MAE/CE 370
MECHANICS OF MATERIALS LABORATORY

INSTRUCTOR MANUAL

Written by
Christina L. Carmen
Edited by
John A. Gilbert
Department of Mechanical and Aerospace Engineering
University of Alabama in Huntsville
Huntsville, Alabama
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CHAPTER 1- INTRODUCTION

The purpose of this manual is to assist both the novice and the experienced laboratory instructor in the to various instructional aspects of the MAE/CE 370 Mechanics of Materials Laboratory. The various aspects range from access to the laboratory to supplementary lectures pertaining to each experiment. The information contained within this manual is a compilation of information based upon the previous experiences of a Graduate Teaching Assistant. The information and recommendations contained within this manual have proven to be beneficial and effective. However, it is highly recommended that each instructor develop his/her own personal style of instruction. In addition, the implementation of improvements is always encouraged.

The laboratory provides an excellent opportunity for the undergraduate student to gain physical knowledge and understanding of the theoretical concepts encountered in the classroom lecture. The benefit and quality of this learning experience is heavily dependent upon the leadership and preparedness of the laboratory instructor. This manual is intended to assist the instructor in this regard. It is not necessary that the instructor become an expert in the field of Mechanics of Materials. However, at a minimum, it is necessary that the instructor is able to conduct all experiments and is knowledgeable with the basic theory pertaining to each experiment. This knowledge can be gained by simply referring to this manual and the MAE/CE 370 Mechanics of Materials Laboratory Manual.

As beneficial as this laboratory is to the student it can be equally beneficial to the laboratory instructor. Invaluable teaching experience is gained through the various responsibilities placed upon the instructor. From learning how to objectively grade technical reports, to preparing and delivering supplementary lectures, this laboratory will provide an excellent teaching experience. However, the quality and value of the experience gained is dependent upon the quality of the input and diligence of the laboratory instructor.

If this manual or the MAE/CE 370 Mechanics of Materials Laboratory Manual fails to answer any questions the instructor is encouraged to contact the class professor or the MAE department, depending upon the information sought.

CHAPTER 2- FAMILIARIZATION WITH THE LABORATORY

2.1 Access to the Laboratory

The MAE/CE 370 Laboratory is located in room N278 of Technology Hall (TH). The MAE office should be contacted as to where the key to the laboratory can be obtained. Currently the only key that is required for this laboratory is the room key. The instructor should verify if any other keys are required such as keys to cabinets and drawers. Finally, the instructor should physically check the laboratory to ensure that all experimental equipment is accessible. Each time the empty laboratory is exited the instructor should check to make sure that the doors are locked. This is to ensure the security of the equipment.

2.2 Location of Experimental Equipment

Currently, most of the equipment utilized in the 370 laboratory is located in a cabinet along the north wall of the classroom. Other larger pieces of apparatus are positioned on tables within the laboratory or are freestanding. These include the torsion testing machine, beam loading apparatus, column buckling machine, and the tensile testing machine.

An inventory listing the MAE/CE 370 active equipment that is currently utilized in the conduction of experiment's, is provided in Appendix A of this manual. Be sure to review the inventory listing at the beginning and end of the semester to ensure all necessary equipment is present. Various people who have access to the laboratory may borrow equipment and inadvertently fail to return the items. Any missing pieces of equipment should be immediately brought to the attention of the MAE office and the class professor.

It is highly recommended that the laboratory instructor secure a personal set of whiteboard markers to bring to every laboratory. Whiteboard markers have proven to be an extremely difficult item to maintain within the laboratory.

2.3 Conducting Experiments

The laboratory instructor should secure a copy of the latest version of the MAE/CE 370 Mechanics of Materials Laboratory Manual edited by John A. Gilbert and Christina L. Carmen. The laboratory students utilize this manual. The manual can be obtained from the MAE office. This manual contains background and procedural information pertaining to each experiment to be conducted during the semester. Obviously, it is vital that the instructor is knowledgeable in regards to the conduction of each experiment. If the instructor has never taught this particular laboratory in the past the following suggestions are recommended:

1) The instructor should go to the laboratory with the student manual and conduct each experiment. Most of the experimental procedures are written such that no other explanation is required to successfully conduct the experiment. It is also recommended that as the instructor is conducting each experiment for the first time that he/she write down all questions pertaining to procedural steps, calculations, equipment, etc. In order to avoid damages to the equipment the instructor should not continue the experiment if any procedural step is unclear.

2) The instructor should attend another session of the laboratory taught by an experienced instructor. This is probably the most beneficial manner to become familiar with the experiments. Not only will the novice instructor learn how to conduct the experiments but also he/she will be exposed to the supplementary lectures/discussions associated with each experiment. The experienced instructor can answer any questions the novice instructor may have. It is also a good idea to review any handouts the experienced instructor distributes to the students. These handouts may contain information regarding grading, scheduling of experiments, number of students per group, etc. The novice instructor may decide to follow the lead of the experienced instructor until he/she has gained more experience.

3) If no experienced instructor is teaching the other sessions of the laboratory be sure to contact the professor of the class and the MAE office. These contacts will be able to provide assistance as to who should be contacted to help the novice instructor become familiar with the conduction of the experiments.

2.4 Student Laboratory Manual

The laboratory instructor will need to secure a copy of the MAE/CE 370 Mechanics of Materials Laboratory Manual for each student in his/her laboratory section. If the official laboratory class roll has not been distributed by the time of the first laboratory session the instructor can contact the MAE office to obtain the number of students currently enrolled in that particular laboratory section. Extra manuals should be obtained for late registering students.

The laboratory manual should be distributed to each student during the first laboratory meeting. The manuals are provided by and are the property of the MAE department. The manuals should be returned to either the laboratory instructor or the MAE office at the end of the semester. The instructor should advise the students not write in the manual as future students will utilize them. The student may copy the experimental data sheets in the manual for recording data during the experiment. The instructor may want to write the students name and the semester the manual is utilized on the inside front cover of the manual to track the return, or failure to return, of the manual.

CHAPTER 3- LABORATORY SEMESTER SCHEDULE

3.1 Scheduling the First Laboratory Session

The instructor should contact the class professor before the first week of classes to inquire if the professor has a preference as to when the first laboratory session is scheduled. If no preference is stated it is recommended that the first session be scheduled the second week of classes. The instructor should post a sign on the laboratory doors stating when the first laboratory session is scheduled and provide your name and phone number in case students have any questions. Be sure to post the sign before the first day of classes. Also, you may want to contact the professor and ask him/her if it would be possible to announce in class when your session will meet for the first time.

3.2 Scheduling of Experiments

The ideal schedule would prescribe the scheduling of an experiment to concur with the classroom lecture pertaining to the objective of that experiment. Due to class size and equipment availability this ideal situation may not be feasible. However, the following sequence of experiments is recommended:

1- Modulus of Elasticity Tension Test	(1 test station)
2- Column Buckling Test	(2 test stations)
3- Torsion Test	(1 test station)
4- Modulus of Elasticity Flexure Test	(4 test stations)
5- Poisson's Ratio Flexure Test	(4 test stations)
6- Cantilever Flexure Test	(4 test stations)
7- Stress Concentration Test	(4 test stations)
8- Principal Stresses and Strains Test	(4 test stations)
9- Beam Deflection Test	(1 test station)

Again, the order and scheduling of experiments is dependent upon the number of students in the laboratory section and equipment availability. Previous experience has shown the number of students in a particular laboratory section to range from approximately 5 students to as many as 20 students. Of course the smaller the number of students in particular section the easier it is to follow the above recommended sequence. Normally, the instructor will encounter a class size requiring 3 or 4 separate groups. These groups should ideally contain 3 or 4 students. The smaller the groups size the more beneficial a learning experience for the student. The group size may be larger depending upon the total number of students in the section. Assigning more than 4 groups may prove difficult to manage as far as allowing the instructor to be accessible to any questions or problems the groups may encounter. Also, as seen from the above sequence list, some of the experiments only have one or two test stations which may require two or three different experiments to be conducted simultaneously during a laboratory session. Therefore, some students may conduct the torsion test before conducting the modulus of elasticity tension test.

The laboratory instructor should develop a schedule prior to the first scheduled laboratory meeting. A copy of the schedule should be provided to each student. Of course, due to unforeseen circumstances the occasion may arise where a scheduled session may need to be cancelled. If this occurs the instructor should try to personally contact each student as soon as possible and post a sign on the laboratory doors stating when the next session will meet. At the next meeting the instructor should provide a revised schedule to each student. For this reason it is important for the instructor to obtain updated home and work telephone numbers during the first laboratory meeting.

Appendix B contains sample laboratory semester schedules that may aid the instructor in developing his/her own schedule for the semester. The ideal schedule should contain information regarding the scheduling of each experiment, when reports are to be submitted, and when graded reports will be available. Note that in the sample schedules in Appendix B it may be necessary that the student will need to submit reports and retrieve graded reports via the instructor's mailbox. The exact location of the instructor's mailbox should be specified. Typically, teaching assistants maintain mailboxes in TH-N277. These schedules are only suggestions and each instructor should develop their own ideal schedule based upon various factors such as class size, which will determine the number of laboratory groups. The sample schedules lists the schedules for four different groups. This is the maximum recommended number of groups per laboratory section. Depending on class size a smaller number of groups may be appropriate.

Note that in the sample schedules in Appendix B that experiments number 4 through 8 are conducted simultaneously among all groups due to the availability of enough test stations. This is the ideal situation since any questions or problems that arise may be encountered by other groups. Thus, logistically, this is the most efficient manner of conducting experiments. However, only experiments 4 through 8 have enough test stations for this situation to occur. Another positive aspect of having all groups conduct the same experiment is that the instructor can present one supplementary lecture to the entire class before the experiments begin. When different groups are conducting different experiments the instructor must discuss theoretical information to each individual group.

Most of the experiments last anywhere from 30 minutes to 1 hour. For larger class sizes the amount of time required conducting each experiment will most likely increase. Schedule B.2 in Appendix B provides an option where groups can conduct two experiments during a laboratory meeting. Previous experience has shown that students prefer conducting more than one experiment, particularly if an experiment only requires 30-45 minutes to conduct. This is most feasible when the class size is small and groups are no larger than 4 members.

3.3 Summer Semester Schedule

It is important for the laboratory instructor to keep in mind that the summer semester is 10 weeks in length as opposed to the fall and spring semester which last 14 weeks. The laboratory sessions are officially scheduled to last longer during the summer semester. During the fall and spring semesters the laboratory session is officially scheduled for 3 hours. The actual amount of time spent in the laboratory usually does not exceed two hours. However, this is dependent upon the number of students and groups within a particular section.

Due to the abbreviated summer schedule it may not be feasible to schedule group presentations. Another option may be to conduct the Modulus of Elasticity Tension Test as a demonstration test for the entire class. Scheduling more than one experiment per laboratory session would be the most ideal situation during the summer due to the extended laboratory meeting time. However, requiring more than one submitted laboratory report per week may be asking too much of the student. If the instructor encounters scheduling problems he/she should check with the professor with respect to the above suggestions.

CHAPTER 4 - LABORATORY GUIDELINES

4.1 Grading Laboratory Reports

It may seem that the most important aspect of the laboratory instructor's responsibilities is to provide quality instruction and guidance during the conduction of the experiments. To the student, however, many hours are spent preparing laboratory reports and careful, objective grading by the instructor is essential. The instructor should determine, before grading the reports, exact point penalties and strictly adhere to these. Potential frustration among students can occur if one is penalized, more or less than another, for similar errors.

It is important for the instructor to assign exact point distributions for each section of the report. The students are provided a laboratory report format in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The recommended format is provided in Appendix C. Each major report section is assigned a point value. It is the discretion of each instructor to determine the exact penalties for errors within each section such as unitless numbers, incorrect calculations, missing dimension, etc. The instructor should penalize with point values that are reasonable with respect to the point value of that particular section of the report. If a particular group obtains a high percent error when comparing an experimentally obtained value to the theoretical value they should not be penalized. High percent errors are the result of a multitude of various possibilities- many that are not due to the experiment conductor. It is important for the students to understand and discuss the many possible sources of error that may contribute to a high percent error within the report. The instructor should keep in mind that grading reports is different than testing the student's knowledge on a particular subject. The student has been provided a specific format for reporting the findings of an experiment. It is possible for a novice instructor to be overzealous when grading reports. The instructor should keep in mind that the goal when grading a report is to assist the student in preparing a technical report that effectively communicates the findings of an experiment.

Many students have access to previously submitted and graded reports. The recommended format in Appendix C, which is discussed in detail in section 4.2, is designed, as best as possible, to prevent duplication of old reports. Previously graded reports aid many students in following the correct report format as well as prevent erroneous data calculations. Students who do not have access to old reports may be at a disadvantage. For this reason it is important for the instructor to convey to students that all report requirements are listed within the recommended format and penalties will result from not following this format.

Another factor about which the instructor should be sensitive to is the grammatical nature of submitted reports. Penalizing for a unitless number, for example, is reasonable whereas penalizing for grammatical errors may not be. Many students may be of foreign origin or simply may not possess grammatical eloquence. It is recommended that grammar errors be noted within the text of the graded report with no points deducted if it is obviously a characteristic of the student's academic nature.

The recommended format in Appendix C also states penalties for late submittal of reports. Previous experience has shown that these penalties effectively encourage the timely submission of reports. These particular penalties are also sensitive to the busy schedule many students maintain where late submittal of a day or two may be necessary. The student should call the instructor after having submitted the late report to the instructor's mailbox. If the student does not call, the instructor may check his/her mailbox several days after the paper was submitted and, thus, the penalty would be greater.

Students must be present in the laboratory for each experiment conducted. If a student will be absent for an upcoming laboratory session he/she should advise the laboratory instructor as soon as possible. The instructor can advise the student to make-up the experiment during another laboratory session or make special arrangements according to the instructor's preferences. However, the instructor should not cater to a student with chronic absences or tardiness.

4.2 Laboratory Report Format

The recommended report format provided in Appendix C is similar to many required by various technical journals. As mentioned previously it is also designed to prevent students from copying old laboratory reports. For example, a Background section normally will provide a discussion of pertinent equations and a theoretical overview of the experiment - similar to the Background section of the student manual. However, the current recommended Background section format states that the instructor will specify exact topics that the student is required to discuss. Requiring the discussion of certain topics prevents the duplication of the background section in the student manual, or old reports, and grading will be less subjective.

The report should be written in third person following the required grammatical format of most technical papers. The student should also be encouraged to word process the paper using the software of their choice. All students have access to the student computer laboratory where this software is available. It is the instructor's discretion as to whether or not word-processed reports are a requirement. However, the report guidelines in Appendix C states that hand written reports will be accepted. Previous experience has shown that most students will word process their reports. However, on occasion, when a printer is malfunctioning or some other cause arises to prevent the submittal of a word-processed report the student is not penalized for submitting a hand written report.

The **Title page or first page header** should include the experiment title, experiment number, student's name, group designation, group member's names, the date the experiment was conducted and the date the report was submitted.

The **Abstract** format is modeled after the abstract sections of most technical journal papers. Many journal and technical paper databases extract this section of the paper and include it in the database. Therefore, this section should include a statement concerning the purpose of the experiment, how it was conducted, a sampling of the final values obtained and how these values compare to standard or theoretical values. This section should be self-contained – that is, no reference to other sections of the report should be made.

The **Background** section of the report, as previously mentioned, should include a discussion of the exact topics identified by the instructor during the experiment. Three distinct topics of discussion worth equal value are recommended. Sample topics of discussion are provided in Appendix D to aid the instructor. It is recommended that the instructor provide a copy of the three topics to be discussed to each group. Verbally discussing the required topics with the group after the experiment is also an option, albeit a more time consuming one. Varying the required Background topics among the different groups is suggested to prevent sharing of information among groups. Surprisingly, many students, when asked, will not know the units of a particular parameter. Therefore, the Background format also requires the definition of each parameter within equations and the corresponding units associated with the parameter.

The **Procedure** section should include any deviations from the procedural steps written in the student manual, a sketch of the experimental set-up, and pertinent dimensions. It is not necessary that the student rewrite the entire procedure for conducting the experiment. Referring to the manual's procedure is sufficient. However, the student should note within this section if any deviation from the written procedure was employed. The purpose of this section is to enable the reader to visualize the experimental set-up and, if needed, to more accurately duplicate the experiment as conducted by the report's author.

The **Data and Calculations** section of the report should include three sub-sections - raw data, calculations, and sample calculations. The RAW DATA sub-section should include all measurements and readings recorded during the experiment. The student should rewrite and present this information neatly within the report. The student should include appropriate units with all values. The CALCULATIONS sub-section should include all required calculations and graphs specified within the student manual. The SAMPLE CALCULATIONS sub-section should include one sample calculation of any and all required calculations. This section will aid the instructor in determining the source of any mathematical calculation errors, if present. The student should be advised that obtaining high percent error values will not negatively affect their grade as long as the calculations are correct.

The **Results** section could arguably be the most important section within the report. The **Data and Calculations** section of the report is a presentation of the numerical findings of the experiment. The **Results** section, however, requires analytical interpretation of the data. The discussion of the sources of error is intended to extrapolate engineering logic from the student. Obtaining a high percent error can be more of a learning experience since it provides the impetus for determining why the values were skewed. The discussion and determination of the various factors leading to high percent error should not be limited to the case when high percent errors are obtained. Even if excellent experiment data is obtained the student should still be required to provide possible sources of error which may adversely affect the data. Previous experience has shown that the laboratory groups benefit from a source of error discussion with the lab instructor immediately following the experiment.

The **Conclusions** section of the report provides a final overview of the success or failure of the experiment. Suggested improvements to the laboratory in terms of instruction, procedure, equipment, etc. should be provided.

The **Reference** portion of the report is flexible as far as the format is concerned. Most technical journals vary in terms of recommended reference format. It is important, however, that the reference includes such information as the author, title, year, publisher, volume, page number, etc.

The **Raw Notes** section of the report is solely for the benefit the instructor grading the report. The student is required to attach the actual notes taken during class. They should not rewrite these notes. The instructor will encounter many reports with missing information that was included within the student's raw notes. Requiring the inclusion of these notes encourages students to review the notes so as not to delete any information from the formal report and, hopefully, encourages better note taking. The student should not refer to these raw notes within the formal report.

4.3 Grading Group Presentations *(Optional)*

Group presentations benefit the students by preparing them for the engineering workplace environment where presentation of their work is often required. The presentation will be an in depth discussion and presentation of the results generated by a particular experiment. The laboratory instructor will assign each group a particular experiment to present to the laboratory class. The experiments should be randomly assigned during the first laboratory session. Every student within the group will receive the same grade obtained by the entire group. The group presentation grade will count equally as a laboratory report grade. Appendix E provides a sample grading guideline for the group presentations. The instructor may want to prepare questions pertaining to each assigned presentation experiment to ask the group during or after the presentation. These questions should not be intended to intimidate the students but should be thought provoking and promote discussion among all class members in order to prepare the students for the laboratory final.

The group presentations are described as being optional primarily due to possible time constraints present during the summer term and the preferences of the class professor. Since the group presentations are discussed within the student laboratory manual the students will not be taken by surprise if presentations are required. However, it would be unfair for one laboratory instructor to require presentations and another does not. Therefore, the instructor should check with the class professor concerning preferences that he/she might have pertaining to these presentations.

Since various modes of presentation are possible the instructor should verify with each group exactly what type of equipment is required for the presentation. The required equipment may include an overhead projector, slide projector, laptop computer, video projector, etc. The instructor should contact the class professor concerning the procurement of these pieces of equipment for the group presentations.

4.4 Group Presentation Format *(Optional)*

The students should be encouraged to utilize the latest presentation software of their choice. A recommended group presentation format is provided in Appendix F. The format is similar to the format of the laboratory report. The students should decide, as a group, the responsibilities of each group member in terms of the preparation and the presentation of the experimental findings.

4.5 Laboratory Final *(Optional)*

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As mentioned previously, grading laboratory reports is not equivalent to testing a student's knowledge on a particular topic. However, testing the student's knowledge on specific topics related to the laboratory and the experiments is valid considering the amount of time spent gathering information in the laboratory and preparing laboratory reports. The laboratory instructor should verify with the class instructor whether or not a laboratory final will be scheduled. It would not be fair for only certain laboratory sections to have a laboratory final. Therefore, the exam should be given to the entire class during the regularly scheduled class meeting. It is not advisable to administer the exam to individual laboratory sections since answers to any questions that arise during the exam may give one section an advantage over another. Also, laboratory sections meeting later in the week may unfairly receive information concerning the exam.

Previously, the laboratory final exam has been written by the laboratory instructors and edited by the class professor. A good protocol is to require each laboratory instructor teaching that particular semester to submit 3 or 4 questions pertaining to each experiment to the class professor. The class professor can then choose, delete, add or edit the questions for the final version of the exam. Also, the professor may choose to include extra material covered in the class.

Appendix G provides study tips for the students to prepare for the laboratory final.

CHAPTER 5 - LABORATORY INSTRUCTION AND SUPPLEMENTARY LABORATORY LECTURES

5.1 Introduction

The procedural steps for each experiment are very clear and straightforward. Particularly for the five experiments involving the use of strain gages and strain meters. The instructor should emphasize and encourage the students to meticulously follow each procedural step. These five experiments involve wire connections and strain meter settings. Any small error or misreading of a step will cause erroneous results. It is difficult for the instructor to locate the error without repeating the procedure from the start. Encourage the students to read the procedure out loud as each step is being performed so that every member is involved and can potentially avoid errors.

Even though the procedure is self explanatory, it is important that instructor provide a supplementary lecture concerning each experiment. The discussion should cover the experimental objective, the theory involved, and important equations used in the calculations. Due to the availability of equipment the five aforementioned experiments utilizing strain gages and meters can be performed by up to four groups at the same time. In regards to these five experiments, since all students will be conducting the same experiment, the instructor should provide a lecture before the start of the experiment. The other experiments require individual group discussions since different groups will be conducting different experiments.

The laboratory setting is unique in regards to the interaction between the students and the instructor. Since it is less formal than the classroom setting it allows the opportunity for much more verbal interaction and discussion with the laboratory instructor. The instructor should keep in mind that he/she has a distinct role in guiding students through the understanding and conduction of an experiment. Being accessible and conversing with students is encouraged. However, the instructor should remain professional and issues such as student performance, attendance, grades and other personal matters should not be discussed in a group environment. Also, when discussing topics related to the experiment it is best not to single out students but rather ask questions of the group as a whole.

The instructor should provide an atmosphere in which students are encouraged to ask questions. Even though the instructor may be familiar with the material he/she should never respond to any question in a condescending manner. There is no such thing as a stupid question- unless the question is not asked. Likewise, the occasion may arise where the instructor is asked a question to which the answer is not known. The instructor should respond to the question by commenting on the validity of the question, that he/she is not certain of the correct answer and will attempt to find out the correct response that will be provided at the next meeting. There is nothing wrong with not knowing the answer to every question. However, it is not appropriate to provide information that may not be accurate.

