segment to be drawn in this exercise. It is shown in Figure 34.2. A higher resolution version of this image is available at the link provided ▷

2 Complete the exercise before class.

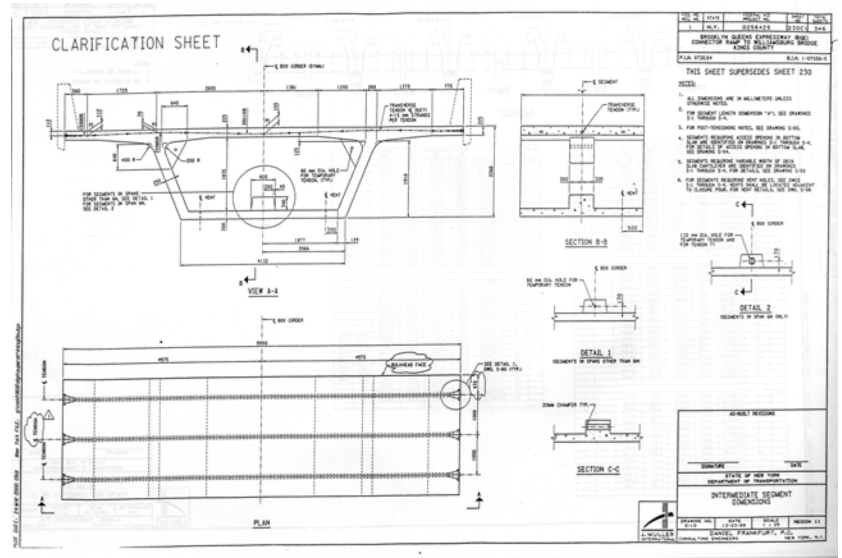


Figure 34.2: Drawing of the precast concrete bridge segment to be drawn.

Click this text to download the drawing of the segment.

34.4 *Resources Provided During Class*

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The drawing of the precast concrete bridge segment to be drawn, identical to the file available at this link ▷ .

Click this text to download the drawing of the segment.

3 The course SketchUp template, identical to the file available at this link ▷ .

Click this text to download the course SketchUp template.

4 The course LayOut template, identical to the file available at this link ▷ .

Click this text to download the course LayOut template.

34.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The drawing to be produced in this exercise shall be as shown in Figure 34.1. The purpose of this drawing is to describe the dimensions required to construct the formwork for building this segment. Information related to the post-tensioning tendons thus need not be considered. The holes in the three blocks in the interior of the box section need not be drawn.

A complete set of dimensions and annotations is required. The information given on the completed drawing shown in Figure 34.1 shall be provided.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 34.1) have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the drawing shown in Figure 34.2. Dimension "A" on this drawing shall be taken to be 3000 mm.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

See Section 6.1.4.

5 *Produce the required drawing.*

Follow the relevant steps of the Recommended Workflow of Classes 3 and 4 ▷ . The SketchUp and LayOut templates are available at the links provided ▷ .

See Sections 32.5 and 33.5.

Click this text to download the course LayOut template.
Click this text to download the course SketchUp template.

The completed drawing shall look like the drawing in Figure 34.1.

6 *Create a pdf of the drawing you created in LayOut* ▷ . Store the pdf file on the `W:\` directory ▷ .

See the article Exporting or Printing Your LayOut Document *in the LayOut Help Centre.*

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

34.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 34.1, is available for download at the link provided ▷ .

Click this text to download the completed exercise.

35
SketchUp Class 6

This class will take place on the date indicated in Table 2.2 for “SketchUp 6” ▷ .

See Section 2.4.

The class will consist of one Special Exercise ▷ .

See Section 2.6.2.

Figure 35.1: An example of the segment to be drawn in this exercise

35.1 Brief Description of Exercise

This exercise consists of creating a SketchUp model of a precast concrete bridge segment, creating views in LayOut, and drawing a complete set of dimensions. The completed drawing will not be provided.

The segment to be drawn is similar to the segments shown in Figure 35.1.

This exercise has as its objectives to improve proficiency and speed in creating SketchUp models, creating views in LayOut, and producing a complete set of dimensions.

35.2 Work to Be Submitted

Students shall submit a pdf version of a LayOut drawing showing plan, front elevation, and longitudinal section of the segment. The viewing plane for the front elevation shall be perpendicular to the longitudinal axis of the bridge that will be built using the segment. The section plane of the longitudinal section shall be vertical and parallel to the longitudinal axis of the bridge.

The LayOut drawing shall be prepared on the course LayOut template ▷ .

Click this text to download the course LayOut template.

The LayOut drawing shall provide a complete set of dimensions and annotations, in accordance with the course drafting standard ▷ .

See Appendix A.

The views in the LayOut drawing shall be created from a SketchUp model of the segment, drawn using the course SketchUp template ▷ .

Click this text to download the course SketchUp template.

35.3 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, 16, and 54.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes.

35.4 Preparation

Before class, students shall prepare as follows:

1 Compile, on paper, all of the information need to create a precise SketchUp model of the segment to be drawn in this exercise. A SketchUp file with a precise three-dimensional model of the segment is available for this purpose ▷ .

Click this text to download the SketchUp file with the three-dimensional model of the segment.

Students will not have access to this file during class, so any information required from it must be put onto paper before class.

2 Complete the exercise before class.

35.5 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course SketchUp template, identical to the file available at this link ▷ .

`Click this text to download the course SketchUp template.`

3 The course LayOut template, identical to the file available at this link ▷ .

`Click this text to download the course LayOut template.`

The SketchUp file with the three-dimensional model the segment ▷ will not be provided in class.

See Section 35.4.

35.6 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced in this exercise is to describe the dimensions required to construct the formwork for building this segment.

A complete set of dimensions and annotations is required.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing all relevant information from the SketchUp file with the three-dimensional model of the segment ▷ .

See Section 35.4.

It is extremely important that this task will be completed by students before class, because there will be no other source of information on the object to be drawn that will be available to students during class.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the required drawing.*

Follow the relevant steps of the Recommended Workflow of Classes 3 and 4 ▷ . The SketchUp and LayOut templates are available at the links provided ▷ .

See Sections 32.5 and 33.5.

`Click this text to download the course LayOut template`.
`Click this text to download the course SketchUp template`.

6 *Create a pdf of the drawing you created in LayOut* ▷ .

See the article `Exporting or Printing Your LayOut Document` *in the LayOut Help Centre.*

Store the pdf file on the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

35.7 Marking

Since this exercise is a Special Exercise ▷, it will be marked in detail.

See Section 2.6.2.

The exercise will be marked according to the marking guide given in Table 35.1. Each item in the marking guide will be assigned an assessment of "√" (no problems), "O" (small problems), or "X" (big problems).

On the basis of this assessment, a mark out of 10 will be assigned according to the following criteria:
All "√": 9 to 10
Mostly "√", a few "O": 8
A significant number of "O" and/or a maximum of one "X": 7
Two "X": 6
More than two "X": 0 to 5

A major point of this exercise is to produce drawings that project a high standard of quality and professionalism. Drawings that present the information correctly but which otherwise contain elements that demonstrate a lack of professionalism are unlikely to receive a mark greater than 7 out of 10.

Table 35.1: Marking Guide for SketchUp Class 6

Item no.	Item	Assessment
1	Drawing projects a high standard of quality and professionalism	
2	Instructions were followed correctly	
3	Drawing is complete	
4	Views are accurate	
5	Dimensions are complete	
6	Dimensions are in accordance with course drafting standard	
7	Annotations are in accordance with course drafting standard	

36
SketchUp Class 7

This class will take place on the date indicated in Table 2.2 for "SketchUp 7" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

36.1 Brief Description of Exercise

The purpose of this exercise is to gain increased proficiency in working with scenes, sections, components, groups, and layers in SketchUp. The exercise involves creating a LayOut document consisting of four drawings, each of which displays a specific arrangement of eight precast concrete bridge segments in three linked orthographic views and a perspective view. An example of one of these drawings is shown in Figure 36.1.

SketchUp models of the individual segments are provided. Each drawing requires a specific setting of properties relating to section planes and layers.

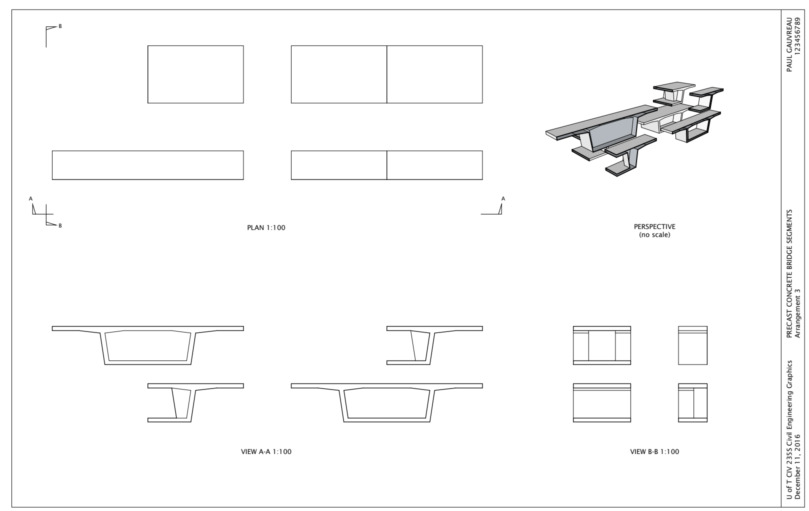


Figure 36.1: SketchUp Class 7: Completed document, Drawing 3

36.1.1 *Description of the Segments*

Three-dimensional models of the segments have already been created and are provided to students ▷ . Four different types of segment have been provided (Fig. 36.2):

Click this text to download the SketchUp file with the three-dimensional models of the segments.

1 Type 1: A basic segment with nothing in the interior cavity of the box girder

2 Type 2: Same basic segment, with a relatively thin solid diaphragm in the interior cavity

3 Type 3: Same basic segment, with a relatively fat solid diaphragm in the interior cavity

4 Type 4: Same basic segment, with a partial diaphragm in the interior cavity

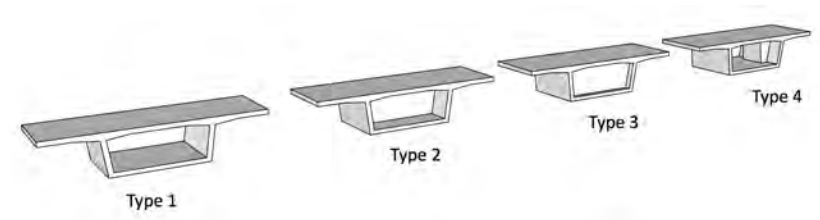


Figure 36.2: Segments provided for this exercise

Each segment model has been made into a component ▷ .

See Section 16.2 and the article Creating a Basic Component *in the SketchUp Help Centre.*

36.1.2 *Arrangement of Segments*

The segment models in the given SketchUp file need to be arranged into a 2 by 2 by 2 three-dimensional arrangement in SketchUp. The arrangement is described in Figure 36.3. Each segment in the arrangement is assigned a letter according to its position.

The type of segment (as defined in the previous section) to be placed at each position is given in Table 36.1.

The spacing between segments shall be in accordance with the dimensions given in Figure 36.3.

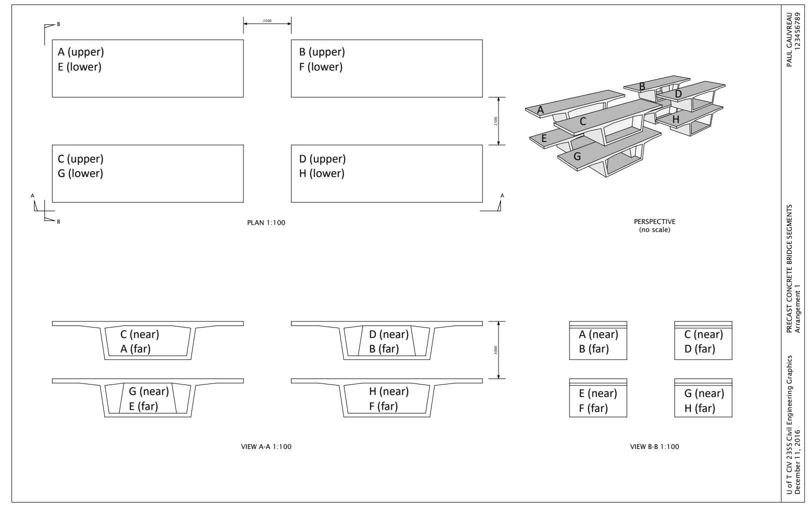


Figure 36.3: Arrangement of segments

Table 36.1: Types of Segment at a Given Position

Position	A	B	C	D	E	F	G	H
Type	3	4	2	1	1	2	4	1

36.1.3 *Drawings in LayOut*

A single LayOut file with four pages needs to be created ▷ . This file must be identical to the completed exercise, which can be downloaded at the link provided ▷ . Each page will have a similar drawing, which will consist of three orthographic views of the eight-segment arrangement (Plan, View A-A, and View B-B), and a perspective view of the eight segments.

See the article `Managing and Navigating Pages` *in the LayOut Help Centre.*

`Click this text to download the completed exercise.`

For a given drawing, each of the four views will correspond to four scenes in SketchUp. These scenes will be determined by the following properties in SketchUp:

1. The presence and position of active section planes. Note that in some of the drawings, there is more than one active section plane. This means that at least one of these planes must be defined in relation to a component rather than globally.

2. Instances of components. It is possible to have two objects that are effectively identical, yet have different behaviour because they are two separate components. Recall that when a section plane is applied to one component, all instances of that component will be cut.

3. Visibility of objects. Objects can be assigned to layers ▷ and these layers can be made visible or hidden.

See the article `Controlling Visibility with Layers` *in the SketchUp Help Centre.*

The arrangement of segments described previously ▷ is the same for all four drawings to be created. Once the segments have been correctly arranged, they do not have to be moved.

See Section 36.1.2.

The first drawing (i.e., Page 1 in LayOut) will be the basic arrangement of segments with no section planes and all segments visible. The remaining three drawings will require an appropriate setting of section planes, component instances, assignment of components to layers, and visibility of layers. These settings must be determined by you.

36.2 Background

Students are expected to be familiar with the following material:

1. Chapters 1, 2, and 4.

2. Section 6.1.

3. Chapters 7, 9, 16, and 54.

4. Applicable sections of the course Drafting Standards (Appendix A).

5. All of the SketchUp and LayOut techniques covered in previous classes.

36.3 Preparation

Before class, students shall prepare as follows:

1 Understand and be capable of applying the principles related to the following features in SketchUp and LayOut:

(a) Sections ▷

See Section 16.6 and the article Slicing a Model to Peer Inside *in the SketchUp Help Centre.*

(b) Components ▷

See Section 16.2 and the article Creating a Basic Component *in the SketchUp Help Centre.*

(c) Groups ▷

See Section 16.2 and the article Grouping Geometry *in the SketchUp Help Centre.*

(d) Layers ▷

See Section 16.3 and the article Controlling Visibility with Layers *in the SketchUp Help Centre.*

(e) Multiple-page documents in LayOut ▷

See the article Managing and Navigating Pages *in the LayOut Help Centre.*

2 Complete the exercise before class.

36.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The SketchUp file with the three-dimensional models of the segments to be drawn, identical to the file available at this link ▷ .

Click this text to download the SketchUp file with the three-dimensional models of the segments.

3 The course LayOut template, identical to the file available at this link ▷ .

Click this text to download the course LayOut template.

36.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The drawings to be produced in this exercise shall essentially identical to the drawings given in the completed exercise, available for download at the link provided ▷ . The purpose of this drawing is purely pedagogical. It does not have a direct link to a drawing that would be encountered in engineering practice.

Click this text to download the completed exercise.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing all of the information required to produce the four drawings in LayOut, including section planes, layers, and instances of components.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the required drawings.*

Proceed as follows:

(a) Arrange the segments into the required 2 by 2 by 2 arrangement ▷ .

See Section 36.1.2.

(b) Define any instances of components that might be required.

(c) Define any layers that might be required.

(d) For a given drawing, proceed as follows:

i. Make layers hidden or visible as required.

ii. Insert section planes and make them active as required.

iii. Create four scenes, each corresponding to one of the required views in the LayOut drawing. Proceed according to the steps given previously for SketchUp Class 1 ▷ .

See Step 7 in Section 30.5.

iv. Save your work in SketchUp.

v. Import the SketchUp file into LayOut, create the views, and add annotations. Proceed according to the steps given previously for SketchUp Class 1 ▷ . You will need to create a separate page in LayOut for each drawing ▷ .

See Steps 9 through 12 in Section 30.5.

See the article `Managing and Navigating Pages` *in the LayOut Help Centre.*

6 *Create a pdf of the drawings you created in LayOut* ▷ .

See the article `Exporting or Printing Your LayOut Document` *in the LayOut Help Centre.*

Store the pdf file on the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

36.6 Completed Drawing

The drawing to be produced in this exerciseis available for download at the link provided ▷ .

Click this text to download the completed exercise.

37
SketchUp Class 8

This class will take place on the date indicated in Table 2.2 for "SketchUp 8" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

37.1 Brief Description of Exercise

The objectives of this exercise are as follows:

1. Apply knowledge of contour mapping ▷ in creating a contour map of a landform from elevation data

See Chapter 10.

2. Acquire proficiency in the use of SketchUp's sandbox tools in creating a three-dimensional model of a landform
3. Acquire proficiency in creating contours from a three-dimensional landform
4. Acquire proficiency in advanced techniques for working with sections in SketchUp, including making a group from the section cut
5. Gain further proficiency in working with increased proficiency in working with scenes, sections, components, groups, and layers in SketchUp.

37.1.1 Information Provided

The drawing shown in Figure 37.1 is provided ▷ . It consists of a grid representing a horizontal plane. Each intersection point of two perpendicular grid lines has a number, which represents the elevation of that point above sea level. These elevations correspond to measured elevations of an existing parcel of terrain.

The drawing also defines the location of three section planes.

`Click this text to download the drawing shown in Figure 37.1.`

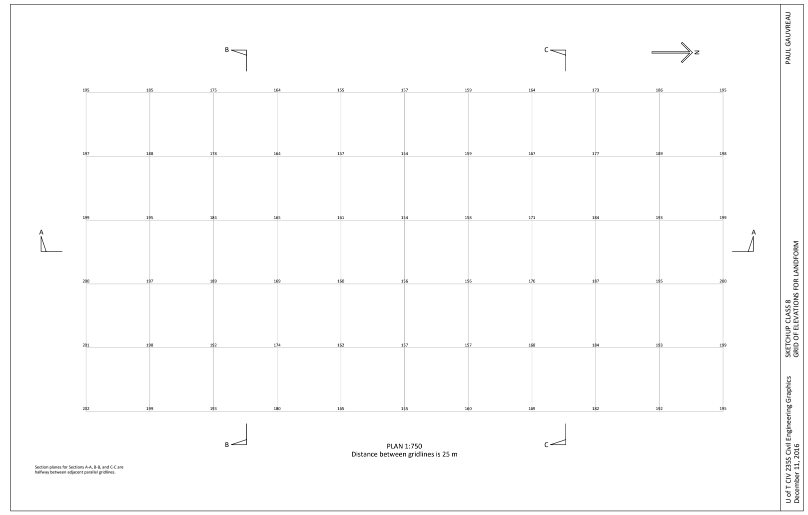


Figure 37.1: SketchUp Class 8: Grid of terrain elevations and location of sections

37.1.2 What to Draw

The drawing to be produced in this exercise is shown in Figure 37.2 and is available for download at the link provided ▷ . The drawing contains the following views: (1) a contour map of the landform obtained from the grid of elevations given in Figure 37.1, (2) three sections cut from the landform at the locations specified in Figure 37.1, and (3) a perspective view of the landform.

The arrangement and scale of views, as well as the annotations provided shall be as shown on this drawing.

`Click this text to download the completed drawing.`

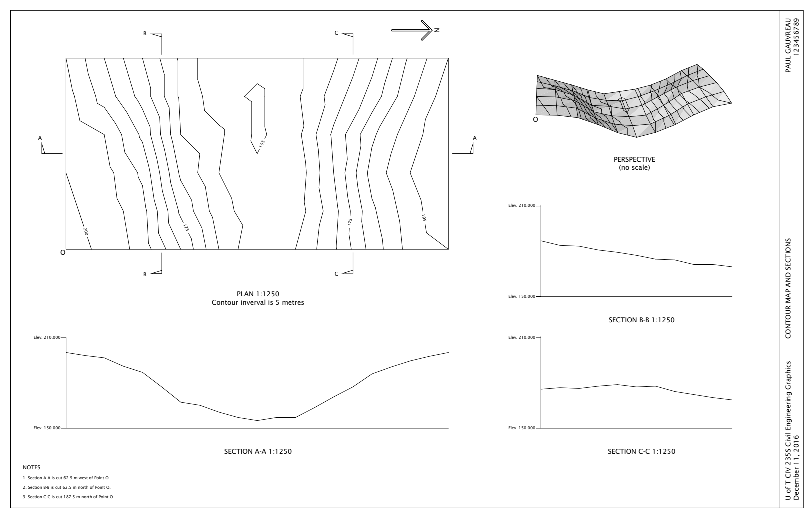


Figure 37.2: SketchUp Class 8: Completed drawing

37.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, and 16.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes.

37.3 Preparation

Before class, students shall prepare as follows:

1 Read Chapter 10.

2 Understand and be capable of applying the principles related to the following features in SketchUp and LayOut:

(a) Sections ▷

See Section 16.6 and the article `Slicing a Model to Peer Inside` *in the SketchUp Help Centre.*

(b) Groups ▷

See Section 16.2 and the article `Grouping Geometry` *in the SketchUp Help Centre.*

(c) The Outliner, a tool for keeping track of groups in a given model ▷

See the article `Working with Hierarchies in the Outliner` *in the SketchUp Help Centre.*

(d) Layers ▷

See Section 16.3 and the article `Controlling Visibility with Layers` *in the SketchUp Help Centre.*

(e) Sandbox tools and creating three-dimensional landforms ▷

See the article `Creating Terrain from Scratch` *in the SketchUp Help Centre.*

3 Complete the exercise before class.

37.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise.

In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course SketchUp template, identical to the file available at this link ▷ .

`Click this text to download the course SketchUp template.`

3 The course LayOut template, identical to the file available at this link ▷ .

`Click this text to download the course LayOut template.`

4 The drawing with the given grid of elevations and location of section planes, identical to the file available at this link ▷ .

`Click this text to download the drawing with the grid of elevations and location of section planes.`

37.5 Recommended Workflow

Steps 1 through 4 of this workflow correspond to the first four steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ . Steps 5 through 19 correspond to the fifth step in the general process ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4.

See Section 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced in this exercise is to represent the three-dimensional characteristics of a parcel of terrain in several different ways: contour map, cross-sections, and a perspective view.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

Most of the information pertaining to the object to be drawn has already been organized in a way that will enable the drawing to be produced efficiently.

See Section 6.1.3.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

This is not a difficult drawing to produce, but doing so efficiently will require good proficiency in the aspects of SketchUp listed previously ▷ . It is therefore important that the steps required to complete the drawing be planned carefully and that this procedure be verified by working through the drawing before class.

See Section 37.3.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

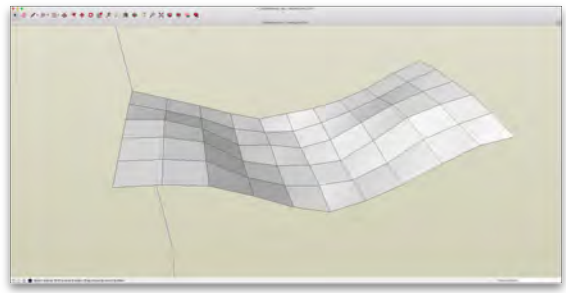


Figure 37.3: The landform

5 *Set up the LayOut file.*

Download and open the course LayOut template and enter the required changes to the title block.

6 *Set up the SketchUp file.*

Download and open the course SketchUp template. Delete the precast concrete bridge segment model. It will not be required.

The template has been set up with millimetres as units. It will probably be easier to do this exercise in metres, so change the units before going further ▷

See the section entitled "Specifying Units of Measurement" in the article `Measuring Angles and Distances to Model Precisely` *in the SketchUp Help Centre.*

7 *Create a* sandbox *from which the landform will be created.*

Using the sandbox tool ▷ , set the grid spacing to 25 m and draw a sandbox grid 250 m long along the red axis and 125 m long along the green axis.

See the section entitled "Creating a flat rectangular TIN" in the article `Creating Terrain from Scratch` *in the SketchUp Help Centre.*

8 *Transform the sandbox you just created into the landform.*

The sandbox created in the previous step is a group and thus must be double-clicked to open it temporarily for editing ▷ .

See the article `Grouping Geometry` *in the SketchUp Help Centre.*

For each point of intersection of a pair of gridlines, use the move tool ▷ to move it up to its required elevation as defined by the numbers given in the drawing of Figure 37.1. Make sure this displacement is always parallel to the blue (vertical) axis. The landform thus created is shown in Figure 37.3.

See the article Moving Entities Around *in the SketchUp Help Centre.*

9 *Assign the landform to its own layer.*

Create a new layer and call it "Landform". Assign the landform you just created to this layer ▷

See Section 16.3 and the article Controlling Visibility with Layers *in the SketchUp Help Centre.*

10 *Rename the landform group.*

This is just for convenience. Open the Outliner and re-name the landform group (which will appear in the Outliner as simply "Group" to "Landform") ▷ .

See the article Working with Hierarchies in the Outliner *in the SketchUp Help Centre.*

11 *Create the cutting planes that will produce the contours.*

For convenience, make the `Landform` layer invisible.

Draw a rectangle 250 m by 125 m in the horizontal plane directly below the landform. Copy it to produce a stack of rectangles one above each other, separated from its neighbours by a distance of 5 m (this is the required contour interval).

Transform these rectangles into a group.

Move the group into position to cut the landform. The lowest rectangle should be at Elevation 150, i.e, just below the landform. The highest rectangle should be clear of the landform.

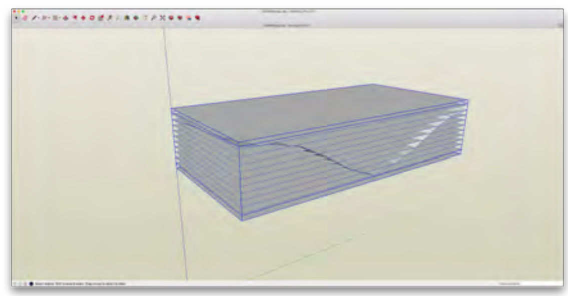


Figure 37.4: The landform with the cutting planes just before the contours are created

12 *Create the contours.*

Make the layer `Landform` visible. Single-click both groups to make them both active (but not open for editing: do not double-click the groups). This is the situation shown in Figure 37.4. Right-click in the activated portion and select `Intersect Faces` → `With Model`. This will create drawing elements at the intersection of the two groups. By definition, these elements are the contours.

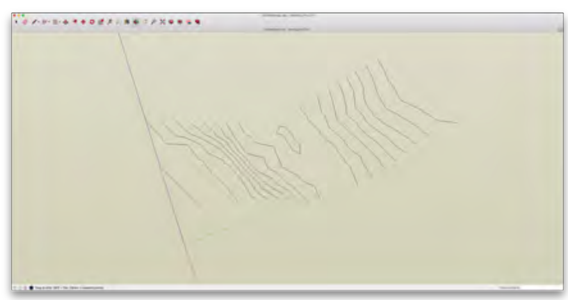


Figure 37.5: The contours (vertically offset)

Delete the group with the rectangles. It will not be required again.

Hide the layer `Landform`. You should see the contours (Fig. 37.5). They are vertically offset (i.e., not in a single horizontal plane), but this will not pose a problem. Select these contours and make them into a group. Change its name from "Group" to "Contours" in the outliner. Create a layer called "Contours" and assign the contour group to this layer.

