Planning, Conducting, and Documenting Civil Engineering Experiments: An Introduction

Tonya Nilsson, Steven Chiesa, Mark Aschheim, and Edwin Maurer

Department of Civil Engineering
Santa Clara University

with input from

Drazen Fabris and Wendelin Wright

Department of Mechanical Engineering
Santa Clara University

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Preface

This document was prepared to help civil engineering students at Santa Clara University plan and conduct experiments and then document the work in formal, written laboratory reports. Students should use this material as an initial reference when they are called upon to plan, conduct, and report experimental work in course exercises that are intended to help satisfy the Civil Engineering Program's expected student learning outcomes. As each departmental course having a laboratory component will provide additional, more specific details and requirements for experimentation and companion documentation, this document covers elements common to all laboratory-based work. While the information provided in this document is directed primarily towards student-produced course-related work but the same concepts, recommendations, guidelines, and detailed instructions are directly applicable to professional laboratory reports as well.

Chapter 1
Basic Guidelines for Planning and Conducting
Civil Engineering-related Experiments

Introduction

On occasion, practicing civil engineers must conduct experimental work as part of the technical process used to help solve a problem. Such experimentation may take place in a laboratory or in the field depending on the type of problem being addressed. Even if a civil engineer is not personally responsible for conducting the experimental work, he or she is often involved with the design of the experimentation, its management and quality control, and in the assessment of the resulting data. While each civil engineering sub-discipline may have a number of their own experimental protocols, there is a great deal of commonality in the manner in which experimental efforts are designed and then conducted. Before any experimentation is conducted, an experimental plan should be prepared to address the major issues associated with the proposed effort. The following sections, presented as a series of steps, represent a set of chronologically-oriented guidelines for developing (designing) and conducting appropriate experiments to ensure that the work conducted ultimately satisfies the need for experimentation.

Step 1. Identify the Desired Experimental Outcome(s)

The first step in preparing an experimental plan is to identifying the type of output information needed to be generated as a result of the experimental work. In other words, why will the experiments be conducted and what information do you expect to gain as a result of the work? Experimentation might be needed if this type of information is not available from other reliable sources or if the information is so site-specific that experimentation will be needed in each similar case where a given technology is being used. Examples of potential experimental outcomes are listed below.

- Detailed design criteria for subsequent component/process/system sizing calculations
- Preliminary proof of concept for an innovative system
- Chemical (or admixture) dosage or application rate requirements
- Component/process/system performance estimates
- Material handling/processing optimization conditions
- Relevant mechanical/chemical/structural properties of a target material
- Optimization of a component/process/system

Identification of any such targeted experimental outcomes should be as specific as possible to reasonably limit the scope of the required work and the time needed for its completion.

Step 2: Identify Key Experimental Conditions/Variables

Many experimental efforts will require that certain conditions/variables be systematically changed to assess their impact on the previously targeted outcome(s). The range of values over which each condition/variable being examined should be held to a reasonable number to address "real world" limitations that would be appropriate for the associated civil engineering unit, component, or system when in actual operation. Examples of potential controllable experimental variables are listed below.

- Environmental conditions
    - Temperature (or temperature pattern)
    - Chemical environment (pH, salinity, corrosivity, etc.)
    - Light intensity
- Chemical (or admixture) dosage
- Loading application rate or loading cycle/pattern
- Relevant process control operating variables
- Time (where results may vary reproducibly over time)

Where it is anticipated that only two controllable conditions/variables will concurrently impact the experimental outcome(s), a simple matrix-based approach may be sufficient to identify combinations of conditions/variables that will systematically be used to provide outcomes that reflect a more complete range of expected field operating conditions. If multiple conditions/variables are expected to influence experimental outcomes, a classic Design of Experiments (DOE) approach should be used to statistically limit the number of condition/variable combinations that will need to be evaluated and still produce sufficient data for analysis and reporting. It is critical that experimentation not allow multiple conditions/variables to be changed simultaneously without using a DOE-based approach to subsequently allow segregation of the relative impacts of the altered conditions/variables. Otherwise, the integrity of the experimental results and ensuing conclusions will be questionable. Supplemental references provided at the end of this chapter can be used to direct students to more detailed information on DOE procedures.

If preliminary experimental results indicate that a new or secondary direction in the experimental plan should be considered to take advantage of promising results, other variables may also be explored.

Step 3: Identify Appropriate Standardized Testing Procedures to be Used

Many material testing and laboratory-based analytical techniques have been standardized by professional and governmental organizations to help ensure consistency and comparability in experimental outcomes. Depending on the type of testing to be conducted, one or more of the following organizational sources of standardized testing procedures can be consulted to obtain detailed instructions for many material testing and analytical techniques together with their associated quality control protocols.