5.2 First Laboratory Session

The first laboratory meeting will consist of the handling of logistical matters such as verifying the roll, distributing manuals, assigning groups, etc. Also, the instructor should provide an introduction to the laboratory with a supplementary lecture pertaining to strain gages. If time permits, especially during the summer semester when the allotted laboratory time is lengthened, conducting the first experiment would be beneficial.

The following items should be completed during the first meeting:

- **Verification of the attendance roll.** If the instructor has not received the official roll by the first meeting the students should sign a roll with their home phone number, work phone number and e-mail address. To conserve time the students can complete this task as they enter the laboratory.

- **Distribute manuals and handouts.** At the same time students are entering and signing the roll the instructor can distribute manuals to the students and the students can pick-up any handouts the instructor has available. The handouts may include the semester schedule, the report guidelines, etc., and they can be reviewed while students are waiting for the class to begin.

- **Instructor introduction.** Once class is ready to begin the laboratory instructor should introduce himself/herself to the class and specify any preferences as to how the class should address the instructor.

- **Assign laboratory groups.** The instructor should have an idea of how many groups to designate based upon the class rolls or contacting the MAE office if the class rolls have not been distributed. Due to carpooling or similar schedules, some students may have preferences in regards to their laboratory group members. If the instructor chooses, he/she should ask for these requests before randomly assigning groups to avoid these requests at a later time. The instructor should write all group assignments on the board with each member's name to avoid confusion.

- **Discuss semester schedule.** The semester schedule should briefly be reviewed to emphasize days on which a laboratory is not scheduled, when more than one experiment will be performed, when reports are due, etc. Also, the instructor should note any days when a report is due but a laboratory session is not scheduled. The schedule should indicate the location where reports can be submitted, and retrieved, when a laboratory is not scheduled. Most laboratory instructors have mailboxes in room TH-N277 where this exchange can take place.

- **Discuss report guidelines.** It is a good idea for the instructor to read aloud the handout concerning laboratory report guidelines and format. Since the students laboratory grade is primarily an average of the laboratory report grades, the students should be encouraged to ask any questions as the instructor discusses this information

- **Discuss laboratory manual.** The instructor should briefly discuss the major sections and the layout of the laboratory manual. The students should be reminded that the manuals need to be returned at the end of the semester and, therefore, should not be written upon. The students may copy the data recording pages pertaining to each experiment for use during the laboratory.

- **Provide an introduction to the laboratory.** This introduction should consist of a brief discussion of the purpose of each experiment and a discussion on how strain gages work. Chapter 6 provides an in depth write-up concerning this information.

5.3 Supplementary Laboratory Lectures

The supplementary laboratory lecture provides an added basis for the student's understanding of the objective of the experiment. These supplementary lectures are to be provided for each experiment conducted. The lectures are intended to provide clarification of the concepts discussed in the manual that the students may not have completely understood during the preparatory reading of the material. Many times students may approach the laboratory session without a clear understanding of the purpose and goal of the experiment. Without this knowledge the subsequent conduction of the experiment becomes merely a data recording session. However, when the student is provided and understands the theoretical concepts of a supplementary lecture the following physical process of conducting a hands-on experiment serves as a tremendous learning experience and reinforcement of theoretical and, sometimes, abstract phenomena. Supplementary lectures should be provided at the beginning of the laboratory session when all groups are conducting the same experiment. When each group is conducting a different experiment it is best to provide these discussions to the individual groups. The supplementary lectures are provided in Chapter 6 through Chapter 15. The recommended information to provide to the students during the lecture is highlighted in blue text. A helpful tool to reinforce the students understanding and retain their attention is to intermittently ask the class questions during the lecture or discussion. Suggested questions to ask the students are provided in the lecture material in Chap. 6-15 and are highlighted in red.

5.4 Experimental Instruction/Guidance

As mentioned previously, the experimental procedures specified within the laboratory manual can be performed without much assistance from the instructor. Therefore, when the individual groups are ready to conduct an experiment the instructor should direct the groups to start by carefully reading the procedure. Once the groups have started the procedure the instructor should begin rotating among the groups to verify that each group is secure in the procedure they are following and answer any questions they may have.

Once each group is confidently progressing with the experiment the instructor should begin asking thought provoking questions concerning the experiment and provide a supplementary lecture/discussion if one was not provided before the experiment started. The supplementary laboratory lectures for each experiment are provided in Chapter 7 through Chapter 15.

CHAPTER 6 – INTRODUCTION TO THE LABORATORY: *LABORATORY LECTURE*

6.1 Introduction

The introduction to the laboratory lecture should be provided during the first laboratory meeting and before the conduction of any experiments. The lecture consists of two parts- an overview of all the experiments and a discussion concerning how strain gages work. The overview of experiments is a brief discussion of the objective of each experiment and how the experiment is conducted. The purpose of the overview of experiments is to familiarize the students with the experiments they will be conducting. The overview should last approximately 15 minutes. It is best to keep this discussion brief since an in-depth discussion of each experiment will be provided before or during the actual conduction of the experiment and since the students will not have had the opportunity to have read the description of each experiment in the manual. The most important portion of the introductory lecture is the discussion concerning how strain gages work. This discussion is vital since five of the nine experiments are directly associated with strain gages. Recall that the recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

6.2 Overview of Experiments

When discussing each of the following nine experiments the instructor should stand by the experimental apparatus. The SATEC tensile testing machine and the computer should be turned on before class. Loading a specimen into the SATEC machine is not necessary. For the five strain gage/strain meter experiments (#4-#8) the instructor should set up, before class, all available flexure frames, strain meters and test beams at different tables so that students can see these components during the discussion.

#1- Modulus of Elasticity Tension Test – The purpose of this experiment is to apply a tensile force to a test specimen until the specimen is pulled to failure. During the course of the tensile load application the computer will monitor properties and generate a stress/strain curve from which various values such as the Modulus of Elasticity of the material can be determined. What is the Modulus of Elasticity? Is the Modulus of Elasticity a material property? What are the various regions on a stress/strain curve? What is Hooke's Law?

#2- Column Buckling Test – The purpose of this experiment is to determine the critical load for various columns. The critical load is the maximum load that the column can support before the column will buckle towards failure. Most likely each group will analyze two columns. These columns will be identical in terms of material type and dimensions. The only difference between the columns will be the end conditions. The possible end conditions are pinned-pinned, fixed-pinned and fixed-fixed. The instructor should physically hold up the various types of columns and walk among the groups showing the students the various end conditions. The fixed end condition implies that a portion (approximately ½”) of the end of the column is embedded in a rigid support. A pinned end condition refers to a “v-notch” end that is not embedded in a rigid support. Therefore, the pinned-pinned column has the “v-notch” geometry at both ends and neither end is embedded in a rigid support. The fixed-fixed column has two flat end conditions and both ends are embedded, approximately ½”, within a rigid support. Another possible test column is the fixed-pinned column having one pinned end condition and one fixed end condition. As mentioned previously, the test columns have identical dimensions. For example, if testing a pinned-pinned column and a fixed-pinned column the width, thickness and total length will be the same even though the fixed-pinned column is ½” longer. This is because ½” of the fixed end will be embedded in a rigid support and the total exposed column length will be the same as the pinned-pinned column. When applying a compressive load to a fixed-pinned column the fixed end will have a zero slope and a large moment while the pinned end will have a visible slope and zero moment. Which column will be able to support the highest compressive load? Before the actual testing of the columns the group will theoretically predict what the critical load should be using a mathematical relationship called Euler’s equation. What type of information will be required within Euler’s equation to predict a critical load? (Answer: material type, column dimensions and end support conditions). This experiment is beneficial and interesting because both the theoretical and experimental values of the critical load will be determined. Engineering logic will be required to determine why these two values may not be equal or even close. Is theoretical value of the critical load expected to be higher or lower than the experimental value? Why?

#3- Torsion Test – In this experiment two or three geometrically identical specimens will be twisted until failure. Instructor can hold up or pass around sample test specimens. Various materials such as aluminum, brass and steel may be tested. The goal of this test is to determine a material property called the Modulus of Rigidity or Shear Modulus. The higher the Shear Modulus the more rigid the material. Which material will have the highest Modulus of Rigidity? Which will have the lowest?

#4-#8- Modulus of Elasticity Flexure Test, Poisson’s Ratio Flexure Test, Cantilever Flexure Test, Stress Concentration Test, Principal Stresses and Strains Test – Each of these five experiments incorporates the use of a flexure frame, a strain meter and an aluminum test beam with one or more strain gages mounted on the surface. The purpose of the flexure frame is to provide a cantilever support of the beam. Instructor should hold up flexure frame with a beam in cantilever support. The strain meter is connected to the strain gages through a configuration of wires and provides a digital readout of the strain as detected by the strain gage. In each of these five experiments an aluminum beam will be in cantilever support at one end and a point load will be applied at the other end causing the beam to bend. Instructor should visually demonstrate this by holding flexure frame with beam attached and pressing down on the free end of the beam. The differences between these five experiments is the objective of the experiment which ranges from the determination of the Modulus of Elasticity, Poisson’s Ratio, stress variations, principal planes and determining where the stress is concentrated when a beam possesses a discontinuity such as a hole. These five experiments provide a beneficial learning experience due to the fact that these are “hands-on” experiments. For example, the Modulus of Elasticity Flexure test is similar to the Modulus of Elasticity Tension Test in that the goal of both experiments is to determine the Modulus of Elasticity of a material. However, the Modulus of Elasticity Tension test utilizes the impressive and high-tech SATEC tensile testing machine whereas the Modulus of Elasticity Flexure test incorporates basic equipment. While students may be impressed with the SATEC apparatus the only "hands-on" experience gained is the loading of the specimen. The SATEC machine and the computer will handle the rest of the work. While this set-up is what engineers may encounter in the workplace it is important for the student to understand exactly how the information, such as that which is automatically provided by the SATEC/computer system, is obtained. These five experiments provide this learning experience. While the equipment utilized may seem simplistic these experiments provide students the opportunity to physically handle each step of the experimental process from wiring connections, to applying loads, to visual inspection of the beam and gages, to balancing the strain meter to obtain a readout. These tasks provide students with a physical understanding of the process involved. A laboratory setting should provide equipment such as the SATEC. However, it would be detrimental to the engineering student if he/she did not understand how simple strain gages function.

#9- Beam Deflection Test – In this experiment various beams of differing materials will be simply supported by two knife edge supports at opposite ends of the beam. Instructor should place a beam on top of the two supports and indicate the location of the two supports. The beams will be loaded in two different ways and the deflection of the beam will be recorded as indicated by the deflection gages. Instructor should place deflection gages on top of beam. The first type of loading is the central loading where a load is placed at the center of the beam, between the supports causing the beam to deflect downward between the supports. The second type of loading is the overhung loading where two equivalent loads are placed at opposite ends of the beam, outside of the supports, causing the beam to deflect upward between the supports. This is all that is involved experimentally. Most of the work involved with this experiment is the theoretical calculations conducted outside of the laboratory. These calculations involve theoretical predictions of the deflections measured experimentally. Since these theoretical calculations are tedious students will be required to utilize a computer code or program. More information concerning these calculations will be provided during the conduction of the experiment. Just as in the Column Buckling experiment the most important aspect of this experiment is the determination and justification of why the experimental measurements and the theoretical predictions differ. What type of information must be supplied in the theoretical deflection equations? Most likely, will the experimental deflections recorded be greater or less than the theoretical deflections?

6.3 How Strain Gages Work

Since five of the nine experiments to be conducted during the semester deal directly with strain gages it is important that the function of a strain gage is physically understood. Each of the various test beams for these five experiments has at least one strain gage mounted on the surface. The instructor should walk among the various groups and identify the location of the strain gage on the test beams. Not every group will have the same test beam at their table. As can be seen strain gages can be very compact measuring devices and are inexpensive to produce. Also, the physical basis on which these devices function is very simplistic. The goal of this discussion is to ensure that everyone understands physically how strain gages operate.

Strain gages are vastly utilized in all types of testing and manufacturing facilities. In our laboratory we will be utilizing electrical resistance strain gages. These gages consist of a fine wire oriented in a zigzag pattern. Instructor should sketch the following schematic on the board:

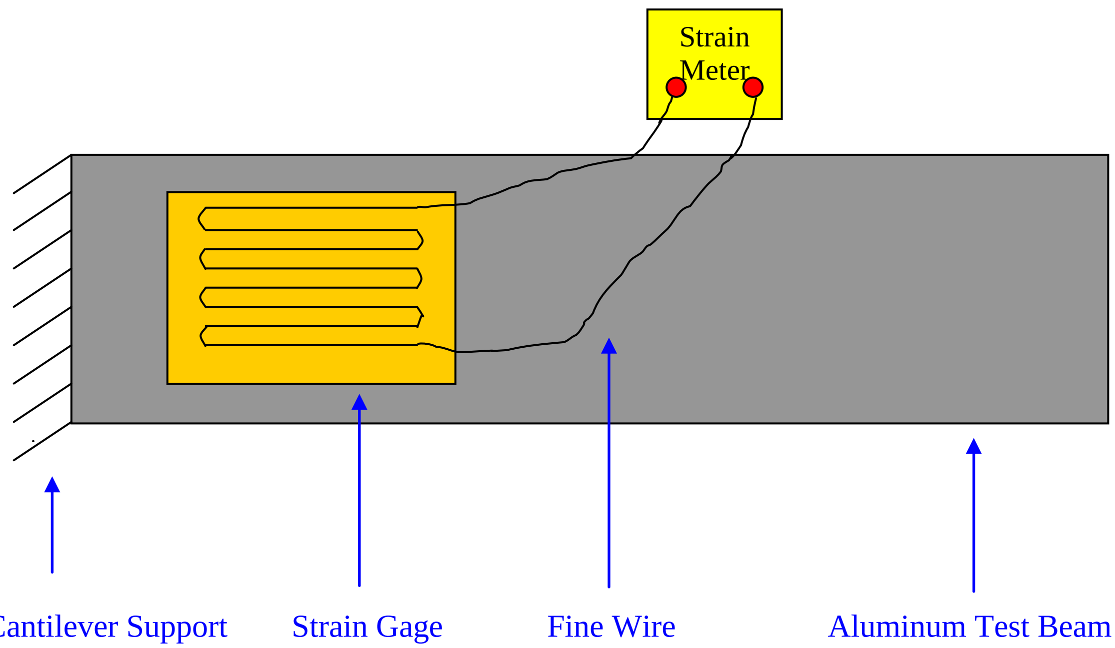


Figure 6.1: Top View of Aluminum Test Beam in Cantilever Support with Strain Gage Mounted in Axial Direction along Test Beam.

The dimensions of the test beam in the above sketch are not drawn to scale and the size of the strain gage has been exaggerated for illustrative purposes. The zigzag pattern of the fine wire of the strain gage serves two purposes. One is to enable the gage to be compact in size and secondly the pattern provides enough length of wire to obtain a measurable resistance. The strain gage is bonded to the surface of the beam so that it will undergo the exact same deformations and changes in length as the surface to which it is bonded will encounter. Looking at a side view of the test beam:

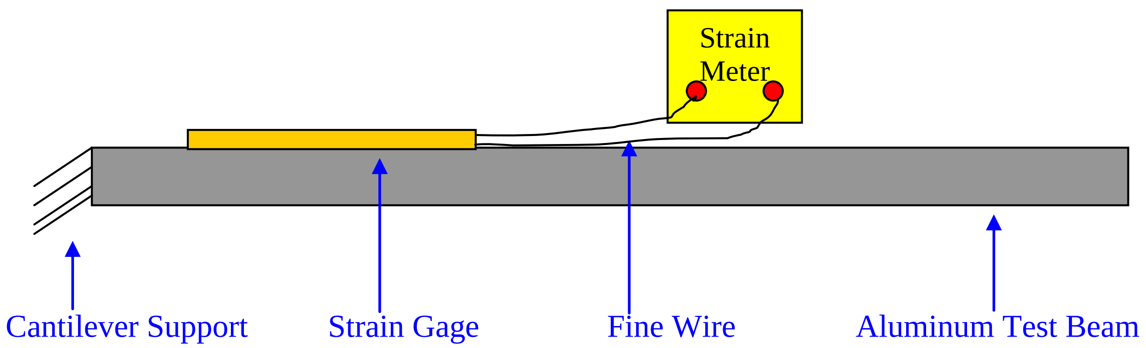


Figure 6.2: Side View of Aluminum Test Beam in Cantilever Support with Strain Gage Mounted on the Top in the Axial Direction along Test Beam.

After a point load is applied at the end of the beam the beam will bend downward as the following schematic illustrates:

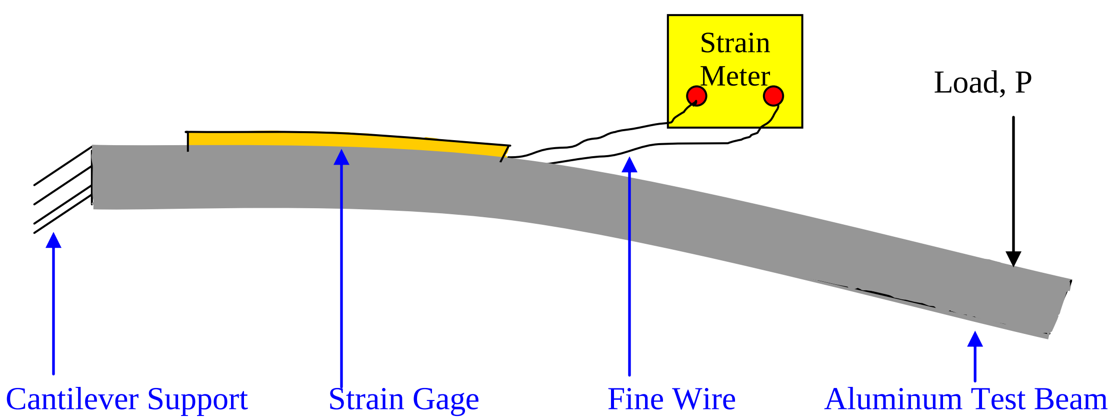


Figure 6.3: Side View of Aluminum Test Beam in Cantilever Support with Strain Gage Mounted on the Top with a Point Load Applied at the End of the Beam.

After the load, P, is applied will the top surface of the beam and the bottom surface of the beam still have the same axial length? (Answer: the top surface elongates in length while the bottom surface contracts in axial length.) Since the top surface of the beam elongates in axial length and the strain gage is bonded to the top surface the strain gage will also elongate in axial length. This is shown in the following schematic:

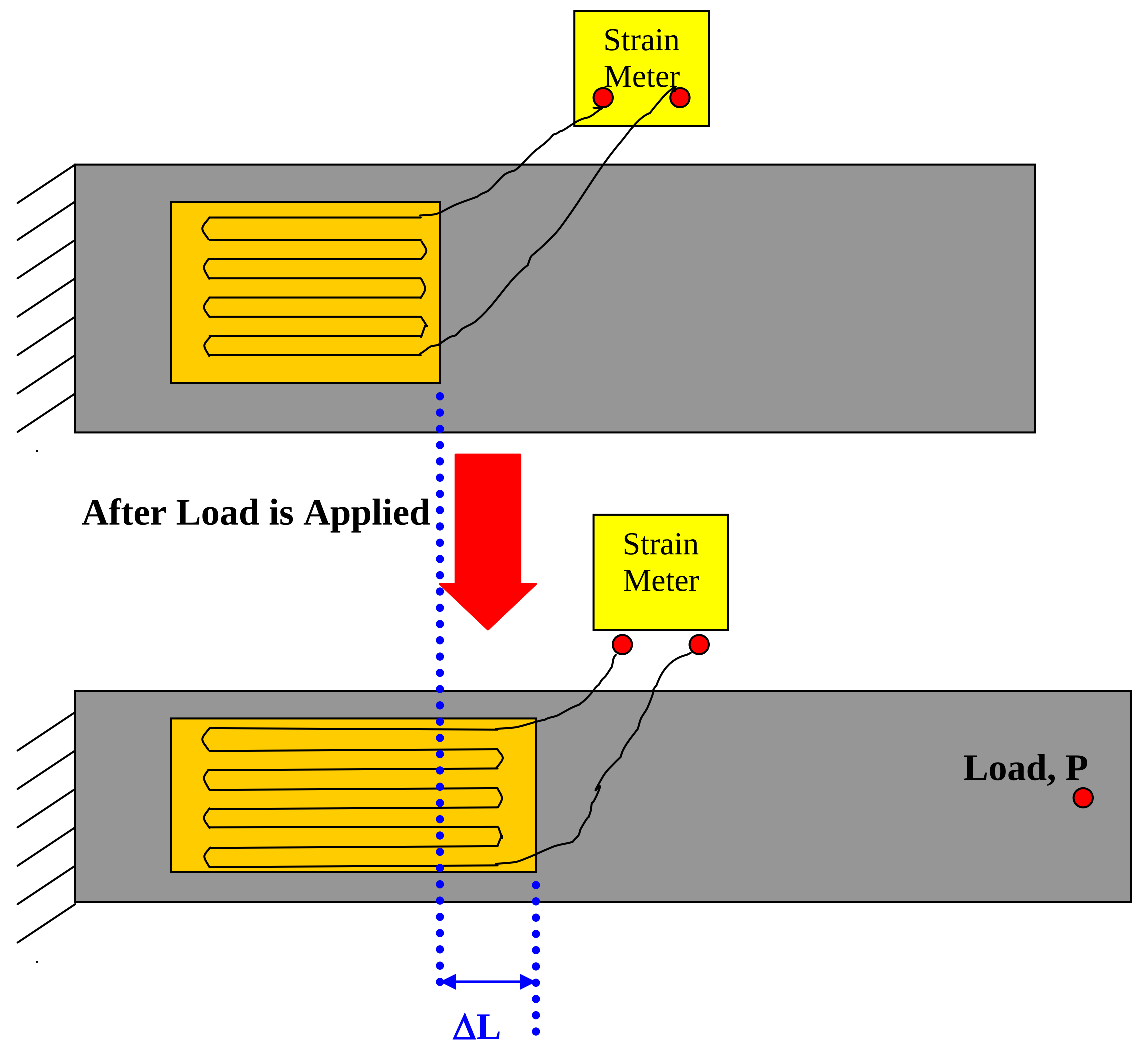


Figure 6.4: Top Surface of Aluminum Test Beam Before and After Load, P, is Applied.

The strain gage will elongate the same amount as location on the top surface of the beam, where the gage is located, elongates. This change in length is ΔL. If the strain gage is positioned along the axial direction on the bottom surface of the beam it would contract the same amount as the bottom surface of the beam contracts. The strain meter provides a current that passes through the wire of the strain gage. The wire of the strain gage has a certain resistance to the flow of the current. When the strain gage elongates causing the total length of the wire to increase will the resistance of the wire to the flow of current increase or decrease? (Answer: As the length of wire increases the resistance will increase because the current has a greater distance over which to flow.) What happens to the cross-sectional area of the wire as its length increases? (Answer: The cross-sectional area of the wire will decrease.) Thus, the basic function of a strain gage is dependant upon the change in length of the wire of the gage which in turn changes the resistance of the current flow within the strain gage. In the aforementioned example the strain gage increases in length causing the resistance measured by the strain meter to increase. This is a simple concept to deduce intuitively. There is, however, a mathematical relationship that verifies the above rationale. This expression defines the resistance of a material, such as the wire within a strain gage, to the flow of current as a function of three parameters. Instructor should write the following on the board and ask the students to provide the parameters that the resistance is dependent upon.

$$R = \frac{??}{?} \qquad (6.3\text{-}1)$$

What three parameters is the resistance of the wire dependent upon? Most likely the students will provide the length of the wire and the cross-sectional area of the wire as two of the parameters.

$$R = \frac{?L}{A} \qquad (6.3\text{-}2)$$

What are the units of the resistance, length of the wire and cross-sectional area of the wire?