13 *Create a frame.*

The completed drawing (Fig. 37.2) requires a rectangle around the contour map and is necessary to draw a frame around the contour map as well as a vertical elevation scale and horizontal baseline for the three sections. By drawing a suitable frame around the landform, these will be drawn automatically when we create the scenes. Proceed by drawing a horizontal rectangle below the landform, 250 m by 125 m, and two vertical rectangles as shown in Figure 37.6. Assign these rectangles to a new layer called "Rectangles".

Activate the guides and place three guide lines in the three section planes. This will ensure that the sections are cut precisely. These guides are also shown in Figure 37.6.

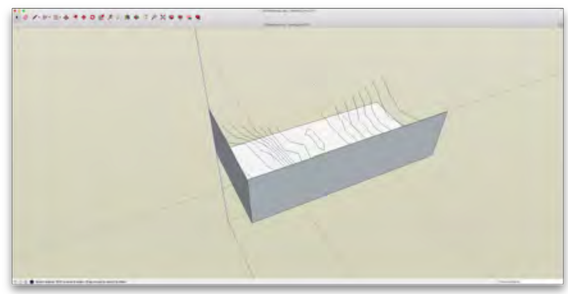


Figure 37.6: The frame and the guides, which will make producing the views easier. For clarity, the `Landform` layer has been hidden

14 *Cut Section A-A.*

Hide the `Contours` layer and make the `Landform` and `Rectangles` layers visible.

Cut the section at the required location using the section tool.

Right-click the section plane and select `Create Group from Slice`. In the Outliner, you will see two groups at the same level in the hierarchy, one called `Landform` and the other called simply `Group`. Change the name of `Group` to "Section A-A".

In the `View` menu, un-check `Section Planes` and `Section Cuts`. The full landform and rectangles re-appear.

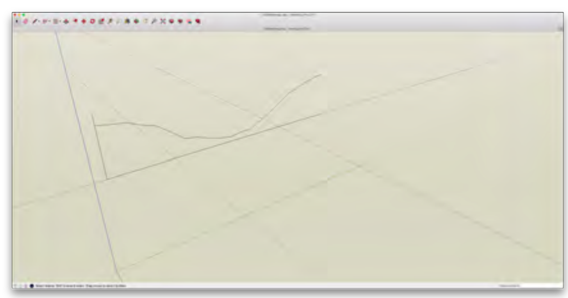


Figure 37.7: Section A-A

Activate the new `Section A-A` group by clicking its name in the Outliner. Hide the layers `Landform` and `Rectangles`. Create a new layer called "Section A-A" and assign the group `Section A-A` to this layer. The section, with all other layers hidden, is shown in Figure 37.7. Note the rectangles have provided the required vertical and horizontal datum lines. Hide the layer `Section A-A` for now.

Note that by defining a new group with the section, we can display the section independent from the portion of the landform beyond the section plane. This makes for a simpler and clearer depiction of the section, since the portion of the landform beyond the section plane is not relevant in this case.

15 *Cut Sections B-B and C-C.*

Follow the procedure defined for Section A-A in Step 14. Make sure each section has its own group and layer.

16 *Create scenes for the required views.*

The required views are: the contour map (plan), Section A-A, Section B-B, Section C-C, and the perspective view.

The procedure is essentially the same as the one used in previous exercises ▷ , except that special attention needs to be paid to which layers must be visible and which must be hidden. Proceed as follows:

See Point 7 in Section 30.5.

(a) Check the boxes in the `Layers` window to make the layers required for the scene visible.

(b) Select the projection (parallel or perspective)

(c) Orient the direction of view or select a standard view

(d) Select a style

(e) Define and save the scene

17 *Save the SketchUp file.*

18 *Import the SketchUp file into LayOut.*

19 *Create the required views in LayOut.*

The procedure is similar to that followed in previous exercises.

Pay special attention to the annotations provided in the completed drawing (Fig. 37.2), all of which will need to be provided in your drawing.

20 *Create a pdf of the drawings you created in LayOut* ▷ .

See the article `Exporting or Printing Your LayOut Document` *in the LayOut Help Centre.*

Store the pdf file on the `W:\` directory ▷ .

See Section 4.2.2.

21 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

22 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

23 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

37.6 Completed Drawing

The drawing to be produced in this exercise is available for download at the link provided ▷ .

`Click this text to download the completed exercise.`

38
SketchUp Class 9

This class will take place on the date indicated in Table 2.2 for "SketchUp 9" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

38.1 Brief Description of Exercise

This exercise involves drawing a landform from coordinates and then, into this landform, incorporating a highway with a given profile grade line. Cuts and fills will be required and must be shown in the plan and also in sections cut at given locations. The completed drawing is shown in Figure 38.1.

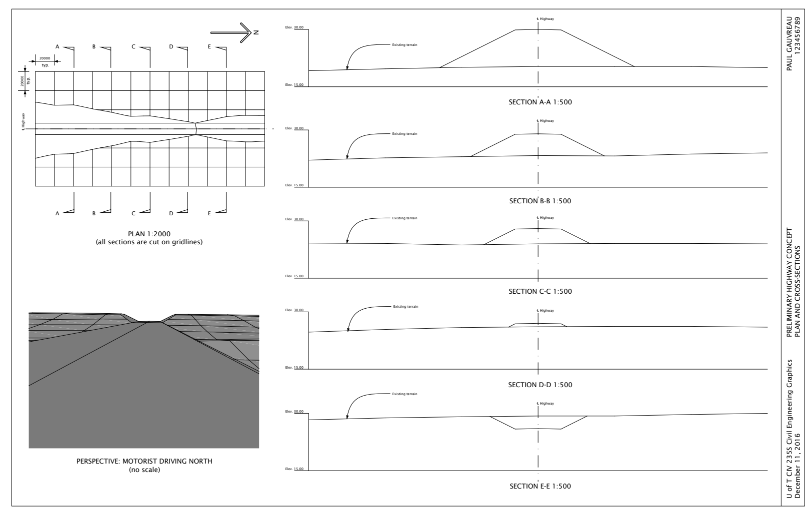


Figure 38.1: SketchUp Class 9: Completed drawing

38.1.1 Objectives of the Exercise

The objectives of this exercise are as follows:

1 Apply knowledge of earthworks in drawing cuts and fills for a given landform, profile grade line, and typical sections ▷ .

See Chapter 56.

2 Gain further proficiency in the use of SketchUp's sandbox tools in creating a three-dimensional model of a landform

3 Gain further proficiency in advanced techniques for working with sections in SketchUp, including making a group from the section cut

4 Gain further proficiency in working with increased proficiency in working with scenes, sections, components, groups, and layers in SketchUp.

38.1.2 Information Provided

The following information is provided:

1 The geometry of the landform into which the highway will be constructed. The geometry is described in terms of elevation of existing terrain above sea level at points in a regular grid. This information is provided on the drawing shown in Figure 38.2, which is available for download at the link provided ▷ .

2 The profile grade line is a straight line. Its projection onto a horizontal plane is coincident with the north-south gridline that is at the middle of the plan shown in Figure 38.2. At the southern edge of the plan, its elevation is 31.0 m. At the northern edge of the plan, its elevation is 25.0 m.

3 Typical sections in cut and on fill are given in Figures 38.3 and 38.4.

38.1.3 What to Draw

The drawing to be produced in this exercise is shown in Figure 38.1, which is available for download at the link provided ▷ . The drawing contains the following views: (1) a plan of the highway in the landform showing cuts and fills, (2) five sections cut perpendicular

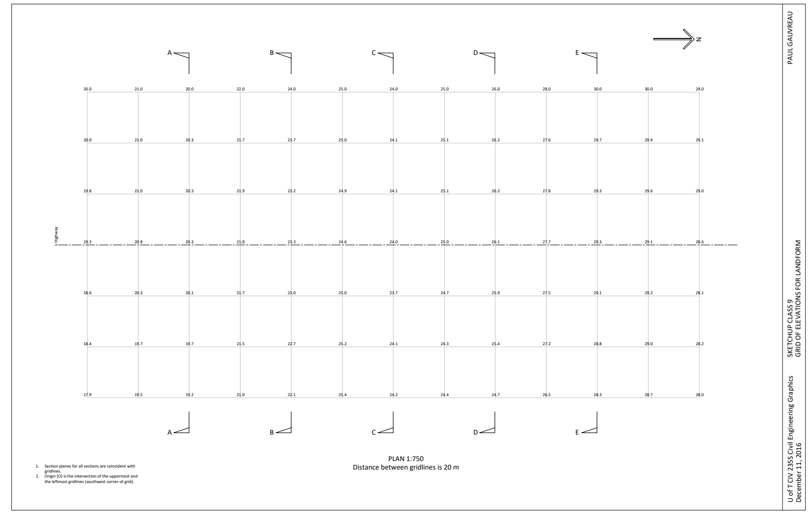


Figure 38.2: Grid of terrain elevations and location of sections

Click this text to download the drawing shown in Figure 38.2.

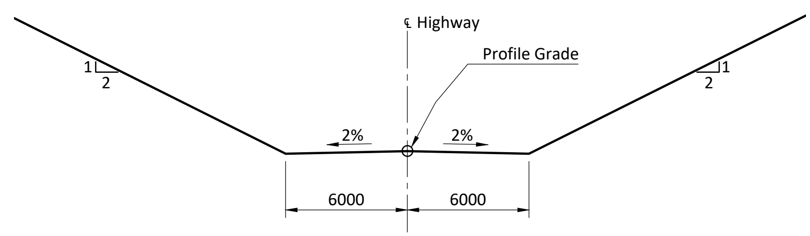


Figure 38.3: Typical section in cut

Click this text to download the completed drawing.

to the axis of the highway showing existing terrain and cuts or fills, and (3) a perspective of the completed highway from the viewpoint of a motorist driving north.

The arrangement and scale of views, as well as the annotations provided shall be as shown on this drawing.

The locations of the sections to be drawn shall be as specified on the drawing shown in Figure 38.2.

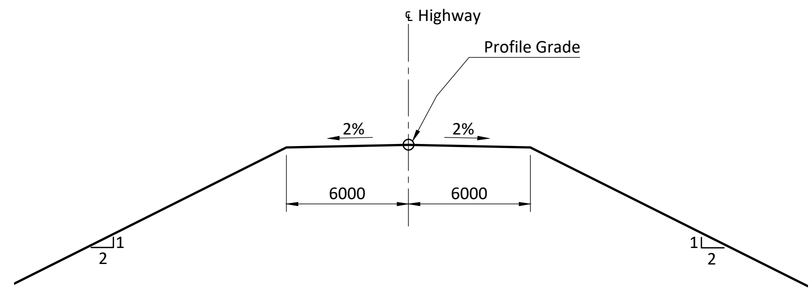


Figure 38.4: Typical section on fill

38.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, and 16.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes, with special emphasis on:

(a) Sections ▷

See Section 16.6 and the article `Slicing a Model to Peer Inside` *in the SketchUp Help Centre.*

(b) Groups ▷

See Section 16.2 and the article `Grouping Geometry` *in the SketchUp Help Centre.*

(c) The Outliner, a tool for keeping track of groups in a given model ▷

See the article `Working with Hierarchies in the Outliner` *in the SketchUp Help Centre.*

(d) Layers ▷

See Section 16.3 and the article `Controlling Visibility with Layers` *in the SketchUp Help Centre.*

(e) Sandbox tools and creating three-dimensional landforms ▷

See the article `Creating Terrain from Scratch` *in the SketchUp Help Centre.*

38.3 Preparation

Before class, students shall prepare as follows:

1 Read Chapter 56.

2 Complete the exercise before class.

38.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course SketchUp template, identical to the file available at this link ▷ .

`Click this text to download the course SketchUp template.`

3 The course LayOut template, identical to the file available at this link ▷ .

`Click this text to download the course LayOut template.`

4 The drawing with the given grid of elevations and location of section planes, identical to the file available at this link ▷ .

`Click this text to download the drawing with the grid of elevations and location of section planes.`

38.5 Recommended Workflow

Steps 1 through 4 of this workflow correspond to the first four steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ . Steps 5 through 20 correspond to the fifth step in the general process ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4.

See Section 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced in this exercise is to describe the cuts and fills required for a stretch of highway over a given alignment.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

Most of the information pertaining to the object to be drawn has already been organized in a way that will enable the drawing to be produced efficiently.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

This is not a difficult drawing to produce, but doing so efficiently will require good proficiency in the aspects of SketchUp listed previously ▷ . It is therefore important that the steps required to complete the drawing be planned carefully and that this procedure be verified by working through the drawing before class.

See Section 38.3.

It is expected that planning will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Set up the LayOut file.*

Download and open the course LayOut template and enter the required changes to the title block.

6 *Set up the SketchUp file.*

Download and open the course SketchUp template. Delete the precast concrete bridge segment model. It will not be required.

The template has been set up with millimetres as units. It will probably be easier to do this exercise in metres, so change the units before going further ▷

See the section entitled "Specifying Units of Measurement" in the article `Measuring Angles and Distances to Model Precisely` *in the SketchUp Help Centre.*

7 *Create a* sandbox *and transform it into the landform.*

Use a similar procedure to the one described for SketchUp Class 8 ▷ . Make sure the geometry of the sandbox is consistent with the drawing of Figure 38.2.

See Points 7 and 8 in Section 37.5.

Do not create a layer for this landform as was done in SketchUp Class 8.

The completed landform is shown in Figure 38.5.

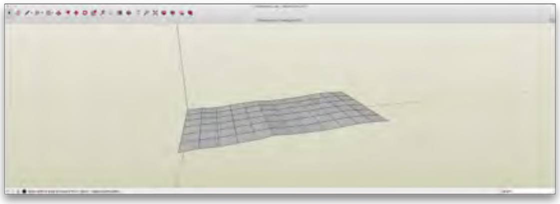


Figure 38.5: The completed landform

8 *Draw in the profile grade line at the proper location.*

The profile grade line and the landform are shown in Figure 38.6.

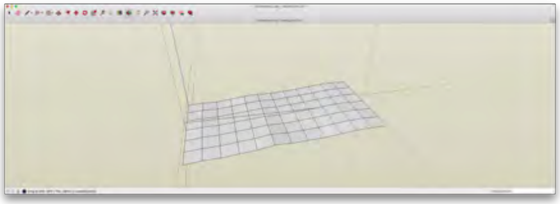


Figure 38.6: Profile grade line has been drawn in at the correct location

9 *At one end of the profile grade line, draw the cross-section of the highway and the fill and cut slopes.*

This situation is illustrated in Figure 38.7. (The landform has been hidden for clarity.) Drawing both the fill and the cut slopes in the same cross-section has been done for convenience.

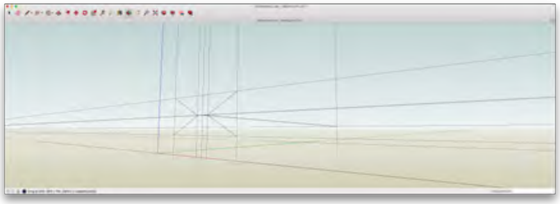


Figure 38.7: Highway cross-section with fill and cut slopes

10 *Copy this cross-section to the other end of the profile grade line and connect the corresponding points.*

This situation is shown in Figure 38.8. The object thus created consists of the highway proper and a "cutting pattern" that will intersect with the landform.

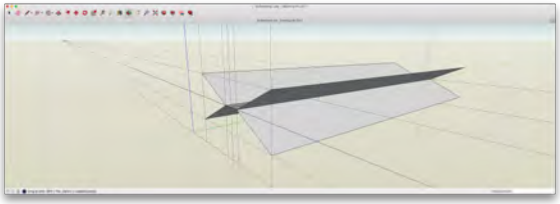


Figure 38.8: "Cutting pattern" completed

11 *Create the edges at the intersection of the cutting pattern and the landform.*

Make the landform visible. Explode it so that it is no longer a group. Select both the landform and the cutting pattern. Right-click anywhere, and then select `Intersect Faces` → `With Model`. This will create edges at the intersection of the landform and the cuting pattern.

12 *Remove the extraneous portions of the cutting pattern.*

Simply use the eraser tool to remove all portions of the cutting pattern that stick out above and below the landform. The result should look like Figures 38.9 and 38.10.

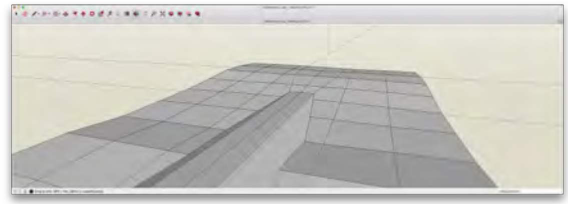


Figure 38.9: Extraneous portions of cutting pattern removed. View from above.

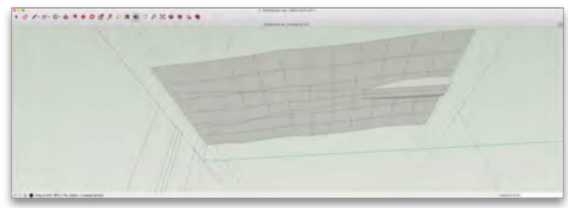


Figure 38.10: Extraneous portions of cutting pattern removed. View from below.

13 *Make a group consisting of the surface of the landform where cuts will be provided.*

We need to make such a group so that it can be made visible or hidden as required for creating views. For the plan view, we want this surface to be hidden. This will show the cut as designed. For the cross-sections, we want this surface to be visible, since we want to convey with these sections how much material needs to be removed to construct the cut.

You will need to select all of the areas bounded by former gridlines, and the former gridlines themselves. Then right-click and select `Make Group`.

Create a layer for this group. Call the layer, say, "Top of cut" and assign the group to the layer.

14 *Make a group for the remainder of the highway, cuts, fills, and landform.*

Hide the `Top of cut` layer. Select everything else that remains, and make it into a group. Create a layer for this group. Call the layer, say, "Landform and highway" and assign the group to the layer.

15 *Create a frame for the sections to be cut.*

The procedure to follow is similar to the one used in SketchUp Class 8 ▷ .

See Point 13 of Section 37.5.

16 *Cut Sections A-A through E-E.*

The procedure to follow is similar to the one used in SketchUp Class 8 ▷ . Make sure each section has its own group and layer.

See Point 14 of Section 37.5.

17 *Create scenes for the required views.*

The procedure is essentially the same as the one used in previous exercises ▷, except that special attention needs to be paid to which layers must be visible and which must be hidden. Proceed as follows:

See Point 7 in Section 30.5.

(a) Check the boxes in the `Layers` window to make the layers required for the scene visible.

(b) Select the projection (parallel or perspective)

(c) Orient the direction of view or select a standard view

(d) Select a style

(e) Define and save the scene

18 *Save the SketchUp file.*

19 *Import the SketchUp file into LayOut.*

20 *Create the required views in LayOut.*

The procedure is similar to that followed in previous exercises.

Pay special attention to the annotations provided in the completed drawing (Fig. 38.1), all of which will need to be provided in your drawing.

21 *Create a pdf of the drawings you created in LayOut* ▷.

See the article `Exporting or Printing Your LayOut Document` *in the LayOut Help Centre.*

Store the pdf file on the `W:\` directory ▷.

See Section 4.2.2.

22 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

23 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

24 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

38.6 Completed Drawing

The drawing to be produced in this exercise is available for download at the link provided ▷ .

Click this text to download the completed exercise.

39
SketchUp Class 10

This class will take place on the date indicated in Table 2.2 for "SketchUp 10" ▷ .

See Section 2.4.

The class will consist of one Special Exercise ▷ .

See Section 2.6.2.

39.1 *Brief Description of Exercise*

This exercise involves drawing a bridge pier, in sufficient detail to provide a complete description of the geometry of formwork required to construct the foundation and pier proper. The pier to be drawn is practically identical to the ones shown in Figure 39.1.

Figure 39.1: Photograph of the pier to be drawn

39.1.1 *Objectives of the Exercise*

The objectives of this exercise are as follows:

1 Plan a drawing in LayOut to provide a complete description of the geometry of a given object, in full accordance with the course drafting standards ▷ . (A completed drawing will not be provided before the exercise.)

See Appendix A.

2. Apply knowledge of all the tools of SketchUp learned thus far, including the use of SketchUp tools for drawing some features not yet drawn in the course.
3. Plan a SketchUp model with groups and layers to facilitate the creation of scenes and views.
4. Create a drawing in LayOut that projects a high level of professionalism.

39.1.2 Information Provided

A sketch of the pier, shown in Figure 39.2, is provided. It consists of the pier proper, two bearings on top, and a footing (foundation). All of the necessary geometric information is provided in this sketch, although the information has not been provided in a format that is in accordance with the course drafting standard.

The sketch of Figure 39.2 is available for download at the link provided ▷ .

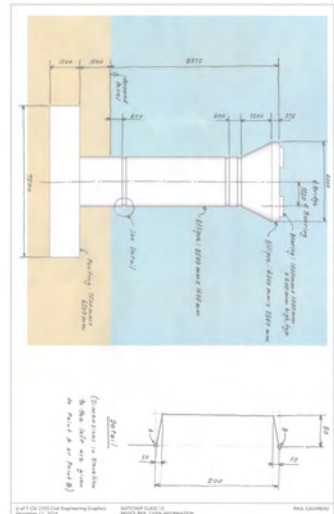


Figure 39.2: Sketch showing basic geometry of the pier to be drawn

Click this text to download the drawing shown in Figure 39.2.

39.1.3 What to Draw

The drawing to be produced in this exercise shall be created on the course LayOut template. It shall consist of orthographic views and shall give a complete geometric description of the pier, including bearings, pier proper, and footing. The choice of views shall ensure that the description of the object is complete, clear, and reasonably concise.

Although it is not required to convey geometric information, include a perspective view of the SketchUp model in the LayOut drawing, as was done in several of the previous exercises.

39.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, and 16.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes.

39.3 Preparation

Success in this exercise depends to a large extent on conscientious preparation. The object to be drawn is not particularly complex, but it does contain some features for which the best method of drawing is not immediately obvious.

It is therefore highly recommended that students complete this exercise before class and come to class with the following knowledge and information:

1 Effective procedures for drawing features such as the three recesses along the height of the pier and the flare at the top of the pier.

2 An effective structure of layers and groups to ensure that views do not show extraneous information.

3 A suitable choice and arrangement of views, dimensions, and annotations for the LayOut drawing.

4 An efficient overall workflow for completing the work on time and with sufficient quality.

39.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course SketchUp template, identical to the file available at this link ▷ .

`Click this text to download the course SketchUp template.`

3 The course LayOut template, identical to the file available at this link ▷ .

`Click this text to download the course LayOut template.`

4 The drawing with the given geometric information, identical to the file available at this link ▷ .

`Click this text to download the given geometric information.`

39.5 Recommended Workflow

A recommended workflow is not provided for this exercise. It is recommended that students prepare a workflow before class based on the workflows of previous exercises. The workflow should then be followed during class.

39.6 Completed Drawing

A completed drawing will not be provided before class.

39.7 Marking

Since this exercise is a Special Exercise ▷, it will be marked in detail.

See Section 2.6.2.

The exercise will be marked according to the marking guide given in Table 41.1. Each item in the marking guide will be assigned an assessment of "√" (no problems), "O" (small problems), or "X" (big problems).

On the basis of this assessment, a mark out of 10 will be assigned according to the following criteria:
All "√": 9 to 10
Mostly "√", a few "O": 8
A significant number of "O" and/or a maximum of one "X": 7
Two "X": 6
More than two "X": 0 to 5

A major point of this exercise is to produce drawings that project a high standard of quality and professionalism. Drawings that present the information correctly but which otherwise contain elements that demonstrate a lack of professionalism are unlikely to receive a mark greater than 7 out of 10. Professionalism is in the details. These details will be given serious consideration in marking.

Table 39.1: Marking Guide for SketchUp Class 10

Item no.	Item	Assessment
1	Drawing projects a high standard of quality and professionalism	
2	Instructions were followed correctly	
3	Drawing provides a complete description of the geometry	
4	Information is presented clearly	
5	Choice of views is logical	
6	Arrangement of views is logical	
7	Views are accurate	
8	Dimensions are complete	
9	Dimensions are in accordance with course drafting standard	
10	Annotations are in accordance with course drafting standard	

40
SketchUp Class 11

This class will take place on the date indicated in Table 2.2 for "SketchUp 11" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

40.1 Brief Description of Exercise

This exercise involves drawing a three-dimensional rendering of a bridge in a landscape. All that is required are three-dimensional views of the bridge. No orthographic views are required.

40.1.1 Objectives of the Exercise

The primary objective of this exercise is to acquire proficiency in creating a three-dimensional rendering of a work of engineering. This is a skill that will be useful in the conceptual design stage of many disciplines of civil engineering, in particular in structural engineering. In addition, this exercise will provide an opportunity to apply knowledge and skills learned thus far in the course, including:

1 Reading of simple engineering drawings.

2 Understanding the basic geometric features of the single-cell box girder bridge ▷ .

See Chapter 54.

3 Working with complex three-dimensional tools in SketchUp.

40.1.2 Information Provided

The following information is provided:

1 A drawing of the bridge to be modeled in three dimensions. This drawing is shown in Figure 40.1, and is available for download at the link provided ▷ .

Click this text to download the drawing shown in Figure 40.1.

The curved underside of the bridge girder can be drawn as a circular arc. It must be tangent to the straight portion of the underside of the girder near the ends of the bridge.

2 A SketchUp model of the landform into which the model of the bridge must be inserted. A view of this landform is given in Figure 40.2. The SketchUp file is available for download at the link provided ▷ .

Click this text to download the SketchUp file containing the landform shown in Figure 40.2.

This file contains a single group consisting of the landform, a guideline that corresponds to the Profile Grade Line referenced in the drawing of Figure 40.1, and a guide point corresponding to midspan of the longest span. This provides enough information to relate the geometry shown in Figure 40.1 to the landform.

The brown coloured portion of the landform is obviously dry land. The blue portion is the river to be crossed by the bridge. There are also two man-made features consisting of fills and structural components called *abutments*. Abutments function as the supports for the ends of the bridge.

3 The sketch of Figure 40.3, which shows that a clear gap of 500 mm shall be provided between the end of the bridge and the face of the abutment.

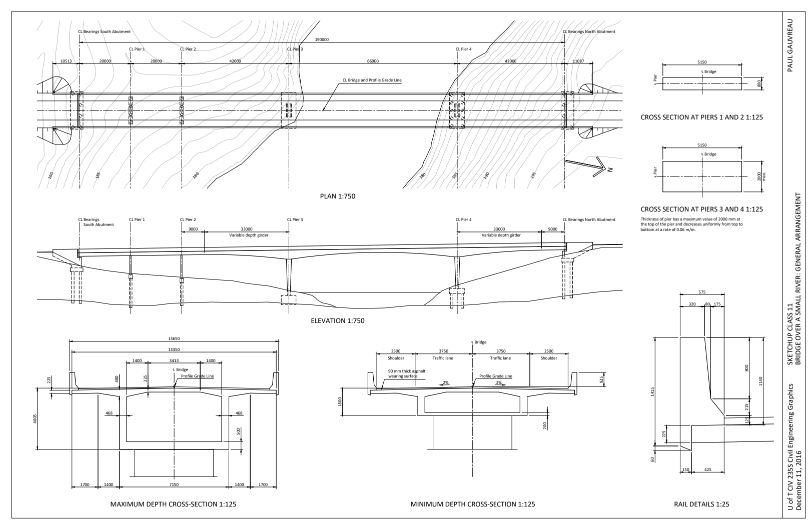


Figure 40.1: General Arrangement drawing of the bridge to be drawn

40.1.3 What to Draw

A LayOut drawing made with the course LayOut template shall be created. It shall contain at least three perspective views of the three-dimensional model of the bridge in the landform. The views shall be carefully chosen to show the primary features of the bridge from a variety of viewpoints, and to create an impression of professionalism.