- American Society for Testing and Materials (ASTM) Standards
- International Standards Organization (ISO) Standard Test Procedures
- American Association of State Highway and Transportation Officials (AASHTO)
- Standard Methods for the Examination of Water and Wastewater
- USEPA Standard Test Procedures for Potable Waters, Wastewaters, and Solid Wastes

These commonly available references provide detailed step-by-step instruction for each testing protocol as well as supporting material, equipment, instrument, and reagent needs. *Included in the identification/selection of analytical testing procedures should be a decision as to how many may replicate samples will be tested to provide a statically relevant, reproducible result.*

Step 4: Document Any Non-Standardized Testing Procedures to be Used

Some experimental efforts will require the use of non-standardized, innovative testing procedures that cannot be found in the reference sources included in Step 3. The technical literature can be searched (using Google Scholar for example) to see if other investigators have developed acceptable equipment and procedures that have not found their way into the aforementioned primary standardization references. If one or more of these novel approaches is selected for use, it must be clearly documented. This documentation should include the original source of the information and any apparent limitations for the intended application of the technique.

Experimental and/or analytical techniques developed first-hand for use in an experimental program also need to be fully documented and approved by the supervising faculty member. This documentation would include producing a detailed step-by-step description of the technique similar to the descriptions provided in the references listed in Step 3. Any novel experimental equipment developed in conjunction with the experimentation should also be similarly detailed for future inclusion use in a final written report and/or oral presentation. Digital photographs (and video, if appropriate) of the assembled testing system(s) during actual operation should be taken and stored securely for future reporting.

Step 5: Identify Relevant Safety Provisions

Safety should be paramount in completing any field or laboratory experimentation project. In preparing to conduct experiments, all student participants should make sure that the following safety-related issues have been fully addressed and that the University's **Environmental Health and Safety Department** policies will all be followed.

- Complete any *general* departmental or institution-based safety awareness program including identifying contact information for emergency services
- Complete any departmental or institution-based training and safety program associated with the use of specific equipment, tools, or *specialized* testing systems or instruments
- Determine if specialized ventilation facilities (chemical hoods, etc.) will be needed and how they are properly operated
- Complete any required forklift training/certification program
- Secure any necessary permits for welding, hot work, or specialty sample cutting
- Identify the need and location for any specialty chemical storage equipment
- Determine what types of safety gear will need to be worn during experimental and supporting analytical work
- Locate where any relevant MSDS information is located
- Locate where chemical spill clean-up kits are located, if applicable
- Determine the types of waste materials that will be generated and the associated storage and disposal requirements that go along with such residuals

Any remaining issues and questions should be directed to the civil engineering lab manager or the faculty member supervising the work. Experimental set-ups for large test samples may need to be inspected and/or approved for use by representatives of the University's **Environmental Health and Safety Department**.

Step 6: Compile Resources Needed to Conduct the Experiment(s) and Associated Testing

Before any experimentation is initiated, a complete list of all related resources that will be needed to safely conduct the experiments should be produced. This list should include resources needed to physically conduct the experiments, complete the associated testing and analytical work, safely dispose of all experimentally-derived residuals, and provide a proper cleaning for the spaces used for testing and analysis. Such a list may include some or all of the following items.

- Physical space (amount needed and location) for the experimental set-up
- Experimental systems (/component/process/system prototypes, pilot or bench-scale reactors, etc.)
- Environmentally controlled space(s) for conducting experiments under non-ambient conditions
- Testing devices and/or instruments (including the number of systems needed and any associated data acquisition systems)
- Special controlled ventilation facilities (chemical hoods, etc.)
- Specialty rooms or tanks required for sample curing (with secondary containment capabilities as needed)
- Calibration data or standards for testing devices and/or instruments
- Utilities (electrical power, natural gas, compressed air, water, etc.)
- Testing reagents and sample preservation agents (chemicals)
- Refrigeration devices for sample storage
- Safety equipment (eye protection, hearing protection, dust/vapor masks, etc.)
- Specialty cleaning chemicals and tools
- Approved waste disposal containers

Where any of the required resources are not immediately available, the lead time associated with obtaining them should be incorporated into the experimental schedule. *If some or all of components making up the experimental system(s)either will be assembled using multiple pre-manufactured components or will require specialty fabrication, schematic diagrams, sketches, and/or detailed drawings should be prepared and then checked by others knowledgeable with the type of project to ensure the ability of the system to function as intended.*

Step 7: Develop a Schedule for the Planned Experimentation Project

Once Steps 1 through 6 have been completed, the information can be used to develop a tentative project schedule for the experimentation and companion analytical work. The schedule should clearly identify what tasks can be completed in parallel and which must be completed in series. The use of a software package such as Microsoft Project can help graphically portray the sequencing of project elements and identify any critical completion path that will determine the minimum expected duration of the project. Experimental task sequencing should take into account the number and availability of test systems and the time needed for each set of experimental conditions/variables to be examined. Once a tentative project schedule has been developed, it should be reviewed by the supervising faculty member(s) to help ensure that time allowances have been adequately estimated and that no critical step have been omitted.

Step 8: Conduct the Experiments

Experiments should be conducted in a manner such that the results and final outcomes are as accurate and reproducible as possible. Before actual experimentation begins, any experimental test systems should be checked for structural worthiness, leaks, and other potential operational and safety issues. If multiple experimental systems are available for use, several experiments can then be run concurrently to examine the impacts of a chosen condition/variable on the targeted system outcome(s) while all other conditions/variables are held constant. Any proposed changes in the experimental plan should be discussed with the supervising faculty member; regular communications between students and the faculty member will be a critical element in the success of experimental program.