Resistance of wire, R $\rightarrow$ohms (Ω)
Length of wire, L $\rightarrow$ meters (m)
Cross-sectional Area of wire, A $\rightarrow$meters^2 (m^2)

Based upon this knowledge what are the units of the final unknown parameter? (Answer: Ω–m.) What is this parameter? Thus far we know that the resistance is dependent upon the length and cross-sectional are of the wire. Is the resistance of the wire dependent upon the type of material that the wire is composed of? (Answer: yes.) The last parameter is the material resistivity, ρ (Ω-m), which is a constant value dependent upon the material. Therefore the final form of the equation is as follows:

$$R = \frac{\rho L}{A}. \qquad (6.3\text{-}3)$$

In summary, a strain gage works by deforming exactly as the surface to which it is bonded deforms. The strain meter provides a flow of electric current through the wire of the strain gage. After application of a load if the length of the wire within the strain gage increases and the cross-sectional area decreases the resistance to the flow of current will increase. Likewise, if the strain gage contracts causing the total length of the wire to decrease and the cross-sectional to increase the resistance will decrease. This is the physical basis of how a strain gage operates. The strain meter provides the actual quantitative measurement of strain encountered by the strain gage. A discussion on how the strain meter operates is included in Chapter 10.

CHAPTER 7 – MODULUS OF ELASTICITY TENSION TEST: *LABORATORY LECTURE*

7.1 Introduction

Objective: The purpose of this experiment is to measure the modulus of elasticity (Young's modulus) of different materials by placing test specimens in uniaxial tension.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory except for the tension test specimens. Since these are tested to failure the instructor should verify at the beginning of the semester that the supply is sufficient. If more test specimens are required the instructor should contact the class professor or the MAE office for the source to contact to replenish the supply. The instructor should also conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment and computer software are functioning properly.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

7.2 Supplementary Laboratory Lecture

The purpose of this experiment is to determine a material property called the modulus of elasticity or Young's modulus. This value is a measure of the strength of a material. In this tension test a test specimen is pulled until failure by the SATEC tensile testing machine. As a tensile load is pulling the specimen the specimen is elongating axially in length. Instructor should sketch the following figure on the board:

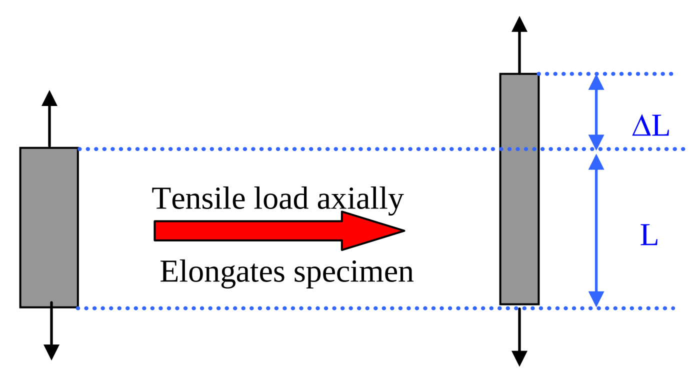


Figure 7.1: Axial Elongation of Tensile Test Specimen

What is the relationship between the axial change in length, ΔL, of the specimen and the axial strain, ε? The axial strain is defined as follows:

$$\varepsilon = \frac{\Delta L}{L} \qquad (7.2\text{-}1)$$

Thus, the axial strain of the test specimen is a non-dimensional value equal to the change in axial length of the specimen divided by the original axial length. Even though the strain is dimensionless it is best to provide the units when providing quantitative strain values to distinguish the numbers from other non-dimensional values. Obviously as the specimen is being pulled toward failure the strain is increasing. How is the value of the stress changing as the specimen is being pulled? (Answer: Within the elastic range the stress increases as the strain increases.) What are the units of stress? (Answer: lb/in^2 or N/m^2 for example.) Within the elastic region the stress, σ, is related to the strain, ε, as follows:

$$\sigma = \underline{?}\ \varepsilon \qquad (7.2\text{-}2)$$

What are the units of the proportionality factor between the stress and strain? (Answer: the same as the units of stress.) What is the proportionality factor? The proportionality factor is the modulus of elasticity, E, or Young's modulus. The modulus of elasticity is a material property that is a constant value. Of course under extreme environmental conditions, such as very low or high temperatures, material properties may change. This relationship between stress and strain within the elastic region is known as Hooke's Law and the final form is as follows:

$$\sigma = E\ \varepsilon \qquad (7.2\text{-}3)$$

Since the modulus of elasticity is a constant value what would a qualitative plot of stress versus strain look like? Instructor can sketch the following figure on the board.

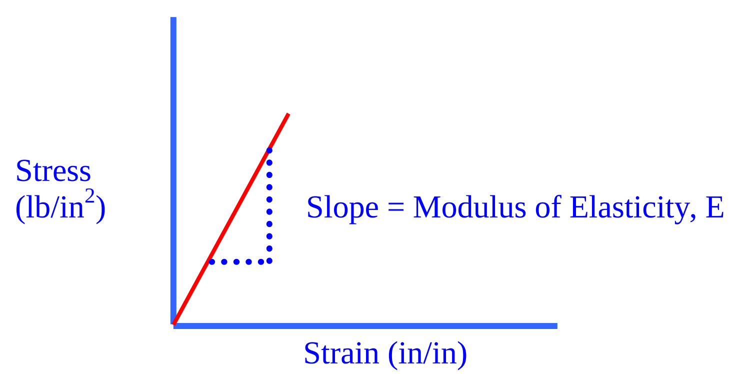


Figure 7.2: Qualitative Representation of Stress Versus Strain in the Elastic Region.

The SATEC tensile testing machine will apply a tensile load on the test specimen until the specimen fails. The computer software will monitor the changes in stress and strain and the plot of stress versus strain can be viewed on the computer monitor while the specimen is being pulled. The computer will also provide the final value of the modulus of elasticity of the test specimen by calculating the slope of the curve represented in Fig. 7.2. Since the actual test specimen will be pulled to the point of failure the final stress/strain curve generated by the computer will be different then the plot represented in Fig. 7.2. The plot in Fig. 7.2 represents a stress/strain curve within the elastic region. What does the elastic region mean? (Answer: Within the elastic region a specimen will behave elastically- meaning that the specimen will return to its original shape, without any permanent deformations, after a load is removed.) In this experiment the elastic limit will be exceeded and the specimen will experience plastic deformation and ultimately failure. However, the only information required in order to determine the modulus of elasticity are the stress and strain values within the elastic region. What does plastic deformation mean? (Answer: Plastic deformation occurs when the elastic limit of a specimen has been exceeded- meaning that the specimen does not return to its original shape and is permanently deformed when a load is removed.) Is Hooke's law valid only within the elastic region? (Answer: Yes.) Will the modulus of elasticity of the test specimen change as the elastic limit is exceeded? (Answer: Yes. The modulus of elasticity is a constant material property that can only be defined as the slope of the stress/strain curve within the elastic region. Outside of the elastic region erroneous values of the modulus of elasticity will be generated.) The final stress versus strain curve generated in this experiment will look similar to the following:

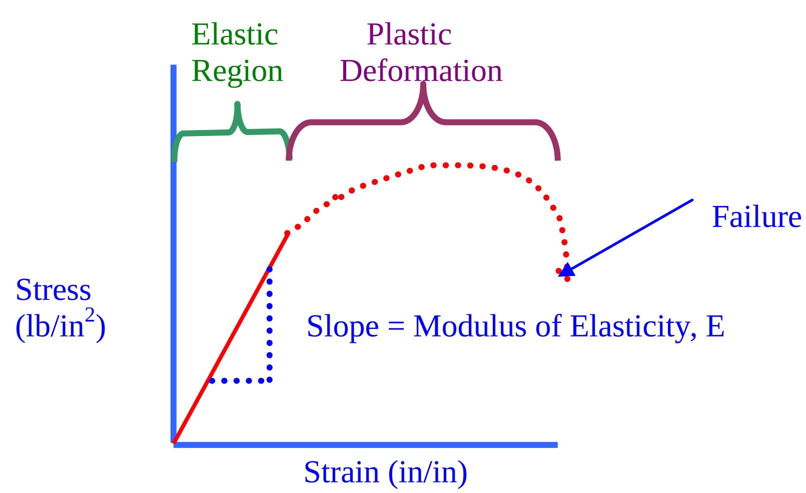


Figure 7.3: Qualitative Representation of Stress Versus Strain Curve of Specimen Stressed to Failure.

7.3 Experimental Instruction and Guidance

- The procedure to conduct the tensile test is provided in Appendix I and also in the appendix of the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure provides a detailed guide through the entire procedure- from turning the power on to turning the power off. The student should not encounter any problems conducting the experiment. The instructor should assign no more than two or three students to handle the inputs and responses to the computer prompts. The instructor can assign other students to measure the dimensions (length, width, and thickness) of the test specimen. Other students can load the specimen in the SATEC tensile testing machine when required by the procedure. It is best for the students themselves to completely conduct the experiment. However, due to the cost of the SATEC tensile testing machine the instructor should oversee the conduction of this experiment as much as possible.

7.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Inaccurate Measurement of Length, Width, and Thickness of Test Specimen.** These dimensions are inputs to the computer software that calculates the modulus of elasticity. The accuracy of this calculation is, in part, based upon these provided dimensions.

- **Material Alloy Composition**. When comparing the experimentally obtained value of the modulus of elasticity of the test specimen with the theoretical or textbook value, consideration must be given to the fact that the exact material alloy composition of the test specimen may be different than the material that the theoretical value assumes.

- **Homogeneous & Isotropic Structure of Test Specimen.** Because the physical history of the test specimen is not known the student should always question the homogeneous and isotropic structure of the specimen. Depending upon the manufacturing process and prior handling or testing, the specimen may have inconsistent granular structure, may have experienced fatigue, creep, prior deformation, or a number of other possible phenomena which may not be physically visible but will affect the outcome of the experiment.

- **SATEC Grips too Tight.** Securing the ends of the test specimen too tightly within the grips of the SATEC may cause a change in thickness of the specimen. This may lead to stress concentrations in that area of the specimen.

CHAPTER 8 – COLUMN BUCKLING TEST: *LABORATORY LECTURE*

8.1 Introduction

Objective: The purpose of this experiment is to verify the Euler buckling equation for steel columns of various lengths subjected to different end conditions.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory. The instructor should conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment is functioning properly.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

8.2 Supplementary Laboratory Lecture

NOTE: Since various groups may be conducting different experiments this information is provided to the group conducting the experiment and not to the entire class. The students may start the experimental procedure before this information is provided.

The purpose of this experiment is to verify the Euler buckling equation by obtaining an experimental critical load for various steel columns. Recall that the critical load is the maximum load the column can support before buckling towards failure. The columns that will be tested are the pined-pinned and the fixed-pinned. Instructor may also include a third test specimen- the fixed-fixed column. Instructor should also hold the columns and indicate to the students the various end conditions. Recall that the test dimensions (length, width and thickness) of each column should be identical even though the fixed-pinned column is ½" longer than the pinned-pinned column. This is because the fixed end of the fixed-pinned column will be embedded ½" within a fixed end support. However the dimensions of each test specimen should be measured and verified since there may be slight differences. Whenever an engineer is in an experimental environment nothing, including dimensions, should be assumed. The first part of this experiment is to theoretically calculate the critical load for each column using the Euler buckling equation. Then each column will be experimentally tested to determine the experimental critical load. A percent error between the experimental and theoretical critical load will be calculated.

8.3 Experimental Instruction and Guidance

- The students can begin the procedure without the instructor's assistance. Therefore, depending on how many other groups are present and conducting experiments, the supplementary lecture provided in section 8.2 could be delivered as soon as the instructor is available to the group.

- The procedure to conduct this experiment is provided in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure is detailed and the students should not encounter any problems conducting the experiment.

- During the course of the experiment the instructor should approach the group and inquire whether anyone has any questions, that the purpose of each component of the experiment is understood, and to encourage the group members to contemplate possible experimental sources of error.

- The instructor should verify the calculated theoretical buckling load obtained by the students for each column. A common error made by students while performing this calculation is the recording of an incorrect 'actual length' for the fixed-pinned and fixed-fixed column. The recording of the 'actual length' for the pinned-pinned column is the total measured length of the beam. However, the 'actual length' recorded for the fixed-pinned and fixed-fixed column should not include the fixed-end length of the column that is embedded within the rigid support of the column-buckling machine. Therefore, when initially calculating the theoretical critical load for the fixed-pinned and fixed-fixed column the student should assume that the 'actual length' of these two columns is the same as the 'actual length of the pinned-pinned' column. The 'actual lengths' for these two columns can then be verified once they are loaded within the column-buckling machine.

During the course of the experiment the instructor could ask the following questions to help solidify the concepts encountered in this experiment:

- The columns tested had virtually identical dimensions and the only difference was the end support conditions. Comparing the pinned-pinned column and the fixed-pinned column what effect did having one end fixed have upon the critical load compared to the critical load encountered by the pinned-pinned column? Answer: The fixed-pinned column encounters a critical approximately twice as great as the critical load of the pinned-pinned column. Therefore, even though the columns are the same material and possess identical dimensions the end support conditions greatly influence the amount of load a column can sustain.

- Assuming two pinned-pinned columns possess identical geometric dimensions with the only difference that one is composed of brass and one is composed of steel, which column would have a greater critical load? Answer: Based upon Euler's equation the material with the higher modulus of elasticity would have the greater critical load. Therefore, steel would have a greater critical load than brass.

- Was the experimentally obtained critical load higher or lower than the critical load predicted by Euler's equation? Answer: The experimental critical load is less than the theoretical critical load due to frequent prior experimental use of the column.

8.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Column Dimension Measurements.** Inaccurate column length, width or thickness measurements result in inaccurate estimates of the critical load based upon Euler's equation.

- **Prior Testing and Deformation of the Column**. The isotropic and homogeneous structure of the column could possibly have been altered due to prior testing. The column may have experienced fatigue or possibly plastic deformation that may not be visible. Most likely a frequently tested column will have a lower experimental critical load than the theoretically predicted critical load.

- **The vertical alignment and loading of the column**. Possible damage to the column can occur if the column is not loaded properly into the column-buckling machine as well as adversely affect the experimental critical load.

- **Parallax Error**. Parallax error is a line-of-sight error that occurs when reading any type of measurement indicators such as the load scale and observing the spirit level. To reduce parallax error the viewer should be positioned perpendicular to the indicator. Any angular deviation from a perpendicular view of the indicator will contribute to parallax error.

- **Column Biasing**. The bias weight applied to the column to ensure buckling away from the deflection gage could possibly lower the experimentally obtained critical load.

- **Material Alloy Composition**. Consideration must be given to the fact that the assumed modulus of elasticity value provided within the manual for the test columns may not be the exact modulus of elasticity value for the test columns. The exact material alloy composition of the test columns may be different than the material that the theoretical value assumes. Also any prior deformation affects the modulus of elasticity value.

CHAPTER 9 – TORSION TEST: *LABORATORY LECTURE*

9.1 Introduction

Objective: The objective of this experiment is to test torsion specimens, made of different materials, to failure. The objective of each test is to determine the modulus of rigidity, the shear stress at the limit of proportionality and verify the analytical relation between the applied torque and the angle of twist.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory except for the torsion test specimens. Normally, these torsion test specimens are available in brass, aluminum and steel. Since these are tested to failure the instructor should verify at the beginning of the semester that the supply is sufficient. If more test specimens are required the instructor should contact the class professor or the MAE office for the source to contact to replenish the supply. The instructor should also conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment is functioning properly.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

9.2 Supplementary Laboratory Lecture

NOTE: Since various groups may be conducting different experiments this information is provided to the group conducting the experiment and not to the entire class. The students may start the experimental procedure before this information is provided.

The primary purpose of this experiment is to determine a material property called the modulus of rigidity or shear modulus. As the two aforementioned names imply, the test specimen will encounter shearing stresses as a result of the twisting of the specimen and the specimen which is more rigid, or more resistant to twisting, will have a higher modulus of rigidity. Again, the modulus of rigidity is a material property and, under non-extreme environmental conditions, is a constant value for each material. In this experiment two or three specimens will be tested. These specimens will possess identical geometric measurements and differ only in material type. The various materials tested may include brass, aluminum and steel. The experimental determination of the modulus of rigidity is similar to the experimental determination of the modulus of elasticity. However, the modulus of elasticity was determined by the application of an axial load and the test specimen was not plastically deformed. The modulus of elasticity was calculated by determining the slope of the axial stress versus axial strain curve. The modulus of rigidity will be determined by twisting the test specimen and calculating the slope of the shear stress versus shear strain curve. In addition, the torsion test specimen will be twisted to failure in order to determine the shear stress at the limit of proportionality. The shear stress at the limit of proportionality is the largest value of the shear stress for which the material will behave elastically. Throughout this discussion the plot of the shear stress versus shear strain has been mentioned. The actual values recorded experimentally, as the specimens are being twisted, are the angle of twist applied to the specimen and the corresponding value of torque at a particular angle of twist. The instructor should indicate location of the 6 degree and 360 degree vernier scale and the torque scale. Equations are provided within the student manual to convert the twist and torque values to the corresponding shear stress and shear strain values.

9.3 Experimental Instruction and Guidance

- The students can begin the procedure without the instructor's assistance. Therefore, depending on how many other groups are present and conducting experiments, the supplementary lecture provided in section 9.2 could be delivered as soon as the instructor is available to the group.

- The procedure to conduct this experiment is provided in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure is detailed and the students should not encounter any problems conducting the experiment.

- During the conduction of the experiment the instructor should approach the group and inquire whether anyone has any questions, that the purpose of each component of the experiment is understood, and to encourage the group members to contemplate possible experimental sources of error.

- The students should be able to test at least two different materials, preferably three. Another option, particularly if only one material type is available, is to test two or three specimens. This can be an interesting investigation for the students in order to determine the consistency of results- thereby providing insight into the manufacturing consistency and process of the test specimens.

During the course of the experiment the instructor could ask the following questions to help solidify the concepts encountered in this experiment:

- Is there a relationship between the modulus of rigidity and the modulus of elasticity of a material? Answer: Yes, the modulus of rigidity of any material has a value between 1/3 to ½ the value of the modulus of elasticity of that material. What are the units of the modulus of rigidity? Answer: The modulus of rigidity has the same units as the modulus of elasticity. The units may be in psi or Gpa.

- Which material, brass or steel, would you expect to have a higher modulus of rigidity? Answer: Steel has a higher modulus of elasticity value than brass and, therefore, would have a higher modulus of rigidity value. This should be reasoned intuitively since the steel is a more rigid material and less ductile than brass.

- If testing steel and aluminum, which material would fail at a higher angle of twist? Answer: The aluminum would fail at a higher angle of twist since the modulus of rigidity of aluminum is less than steel and aluminum is more ductile than steel. Because of these two factors the aluminum will be able to sustain more twist than the steel. Which specimen would have a greater value of torque at failure? Answer: The steel would have a greater value of torque at failure than aluminum even though aluminum is able to sustain a higher angle of twist. Because steel is a stronger and more rigid material than aluminum it takes more work, or torque, to twist steel than aluminum.

9.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Material Alloy Composition**. The test specimen's provided in the laboratory are identified only as brass, aluminum and steel. The exact type and alloy percentage of each material is not known. Therefore, consideration must be given to this fact when referencing the theoretical value of the modulus of rigidity. The exact material alloy composition of the test specimens may be different than the material that the theoretical value assumes. Also, even if the material was explicitly identified the exact material composition should still be questioned based upon the quality of the manufacturing process of the test specimen.

- **Homogeneous and Isotropic Composition**. The isotropic and homogeneous structure of the test could possibly have been altered due to prior testing. Also, the quality of the manufacturing process may impact the consistency of the internal granular structure of the test specimen.

- **Parallax Error**. Parallax error is a line-of-sight error that occurs when reading any type of measurement indicators such as the torque scale, vernier scales and observing the spirit level. To reduce parallax error the viewer should be positioned perpendicular to the indicator. Any angular deviation from a perpendicular view of the indicator will contribute to parallax error.

- **Slip of Test Specimen**. Each end of a test specimen has a hexagonal shape. The ends are inserted into hexagonal shaped chucks on the torsion-testing machine. The hexagonal shaped chucks are tightened around the hexagonal shaped ends of the test specimen. The test specimen should be aligned so that the chucks are tightened such that the hexagonal sides of both the specimen and the chucks are flush with one another. Possible slip of the test specimen may occur as the specimen is twisted resulting in erroneous readings.

CHAPTER 10 – MODULUS OF ELASTICITY FLEXURE TEST: *LABORATORY LECTURE*

10.1 Introduction

Objective: The purpose of this experiment is to measure the modulus of elasticity (Young's modulus) of an aluminum beam by loading the beam in cantilever bending.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory. The instructor should conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment is functioning properly. The loads will be applied to the end of the beam using hook hangers and individual slotted weights.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

10.2 Supplementary Laboratory Lecture

10.2.1 Modulus of Elasticity Flexure Test

The modulus of elasticity, or Young's modulus, of a material was previously determined experimentally while conducting the Modulus of Elasticity Tensile Test using the SATEC tensile testing machine. The difference between that experiment and the one to be presently conducted is that the tensile test utilized an axial tensile load that pulled the specimen to failure. The beam utilized in the current flexure test will experience a state of bending as weights are added incrementally at one end while the other end remains in a cantilever support. The instructor can hold up a flexure frame with the beam attached and hand apply a force at the free end to demonstrate this state of bending. Experimentally the first step in the procedure will be the calculation of a maximum load, P_{max}, so that the elastic limit of the aluminum test beam will not be exceeded. Was the elastic limit exceeded in the tensile test? (Answer: Yes. The beam was plastically deformed and loaded until failure.) Be sure your group verifies the accuracy of the calculation of P_{max} before proceeding with the rest of the experiment. Mathematical errors are often made when calculating P_{max} and possible beam damage may occur if too great a load is placed on the beam. Once the maximum load is calculated the remainder of the experiment consists of recording the strain, as indicated by the strain meter, for each incremental addition of a weight placed on the beam. The manual specifies that ten weights should be added with the sum of the weights not exceeding P_{max}. However the number of weights utilized can be more or less than ten as long as P_{max} is not exceeded. The data recorded will consist of the load applied and the corresponding strain readings. How was the modulus of elasticity value determined in the tensile test? (Answer: the modulus of elasticity is the slope of the elastic region of the stress/strain curve.) Since, in the present flexure test, the load and strain values are recorded a conversion from load values to stress values is required. The flexure formula discussed in the MAE/CE 370 Mechanics of Materials Laboratory Manual yields a relationship that defines the stress as a function of the applied load, the width and thickness of the beam, and the distance between the gage and the point where the load is applied. The following equation can then be used to calculate the stress on the surface of the beam, at the location of the gage, for each incremental addition of a load:

$$\sigma = \frac{6PL_e}{bt^2} \qquad (10.2.1\text{-}1)$$

In the above equation P is the applied load, L_e is the effective length, b is the beam width, and t is the beam thickness. The effective length is the distance between the gage and the point at which the load is applied on the beam.