The sole purpose of this drawing is to represent the visible features of the bridge, including the concrete rails. There will be no sections cut, nor will there be any orthographic views. None of the invisible features of the bridge shown in Figure 40.1 need therefore be modeled. It is therefore not necessary to draw the interior of the box girder, nor is it necessary to draw the foundations. We will never look inside the box nor under the surface of the earth with this SketchUp model.

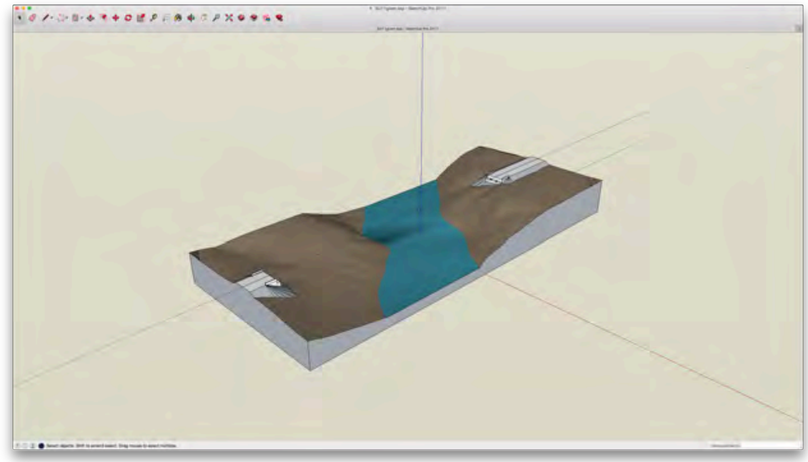


Figure 40.2: The given landform into which the bridge must be drawn

40.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, 16, and 54.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes.

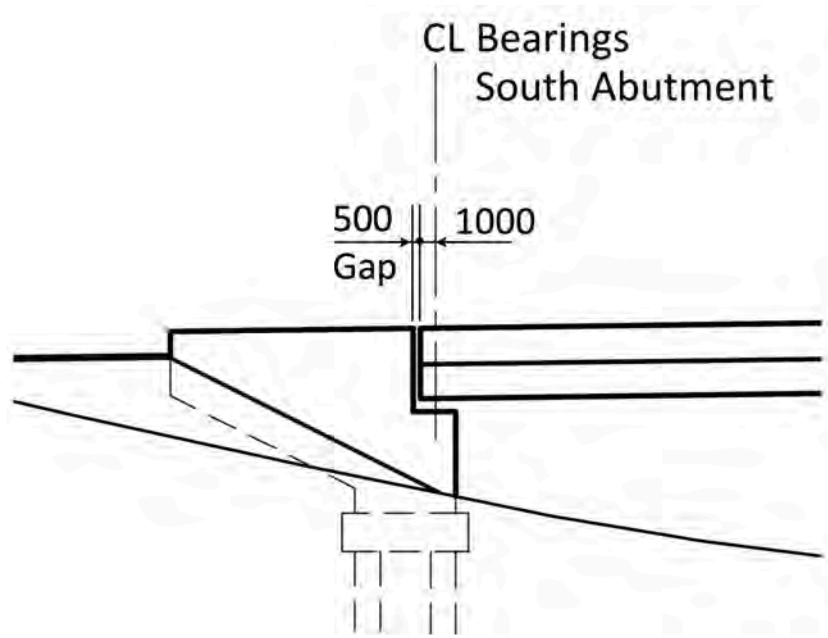


Figure 40.3: SketchUp Class 11: Given landform

40.3 Preparation

Success in this exercise depends to a large extent on conscientious preparation. The object to be drawn is not particularly complex, but it does contain some features for which the best method of drawing is not immediately obvious.

It is therefore highly recommended that students complete this exercise before class and come to class with an efficient overall workflow for completing the work on time and with sufficient quality.

Students who are well prepared should have no trouble in completing this drawing well ahead of the end of the class period. This is not a question of executing SketchUp commands quickly, but rather a question of choosing a sequence of operations that simplifies the work and saves time.

40.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The SketchUp file with the landform shown in Figure 40.2, identical to the file available at this link ▷ .

`Click this text to download the SketchUp file containing the landform shown in Figure 40.2.`

3 The course LayOut template, identical to the file available at this link ▷ .

`Click this text to download the course LayOut template.`

4 The General Arrangement drawing of the bridge, shown in Figure 40.1, identical to the file available at this link ▷ .

`Click this text to download the General Arrangement drawing of the bridge.`

40.5 Recommended Workflow

A recommended workflow is not provided for this exercise. It is recommended that students prepare a workflow before class based on the workflows of previous exercises. The workflow should then be followed during class.

40.6 Completed Drawing

A completed drawing will not be provided before class.

41
SketchUp Class 12

This class will take place on the date indicated in Table 2.2 for "SketchUp 12" ▷ .

See Section 2.4.

The class will consist of one Special Exercise ▷ .

See Section 2.6.2.

41.1 Brief Description of Exercise

This exercise involves creating a three-dimensional model of a portion of the superstructure of the Hodariyat Bridge. This bridge, in Abu Dhabi, is shown in Figure 41.1.

Figure 41.1: Hodariyat Bridge, Abu Dhabi
Source of image: Daniel Tassin

41.1.1 Objectives of the Exercise

The objectives of this exercise are primarily related to demonstrating good technique in modeling, accurately and with good speed, a relatively complex component.

A major component of the effort involved in this exercise is organizing the information related to the geometry of the object to be drawn before class.

41.1.2 *Information Provided*

The information required to create the three-dimensional SketchUp model is given on two drawings, shown in Figures 41.2 and 41.3. These drawings are available for download at the link provided ▷ .

The following additional information is also provided:

Click this text to download the drawings shown in Figures 41.2 and 41.3.

1 Draw only the details for *Deviator 2* as shown on Drawing no. 7.

2 Total width of the cross-section shall be 35 800 mm.

3 The variable dimension of the deck slab cantilever ("varies from 2150 to 2400") given on Drawing no. 6 shall be taken to be 2150 mm.

4 On Drawing no. 6, the centreline shown in the bottom slab shall be taken to be 110 mm below the top of the bottom slab.

5 On Drawing no. 6, where the outer struts meet the top slab, the thickened portion of the strut shall be square in cross-section, 500 mm by 500 mm.

6 On Drawing no. 6, for the vertical dimensions 555 and 700 located to the right of the left web, the extension line between 555 and 700 is missing. It should points to the top of the thickened portion of the deck slab near the web, and not to the wide central portion of the deck slab.

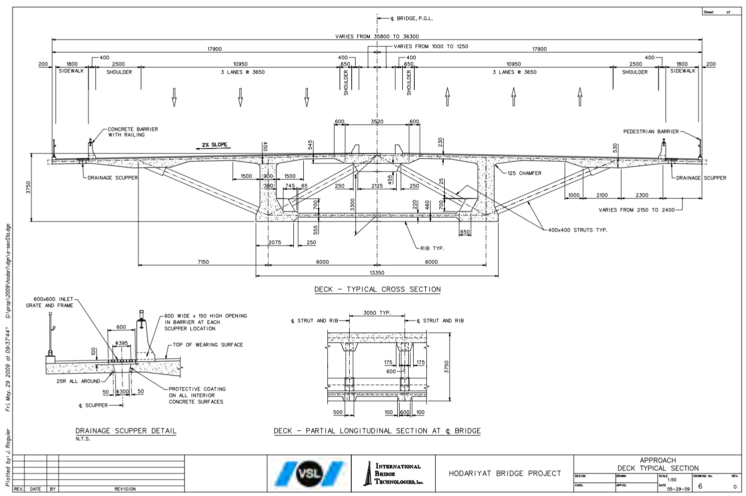


Figure 41.2: Drawing of typical section through girder

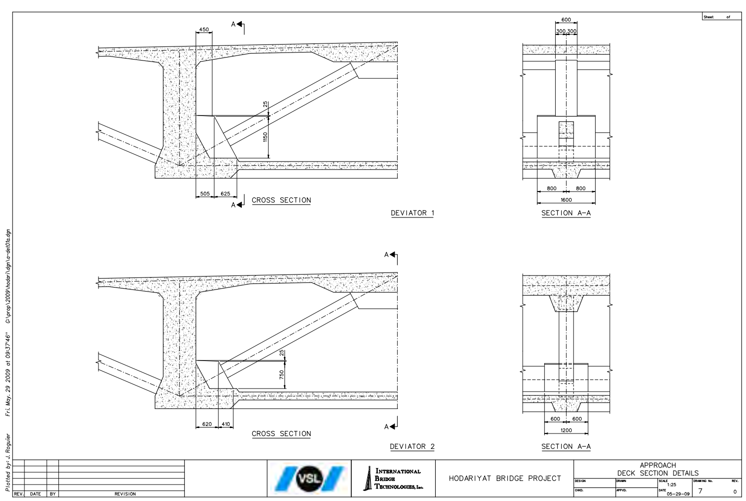


Figure 41.3: Additional details of the bridge girder

41.1.3 *What to Draw*

A three-dimensional model of the bridge is to be drawn in SketchUp. The total length of the model (in the direction of the longitudinal axis of the bridge) shall be 6100 mm. The struts and ribs shall be centered within this length.

Do not include any barriers, railings, or scuppers in the model. Do not draw the wearing surface.

From the three-dimensional model, create views in LayOut as shown in Figure 41.4. This drawing is also available for download at the link provided ▷ . The course LayOut template shall be used.

Click this text to download the completed exercise.

41.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, and 4.

2 Section 6.1.

3 Chapters 7, 9, 16, and 54.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 All of the SketchUp and LayOut techniques covered in previous classes.

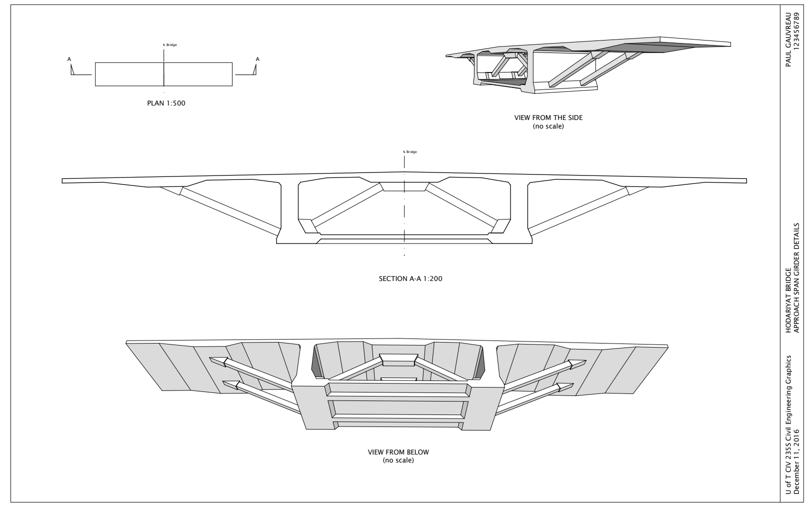


Figure 41.4: Completed drawing

41.3 Preparation

Success in this exercise depends to a large extent on the availability of a complete set of geometrical information, organized in such as way as to permit the model to be drawn quickly, i.e., with a minimum number of SketchUp commands and with a minimum amount of time spent figuring out geometrical relations needed to place lines and other drawing elements.

The information as presented in the drawings is poorly suited for this purpose. Time will therefore have to be invested before class to plan an efficient set of steps for creating the model, and then express dimensions and locations of key points in a way that makes this set of steps possible.

Although it is always advisable to complete the exercise before class, simply "bashing through" the exercise without first planning the steps and organizing the geometrical information accordingly is likely to be of relatively little benefit.

41.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course SketchUp template, identical to the file available at this link ▷ .

Click this text to download the course SketchUp template.

3 The course LayOut template, identical to the file available at this link ▷ .

Click this text to download the course LayOut template.

4 The drawings with the given geometric information, identical to the file available at this link ▷ .

Click this text to download the drawings shown in Figures 41.2 and 41.3.

41.5 Recommended Workflow

A recommended workflow is not provided for this exercise. It is recommended that students prepare a workflow before class based on the workflows of previous exercises. The workflow should then be followed during class.

41.6 Completed Drawing

The drawing to be produced in this exercise is available for download at the link provided ▷ .

Click this text to download the completed exercise.

41.7 Marking

Since this exercise is a Special Exercise ▷ , it will be marked in detail.

See Section 2.6.2.

The exercise will be marked according to the marking guide given in Table 41.1. Each item in the marking guide will be assigned an assessment of "√" (no problems), "O" (small problems), or "X" (big problems).

On the basis of this assessment, a mark out of 10 will be assigned according to the following criteria:
All "√": *9* to 10
Mostly "√", a few "O": 8
A significant number of "O" and/or a maximum of one "X": *7*
Two "X": *6*
More than two "X": 0 to 5

A major point of this exercise is to produce drawings that project a high standard of quality and professionalism. Drawings that present the information correctly but which otherwise contain elements that demonstrate a lack of professionalism are unlikely to receive a mark greater than *7* out of 10. Professionalism is in the details. These details will be given serious consideration in marking.

Table 41.1: Marking Guide for SketchUp Class 10

Item no.	Item	Assessment
1	Drawing projects a high standard of quality and professionalism	
2	Instructions were followed correctly	
3	Drawing provides a complete description of the geometry	
4	Information is presented clearly	
5	Choice of views is logical	
6	Arrangement of views is logical	
7	Views are accurate	
8	Annotations are in accordance with course drafting standard	

Part VIII

Description of Classes: AutoCAD

42
AutoCAD Class 1

This class will take place on the date indicated in Table 2.2 for "AutoCad 1" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

42.1 Brief Description of Exercise

This exercise consists of 35 simple tasks, each of which introduces an important AutoCad command. The exercise is to be performed in the AutoCad environment and its outcome will be an AutoCad drawing. The completed drawing is shown in Figure 42.1.

The intent of this exercise is to provide an introduction to basic tasks in AutoCad that include:

1 Learning a set of the most important AutoCad commands that will be used in this course

2 Basic use of Model Space and Paper Space

3 Plotting a drawing to create a pdf file

4 Submitting a pdf of the completed drawing to the secure network environment

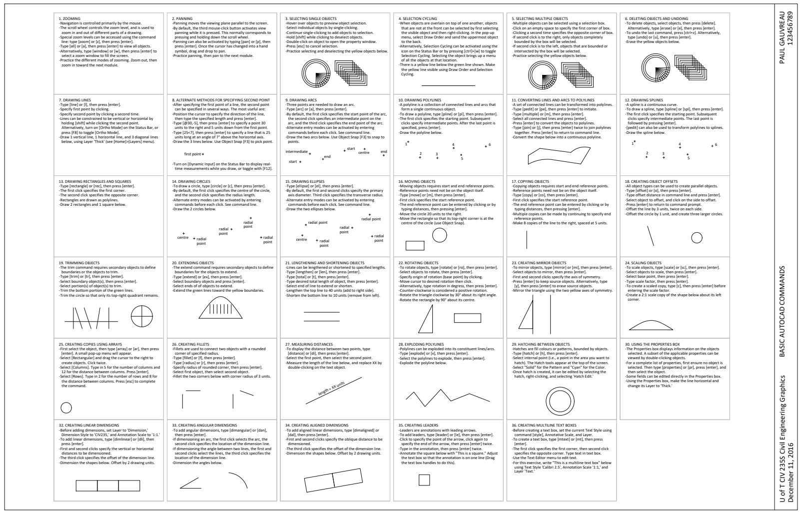


Figure 42.1: AutoCad Class 1: Completed drawing.

42.2 Background

Students are expected to be familiar with the following material:

1. Chapters 1, 2, and 4.

42.3 Preparation

Before class, students shall prepare as follows:

1. Read Chapter 17.
2. Read the online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

   Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.
3. Complete the exercise before class.

42.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1. These course notes. The external hyperlinks (in green) will generally not work.
2. An AutoCad file with a description of the exercise tasks, and in which the exercise will be completed, identical to the file available at this link ▷ .

   Click this text to download the exercise file.
3. The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

   Click this text to download the Colour-Dependent Plot Style Table. *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

42.5 Recommended Workflow

This is a simple exercise. To complete it, proceed as follows:

1 *Set up the AutoCad file.*

(a) Download and open the AutoCad exercise file ▷ .

Click this text to download the exercise file.

(b) Enter the required changes to the title block ▷ .

See Section A.4 for requirements. The title of the drawing shall be taken from Figure 42.1.

2 *Enter Model Space.*

Click on the `Model` tab in the bottom left-hand corner of the window.

3 *Complete each task in the exercise.*

Proceed from Task 1 to Task 35. Each task gives a description of what needs to be done.

4 *Return to Paper Space.*

Click on the `Layout1` tab in the bottom left-hand corner of the window.

5 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

6 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

7 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

8 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

42.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 42.1, is available for download at the link provided ▷ .

Click this text to download the completed exercise.

43
AutoCAD Class 2

This class will take place on the date indicated in Table 2.2 for "AutoCad 2" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

43.1 Brief Description of Exercise

This exercise consists of producing a drawing that consists of four views at specified scales of the single-cell box girder cross-section provided in the course AutoCad template. The completed drawing is shown in Figure 43.1.

This exercise requires no drawing per se in AutoCad, i.e., only the creation of dimensions and annotations. The intent of this exercise is to provide an introduction to basic tasks in AutoCad that include:

1 Working with the course AutoCad template

2 Creating, arranging, and scaling viewports in Paper Space

3 Creating and modifying dimensions in Paper Space

4 Adding annotations and working with annotation scaling

5 Plotting a drawing to create a pdf file

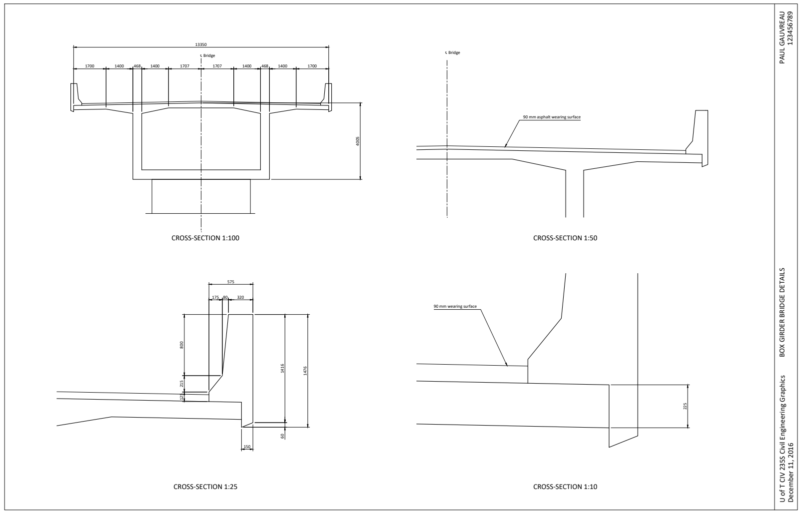


Figure 43.1: AutoCad Class 2: Completed drawing.

6 Submitting a pdf of the completed drawing to the secure network environment

Students are expected to produce a drawing that projects a high degree of professionalism.

43.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, 4, 6, 7, 9, and 17.

2 Applicable sections of the course Drafting Standards (Appendix A).

3 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

43.3 Preparation

Before class, students shall prepare as follows:

1 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

43.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course AutoCad template, identical to the file available at this link ▷ .

Click this text to download the course AutoCad template.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

Click this text to download the Colour-Dependent Plot Style Table.
For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.

43.5 Recommended Workflow

Steps 1 through 4 of this workflow correspond to the first four steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ . Steps 5 through *9* implement the fifth step of the general drawing process ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4.

See Section 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 43.1) have been defined in advance by course staff.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 43.1) have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Set up the AutoCad file.*

(a) Download and open the course AutoCad template ▷ .

(b) Enter the required changes to the title block ▷ .

(c) *Move the section cut symbols and north arrow out of the drawing area.*

`Click this text to download the course AutoCad template.`

See Section A.4 for requirements. The title of the drawing shall be taken from Figure 43.1.

6 *In Paper Space, create the required viewports.*

A total of four viewports will be required. The viewport that has been provided in the AutoCad template can be copied three times.

7 *Re-size and position the viewports as required, and add titles.*

8 *Set the scales of the viewports.*

One of the required scales is 1:25 which is not present in the list of scales built into the AutoCad template. It will need to be added. Select `Custom...` from the scale button in the lower right-hand corner of the drawing frame. Then proceed as desribed in the link provided ▷ .

See the article `Add Scale Dialog Box` *in the AutoCad Help Centre.*

9 *Create each of the required views.*

Proceed as follows for each viewport:

(a) In Paper Space, use the `Pan` command to bring the required portion of the object into view.

(b) If required, set the layer to `Dimension` and create dimensions in Paper Space.

Modify dimensions as required to ensure they are in accordance with the course drafting standard ▷ . Do this by right-clicking on the dimension you wish to modify and selecting `Properties` from the pop-up menu. Then modify specific properties as required. The most common modifications will be to switch `Ext line 1` or `Ext line 2` to `Off` (these settings are in the `Lines & Arrows` section , and to switch `Text inside` to `On` (this setting is in the `Fit` section.)

See Section A.10.

Make sure `Osnap` ▷ is set to `On` before creating dimensions.

See the article `OSNAP (Command)` *in the AutoCad Help Centre.*

(c) If required, create annotations in Model Space. Use the `Leader` command or the `Mtext` command as appropriate. Before invoking these commands, make sure the annotation scaling has been set as required for the view you wish to create. Any annotations created in this way will show up only in those viewports with the same scale.

(d) In Paper Space, modify the titles of the views as required.

10 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

11 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

12 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

13 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

43.6 *Completed Drawing*

The drawing to be produced in this exercise, shown in Figure 43.1, is available for download at the link provided ▷ .

Click this text to download the completed exercise.

44
AutoCAD Class 3

This class will take place on the date indicated in Table 2.2 for "AutoCad 3" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

44.1 Brief Description of Exercise

This exercise consists of drawing a precast concrete box-girder bridge segment in three orthographic views with a complete set of dimensions. The drawing shall be produced on the course AutoCad template. The completed drawing is shown in Figure 44.1.

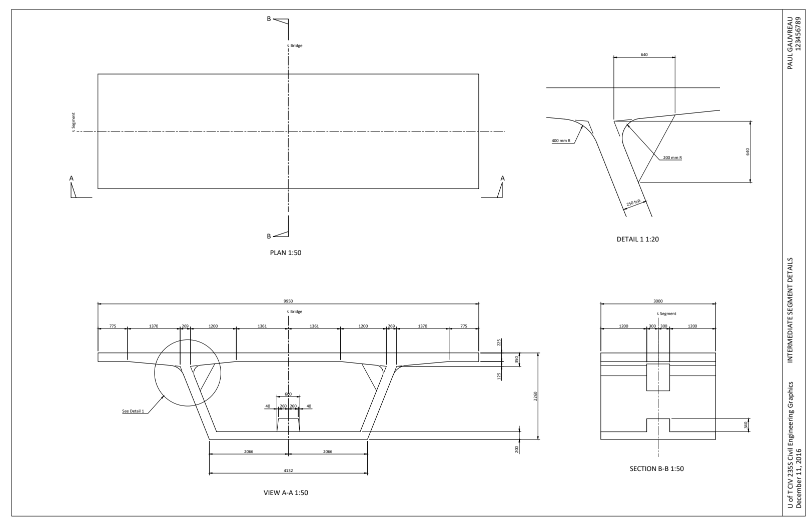


Figure 44.1: AutoCad Class 3: Completed drawing.

44.1.1 Objectives of the Exercise

The objectives of this exercise are as follows:

1 Develop proficiency in working with a variety of AutoCad commands

2 Develop proficiency in working with Model Space, Paper Space, and viewports

3 Develop proficiency in arranging views, dimensions, and annotations in a way that produces clarity and reflects professionalism

4 Gain further proficiency in all the aspects of AutoCad drawing developed thus far

44.1.2 Information Provided

A complete drawing of the segment, shown in Figure 44.2, is provided. A higher resolution version of this image is available at the link provided ▷ .

Click this text to download the drawing of the segment.

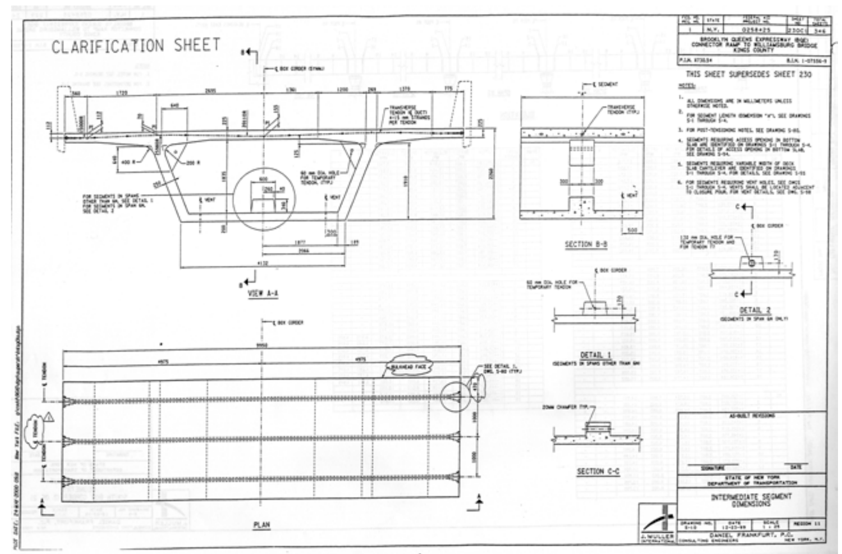


Figure 44.2: Drawing of the precast concrete bridge segment to be drawn.

44.1.3 What to Draw

Produce a drawing like the one shown in Figure 44.1. It shall contain the same information and must be arranged in a similar manner. A complete set of dimensions and annotations is required.

Dimension "A" on this drawing shall be taken to be 3000 mm.

Information relating to the post-tensioning tendons need not be considered. The holes in the three blocks in the interior of the box section need not be drawn.

The dimensions provided on the drawing of Figure 44.2 are not in accordance with the course drafting standard.

44.2 Background

Students are expected to be familiar with the following material:

1 Chapters 1, 2, 4, 6, 7, 9, 17, and 54.

2 Applicable sections of the course Drafting Standards (Appendix A).

3 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

44.3 Preparation

Before class, students shall prepare as follows:

1 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

2 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and back-tracking.

3 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

44.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course AutoCad template, identical to the file available at this link ▷ .

`Click this text to download the course AutoCad template`.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

`Click this text to download the Colour-Dependent Plot Style Table`. *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

44.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The drawing to be produced in this exercise shall be as shown in Figure 44.1. The purpose of this drawing is to describe the dimensions required to construct the formwork for building this segment.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 44.1) have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the drawing shown in Figure 44.2.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow you have prepared in Step 4.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

44.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 44.1, is available for download at the link provided ▷ .

`Click this text to download the completed exercise.`

45 AutoCAD Class 4

This class will take place on the date indicated in Table 2.2 for "AutoCad 4" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

45.1 Brief Description of Exercise

This exercise consists of drawing a precast concrete bridge segment in three orthographic views with a complete set of dimensions. The drawing shall be produced on the course AutoCad template. The view of an incomplete drawing, which gives an indication of the required views and their arrangement, is shown in Figure 45.1.

