

**PRESENTATION OF EXPERIMENTS FOR HIGH SCHOOL STUDENTS
WITH CIVIL ENGINEERING RELATED INTERESTS**

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ABSTRACT

In February of 1999, the National Science Foundation developed a \$7.5 million program to provide graduate and undergraduate students with the opportunity to serve as teaching fellows and academic resources in kindergarten through grade twelve in the fields of science, mathematics, engineering, and technology. This program enabled university students to introduce new concepts to address science, mathematics, engineering and technology weaknesses found in many of the nation's schools. Efforts at the University of Kansas were modeled after similar programs, in which graduate students are used to promote science and technology.

This report describes six experiments dealing with civil engineering materials and structures. Each of the experiments includes worksheets for the student and the instructor. The worksheets provide background information, an explanation of the processes followed to develop the experiment, a summary of the necessary materials, and a review section including discussion questions or a calculation worksheet. The worksheet for the instructor also provides scheduling recommendations and solutions to questions in the review section.

Key Words: bridge competition, concrete, corrosion, end reactions, engineering, GK-12, graduate students, graphing, high school, mathematics, moment of inertia, National Science Foundation, science, technology, University of Kansas

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TABLE OF CONTENTS

Page	
ABSTRACT	ii
ACKNOWLEDGEMENTS.....	iii
LIST OF TABLES	x
LIST OF FIGURES.....	xi
CHAPTER 1: INTRODUCTION	1
1.1 General	1
1.2 GK-12 at The University of Kansas	2
1.3 Object and Scope	3
CHAPTER 2: SIMILAR PROJECTS	5
2.1 General	5
2.2 Monarch Watch	5
2.3 K-12 Engineering Outreach Program	7
2.4 Wisconsin Initiative for Space Education (WISE)	8
CHAPTER 3: CLASSROOM LABORATORIES	10
3.0 General.....	10
3.1 Corrosion Laboratory: Experiment Number 1	12
3.1.1 Purpose	12
3.1.2 Introduction.....	12
3.1.3 Corrosion Background.....	13
3.1.4 How This Experiment is Similar to the Process of Corrosion...	14
3.1.5 What You Will Need	15
3.1.6 Schedule.....	16
3.1.7 Procedure	16

3.1.8 Observations.....	17
3.1.9 Answers to Discussion Questions	17
E1.0 Creating Rust: Electrolysis of Water	18
E1.1 Purpose	18
E1.2 Introduction	18
E1.3 Corrosion Background	19
E1.4 How This Experiment is Similar to the Process of Corrosion....	20
E1.5 What You Will Need.....	21
E1.6 Procedure.....	22
E1.7 Discussion Questions	23
3.2 Concrete Mix Design Experiment: Experiment Number 2.....	24
3.2.1 Purpose	24
3.2.2 Introduction.....	24
3.2.3 Background	25
3.2.4 Testing	26
3.2.5 What You Will Need (Per Group).....	27
3.5.6 Schedule.....	27
3.2.7 Procedure	28
3.2.8 Observations.....	28
3.2.9 Summary	28
3.2.10 Answers To Discussion Questions	29
E2.0 Concrete Mix Design Experiment	30
E2.1 Purpose	30
E2.2 Introduction	30
E2.3 Background.....	32

E2.4 Testing.....	32
E2.5 What You Will Need (Per Group)	33
E2.6 Procedure.....	34
E2.7 Useful Conversions.....	36
E2.8 Discussion Questions	36
3.3 Graphing with Microsoft Excel: Experiment Number 3.....	37
3.3.1 Purpose	37
3.3.2 Introduction.....	37
3.3.3 Background.....	38
3.3.4 What You Will Need (per group).....	38
3.3.5 Schedule.....	38
3.3.6 Procedure	39
3.3.7 Summary	39
3.3.8 Answer to Discussion Questions.....	39
E3.0 Graphing.....	41
E3.1 Purpose	41
E3.2 Graphing Background.....	41
E3.3 Sample Graph	42
E3.4 Graphing with Microsoft Excel	44
E3.5 Discussion Questions	44
E3.6 How to Graph Using Microsoft Excel	45
3.4 Moment of Inertia Experiment: Experiment Number 4.....	49
3.4.1 Purpose	49
3.4.2 Introduction.....	49
3.4.3 Background.....	50

3.4.4 What You Will Need	51
3.4.5 Schedule.....	51
3.4.6 Procedure	51
3.4.7 Observations.....	52
3.4.8 Summary	52
3.4.8 Worksheet Solutions.....	53
E4.0 Moment of Inertia	57
E4.1 Purpose	57
E4.2 Moment of Inertia Background	57
E4.3 Moment of Inertia Equations.....	59
E4.4 Moment of Inertia Questions.....	60
3.5 Calculating End Reactions: Experiment Number 5.....	64
3.5.1 Purpose	64
3.5.2 Introduction.....	64
3.5.3 Background	65
3.5.4 Step-By-Step Instruction to Calculating End Reactions.....	67
3.5.5 What You Will Need (per group of four)	68
3.5.6 Schedule.....	68
3.5.7 Procedure	69
3.5.8 Summary	69
3.5.9 Answers to Worksheet.....	69
3.5.10 Worksheet Solution Guide	70
E5.0 Solving End Reactions	73
E5.1 Purpose	73
E5.2 Introduction	73

E5.3 Background.....	74
E5.4 Solving End Reactions	75
E5.5 Step-By-Step Instruction to Calculating End Reactions	76
E5.6 What You Will Need (per group of four).....	77
E5.7 Procedure.....	77
E5.8 End Reaction Questions	78
3.6 Bridge Building Competition: Experiment Number 6.....	81
3.6.1 Purpose	81
3.6.2 Introduction.....	81
3.6.3 Competition Rules.....	81
3.6.3.1 Bridge Dimensions.....	81
3.6.3.2 Bridge Materials	81
3.6.3.3 Cost	82
3.6.3.4 Judging	83
3.6.3.5 Loading.....	83
3.6.4 What You Will Need (per class)	83
3.6.5 Schedule.....	84
3.6.6 Procedure	84
3.6.7 Summary.....	85
E6.0 Bridge Building Competition.....	86
E6.1 Purpose	86
E6.2 Bridge Building Background	86
E6.2.1 Dimensions	86
E6.2.2 Cost of Labor and Bridge Materials.....	86
E6.2.3 Loading.....	87

E6.2.4 Judging	87
E6.3 Procedure	87
CHAPTER 4: SUMMARY AND CONCLUSION	88
4.1 SUMMARY	88
4.2 CONCLUSION	89
REFERENCES	90

LIST OF TABLES

<u>Table</u>	Page
E2.1 Unit Weight Values	35
E2.2 Concrete Mixture Specifications	35
E2.3 Compressive Strength Values.....	36
5.1 Descriptions of the Primary Support Conditions.....	65
E5.1 Descriptions of the Primary Support Conditions.....	74

LIST OF FIGURES

<u>Table</u>	Page
3.1.1 Electrolysis Diagram.....	15
E1.1 Electrolysis Diagram.....	21
3.4.1 Beam Loaded at Midspan.....	49
3.4.2 Effect of Beam Orientation on Moment of Inertia	50
E4.1 Beam Loaded at Midspan.....	57
E4.2 Effect of Beam Orientation on Moment of Inertia	58
3.5.1 Bridge Reactions.....	64
E5.1 Bridge Reactions.....	73

CHAPTER 1

INTRODUCTION

1.1 GENERAL

“Enlisting the knowledge and skills of graduate students and advanced undergraduates who are working toward science...related degrees will be a positive step in improving K-12 learning.” Luther Williams, the National Science Foundation’s (NSF) assistant director for education and human resources, made this statement at the unveiling of the NSF GK-12 Fellowship program in February 1999 (Herring 1999). This \$7.5 million program provides graduate and undergraduate students with the opportunity to serve as teaching fellows and academic resources in kindergarten through grade twelve (K-12) in the fields of science, mathematics and technology (Herring 1999). The National Science Foundation is a government agency accountable for promoting science and engineering through programs that invest over \$3.3 billion per year in almost 20,000 research and education projects (Introduction 1999).