10.2.2 How a Strain Meter Works

On the top surface of the test beam, utilized in this experiment, is an electrical resistance strain gage that is positioned axially, or longitudinally, on the beam. Each group should have the test beam at their table and the instructor should verify that everyone is able to identify the location of the strain gage. During the introductory laboratory lecture the physical operation of how a strain gage works was discussed. Recall that a strain gage is composed of a fine wire oriented in a zigzag pattern. The strain gage is bonded to a surface in order to deform exactly as the surface deforms when a stress is applied to the surface. If the surface where the gage is bonded, elongates or contracts a distance ΔL the strain gage will also elongate or contract by ΔL. The instructor should sketch the following schematic on the board in order for the students to visualize the current discussion:

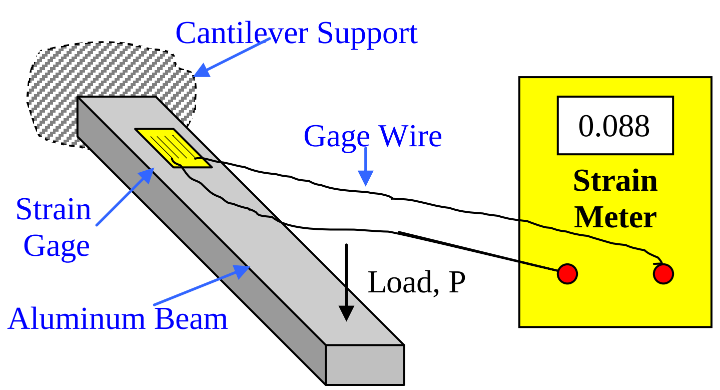


Figure 10.1: Aluminum Beam, Strain Gage and Strain Meter Configuration. (**NOTE**: For simpler illustrative purposes the strain gage wires are shown directly connected to the strain meter. In experimental conditions the wires have an intermediary connection to the flexure frame.)

The wire ends of the strain gage are connected to a strain meter and an electrical current, supplied by the strain meter, is conducted through the wire. As the strain gage changes length, due to the deformation of the surface to which it is bonded, the wire changes in length and cross-sectional area. As the wire changes in length and cross-sectional area the resistance of the wire to the flow of current also changes. Recall that if the strain gage elongates the resistance the flow of current increases, whereas if the strain gage contracts the resistance to the flow of current decreases. The strain meter provides the flow of current through the wire of the strain gage and as the resistance through the wire changes, by an amount ΔR, the voltage to the strain meter will also change (recall Ohm's law; V=IR). The strain meter converts this resistance change into the corresponding strain encountered by the strain gage. What type of electrical component, internal to the strain meter, measures changes in resistance? Answer: A Wheatstone Bridge. Instructor should add a sketch of a Wheatstone Bridge to Fig. 10.1 so that the following schematic is shown on the board:

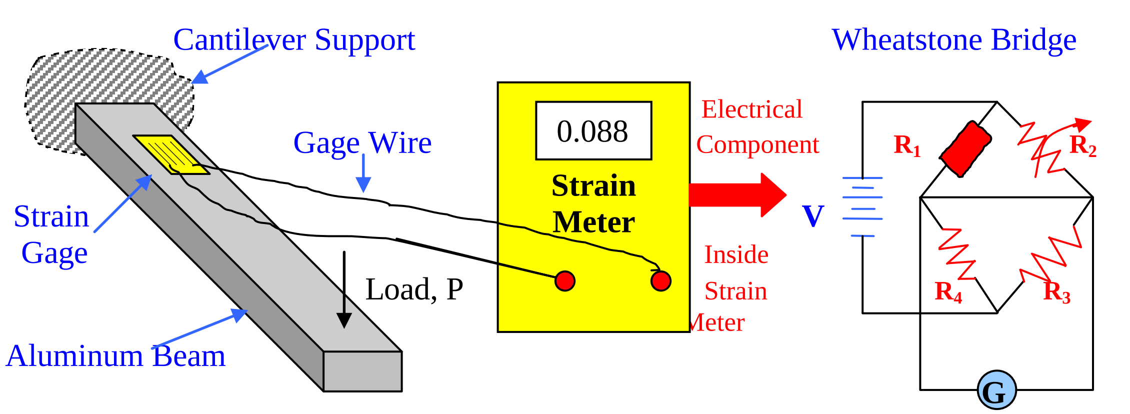


Figure 10.2: Aluminum Beam, Strain Gage, Strain Meter and Wheatstone Bridge Configuration. (**NOTE**: For simpler illustrative purposes the strain gage wires are shown directly connected to the strain meter. In experimental conditions the wires have an intermediary connection to the flexure frame.)

The Wheatstone Bridge is an electrical circuit composed of an input voltage source, V, a galvanometer, G, and four resistors, $R_{1\text{-}4}$. R_1 is normally replaced by a strain gage, R_2 is a variable resistor used to balance the Wheatstone bridge, and R_3 and R_4 remain constant. The Wheatstone bridge, is balanced when the following equation is satisfied:

$$\frac{R_1}{R_4} = \frac{R_2}{R_3} \qquad (10.2.2\text{-}1)$$

When the strain gage, represented by R_1, is strained, the Wheatstone bridge becomes unbalanced and the following is true:

$$\frac{R_1 + \Delta R}{R_4} \neq \frac{R_2}{R_3} \tag{10.2.2-2}$$

The Wheatstone bridge is rebalanced by adjusting the variable resistor, represented by R_2, an amount ΔR_m such that

$$\frac{R_1 + \Delta R}{R_4} = \frac{R_2 + \Delta R_m}{R_3} \tag{10.2.2-3}$$

ΔR_m is measured by the strain meter and is correlated to the corresponding strain encountered by the strain gage by the following relationship:

$$\varepsilon = \frac{\Delta R_m}{RS_g} \tag{10.2.2-4}$$

The digital readout of the strain, ε, is provided by the strain meter. Two strain gage specifications are manual inputs to the strain meter. These two values are the unstrained resistance of the gage, R, and the gage factor, S_g. The gage factor is provided by the gage manufacturer and, in this laboratory, the value is provided on the test beam. The gage factor is a dimensionless value having a magnitude around 2. Typically the gage resistance, R, is 120 ohms.

10.3 Experimental Instruction and Guidance

- The procedure to conduct this experiment is provided in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure is detailed and the students should not encounter any problems conducting the experiment.

- During the course of the experiment the instructor should approach the group and inquire whether anyone has any questions, that the purpose of each component of the experiment is understood, and to encourage the group members to contemplate possible experimental sources of error.

- The instructor should check the value of P_{max} that each group as calculated. Calculation errors are frequently made and if too great a load is placed on the beam permanent damage may occur. The calculated value of P_{max} should be around 3.8 lbs.

- Most likely, this will be the first time the students will encounter a wiring diagram in the student manual. These wiring diagrams illustrate the wiring connections between the gage and the flexure frame and between the flexure frame and the strain meter. These diagrams often intimidate students, especially the first time they conduct these connections. However, the students should be able to decipher the wiring connections without the instructor's assistance. Encourage all group members to participate in this process and to proceed slowly so that everyone understands the connections.

- The slotted weights placed on the hook hanger at the end of the beam are metric weights. Since the calculations are conducted in English units the students have a choice of mathematically converting the metric weights into the corresponding English unit value or they may choose to weigh the weights using the scales provided in the equipment cabinet. The students should consider the error associated with each of these methods.

10.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Calculate Slope-not Point Values**. The value of the experimental modulus of elasticity is equal to the slope of the elastic region of the experimentally derived stress/strain curve. Erroneously, students may calculate the modulus of elasticity using one data point; i.e. they will divide a stress data point value by the associated strain data point value.

- **Calculation of P_{max}.** Mathematical errors are often associated with the calculation of P_{max}. Also, the accuracy and preciseness of the measurements beam width, beam thickness, and the effective length, affects the calculated value of P_{max}.

- **Wire contact resistance**. Wires may not have a secure mechanical connection that may cause erroneous readings. Also, tarnished or dirty wire connections may affect accuracy of the electrical connections.

- **Axial alignment of test beam**. Upon application of a load on the beam the beam may shift slightly causing non-axial loading. This problem is more prevalent with the use of the Flexor loading screw.

- **Strain Meter Adjustments.** The adjustments of the AMP ZERO button, the gage factor and the balance control, are sensitive controls. The gage factor control and the balance control have lever locks that lock the desired value in place to minimize this error.

- **Weak Strain Meter Batteries**. Ideally the students should utilize the A/C adapters with the strain meters. This avoids any potential errors associated with weak batteries that may affect the strain meter readings.

- **Weights (Accuracy)**. In the experimental environment nothing should be assumed and everything should be verified. This includes verifying the stamped weight imprint on the slotted weights by using the scales supplied in the laboratory.

- **Swinging Weights**. The slotted weights on the hook hangers applied to one end of the beam may swing which, in turn may affect the strain reading.

- **Bumping Table**. Physical disturbance of the experimental set-up, however slight, may contribute to swinging weights, shifting of the test beam, wiggling of the wire connection, and strain meter control settings.

CHAPTER 11 – POISSON'S RATIO FLEXURE TEST: *LABORATORY LECTURE*

11.1 Introduction

Objective: The purpose of this experiment is to measure the Poisson's Ratio of an aluminum beam by loading it as a cantilever.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory. The instructor should conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment is functioning properly.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

11.2 Supplementary Laboratory Lecture

This experiment is the quickest and one of the easiest to perform. Also, the objective of the experiment, which is to determine Poisson's Ratio of aluminum, is a straightforward concept to understand. Poisson's Ratio, ν, is defined as the lateral strain, $\varepsilon_{lateral}$, divided by the longitudinal strain, $\varepsilon_{longitudinal}$, or:

$$\nu = -\left[\frac{\varepsilon_{\text{lateral}}}{\varepsilon_{\text{longitudinal}}}\right] \qquad (11.2\text{-}1)$$

Poisson's Ratio is a material property and has a dimensionless, positive value- the negative sign in Eqn. 11.2-1 will be subsequently explained. There are two strain gages positioned on the beam. One is positioned on the top of the beam in the longitudinal or axial direction. The longitudinal gage will provide the longitudinal strain reading as the beam deflects downward when a point load is applied. The other gage is positioned on the bottom of the beam in the lateral, or transverse, direction and will provide the lateral strain reading. Instructor can sketch the following schematic on the board:

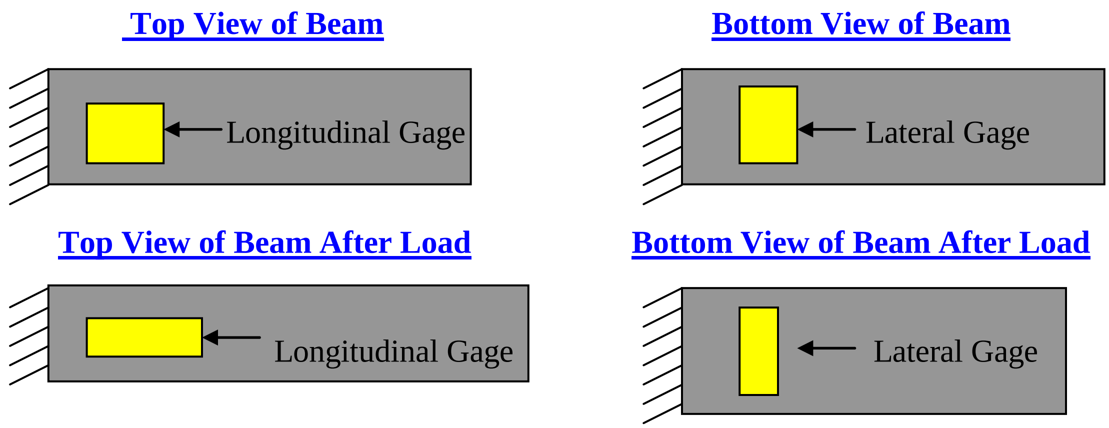


Figure 11.2: Top and Bottom View of Beams Showing Longitudinal and Lateral Gage Positioning Before and After Load Application.

When a point load is applied on the top surface of the beam the top surface will elongate in the axial or longitudinal direction. The top surface will also contract in the transverse or lateral direction. This phenomenon is known as Poisson's Effect. Likewise, the bottom surface will contract longitudinally and expand laterally. Quantitatively, the longitudinal elongation or contraction is much larger than the lateral contraction or expansion. Therefore, Poisson's Ratio is a value less than one. Poisson's Ratio is also a positive value since the longitudinal and lateral strain should be measured at the same point on the beam. For example, if measuring the strains on the top surface of the beam the longitudinal strain would be positive (beam elongates longitudinally) and the lateral strain would be negative (beam contracts laterally). Therefore, according to Eqn. 11.2-1 these values result in a positive value of Poisson's Ratio. In this experiment it would be impossible to position both the longitudinal and the lateral strain gages at the same point on the beam. Therefore, the longitudinal gage is positioned on the top surface and the lateral gage is positioned at the same location on the bottom of the beam. Because of the unique positioning in this experiment, a negative sign is artificially added to the calculation of Poisson's Ratio since both the longitudinal and lateral gages will measure positive strain readings.

In this experiment a correction factor will be introduced into the calculations. The correction factor is related to the transverse sensitivity of the strain gages. The following figure will help clarify this phenomenon:

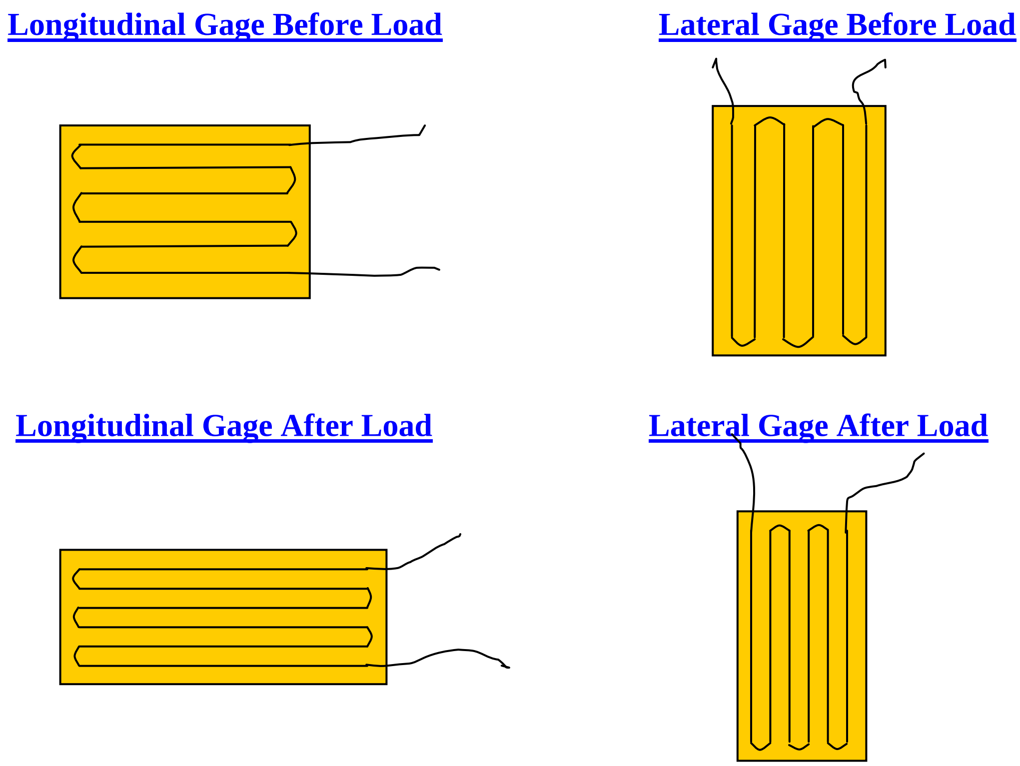


Figure 11.3: Contraction and Elongation of the Longitudinal and Lateral Strain Gages.

The greatest change in the length of the wires of the longitudinal strain gage on the top surface of the beam is due to the elongation in the longitudinal direction. However, since the top surface of the beam also contracts slightly in the lateral direction the looped ends of the longitudinal strain gage will contract. This contraction is due to the lateral strain encountered by the top surface of the beam and will slightly reduce the total increase in length of the wire within the strain gage. This will cause the total longitudinal strain reading to slightly decrease. Thus, a completely accurate strain reading of the longitudinal strain is not possible. This lateral strain encountered by the top surface of the beam is very small compared to the longitudinal strain and is usually neglected. However, if extreme accuracy is required when measuring the longitudinal strain and the change in length of the looped ends of the gage cannot be neglected, the transverse sensitivity factor, K_T, is utilized. The transverse sensitivity factor is a gage manufacturer supplied value that is normally given on the beams. The true strain in the direction parallel to which a gage is aligned can be determined by a correction factor that is based on the transverse sensitivity factor and the ratio of lateral to longitudinal strain. In this experiment since the longitudinal elongation of the longitudinal gage is so much greater than the lateral contraction of the gage the error associated with the looped ends of the gage is not as significant as it is with the lateral gage on the bottom side of the beam. The lateral gage on the bottom of the surface is experiencing a greater longitudinal contraction than a lateral elongation. Therefore the error associated with the longitudinal contraction experienced by the looped ends of the lateral strain gage is significant since only the lateral strain is to be measured. In the calculations of this experiment a correction factor will be determined in order to more accurately predict the lateral strain.

11.3 Experimental Instruction and Guidance

- The procedure to conduct this experiment is provided in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure is detailed and the students should not encounter any problems conducting the experiment.

- During the course of the experiment the instructor should approach the group and inquire whether anyone has any questions, that the purpose of each component of the experiment is understood, and to encourage the group members to contemplate possible experimental sources of error.

To further promote the students understanding of the experiment the following items should be verified:

- Check that students are able to identify the independent and dependent wire leads from both strain gages.

11.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Gages on opposite sides of the beam.** Poisson's Ratio is a measure of the ratio of the lateral strain to the longitudinal strain at a particular point on the beam. Since one gage cannot be placed on top of another gage the longitudinal gage is placed on the top surface and the lateral gage is place at the same position on the bottom surface. Ideally, both gages should measure strain at the same location on the same side of the beam.

- **Top longitudinal gage not corrected for transverse sensitivity.** Since the lateral strain is so much smaller than the longitudinal strain the lateral strain error of the looped ends of the longitudinal strain gage is neglected.

- **Wire contact resistance**. Wires may not have a secure mechanical connection that may cause erroneous readings. Also, tarnished or dirty wire connections may affect accuracy of the electrical connections

- **Precision of Correction Factor chart.** Due to the coarseness of the graduations on the chart accuracy may be diminished.

- **Axial alignment of test beam**. Upon application of a load on the beam the beam may shift slightly causing non-axial loading. This problem is more prevalent with the use of the Flexor loading screw.

- **Strain Meter Adjustments.** The adjustments of the AMP ZERO button, the gage factor and the balance control, are sensitive controls. The gage factor control and the balance control have lever locks that lock the desired value in place to minimize this error.

- **Weak Strain Meter Batteries**. Ideally the students should utilize the A/C adapters with the strain meters. This avoids any potential errors associated with weak batteries that may affect the strain meter readings.

- **Bumping Table**. Physical disturbance of the experimental set-up, however slight, may contribute to shifting of the test beam, wiggling of the wire connection, and strain meter control settings.

CHAPTER 12 – CANTILEVER FLEXURE TEST: *LABORATORY LECTURE*

12.1 Introduction

Objective: The purpose of this experiment is to (1) determine the applied load and shear force from strain measurements, (2) verify the linearity of strain along the longitudinal axis of the beam, and (3) confirm the shear force and moment relationships by comparing two different stress determinations.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory. The instructor should conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment is functioning properly.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

12.2 Supplementary Laboratory Lecture

The primary objective of this experiment is to aid in the understanding of how stress and strain varies along the length of a beam subjected to uniaxial bending. The beam is in a state of uniaxial bending due to the cantilever support at one end of the beam and a point load at the other end. The instructor should sketch the following schematic on the board:

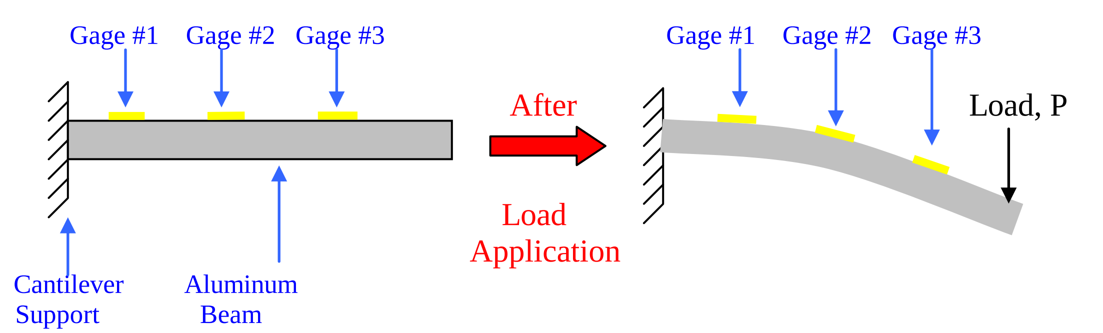


Figure 12.1: Aluminum Test Beam with Three Strain Gages Mounted on Top Surface, Before and After Load Application.

The beam has three strain gages mounted on the top surface of the beam. As noted in previous experiments, the top surface will elongate longitudinally and the bottom surface will contract longitudinally. Will the magnitude of longitudinal strain remain the same along the longitudinal length of the top surface of the beam or will it vary? Answer: It will vary. How does the strain vary with distance from the cantilever support? Answer: The greatest strain occurs at the cantilever support and decreases with longitudinal distance from the cantilever support. Will the magnitude of longitudinal stress vary along the longitudinal length of the top surface of the beam? Answer: Yes. How does the stress vary with distance from the cantilever support? Answer: The stress, as the strain, will decrease with longitudinal distance from the cantilever support. Recall Hooke's law where $\sigma = E\varepsilon$ within the elastic region of the specimen. The experimental data obtained in this experiment will support the fact that stress and strain decrease with distance from the cantilever support.