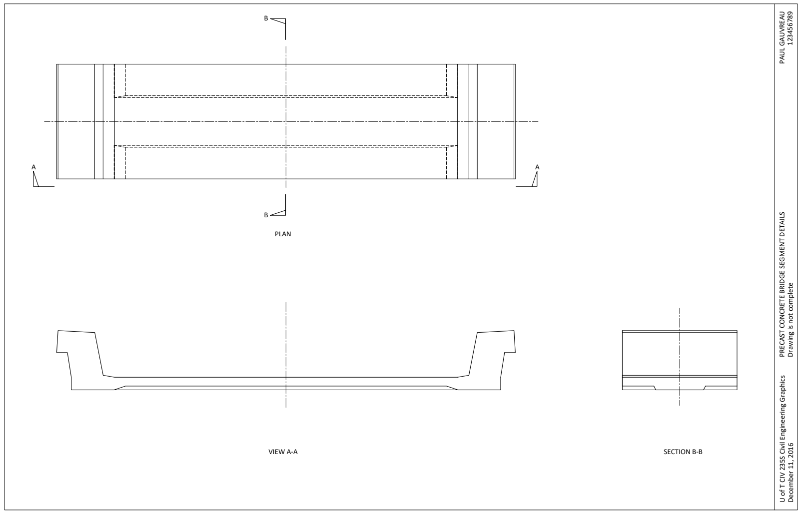


Figure 45.1: AutoCad Class 4: An incomplete version of the required drawing

45.1.1 Objectives of the Exercise

The objectives of this exercise are as follows:

1 Develop proficiency in working with a variety of AutoCad commands

2 Develop proficiency in working with Model Space, Paper Space, and viewports

3 Develop proficiency in arranging views, dimensions, and annotations in a way that produces clarity and reflects professionalism

4 Gain further proficiency in organizing the geometric information of the object to be drawn in a way that will enable maximum efficiency in drawing

5 Gain further proficiency in all the aspects of AutoCad drawing developed thus far

45.1.2 *Information Provided*

The precast concrete bridge segment to be drawn is similar to the one drawn in SketchUp Class 6 ▷ .

See Chapter 35 and Figure 35.1.

A precisely drawn SketchUp model, shown in Figure 45.2, is provided ▷ . All of the required geometric information shall be extracted from this file.

Click this text to download the SketchUp file.

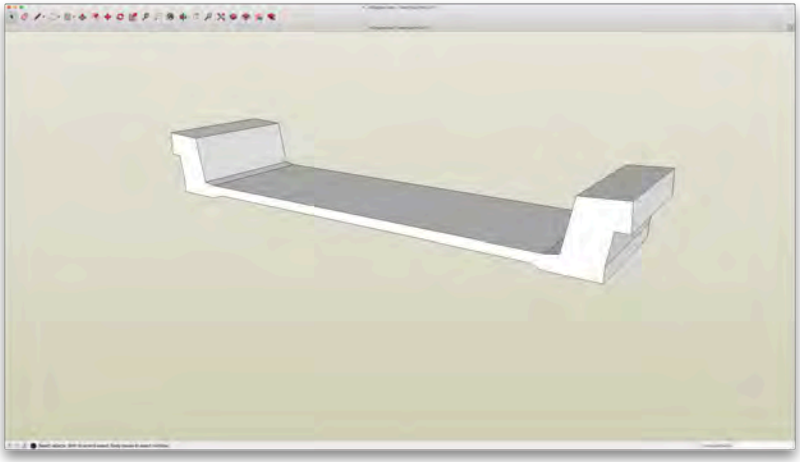


Figure 45.2: View of the SketchUp model of the segment to be drawn

45.1.3 *What to Draw*

Produce a drawing like the one shown in Figure 45.1. It shall contain the same information and must be arranged in a similar manner. A complete set of dimensions and annotations is required.

45.2 *Background*

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, 17, and 54.

3 Applicable sections of the course Drafting Standards (Appendix A).

4 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

45.3 *Preparation*

Before class, students shall prepare as follows:

1 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

2 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and back-tracking.

3 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

45.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course AutoCad template, identical to the file available at this link ▷ .

`Click this text to download the course AutoCad template`.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

`Click this text to download the Colour-Dependent Plot Style Table`. *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

The SketchUp file of the segment will not be provided during class. All of the information required from this file must be put onto paper before class.

45.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The drawing to be produced in this exercise shall be as shown in Figure 45.1. The purpose of this drawing is to describe the dimensions required to construct the formwork for building this segment. A complete set of dimensions and annotations is required.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

This task is not applicable here since all aspects of the drawing to be produced (as shown in Figure 45.1) have been defined in advance by course staff.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the SketchUp file that will be available before class.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

45.6 Completed Drawing

A completed drawing of this exercise will not be provided before class.

46
AutoCAD Class 5

This class will take place on the date indicated in Table 2.2 for "AutoCad 5" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

46.1 Brief Description of Exercise

This exercise consists of drawing a concrete bridge segment using orthographic views and providing a complete set of dimensions. The drawing shall be produced on the course AutoCad template.

46.1.1 Objectives of the Exercise

The objectives of this exercise are as follows:

1 Develop proficiency in exporting a SketchUp model for import into AutoCad

2 Develop proficiency in working with a variety of AutoCad commands

3 Develop proficiency in working with Model Space, Paper Space, and viewports

4 Develop proficiency in selecting and arranging views, dimensions, and annotations in a way that produces clarity and reflects professionalism

5 Gain further proficiency in organizing the geometric information of the object to be drawn in a way that will enable maximum efficiency in drawing

6 Gain further proficiency in all the aspects of AutoCad drawing developed thus far

46.1.2 Information Provided

The precast concrete bridge segment to be drawn is similar to the one drawn in SketchUp Class 12 ▷ .

See Chapter 41.

A precisely drawn SketchUp model, shown in Figure 46.1, is provided ▷ . This SketchUp file will be available in class.

Click this text to download the SketchUp file.

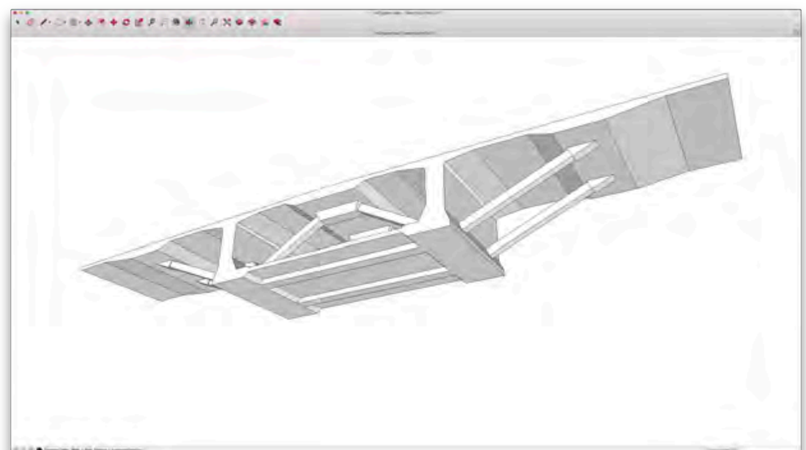


Figure 46.1: View of the SketchUp model of the segment to be drawn

46.1.3 What to Draw

Produce a drawing that contains a combination of orthographic views that provides a clear and complete description of the geometry of the segment.

46.2 Background

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, 17, and 54.

3 Applicable sections of the course Drafting Standards (Appendix A).

4 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

46.3 Preparation

Before class, students shall prepare as follows:

1 Learn about exporting SketchUp models into `.dwg` format, i.e., as an AutoCad file ▷

See the article Importing and Exporting CAD Files. *The relevant section is* Exporting a SketchUp Model as a 2D CAD file.

2 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

3 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and backtracking.

4 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

46.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course AutoCad template, identical to the file available at this link ▷ .

Click this text to download the course AutoCad template.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

Click this text to download the Colour-Dependent Plot Style Table. *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

4 The SketchUp file with the bridge segment shown in Figure 46.1 ▷ .

Click this text to download the SketchUp file.

46.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced is to describe the dimensions required to construct the formwork for building this segment. A complete set of dimensions and annotations is required.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

It is possible to produce a single drawing that performs the function specified under Point 1.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the SketchUp file that will be available before class.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

Students will have access to the SketchUp file and to the SketchUp software during class. It is highly recommended that students export the SketchUp file in `.dwg` format. This will eliminate the need to draw the segment form scratch in AutoCad. The bulk of the work required for this exercise is thus producing the required views, and adding dimensions and annotations as appropriate to describe the segment clearly and completely. Students should therefore plan their workflow accordingly.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

46.6 Completed Drawing

A completed drawing of this exercise will not be provided before class.

47
AutoCAD Class 6

This class will take place on the date indicated in Table 2.2 for "AutoCad 6" ▷ . See Section 2.4.
The class will consist of one Special Exercise ▷ . See Section 2.6.2.

47.1 Brief Description of Exercise

This exercise consists of drawing a concrete bridge segment using orthographic views and providing a complete set of dimensions. The drawing shall be produced on the course AutoCad template.

47.1.1 Objectives of the Exercise

The objectives of this exercise are to develop proficiency in the following aspects of drawing:

1 Working with a variety of AutoCad commands

2 Working with Model Space, Paper Space, and viewports

3 Selecting and arranging views, dimensions, and annotations in a way that produces clarity and reflects professionalism

4 Organizing the geometric information of the object to be drawn in a way that will enable maximum efficiency in drawing

5 Gaining further proficiency in all the aspects of AutoCad drawing developed thus far

47.1.2 Information Provided

The precast concrete bridge segment to be drawn shown in Figure 47.1, is provided ▷ .

Click this text to download a higher-resolution version of this file.

The dimensions provided in this drawing are not necessarily in accordance with the course design standard.

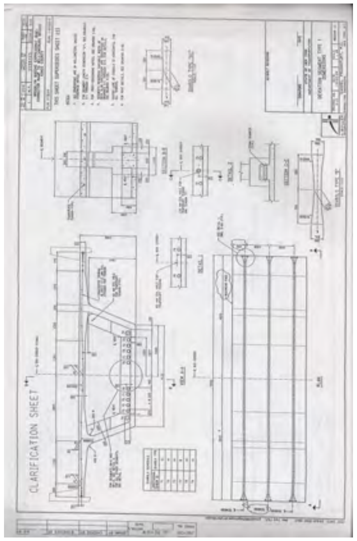


Figure 47.1: Drawing of the segment

47.1.3 What to Draw

Produce a drawing that contains a combination of orthographic views that provides a clear and complete description of the geometry of the segment.

47.2 Background

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, 17, and 54.

3 Applicable sections of the course Drafting Standards (Appendix A).

4 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

47.3 Preparation

Before class, students shall prepare as follows:

1 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

2 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and backtracking.

3 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

47.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course AutoCad template, identical to the file available at this link ▷ .

`Click this text to download the course AutoCad template`.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

`Click this text to download the Colour-Dependent Plot Style Table`. *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

47.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced is to describe the dimensions required to construct the formwork for building this segment. A complete set of dimensions and annotations is required.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

It is possible to produce a single drawing that performs the function specified under Point 1.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the drawing shown in Figure 47.1. Students will not have access to this file during class. Students should therefore plan their workflow accordingly.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

47.6 Completed Drawing

A completed drawing of this exercise will not be provided before class.

47.7 Marking

Since this exercise is a Special Exercise ▷ , it will be marked in detail.

See Section 2.6.2.

The exercise will be marked according to the marking guide given in Table 47.1. Each item in the marking guide will be assigned an assessment of "√" (no problems), "O" (small problems), or "X" (big problems).

On the basis of this assessment, a mark out of 10 will be assigned according to the following criteria:
All "√": 9 to 10
Mostly "√", a few "O": 8
A significant number of "O" and/or a maximum of one "X": 7
Two "X": 6
More than two "X": 0 to 5

A major point of this exercise is to produce drawings that project a high standard of quality and professionalism. Drawings that present the information correctly but which otherwise contain elements

Table 47.1: Marking Guide for AutoCad Class 6

Item no.	Item	Assessment
1	Drawing projects a high standard of quality and professionalism	
2	Instructions were followed correctly	
3	Drawing is complete	
4	Views are accurate	
5	Dimensions are complete	
6	Dimensions are in accordance with course drafting standard	
7	Annotations are in accordance with course drafting standard	

that demonstrate a lack of professionalism are unlikely to receive a mark greater than 7 out of 10.

48
AutoCAD Class 7

This class will take place on the date indicated in Table 2.2 for "AutoCad 7" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

48.1 Brief Description of Exercise

This exercise consists of drawing a concrete bridge pier segment using orthographic views and providing a set of dimensions. The views, dimensions, and annotations shall provide a complete description of the geometry of the segment. The geometrical information shall be compiled from a precise SketchUp model. Figure 48.1 shows a view of this model. The drawing shall be produced on the course AutoCad template.

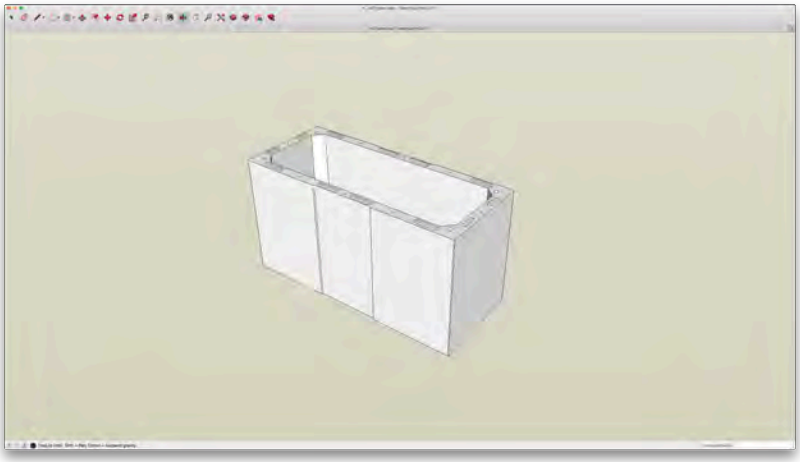


Figure 48.1: View of a SketchUp model of the segment to be drawn in this exercise

48.1.1 Objectives of the Exercise

The objectives of this exercise are to develop proficiency in the following aspects of drawing:

1 Working with a variety of AutoCad commands

2 Working with Model Space, Paper Space, and viewports

3 Selecting and arranging views, dimensions, and annotations in a way that produces clarity and reflects professionalism

4 Organizing the geometric information of the object to be drawn in a way that will enable maximum efficiency in drawing

5 Gaining further proficiency in all the aspects of AutoCad drawing developed thus far

48.1.2 Information Provided

The precast concrete bridge pier segment is similar to the ones shown in Figure 48.2.

A precisely drawn SketchUp model, shown in Figure 48.1, is provided ▷ . This SketchUp file will not be available in class, so all information required from this file must be put onto paper before class.

Click this text to download the SketchUp file.

48.1.3 What to Draw

Produce a drawing that contains a combination of orthographic views which together provide a clear and complete description of the geometry of the segment. The drawing shall be in accordance with the course drafting standards.

It is likely that smaller scale details will be required for some of the features of the segment.

The title of the drawing shall be "PIER SEGMENT DETAILS".

48.2 Background

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, 17, and 54.

Figure 48.2: Bridge piers constructed from precast box pier segments. Note the horizontal joints between the segments. Chesapeake and Delaware Bridge, USA.

3 Applicable sections of the course Drafting Standards (Appendix A).

4 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

48.3 Preparation

Before class, students shall prepare as follows:

1 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

2 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and back-tracking.

3 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

48.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course AutoCad template, identical to the file available at this link ▷ .

Click this text to download the course AutoCad template.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

Click this text to download the Colour-Dependent Plot Style Table. *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

The SketchUp file with the bridge segment will not be available during class.

48.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced is to describe the dimensions required to construct the formwork for building this segment. A complete set of dimensions and annotations is required.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

It is possible to produce a single drawing that performs the function specified under Point 1.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the SketchUp file. This file will not be available during class.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

48.6 Completed Drawing

A completed drawing of this exercise will not be provided before class.

49
AutoCAD Class 8

This class will take place on the date indicated in Table 2.2 for "AutoCad 8" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

49.1 Brief Description of Exercise

This exercise consists of drawing a cross-sections at regular intervals along a highway showing existing ground and cuts or fills as required. The toe of fills and top of cuts must then be drawn onto a plan. The completed drawing is shown in Figure 49.1.

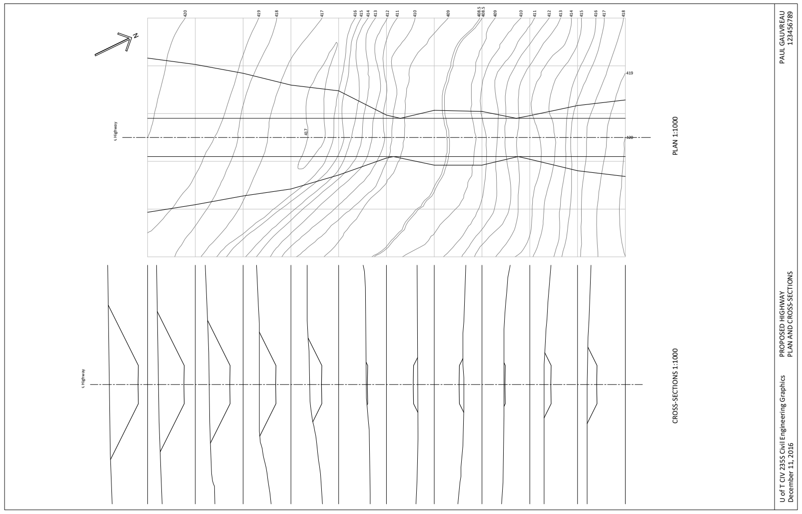


Figure 49.1: AutoCad Class 8: Completed drawing

The end product of this exercise is similar to that of the exercise in SketchUp Class 9 ▷ . Whereas the earthworks were drawn on the basis of full three-dimensional methods using SketchUp, in this ex-

See Chapter 38.

ercise they will be drawn on the basis of two-dimensional methods.

49.1.1 Objectives of the Exercise

The objectives of this exercise are to develop proficiency in the following aspects of drawing:

1 Working with a variety of AutoCad commands

2 Working with Model Space, Paper Space, and viewports

3 Organizing the geometric information of the object to be drawn in a way that will enable maximum efficiency in drawing

4 Gaining further proficiency in all the aspects of AutoCad drawing developed thus far

In addition, this exercise will provide another opportunity to apply knowledge of earthworks in civil engineering.

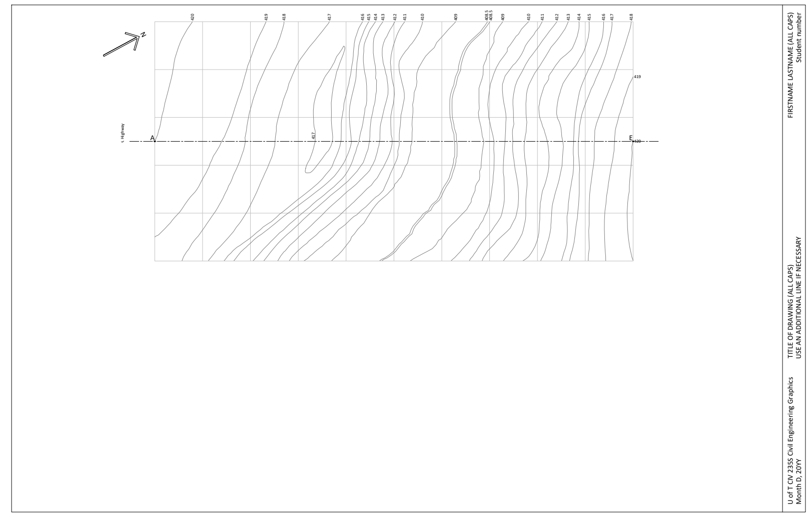


Figure 49.2: The given AutoCad file

49.1.2 Information Provided

An AutoCad file with a contour map, highway cross-sections, and information on the profile grade line is provided ▷ . The Paper Space view of this file is shown in Figure 49.2.

Click this text to download the AutoCad file.

The profile grade line follows the centreline in the given plan, from Point A to Point E. It is a straight line. Elevations of the profile grade line are 405.00 m at Point A and 415.00 m at Point E.

49.1.3 What to Draw

Produce a drawing like the one shown in Figure 49.1, showing cross-sections cut at each of the vertical gridlines, and the toe of fill or top of cut shown on the plan. The edges of the highway shall also be shown on the plan. Arrangement of views and annotations shall be as shown in Figure 49.1.

49.2 Background

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, and 17.

3 Applicable sections of the course Drafting Standards (Appendix A).

4 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

49.3 Preparation

Before class, students shall prepare as follows:

1 Read the Chapter 56 on earthworks, with particular emphasis on Section 56.2.3, which describes the theoretical foundations of the method to be followed.

2 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

3 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and back-tracking. This is particularly important. This is an exercise that can be performed quickly and efficiently, or can be performed slowly and inefficiently depending on the workflow and organization of information.

4 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

49.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The AutoCad file with the contour map, highway cross-sections, and profile grade line, identical to the file available at this link ▷ .

`Click this text to download the course AutoCad file`.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

`Click this text to download the Colour-Dependent Plot Style Table`. *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

49.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced is to describe the cuts and fills required for a stretch of highway, and to provide cross-sections that will enable the volume of materials to be cut and filled to be estimated.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

It is possible to produce a single drawing that performs the function specified under Point 1.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

Most of the geometric information required to completed this exercise will be available in a useful format on the given AutoCad drawing.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

This is particularly important for this exercise. It is absolutely essential that students think through the procedure they will follow, write it out, try it out beforehand, and modify it as required before class.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

49.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 49.1, is available for download at the link provided ▷ .

Click this text to download the completed exercise.

50 AutoCAD Class 9

This class will take place on the date indicated in Table 2.2 for "AutoCad 9" ▷ .

See Section 2.4.

The class will consist of one Special Exercise ▷ .

See Section 2.6.2.

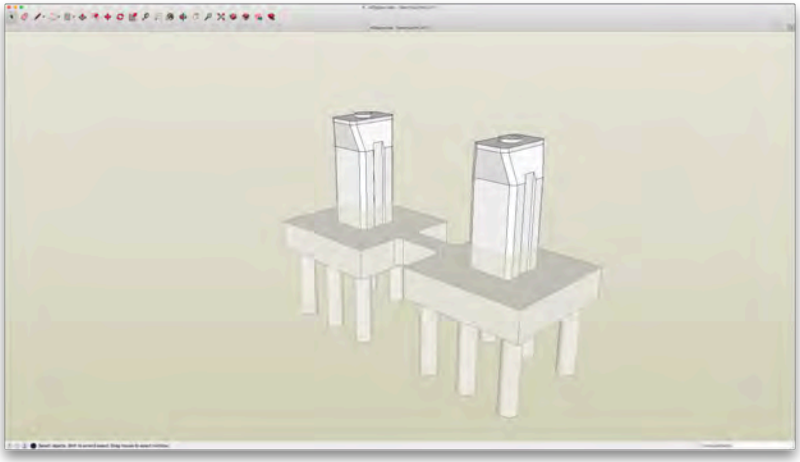


Figure 50.1: View of a SketchUp model of the pier to be drawn in this exercise

50.1 Brief Description of Exercise

This exercise consists of drawing a concrete bridge pier using orthographic views and providing a set of dimensions. The views, dimensions, and annotations shall provide a complete description of the geometry of the pier. A precise SketchUp file will be provided during class. A view from this model is shown in Figure 50.1. It is recommended that students export views from SketchUp as `.dwg` files, to minimize the drawing work required in AutoCad. The drawing shall be produced on the course AutoCad template.

50.1.1 Objectives of the Exercise

The objectives of this exercise are to develop proficiency in the following aspects of drawing:

1 Working with a variety of AutoCad commands

2 Working with Model Space, Paper Space, and viewports

3 Selecting and arranging views, dimensions, and annotations in a way that produces clarity and reflects professionalism

4 Organizing the geometric information of the object to be drawn in a way that will enable maximum efficiency in drawing

5 Gaining further proficiency in all the aspects of AutoCad drawing developed thus far

6 Gaining further proficiency in exporting views from SketchUp for use in AutoCad

50.1.2 *Information Provided*

The bridge pier supports the approach spans of the Hodaryat Bridge, a photograph of which is shown in Figure 41.1.

A precisely drawn SketchUp model, shown in Figure 50.1, is provided ▷ . This SketchUp file will be available in class.

Click this text to download the SketchUp file.

50.1.3 *What to Draw*

Produce a drawing that contains a combination of orthographic views which together provide a clear and complete description of the geometry of the pier. The drawing shall be in accordance with the course drafting standards.

It is likely that smaller scale details will be required for some of the features of the segment.

The title of the drawing shall be "PIER DETAILS".

50.2 *Background*

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, and 17.

3 Exporting SketchUp models into `.dwg` format, i.e., as an AutoCad file ▷

See the article Importing and Exporting CAD Files. *The relevant section is* Exporting a SketchUp Model as a 2D CAD file.

4 Applicable sections of the course Drafting Standards (Appendix A).

5 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

50.3 Preparation

Before class, students shall prepare as follows:

1 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

2 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and back-tracking.

3 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

50.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course AutoCad template, identical to the file available at this link ▷ .

Click this text to download the course AutoCad template.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

Click this text to download the Colour-Dependent Plot Style Table.

For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.

4 The SketchUp file with the bridge pier shown in Figure 50.1 ▷ .

Click this text to download the SketchUp file.

50.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced is to describe the dimensions required to construct the formwork for building this pier. A complete set of dimensions and annotations is required.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

It is possible to produce a single drawing that performs the function specified under Point 1.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

This task will involve compiling and organizing relevant information from the SketchUp file. This file will be available during class.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` in the AutoCad Help Centre.

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

50.6 Completed Drawing

A completed drawing of this exercise will not be provided before class.

50.7 Marking

Since this exercise is a Special Exercise ▷ , it will be marked in detail.

See Section 2.6.2.

The exercise will be marked according to the marking guide given in Table 50.1. Each item in the marking guide will be assigned an assessment of "√" (no problems), "O" (small problems), or "X" (big problems).

On the basis of this assessment, a mark out of 10 will be assigned according to the following criteria:
All "√": *9* to 10
Mostly "√", a few "O": 8
A significant number of "O" and/or a maximum of one "X": *7*
Two "X": *6*
More than two "X": 0 to 5

A major point of this exercise is to produce drawings that project a high standard of quality and professionalism. Drawings that present the information correctly but which otherwise contain elements that demonstrate a lack of professionalism are unlikely to receive a mark greater than *7* out of 10.

Table 50.1: Marking Guide for AutoCad Class *9*

Item no.	Item	Assessment
1	Drawing projects a high standard of quality and professionalism	
2	Instructions were followed correctly	
3	Drawing is complete	
4	Views are accurate	
5	Dimensions are complete	
6	Dimensions are in accordance with course drafting standard	
7	Annotations are in accordance with course drafting standard	

51
AutoCAD Class 10

This class will take place on the date indicated in Table 2.2 for "AutoCad 10" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

51.1 Brief Description of Exercise

This exercise consists of dimensioning and annotating a simplified version of a steel connection used to connect two cables in a pedestrian suspension bridge. The real connection is shown in Figure 51.1. The simplified component has already been drawn. All that is required are a complete set of dimensions and annotations, sufficient to enable the geometry of the component to be completely defined.

Figure 51.1: AutoCad Class 10: Cable connector to be dimensioned
Bridge over the Neckarstrasse in Stuttgart, Germany. Design: Jörg Schlaich.

51.1.1 *Objectives of the Exercise*

The objectives of this exercise are to develop proficiency in the following aspects of drawing:

1. Working with a variety of AutoCad commands
2. Working with Model Space, Paper Space, and viewports
3. Developing an awareness for what constitutes a complete and clear set of dimensions for a relatively complex component
4. Gaining further proficiency in all the aspects of AutoCad drawing developed thus far

51.1.2 *Information Provided*

An AutoCad file is provided ▷ . The Paper Space view of this file is shown in Figure 51.2. This file contains one view of the object. It has been precisely and correctly drawn. Some lines on the `Nonprint` layer that were used to draw the object have been left in Model Space. These might be helpful in completing this exercise.

The viewport has not been properly arranged or scaled. Proper information has not been entered into the title block. No dimensions or annotations have been provided.