The National Science Foundation recognized that students in higher education could assist in addressing the science, mathematics, engineering and technology (SMET) weaknesses found in the nation’s K-12 schools. The problems this program aims to resolve include (1) the absence of knowledge of science and technology fields for K-12 students, (2) the lack of professional development opportunities for K-12 teachers, and (3) the weak links between local school districts and higher education institutions. To address these issues, the GK-12 Fellows work directly with teachers to:

- convey key SMET concepts;
- act as role models for future SMET professionals;

- enrich teachers' knowledge and understanding of science and mathematics and;
- assist in science and mathematics instruction.

To accomplish these goals, approximately \$7.5 million were made available over three years to universities across the nation. Individual awards totaled \$200,000 to \$500,000 per year.

1.2 GK-12 AT THE UNIVERSITY OF KANSAS

The 1999-2000 school calendar marked the inaugural year for the GK-12 Program serving students and faculty at Wyandotte High School, located in Kansas City, Kansas. Six graduate students from engineering, science, and mathematics including Civil and Environmental Engineering, Mathematics, Chemistry, and Biology, met with teachers to conduct lectures and laboratory experiments. The experiments were aimed at interesting high school students in participating in the graduate student's respective field of study.

As a Civil Engineering graduate student, the author had the opportunity to work with chemistry and physics classes. The students in the chemistry class were freshman and juniors, while the students in the physics class were juniors and seniors. Since enrollment in chemistry was mandatory and the students had a wide range in age and educational experience, an attempt was made to develop experiments and lectures to provide variety and to keep the students engaged during the duration of the class. The topics covered included:

- Recycled Asphalt Paving Construction (RAP);
- Normal versus Lightweight Concrete Mix Designs;
- Graphing in Microsoft Excel and;

- Reinforcing Steel Corrosion.

Meanwhile, because physics was an elective, the experiments and lectures were designed to help the students develop quantitative reasoning skills and/or to consider engineering design, while considering the effects of every engineering design based decision. This was accomplished by studying:

- Moment of Inertia;
- Methods of Solving for End Reactions;
- Bridge Building Competition.

Throughout the one-year tenure at Wyandotte High School, the author gained experience and learned many lessons about teaching and teachers and students at an inner city public school. Many of the lessons were learned by trial and error. Meanwhile, many positive relationships were developed with students and faculty members; the relationships were made possible by taking the time to treat everyone with great respect.

1.3 OBJECT AND SCOPE

The National Science Foundation developed the GK-12 Fellowship program to encourage the teaching of math, science, and engineering technology (SMET) in grades K-12. The program is based on the recognition that students in higher education programs in SMET can contribute to the understanding of K-12 students. In particular, SMET graduate students can serve K-12 teachers and schools as valuable resources in the field.

This report reviews programs that influenced the development of the GK-12 Fellowship program and describes six laboratory experiments that were designed to interest high school students, with special emphasis in the area of civil engineering, in

SMET. The experiments include: (1) corrosion of steel, including the electrolysis of water; (2) concrete mix design, summarizing the applications and design of normal weight and lightweight concrete; (3) graphing, first by hand then using Microsoft Excel; (4) moment of inertia, demonstrated by hands-on experiments and a calculation worksheet; (5) end reactions of beams, demonstrated by hands-on experiments and a calculation worksheet; and (6) bridge building competition, with rules and judging criteria.

The object of this report is to:

- (1) Offer engineering experiments for use by future fellowship participants,
and
- (2) Provide educational tools and ideas for the program.

CHAPTER 2

SIMILAR PROJECTS

2.1 GENERAL

The National Science Foundation's GK-12 program placed graduate students in classrooms to teach science and technology material to students in kindergarten through the twelfth grade. The GK-12 program is similar to other programs found at different universities in that graduate students are used to promote science and technology instruction. This chapter describes three of those programs.

2.2 MONARCH WATCH

Monarch Watch is an educational outreach program that was initiated at the University of Kansas in 1993. The program has participants, including K-12 students, teachers, and undergraduates who study the Monarch butterfly. This ongoing project allows participants to learn about the butterfly while:

1. promoting science education in primary and secondary schools;
2. supporting conservation of Monarch butterflies; and
3. involving thousands of students and adults in a study of the Monarch's migration.

These goals have been achieved during the rapid growth of the Monarch Watch program, involving an increasing number of students and adults. It is estimated that, since the program started, more than 100,000 students in thirty-nine states and three Canadian provinces have tagged and studied over 76,000 Monarch butterflies (About 1999). Due to the large interest of students in K-12 science curriculums, the

educational experience gained from participating in this study has been extremely valuable.

Students in the program have the opportunity to participate in a genuine science experiment that explores the migration patterns of the Monarch butterfly. A comprehensive kindergarten through eighth grade (K-8) science curriculum, *Monarchs in the Classroom*, has been developed to lead teachers and students through an inquiry-based study of the butterfly.

As winter approaches, the Monarchs in North America travel southward, up to three thousand miles—much farther than any other tropical butterfly. Their migration patterns can be easily predicted since they use the same winter roosts year after year—often to the same trees (Migration 1999). Since the pattern can be forecasted, students from Canada to Mexico have a high probability of producing successful tracking data. To encourage a large number of participants, directions on how to tag or read the tag are given on the official Monarch Watch website: <http://www.monarchwatch.org>. Participants have been able to help answer the following questions related to Monarchs moving across the continent:

- (1) Do they move in specific directions or take certain pathways?
- (2) How is migration influenced by the weather?
- (3) Are there differences in the migration from year to year?

Due to the Monarch's natural beauty and charm, children naturally enjoy engaging in activity with the butterfly (Migration 1999). As a result, this project has served as a popular and successful activity to introduce students to science and have them contribute to a real scientific study.

2.3 K-12 ENGINEERING OUTREACH PROGRAM

The college of engineering at the University of Wisconsin at Madison initiated a program that benefited students, from kindergarten to the twelfth grade (K-12), within local school districts. Engineering undergraduates visited classrooms to familiarize the students with the major influences that professional engineers have placed on society. While producing an interesting and challenging science and technology environment for K-12 students, the goal of this project was to "improve K-12 science and engineering literacy, to engage and interest school children and their teachers towards science and technology, and to expose undergraduate students to outreach and to its rewards." This was accomplished by making a variety of presentations to K-12 students (Mission 1999).

Due to the vast difference in attention spans between kindergarten and twelfth grade students, separate presentations were developed for: (1) elementary school students, (2) middle school students, and (3) high school students. The elementary school students were given lectures, which included a large number of experiments and applied activities to capture their attention. Middle school students were exposed to a variety of engineering and science-related technologies. This was accomplished by explaining the engineering concepts behind designing certain structures, such as sidewalks and buildings. Also, many common questions (i.e., how airplanes fly and why the sky is blue) were answered. The high school students were encouraged to discuss science and technology theories while also exploring career and educational options. To optimize the effectiveness of these presentations, a general format was specifically designed for each age group (Mission 1999).