Experimental procedures and processes should be fully documented before experimental work is initiated (using a checklist for example) so that the exact same process is used every time an experiment is conducted. This will help eliminate experimental artifacts where observed results can be shown to vary just by the way basic aspects of the testing process are intentionally or unintentionally varied. Here again, the supervising faculty member should be allowed to examine the proposed experimental procedures and specify necessary modifications before actual work commences. All participants should agree on the manner in which quality control should be maintained as part of the experimentation and analytical phases if such quality control protocols have not already been identified as part of the standardized test procedures selected for use.

In many experimental programs, a “control” system is used strategically to establish a baseline reference for comparison purposes. The control system is operated identically to other test systems except for the fact that it does not receive the change in selected testing condition/variable that any of the other “test” systems receive. If material properties of an innovative construction material are being investigated, a traditional material can be used as a “control” to show differences in performance under essentially identical experimental conditions. Alternatively, material properties for traditional materials can often be found in published literature and this information can be used for comparison purposes if side-by-side testing cannot be conducted.

Data collection during experimentation can either be automatic using a computer-based data acquisition system or manual using direct entry into a pre-formatted computer program or pre-prepared data entry hard copy form. In hard copy form, data should be recorded in ink. Data should not be recorded on napkins or paper towels as these materials are too easily discarded unintentionally with the loss of key data. Data collected and initially stored electronically should be duplicated (backed up) in two or more locations as soon as possible to ensure that there is long-term accessibility and safety of the data (the dog ate my flash drive is not an acceptable excuse).

Any samples generated during experimental work that will be designated to testing later should be preserved and stored in accordance with accepted, standardized procedures. Stored and preserved samples should be subsequently tested within the period of time specified to prevent deterioration.

After all experimentation and associated analytical work are completed, the space used for the work should be cleaned and returned to the department in a state at least as useable and clean as before the work was started.

Step 9: Reduce, Assess, and Evaluate the Experimental Data

Data reduction should focus on assembling, combining, and/or integrating data so that the targeted outcome(s) can be assessed. This would include ultimately using the reduced data to determine relevant trends and correlations. The built-in statistical functions of commercially available spreadsheet programs should be used to facilitate data reduction and assessment. Variability in raw and reduced data should be quantified and linked back to potential sources of error in the experimentation and any companion analytical techniques. The reduced data can then be used to graphically depict the experimental results in an appropriate format. When a limited number of conditions/variables have been examined, traditional two dimensional plots can be used to graphically demonstrate trends and correlations. The more refined Response Surface Methodology (RSM) approach can be used to graphically portray the impacts of multiple conditions/variables simultaneously. Additional details on the RSM technique can be found in the technical references included at the end of this chapter. Detailed instructions for properly formatting and documenting data tables and graphs for inclusion in final written reports and presentations are included in Chapter 3 of this document.

Step 10: Preparation of a Written Report

Written reports detailing experimental work vary in organization and complexity depending on the intended audience. The first step in putting together any written report is to develop an organizational outline that is consistent with the need to communicate sufficient information. Internal reports, used to distribute information to a limited audience of co-workers can be concise and omit many of the experimental details since co-workers already tend to be familiar with the project. Reports intended for large audiences and external peer review normally include extensive background information, detailed experimental procedures, and experimental results presented in classical tabular and/or graphical formats. For additional information on the preparation of written reports for experimental (laboratory) work, the reader should examine the next two chapters of this reference.

Additional Information / Select Supplemental Reference Material

For more detailed explanations of the concepts embodied in this set of basic guidelines, as well as description of more advanced concepts in experimental design and data analysis, students can consult one or more of the following references.

Barrentine, L.B., An Introduction to Design of Experiments: A Simplified Approach, American Society for Quality, 1999.

Box, E.P., Hunter, J.S., and Hunter, W.G., Statistics for Experimenters: Design, Innovation, and Discovery, 2nd edition, Wiley, 2005.

Canavos, G.C. and Koutrouvelis, J.A., Introduction to the Design & Analysis of Experiments, Pearson, 2008.

Whitcomb, P.J. and Anderson, M.J., RSM Simplified: Optimizing Processes Using Response Surface Methods for Design of Experiments, Productivity Press, 2004.

Chapter 2

Quick Summary: Writing Formal Laboratory Reports

Report Objectives

Laboratory reports are used to present experimental results and associated conclusions in a format commensurate with the anticipated use and intended audience. Results and conclusions should be provided within the context of the stated need for the work and the experimental procedures chosen for use. Formal laboratory reports provide a detailed description of the work completed in such a way that the experimentation and summary conclusion are unambiguous and the work is reproducible by others if there is a need to provide external verification. In some courses, more informal laboratory reports may be required on occasion to provide evidence of proper experimental technique, effective data reduction, and reasonable assessment of the reduced data. A formal laboratory report will include these key elements but will also provide additional details that ultimately provide a higher degree of traditional scientific inquiry and completeness.

Unless instructed otherwise, student formal laboratory reports, at a minimum should be organized sequentially to:

- Describe the <u>purpose</u> of the lab work
- Detail the <u>experimental approach</u> used in the lab work
- Present the <u>results</u> of the work, and
- <u>Discuss/evaluate</u> the results

While the information provided in this document is directed primarily towards student-produced course-related work, the same concepts, recommendations, guidelines, and detailed instructions are directly applicable to professional laboratory reports as well.