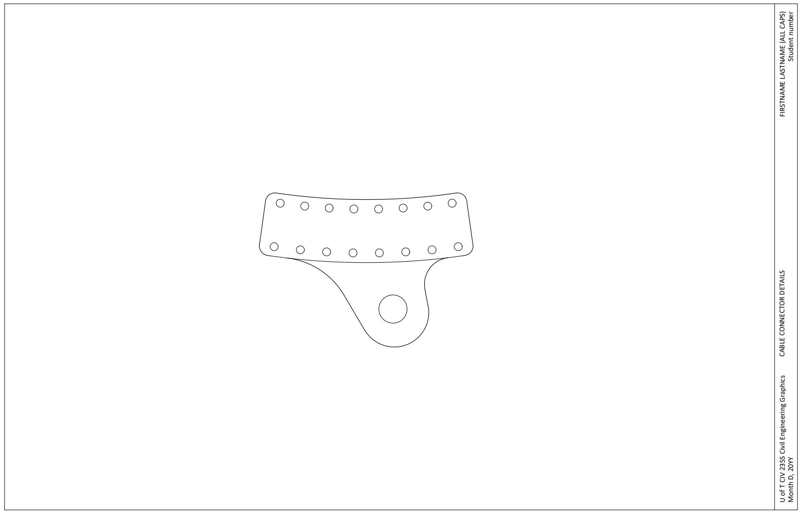


Figure 51.2: The given AutoCad file

Click this text to download the AutoCad file.

51.1.3 *What to Draw*

Produce a single-view drawing of the object that contains a complete set of dimensions and annotations. The dimensions shall be sufficient to define completely the geometry of the object.

51.2 *Background*

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, and 17.

3 Applicable sections of the course Drafting Standards (Appendix A).

4 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

51.3 Preparation

Before class, students shall prepare as follows:

1 Read up on anglar dimensions in AutoCad ▷ . You will need to use them.

Begin with the article To Create an Angular Dimension *from the AutoCad Help Centre.*

2 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

3 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and backtracking.

4 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

51.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The AutoCad file with the as shown in Figure 51.2, identical to the file available at this link ▷ .

Click this text to download the course AutoCad file.

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

Click this text to download the Colour-Dependent Plot Style Table. *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

51.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced is to provide a complete geometric description of the simplified cable connector.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

It is possible to produce a single drawing that performs the function specified under Point 1.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article To Plot a Drawing *in the AutoCad Help Centre.*

In the dialog box that appears after the Plot command has been invoked, make sure the Plot style table (pen assignments) is set to CIV235.ctb. If not, cancel the command and install the CIV235.ctb file ▷ .

See Section A.1.2.

In the Plot command dialog box, also ensure that the Printer/plotter Name has been set to DWG To PDF.pc3. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the W:\ directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* S:\Courses\civ235\Submit\235civXXXX\ *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

51.6 Completed Drawing

A completed drawing of this exercise will not be provided before class.

52
AutoCAD Class 11

This class will take place on the date indicated in Table 2.2 for "AutoCad 11" ▷ .

See Section 2.4.

The class will consist of one Basic Exercise ▷ .

See Section 2.6.1.

52.1 Brief Description of Exercise

This exercise consists of duplicating a relatively complex drawing, shown in Figure 52.1. An AutoCad drawing of the post-tensioning anchor has been provided.

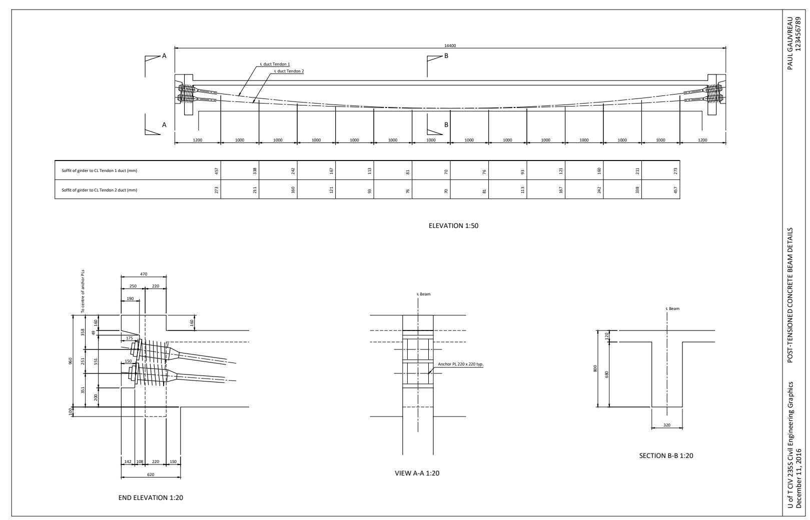


Figure 52.1: AutoCad Class 11: Completed drawing

52.1.1 Objectives of the Exercise

The objectives of this exercise are to gain further proficiency in all the aspects of AutoCad drawing developed thus far in the course, especially with regard to advance planning of the activities required to produce a relatively complex drawing in a limited amount of time.

52.1.2 Information Provided

A pdf file of the completed drawing, shown in Figure **??**, is provided ▷ .

`Click this text to download the pdf file of the completed drawing.`

An AutoCad file with the post-tensioning anchor already drawn is also provided ▷ .

Click this text to download the pdf file of the completed drawing.

52.1.3 What to Draw

Copy the drawing shown in Figure **??** as closely as possible.

52.2 Background

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, and 17.

3 Applicable sections of the course Drafting Standards (Appendix A).

4 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

52.3 Preparation

Before class, students shall prepare as follows:

1 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

2 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and backtracking.

3 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

52.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The course AutoCad template, identical to the file available at this link ▷ .

`Click this text to download the course AutoCad template.`

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

`Click this text to download the Colour-Dependent Plot Style Table.`
For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.

4 An AutoCad file with the post-tensioning anchor already drawn, identical to the file available at this link ▷ .

`Click this text to download the AutoCad file with the post-tensioning anchor.`

52.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced is to provide a complete geometric description of the simplified cable connector.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

It is possible to produce a single drawing that performs the function specified under Point 1.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

52.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 52.1, is available for download at the link provided ▷ .

Click this text to download the completed exercise.

53
AutoCAD Class 12

This class will take place on the date indicated in Table 2.2 for "AutoCad 12" ▷ .

The class will consist of one Special Exercise ▷ .

See Section 2.4.

See Section 2.6.2.

53.1 Brief Description of Exercise

This exercise consists of duplicating a relatively complex drawing, shown in Figure 53.1. An AutoCad file with the contours, profile of existing terrain, abutments, foundations, and profile grade line, all precisely drawn, has been provided.

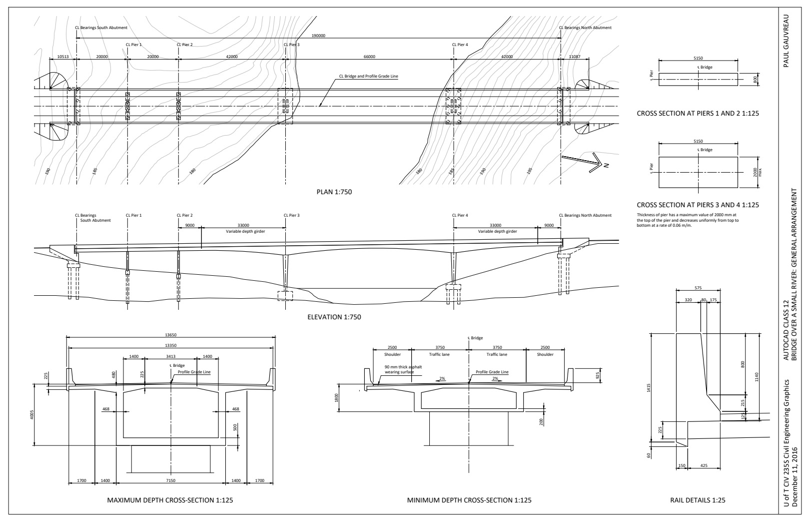


Figure 53.1: AutoCad Class 12: Completed drawing

53.1.1 Objectives of the Exercise

The objectives of this exercise are to gain further proficiency in all the aspects of AutoCad drawing developed thus far in the course, especially with regard to advance planning of the activities required to produce a relatively complex drawing in a limited amount of time.

53.1.2 Information Provided

A pdf file of the completed drawing, shown in Figure **??**, is provided ▷ .

`Click this text to download the pdf file of the completed drawing.`

An AutoCad file to be used as a base drawing is also provided ▷ . It contains the contours, profile of existing terrain, abutments, foundations, and profile grade line, all precisely drawn.

Click this text to download the pdf file of the completed drawing.

53.1.3 What to Draw

Copy the drawing shown in Figure **??** as closely as possible.

53.2 Background

Students are expected to be familiar with the following material:

1 All of the SketchUp techniques covered in previous classes.

2 Chapters 1, 2, 4, 6, 7, 9, 17, and 54.

3 Applicable sections of the course Drafting Standards (Appendix A).

4 The online document *The Hitchhiker's Guide to AutoCAD Basics* ▷ .

Click this text to visit the online document The Hitchhiker's Guide to AutoCAD Basics.

53.3 Preparation

Before class, students shall prepare as follows:

1 Organize the geometrical information related to the segment, in a way that will permit an efficient workflow.

2 Plan an efficient workflow to produce the required drawing, which enables the work to proceed with a minimum of delay and back-tracking.

3 Complete the exercise before class. This will involve reading and understanding the material available at the links to the AutoCad Help Centre provided in the Recommended Workflow.

53.4 Resources Provided During Class

The description of this exercise provides hyperlinks to materials available on external websites for use in preparing for this exercise. In class, all work will be performed within the secure network environment ▷ , so these hyperlinks will generally not work.

See Section 4.2.

During class, the following minimum set of materials that will enable students to complete the exercise will be available on the secure network environment ▷ :

The directory is `S:\Courses\civ235\Source\`.

1 These course notes. The external hyperlinks (in green) will generally not work.

2 The AutoCad file that will be used as a base drawing, identical to the file available at this link ▷ .

`Click this text to download the AutoCad file with the given information.`

3 The associated Colour-Dependent Plot Style Table, identical to the file available at this link ▷ .

`Click this text to download the Colour-Dependent Plot Style Table.` *For information on how to use the Colour-Dependent Plot Style Table, see Section A.1.2.*

53.5 Recommended Workflow

Steps 1 through 5 of this workflow correspond to the first first five steps in the general process of creating drawings intended to communicate the outcome of a design process defined previously ▷ .

See Sections 6.1.1, 6.1.2, 6.1.3, 6.1.4, and 6.1.5.

1 *Define the function to be performed by the drawing* ▷ .

See Section 6.1.1.

The purpose of the drawing to be produced is to provide a complete geometric description of the simplified cable connector.

2 *Confirm that the drawing can perform the function as intended* ▷ .

See Section 6.1.2.

It is possible to produce a single drawing that performs the function specified under Point 1.

3 *Organize information pertaining to the object to be drawn* ▷ .

See Section 6.1.3.

It is expected that this task will be completed by students before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

4 *Plan the steps to be followed in producing the drawing* ▷ .

See Section 6.1.4.

It is expected that students will produce a detailed workflow before class. It is unlikely that there will be enough time in class to complete this task and the steps required to create the drawing.

5 *Produce the drawing according to the workflow.*

6 *Create a pdf of the drawing you created* ▷ .

See the article `To Plot a Drawing` *in the AutoCad Help Centre.*

In the dialog box that appears after the `Plot` command has been invoked, make sure the `Plot style table (pen assignments)` is set to `CIV235.ctb`. If not, cancel the command and install the `CIV235.ctb` file ▷ .

See Section A.1.2.

In the `Plot` command dialog box, also ensure that the `Printer/plotter Name` has been set to `DWG To PDF.pc3`. Other than these two settings, all of the other information required to create a proper drawing should already be present in the AutoCad template.

When asked for a destination for the pdf file, choose the `W:\` directory ▷ .

See Section 4.2.2.

7 *Print the pdf file thus created and examine it carefully to ensure it is free of errors and reflects a high degree of professionalism.*

If not, make any necessary corrections.

8 *Copy your pdf file to the* `S:\Courses\civ235\Submit\235civXXXX\` *directory following the instructions given on the sheet with your log-in credentials that you were given at the beginning of class.*

9 *Print a hard copy of your drawing to hand in to the teaching assistants. You may print using either printer A or B in MB400, located on opposite sends of the classroom.*

53.6 Completed Drawing

The drawing to be produced in this exercise, shown in Figure 53.1, is available for download at the link provided ▷ .

Click this text to download the completed exercise.

53.7 Marking

Since this exercise is a Special Exercise ▷ , it will be marked in detail.

See Section 2.6.2.

The exercise will be marked according to the marking guide given in Table 53.1. Each item in the marking guide will be assigned an assessment of "√" (no problems), "O" (small problems), or "X" (big problems).

On the basis of this assessment, a mark out of 10 will be assigned according to the following criteria:
All "√": 9 to 10
Mostly "√", a few "O": 8
A significant number of "O" and/or a maximum of one "X": 7
Two "X": 6
More than two "X": 0 to 5

A major point of this exercise is to produce drawings that project a high standard of quality and professionalism. Drawings that present the information correctly but which otherwise contain elements that demonstrate a lack of professionalism are unlikely to receive a mark greater than 7 out of 10.

Table 53.1: Marking Guide for AutoCad Class 12

Item no.	Item	Assessment
1	Drawing projects a high standard of quality and professionalism	
2	Instructions were followed correctly	
3	Drawing is complete	
4	Views are accurate	
5	Dimensions are complete	
6	Dimensions are in accordance with course drafting standard	
7	Annotations are in accordance with course drafting standard	

Part IX

Reference Material

54
The Single-Cell Box Girder

This chapter gives a brief introduction to the single-cell concrete box girder as used in bridges. This material is provided to help students to understand the objects they will draw in the course.

54.1 The Basic Structural System

Beam is a general term that refers to structural members that carry load primarily in bending. A *girder* is a type of beam. Girders carry load over the primary spans in a given structure.

In Figure 54.1, we see a multiple-span bridge. The superstructure of the bridge, i.e., the part of the bridge that is supported by the vertical piers, carries load primarily in bending and is thus a beam. Because this beam carries load over the primary spans of the bridge (there are no longer spans than the ones shown in the figure), it is referred to as a girder.

Figure 54.1: Pregorda Bridge, Switzerland. Design by Christian Menn. Photo by Ralph Feiner.

Figure 54.2 shows a cross-section through the girder. The cross-section consists of two essentially horizontal components, called *top slab* and *bottom slab* respectively, and two essentially vertical components called *webs*. These components form the boundaries of an open area in the middle of the cross-section.

Figure 54.3 shows a longitudinal section through the centreline of the bridge. (Since the bridge is curved in plan (see Fig. 54.1), this is a *developed* view, created by cutting vertically through the centreline of the bridge, removing one half, and then flattening the remainder onto a plane.) It shows that the open area bounded by the top slab, webs, and bottom slab generally extends over the entire length of the bridge, except over the piers where the open area is blocked by solid walls called *diaphragms*. The top slab, webs, and bottom slab thus form the boundaries of a volume that is roughly rectangular, like a box, and for this reason this type of girder is called a *box girder*. Because there is only one cavity within the cross-section, the term can be further refined to *single-cell box girder*.

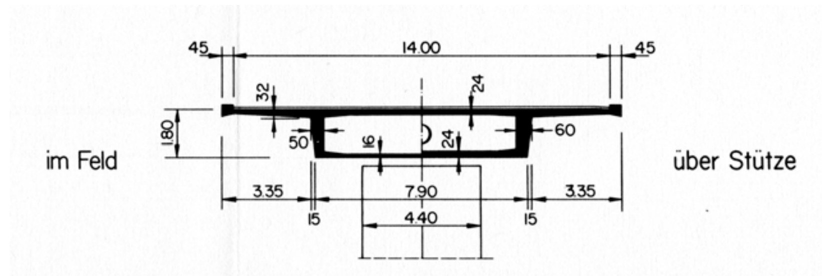


Figure 54.2: Pregorda Bridge, Switzerland. Typical cross-section.

Translation of German terminology: *im Feld*: in the span, *über Stütze*: over the piers. The diagram thus actually shows two half cross-sections, a rather compact way of showing two cross-sections in the space of one. This type of drawing should generally be avoided, and should only be done for components that have an axis of symmetry. Units in this cross-section are either in metres (for numbers with a decimal point) or centimetres (for numbers without a decimal point).

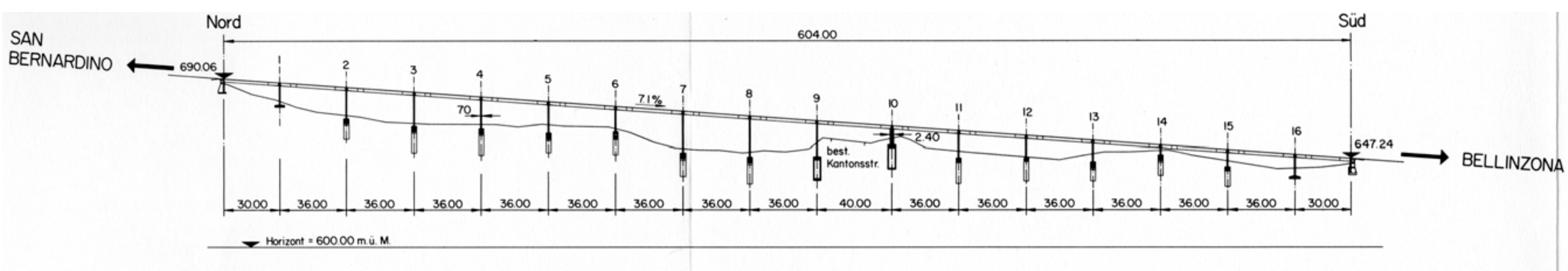


Figure 54.3: Pregorda Bridge, Switzerland. Longitudinal section.

The interior cavity of single-cell box girders can be large. Based on the dimensions given in Figure 54.2, the floor-to-ceiling height of the interior of the Pregorda Bridge girder is about 1.4 m. This height can be much larger, depending on the overall depth of the cross-section, which in turn is generally determined by the span. Figure 54.4 shows the interior of a box girder that spans approximately 140

m. In comparison, the typical span of the Pregorda Bridge is 36 m.

The single-cell box girder is a highly efficient structural system, i.e., it provides high structural capacity with minimum materials. By concentrating as much of the concrete in two relatively thin components at the upper and lower edges of the cross-section (i.e., the top slab and bottom slab), it minimizes the concrete required to provide the couple of forces necessary to resist bending moments. The closed rectangle formed by the webs, bottom slab, and the portion of the top slab between the webs is an efficient means of providing high strength and stiffness in torsion, which makes the single-cell box girder an excellent choice for girders that are curved in plan, such as Pregorda (see Fig. 54.1) and even more daring examples such as the bridge shown in Figure 54.5.

Single-cell box girders provide feasible, competitive solutions for span lengths ranging from about 30 m to over 300 m, and for a wide variety of other geometrical conditions, including bridge deck width. The actual dimensions of the cross-section will of course vary according to the specific requirements of a given project, but the generally arrangement will remain similar to what is shown in Figure 54.2.

Figure 54.4: Interior of a single-cell box girder bridge.

Figure 54.5: A curved single-cell box girder bridge in China.

54.2 Precast Concrete Bridge Segments

Single-cell box girder bridges can be built economically using a variety of construction methods, including the more traditional method of cast-in-place construction on falsework, and the more modern method of precast segments. The latter method involves the use of components that are relatively simple to define and which provide realistic objects for drawing in two and three dimensions. This section describes the method of precast segmental construction.[1]

Precast concrete bridge segments can be regarded as slices from a single-cell concrete box girder. Bridges that are constructed of segments can usually be easily recognized by the regularly spaced joints between segments, as shown in Figure 54.6.

[1] For additional information on precast concrete segmental bridges, see: Paul Gauvreau. "Bridges". In: *Post-Tensioning Manual.* Phoenix: Post-Tensioning Institute, 2006, pp. 195–240.

Figure 54.6: A precast segmental bridge in Hong Kong.

Segments are fabricated off-site and then transported to site for immediate erection. Figure 54.7 shows a segment awaiting transportation to site. Note the indentations along the top slab, webs, and bottom slab. These are called *shear keys*. They assist in aligning the segments when they are erected and also transfer shear across the joints between segments.

At the heart of the precast segmental method of construction is the way the segments are fabricated. Concrete for a given segment is placed against the segment that will be its mate in the completed structure. In this way, the pattern of shear keys on one segment is imprinted into its adjacent segment. This enables a perfect fit, and thus makes it possible for hardened concrete to abut hardened concrete without the need for cast-in-place concrete between the precast concrete components. This type of joint is called a *match-cast joint*. Before concrete is placed, the faces of the previously cast segment are coated with a *bond breaker* that enables the two segments to be detached from each other easily once the concrete has hardened.

Segments can be erected in several different ways, all of which involve supporting the segments temporarily in their intended location until they can be self-supporting. Figure 54.8 shows one possible method, which uses an overhead erection girder from which all of the segments for a given span are suspended. The joints between segments are then coated in adhesive and the segments are stressed together using post-tensioning. The span is then self-supporting and the erection girder can be advanced into position to help erect the next span.

The primary advantage of precast segmental construction is speed of erection. Because the method requires effectively no cast-in-place concrete, there is no need to wait until concrete has gained strength. Spans can be built using this method at rates of as high as one completed span per day.

Figure 54.7: A precast concrete bridge segment.

Figure 54.8: Erection of precast concrete bridge segments using an overhead erection girder.

54.3 Types of Segment

In this course, we will work with three main types of segment: intermediate segments, deviation segments, and pier segments. The following sections give examples of each type of segment. The figures included in this section all depict segments used on the same bridge.

54.3.1 Intermediate Segments

The segment shown in Figure 54.9 is used to demonstrate the primary geometric properties of intermediate segments. Although all bridges are different, the properties of the segment shown here can be found in many precast concrete bridge segments. The four primary components of the single-cell box girder cross-section ▷ are visible. The thickness of the top slab is variable, whereas the thickness of the webs and bottom slab are constant. The webs are inclined. The cross-section has a vertical axis of symmetry, labeled F-F′ in the figure. The webs intersect the top slab roughly halfway between the outer edges of the slab and the axis of symmetry.

See Section 54.1.

The area highlighted in Figure 54.9 will be called the *basic cross-section*. It is defined by the edges of the top slab, webs, and bottom slab at the face of the segment. The corners at C and C″ (and their counterparts at the other web) have been shown as angular for convenience. They are actually not sharp corners but rather are rounded. The lines A-A′, E-E1, E3-E3, E4-E5, D-D′, and B-B′ are all horizontal and hence parallel. Lines B-C and D-C″ are parallel, as are their counterparts in the other web.

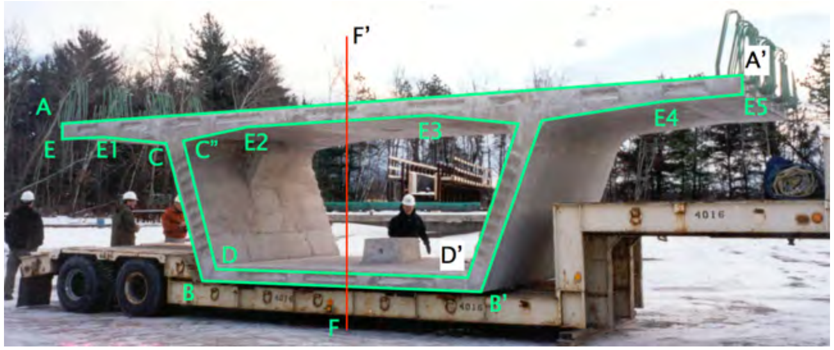


Figure 54.9: Primary geometric properties of an intermediate segment.

The segment can be visualized as an *extrusion of the basic cross-section*, with the exception of three relatively small build-outs, two of which are visible in the figure. The first is on the top surface of the bottom slab, near the letter D′ in the figure, and the second is at the intersection of top slab and web, near the letter E2. These are used to accommodate temporary post-tensioning tendons.

The total length of the segment is defined as the distance between face A-A′-B′-B and the opposite face. Although this is not the longest dimension of the segment, it is referred to as length since this dimension is in the same direction as the primary longitudinal dimension of the span in the completed bridge. Length of a given segment generally is about 3.0 metres, since this is the maximum width of load that can be trucked without a special permit. Weight restrictions also apply for transportation and lifting of segments, which might require segments with length shorter than 3.0 metres.

Figure 54.10: Pier segment being erected onto a pier. The basic cross-section has been highlighted.

54.3.2 Pier Segments

A segment that rests directly on a given pier is called a *pier segment*. Pier segments used only at these locations. An example of a pier segment, from the same bridge as the intermediate segment of Figure 54.9, is shown in Figure 54.11. The basic cross-section, which has been highlighted in Figure 54.11, is identical to the basic cross-section of the intermediate segment described previously.

The pier segment can thus be regarded as an intermediate segment in which the interior cavity has largely been filled by a solid concrete block called a *diaphragm*. The diaphragm performs several structural functions. It transfers vertical and horizontal load from the girder down to the bearings and pier. It also provides a means of anchoring the post-tensioning tendons that are used to clamp the girder segments together. The square block-outs and circular holes visible on the surface of the diaphragm are all components of the post-tensioning tendons. The large trapezoidal hole in the middle of the diaphragm is to enable construction workers and inspectors to move from a given span to the adjacent span across the pier.

54.3.3 Deviation Segments

Figure 54.11 shows a deviation segment. Its basic cross-section, highlighted in the figure, is also identical to the basic cross-section of the intermediate segment.

Deviation segments can thus be regarded as intermediate segments that have a partial wall in its central cavity, centered mid-way along the length of the segment. This wall is used to deviate (i.e., change the angle of) the post-tensioning tendons. The shape of the wall will vary from project to project.

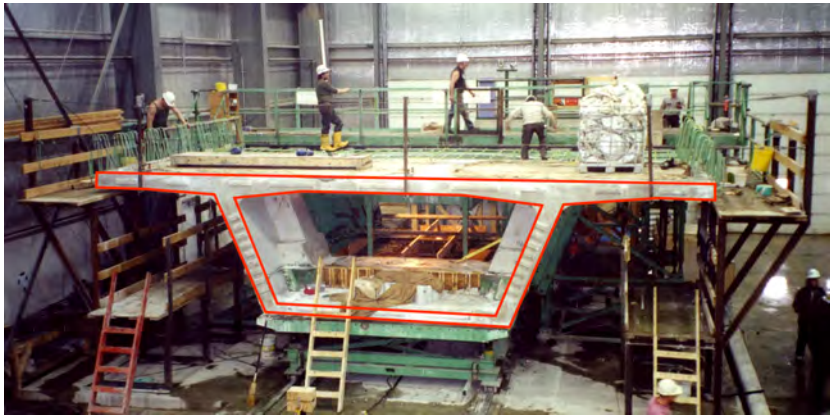


Figure 54.11: Deviation segment in the precasting facility. The basic cross-section has been highlighted.

55
Arch Bridges

This chapter provides a very brief introduction to arch bridges. It covers only those aspects of arch bridges that are needed to complete the drawing exercises in the course, including basic terminology and some fundamental geometric relationships. These are illustrated using Figure 55.1, which is a longitudinal section through the Nanin Bridge in Switzerland, designed by Christian Menn. (Figure 55.2 is a photograph of this bridge.)

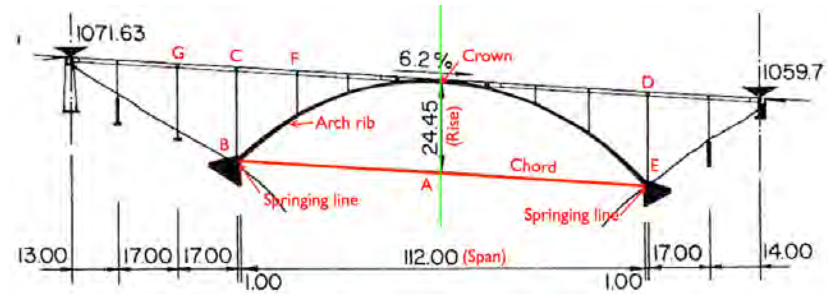


Figure 55.1: Longitudinal section through the Nanin Bridge, Switzerland. Design by Christian Menn.