Another purpose of this experiment is to determine the amount of load placed on the end of the beam. In this experiment the load will be applied using the load micrometer. The instructor should hold up a flexure frame/beam set-up and apply a load to the end of the beam by rotating the load micrometer. The load micrometer will vertically displace the end of the beam but the amount of load placed on the beam is unknown. The unknown load will be determined based upon the experimentally obtained values of strain at the three different gage locations and by knowing the magnitude of the vertical displacement of the beam at the point of load application. How does the moment vary along the length of the beam? Does the moment increase, decrease, or stay the same with distance from the cantilever? Answer: The moment is greatest at the cantilever and decreases to a value of zero at the point of load application. How does the shear force vary along the length of the beam? Answer: The shear is constant along the length of the beam and the magnitude of the shear is equal to the applied load.

12.3 Experimental Instruction and Guidance

- The procedure to conduct this experiment is provided in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure is detailed and the students should not encounter any problems conducting the experiment.

- During the course of the experiment the instructor should approach the group and inquire whether anyone has any questions, that the purpose of each component of the experiment is understood, and to encourage the group members to contemplate possible experimental sources of error.

To further promote the students understanding of the experiment the following items should be verified:

- Check that students are able to identify the independent and dependent wire leads from all three strain gages.

12.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Wire contact resistance**. Wires may not have a secure mechanical connection that may cause erroneous readings. Also, tarnished or dirty wire connections may affect accuracy of the electrical connections.

- **Axial alignment of test beam**. Upon application of a load on the beam the beam may shift slightly causing non-axial loading. This problem is more prevalent with the use of the Flexor loading screw.

- **Strain Meter Adjustments.** The adjustments of the AMP ZERO button, the gage factor and the balance control, are sensitive controls. The gage factor control and the balance control have lever locks that lock the desired value in place to minimize this error.

- **Weak Strain Meter Batteries**. Ideally the students should utilize the A/C adapters with the strain meters. This avoids any potential errors associated with weak batteries that may affect the strain meter readings.

- **Bumping Table**. Physical disturbance of the experimental set-up, however slight, may contribute to shifting of the test beam, wiggling of the wire connection, and strain meter control settings.

- **Measurement Errors**. Several calculations, including the calculation of the load, are dependent upon the experimentally measured beam dimensions and gage locations. Therefore, the accuracy and preciseness of these measurements will affect the various calculated values.

- **Displacement of the Loading Screw**. The graduations on the loading screw are sometimes difficult for the novice user to decipher. The loading screw displacement should be verified by at least two group members.

CHAPTER 13 – STRESS CONCENTRATION: *LABORATORY LECTURE*

13.1 Introduction

Objective: The purpose of this experiment is to verify the existence of a stress and strain concentration in the vicinity of a geometric discontinuity in a cantilever beam. In this experiment the geometric discontinuity will be a circular hole drilled through the thickness of the beam on the centerline. Also, the experimentally obtained value of the stress concentration factor, K_t, will be compared to the theoretical value.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory. The instructor should conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment is functioning properly.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

13.2 Supplementary Laboratory Lecture

In this experiment a beam with a geometric discontinuity will be analyzed to determine how this change in geometry will affect the stresses and strains encountered by the beam. The particular geometric discontinuity of the test beam is a circular hole. The instructor should hold up a test beam and point to the discontinuity. As in previous experiments the beam will have a cantilever support at one end and a point load at the other. The concepts encountered in this experiment are vital to understand for any engineer. The majority of engineering structures possess some type of discontinuity that, in turn, creates stress concentrations. In the middle of the twentieth century several aircraft experienced catastrophic failure due to the lack of consideration regarding stress concentrations due to geometric discontinuities. Aircraft frames require circular holes for fasteners (i.e. screws, rivets, bolts, etc.). Due to the various stresses placed upon the aircraft many aircraft failures originated from cracks forming around the discontinuity. Thus, whenever a structure changes shape- particularly a location where the geometric cross-section decreases- it is important for the engineer to analyze stress concentrations. Where along the circumference of the hole on the test beam will the stress be greatest? Instructor should sketch the following schematic on the board:

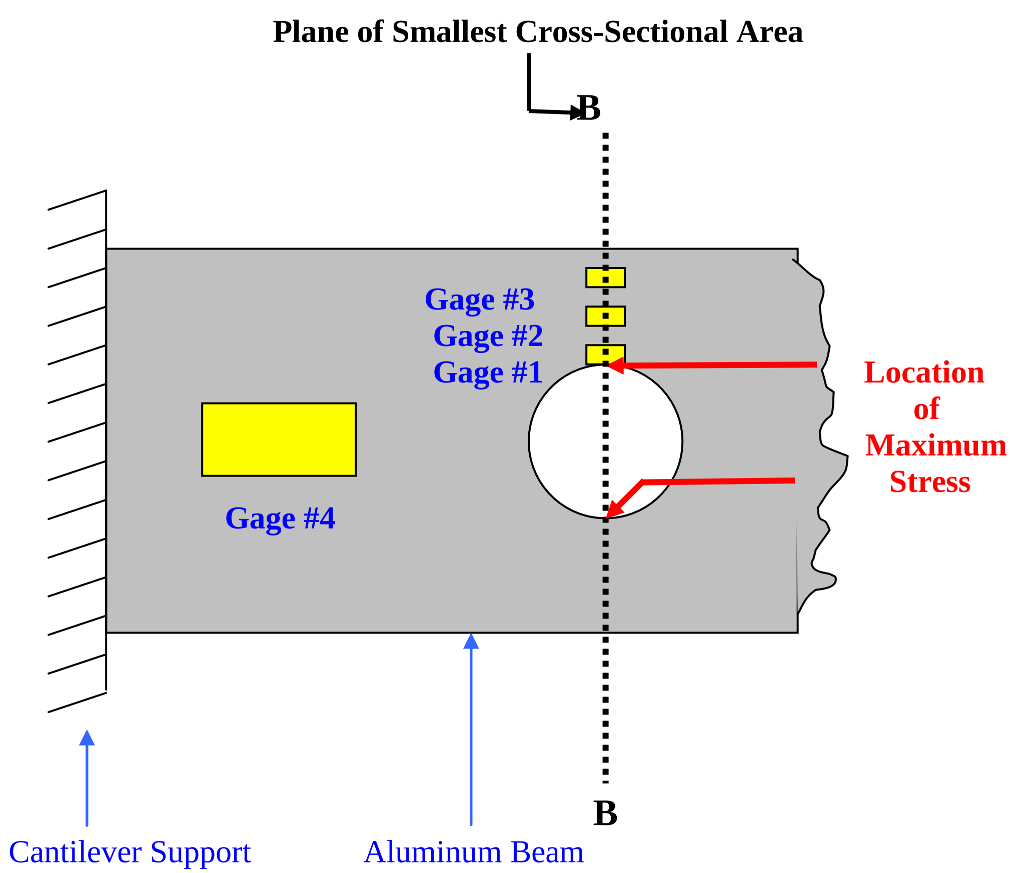


Figure 13.1: Location of Maximum Stress on Aluminum Beam with Circular Hole.

The maximum stress is located on the plane where the discontinuity creates the smallest cross-sectional area. For the test beam utilized in this experiment the location of maximum stress are two points on the circumference of the circular hole. These two points are located where the diameter of the circle is perpendicular to the longitudinal axis of the beam. Gage #1 is positioned as close as possible to the edge of the hole where the stress will be the greatest. How does the stress vary with transverse distance from the point of maximum stress to the edge of the beam? The instructor should add the stress distribution profile to Fig. 13.1 so that the final schematic is as follows:

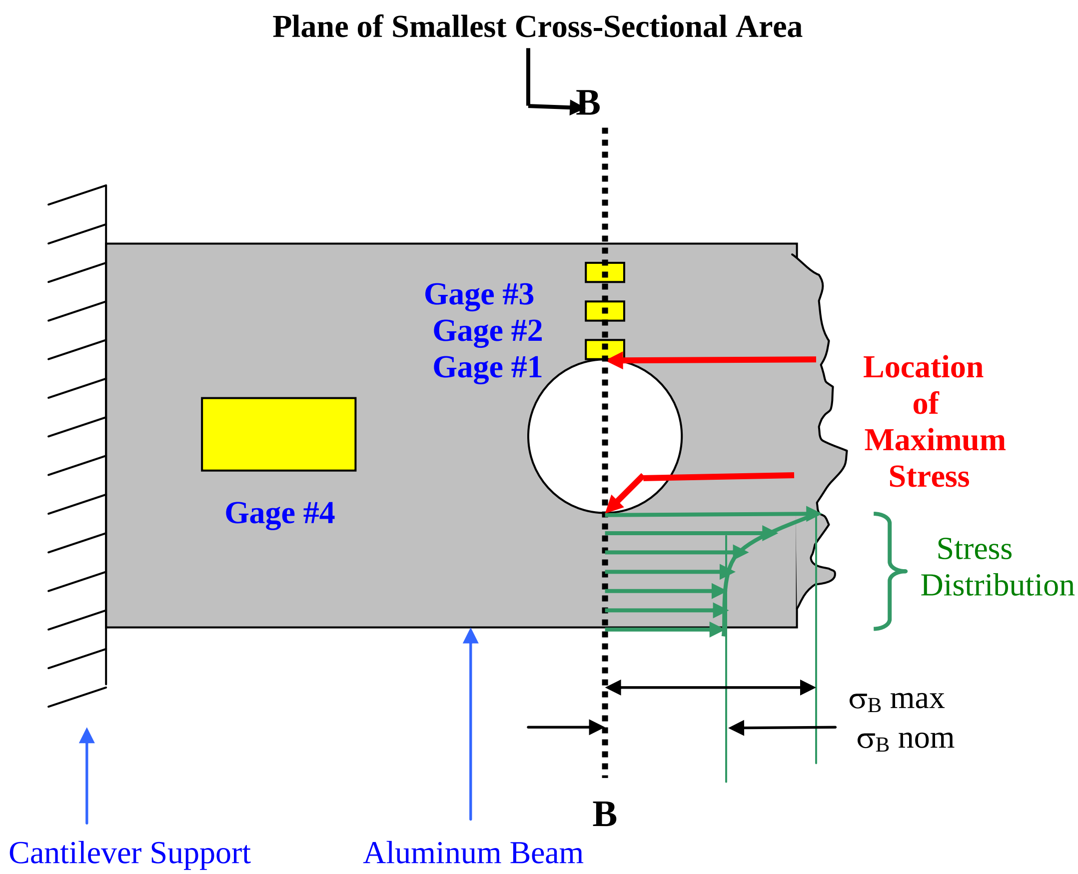


Figure 13.2: Location of Maximum Stress and Stress Distribution on Aluminum Beam with Circular Hole.

As can be seen from the stress distribution profile in Fig. 13.2, the stress decreases with transverse distance from the point of maximum stress, $\sigma_B$max, at the edge of the hole, to the edge of the beam. The nominal stress, $\sigma_B$nom, is the average stress of the stress distribution profile. Three other gages are positioned on the beam. How should the strain reading of gage #1 compare with the strain reading of gage #3? Answer: The strain/stress at the location of gage #1 will be greater than at gage #3 since gage #1 is closest to the point of maximum stress at the circular hole.

The stress concentration factor, K_t, is a non-dimensional value important in structural design and analysis. The stress concentration factor is defined as the ratio of the maximum stress at the discontinuity to the nominal stress at that point:

$$K_t = \frac{\sigma_B \max}{\sigma_B \text{nom}} \tag{13.2-1}$$

$\sigma_B$max will equal the stress at the location of gage #1. However, instead of calculating $\sigma_B$nom at the location of the discontinuity it is easier to calculate the stress at a location that is offset from the hole yet has a stress value that is equal to the nominal stress at the discontinuity. In our experiment this offset location is the location of gage #4. Therefore, the stress at gage #4 will equal the nominal stress, $\sigma_B$nom, at the location of the hole. The mathematical proof of this equality is in the student laboratory manual and should be reviewed.

The experimental value of K_t is calculated directly by measuring the maximum and nominal stresses at the hole. This experimental value will then be compared to a theoretical value of the stress concentration factor. The theoretical value of K_t can be found by referring to a stress concentration factor chart; one of which is found in the student laboratory manual. The students should be instructed to access the stress concentration factor chart on page 9.5 in the laboratory manual. In order to determine the theoretical value of K_t, the beam width, beam thickness and the circular hole diameter must be known.

13.3 Experimental Instruction and Guidance

- The procedure to conduct this experiment is provided in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure is detailed and the students should not encounter any problems conducting the experiment.

- During the course of the experiment the instructor should approach the group and inquire whether anyone has any questions, that the purpose of each component of the experiment is understood, and to encourage the group members to contemplate possible experimental sources of error.

- The instructor should provide the group the opportunity to view the photo-elastic stress specimens. These devices are located in the equipment cabinet in a light blue case. The students are not required to report any findings from these specimens within the formal laboratory report; these specimens are for viewing purposes only. These specimens are particularly beneficial, and popular, among the students as they are able to physically view locations of maximum stress for irregular geometric shapes.

To further promote the students understanding of the experiment the following items should be verified:

- Check that students are able to identify the independent and dependent wire leads from all four strain gages.

13.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Wire contact resistance**. Wires may not have a secure mechanical connection that may cause erroneous readings. Also, tarnished or dirty wire connections may affect accuracy of the electrical connections.

- **Axial alignment of test beam**. Upon application of a load on the beam the beam may shift slightly causing non-axial loading. This problem is more prevalent with the use of the Flexor loading screw.

- **Strain Meter Adjustments.** The adjustments of the AMP ZERO button, the gage factor and the balance control, are sensitive controls. The gage factor control and the balance control have lever locks that lock the desired value in place to minimize this error.

- **Weak Strain Meter Batteries**. Ideally the students should utilize the A/C adapters with the strain meters. This avoids any potential errors associated with weak batteries that may affect the strain meter readings.

- **Bumping Table**. Physical disturbance of the experimental set-up, however slight, may contribute to shifting of the test beam, wiggling of the wire connection, and strain meter control settings.

- **Position of Gage #1**. The maximum stress due to the discontinuity is located at the edge of the circular hole. Gage #1 is positioned as closely as possible to the edge of the hole. However, due to the length of the gage, the gage cannot be positioned exactly at the edge of the hole.

- **Measurement Accuracy**. The value of the theoretical stress concentration factor is obtained by knowing the beam width, beam thickness and circular hole diameter. Therefore, accuracy in these measurements affects the accuracy of the theoretical K_t value.

CHAPTER 14 – PRINCIPAL STRESSES AND STRAINS: *LABORATORY LECTURE*

14.1 Introduction

Objective: The purpose of this experiment is to measure the strains on three different axes surrounding a point on a cantilever beam. From these strain measurements the value of the principal strains and principal stresses can be calculated and the principal stress can be compared to the theoretical value provided by the flexure formula.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory. The instructor should conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment is functioning properly.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

14.2 Supplementary Laboratory Lecture

In this experiment the concept of principal planes, principal strains and principal stresses will be encountered. On the aluminum test beam there are three strain gages located on three separate axes surrounding one particular point on the surface of the beam. The instructor should sketch the following schematic on the board:

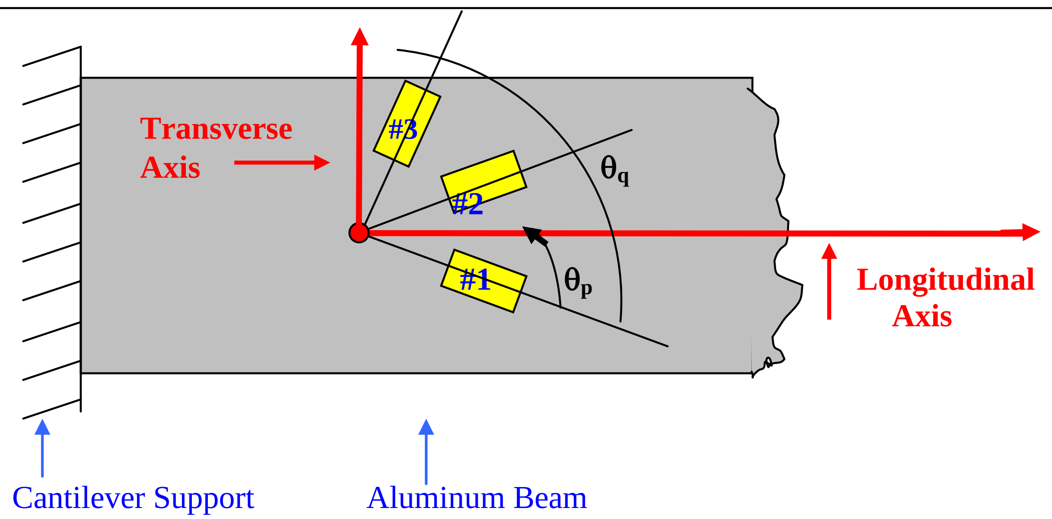


Figure 14.1: Orientation of Three Strain Gages Surrounding a Point on the Surface of an Aluminum Test Beam.

θ_p and θ_q are the angles of orientation of Gage #1 with respect to the longitudinal and transverse axes, respectively. At every point on and within the test beam there are three mutually perpendicular planes that are called the principal planes. The point under consideration in this experiment is located on the top surface of the beam and gages #1-#3 are positioned on axes emanating from this point. However, the gages are not aligned on the principal planes of this particular point. Two of the principal planes of the point under consideration are positioned normal to the longitudinal axes and the transverse axis. The instructor should sketch the following schematic on the board:

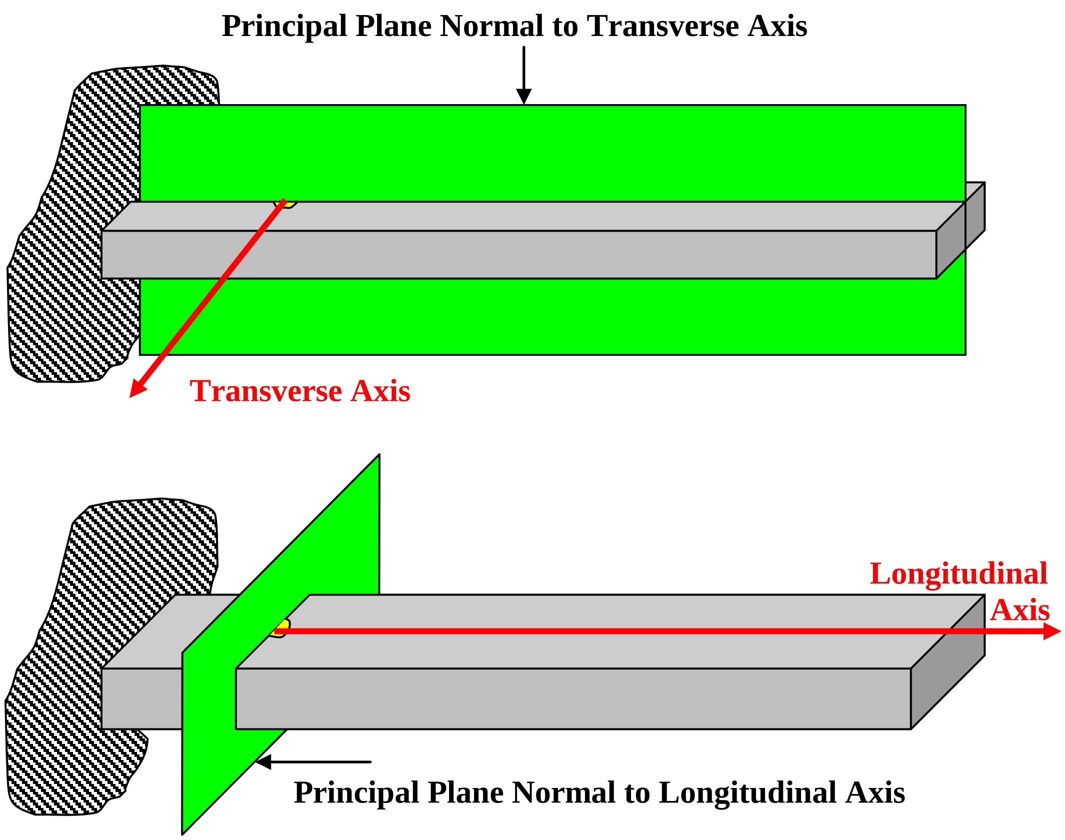


Figure 14.2: Representation of Two of the Principal Planes of a Point on the Aluminum Test Beam.

Since the point under consideration is located on the top surface of the beam, which is a free surface, the third principal plane is aligned with the top surface of the beam. Every point within a solid body has its own unique set of principal planes. Two important facts are associated with principal planes. First, there are no shearing stresses on the principal planes. Second, the principal planes of a point contain the maximum and minimum normal stresses, and strains, of the point. The normal stresses and strains are known as the principal stresses and strains. Which principal plane in Fig. 14.2 contains the maximum normal stress? Answer: As discovered in the Poisson's Ratio experiment, for the cantilever beam in bending, the magnitude of the longitudinal stress was much greater than the transverse stress that should, theoretically, have a magnitude of zero. Therefore the principal plane that is normal to the longitudinal axis contains the maximum normal stress. Since there is no shear stresses on both the principal plane normal to the longitudinal axis and the principal plane normal to the transverse axis, how does the shear stress vary between these two planes? Instructor should refer to Fig. 14.1 that was previously sketched on the board and add the following information to the graphic:

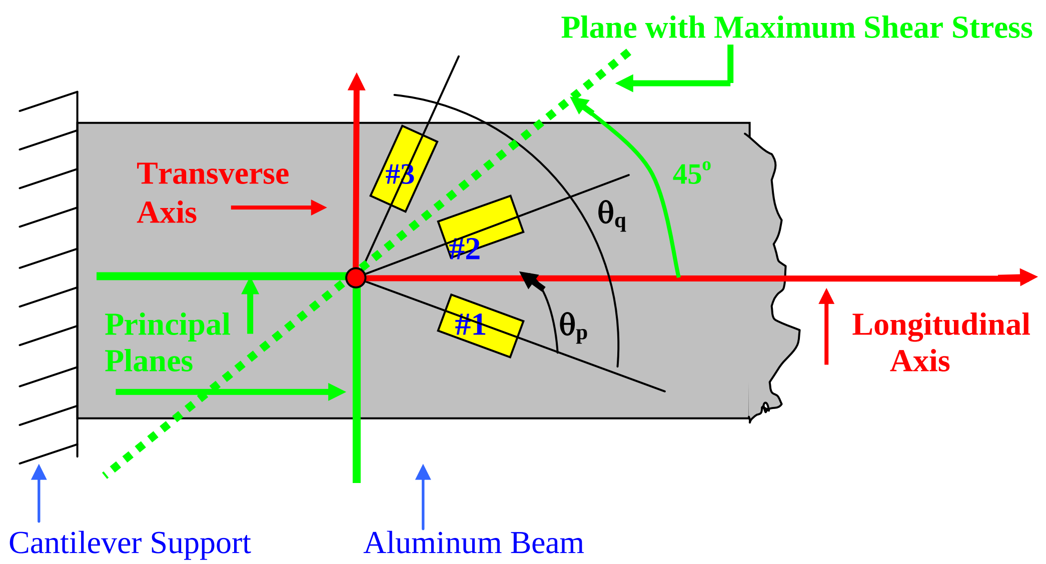


Figure 14.3: Principal Planes and Plane of Maximum Shear Stress of a Point on the Surface of an Aluminum Test Beam.