Report Audience

Laboratory reports may be written for internal use (peers and co-workers), external use (outside technical and non-technical groups), or both. Student-produced formal laboratory reports should be written assuming that the reader has some technical knowledge of the subject being addressed in the report and is capable of providing feedback on both the presentation of information and the technical accuracy of the reported results and conclusions. Where reports are being prepared less technically trained readers, additional background information may need to be provided.

Report Development

Organizing your report writing efforts will reduce the time required to develop well-written reports. Students should consider the following recommendations for helping produce quality formal (and informal) laboratory reports:

- Record data on data sheets as soon as it becomes available. Label all data columns before you start recording. Write down observations or ideas about the experiment as you think of them.
- Develop a rough draft of the report, making it as concise as possible.
- Prepare a draft a few days in advance and let it sit for a day or two. Then review the draft for errors and/or omissions. Make corrections, print final copy and combine with any charts and data sheets.
- Develop a template of a generic report form with sections formatted. Fill this in for each new report.

Evaluation Criteria

Laboratory reports are normally graded both on content, logical arrangement, and proper use of the English language. Reports should be:

- easy to read,
- formatted according to specified directions,
- free of spelling, grammar, and punctuation errors,
- **<u>suitably referenced so that external supporting information is properly credited,</u>**
- original, and
- organized to provide clear and convincing explanations, conclusions, and arguments.

Reports are typically evaluated with the following criteria in mind:

- Did you make careful, relevant observations during the experiment? Have you provided a clear and accurate description of what you did?
- Did you understand the major ideas involved in the experiment and relate your test results and discussion to these ideas?
- Are experimental observations and data presented in a logical sequence?
- Were you able to present your work, data and results clearly and support your conclusion(s) with convincing evidence?
- Did you answer all the questions asked in the lab?

Report Contents

In the absence of any more specific instructions, formal lab reports should contain the following eight components arranged in the indicated sequence:

<u>Title Page:</u> a single page that should include basic identifying information that provides potential readers with simple what, who, and when type data. The information provided as part of the title page should include the following.

- Lab number and experiment name
- Name of the author(s) and any lab group designation
- Date of the lab work and date of report submitted

<u>Introduction:</u> a description of the objectives behind the experimentation. The introduction should also provide a short overview of the experimental work and the potential application(s) of the experimental

results. Copying or including the lab handout for the objective is not acceptable as part of a formal lab report unless approved in advanced by the course instructor. The sources of background information should be cited, with references listed as described below.

Experimental Procedures: a clear description of the work done. The experimental procedures section describes in appropriate detail the materials examined, any pre-experimental processing of the materials, how the experiments were performed, how the equipment was used, and how the data was analyzed. The narrative description may refer to standard test procedures (e.g. a specific ASTM test procedures) or should describe the main steps, noting any deviations from standard procedures or any special or unusual steps in detail, so that the reader has sufficient information to potentially replicate the experiment. Do not use excessive detail to describe basic laboratory procedures; for example, do not write “Safety glasses were worn” or “Data was acquired with a computer.” Write the procedures section in the past tense and in paragraph form. Do not number the steps of the procedure. Do not say “next” or “then.” (Note: many tests follow ASTM Standards, Standard Methods for the Examination of Water and Wastewater, and similar standardized experimental guides) which are all available for your review in the reserve section of the University library.)

Results: a detailed description of the results of the experiment. It is not appropriate to discuss the validity of the results in this section, just report them. The results usually include figures and/or tables. Figures may present graphs, photographs, and/or drawings. *The text of this section and the figures and tables should complement each other, but must contain enough information to stand independently*. Text for this section must be in paragraph form; figure captions alone are not sufficient. In this section, or in the intro, you need to provide any formulas you used to derive the results. Follow the format for presenting formulas given in the next chapter.

To organize the presentation of results, first decide upon a logical flow for presenting the information. Once this is determined, decide how the information will best be presented using tables and/or figures. The requisite tables and figures with their associated captions can then be created. As a last step, write the text that refers to these tables and figures. Well–designed tables and figures will convey the essence of the report; the text should provide the narrative that explains what the information contained in the tables and figures and its significance. To reiterate this critical point, every figure and table should be sufficient to stand alone (be fully understood from the caption and data), but every figure and table must also be explained in the text of the report to add context and summarize key trends.

Decide whether a particular dataset is best presented in a table or plotted as a graph. Plots are useful for identifying trends and comparing the performance of different samples/specimens. Tables are useful for concisely presenting numerical data, which if presented in paragraph form would be difficult to follow. Tables of raw data are typically not useful if a plot would better convey trends of the data. See the following chapter for proper formatting of charts and tables.

Discussion: an evaluation of the work done and an evaluation of the validity of the results. Possible tools for measuring the validity could be a comparison to anticipated results, the statistical distribution of the data, results of other teams, etc. Students are encouraged to use (and cite) other published information (taken from textbooks, standard handbooks, journal articles, etc.) as a baseline from which their experimental results can be compared.