Typically, two or three presenters visited schools within a thirty-five mile radius of the university, making three or more consecutive presentations per day. To

help demonstrate that the science and technology field is open to anybody who is interested, the teams included men, women, minorities, and international students. The presentations usually lasted thirty to forty-five minutes, depending on the age group.

The program was deemed successful based on the benefits to the participants. Science teachers were familiarized with new science and technology research, while exploring new ideas for hands-on projects and classroom discussions. The undergraduates gained beneficial public speaking skills, while the K-12 students had the opportunity to observe the undergraduates as role models by listening and acknowledging the benefits of studying science and mathematics.

2.4 WISCONSIN INITIATIVE FOR SPACE EDUCATION (WISE)

The Wisconsin Initiative for Space Education (WISE) was developed at the University of Wisconsin's Space and Engineering Science Center in response to the need for an organized program devoted to K-12 education and public outreach. Studies at the federal and state level have shown that teaching expertise and learning standards for K-12 students have been lacking in the space-related physical sciences. To alleviate these problems, the WISE program sent representatives to the local schools (Mission 1998).

WISE members visited schools, initiating programs, such as the Mars Exploration Curriculum, as well as several teacher seminars to spark interest in the space science and technology field. The Mars Exploration Curriculum involved spending four to five hours a week during the school year with fourth and fifth grade classes exploring the concept of Mars exploration (Mission 1998). While considering the basic environmental conditions for human survival, the students investigated and

discussed ideas of human exploration and habitation of Mars. Ultimately, several presentations were given, with the intention of expanding the project to several other schools in the immediate area. As students benefited from the opportunities provided by the WISE program, teachers also gained by participating in the programs which offered unique exposure into the space science and technology field.

With help from the School of Education, WISE developed proposals, which funded two, one-week workshops. With help from WISE representatives, the workshops supported professional development opportunities for teachers to learn new techniques to educate students in the space-related sciences. While serving as a resource in space science education, the programs offered by WISE successfully initiated partnerships between undergraduate students, teachers, and space scientists, improving the quality of math and physical science instruction.

CHAPTER 3

CLASSROOM LABORATORIES

3.0 GENERAL

This chapter describes civil engineering-based experiments that can be performed in public school classrooms. Each experiment includes three basic items: (1) a brief introduction into the background of the experiment, for the graduate student who will conduct the class, (2) recommended methods of instruction, and (3) a summary of the materials and procedure required for the experiment. Several experiments include worksheets, to be used as homework problems or for classroom discussion, which include background information relating to the experiment. In some cases, equation worksheets and practice problems for the students are also included. Six experiments are described below:

1. Corrosion Laboratory

- Explains the process of corrosion and how it relates to the rusting of reinforcing steel (rebar) in concrete while becoming familiar with chemical formulas and the electrolysis of water.

2. Concrete Mix Design Laboratory

- Demonstrates the differences and similarities between lightweight and normal weight concrete mix designs. Students will have the opportunity to develop their own mixture while determining the effect of the water/cement ratio by varying the amount of water.

3. Graphing With Microsoft Excel

- Promotes an understanding of relationships between variables on a graph and the basic techniques needed to graph values by hand and by using Microsoft Excel

4. Moment of Inertia Experiment

- Illustrates the concept of moment of inertia. Calculation and equation worksheets are included.

5. Calculating End Reactions

- Students should be able to successfully calculate the end reactions of a simply supported beam subjected to point loads. Practice problems are included.

6. Bridge Building Competition

- The students compete with each other to develop a popsicle stick bridge. Using the methods for calculating moment of inertia and end reactions, combined with the opportunity to make decisions considering bridge aesthetics, strength, cost, and weight, this project lets students operate like structural design engineers. The graduate student and head instructor serve as the judges in the competition.

The experiments in this chapter have been used in high school science and mathematics classes (grades 9 – 12), enhancing student interest in civil engineering and in the science and technology, in general.

3.1 CORROSION LABORATORY (2 Class Periods)

EXPERIMENT NUMBER 1

3.1.1 Purpose

Explain the process of corrosion and how it relates to the rusting of reinforcing steel (rebar) in concrete while becoming familiar with chemical formulas and the electrolysis of water.

3.1.2 Introduction

Throughout the world, particularly in areas where road salt is used and high exposure to salty environments exists, corrosion of rebar in concrete annually results in billions of dollars of repairs. The most familiar example of corrosion is the rusting of iron, a complex chemical reaction in which the iron combines with both oxygen and water to form hydrated iron oxide. The problem with iron, as well as many other metals, is that the rust formed by the oxidation reaction does not firmly adhere to the surface of the metal and flakes off easily, which causes pitting. Extensive pitting eventually causes structural weakness and disintegration of the metal.

Corrosion of rebar occurs when chlorides from road salts or seawater penetrate into reinforced concrete. With water present, the chlorides serve as a catalyst, which help transport electrons to complete the iron oxidation, or rusting, process. Not only will corrosion weaken the metal, but rust also occupies more space than the initial metal and leads to cracking and spalling of the concrete.

3.1.3 Corrosion Background

Corrosion is defined as a partial or complete wearing away, dissolving, or softening of any substance by chemical or electrochemical reaction with its environment (Corrosion 2001). The corrosion of iron (and reinforcing steel) occurs as the result of an oxidation-reduction reaction. For an oxidation-reduction reaction to begin, water and oxygen must be present. Oxidation, or the loss of electrons, occurs at the anode producing two electrons and a ferrous ion.

Anode (+)



Meanwhile, a reduction reaction occurs at the cathode. This reaction uses the two electrons produced at the anode, which travel through the iron, plus oxygen and water. As water and oxygen are reduced, or gain electrons, hydroxyl (OH^-) ions are produced (Mindess, Young, and Darwin 2002).

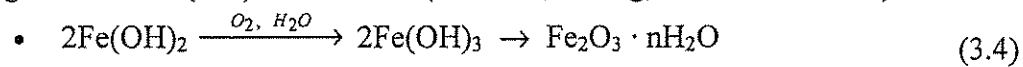
Cathode (-)



To complete the formation of ferrous hydroxide, $\text{Fe}(\text{OH})_2$, the hydroxyl ions migrate back to the anode through the water.



Lastly, the ferrous hydroxide will oxidize in the presence of oxygen and water, creating ferric oxide (rust) at the anode (Mindess, Young, and Darwin 2002).



3.1.4 How This Experiment is Similar to the Process of Corrosion

To demonstrate the process of corrosion this experiment involves the oxidation of iron wire, which occurs during the electrolysis of water. Electrolysis is an electrochemical process by which electrical energy is used to promote chemical reactions that occur at electrodes. In a naturally occurring oxidation-reduction reaction, an electric charge is created when electrons are transferred. This naturally occurring reaction requires a large amount of time before its results can be seen with the naked eye. Therefore, this experiment uses an external battery to increase the rate of reaction by transferring more electrons between two electrodes. The electrodes are inserted in a container filled with an electrolyte solution. Saltwater, a common electrolyte, should be used to promote the exchange of electrons between ions. As a result of electrolysis, water is split into oxygen and hydrogen. The electrode that generates oxygen (anode) will oxidize and form iron oxide (rust) while the other electrode (cathode) will produce hydrogen gas.

Anode (+)



Cathode (-)



As the experiment continues, determining which wires serve as the cathode and the anode is easily accomplished. The volume of hydrogen gas (H_2) produced is twice the volume of oxygen (O_2).