Figure 55.2: Nanin Bridge, Switzerland. Design by Christian Menn.

55.1 Terminology

The arch proper is commonly referred to as the *arch rib*. The points where an arch rib reaches its foundation are called *springing lines*. The straight line joining the two springing lines is called the *chord*.

The distance between the springing lines, measured horizontally, is the *span* of the arch. The point where a vertical line drawn through midspan intersects the arch rib is called the *crown* of the arch. The vertical distance from the crown to the chord is called the *rise* of the arch.

Arches such as the Nanin Bridge consist of an arch rib, several columns called *spandrel columns*, and a girder. The portion of the girder that is not above the arch (i.e., the portions of the girder to the left of Point C and the right of Point D in Figure 55.1 are called *approach spans*.

The spandrel columns carry vertical load from the girder down to the arch rib. Spandrel columns must be supported on the arch rib or on the arch foundation. Columns that support the approach spans (i.e., to the left of Point C and the right of Point D in Figure 55.1) are called *approach piers* or simply *piers*. The supports at the ends of the girder are called *abutments*.

55.2 Fundamental Geometric Relationships

The arch rib is almost always parabolic in shape. This enables the arch to carry uniform loads in a state of pure compression, which is a highly efficient way of carrying load. Although the load originating from the girder is applied at discrete points through the spandrel columns and thus is not, strictly speaking, a uniform load, a parabola is usually a good approximation of the shape required to carry load in pure compression for this arrangement of load.

The span to rise ratio usually varies between 4:1 and 8:1, although values outside this range are also possible.

The chord should be parallel to the girder, as shown in Figure 55.1. Although the structural system can be made to work if this condition is not satisfied, keeping the chord parallel to the girder rationlizes construction and usually makes possible a better looking bridge. For the purposes of drawing the arch, therefore, we must draw a parabola within a parallelogram.

Providing an odd number of spans over the arch usually results in a better looking bridge. These spans can be increased slightly as we move outward from the crown. The approach spans should generally be of constant length (except possibly for the spans adjacent to the abutments). Their length should be no less than the longest girder span over the arch, and can be slightly longer than this length.

56
Earthworks

This chapter provides a brief introduction to the basic principles underlying the design of earthworks associated with highways and railways. It is not intended to be a comprehensive treatment of the topic. Rather, it provides a minimal body of knowledge that will enable students to produce some of the drawings normally encountered in the design of these works. The material presented is correct, but it has been simplified.

Three primary types of earthworks will be described: fills, cuts, and retaining walls. Fills and cuts are pure earthworks in the sense that they consist only of the placing or removal of soil and/or rock. Retaining walls are simple structures, usually built of reinforced concrete, that are often used in conjunction with cuts and fills. They enable cuts and fills to be built at steeper angles than would otherwise be possible with natural slopes.

Figure 56.1: Fills used for the approaches to a highway overpass

56.1 Examples of Earthworks

Figure 56.1 shows an example of fills used in conjunction with a highway overpass. The lower highway has been built at or near the level of natural terrain. The upper highway must therefore rise above the natural terrain to cross the lower highway. Immediately above the highway, this is best accomplished with a bridge. Outside the right-of-way of the lower highway, however, the designers chose to locate the upper highway on an embankment made of crushed rock, i.e., a fill. We can see how the sides of the fill are sloped transversely to the axis of the upper highway.

The primary characteristics of fills are shown in the Figure 56.2. The sketch is a cross-section through a new highway that will be built above natural terrain. The highway could be supported on a structure such as a bridge, but if there is no specific obstacle to be crossed (such as another highway or a river), it is often cheaper and easier just to build the highway on earth that has been moved in to fill the gap between natural terrain and the highway. The fill is shown in red.

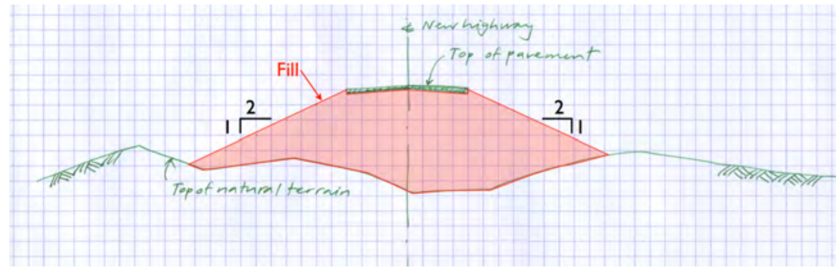


Figure 56.2: Cross-section through a new highway located above natural terrain. Section plane is vertical and intersects the path of the highway at 90 degrees.

The slope of the fill transverse to the axis of the highway cannot be made arbitrarily steep. The steeper the slope, the more likely that it will be unstable and fail by sliding downward. Such an event would have severe consequences for the safety of motorists using the highway supported by the fill. The steepest slope at which fill can be placed can be determined using the principles of geotechnical engineering. In the absence of more specific information, a slope of 2 horizontal to 1 vertical can generally be considered to be stable. Fills drawn in this course must not be steeper than the 2 to 1 slope shown in the sketch.

Figure 56.3: Examples of cuts used in highway construction

Figure 56.3 shows examples of cuts. The left image was taken during construction of a new elevated highway. The path of this highway would take it below the level of natural terrain. To accommodate this, a small hill has been partially removed to accommodate the highway. Because the material removed is soil, it was necessary to slope the cut back away from the highway to provide sufficient stability of the remaining portion of the hill. This is an asymmetrical cut, in the sense that material has been cut only on one side of the new highway.

In the right image of Figure 56.3, the highway in the foreground is likewise built lower than the natural terrain. It was therefore necessary to remove material to build the highway. In this case, the material to be removed was rock. This resulted in a cut that had nearly vertical faces, as can be seen from the photo.

The primary characteristics of cuts are shown in Figure 56.4. The sketch is a cross-section through a new highway that will be built above natural terrain. Here, the highway needs to be lower than the natural terrain, so material needs to be removed. The material to be removed is shown in yellow. The final face of the terrain is shown in red.

This situation is typical of a cut through soil. As for fills discussed previously, the steepest allowable slope of the earth remaining after material has been removed can likewise be determined from the principles of geotechnical engineering. The steeper the slope, the more likely there will be problems with stability. A slope of 2 horizontal to 1 vertical is generally regarded to be stable in a wide range of conditions. In this course, slopes in cuts through soil must not be drawn steeper than 2 horizontal to 1 vertical.

Another common type of cut is a cut through sound rock. This situation is illustrated in Figure 56.5. Again, the material to be removed is shown in yellow and the remaining faces are shown in red. Because the rock mass has considerable structural integrity, it can remain stable with very steep slopes. In excellent rock, vertical faces are possible. The allowable angle of slope in rock must be determined in consultation with a geotechnical engineer.

It is not always possible to place fill or make cuts in soil at a 2 to 1 slope. This situation can arise when the required fill or cut will encroach on a feature that must not be affected by the construction. An example of such a situation is shown in Figure 56.6. The two images in this figure are different views of the same situation.

We have two highways that are approximately parallel in plan. One (the Upper highway) rises above the other (the Lower highway). The two highways are visible in the right image of Figure 56.6. In

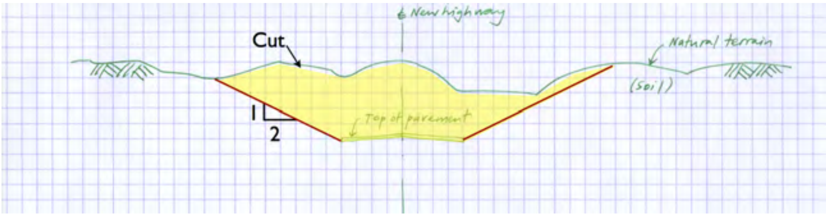


Figure 56.4: Cross-section through a new highway located below natural terrain. Section plane is vertical and intersects the path of the highway at 90 degrees.

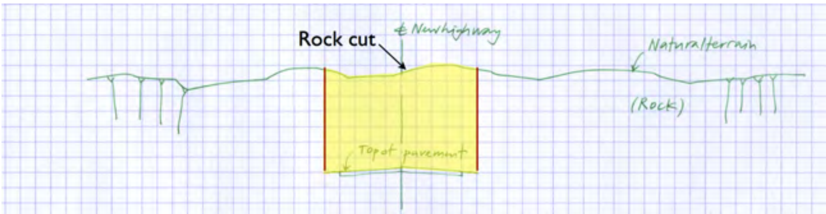


Figure 56.5: Cross-section of rock cut. Rock is sound, so vertical faces are possible

Figure 56.6: Retaining walls

the left image, the Upper highway rises from bottom left. Only the concrete barrier on the left edge of the Lower highway is visible in the left photo. The two highways are separated by a retaining wall.

The need for a retaining wall is made clear in the cross-section shown in the Figure 56.7, which is a schematic representation of the conditions shown in Figure 56.6. The section plane is vertical and perpendicular to the path of the highways. It is clear from Figure 56.7 that supporting the Upper highway on a fill sloped at 2 horizontal to 1 vertical would cover the existing Lower highway, which is not acceptable.

A common solution is to provide a retaining wall to hold back the fill. This condition is shown in Figure 56.8. The wall, most commonly made of reinforced concrete, has been designed and dimensioned to resist the horizontal pressure applied to it by the mass of soil it holds back. The retaining wall thus enables the Upper highway to be located relatively close to the Lower highway.

Retaining walls can be applied with equal effectiveness to cuts, where they are also used when a cut at 2 to 1 slope would result in an unacceptable encroachment on a specific feature.

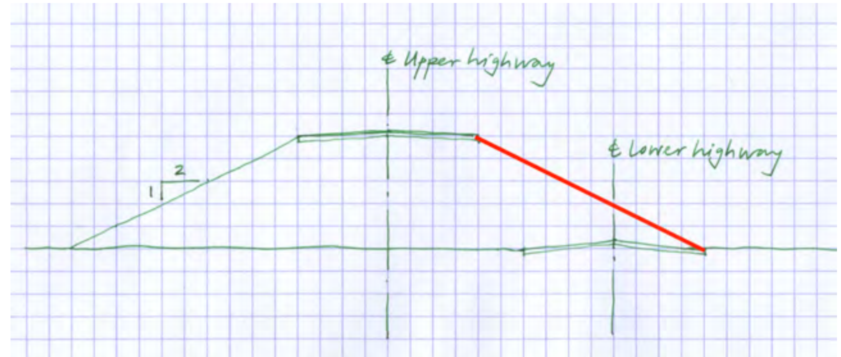


Figure 56.7: Earth fill for Upper highway at 2 horizontal to 1 vertical encroaches on Lower highway

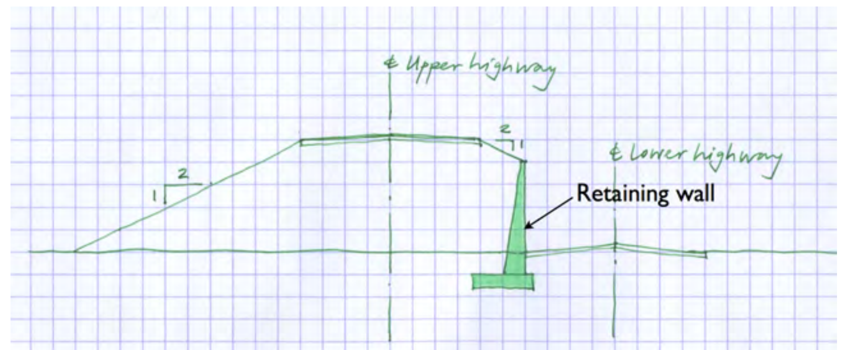


Figure 56.8: Solving the problem of Figure 56.7 with a retaining wall

56.2 *Drawing Cuts and Fills*

A common task in highway engineering is to locate and define geometrically the cuts and fills required for a new highway project. This information not only tells the contractor where to construct the required earthworks, it also enables the volume of earth that needs to be cut and filled to be estimated before the project has been bid. Ideally, the volume of earth that is cut should be approximately equal to the volume of fill that is required. In this way, little or no earth needs to be bought from other sources and little or no earth must be disposed of outside of the project.

56.2.1 Given Information

To define cuts and fills geometrically, a precise geometrical definition of the following features must be available at the outset:

1 *The existing terrain.* This is often natural terrain but it can also include previously constructed features. This information is generally represented by a contour map ▷ or by a precisely drawn three-dimensional landform.

See Chapter 10.

2 *The path of the new highway.* This is usually defined in terms of a *profile grade line*, which can be regarded as the path through three-dimensional space of a specific point that is present at each cross-section through the highway. A commonly used point is the top of finished pavement at the centreline of the highway.

3 *Typical cross-sections.* These are sections that are cut at 90 degrees to the profile grade line. They are not real cross-sections in the sense that they show only the primary features to be constructed. They do not show existing terrain. They must always show a point giving the location of the profile grade line. In general, one typical cross-section needs to be defined for each type of feature to be constructed. As a minimum, there will generally be a typical cross-section showing the highway on fill and the highway in cut.

Figure 56.9 shows three typical cross-sections. The top section shows the highway on fill. The middle section shows the highway in cut, and the bottom section shows the highway on structure. In all cases, the sections show the location of the profile grade line, the cross-slope of the highway (in this case 2%), and arrangement of traffic lanes, shoulders, sidewalks, and other features (in this case, there is a 2.0 m wide shoulder, two 3.6 m wide lanes, and another 2.0 m wide shoulder). Also given, where applicable, are the general geometric characteristics of the fill or cut slopes. In this case, a slope of 2 horizontal to 1 vertical is given. The height of the slopes is not given, since this depends on the conditions present at a real cross-section,

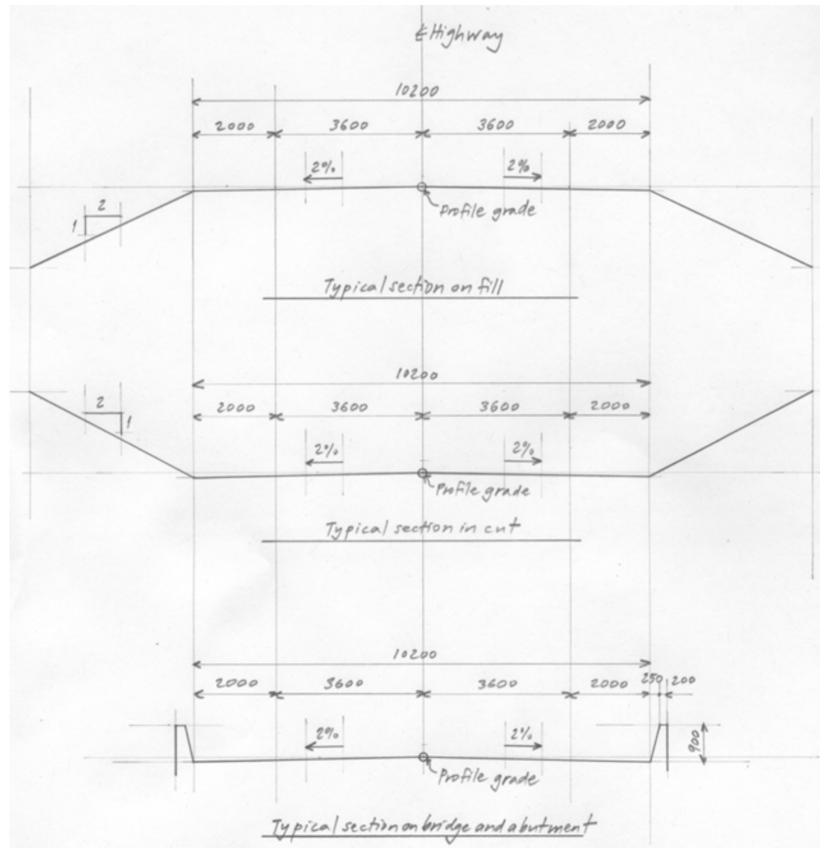


Figure 56.9: Typical highway cross-sections: on fill, in cut, and on bridge or abutment

i.e., the relation between the actual existing terrain and the typical section.

56.2.2 Required Drawings

To define cuts and fills geometrically, the following drawings must generally be produced:

1 A plan showing the highway and the terrain as modified by the proposed highway construction. On either side of the highway, it will show the extent of cuts and fills. One such drawing is shown in Figure 56.10. Although this drawing is not normally made in colour, colours have been provided here for additional clarity.

2 Cross-sections at regular intervals showing the geometric relation between the highway to be constructed and existing terrain. One such section is shown in Figure 56.11. This type of cross-section is relatively straightforward to draw if we know the vertical distance between profile grade line and existing grade, the cross-section of existing grade, and the typical cross-section. The area of fill or of cut can be calculated from this cross-section. If the cross-sections are provided at sufficiently close spacing, the areas obtained from the cross-sections can then be used to calculate the amount of cut or fill required along a given length of proposed highway.

56.2.3 Producing the Required Drawings: Two-Dimensional Method

The method used to produce the drawings described in the preceding section depends on the medium used for drawing. In this section, a method is described that is suitable for use when drawing by hand with instruments or when using only the two-dimensional functions of AutoCad.

1 Define a set of locations along the highway alignment at which sections will be drawn and calculations will be made.

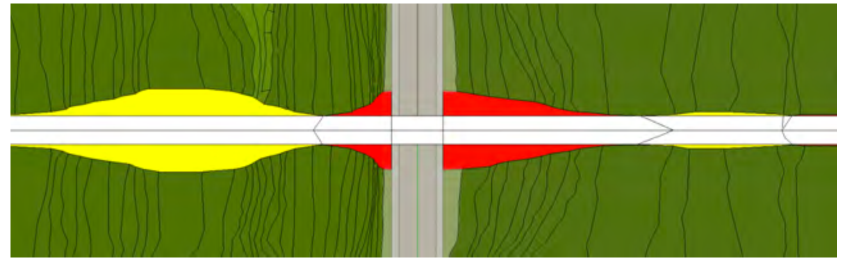


Figure 56.10: Plan showing proposed highway (running left to right), existing terrain (green), cuts (yellow), and fills (red). A bridge will be provided for the highway to cross the larger highway perpendicular to it.

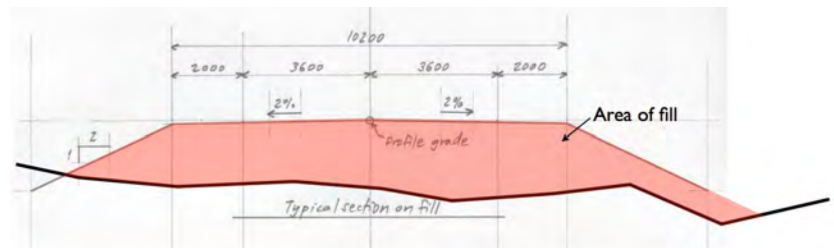


Figure 56.11: Example of a "real" cross-section on fill showing the relation between the typical highway cross-section (profile grade, lanes and shoulders, and fill slopes) and the existing terrain

2 At a given location, calculate the elevation of the profile grade line and the elevation of the terrain directly above or below profile grade. If profile grade is above terrain, then the highway must be on fill at this location. If profile grade is below terrain, then the highway must be in cut at this location.

3 Draw the cross-section of the highway and the terrain at this location. First draw the cross-section of the terrain ▷ . Then draw the typical section of the highway, making sure that the vertical distance between existing terrain and profile grade is the same as the distance calculated in the previous step.

The resulting cross-section will look similar to the section shown in Figure 56.12.

Use the method described in Section 10.4.

4 Measure the horizontal distance from centreline of highway to the points of intersection of the existing terrain and the man-made cut or fill lines. In Figure 56.12, these will be the distances from the centreline of highway to Points M and N. These are referred to as "toe" of fill or top of cut.

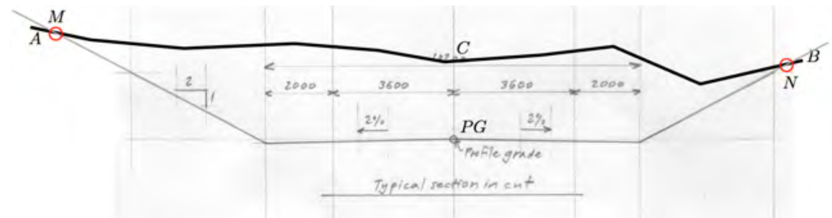


Figure 56.12: Example of a "real" cross-section in cut

5 On the plan, plot the top of cut or toe of fill determined in the previous step. (At the given location along the highway, measure perpendicular to the highway the distances determined in the previous step.)

6 Proceed in this way for every location in the set defined in the first step of this procedure.

7 On the plan, join the points corresponding to toe of fill and top of cut. The resulting drawing will look like the one in Figure 56.10, without the colours.

This method is generally applied at discrete points, and thus it cannot determine directly the point at which cut transitions to fill and vice versa. The situation is illustrated using the two cross-sections shown in Figures 56.13 and 56.14.

The plan drawn in Figure 56.14 is not correct, since the line defining the toe of fill and top of cut is straight between Points C and D one one side of the highway, and between Points E and F on the other. This would imply that between Sections 1 and 2, it is either entirely cut or entirely fill, which is incorrect. We need to locate a point on both sides of the highway at which fill transitions into cut.

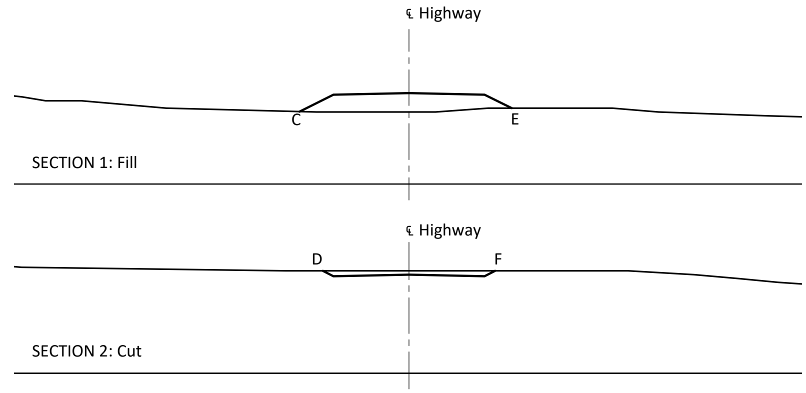


Figure 56.13: Two adjacent cross-sections: Section 1 is in cut and Section 2 is on fill

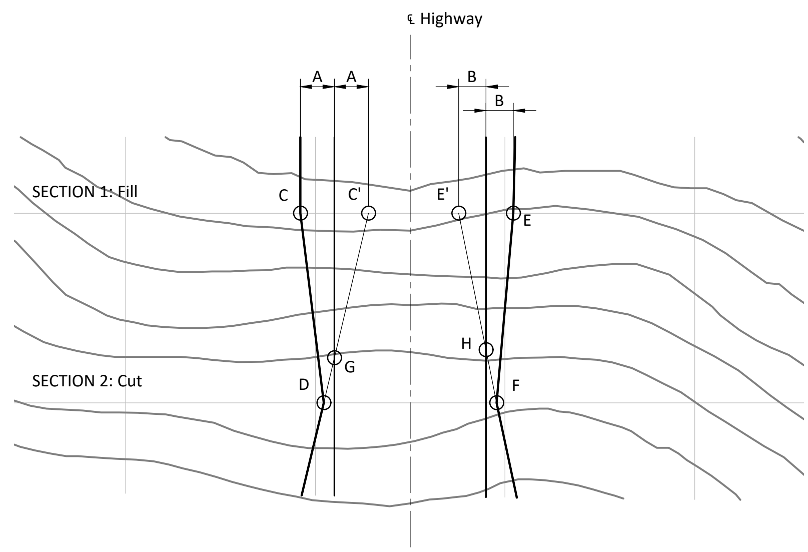


Figure 56.14: Plan showing the location of the two sections of Figure 56.13

We could cut more sections at intervals between Sections 1 and 2, but instead we will use an approximate graphical method based on linear interpolation. This is shown in Figures 56.14 and 56.15. We begin by marking off Points C′ and E′, which are equidistant from the edge of the roadway from the corresponding points C and E. We then draw straight lines C′D and E′F. The intersections of these lines with the edge of the roadway, Points G and H, are linear approximations to the points of transition between cut and fill.

We can the draw the approximate curve corresponding to toe of fill/top of cut as CGD on one side of the highway and EHF on the other (Fig. 56.15).

56.2.4 Producing the Required Drawings:Three-Dimensional Method

If a CAD software with good three-dimensional functions (like SketchUp) is available, then the process just described can be automated considerably. Before we begin, a precise three-dimensional landform of the existing terrain and a three-dimensional line corresponding to profile grade must be available.

We proceed as follows:

1 Starting from the profile grade line, draw a surface consisting of the top of the roadway and shoulders on both sides of profile grade and then, on both sides, sloping surfaces corresponding to the cut slopes. The same can be done at the same time for fills.

This should be made into a group and assigned to a layer so it can be hidden and made visible easily.

2 Move this surface into the proper position in the landform. The situation is shown in Figure 56.16.

3 Selecting both the surface just described and the landform. Then, right-click anywhere in the selected objects and choose `Intersect`

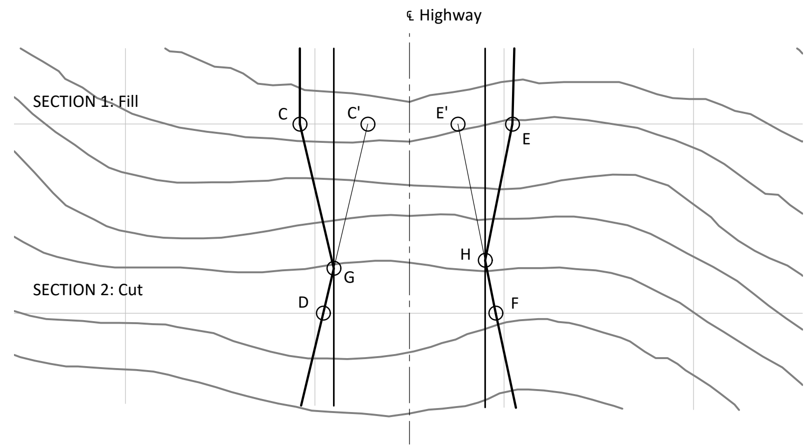


Figure 56.15: Plan showing the location of the approximate curve for the transition between cut and fill

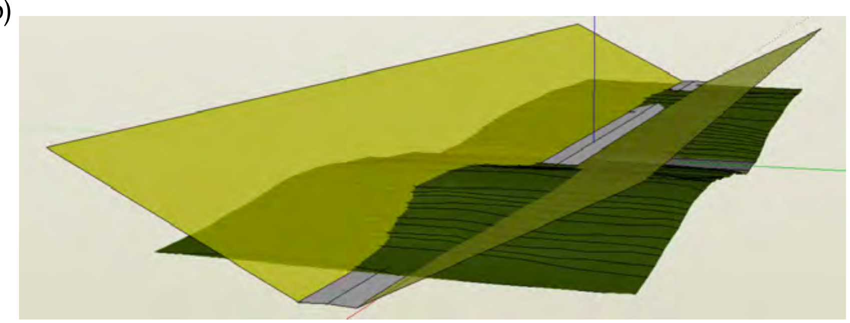


Figure 56.16: Defining top of cut in SketchUp

`Faces → With Model`. This creates an edge along the intersection of the inclined surface corresponding to the cut or fill slope and the existing landform.

4 Using the Eraser tool, trim off all portions of the cut and fill planes that extend beyond the landform.

5 If the landform is a group, explode it.

6 Where the landform will be trimmed back to make cuts, select the portion of the landform between the cut lines and make this portion of the landform into a group (called, say, "Earth in cut"). Put it on its own layer.