- If your results are questionable, this is where you would discuss your analysis of the probable cause (human error or bad equipment are typically not acceptable error sources).
- If the lab suggests any discussion questions, this is where you would discuss them.
- This is where you can also state observations of behavior made during the experiment.

Conclusions: a brief summary of the basic results and conclusions of the study in about one–half page. Each conclusion stated in this section must be supported by the data, analysis, and discussion of the preceding sections. *No new information should be presented in the conclusions*.

References: proper credit to any outside source of information including the course text. References should be made in the text to external sources of information or ideas. Doing so demonstrates your awareness of the contributions of others to the scholarly community of which you are a member. Additionally, provide the citation in the main body of the text immediately after the reference information is presented or an observation or conclusion attributed to others is quoted or paraphrased. References can be indicated in the paragraph using a format found in the next chapter. All references made in the main body of the text must also be listed in the References section.

You must list the references you have used, including the author, title, journal, volume, number, page numbers (if appropriate), and year. Plagiarism is never tolerated. Avoid using references to web pages. If such a reference is critical, be sure the source is reputable. References to Wikipedia are not acceptable. A highly recommended search engine for locating references is Web of Science (http://www.isiknowledge.com).

Sample Calculations Show an example of each calculation that you used to analyze your data as part of an appendix to the main body of the report. If you use a spreadsheet for your calculations and it is all wrong, having a single sample calculation allows your evaluator to determine if the mistake was a typo or conceptual. (This can be done on engineering paper and hand written.)

Chapter 3

Formatting Guidelines for Written Laboratory Reports

General Guidelines for Formatting

1. The report should be formatted in one column and a 12–point font with 1.5 line spacing and 1-inch margins on all sides.
2. If using a monospaced font such as Courier, there should be two blank spaces after a period at the end of a sentence.
3. Label each section (except for the title page); do not have each section start on a new page.
4. Number the pages. Page 1 should start with your first page of text. A title page is not numbered. Insert a "Next Page – Section Break" between your title page and first page and then apply page numbers in the footer of the second section. Section breaks can be inserted using the "Break" drop-down menu under the "Page Layout" ribbon.
5. Whenever possible, make sizes, formatting, and fonts of figures consistent.
6. Number figures and tables separately.
7. Integrate your figures and tables into the text using the "Wrap Text" feature in Microsoft WORD. Do not simply attach them to the end of your report. You can force text to wrap around an object by selecting the object and choosing your wrap type as shown under the "Wrap Text" drop-down menu found on the "Picture-Format" ribbon. "Square" or "Tight" will incorporate the figure into a paragraph. "In-line" will place the object in-line with your existing text as shown in Figure 1.
8. The report may need to include equations to adequately describe pertinent theory (in the Introduction) or techniques used in data processing or data analysis (in the Experimental Results or Discussion). Of course, their sources must be cited. Place equations on lines separated from the text, and number equations separately in parentheses at the right margin. Equations, such as Equation 1 below, can be produced in Microsoft WORD using the Equation Editor found on the "Insert" ribbon. If the Equation Editor was installed, "Equation" will be highlighted on the Insert menu. Otherwise, select "Object" from the "Object" drop-down menu and open Microsoft Equation 3.0.

   Example formula presentation:

   As an example, the strain ε may be defined as

   $$\varepsilon = \frac{\Delta}{L}, \tag{1}$$

   where Δ is the displacement and L is the length of the specimen. Note that the definition of each symbol is made in a sentence, not as a list.

   Equations should be numbered, and all terms used in the equation must be explicitly defined as illustrated by the previous sentence. Greek symbols can be printed using the Symbol font. Variables are typically denoted by italics. Punctuate an equation as part of the sentence in which it is presented. For example, if the equation ends a sentence, place a period immediately following the equation.

9. Do not report the magnification of images since magnification is easily altered during imaging processing. Use calibrated scale markers instead.

Guidelines for Formatting Tables and Figures

1. Each figure and table requires a caption. The caption for a figure appears below the figure. The caption for a table appears above the table. Give complete descriptions in the captions. For example, "True stress versus true strain for cartridge brass as a function of annealing temperature" is a good caption. "Stress vs. Strain" is insufficient.
2. Remember every figure and table should be sufficient to stand alone (be fully understood from the caption and data), but every figure and table must also be explained in the text of the report.
3. Figures and tables should be referred to in the text before they first appear.
4. Tables are numbered consecutively and should appear with a caption above the table. Table 1 illustrates this. Table 1 is clearly organized, has clear labels (with units where appropriate), and is easily understood. Tables can be produced in Microsoft WORD using the "Table" drop-down menu on the "Insert" ribbon. Tables and their captions should be centered horizontally on the page. While the caption should be centered on the page, titles with multiple lines should also be left justified as shown in Figure 2. Place a period at the end of each caption.

Table 1: The ultimate tensile strengths of five samples of as–rolled 1020 steel tested to failure.

Sample	**Ultimate Tensile Strength (MPa)**
1	410
2	422
3	417
Mean	**416**
Standard Deviation	**6.0**

5. Figures are numbered sequentially and may present photographs, drawings, and plots. Large figures and their captions should be centered horizontally on the page. Smaller figures and their captions should be incorporated into the text using text wrap.