After the experiment continues for roughly one hour, the accelerated version of the naturally occurring process of corrosion is witnessed at the anode. Rust will be developed on the anode once (Fig. 3.1.1):

1. electrons leave the iron atoms at the anode, and migrate through the iron wire (accelerated by the battery), to the cathode;
2. hydroxyl ions produced at the cathode travel through the electrolyte (saltwater) solution, producing ferrous hydroxide at the anode; and
3. ferrous hydroxide molecules oxidize at the anode, producing rust.

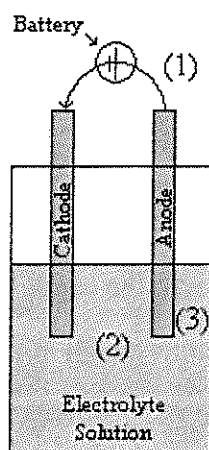


Figure 3.1.1 Electrolysis Diagram

3.1.5 What You Will Need

- 2 – 1.5 ft lengths of insulated steel wiring
- 1 – 12 volt battery
- 1 – 500 mL glass beaker
- 2 – test tubes
- table salt, sodium chloride
- water
- piece of cardboard

3.1.6 Schedule

Day 1: Introduce the process of corrosion. Afterwards, setup and begin laboratory experiment. Students should document observations and any changes that have occurred.

Day 2: Students should document changes and answer the discussion questions.

3.1.7 Procedure

1. Remove two inches of insulation from each length of steel wiring.
2. Cut cardboard to fit over beaker.
3. Push the two wires into the cardboard, roughly two inches apart.
4. Dissolve two teaspoons of salt in the water.
5. Connect one wire to the positive terminal on the battery and the other wire to the negative terminal.
6. Place the free ends of the wires into separate test tubes and insert into the salt-water solution.

3.1.8 Observations

As the electricity from the battery passes through the wires and between the electrodes, the water splits into hydrogen and oxygen, which collect as tiny bubbles around the end of the wires. This also creates an oxidation-reduction reaction and generates a red precipitate (iron oxide) on the positively charged electrode (anode).

3.1.9 Answers to Discussion Questions

1. Does the positive or negative wire generate hydrogen? Why?

- Negative Wire; water is reduced at the cathode (–) from the introduction of electrons at the anode. This reaction produces hydrogen molecules and hydroxyl ions [Eq. (3.6)].

2. What is the red precipitate found at one of the electrodes?

- Rust (Ferric Oxide); it is formed on the anode (+).

3. Recommend methods to separate the hydrogen and oxygen from water at a faster pace.

- Increase the current by increasing the voltage; increase the surface area of the wire (this works by reducing the resistance through the electrolyte); introduce more electrolytes (salt) into the solution.

4. Recommend a method to prevent corrosion in metallic materials.

- Provide a protective coating (epoxy, paint, etc.).

Date: _____ Name: _____

Experiment Number 1 Worksheet

E1.0 CREATING RUST: ELECTROLYSIS OF WATER

E1.1 Purpose

Explain the process of corrosion and how it relates to the rusting of reinforcing steel (rebar) in concrete while becoming familiar with chemical formulas and the electrolysis of water.

E1.2 Introduction

Throughout the world, particularly in areas where road salt is used and high exposure to salty environments exists, corrosion of rebar in concrete annually results in billions of dollars of repairs. The most familiar example of corrosion is the rusting of iron, a complex chemical reaction in which the iron combines with both oxygen and water to form hydrated iron oxide. The problem with iron, as well as many other metals, is that the rust formed by the oxidation reaction does not firmly adhere to the surface of the metal and flakes off easily, which causes pitting. Extensive pitting eventually causes structural weakness and disintegration of the metal.

Corrosion of rebar occurs when chlorides from road salts or seawater penetrate into reinforced concrete. With water present, the chlorides serve as a catalyst, which help transport electrons to complete the iron oxidation, or rusting, process. Not only will corrosion weaken the metal, but rust also occupies more space than the initial metal and leads to cracking and spalling of the concrete.

E1.3 Corrosion Background

Corrosion is defined as a partial or complete wearing away, dissolving, or softening of any substance by chemical or electrochemical reaction with its environment (Corrosion 2001). The corrosion of iron in reinforcing steel occurs as a result of an oxidation-reduction reaction. For an oxidation-reduction reaction to begin, water and oxygen must be present. Oxidation, or the loss of electrons, occurs at the anode producing two electrons and a ferrous ion.

Anode (+)



Meanwhile, a reduction reaction occurs at the cathode. This reaction uses the two electrons produced at the anode, which travel through the iron plus oxygen and water. As water and oxygen are reduced, or gain electrons, hydroxyl (OH^-) ions are produced (Mindess, Young, and Darwin 2002).

Cathode (−)



To complete the formation of ferrous hydroxide, $\text{Fe}(\text{OH})_2$, the hydroxyl ions migrate back to the anode through the water.



Lastly, the ferrous hydroxide will oxidize in the presence of oxygen and water, creating ferric oxide (rust) at the anode (Mindess, Young, and Darwin 2002).



E1.4 How This Experiment is Similar to the Process of Corrosion

To demonstrate the process of corrosion this experiment involves the oxidation of iron wire, which occurs during the electrolysis of water. Electrolysis is an electrochemical process by which electrical energy is used to promote chemical reactions that occur at electrodes. In a naturally occurring oxidation-reduction reaction, an electric charge is created when electrons are transferred. This naturally occurring reaction requires a large amount of time before its results can be seen with the naked eye. Therefore, this experiment uses an external battery to increase the rate of reaction by transferring more electrons between two electrodes. The electrodes are inserted in a container filled with an electrolyte solution. Saltwater, a common electrolyte, should be used to promote the exchange of electrons between ions. As a result of electrolysis, water is split into oxygen and hydrogen. The electrode that generates oxygen (anode) will oxidize and form iron oxide (rust) while the other electrode (cathode) will produce hydrogen gas.

Anode (+)



Cathode (-)



As the experiment continues, determining which wires serve as the cathode and the anode is easily accomplished. The volume of hydrogen gas (H_2) produced is twice the volume of oxygen (O_2).



After the experiment continues for roughly one hour, the accelerated version of the naturally occurring process of corrosion is witnessed at the anode. Rust will be developed on the anode once (Fig. E1.1):

1. electrons leave the iron atoms at the anode, and migrate through the iron wire (accelerated by the battery), to the cathode;
2. hydroxyl ions produced at the cathode travel through the electrolyte (saltwater) solution, producing ferrous hydroxide at the anode; and
3. ferrous hydroxide molecules oxidize at the anode, producing rust.

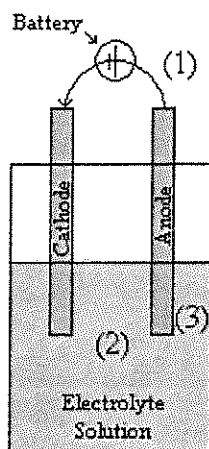


Figure E1.1 Electrolysis Diagram

E1.5 What You Will Need

- 2 – 1.5 ft lengths of insulated steel wiring
- 1 – 12 volt battery
- 1 – 500 mL glass beaker
- 2 – test tubes
- table salt, sodium chloride
- water
- piece of cardboard

E1.6 Procedure

1. Remove two inches of insulation from each length of steel wiring.
2. Cut cardboard to fit over beaker.
3. Push the two wires into the cardboard, roughly two inches apart.
4. Dissolve two teaspoons of salt in the water.
5. Connect one wire to the positive terminal on the battery and the other wire to the negative terminal.
6. Place the free ends of the wires into separate test tubes and insert into the salt-water solution.