The plane with the maximum shear stress is positioned 45 degrees from the principal plane normal to the longitudinal axis and the plane normal to the transverse axis. Since the shear stress is zero on the principal planes the shear stress increases with angular rotation from a principal plane to a maximum shear stress on the plane located 45 degrees between the principal planes.

In this experiment the strains at locations along three separate axes, none of which are aligned with a principal plane, are to be measured. By knowing these strain values and the angles between the gages (45^o), the principal strains and stresses can be calculated and the angles, θ_p and θ_q, can be mathematically verified.

14.3 Experimental Instruction and Guidance

- The procedure to conduct this experiment is provided in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure is detailed and the students should not encounter any problems conducting the experiment. **Note: The second procedural step requires the measurement of θ_p and θ_q. Since these angles are difficult to measure, due to the size of the strain gage arrangement, the instructor should provide these angles to the students. ($\theta_p = 30^o$ and $\theta_q = 120^o$.)**

- During the course of the experiment the instructor should approach the group and inquire whether anyone has any questions, that the purpose of each component of the experiment is understood, and to encourage the group members to contemplate possible experimental sources of error.

To further promote the students understanding of the experiment the following items should be verified:

- Check that students are able to identify the independent and dependent wire leads from all three strain gages.

- Discuss that this particular arrangement of strain gages is known as a rosette strain gage arrangement. Instruct the group members to refer to Fig.1 on page 10.2 of the student manual to view the delta strain gage arrangement.

During the course of the experiment the instructor could ask the following questions to help solidify the concepts encountered in this experiment:

- Which strain gage should have the highest strain reading? Answer: Since the maximum strain is the strain in the longitudinal direction, the gage that is aligned closest to the longitudinal direction will have the largest strain reading. In this experiment gage #2 is 15^o off of the longitudinal axis and will have the largest strain reading.

14.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Wire contact resistance**. Wires may not have a secure mechanical connection that may cause erroneous readings. Also, tarnished or dirty wire connections may affect accuracy of the electrical connections.

- **Axial alignment of test beam**. Upon application of a load on the beam the beam may shift slightly causing non-axial loading. This problem is more prevalent with the use of the Flexor loading screw.

- **Strain Meter Adjustments.** The adjustments of the AMP ZERO button, the gage factor and the balance control, are sensitive controls. The gage factor control and the balance control have lever locks that lock the desired value in place to minimize this error.

- **Weak Strain Meter Batteries**. Ideally the students should utilize the A/C adapters with the strain meters. This avoids any potential errors associated with weak batteries that may affect the strain meter readings.

- **Bumping Table**. Physical disturbance of the experimental set-up, however slight, may contribute to shifting of the test beam, wiggling of the wire connection, and strain meter control settings.

CHAPTER 15 – BEAM DEFLECTION TEST: *LABORATORY LECTURE*

15.1 Introduction

Objective: The purpose of the first part of this experiment is to experimentally measure the vertical deflection of a simply supported beam. The simply supported beam will be subjected to two different types of loading conditions- the central load and the overhung load. The second part of the experiment consists of determining the corresponding theoretical deflections at each location an experimental deflection was measured. The theoretical deflections are calculated using a deflection equation derived for each type of loading condition by the double integration method. Comparisons between the experimental measurements and the theoretical predictions will be made.

Equipment Check: All of the required equipment specified within the MAE/CE 370 Mechanics of Materials Laboratory Manual are permanent fixtures within the laboratory. The instructor should conduct a test run of this experiment before the start of the first laboratory meeting to ensure that the equipment is functioning properly.

Text Color Code: The recommended information to provide to the students during the lecture is highlighted in blue text and suggested questions to ask the students are highlighted in red.

15.2 Supplementary Laboratory Lecture

NOTE: Since various groups may be conducting different experiments this information is provided to the group conducting the experiment and not to the entire class. The students may start the experimental procedure before this information is provided.

The purpose of this experiment is to measure experimentally the deflection of a simply supported beam that is subjected to two different types of loading conditions and compare the experimental measurements to theoretical predictions. The simply supported beam has two knife-edge supports at both ends of the beam. The instructor should indicate the location of the two knife edge supports. The two types of loading the beam will encounter are the central loading and the overhung loading. The central load configuration consists of a hanger and weights placed on the beam midway between the knife edge supports. The deflection at four deflection gages is recorded at each addition of a weight. The instructor should place a hanger on the beam midway between the supports and add some weights to demonstrate how the beam will deflect. For the central load configuration the beam will deflect vertically downward between the supports and upward outside of the supports. All four deflection gages should be randomly positioned between the supports. The overhung load configuration consists of two hangers- each one positioned outside of the knife-edge supports. Under this type of loading the beam will deflect vertically upward between the two supports, and downward outside of the supports. Three deflection gages are utilized and are positioned randomly between the supports. Therefore, the experimental portion of this experiment consists of recording the deflection of the beam at each gage location. These deflections are recorded at each incremental addition of a weight for the two different loading configurations. When the experimental portion of the experiment is completed the theoretical calculation procedure will be discussed.

Following the experimental deflection measurements the theoretical calculation procedure is discussed. The second part of this experiment will be completed outside of the laboratory. This part consists of calculating the theoretical deflections corresponding to the locations experimental measurements were recorded. These theoretical predictions will be calculated at each weight addition for both the central and overhung load conditions. The theoretical deflection equations are derived by the double integration method. The student manual provides the derivation of the theoretical deflection equation for both types of loading. Since these calculations are extensive it is required that the theoretical results be computer generated. Section 11.6 in the student manual is provided as a guide through this computational calculation. The instructor should go over the information in Section 11.6 of the student manual with the group.

15.3 Experimental Instruction and Guidance

- The students can begin the procedure without the instructor's assistance. Therefore, depending on how many other groups are present and conducting experiments, the supplementary lecture provided in section 15.2 could be delivered as soon as the instructor is available to the group.

- The procedure to conduct this experiment is provided in the MAE/CE 370 Mechanics of Materials Laboratory Manual. The procedure is detailed and the students should not encounter any problems conducting the experiment.

- During the conduction of the experiment the instructor should approach the group and inquire whether anyone has any questions, that the purpose of each component of the experiment is understood, and to encourage the group members to contemplate possible experimental sources of error.

- The instructor should verify that the deflection gages are read correctly. Depending upon the manufacturer of the gage, some deflection gage dial indicators rotate clockwise and others counterclockwise. Even though the difference in gages may be visibly apparent, the students should be alerted to these possible differences in order to avoid recording erroneous readings.

- During the course of the experiment the instructor could ask the following questions to help solidify the concepts encountered in this experiment:

  Most likely, will the measured experimental deflections be greater or less than the theoretical predictions? Answer: Due to prior testing of the beams and possible fatigue, the test beams, most likely, will deflect more than what is predicted theoretically.

15.4 Experimental Sources of Error

The following are possible sources of error encountered in this experiment:

- **Beam Dimension Measurements.** The theoretical deflection is a function of the beam width, beam thickness and the distance between supports. Therefore, preciseness and accuracy of these measurements will affect the accuracy of the theoretical predictions.

- **Prior Testing and Deformation of the Beams**. The isotropic and homogeneous structure of the beams could possibly have been altered due to prior testing. The beam may have experienced fatigue or possibly plastic deformation that may not be visible. Most likely, a frequently tested beam will deflect more.

- **Parallax Error**. Parallax error is a line-of-sight error that occurs when reading any type of measurement indicators such as deflection gages. To reduce parallax error the viewer should be positioned perpendicular to the indicator. Any angular deviation from a perpendicular view of the indicator will contribute to parallax error.

- **Material Alloy Composition**. Consideration must be given to the fact that the modulus of elasticity value utilized in the theoretical deflection equations may not be the exact modulus of elasticity value for the test beam. The exact material alloy composition of the test beams may be different than the material that the theoretical value assumes. Also any prior deformation affects the modulus of elasticity value.

APPENDIX A- ACTIVE EQUIPMENT INVENTORY

Modulus of Elasticity Beams – Vishay/Measurements Group

Beam I.D.	Gage Type	Resistance	G.F. $\pm$ 0.5%	K_T%
B-101	125 AD	120.0	2.085	+1.1
B101-62	125 AD	120	2.075	+0.8
B-101/137229	125 AD	120.0	2.085	1.0
B-101/137231	125 AD	120.0	2.085	1.0
B-101/137233	125 AD	120.0	2.085	1.0

Poisson's Ratio Beams – Vishay/Measurements Group

Beam I.D.	Gage Type	Resistance	G.F. $\pm$ 0.5%	K_T%
B-102	125 AD	120.0	2.085	+1.1
B-102A	125 AD (2)	120.0	2.095	+1.2
B-102/137235	125 AD	120	2.085	1.0
B-102/137237	125 AD	120	2.085	1.0
B-102/137248	125 AD	120	2.085	1.0

Cantilever Flexure Beams – Vishay/Measurements Group

Beam I.D.	Gage Type	Resistance	G.F. $\pm$ 0.5%	K_T%
B-105	125 AD (3)	120.0	2.085	+1.1
B-105/137193	125 AD	120.0	2.085	1.0
B-105/137194	125 AD	120.0	2.085	1.0
B-105/137196	125 AD	120.0	2.085	1.0
B-105/137202	125 AD	120.0	2.085	1.0

Principle Stresses and Strains Beams – Vishay/Measurements Group

Beam I.D.	Gage Type	Resistance	G.F. $\pm$ 0.5%	K_T%
B-103	125 RA	120.0	2.05, 2.08, 2.05	+1.2, +0.9, +1.2
B-103/137157	125 RA	120.0	2.060, 2.075, 2.060	+1.3, +0.9, +1.3
B-103/137162	125 RA	120.0	2.060, 2.075, 2.060	+1.3, +0.9, +1.3
B-103/137163	125 RA	120.0	2.060, 2.075, 2.060	+1.3, +0.9, +1.3
B-103/137250	125 RA	120.0	2.060, 2.075, 2.060	+1.3, +0.9, +1.3

Stress Concentration Beams – Vishay/Measurements Group

Beam I.D.	Gage Type	Resistance	G.F. $\pm$ 0.5%	K_T%
B-104	125 AD (1)	120.0	2.095	+1.2
	031 DE (3)	120.0	2.080	+1.2
B-104	125 AD (1)	120.0	2.095	+1.2
	031 DE (3)	120.0	2.06	+1.1
B-104/137181	125 AD (1)	120.0	2.085	+1.0
	031 DE (3)	120.0	2.11	+1.5
B-104/137183	125 AD (1)	120.0	2.085	+1.0
	031 DE (3)	120.0	2.11	+1.5
B-104/137184	125 AD (1)	120.0	2.085	+1.0
	031 DE (3)	120.0	2.11	+1.5

Cantilever Flexure Frames –Measurements Group

Frame Type	Quantity
With Load Micrometer	4
Without Load Micrometer	1

Strain Indicators –Vishay

	Quantity
P-3500 Digital Strain Indicator	4
P-3500 Digital Strain Indicator A/C Adapter	4

Measurement Instruments

Instrument	Description	Quantity
Scale	OHaus Model	4
Micrometer	0-24 mm	10
Tape Measure	Great Neck 10ft/3m	6
Tape Measure	Sears Craftsman 12 ft	1
Caliper	Plastic	2
Caliper	metal	1

Weights and Weight Hangers

	Description	Quantity
Slotted Weight	100 g	45
Slotted Weight	200 g	24
Slotted Weight Support Stand	Black plastic	4
Slotted Weight Hanger	50 g	3
Slotted Weight Hanger	0.5 N	3

Tensile Testing Apparatus

Instrument	Description	Quantity
Tensile Testing Machine	SATEC Systems, Inc. Model T10000 Materials Testing Systems	1
Computer	Gateway 2000 P4D-66	1
Computer Monitor	DAEWOO	1
Computer Keyboard	Gateway 2000	1
Printer	EPSON LX-300	1

Torsion Testing Apparatus

Instrument	Description	Quantity
tecquipment Torsion Testing Machine	Unit No. 030 Type No. SM1	1

Strut Loading Apparatus

Instrument	Description	Quantity
Strut Loading Machine	900 lbf	1
tecquipment Strut Loading Machine	90 lbf	1

Simply Supported Beam Apparatus

Instrument	Description	Quantity
tecquipment Universal Beam Testing Rig	Ref. No. B447271	1

APPENDIX B- SAMPLE LABORATORY SEMESTER SCHEDULES

The following charts designate experiment numbers that are defined as follows:

Exp. #1 - Modulus of Elasticity Tension Test	(1 test station)
Exp. #2 - Column Buckling Test	(2 test stations)
Exp. #3 - Torsion Test	(1 test station)
Exp. #4 - Modulus of Elasticity Flexure Test	(4 test stations)
Exp. #5 - Poisson's Ratio Flexure Test	(4 test stations)
Exp. #6 - Cantilever Flexure Test	(4 test stations)
Exp. #7 - Stress Concentration Test	(4 test stations)
Exp. #8 - Principal Stresses and Strains Test	(4 test stations)
Exp. #9 - Beam Deflection Test	(1 test station)

Note: Sample schedule #1 would be appropriate for larger group sizes and sample schedule #2 would be more suitable for smaller group sizes.

B.1 Sample Schedule #1 :

DATE	GROUP A	GROUP B	GROUP C	GROUP D
Week #1	Introduction	Introduction	Introduction	Introduction
Week #2	Conduct #1	Conduct #2	Conduct #9	Conduct #3
Week #3	Conduct #2 **Turn in #1**	Conduct #1 **Turn in #2**	Conduct #3 **Turn in #9**	Conduct #9 **Turn in #3**
Week #4	Conduct #3 **Turn in #2** #1 returned	Conduct #9 **Turn in #1** #2 returned	Conduct #1 **Turn in #3** #9 returned	Conduct #2 **Turn in #9** #3 returned
Week #5	Conduct #4 **Turn in #3** #2 returned	Conduct #4 **Turn in #9** #1 returned	Conduct #4 **Turn in #1** #3 returned	Conduct #4 **Turn in #2** #9 returned
Week #6	Conduct #5 **Turn in #4** #3 returned	Conduct #5 **Turn in #4** #9 returned	Conduct #5 **Turn in #4** #1 returned	Conduct #5 **Turn in #4** #2 returned
Week #7	Conduct #6 **Turn in #5** #4 returned	Conduct #6 **Turn in #5** #4 returned	Conduct #6 **Turn in #5** #4 returned	Conduct #6 **Turn in #5** #4 returned
Week #8	Conduct #7 **Turn in #6** #5 returned	Conduct #7 **Turn in #6** #5 returned	Conduct #7 **Turn in #6** #5 returned	Conduct #7 **Turn in #6** #5 returned
Week #9	Conduct #8 **Turn in #7** #6 returned	Conduct #8 **Turn in #7** #6 returned	Conduct #8 **Turn in #7** #6 returned	Conduct #8 **Turn in #7** #6 returned
Week #10	Conduct #9 **Turn in #8** #7 returned	Conduct #3 **Turn in #8** #7 returned	Conduct #2 **Turn in #8** #7 returned	Conduct #1 **Turn in #8** #7 returned
Week #11	**Turn in #9** #8 returned **(Instr. Mailbox)**	**Turn in #3** #8 returned **(Instr. Mailbox)**	**Turn in #2** #8 returned **(Instr. Mailbox)**	**Turn in #1** #8 returned **(Instr. Mailbox)**

Week #12	Lab Presentation (If required) #9 returned	Lab Presentation (If required) #3 returned	Lab Presentation (If required) #2 returned	Lab Presentation (If required) #1 returned

B.2 Sample Schedule #2 :

DATE	GROUP A	GROUP B	GROUP C	GROUP D
Week #1	Introduction Conduct #1	Introduction Conduct #9	Introduction Conduct #2	Introduction Conduct #3
Week #2	Conduct #2 **Turn in #1**	Conduct #3 **Turn in #9**	Conduct #1 **Turn in #2**	Conduct #9 **Turn in #3**
Week #3	Conduct #3 **Turn in #2** #1 returned	Conduct #1 **Turn in #3** #9 returned	Conduct #9 **Turn in #1** #2 returned	Conduct #2 **Turn in #9** #3 returned
Week #4	Conduct #4,5 **Turn in #3** #2 returned	Conduct #4,5 **Turn in #1** #3 returned	Conduct #4,5 **Turn in #9** #1 returned	Conduct #4,5 **Turn in #2** #9 returned
Week #5	No Class #3 returned (Instruc. Mailbox)	No Class #1 returned (Instruc. Mailbox)	No Class #9 returned (Instruc. Mailbox)	No Class #2 returned (Instruc. Mailbox)
Week #6	Conduct #6,7 **Turn in #4,5**	Conduct #6,7 **Turn in #4,5**	Conduct #6,7 **Turn in #4,5**	Conduct #6,7 **Turn in #4,5**
Week #7	Conduct #8,9 #4,5 returned **Turn in #6**	Conduct #8,2 #4,5 returned **Turn in #6**	Conduct #8,3 #4,5 returned **Turn in #6**	Conduct #8,1 #4,5 returned **Turn in #6**
Week #8	#6 returned	#6 returned	#6 returned	#6 returned
Week #9	**Turn in #8,9**	**Turn in #8,2**	**Turn in #8,3**	**Turn in #8,1**
Week #10	Lab Presentation (If required) #8,9 returned	Lab Presentation (If required) #8,2 returned	Lab Presentation (If required) #8,3 returned	Lab Presentation (If required) #8,1 returned

APPENDIX C- RECOMMENDED LABORATORY REPORT GUIDELINES AND FORMAT

Lab Reports: 8 lab reports @ 100 pts each. These reports will be due on the date specified on the lab schedule. Late reports will be penalized 4 points per day. Any report turned in after 5 business days will automatically have 20 points deducted. These penalties will be strictly enforced in fairness to those who submit reports on time**.** Late reports must be turned in to the instructor's mailbox (TH N277) with a phone call to the instructor.

Laboratory Report Guidelines: The report must be written in third person. It is encouraged that the report be word-processed. However, you may hand write the report if necessary. The report must be written in the following format:

-Title page or first page header: Include the class title, experiment #, experiment title, date experiment conducted, date report submitted, your name, your group number, and list each members name.

-Abstract (5 points): State the purpose of the experiment. Briefly discuss how it was conducted. State the final values obtained and how they compare to theory. If the resulting data is extensive be sure to provide a representative sampling of the final values.

-Background (15 points): The lab instructor will always inform the students at the end of each experiment exactly what to discuss in this section. When asked to discuss a particular equation be sure to discuss the equation (name and purpose) and define each parameter in the equation with the corresponding units.

-Procedure (15 points): In this section refer the reader to the lab manual (be sure to list manual in Reference Section) for the exact procedure. However, be sure to list any deviations from the manual's procedure. A sketch of the experimental set-up must be provided and must be neat! Each component must be labeled and the important dimensions should be provided in this section (i.e. anything you measured in the lab as far as lengths, weights, material type, etc.).

-Data and Calculations (35 points): This section should include the following sub-sections:

RAW DATA: All of the recorded and measured values from the experiment. Be sure to rewrite this information.

CALCULATIONS: Provide all of the required calculated data, plots, tables, etc. These calculations are specified at the end of each laboratory section in the manual. The lab instructor may revise or add to these calculations.

SAMPLE CALCULATIONS: Always provide sample calculations showing how values were obtained and the equations utilized.

- Results (15 points): Discuss and provide the final resulting values and how they compare to theoretical values. Are the results as expected? Explain. Discuss at least 5 sources of error that may have affected the data with the entire group before the experiment is over. These sources of error must be listed <u>and explained</u> in this section.

- Conclusions (5 points): State whether the resulting values were acceptable (no need to provide specific numbers) and state suggested improvements to the laboratory (i.e. procedure, equipment, etc.). Be sure to provide these and be specific!

- References (5 points): Provide author, year, title, and publisher.

- Raw Notes (5 points): Attach the actual paper notes were recorded upon during the experiment. There is no need to rewrite these notes.

APPENDIX D- SAMPLE BACKGROUND TOPICS

MAE/CE 370
MECHANICS OF MATERIALS LABORATORY
SAMPLE BACKGROUND TOPICS

REFERENCES FOR SAMPLE BACKGROUND TOPICS

[1] Beer, F.P. and Johnston, JR., E.R. **Mechanics of Materials**, second edition.1992, McGraw-Hill, Inc.
[2] MAE/CE 370 Mechanics of Materials Laboratory Manual, edited by J. A. Gilbert and C. L. Carmen. June 2000

GENERAL TOPICS:

- Explain how a strain gage works. Use Fig. 6.74 [1] and the equation $R = \frac{\rho L}{A}$ in your discussion.

- Explain how a strain gage and a Wheatstone Bridge work along with a sketch of a Wheatstone Bridge.
- Discuss fatigue and fatigue testing.
- Discuss the strain gage equation.
- Explain how a strain meter measures changes in resistance.
- Discuss transverse sensitivity.

EXP. #1 - MODULUS OF ELASTICITY TENSION TEST

- Discuss the physical meaning of the modulus of elasticity and how this value is obtained experimentally.
- Discuss the generalized Hooke's Law equations for multi-axial loading. Discuss the meaning of the positive or negative sign for each term.
- Discuss Hooke's Law.
- Copy and discuss Fig. 2.15 [1]. Define yield stress and ultimate strength.
- Define proportional limit, elastic limit and plastic deformation
- Provide five values of the modulus of elasticity of various materials.
- Discuss the flexure formula.
- Sketch a generic stress v/s strain curve and label the various regions.

EXP. #2 - COLUMN BUCKLING TEST

- Discuss Euler's equation.

- Discuss Eqn. 11.13 [1].
- Copy and discuss Fig. 11.17 [1].
- Discuss how varying K, b, t and L will affect the calculated buckling load.
- Discuss the critical factors in loading struts.
- Discuss whether the experimental buckling load will most likely be higher or lower than the theoretical.
- Define the buckling load in terms of radius of gyration.

EXP. #3 – TORSION TEST

- Define shear modulus.
- How is the value of the shear modulus obtained experimentally?
- Discuss Eqn. 2.36 [1].
- Discuss any similarities between the modulus of elasticity and the modulus of rigidity. How do they compare?
- Copy and discuss Fig. 3.8 [1].
- Copy and discuss Fig. 3.31 [1].

EXP. #4 - MODULUS OF ELASTICITY FLEXURE TEST

- Discuss the physical meaning of the modulus of elasticity and how this value is obtained experimentally.
- Discuss the generalized Hooke's Law equations for multi-axial loading. Discuss the meaning of the positive or negative sign for each term.
- Discuss Hooke's Law.
- Copy and discuss Fig. 2.15 [1]. Define yield stress and ultimate strength.
- Define proportional limit, elastic limit and plastic deformation
- Provide five values of the modulus of elasticity of various materials.
- Discuss the flexure formula.
- Sketch a generic stress v/s strain curve and label the various regions.