   Example figure reference in text:

   For example, Figure 1 shown on the next page is a plot of true stress versus true strain for uniaxial compression of Ti–6Al–4V and pure aluminum. The titanium alloy has a much higher yield stress and a larger strain to failure.

   Descriptive, summary statements such as the last one are necessary to ensure that the reader understands the plots correctly. Other noteworthy features of the plot presented in Figure 1 are outlined below.

   - The abscissa (horizontal axis) and ordinate (vertical axis) both have titles, with appropriate units indicated. Always provide the units on the axes labels in parentheses and be consistent (note that strain is unitless). Use the most relevant unit of measure. For example, if you measure stresses up to 200×10^6 Pa, label the axes in MPa. No plot title is included, the figure title/caption describes the plot.

- A legend should be provided to allow multiple data series to be identified. If only one data series is plotted, a legend should not be used; the caption is sufficient. In EXCEL, specifically name each data series. The default “Series 1”, “Series 2” labels are not adequate descriptors.

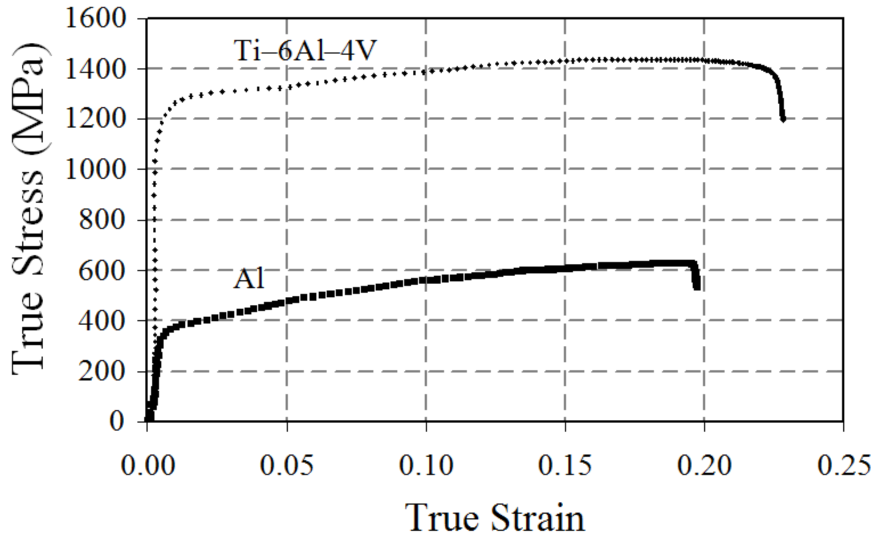

Figure 1. True stress versus true strain for Ti–6Al–4V and pure aluminum in uniaxial compression.

- At times, it may be appropriate to label the data series rather than use a legend. This point is illustrated in Figure 1. The two data series are labeled with a text box rather than using a legend. This is particularly helpful when it may be difficult to distinguish between data sets according to the symbol data markers (e.g. circle versus square markers in Figure 1.)
- The typical EXCEL plot to be used is an XY Scatter Plot, rather than some other type such as a Line Plot (which plots Y values at regular intervals on the abscissa).
- Within EXCEL, to allow the data to be seen clearly and to eliminate distractions, format the plot as follows:
  - ♦ Turn on gridlines for both axes, and set the line type for the grid to a dashed line that is 50% gray, not black.
  - ♦ Format the plot area to have no color.
  - ♦ Format the chart area to have no border.
  - ♦ Have the abscissa and ordinate lines (and labels) located at the bottom and left edges of the plot, respectively, rather than having them run through the data. Pick suitable limits and intervals for each axis scale. This will often require manually selecting the plotting range in EXCEL. The plotting range in all coordinate directions should exceed the maximum plotted data values by approximately 10 to 20 percent. Also avoid the temptation to truncate the vertical axis unless you clearly specify that you have done so in the figure caption. Shifting the origin from zero along the ordinate axis causes trends to appear more dramatic than they actually are.
  - ♦ If EXCEL is used to plot data, to avoid having large file sizes, copy and paste the plot from EXCEL into WORD (as a figure if possible) using the “Paste Special” command on the right-click menu or under the “Paste” drop-down menu on the “Home” menu tab.

- If Microsoft WORD is used to produce the report, a convenient trick to place figures in the report is to insert a new table (1 column wide by 2 rows long), change the borders to not print, and use the preceding command sequence to paste the plot into the first row of the table. The caption for the figure is written in the second row of the table. An alternative is to display the plot on the screen, hit the "Print Screen" key, then place the cursor in the document where you wish the image to appear, and insert using Ctrl–V. Using this approach requires that the image be cropped on all four sides using the "Format Object" command, available by right clicking the inserted image.

6. Make the figures in documents and reports physically large enough to show sufficient resolution for readers to see and understand the data being presented but not excessively large so as to just help meet some specified document length requirement.
7. You should only use a curve fit that is based on known behavior. For example, use a linear fit to calculate the elastic modulus of a material based on a stress–strain curve. Do not use a spline fit to simply draw a curve through all of the data points. Such a fit does not have a scientific basis and should not be used.
8. Curve fits are always shown as solid lines. Data are shown as discrete points. Sometimes when large amounts of data have been acquired, the data appears as a solid line even though the points are actually discrete. This is acceptable. The size of the symbols may be reduced to improve clarity.
9. When curve fits have been made, display the equation on the graph in the appropriate form. The last two points regarding curve fits are illustrated in Figure 2. Notice that the curve fit equation has been modified to use "τ" and "γ" not "*x*" and "*y*."