E1.7 Discussion Questions

1. Does the positive or negative wire generate hydrogen? Why?

2. What is the red precipitate found at one of the electrodes?

3. Recommend methods to separate the hydrogen and oxygen from water at a faster pace.

1) _____

2) _____

4. Recommend a method to prevent corrosion in metallic materials.

3.2 CONCRETE MIX DESIGN EXPERIMENT (2 Class Periods)

EXPERIMENT NUMBER 2

3.2.1 Purpose

To demonstrate the differences and similarities between lightweight and normal weight concrete mix designs. Students will have the opportunity to develop a unique mixture while determining the effects of changing the water/cement ratio.

3.2.2 Introduction

Considered the most widely used construction material in the world, concrete is a heterogeneous mixture used in many different applications. Concrete consists of portland cement, water, fine and coarse aggregates, and a small amount of air. It can be molded into virtually any form or shape and given a variety of surface textures and colors. Concrete is used to construct a wide variety of structures including sidewalks, highways and streets, bridges, dams, large buildings, airports, silos and farm buildings, homes, and even barges and ships. Evidence of the durability of concrete is provided by the existence of structures fabricated by the Romans more than 2000 years ago, which are still standing (Concrete 2001).

Basic concrete mixes are composed of two major items—cement paste and aggregate. Cement paste consists of portland cement, water, and air voids, either intentionally placed or existing as naturally entrapped bubbles. When portland cement is mixed with water, the compounds in cement chemically react with water to form a cementing substance. In properly mixed concrete, each particle of aggregate is completely surrounded by cement paste and fills the spaces between the particles. As the cement paste cures, it hardens and binds the aggregates into a solid mixture. The

aggregate is divided into two different categories: fine and coarse. Fine aggregate (sand) is generally smaller than 4.75 mm (3/16 inches) while coarse aggregate (gravel or crushed stone) is larger.

Depending on the type of application, concrete can be mixed in two forms: normal weight and lightweight. The primary difference between the two types of concrete is the type of aggregate. Normal weight concrete includes sand and gravel in its mixtures whereas lightweight concrete includes lightweight aggregate (e.g., expanded shale). Normal weight concrete is normally used as a structural material whereas lightweight concrete is used in aerated concrete blocks and panels, sound and thermal insulation, and in structures with lower compressive strength (although high-strength lightweight concrete can be made).

3.2.3 Background

This experiment requires dividing the class into multiple groups, and allowing each group to create a lightweight and a normal weight concrete mixture. Each group is given the same quantity of aggregate and cement, varying the water/cement ratio (between 0.35 and 0.5). Be sure that each group has been assigned a different water/cement ratio. This is done to demonstrate that altering the water/cement ratio will have a significant impact on the final strength (higher water/cement ratio yields lower strength). The concrete should be tested after the mixture has cured enough to develop strength (5 days). Refer to Section 3.2.4 for a summary of the testing procedure.

Once the specimens have been made, one will find that the lightweight sample actually floats on water! This occurs because the density of the lightweight concrete is less than that of water. Once both normal and lightweight samples have been tested

for compressive strength, the class can discuss the effect of the water/cement ratio on strength. Afterwards, the data from the laboratory can be used in Lab Number Three: Graphing with Microsoft Excel.

3.2.4 Testing

After concrete properly cures for twenty-eight days, most of the strength gain that can occur will have occurred. Following the twenty-eight day curing period, concrete will continue to hydrate and get stronger, provided sufficient moisture is available. In fact, the concrete in the center of Hoover Dam is expected to still be curing, slowly gaining in strength! Due to the early strength development in concrete, compressive tests are typically performed after seven and twenty-eight days.

For example, at a construction site, a seven-day test would give the engineer an opportunity to determine if the strength of the concrete is developing as expected. The seven-day test is extremely useful because it indicates whether the concrete will meet the design strength. The twenty-eight day test will prove to the engineer if the concrete has reached the design strength. Compressive tests are rarely performed after twenty-eight days if the design strength has been reached.

The specimens in this laboratory should be tested, using a certified concrete compression machine, no earlier than five days after the start of curing. The test will determine the maximum force each sample can support. Students can use the data to observe the effects on strength by changing the water/cement ratio and using lightweight and normal weight aggregates.

3.2.5 What You Will Need (Per Group)

- 1 – empty 5 gallon bucket
- 2 – thin plastic cups (volume of each cup should be approximately 1 pint \approx 30.0 cm³)
- 1 mixing spoon
- 1 weighing scale
- Normal Weight Mixture
 - 450 grams of sand
 - 500 grams of 1/4-inch gravel (normal weight aggregate)
 - 350 grams of Portland Cement
- Lightweight Mixture
 - 200 grams of perlite (lightweight aggregate)
 - 460 grams of Portland Cement

3.5.6 Schedule

Day 1: Summarize the characteristics of lightweight and normal weight concrete. Afterwards, students should be divided into groups and develop the two concrete mixtures.

Day 2 – 5: Concrete should cure in a water bath.

Day 6: Test the concrete samples for compressive strength.

Day 7: Discuss the test results with the students and summarize the effect of changing the water/cement ratio. Give the students an opportunity to answer the discussion questions provided in this write-up.

3.2.7 Procedure

1. Assign each group a different water/cement ratio (between 0.35 and 0.5)
2. Record the weight and volume of the thin plastic cup.
3. Calculate the mass of water needed.

$$(w/c \text{ ratio}) \text{ mass cement} = \text{mass water}$$

4. Mix water and cement in the bucket until a paste is formed.
5. While mixing, slowly add all of the measured normal weight aggregate (sand and gravel).
6. Completely fill the empty thin plastic cups with the concrete and smooth the top, to give a surface that is even along the lip of the cup.
7. Weigh the thin plastic cup filled with the final mixture.
8. Rinse the bucket.
9. Fill out the laboratory worksheet.
10. Repeat Steps 2-8 and add lightweight aggregate (perlite) instead of normal weight aggregate in Step 5.

3.2.8 Observations

Both concrete mixes will begin to set and harden shortly after adding all of the ingredients. The lightweight concrete will be considerably lighter than the normal weight concrete.

3.2.9 Summary

Once the concrete cures for five days, compressive tests can be performed. Use the compressive strength data to explain the relationship between the water/cement ratio and the strength of the normal weight and lightweight mixtures.

3.2.10 Answers To Discussion Questions

1. Does the lightweight concrete float in water? Why?

- The lightweight concrete floats because its density is less than the density of water.

2. What effect does the water/cement ratio have on the final strength of concrete?

- The strength of the concrete decreases as the water/cement ratio increases.

3. Why is the lightweight concrete weaker than the normal weight concrete?

- Since the water/cement ratio was the same, the major factor in the concrete strength was the aggregate. The aggregate within the lightweight concrete (perlite) is weaker than the normal weight aggregate (gravel).

Date: _____ Name: _____

Experiment Number 2 Worksheet

E2.0 CONCRETE MIX DESIGN EXPERIMENT

E2.1 Purpose

To demonstrate the differences and similarities between lightweight and normal weight concrete mix designs. Students will have the opportunity to develop a unique mixture while determining the effects of changing the water/cement ratio.