7 Make a group of the remaining landform and assign it to its own layer.

8 Plot the plan by hiding the `Earth in cut` group.

9 Plot sections by showing the `Earth in cut` group.

Appendices

A
Course Drafting Standards

It is common for engineering firms and organizations that retain the services of engineers (such as the Ministry of Transportation of Ontario) to require that drawings be prepared in accordance with *drafting standards* ▷ . Drafting standards prescribe requirements that include specifications for borders, title blocks, arrangement of views, line weights, text size and shape, dimensioning, and annotation. When these requirements are followed, drawings prepared by different people will project a high degree of uniformity in their appearance.

The Ministry of Transportation of Ontario's drafting standards, for example, can be found in the Ministry's Structural Manual*, which can be downloaded from the Ministry's Online Technical Library:* https://www.library.mto.gov.on.ca/search.asp?mode=search*. Just type "Structual Manual" into the search engine.*

Drafting standards restrict the freedom of engineers to present their drawings in the way they see fit. It is therefore important that standards be developed with due care and attention to the clarity and completeness of the drawings that will result from their use. Standards must not lead to drawings that are difficult to work with.

This appendix presents the drafting standards that will be used in this course. They apply to drawings prepared using AutoCad and the SketchUp/LayOut combination. (They do not apply to freehand drawings.)

The ultimate objective remains the creation of drawings that are correct, clear, and complete. Application of these and any drafting standards will generally be of considerable help in achieving this objective. For this reason, compliance with the standards defined in this appendix is generally expected for all CAD work in the course. Even the best standards, however, cannot anticipate all situations that will be encountered in the process of creating drawings. Some of the provisions in these standards are therefore not written in purely prescriptive language but rather require decisions to be made based on the specific factors related to a given drawing. There will also be cases where compliance with specific provisions in these standards will make it difficult or impossible to create drawings that are correct, clear, and complete. In such cases, (and only in such cases), it is preferable to take such steps as necessary to produce drawings that are correct, clear, and complete rather than to comply with the standard.

A.1 Drawing Templates

A.1.1 General

1 *Drawings shall be created using the template files provided.*

Many of the details of these drafting standards are implemented by means of the template files. They contain many of the standard settings such as line weights, text size and shape, border, and title block. Saving all of these items in a standard template means that students do not have to set these items themselves every time they draw. This saves considerable time.

In this course, templates have been provided for AutoCad, SketchUp, and LayOut ▷ .

See Sections A.1.2, A.1.3, and A.1.4.

2 *The templates provided for this course shall not be modified, except as directed in this Standard or in the instructions for the Exercises given in these Course Notes.*

A.1.2 AutoCad

1 *The AutoCad template available at the link given to the right shall be used ▷ .*

Link to download the course AutoCad template: `http://www.ecf.utoronto.ca/apsc/courses/civ235s/Templates/CIV_235_template.dwg`.

The AutoCad template has a Model Space that contains a cross-section of a single-cell box girder bridge. It contains one Layout in Paper Space, which is shown in Figure A.1. This layout contains a border, a title block, section symbols, and a north arrow. It also contains a single viewport that shows the cross-section drawn in the Model Space.

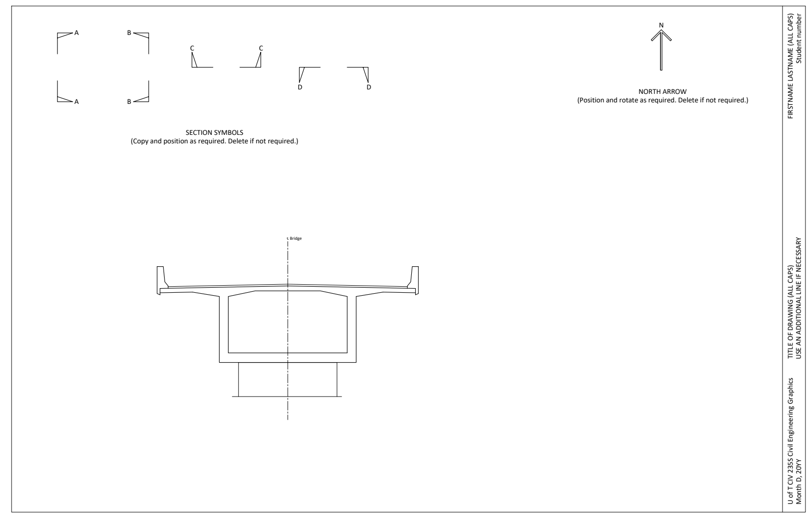


Figure A.1: A view of Layout1 (Paper Space) provided in the AutoCad template

Section cut symbols have been provided ▷ . These can be copied and positioned as required. If they are not required, they must be deleted. The title that begins with "SECTION SYMBOLS" can be re-used as a template for other titles or deleted.

See Section A.13.

A north arrow has been provided ▷ . It can be positioned and rotated as required. If it is not required, it must be deleted.

See Section A.14.

The AutoCad template also contains all of the layers and text styles required to create drawings in this course.

2 *A specific Colour-Dependent Plot Style Table, or* `.ctb` *file shall be used in conjunction with the AutoCad template.*

The required `.ctb` file is available at the link given to the right ▷ .

Link to download the corresponding `.ctb` file: http://www.ecf.utoronto.ca/apsc/courses/civ235s/Templates/CIV235.ctb.

This file must be linked to the AutoCad software running on your computer. To do so, proceed as follows:

(a) Start up AutoCad.

(b) Return to Windows and copy the `CIV235.ctb` file.

If you are logged into the ecf secure network environment ▷ during class, navigate to the `S:\Courses\civ235\Source\` directory and copy the `CIV235.ctb` file.

See Section 4.2.

If you are working on your own computer, download the `CIV235.ctb` file to your computer using the link given previously and copy it in Windows.

(c) Return to AutoCAD and locate the directory in which the plot style files reside by typing the command `stylesmanager` and `enter`. This will open a window that contains the plot style files. Paste the `CIV235.ctb` file into this directory.

A.1.3 SketchUp

1 *The SketchUp template available at the link given to the right shall be used* ▷ .

Link to download the course SketchUp template: http://www.ecf.utoronto.ca/apsc/courses/civ235s/Templates/CIV_235_template.skp.

This template contains one component representing a concrete bridge segment.

It also contains standard styles ▷ that must be used in the drawings to be created in this course.

See Section A.16.

2 *The SketchUp template shall be used in conjunction with the LayOut template* ▷ .

See Section A.1.4.

A.1.4 LayOut

1 *The LayOut template available at the link given to the right shall be used* ▷ .

Link to download the course LayOut template: http://www.ecf.utoronto.ca/apsc/courses/civ235s/Templates/CIV_235_template.layout.

As shown in Figure A.2, samples of text, line types, section symbols, and a north arrow are provided outside the page boundary. All of these items have been assigned to a layer called "Style Samples". This layer has been locked to prevent inadvertent modification. These items not be printed, and do not need to be deleted. These can be moved and copied as required. The centrelines, dimensions, leaders, and different types of text that appear outside the page boundary are correctly formatted, and these formats must be applied in the drawing (i.e., within the print area).

To do so, use the Style Tool (Fig. A.3). Click on an example given to the left of the print area to sample the style and then click on the object in the print area to apply the style you have sampled.

The LayOut template contains no links to SketchUp files. These must be added as drawings are created.

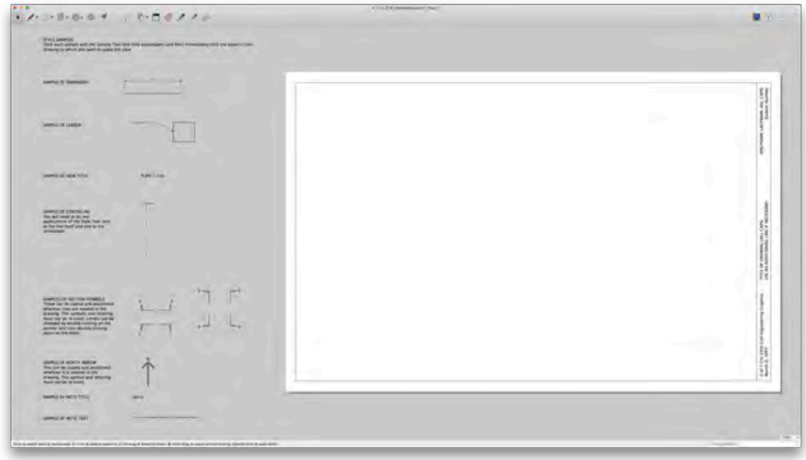


Figure A.2: A view of the LayOut template

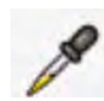


Figure A.3: LayOut Style tool

2 *The LayOut template shall be used in conjunction with the SketchUp template* ▷ .

See Section A.1.3.

A.2 Units

1 *All drawings created in this course shall use metric units.*

The drawing templates for AutoCad, SketchUp, and LayOut ▷ have all been set up in metric units.

See Sections A.1.2, A.1.3, and A.1.4.

A.3 Format of Work for Submission

1 *All drawings shall be formatted for printing (or output to pdf) on 11 by 17 (Tabloid) paper, in landscape orientation (long side horizontal).*

The drawing templates for AutoCad and LayOut ▷ have been set up for printing in this format.

See Sections A.1.2 and A.1.4.

2 *Drawings prepared in AutoCad shall be printed (or output to pdf) from Paper Space.*

3 *Drawings prepared in SketchUp shall be printed (or output to pdf) from LayOut.*

A.4 Border and Title Block

1 *Drawing shall use the standard border and title block.*

Border and title block have been provided in the AutoCad and LayOut templates ▷ .

See Sections A.1.2 and A.1.4.

2 *The border and title block given in the AutoCad and LayOut templates shall not be changed, except as follows*:

(a) Change the generic date "Month D, 20YY" to the current date. The format must be maintained, so "January 15, 2020" is valid but other formats such as "01/15/20" are not valid.

(b) Change the text beginning "TITLE OF DRAWING" to the actual title of the drawing. The title can occupy one or two lines.

(c) Change the text "FIRSTNAME LASTNAME (ALL CAPS)" to your name.

(d) Change the text "Student number" to your student number.

In all cases, the capitalization and text style as given in the template shall be maintained.

A.5 Primary Linework

Primary linework refers to the appearance (type and weight) of the lines used to delineate the objects depicted in the drawings. Requirements governing other types of line, including centrelines, dimension lines, and leaders, will be defined in other sections ▷ .

See Sections A.10, A.13, and A.11.

A.5.1 AutoCad

1 *Primary linework shall be drawn in Model Space.*

2 *Lines shall generally be assigned to layers according to their position relative to the viewing plane and the viewpoint ▷ , according to Table A.1*

See Sections 7.1 and 7.2.

When the view is a section, the *primary edges* are formed by the intersection of the object and the section plane ▷ . When the view is not a section, the primary edges are normally those that define the visible outline of the object and, in some cases, important features within the outline.

See Section 7.4.

Table A.1: Layer Assignments for Primary Linework in AutoCad

Layer Name	Application
Thicker	Primary edges
Thick	Primary edges
Thin	Visible edges other than primary edges
Hidden	Edges that are hidden by other features of the object

3 *It is up to the person creating the drawing to decide on whether or not the primary edges should be assigned to the "Thick" layer or the "Thicker" layer.*

In most cases, the greater the complexity of the primary edges, the greater the benefit in choosing "Thick" instead of "Thicker". The decision should be made on which layer results in the greater clarity. In a given view, only one layer shall generally be used for all of the primary edges.

4 *Hidden lines shall be drawn only when doing so will enhance the clarity of a given view. When hidden lines detract from clarity, they shall not be drawn.*

A.5.2 SketchUp/LayOut

1 *Primary linework shall be drawn in SketchUp.*

2 *The appearance of the lines that delineate the objects depicted in a given drawing is not determined individually using layers, as in AutoCad, but rather is determined for all lines in a given view based on the choice of style in SketchUp ▷ .*

See Section A.16.

Although there is a way SketchUp to display hidden lines, there no suitable way to gain control over which hidden lines are actually displayed. It is either all are displayed or none. This can lead to confusing views that contain a jumble of hidden lines that add little value to the drawing. For this reason, hidden lines will not be drawn in this course when SketchUp and LayOut are used.

A.6 Centrelines

A.6.1 General

1 *When a given view of an object has one or more axes of symmetry, these shall be shown by drawing centrelines using the correct linetype.*

The cross-section shown in Figure A.4 has an overall vertical axis of symmetry. It has been indicated using a line with a distinctive long-short-long dashed style. This line has been labeled as the centreline of the bridge. (The centreline symbol shown in the drawing is not available in most font families used in text processing, so it cannot be reproduced here.) In addition each of the webs (the two vertical components of the cross-section) are locally symmetrical. They have also been indicated using a centreline and have been labeled as such.

2 *Centrelines shall be labeled with the standard centreline symbol followed by the name of the component associated with that centreline. In situations where the standard centreline symbol cannot be produced by the software in use, the letters "CL" my be used.*

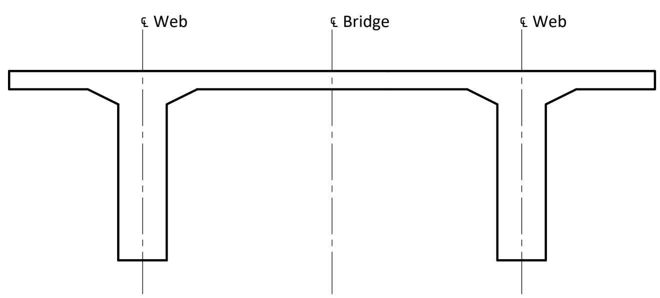


Figure A.4: Example of centrelines

Examples are given in Figure A.4.

3 *The label shall normally be positioned at the top of the centreline. For horizontal lines, the label shall normally be positioned to the left. Where this kind of labeling reduces clarity, it is acceptable to position the label at the bottom of the centreline or to use a leader ▷ .*

See Section A.11.

When centrelines are used as a reference for dimensioning ▷ , it is sometimes necessary to position the centreline label at the bottom of the centreline or to use a leader, since positioning the label at the top of the centreline can conflict with dimensions.

See Section A.10.

A.6.2 AutoCad

1 *Centrelines shall be assigned to the layer "Centre".*

This automatically sets the line style (weight and pattern of dashes) correctly.

2 *Labels shall be assigned to the layer "Text" text layer. Text style shall be "Calibri 1.5mm".*

3 *When labels are drawn in Model Space, annotation scaling shall be set to the scale at which the view will be plotted in Paper Space.*

Setting the Annotation Scaling ▷ correctly ensures that the text will appear at a uniform size in Paper Space even though views might be drawn at different scales.

See Section 17.3.

A.6.3 SketchUp/LayOut

1 *In SketchUp/LayOut, centrelines shall be drawn in LayOut.*

Objects in LayOut can be snapped to relevant points in the embedded SketchUp model.

2 *In LayOut, type and style of centreline as well as shape and size of text shall be sampled from the area to the left of the drawing area and applied to the centrelines and labels in the drawing area.*

A.7 Scale

1 *All drawings shall be made to scale* ▷ . *See Chapter 9.*

2 *Only standard metric scales shall be used* ▷ . *See Section 9.3.*

3 *The choice of scale shall enable a rational arrangement of views that maximizes the clarity of a given drawing.*

4 *Second preference scales shall only be used when use of a first preference scale produces an unacceptable arrangement of views* ▷ . *See Section A.8.*

5 *Linked views* ▷ *shall all be drawn to the same scale.* *See Section 7.5.*

A.8 Arrangement of Views

1 *Views shall be arranged in a manner that is logical, that maximizes clarity, and that reflects professionalism.*

2 *Unless it detracts from clarity, linked views* ▷ *shall be aligned according to shared geometric relationships* ▷ *See Section 7.5.* *See Figures 7.23 and 7.25.*

A.9 View Titles

A.9.1 General

1 *All views shall be given a suitable one-line title that consists of the type and scale of the view. Text shall be ALL CAPS.*

Examples of suitable view titles include: PLAN 1:100, SECTION 1:20, and ELEVATION 1:500.

2 *A second line, written in upper and lower case letters, may be included if required.*

This will often be an identification of the location in the object from which the view was taken.

3 *Titles shall be located below the view to which they are associated. They shall be centered on the perceived centre of the view.*

The perceived centre of the view is the point that *looks like* the centre. It may be different from the midpoint between the extreme left and right points of the view.

A.9.2 AutoCad

1 *View titles shall be added in Paper Space.*

2 *View titles shall be assigned to the layer* `Text`.

3 *View titles shall be assigned the text style* `Calibri 2.5mm`.

A.9.3 SketchUp/LayOut

1 *View titles shall be added in LayOut.*

2 *Style information (shape and size of text) shall be as given for the "SAMPLE OF VIEW TITLE" in the set of samples given to the left of the drawing area in the LayOut template.*

This information should be sampled using the Style tool ▷ and applied to the view title text.

See Section A.1.4.

A.10 Dimensions

A.10.1 General

An example of *basic linear dimensions* is shown in Figure A.5, a cross-section of a precast concrete I-girder. (Figure A.6 shows the use of concrete I-girders in bridge construction.) Each dimension consists of:

1. *The dimension quantity.* All of the numbers given in Figure A.5 are dimension quantities. The dimension quantity is the length of the component of the object indicated.
2. *The dimension line.* This is a line that generally has arrows at both ends. The line directly beneath the number "910" in Figure A.5 is a dimension line.
3. *Extension lines.* Each dimension has two extension lines. They touch the ends of the dimension line and are perpendicular to it. They extend from a point close to the object to a point beyond the dimension line.

Dimensions shall be drawn in accordance with the following requirements:

1. *A complete set of dimensions shall be provided for all objects unless stated otherwise in a given drawing exercise.*

   A complete set of dimensions has been given for the cross-section shown in Figure A.5. The dimensions provided are sufficient to enable formwork to be constructed for a concrete girder with a cross-section identical to the one shown in the figure.

   In some cases, it is necessary to provide more than one view to create a complete set of dimensions.

2. *Dimensions shall be arranged logically. Related features of a given object shall be dimensioned using multiple collinear dimension lines together with several extension lines, unless this compromises clarity.*

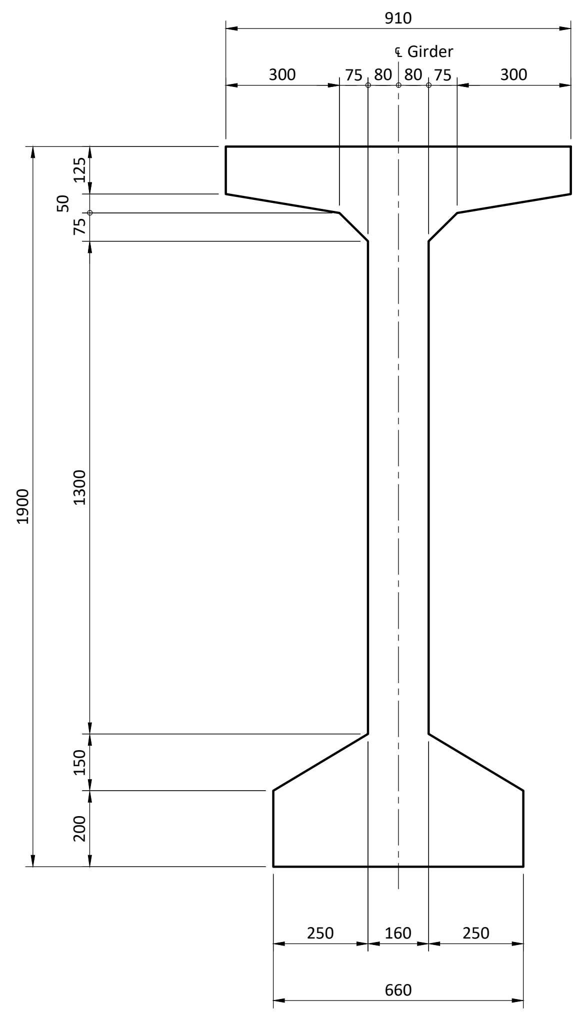


Figure A.5: Example of dimensions for the cross-section of a precast concrete I-girder. For a photograph of a typical application of precast concrete I-girders in bridge construction, see Figure A.6

In Figure A.5, for example, the vertical dimensions of the points on the left-hand face of the girder have drawn using collinear dimension lines that appear as one vertical line of dimensions, which has been positioned to the right of the overall "1900" dimension.

3 *Hierarchical dimensions shall be provided.*

When a line of multiple dimensions is given, such as the line of vertical dimensions immediately to the left of the cross-section in Figure A.5 or the horizontal row of dimensions immediately above the cross-section, another dimension shall be provided with *the sum of this line of mutiple dimensions.* In Figure A.5, for example, the sums of these two lines of dimensions (1900 for the vertical line and 910 for the horizontal line) have also been dimensioned.

Several levels of hierarchical dimensions shall be provided as required. Figure A.7, for example, shows multiple levels of hierarchical dimensions.

4 *Redundant dimensions shall not be provided, except when hierarchical dimensions are used or in situations where not providing them would result in a significant loss of clarity.*

A redundant dimension is one that can be omitted from the view without compromising the completeness of the the description of the object. Strictly speaking, hierarchical dimensions are always redundant, because the innermost level row of multiple dimensions provides a complete description. The outer level dimensions, such as the "910" dimension in Figure A.5, have been provided for convenience. It is common for users of drawings to require the overall dimensions of a given object and inconvenient (and possibly a source of error) to have to add up inner-level dimensions each time the overall dimension is required.

Figure A.6: Application of precast concrete I-girders (with cross-section similar to the one shown in Figure A.5) in bridge construction

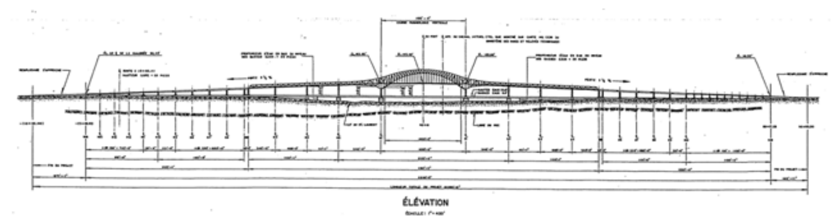


Figure A.7: Elevation of the Laviolette Bridge across the St. Lawrence River near Trois-Rivières, Québec. For a photograph of this bridge, see Figure 7.28.

In the cross-section of Figure A.8, the dimensions in the horizontal row immediately above the object, and to the right of the centreline ("80", "75", and "300") are strictly speaking redundant, since the centreline implies an axis of symmetry ▷ . Providing only the dimensions to the left of the centreline as shown in Figure A.8, together with the symmetry of the object as established by the centreline, provides enough information to define the geometry of the cross-section completely.

See Section A.6.

When we use hierarchical dimensioning as required by this Drafting Standard, however, we need to provide the dimensions on both sides of the centreline since the outer level dimension must be the sum of the dimensions on the inner row. The cross-section of Figure A.8 is thus incorrect.

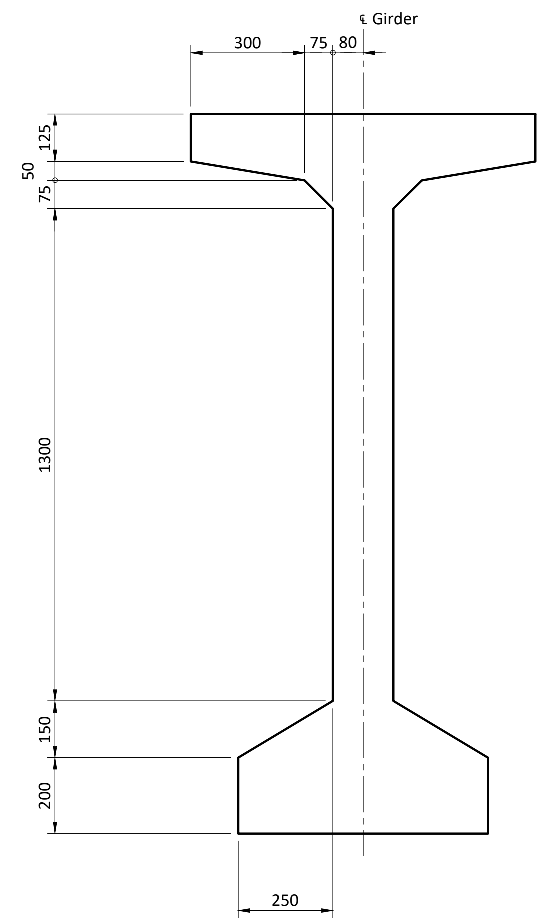


Figure A.8: A complete set of dimensions for the cross-section shown in Figure A.5. This set of dimensions, which has taken advantage of symmetry and omitted hierarchical dimensioning, is not in accordance with the Drawing Standard of this course

5 *The dimension quantity shall be the length of the object between extension lines, projected onto a line parallel to the dimension line.*

In Figure A.9, for example, the dimension quantity "150" is not the true length of the true length of segment AB. The dimension quantity indicates the length of the projection of this segment onto a line parallel to the dimension line, which in this case is vertical. In most cases, better clarity is gained when dimensions are given as projections on the horizontal or vertical axis, rather than true lengths of inclined lines.

6 *Centrelines shall be used, where possible, as references for dimensions. In such cases, the corresponding extension line shall not be drawn. The centreline serves this purpose.*

The centreline is used in Figure A.9, for example, as a reference form the inner row of dimensions above the object. Note that no extension line has been provided at the centreline, i.e., the centreline has not been obscured by a solid extension line.

7 *Centrelines shall not cross dimension lines except where they serve as extension lines.*

This is also shown in Figure A.9. The centreline crosses the inner line of dimensions above the object because the centreline serves as an extension line for the two "80" dimensions. It does not cross the "910" dimension, however, because the extension lines for this dimension are at the edges of the object.

8 *Keep dimensions outside the object, except if this compromises clarity. It is acceptable for extension lines to enter a given object, provided the dimension lines and the dimension quantity are outside.*

9 *Extension lines shall point to visible features in the object. Use additional views to avoid having to dimension to hidden lines.*

10 *Sufficient space shall be provided between the object and dimension lines, and between parallel dimension lines. The space provided shall*

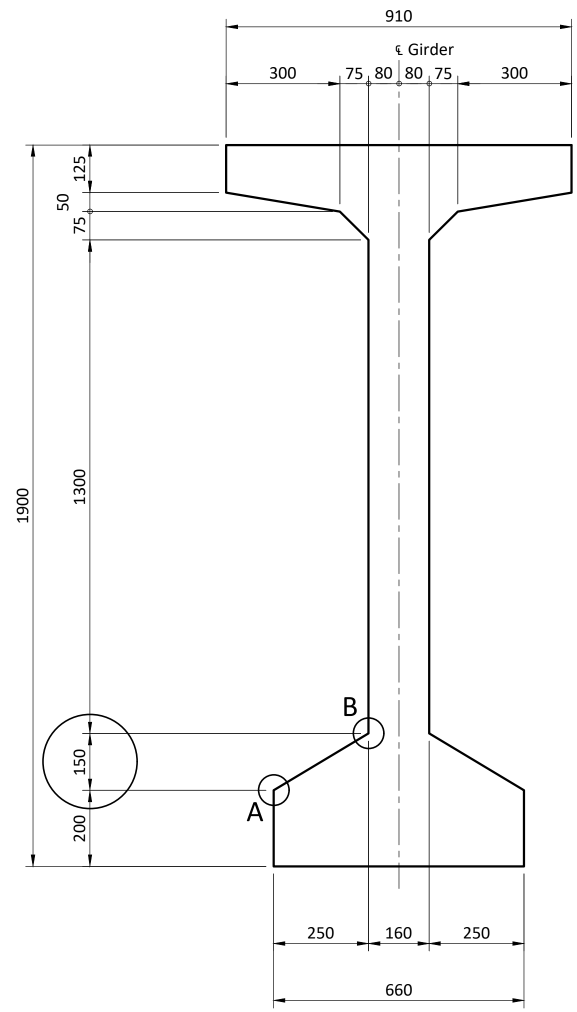


Figure A.9: Example of dimensions for the cross-section of a precast concrete I-girder. The circles and the annotations "A" and "B" refer to discussions in the text and do not form part of the drawing.

be consistent within the entire drawing. In cases where there are no centreline labels between dimension lines and no "tight" dimensions need be accommodated ▷ *, the space shall be approximately 7 mm.*

See Point 12.