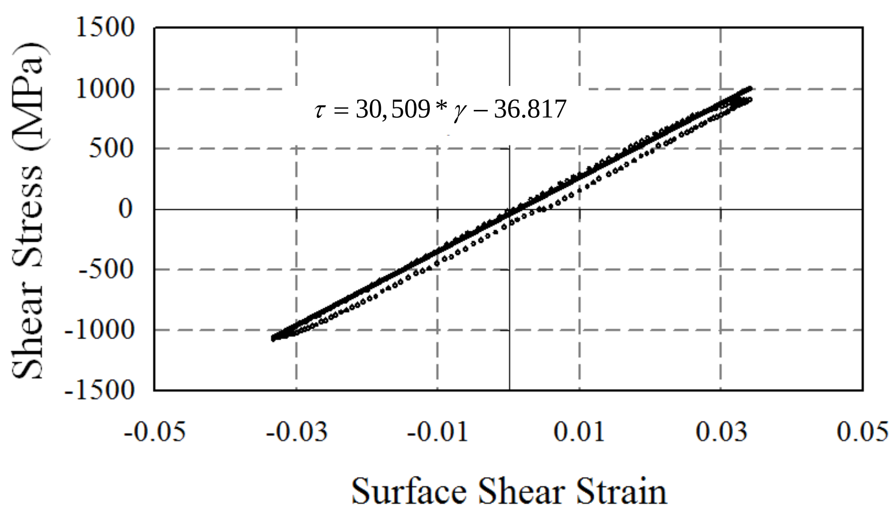

Figure 2. Surface shear stress versus surface shear strain for a Zr alloy tested in shear while subjected to a tensile stress of 920 MPa. The slope of the linear fit is the shear modulus of the material, which is calculated to be 30.5 GPa.

10. Photographs of experimental systems and test specimens may also be used to provide needed detail and documentation. Photographs taken with digital cameras should be later modified to include in–photo captions (text boxes), as needed, to identify particularly relevant system elements and characteristics.

Some Additional Guidelines for Number Use and Precision

1. The numbers presented in the text or tables cannot have more precision than the precision of the instrument used to acquire the data. For example, consider three temperature measurements taken over a period of 1 hour using a thermocouple with a digital indicator that reports the temperature to a tenth of a degree: 350.3 K, 354.1 K, and 352.6 K. The average temperature during the one hour period is 352.333 K, but this number should be reported as 352.3 K since the temperature is not known precisely to the one–thousandth of a degree. The standard deviation should be reported with the same precision as the measurement. In this example, the standard deviation is 1.6 K. Note that the standard deviation has the same units as the measurement of interest. In some instances, it may be appropriate to report the uncertainty in the measurement or the accuracy of the instrument when measured against a calibration standard, but, in general, these values are not required in this course.
2. Consider another example. If you are determining grain size using measurements from optical microscopy, you might report an average grain diameter of 5.1 µm, because " 5.145 µm" would imply more precision than can be justified due to the resolution of the instrument, i.e. an optical microscope cannot measure 0.001 um (or 1 nm) features.
3. Note that when data is acquired digitally, the digital format may have more precision than the instrument that was used to acquire it. The precision should be reduced to match that of the instrument when reported in tables or the text of the report. Ask your lab instructor to specify the precision of each instrument that you use.
4. When converting between units, use all of the significant figures available for the data and the conversion factor. For the purposes of reporting values in tables or in the text of the report, the precision should then be reduced as outlined above.
5. Even if the precision of a value is appropriate, consider whether all of the significant figures carry pertinent information. For example, it is likely that a stress measurement can be made with a precision of 0.1 MPa; however, it is common practice to report measurements rounded to the nearest MPa (61 MPa rather than 61.3 MPa).
6. If a number is less than one and written in decimal form, use a zero before the decimal point, e.g. 0.25 kg, not .25 kg.
7. The sample standard deviation σ is a measure of the variation of a set of values from the mean. It is calculated according to the following formula.

$$\sigma = \sqrt{\frac{\sum_{n=1}^{N} \left(x_i - \bar{x}\right)^2}{N}}, \tag{A1}$$

   where x_i represents each individual data point numbered from *i* to *N* and $\bar{x}$ is the mean of the data points.
8. Do not start a sentence with a number written in numerical form. In general, write all numbers that precede units as numerals.
9. Use SI prefixes or scientific notation to eliminate unnecessary zeros. Be aware of the appropriate number of significant figures to use when using scientific notation (see 1 above).
10. Where possible, exponents should be shown as superscripted characters (e.g. use 10^3 and not 10^3).

11. There should always be a space between a number and its unit. The number should not be separated from its unit at the end of a line; this can be assured in Microsoft WORD by pressing “Option + Space” simultaneously, to produce a space that will keep the words before and after the space together on a single line.
12. Use the most relevant unit of measure and conventional units, e.g. use MPa when reporting stress values and GPa when reporting elastic modulus values. If the testing equipment reported US Customary units, you can report in US units.