E2.2 Introduction

Considered the most widely used construction material in the world, concrete is a heterogeneous mixture used in many different applications. Concrete consists of portland cement, water, fine and coarse aggregates, and a small amount of air. It can be molded into virtually any form or shape and given a variety of surface textures and colors. Concrete is used to construct a wide variety of structures including sidewalks, highways and streets, bridges, dams, large buildings, airports, silos and farm buildings, homes, and even barges and ships. Evidence of the durability of concrete is provided by the existence of structures fabricated by the Romans more than 2000 years ago, which are still standing (Concrete 2001).

Basic concrete mixes are composed of two major items—cement paste and aggregate. Cement paste consists of portland cement, water, and air voids, either intentionally placed or existing as naturally entrapped bubbles. When portland cement is mixed with water, the compounds in cement chemically react with water to form a cementing substance. In properly mixed concrete, each particle of aggregate is

completely surrounded by cement paste and fills the spaces between the particles. As the cement paste cures, it hardens and binds the aggregates into a solid mixture. The aggregate is divided into two different categories: fine and coarse. Fine aggregate (sand) is generally smaller than 4.75 mm (3/16 inches) while coarse aggregate (gravel or crushed stone) is larger.

Depending on the type of application, concrete can be mixed in two forms: normal weight and lightweight. The primary difference between the two types of concrete is the type of aggregate. Normal weight concrete includes sand and gravel in its mixtures whereas lightweight concrete includes lightweight aggregate (e.g., expanded shale). Normal weight concrete is normally used as a structural material whereas lightweight concrete is used in aerated concrete blocks and panels, sound and thermal insulation, and in structures with lower compressive strength (although high-strength lightweight concrete can be made).

Depending on the type of application concrete exists in two forms: normal weight and lightweight.

1. Normal Weight Concrete

- approximate mass: 2.32 g/cm^3 (145 lb/ft^3)
- uses normal weight aggregate (e.g., gravel and sand)

2. Lightweight Concrete

- approximate mass: 1.68 g/cm^3 (105 lb/ft^3)
- uses light-weight aggregate (e.g., expanded shale and perlite)
- will float in water

Normal weight concrete is normally used as a structural material whereas lightweight concrete is used in aerated concrete blocks and panels, sound and thermal insulation, and in structures with low compressive strength.

E2.3 Background

This experiment requires dividing the class into multiple groups, and allowing each group to create a lightweight and a normal weight concrete mixture. Each group will be given the same quantity of aggregate and cement, varying the water/cement ratio (between 0.35 and 0.5). Make sure that your group has been assigned a different water/cement ratio than the others. This is done to demonstrate that altering the water/cement ratio will have a significant impact on the final strength (higher water/cement ratio yields lower strength). The concrete should be tested after the mixture has cured enough to develop strength (5 days). Refer to Section E2.4 for a summary of the testing procedure.

Once the specimens have been made, one will find that the lightweight sample actually floats on water! This occurs because the density of the lightweight concrete is less than that of water. Once both normal and lightweight samples have been tested for compressive strength, the class can discuss the effect of the water/cement ratio on strength. Afterwards, the data from the laboratory can be used in Lab Number Three: Graphing with Microsoft Excel.

E2.4 Testing

After concrete properly cures for twenty-eight days, most of the strength gain that can occur will have occurred. Following the twenty-eight day curing period, concrete will continue to hydrate and get stronger, provided sufficient moisture is available. In fact, the concrete in the center of Hoover Dam is expected to still be curing, slowly gaining in strength! Due to the early strength development in concrete, compressive tests are typically performed after seven and twenty-eight days.

For example, at a construction site, a seven-day test would give the engineer an opportunity to determine if the strength of the concrete is developing as expected. The seven-day test is extremely useful because it indicates whether the concrete will meet the design strength. The twenty-eight day test will prove to the engineer if the concrete has reached the design strength. Compressive tests are rarely performed after twenty-eight days if the design strength has been reached.

The specimens in this laboratory should be tested, using a certified concrete compression machine, no earlier than five days after the start of curing. The test will determine the maximum force each sample can support. Students can use the data to observe the effects on strength by changing the water/cement ratio and using lightweight and normal weight aggregates.

E2.5 What You Will Need (Per Group)

- 1 – empty 5 gallon bucket
- 2 – thin plastic cups (volume of each cup should be approximately 1 pint \approx 30.0 cm³)
- 1 mixing spoon
- 1 weighing scale
- Normal Weight Mixture
 - 450 grams of sand
 - 500 grams of 1/4-inch gravel (normal weight aggregate)
 - 350 grams of Portland Cement
- Lightweight Mixture
 - 200 grams of perlite (lightweight aggregate)
 - 460 grams of Portland Cement

E2.6 Procedure

1. Ask for your assigned water/cement ratio (between 0.35 and 0.5)
2. Record the weight and volume of the thin plastic cup.
3. Calculate the mass of water needed.

$$(w/c \text{ ratio}) \text{ mass cement} = \text{mass water}$$

4. Mix water and cement in the bucket until a paste is formed.
5. While mixing, slowly add all of the measured normal weight aggregate (sand and gravel).
6. Completely fill the empty thin plastic cups with the concrete and smooth the top, to give a surface that is even along the lip of the cup.
7. Weigh the thin plastic cup filled with the final mixture.
8. Rinse the bucket.
9. Fill out the laboratory worksheet.
10. Repeat Steps 2-8 and add lightweight aggregate (perlite) instead of normal weight aggregate in Step 5.

Table E2.1 Unit Weight Values

	Volume of Cup (cm ³) *	Unit Weight (g/cm ³) **
Normal Weight Concrete		
Lightweight Concrete		

Table E2.2 Concrete Mixture Specifications

		Wt. of Cup	Wt. of Cement	Wt. of Water	w/c Ratio	Wt. of Sand	Wt. of Rocks	Wt. of Filled Cup
Normal Weight	<i>pounds</i>							
	<i>grams</i>							
Light- Weight	<i>pounds</i>							
	<i>grams</i>							

$$\text{Vol. of Cup (cm}^3\text{)} = \frac{(\text{Mass of Filled Cup (g)}) - (\text{Mass of Cup (g)})}{1 \frac{\text{g}}{\text{cm}^3}} \quad (\text{E2.1})$$

$$\text{Unit Wt. } \left(\frac{\text{g}}{\text{cm}^3} \right) = \frac{(\text{Mass of Filled Cup (g)}) - (\text{Mass of Cup (g)})}{\text{Volume of Cup (cm}^3\text{)}} \quad (\text{E2.2})$$

* The volume of the cup can be found using Eq. (E2.1), which considers the density, or unit weight of water, 1 g/cm³ (62.4 lb/ft³), and the mass of the plastic cup--empty and filled with water.

** The density, or unit weight, of concrete can be found using Eq. (E2.2).

Table E2.3 Compressive Strength Values

	Pressure (lbs/in ²)	Maximum Force (N)	Maximum Weight (lbs)
Lightweight Concrete			
Normal Weight Concrete			

E2.7 Useful Conversions

- 1 pound = 453.6 grams
- 1 ft³ = 1728 cm³
- $N = kg \cdot 9.81 \frac{m}{s^2}$

E2.8 Discussion Questions

1. Does the lightweight concrete float in water? Why?

2. What effect does the water/cement ratio have on the final strength of concrete?

3. Why is the lightweight concrete weaker than the normal weight concrete?

3.3 GRAPHING WITH MICROSOFT EXCEL (2 Class Periods)

EXPERIMENT NUMBER 3

3.3.1 Purpose

To understand relationships between variables on a graph and to comprehend the basic techniques needed to graph values by hand and by using Microsoft Excel.