EXP. #5 - POISSON'S RATIO FLEXURE TEST

- Define poisson's ratio.
- Provide five different values of poisson's ratio of various materials.
- Discuss Eqn.'s 2.25, 2.26 and 2.27 along with Fig. 2.37 [1].
- Copy Fig. 8.8(c) [1] and discuss the boundary conditions for a cantilever beam.
- Discuss poisson's effect and provide a sketch representing this phenomenon.
- Explain why a correction factor is utilized in the calculations.

EXP. #6 - CANTILEVER FLEXURE TEST

- Discuss and provide equations showing how stress and strain vary with distance from the load.
- Discuss the three methods of how the applied load will be determined (provide equations).

- Discuss the two methods used to calculate stress at any point on the beam (provide equations).

EXP. #7 – STRESS CONCENTRATION TEST

- Define the stress concentration factor.
- Sketch and discuss Fig. 2.57 [1].
- Discuss Eqn. 4.29 [1].
- Copy Fig. 2.57 and Fig. 2.58 [1] and discuss the location of maximum stress.
- Rank gages 1 through 4 from highest to lowest stress reading.
- Discuss Eqn. 5 and Eqn. 6 [2]. How do these compare?

EXP. #8 – PRINCIPLE STRESSES AND STRAIN TEST

- Discuss and sketch delta and strain gage rosettes.
- Discuss how the shearing stresses vary during a 90 degree rotation from one principle plane to another.
- Using Fig. 2 [2] rank the gages (#1,2 and 3) from highest to lowest in terms of the following quantities: 1) axial stress, 2) transverse stress and 3) shear loading.
- Discuss the equations used to theoretically calculate the angles between gage #1 and the principle axis.
- Sketch the location of the principle axis on Fig. 2 [2].

EXP. #9 – BEAM DEFLECTION TEST

- Define radius of curvature.
- Define flexural rigidity.
- Copy and discuss Fig. 8.6 [1] and define the elastic curve (provide equations).
- Copy Fig. 8.8 (a and b) and discuss the boundary conditions.
- Discuss the seven steps employed in the double integration method.
- Discuss the deflection equations for each of the two different types of loading.
- Provide the free body diagrams for the shear and moment for each type of loading.

APPENDIX E – GRADING GUIDELINE FOR GROUP PRESENTATIONS

Visual Presentation (75%)

- **Content (50%)** __________
- **Organization(15%)** __________
- **Neatness (10%)** __________

Oral Presentation (25%)

- **Clarity (10%)** __________
- **Organization (10%)** __________
- **Time Limit (5%)** __________

TOTAL SCORE: __________

APPENDIX F- RECOMMENDED GROUP PRESENTATION FORMAT

<u>Group Presentations</u>: This presentation is worth 100 pt. Individual group members will each receive the grade obtained by the group. This presentation will consist of an in depth discussion on one particular experiment. The group will determine assignments and responsibilities of individual group members. The presentation must be professionally prepared using overheads generated by such programs as Microsoft Word, WordPerfect, Excel, etc.

MAE/CE 370
MECHANICS OF MATERIALS LABORATORY PRESENTATIONS

Each laboratory group will provide a presentation to their laboratory section on <u>*state date*</u> at <u>*state time*</u> in the laboratory. The topic of the presentation will be a particular experiment that has been assigned to each group. The presentation should last approximately 15-20 minutes.

You may utilize the software of your choosing to generate the presentation. This may include, but is not limited to, Microsoft Word, Power Point, etc. Equipment such as a slide projector, overhead projector, video projector and laptop computer will be available for your use in the laboratory.

Every person within the group must participate. It will be up to the individual groups to decide the assignment for each member. For example, some members may be responsible for generating the information for the presentation; some may generate the actual slides/presentation, while others may present the material to the class. Remember that each group member will receive the grade that the group receives as a whole.

<u>Format of Presentation:</u>
(Note: the number of slides is only a recommendation.)

<u>Title (1 slide)</u>

<u>Purpose of Experiment</u>:
- State objective (1 slide)
- Importance of experiment (1 slide)

<u>Background:</u>
- Brief discussion of theory (1 slide)
- Pertinent equations used (1 slide.) Note: Be sure to define parameter with units.

<u>Equipment (1 or 2 slides):</u>
- Show all equipment; beam dimensions, location of gages.
- No wiring diagrams necessary.

<u>Data:</u>
- Raw Data (1 slide)
- Final resulting values/plots (1 or 2 slides)

Results (1 slide):

- Were results as expected? Discuss Errors.

Conclusions (1 slide):

- What did you learn from experiment?
- Any suggestions for improvement?

Group Member Assignments (1 slide):

- List the responsibility of each member in preparation of presentation

APPENDIX G - SUGGESTED PREPARATION/STUDY TIPS FOR LABORATORY FINAL

MAE/CE 370
MECHANICS OF MATERIALS LABORATORY
LAB FINAL
PREPARATION/STUDY TIPS

The laboratory final will be given during the regularly scheduled class time on *Enter Date*. This exam will cover topics related to each of the nine experiments conducted during the laboratory. Questions will only cover material contained within the MAE/CE 370 Mechanics of Materials Laboratory Manual edited by John A. Gilbert and Christina L. Carmen. These preparation/study tips are intended to aid the student in preparation for the exam.

The exam will be theoretical with the format consisting of multiple choice questions, short answer questions, short discussion questions and possible schematic sketches.

Preparation/Study Tips:

1) Understand how strain gages function.

2) For each experiment be able to visualize the physical set-up and equipment utilized.

3) Understand the objective of each experiment.

4) Understand the background/theoretical information.

5) Recognize and understand the pertinent equations utilized in the calculations.

6) Predict and understand trends within any plots generated.

7) Provide approximate final values obtained (no need to memorize all resulting numerical values).

8) Be familiar with the major experimental sources of error associated with each experiment.

APPENDIX H- SAMPLE BEAM DEFLECTION COMPUTATIONAL ANALYSIS HANDOUT

MAE/CE 370
MECHANICS OF MATERIALS LABORATORY
Simply Supported Beam/Double Integration Method

- The calculations within the Simply Supported Beam/Double Integration Method require the calculation of the theoretical deflections for each load and position for both the center loading and the overhung loading.

- The theoretical deflection equations for both loading methods are provided in the manual and are as follows:

  Center loading:

  $E\,I\,y = (P/12)\,x^3 - (PL^2/16)\,x \quad (0 \leq x \leq L/2)$

  $E\,I\,y = -(P/12)\,x^3 + (PL/4)\,x^2 - 3(PL^2/16)\,x + (PL^3/48) \quad (L/2 \leq x \leq L)$

  Overhung loading:

  $E\,I\,y = (P/6L)\,x^3\,(a - b) - (Pa/2)\,x^2 + (PL/6)\,x\,(2a + b)$

- Note: In the above equations the only unknown is the theoretical deflection "y". All other parameters are known. The goal is to solve for a theoretical deflection for each load and at each location at which an experiment deflection was recorded.

- The requirement for solving this equation is that the solution must be computer generated. For instance, you may generate a simple computer code using any language you prefer, you can use excel to solve the equation, or you may use other mathematical solvers. Be sure to provide the solution method within your report and provide a table of the resulting theoretical values. See manual for other required data calculations.

- A sample solution utilizing excel is provided. See the following Excel Example.

Excel Example:

	A	B	C	D	E	F
1	E (psi)	I (in^4)	P (LB)	x (in)	L (in)	y (in)
2	30000000	0.0013	2	4	20	-0.0048547

- The above table was generated using Microsoft Excel. This is one possible method of solving the deflection equations.

- The above example solves for the deflection, y, for the center loading which is governed by the following equation:

$$y = \left((P/12)\ x^3 - (PL^2/16)x \right)/(E\ I) \qquad \text{for } 0 \leq x \leq L/2$$

- Again, note that the only unknown is the value of "y".

Solution Instructions for above Example:

- In row 1 label each cell by the parameter associated with that cell.
- In row 2 provide the actual values of all <u>known</u> values. Note that in the above example random values have been chosen for E, I, P, x, and L.
- In row 2, column F, you must type in the equation to solve for 'y'. The following is exactly what you type into this cell:

=((c2/12)*d2^3-(c2*e2^2/16)*d2)/(a2*b2)

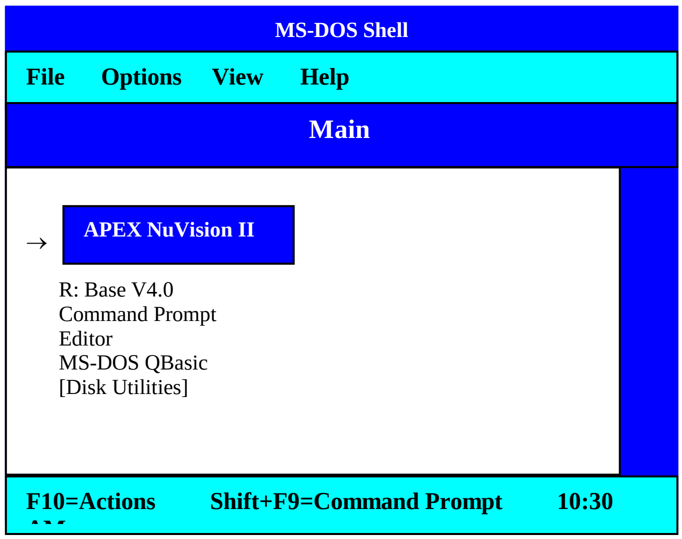
Note: 'c2' refers to the number in column c and row 2. The '^' symbol is used for exponents.

- Once you have typed in the above formula in column f, row 2, press enter or return and the value for 'y' will appear.

APPENDIX I - MODULUS OF ELASTICITY TENSION TEST PROCEDURE

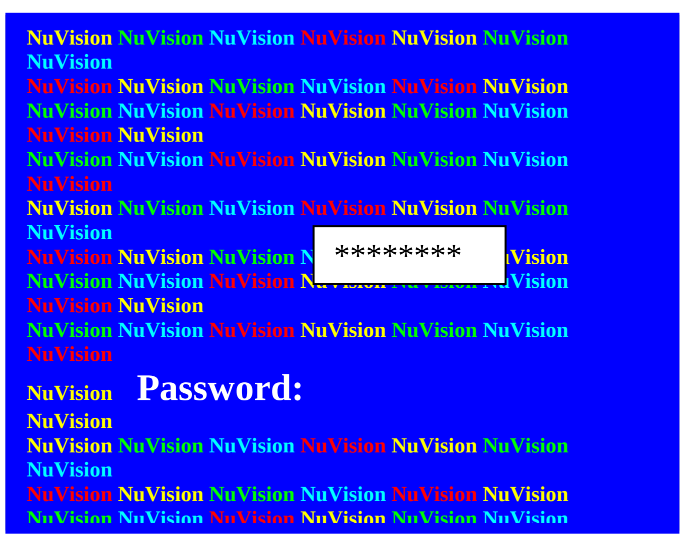
1. Turn on power surge protector. Turn on the computer, monitor and printer. The tensile testing machine does not have an on/off control- it is controlled by the computer.

2. The following screen will appear on the computer monitor:



APEX NuVision II should be highlighted. If not use the up and down arrow keys to highlight **APEX NuVision II**. Press **[ENTER].**

3. The following screen will appear on the monitor:

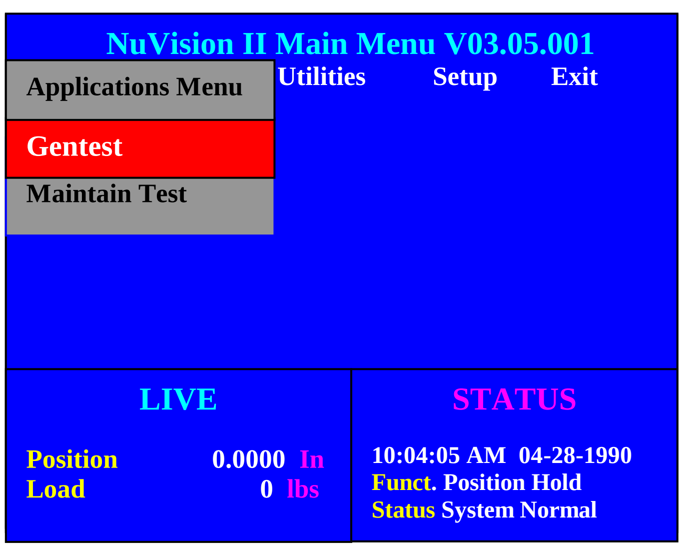


Enter your password. The password has been previously assigned to the laboratory instructor. If a password is not known the instructor should contact the MAE office for instructions on how to obtain one.

4. After entering the password the following screen will appear on the monitor:

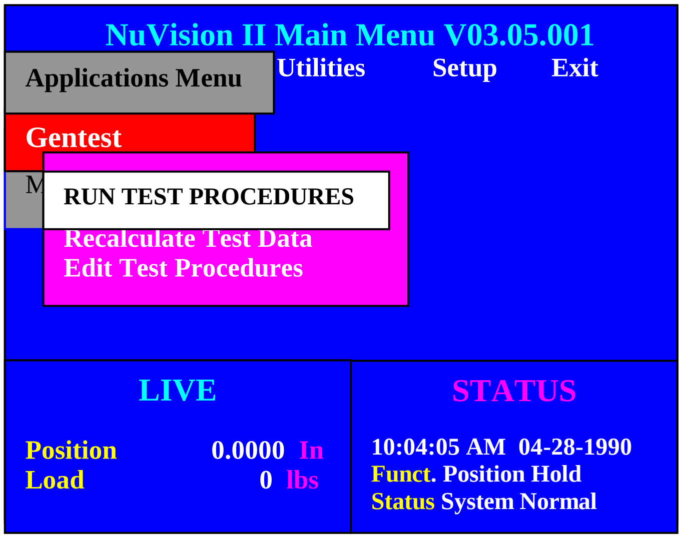
Be sure to remove any specimen located in the test space. Press **[ENTER].**

5. The following screen will appear on the monitor:



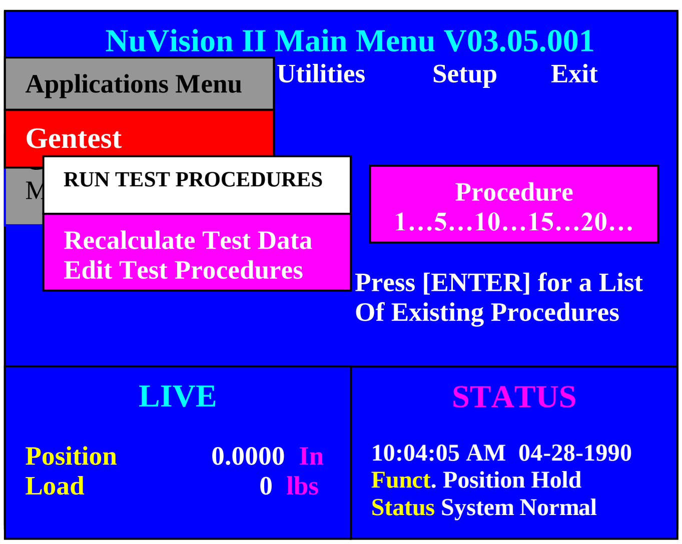
Gentest should be highlighted. If not, use the arrow keys to highlight **Gentest**. Press **[ENTER].**

6. The following screen will appear on the monitor:



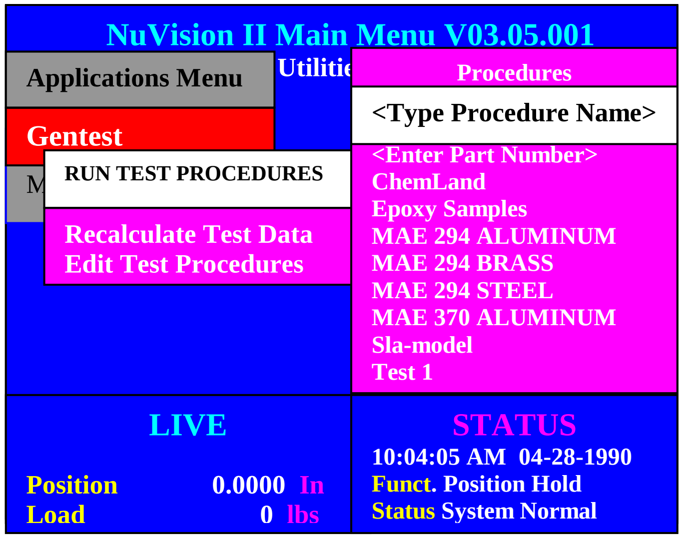
Run Test Procedures will be highlighted. If not, use the arrow keys to highlight **Run Test Procedures**. Press **[ENTER]**.

7. The following screen will appear on the monitor:



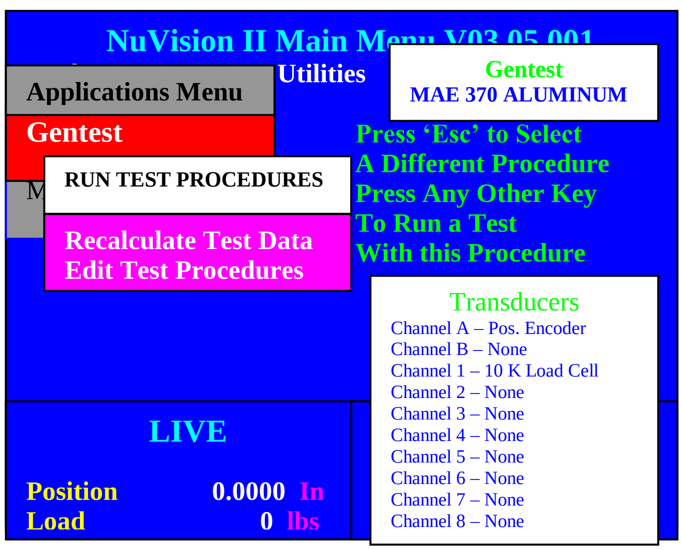
Press **[ENTER]** for a list of existing procedures.

8. The following screen will appear on the monitor:



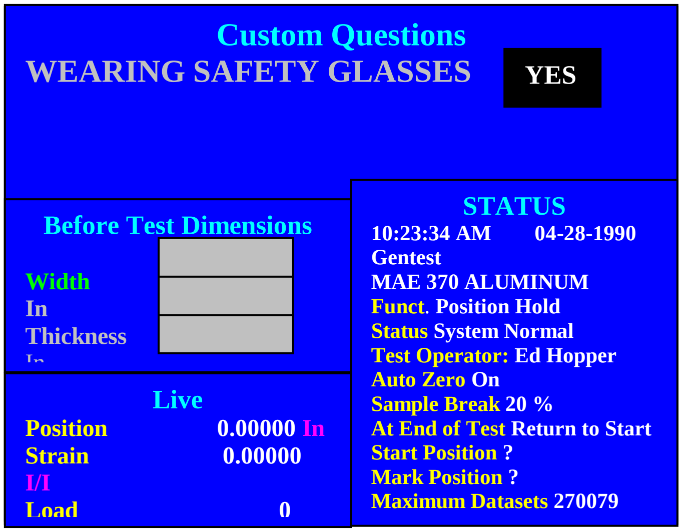
<u><Type Procedure Name></u> will be highlighted. Use the down arrow key to instead highlight **<u>MAE 370 ALUMINUM.</u>** Press **[ENTER]**.

9. The following screen will appear on the monitor:



The default test procedure appears on the screen. Press **[ENTER]** to run a test with this procedure.

10. The following screen will appear on the monitor:



The **Before Test Dimensions** section of the screen will be highlighted. These are the only numbers that need to be changed. The arrow keys are used to move the cursor up and down among the width, thickness, and height indicators.

Measure the exact width, thickness and height of the test specimen. If, for example, the width indicated on screen is different than the measured width of the test specimen then change the indicated screen value as follows:

- use the up or down arrow key to highlight the width value
- use the right arrow key to position the cursor on the smallest decimal value of the number indicated on screen for the width
- use the backspace key to delete the value
- type in the correct measured width of test specimen.

Repeat for the thickness and height of the test specimen.

11. After entering the correct **Before Test Dimensions** of the specimen the specimen can be loaded into the SATEC tensile testing machine as follows:

- Use the blue up and yellow down buttons on the tensile testing machine to raise or lower the upper grip to a height above the lower grip of approximately 1” less than the measured height of the test specimen. For example, if the measured height of the test specimen is 6” then align the upper grip a distance of 5” above the lower grip.

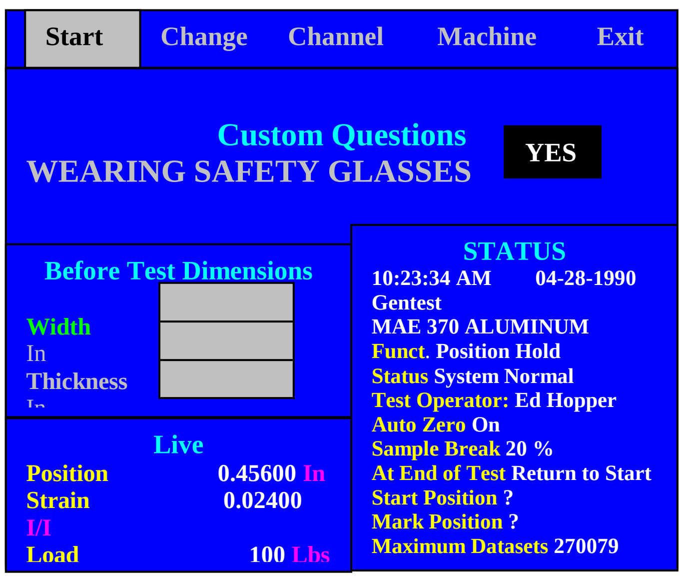
- Insert test specimen approximately ½” into the upper grip of the tensile testing machine and tighten by rotating the grip handle clockwise. Be sure the test specimen is aligned vertically.

- Insert test specimen approximately ½" into the lower grip and tighten by rotating the grip handle counter clockwise. Again, check for vertical alignment of the specimen.