Some Additional Guidelines for Style

1. Write the report from the point of view of a professional scientist; i.e., do not refer to “the student,” “this lab,” or “the instructor.”
2. As a general rule of thumb for appropriate verb tense for various sections of the report, use past tense for the procedures section and present tense for other sections. (The procedures were performed in the past; the results and findings continue to exist in the present.)
3. Acronyms should normally only be used after they are spelled out completely the first time they appear in a document. The following sentence is provided as an example of the proper format. “American Society for Testing and Materials (ASTM) procedure D1894–06 was used to determine the static and kinetic friction coefficients for the surface.” If many acronyms and abbreviations will be used within a long report, a summary table of such information can be included after the abstract to provide readers with a single, easily locatable reference.
4. The names of elements are not capitalized. The chemical symbols for elements are capitalized. A chemical symbol is not an acronym; therefore, it is not necessary to explain its meaning.
5. Technical papers typically use the SI system of units (m, kg, s, N, Pa). These conventional unit abbreviations do not need to be spelled out the first time they are used. Since the majority of our equipment gives output measurements in US customary units, use the system of units the data is collected in.
6. Refer to the figures and tables by number, i.e. do not refer to “the figure below,” “the following figure,” etc.
7. **Aim for brevity; eliminating unneeded words aids the reader.**
8. Use words correctly, and once their usage is established, do not substitute other words for the same term.
9. Avoid using contractions and slang.
10. Avoid subjective statements (e.g. whether a result is “good” or “bad” depends on the context and perspective of the observer and such language should not be used).
11. Do not refer to the “*y*–axis” or “*x*–axis.” Refer to the “ordinate” or “abscissa.”
12. A variety of Greek symbols and other special characters can easily be added to a Microsoft WORD document using the “Symbols” drop-down menu on the “Insert” ribbon or simply changing the font style to Symbol, e.g. σ is ‘s’, τ is ‘t’, δ is ‘d’ and Δ is ‘D’. These symbols should not be added manually by hand with ink.
13. Do not start sentences with “However.”
14. Refer to “materials properties” not “material properties” when addressing the properties of *multiple* materials.

Reference Formatting Examples Using the Guidelines Provided by the American Society of Civil Engineers

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Appendix A.

Sample Report Checklist

(Based on a grading checklist provided by Dr. Drazen Fabris)

This checklist contains some of the most important guidelines provided in this document for writing technical reports for Civil and Mechanical Engineering courses. After writing your report, you should compare it against this checklist to ensure compliance with the guidelines.

Overall

a. Professional (e.g. no references to "this lab" or "the instructor") ________
b. Logical and clear overall organization of the report ________
c. Logical and clear organization of individual sections ________
d. Logical and coherent presentation of arguments ________
e. Mechanics: grammar, syntax, and punctuation ________
f. Spell check performed ________
g. Clarity of figures and tables ________
h. Completeness in terms of required report components as provided in the lab description ________
i. Were you able to present your work, data and results clearly and support your conclusion(s) with convincing evidence? __________
j. Quality of writing is readable, fluid and at a level expected of a college sophomore ____________________
k. Accurately completed experiment: ____

Title Page

a. Appropriate title ________
b. Name, group number, group member names, dates included ________
c. No more than approximately 15 words ________

Introduction

a. States the goals of the experiment ________
b. Describes material being tested ________
c. Concise presentation of applications of the material ________
d. Cites appropriate sources ________
e. Does not reference the lab handout ________

Experimental Procedures

a. Accurate and complete description of experimental method ________
b. Written in paragraph form and not as a list of instructions _______
c. Appropriate level of detail in description of experimental method _____
d. Past verb tense is used for this section ________
e. Not full of then and next ______________
f. Found correct ASTM standard and properly referenced instead of a & c_______________

Experimental Results

a. Required figures and tables presented ________

b. Text in paragraph form (in addition to captions for figures and tables) describes the results ________

c. Text and figures contain enough information to stand independently ________

d. Captions are detailed ________

e. Appropriate precision for the results ________

f. Figures appropriately formatted (no gray background, axes labeled with units, legend or labels for multiple data series) ________

g. Formulas provided to support necessary calculations (could be in intro too): ________

h. Presentation is easy to follow: readable: ________________

i. Made careful observations during the experiment ________

j. Accuracy of results (did data analysis correctly) ____

____

Discussion

a. Detailed data analysis ________

b. Evaluation of error sources if appropriate ________

c. Draws key technical conclusions ________

d. Questions asked in the lab handout are answered ________

e. Accuracy/quality of thought process in answering questions: ____

____

Conclusions

a. Precise and concise ________

b. Consistent with prior sections ________

c. Do not present any new information ________

References

a. Appropriate use of references ________

b. Consistent formatting of references ________

c. Use of reputable sources (no Wikipedia citations) ________

Formatting and Style Details

a. One column in 12–point font with 1.5 inch line spacing and 1 inch margins ________

b. Pages are numbered ________

c. Figures and tables are numbered separately ________

d. Figures and tables are incorporated into the text ________

e. All symbols are defined ________

f. Equations are numbered ________

g. Each figure and table has a caption ________

h. Acronyms are defined ________