3.3.2 Introduction

A graph can be defined as a diagram that illustrates relationships between two variables. Graphs provide a means to display numerical information so that it is possible to see patterns or trends in the relationships between variables. The variables can be classified as being either dependant or independent. The dependent variable will change when influenced by the independent variable, whereas the independent variable is not affected by the dependent variable. If considering a tire factory, a graph could be plotted using the number of tires produced as a reflection of the number of factory workers. In this graph, the number of factory workers would be the independent variable because tire production will not alter the number of workers. Meanwhile, the dependent variable, or the number of tires produced, would depend on the number of people working in the factory. Once these relationships have been established, it is very important to label the graph correctly to avoid confusion.

When labeling the axes on a graph, the independent variable is plotted on the x-axis (horizontal), while the dependent variable is plotted on the y-axis (vertical). When writing the title for a graph, the variable that is plotted on the y-axis (dependant variable) is usually listed first, while the variable that is plotted on the x-axis (independent variable) is listed second.

3.3.3 Background

The class should be equally divided into as many groups as there are computers. Every person will be given a copy of the attached laboratory worksheet and will develop a graph using the given data. The data will illustrate that as the water/cement ratio in concrete increases, the strength of the concrete decreases. Once every student understands the relationship displayed on the graph, the students will replot the graph using Microsoft Excel.

A guide is provided along with the laboratory worksheets to assist while learning to graph with Microsoft Excel. The guide offers pictures with written descriptions for each step needed to correctly plot and label a graph.

3.3.4 What You Will Need (per group)

- 1 – straight edge
- 1 – computer with Microsoft Excel

3.3.5 Schedule

Day 1: Define the purpose of a graph and summarize the purpose of dependent and independent variables. Try graphing without the assistance of a computer.

Day 2: Graph with Microsoft Excel.

3.3.6 Procedure

1. By hand, plot a graph based on the values of the variables listed on the laboratory worksheet.
2. Identify the relationship.
3. Plot the same graph using Microsoft Excel.
4. Explore the program and have some fun!

3.3.7 Summary

Both graphs should demonstrate that concrete strength increases as the water/cement ratio decreases. After developing the graphs, it is apparent that an inverse relationship exists between the two variables.

3.3.8 Answer to Discussion Questions

1. **Should the first or second variable in the graph title be placed on the x-axis?**
 - The second variable in the graph title is placed on the x-axis
2. **If the water/cement ratio in concrete is increased, what happens to the strength of the concrete?**
 - The strength of the concrete will decrease if the water/cement ratio is increased.
3. **What window will the Chart Wizard button bring up when pressed?**
 - When the Chart Wizard button is pressed, a window will appear requesting the user to choose a chart type.

4. What other kinds of graphs can be created in Microsoft Excel?

- Other kinds of graphs Microsoft Excel can create can be viewed in the Chart Type window—after the Chart Wizard button has been pressed (i.e., Column, Bar, Line, Pie, Area, Doughnut, and Radar graphs).

Date: _____

Name: _____

Experiment Number 3 Worksheet**E3.0 Graphing****E3.1 Purpose**

To understand relationships between variables on a graph and the basic techniques needed to graph values by hand and by using Microsoft Excel.

E3.2 Graphing Background

A graph can be defined as a diagram that illustrates relationships between two variables. Graphs provide a means to display numerical information so that it is possible to see patterns or trends in the relationships between variables. The variables can be classified as being either dependant or independent. The dependent variable will change when influenced by the independent variable, whereas the independent variable is not affected by the dependent variable. If considering a tire factory, a graph could be plotted using the number of tires produced as a reflection of the number of factory workers. In this graph, the number of factory workers would be the independent variable because tire production will not alter the number of workers. Meanwhile, the dependent variable, or the number of tires produced, would depend on the number of people working in the factory. Once these relationships have been established, it is very important to label the graph correctly to avoid confusion.

When labeling the axes on a graph, the independent variable is plotted on the x-axis (horizontal), while the dependent variable is plotted on the y-axis (vertical). When writing the title for a graph, the variable that is plotted on the y-axis (dependant

variable) is usually listed first, while the variable that is plotted on the x-axis (independent variable) is listed second. For example, in the following case,

- *Number of Tires Produced* \Rightarrow *y-axis (dependent variable)*
- *Number of Factory Workers* \Rightarrow *x-axis (independent variable)*

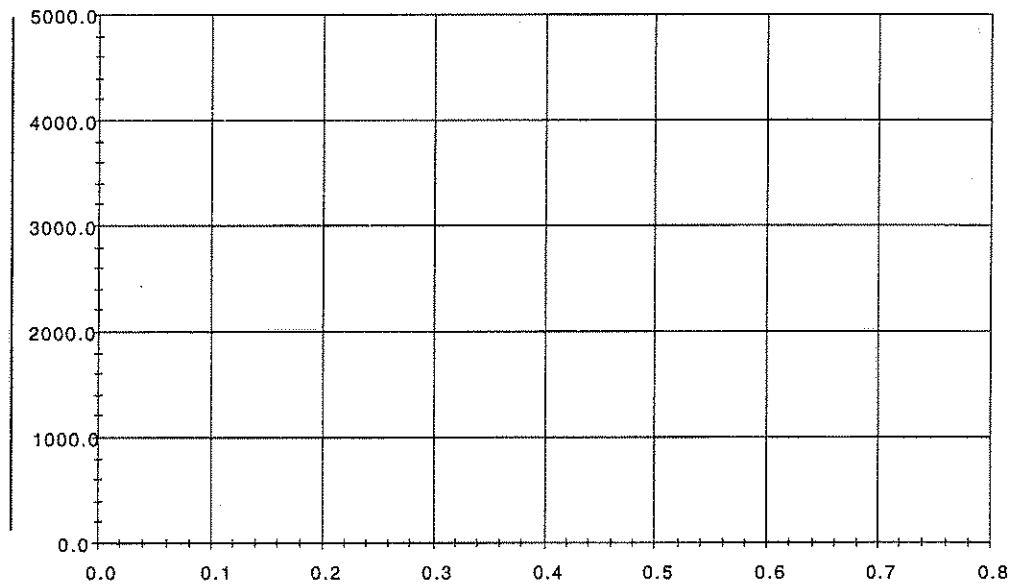
the title of the graph would be “The Number of Tires Produced vs. The Number Factory Workers”:

E3.3 Sample Graph

On the next page, plot a graph using the provided water/cement ratio and concrete strength values (Scientific 2000).

Water/Cement Ratio**Concrete Strength**

0.40	4100
0.45	3800
0.50	3300
0.55	3000
0.60	2800
0.65	2700
0.70	2650



E3.4 Graphing with Microsoft Excel

To create a graph using Microsoft Excel, please use the instruction guide on the following page.