12. After inserting the specimen into the test machine a pre-load of approximately 100 lbs. should be applied to the test specimen. The amount of pre-load will be indicated on the computer screen in the lower left hand corner under the **Live** readings indicated by **Load** in **lbs**. The test specimen should be pre-loaded as follows:

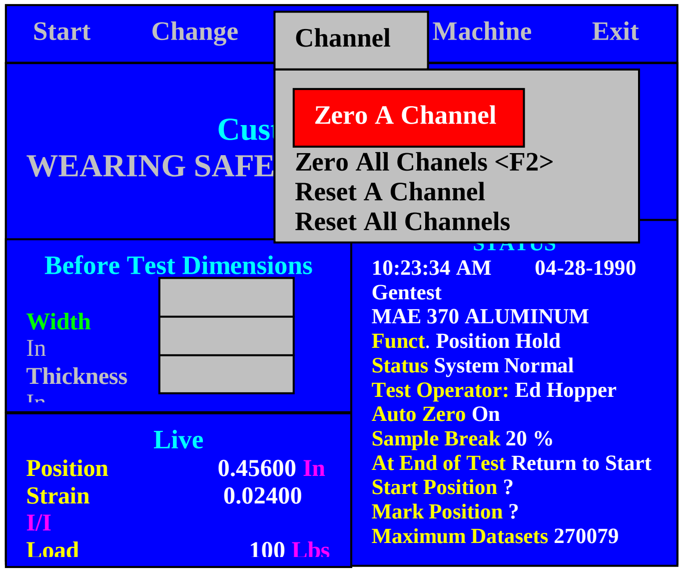
    - Use the up button on the tensile testing machine to *slowly* raise the upper grip in order to apply a tensile load on the test specimen. The amount of load can be simultaneously viewed on the computer screen by the **Load** reading in **lbs.** The pre-load should be at approximately 100 lbs. ***Note:*** *If this step is being repeated due to insufficient pre-load add an extra 50 Lbs. to the previous pre-load amount.*

13. Once the specimen has been pre-loaded the channels must be zeroed. To accomplish this press the **[TAB]** key twice and the following screen will appear on the monitor:



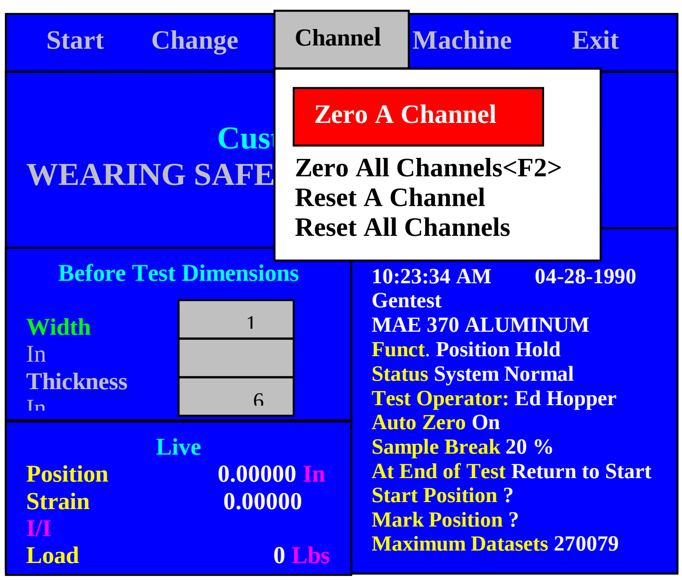
Start at the top left-hand corner of the screen will be highlighted. Use the right arrow key to highlight **Channel** instead. Press **[ENTER]**.

14. The following screen will appear on the monitor:

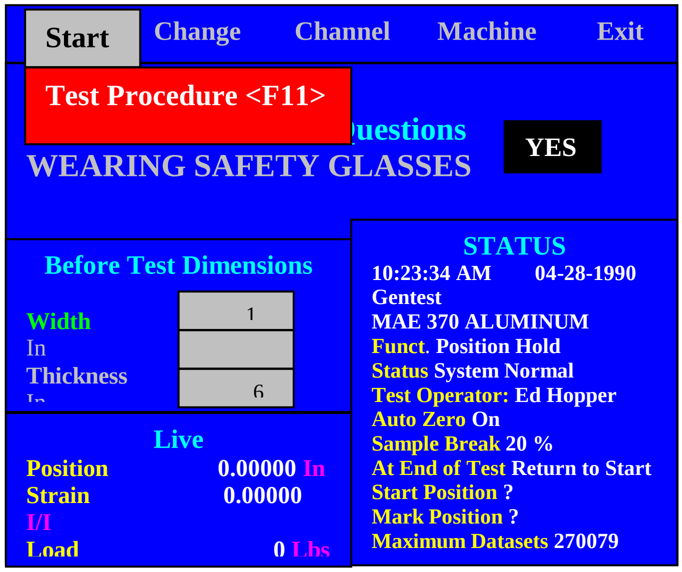


<u>Zero A Channel</u> will be highlighted. Use the down arrow key to highlight **<u>Zero All Channels <F2></u>**. Press **[ENTER]**.

15. The following screen will appear on the monitor:

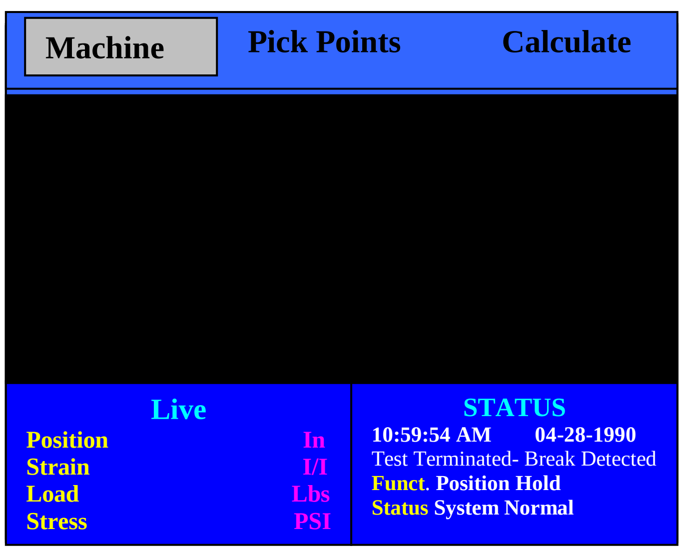


Notice that the **<u>Live</u>** readings have been zeroed. Use the left arrow key to highlight **<u>Start</u>** instead of **<u>Channel</u>** at the top of the screen (***<u>do not</u>*** press the **[ENTER]** key after highlighting **<u>Start</u>**). The following screen will appear on the monitor:

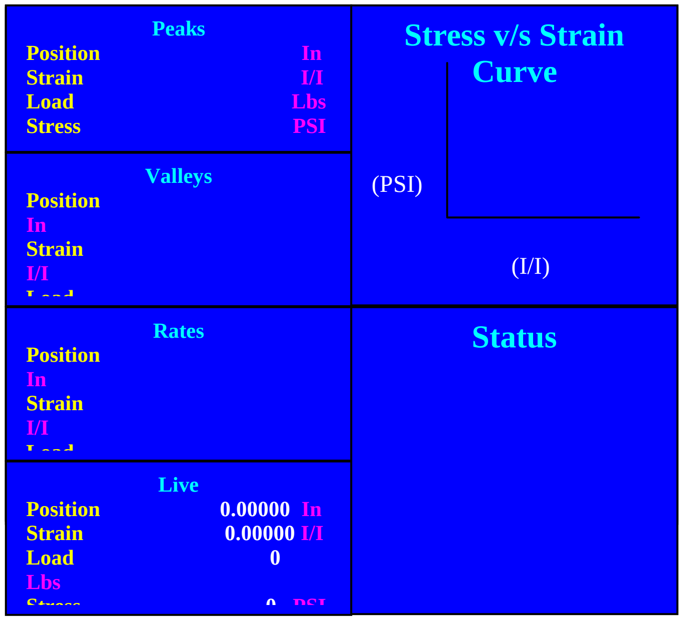


<u>**Test Procedure <F11>**</u> will be highlighted. When ready to begin the tensile test press **[ENTER]**. If at any time after starting the test there is a need to abort the test press **[TAB]**.

Note: if the specimen was not inserted correctly or the pre-load was insufficient the test will automatically terminate, the following screen will appear on the monitor and the user should skip to step #26:

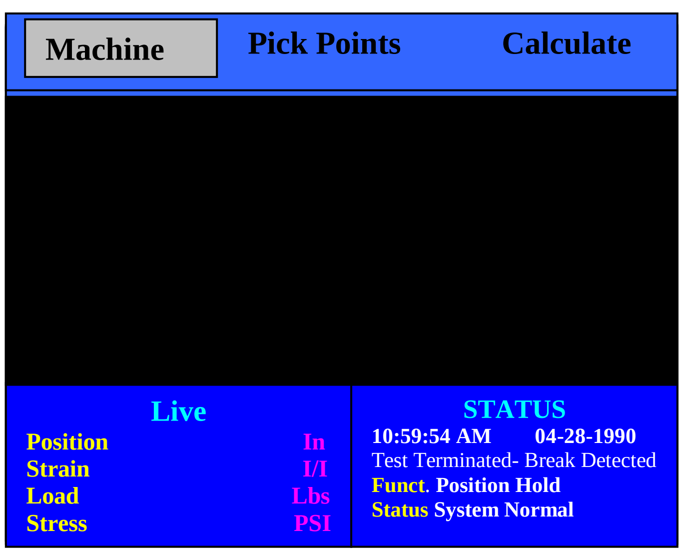


16. If the specimen was inserted correctly and enough pre-load was applied the test should run properly and the following screen will appear on the monitor with the values constantly changing as the specimen is being pulled in tension:



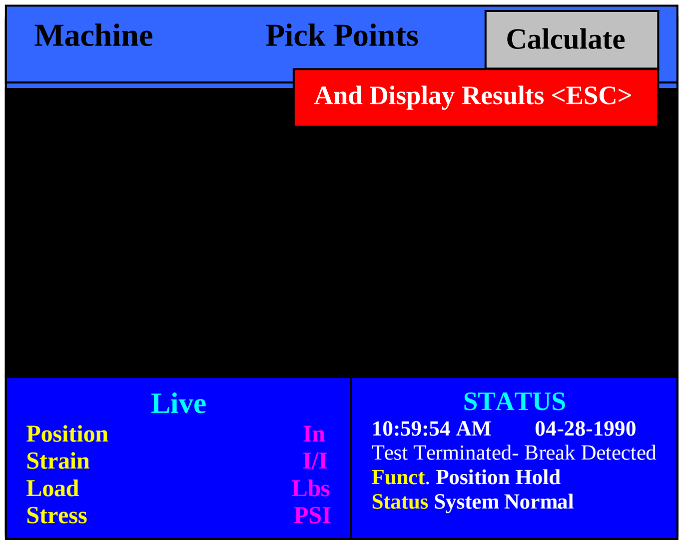
Press the space bar to switch between the above screen and a full screen representation of the Stress v/s Strain curve. When the specimen breaks remove the two remaining pieces from the tensile testing machine.

18. After the specimen breaks the screen represented on the monitor will be the following:



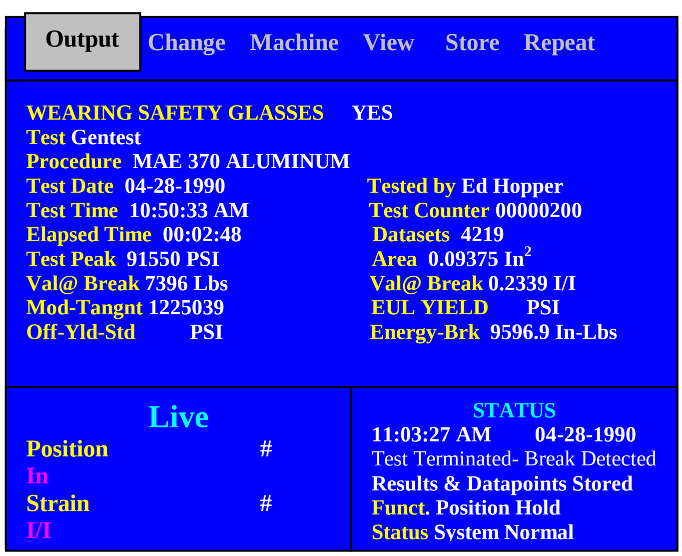
Machine will be highlighted. Use the right arrow key to highlight **Calculate**. Press **[ENTER]**.

19. The following screen will appear on the monitor:



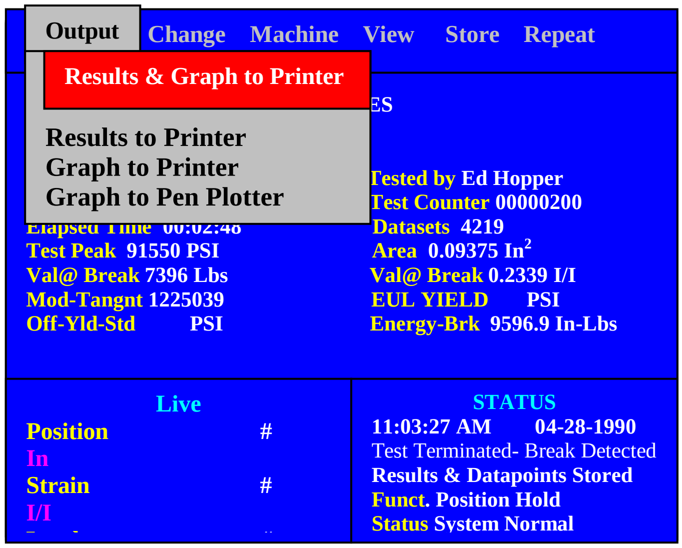
And Display Results <ESC> will be highlighted. Press **[ENTER]**.

20. The following screen will appear on the monitor:



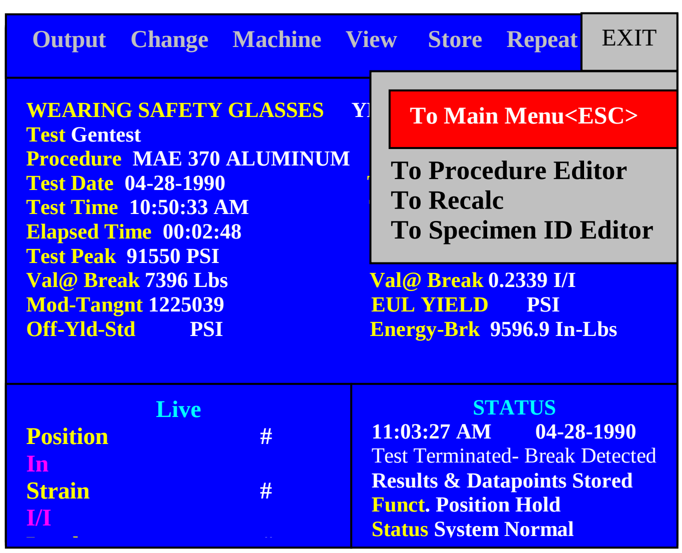
<u>Output</u> will be highlighted in the upper left-hand corner of the screen. Press **[ENTER]**.

21. The following screen will appear on the monitor:



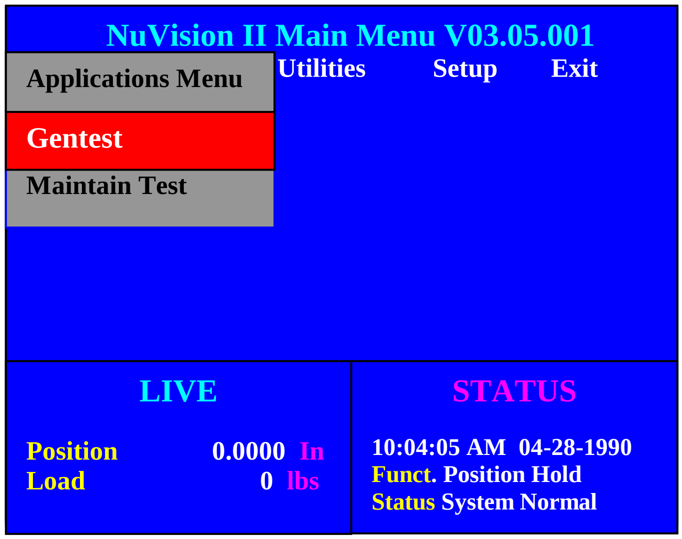
<u>Results and Graph to Printer</u> will be highlighted. Verify that the printer is turned on and that sufficient paper is present within printer. Press **[ENTER]**. While the results and graph are printing the screen will display the full Stress v/s Strain curve and finally, once again, the screen represented above.

22. To shutdown the computer use the arrow key to highlight **<u>Exit</u>** in the upper right-hand corner of the screen. Press **[ENTER]** and the following screen will appear:



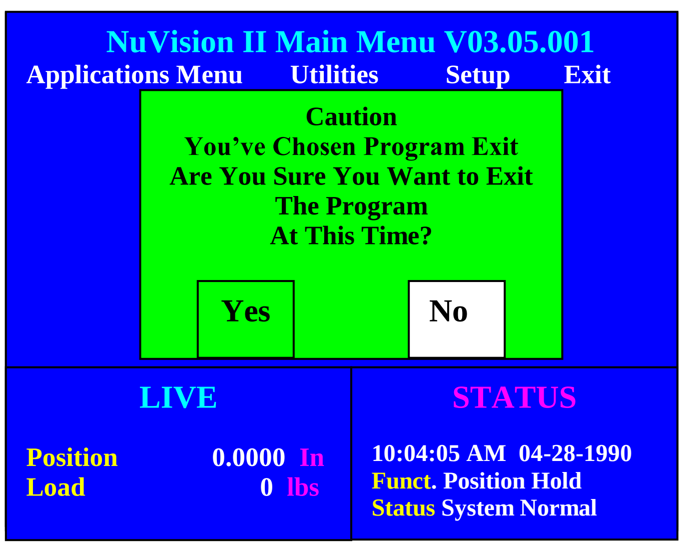
To Main Menu <ESC> will be highlighted. Press **[ENTER]**.

23. The following screen will appear on the monitor:



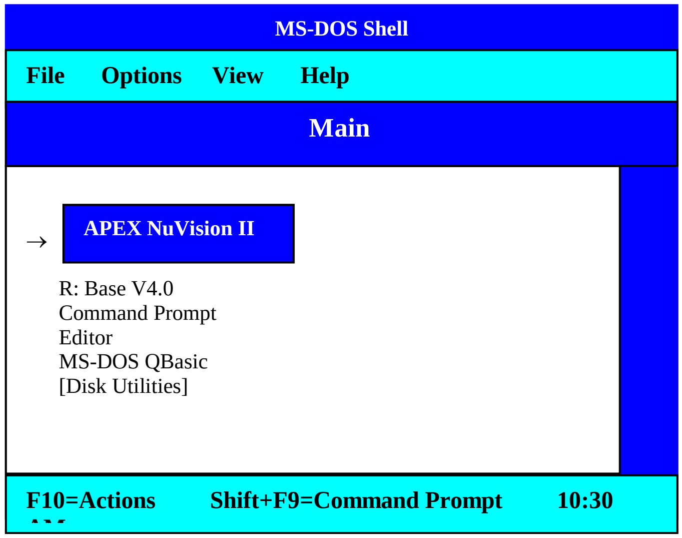
Gentest is highlighted. Use the arrow key to highlight **Exit** instead. Press **[ENTER]**.

24. The following screen will appear on the monitor:



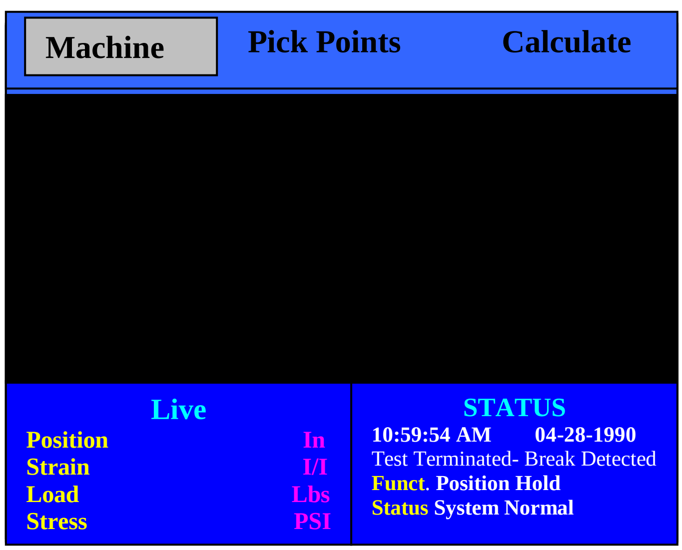
No will be highlighted. Use the arrow key to highlight **Yes**. Press **[ENTER]**.

25. The following screen will appear on the monitor:

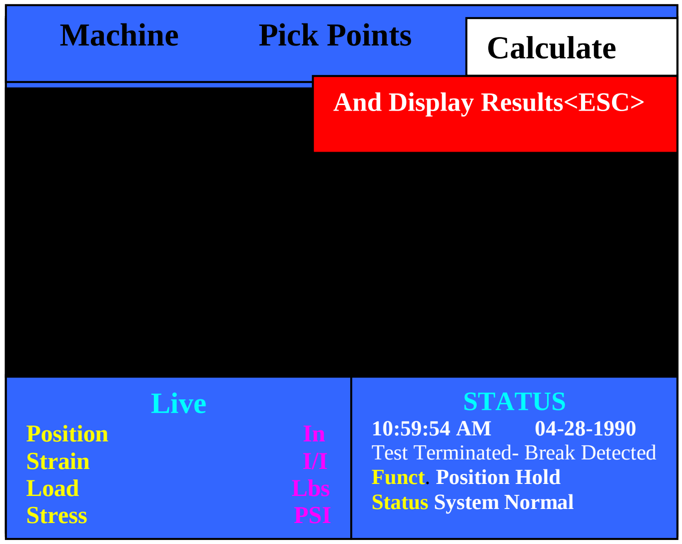


Press the **[SHIFT]** plus the **[F9]** key to return to the command prompt. The command prompt **C:\>** will appear and the computer, printer, monitor, and surge protector can be turned off.

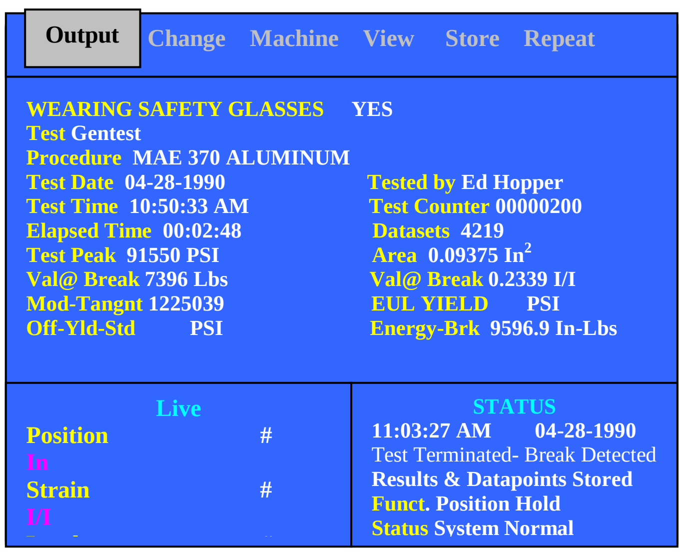
26. <u>Note:</u> This step should be completed only if the test was terminated due to incorrect specimen insertion or insufficient preload. The following screen appears if the test is terminated:



<u>Machine</u> will be highlighted. Use the right arrow key to instead highlight **<u>Calculate.</u>** Press **[ENTER].** The following screen will appear on the monitor:



<u>And Display Results<ESC></u> will be highlighted. Press **[ENTER]**. The following screen will appear on the monitor:



<u>Output</u> will be highlighted. Use the right arrow key to instead highlight **<u>Repeat</u>**. Press **[ENTER]. <u>Test Procedure <F9></u>** will be highlighted. Press **[ENTER].** The screen represented in step #10 will appear on the monitor. Return and repeat procedure starting with step #10.