11 *Dimensions shall be created using the appropriate commands and styles in the AutoCad and LayOut templates.*

The appropriate commands and styles in the templates provide a correct implementation of the following requirements governing dimensions:

(a) *All dimensions shall be given in millimetres. The units shall not be given.*

So in Figure A.10, the dimension with dimension quantity "910" refers to a length of 910 mm.

(b) *Extension lines shall not touch the object they are dimensioning.*

The gap between extension lines and the object is visible in Figure A.10. It shall be large enough to be evident but small enough so that it clearly identifies the point on the object that the extension line is pointing to.

The gap drawn using the AutoCad template is optimal. Due to limitations of the software, the gap drawn using the Dimension command in LayOut is generally larger than optimal. This does not need to be modified.

(c) *Dimension quantities shall be placed above horizontal dimension lines and to the left of vertical dimension lines, and oriented parallel to the corresponding dimension lines.*

As shown in Figure A.10, for example, the dimension "1900" has been rotated to align it with the vertical dimension line. The dimension lines are continuous from extension line to extension line. They are not broken to accommodate the dimension quantity.

(d) *Arrowheads shall be provided at the ends of dimension lines, except as specified in Point 12.*

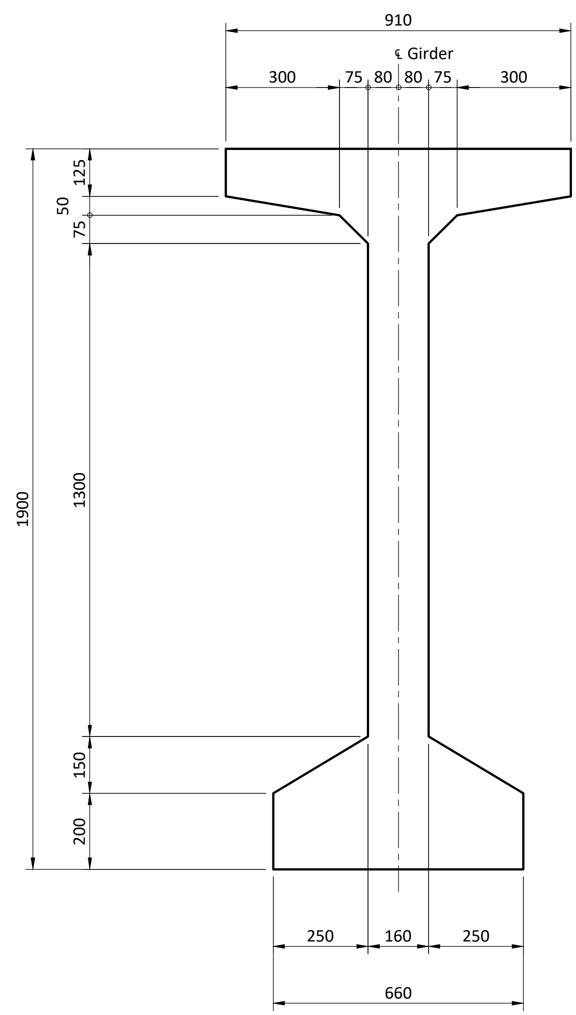


Figure A.10: Example of dimensions for the cross-section of a precast concrete I-girder

12 *The dimension quantity shall fit within the extension lines and within the "fat" ends of the dimension arrows. When these conditions cannot be satisfied, the dimension quantity shall be moved and, in some cases, the arrow shall be replaced with a dot.*

This requirement is illustrated in Figures A.11 and A.12.

Figure A.11 shows dimensions as output from AutoCad without any significant intervention by the draftsman. The "300" dimensions (B, D, F, I, and L) are displayed in accordance with this Drawing Standard. The other dimensions are incorrect. It is not a coincidence that the problems all lie with the short or "tight" dimensions.

Figure A.12 shows the same dimensions after modification by the draftsman. They are now fully in accordance with the Drawing Standard. Individual modifications are described in the following list:

(a) *Dimensions A and C.* The problem is that AutoCad does not draw the dimension line between the two arrowheads. These lines were added by the draftsman and are shown in Figure A.12.

(b) *Dimension E.* AutoCad places the dimension quantity to the side of the two arrowheads, as it did for Dimension A. Unfortunately, it is now in conflict with the dimension quantity for Dimension F. In addition, the dimension line is not drawn between the two arrowheads. To correct this dimension, it is necessary to *explode* the dimension. This divides the dimension into its individual components, which enables the dimension quantity to be moved into a better location. In this case, it is centered between the extension lines and slightly above the other dimension quantities, so that it does not touch the extension lines. The dimension line is then drawn between the two arrowheads.

(c) *Dimensions G and H.* Here, the dimensions produced by AutoCad have illogical arrowheads. When two arrowheads meet at a point, we expect to have another arrowhead at the opposite end of the dimension. This is not the case. In such cases, the solution is to remove the arrows at the extension line between G and H, and to

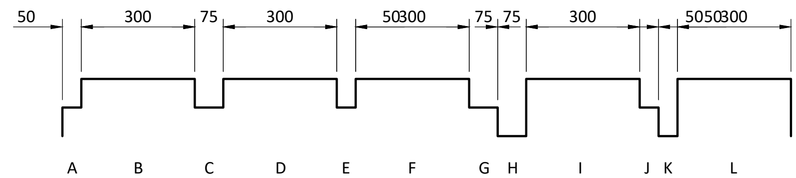


Figure A.11: Examples of the display of "tight dimensions" as produced by AutoCad with no subsequent intervention. Dimensions are generally not in accordance with the Drawing Standard

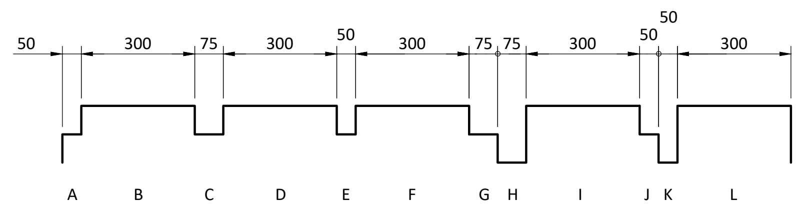
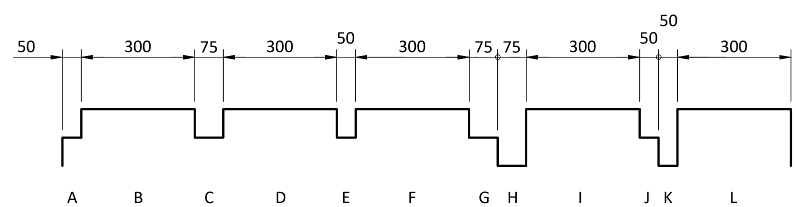


Figure A.12: Examples of the display of "tight dimensions" as produced by AutoCad with subsequent modification to create a set of dimensions in accordance with the Drawing Standard



replace them a point. The dimension lines have also been added to make the overall dimension line continuous.

(d) *Dimensions J and K*. The situation is a combination of the problems with Dimensions G and H and Dimension E. It is necessary to remove the arrowheads and add the point, and also to shift the dimension quantities upward. In this case, it was necessary to use two different levels for the dimension quantities.

A.10.2 AutoCad

1 *Dimensions shall be assigned to the layer "Dimension".*

2 *If dimensions are added in Model Space, then the* annotation scale *of the dimension shall correspond to the scale at which the view will be drawn in Paper Space.*

It is recommended that dimensions be added in Paper Space, which will automatically ensure that dimension text and arrows are of the correct size.

A.10.3 SketchUp/LayOut

1 *Dimensions shall be added in LayOut.*

2 *Style information (line type and weight, shape and size of text) shall be as given for the "SAMPLE OF DIMENSION" in the set of samples given to the left of the drawing area in the LayOut template.*

This information should be sampled using the Style tool ▷ and applied to the view title text.

See Section A.1.4.

A.11 Leaders

A.11.1 General

Leaders are lines that link a feature in an object to a textual annotation. In Figure A.13, for example, a leader has been drawn to identify the circular objects (piles) and to state their diameter.

1 *Leaders shall be used to dimension circles and circular arcs, and otherwise only when they increase clarity.*

In Figure A.13, for example, the leader gives the diameter of the circular piles.

In general, leader text shall be written in standard plain English. Some standard abbreviations can, however, be used, such as the abbreviation "typ." as shown in Figure A.13. This abbreviation stands for the word "typical", which means that the annotation that precedes it (600 mm diameter pile) applies to all instances of identical objects in the view, i.e., all circles of the same size.

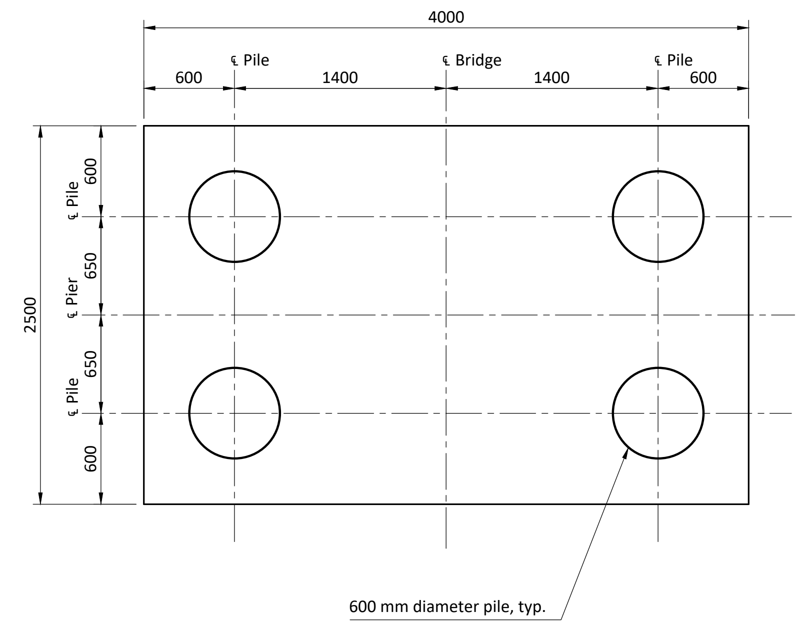


Figure A.13: Plan of pilecap with centrelines, dimensions, and a leader

A.11.2 AutoCad

1 *Leaders shall be assigned to the layer "Dimension".*

2 *If leaders are added in Model Space, then the* annotation scale *of the leader shall correspond to the scale at which the view will be drawn in Paper Space.*

3 *Leaders shall consist of one or more diagonal straight lines and horizontal text. The leader line in direct contact with the feature in the object shall be as close as possible to normal to the feature.*

A.11.3 SketchUp/LayOut

1 *Leaders shall be added in LayOut.*

2 *Style information (line type and weight, shape and size of text) shall be as given for the "SAMPLE OF LEADER" in the set of samples given to the left of the drawing area in the LayOut template.*

This information should be sampled using the Style tool ▷ and applied to the leader text.

See Section A.1.4.

3 *Leaders shall consist of a single curved line and horizontal text. The leader line in direct contact with the feature in the object shall be as close as possible to normal to the feature.*

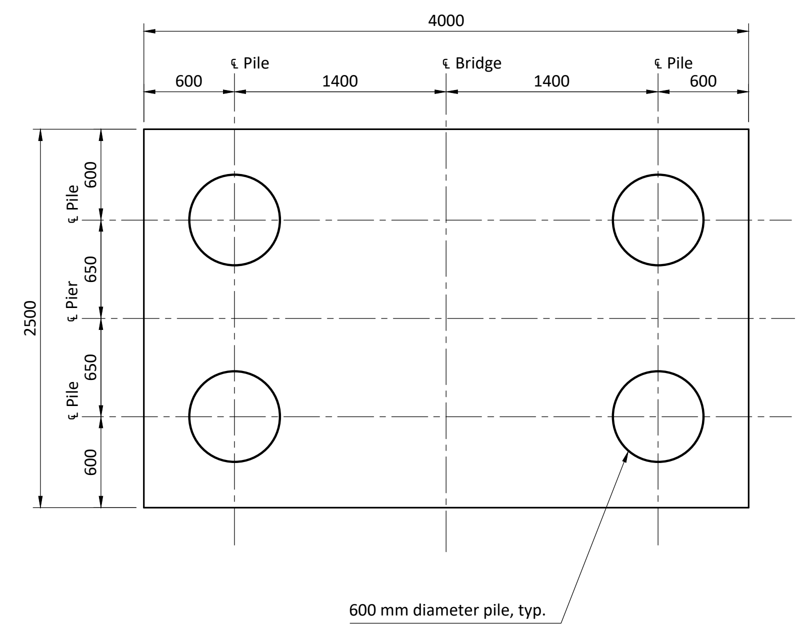


Figure A.14: Plan of pilecap with centrelines, dimensions, and a leader

A.12 Dimensioning Circles

1 *Circles and circular arcs shall be dimensioned using leaders and suitable annotations, not using linear dimensions.*

The normal way of dimensioning circles is shown in Figure A.14.

The position of a given circle is normally identified through the use of two perpendicular centrelines as shown in Figure A.14. In this case, both centrelines are labeled "CL Pile". A leader is then used to specify the diameter of the circle. Units are always given, e.g. "600 mm diameter" in Fig. A.14. This is in contrast to linear dimensions ▷ , for which units are not given.

See Section A.10.1.

2 *Style and other requirements for dimensioning circles in AutoCad and SketchUp/LayOut are as given for leaders* ▷ .

See Sections A.11.2 and A.11.3.

A.13 Sections

A.13.1 General

1 *View titles for sections shall be of the form: SECTION X-X, where X is a unique letter identifier for the section.*

2 *In a given drawing, the letter identifiers for sections shall begin with A and increase in alphabetical order.*

3 *For each section view, there shall be another view, that shall not be a section, that clearly shows the location of the section plane, the direction of view, and the unique letter identifier of the section.*

In Figure A.15, for example, the location of the section plane and direction of view of Section A-A are identified by the section symbol shown in the Elevation view. The two vertical lines of the section symbol correspond to the location of the section plane. The pointed ends of the section symbol indicate the direction of view. The letters A and A at the ends of the points identify the section view elsewhere in the drawing.

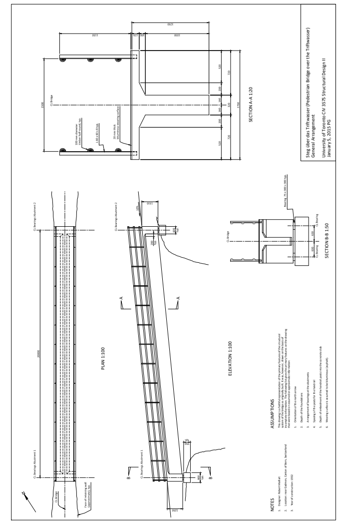


Figure A.15: Footbridge over the Triftwasser, Switzerland. Design: Robert Maillart. General Arrangement containing Sections A-A and B-B, together with section symbols in the Elevation view.

The view that shows the location of the section cut shall not be a section itself. In other words, do not cut a section from a section.

4 *Standard section symbols shall be used.*

5 *The choice of whether or not to show features that are on the opposite side of the section plane from the viewpoint shall be made to maximize the clarity of the drawing.*

Strictly speaking, sections should show all features that lie behind the section plane ▷ . In many cases, however, doing so diminishes the clarity of the drawing without providing significant additional meaning. An example is Seciton A-A in Figure A.15. This view shows only those edges defined by the intersection of the object and the section plane. Features beyond the section plane have not been drawn. The purpose of this view was to define the shape of the

See Section 7.4.

concrete cross-section, and showing what lies beyond the section plane does not contribute to accomplishing this goal. Section B-B on the same drawing, however, does show what lies beyond the section plane. In this case, it was important to show the diaphragm at the end of the span and the arrangement of supports.

A.13.2 AutoCad

1 *Section symbols shall be added in Paper Space.*

2 *The symbols provided in the AutoCad template shall be used. They may be separared from each other in the direction of the section plane, but shall not be re-scaled. The letters may be changed.*

A.13.3 SketchUp/LayOut

1 *Section symbols shall be added in LayOut.*

2 *Symbols shall be copied from the examples given to the left of the drawing area in the LayOut template. They may be separared from each other in the direction of the section plane, but shall not be re-scaled. The letters may be changed.*

A.14 North Arrow

A.14.1 General

1 *The standard north arrow shall be provided for all plan views* that are related to a specific location on earth. *Standard north arrows are provided in the AutoCad and LayOut templates.*

For example, the plan view of a bridge is obviously related to a specific location on earth. This can be seen in the plan view (*Draufsicht* in German) given in Figure A.16. This view has been precisely

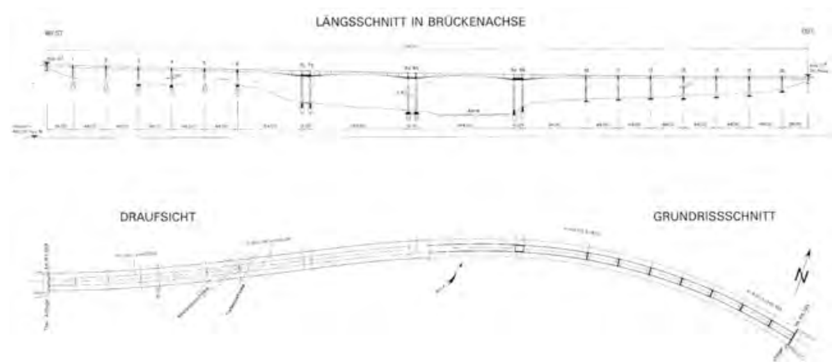


Figure A.16: Longitudinal Section and Plan of the Felsenau Bridge, Switzerland. Design: Christian Menn. (See Figure 7.30 for a photograph of this bridge.)

positioned relative to the river (Aare) and two roads (Reichenbachstrasse and Tiefenaustrasse) crossed by the bridge. So the bridge has a definitive orientation and this is defined by the north arrow.

In contrast, Figure A.17 is a drawing that contains a plan view that is not related to a specific location on earth and thus does not require a north arrow. This drawing is intended to describe a type of segment to enable it to be fabricated off-site. Although it will be incorporated into a bridge after it has been fabricated, its orientation is of little relevance to the fabrication process. For this reason, the plan given in the lower left-hand portion of the drawing contains no north arrow.

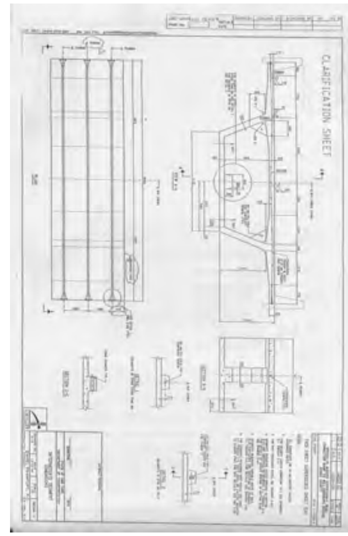


Figure A.17: Precast concrete bridge segment

2 *The north arrow shall be oriented correctly, i.e., it must point towards true north.*

3 *Whenever possible, the plan associated with the north arrow should be oriented so that the north arrow points towards the top of the page. If this is not possible, it should point to the right of the page. North arrows pointing down or to the left are to be avoided whenever possible.*

A.14.2 AutoCad

1 *The north arrow contained in the AutoCad template ▷ shall be used. It shall not be modified other than re-positioning and rotating it.*

See Section A.1.2.

2 *The north arrow shall be drawn in Paper Space.*

A.14.3 SketchUp/LayOut

1 *The north arrow contained in the LayOut template ▷ shall be used. It shall not be modified other than re-positioning and rotating it.*

See Section A.1.4.

2 *The north arrow shall always be drawn in LayOut.*

A.15 Notes

A.15.1 General

1 *Notes shall be used in situations where the use of text provides a clearer and more compact way of describing a given object than would be possible with images alone.*

2 *A suitable title shall be provided for all notes.*

The drawing shown in Figure A.18 has two sets of notes, one entitled simply "Notes" and the other entitled "Assumptions".

3 *Titles for notes shall be in all caps and shall be left-justified above the notes.*

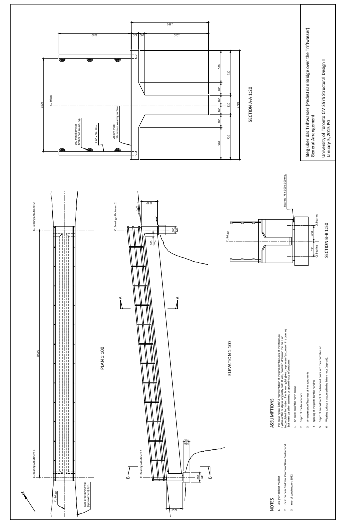


Figure A.18: Footbridge over the Triftwasser, Switzerland. Design: Robert Maillart. General Arrangement containing Sections A-A and B-B, together with section symbols in the Elevation view.

A.15.2 AutoCad

1 *In AutoCad, notes shall be written in Paper Space.*

2 *Notes shall be assigned to the layer "Text".*

3 *Titles for notes shall be in text style Calibri 2.5mm.*

4 *Notes shall be in upper and lower case, text style Calibri 1.5 mm.*

A.15.3 SketchUp/LayOut

1 *Notes shall be written in LayOut.*

2 *Styles for notes and note titles shall be shall be as given for the "SAMPLE OF NOTE TITLE" and "SAMPLE OF NOTE TEXT" in the set of samples given to the left of the drawing area in the LayOut template.*

This information should be sampled using the Style tool ▷ and applied to the note and note title text.

See Section A.1.4.

A.16 Styles in SketchUp

1 *Standard styles shall be used in SketchUp to create views suitable for plotting in LayOut. A given style shall be chosen according to the type of view to be created in LayOut.*

Six standard *styles* have been provided in the SketchUp template ▷ to be used in this course. They have been set up with face styles, line types, and section characteristics that will enable the creation of scenes depicting either two-dimensional orthographic views or three-dimensional perspective views. Details are as follows:

See Seciton A.1.3.

(a) Style name: *For 2D views in LayOut* (Fig. A.19). This style is used for generating 2D orthographic views in LayOut that do not involve section cuts. Any section cuts present in the model will not be displayed.

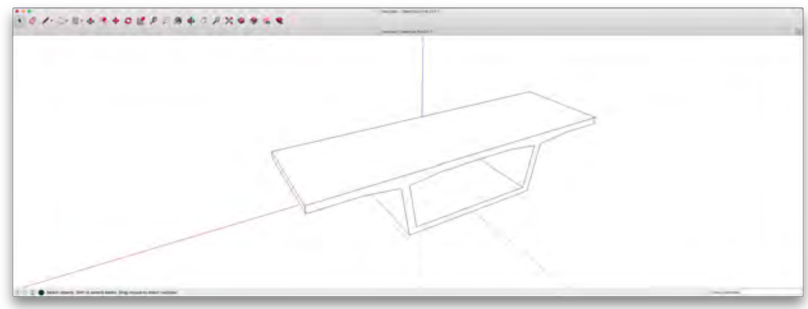


Figure A.19: For 2D views in LayOut

(b) Style name: *For 2D sections in LayOut* (Fig. A.20). This style is used for generating 2D orthographic sections in LayOut. Section cuts present in the model will be displayed as selected.

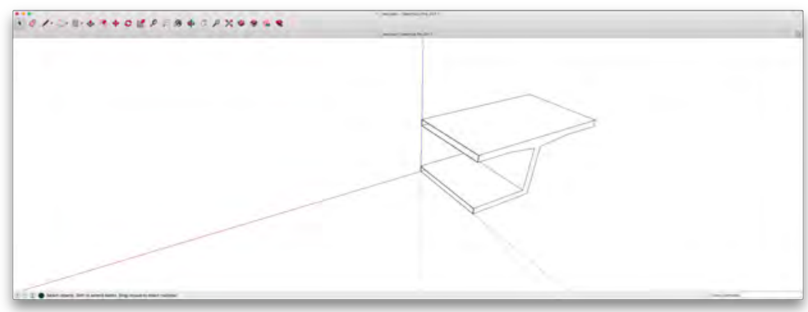


Figure A.20: For 2D sections in LayOut

(c) Style name: *3D drawings without sections* (Fig. A.21). This style is used for generating 3D views in LayOut. Any section cuts present in the model will not be displayed.

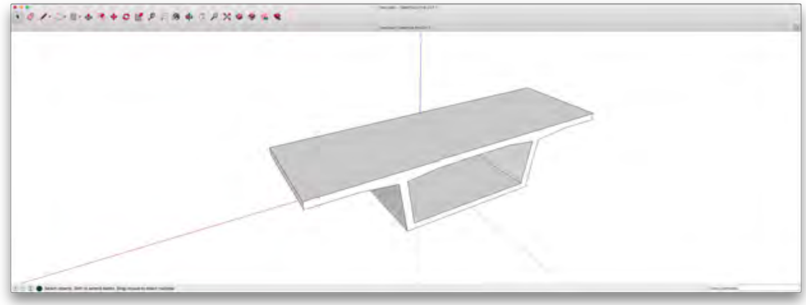


Figure A.21: 3D drawings without sections

(d) Style name: *3D drawings with sections* (Fig. A.22). This style is used for generating 3D sections in LayOut. Section cuts present in the model will be displayed as selected.

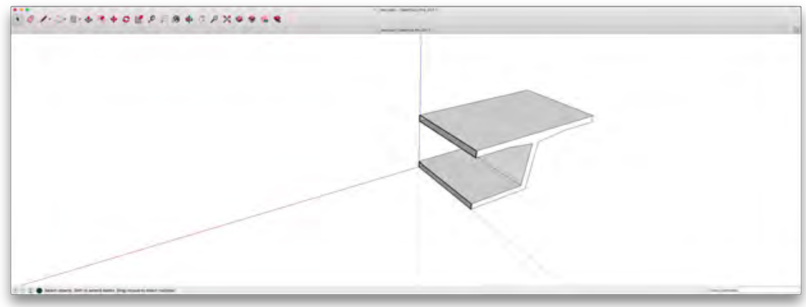


Figure A.22: 3D drawings with sections

(e) Style name: *3D without sections with background* (Fig. A.23). This style is used for generating 3D views in LayOut that require a background showing ground and sky. Any section cuts present in the model will not be displayed.

Figure A.23: 3D without sections with background

(f) Style name: *3D with sections with background* (Fig. A.24). This style is used for generating 3D sections in LayOut that require a background showing ground and sky. Section cuts present in the model will be displayed as selected.

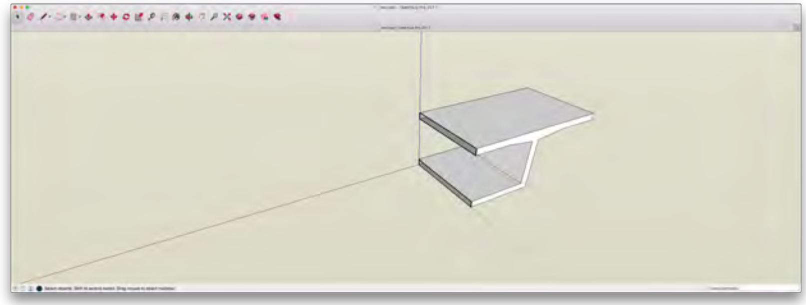


Figure A.24: 3D drawings with sections

2 *The standard styles in SketchUp shall not be modified unless specifically requested in the instructions of a drawing exercise.*