E3.5 Discussion Questions

1. Which variable in the title should be placed on the x-axis?

2. If the water/cement ratio in concrete is increased, what happens to the strength of the concrete?

3. What window will the Chart Wizard button bring up when pressed?

4. What other kinds of graphs can be created in Microsoft Excel?

E3.6 How to Graph Using Microsoft Excel

1. Enter data to be graphed in two columns.

Microsoft Excel - Book1

File Edit View Insert Format Tools Data Window Help

Arial 10 B I U

C29 =

	A	B	C	D	E	F
1	0.4	4100				
2	0.45	3600				
3	0.5	3300				
4	0.55	3000				
5	0.6	2800				
6	0.65	2700				
7	0.7	2650				
8						

2. Highlight the data in both columns.

Microsoft Excel - Book1

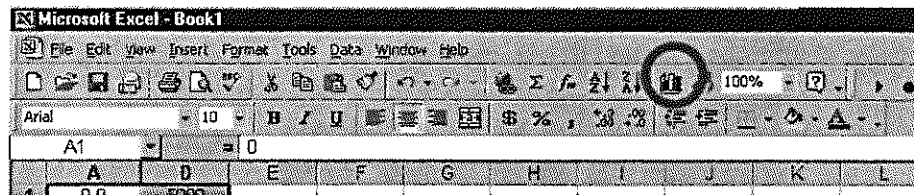
File Edit View Insert Format Tools Data Window Help

Times New Roman 12 B I U

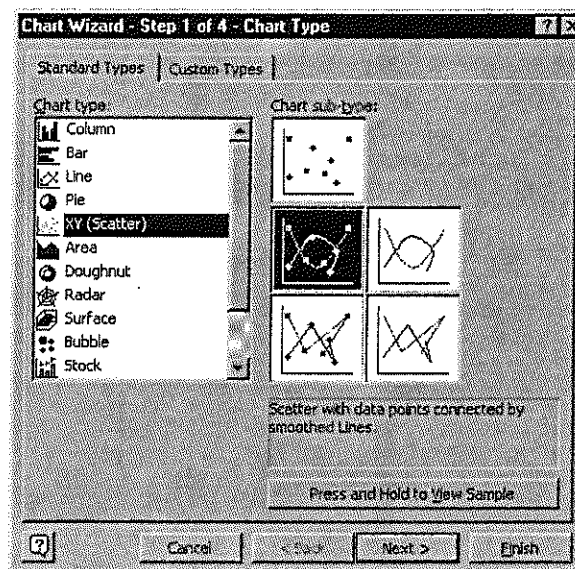
A1 = 0.4

	A	B	C	D	E	F
1	0.4	4100				
2	0.45	3600				
3	0.5	3300				
4	0.55	3000				
5	0.6	2800				
6	0.65	2700				
7	0.7	2650				
8						

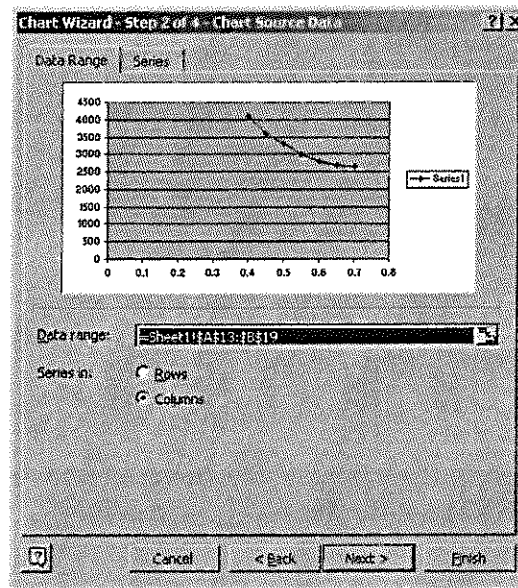
3. Click on the "Chart Wizard" button.



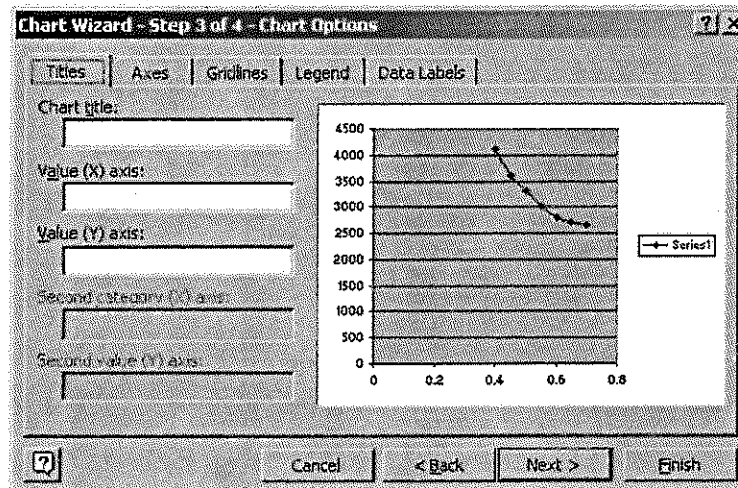
4. Select X-Y Scatter Plot on menu and click "Next."



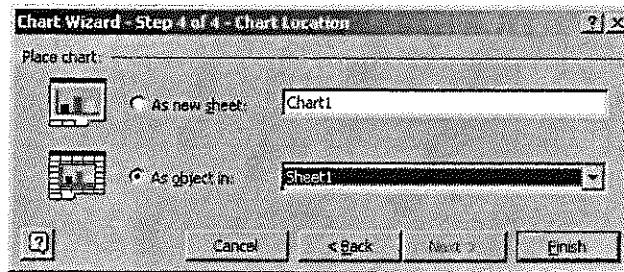
5. Compare the chart below with the one on your screen. If they look similar, click “Next.”



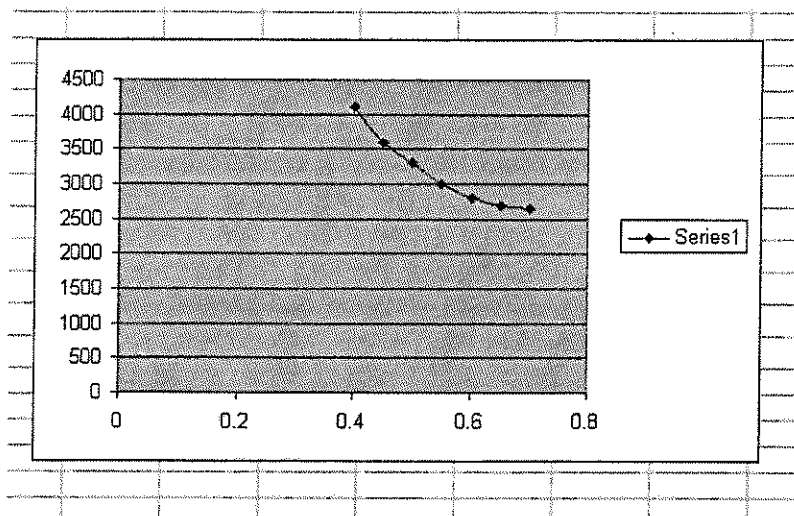
6. Fill in the chart title and titles of the x and y-axes and click, “Next.”



7. Click on, "Finish."



8. Graph should look like this (with correct titles):



3.4 MOMENT OF INERTIA EXPERIMENT (2 Class Periods)

EXPERIMENT NUMBER 4

3.4.1 Purpose

This experiment illustrates the concept of moment of inertia. This laboratory should be completed, along with an introduction to bending moment (Experiment Number Five), to prepare the students for the bridge building competition (Experiment Number Six).

3.4.2 Introduction

Moment of inertia represents the ability of an object to resist bending about an axis. This concept is best demonstrated by examining a 2x4 that spans between two supports (Fig 3.4.1), with a load placed at midspan.

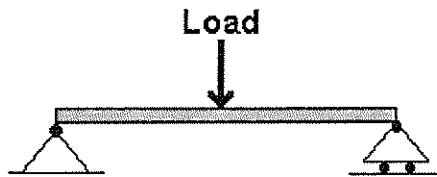


Figure 3.4.1 Beam Loaded at Midspan

To limit bending deflection, the most efficient way to place the 2x4 would be on edge so the load is parallel to the wider portion of the cross-section (Fig. 3.2a). Under this condition, the compression and tension forces are largest at the top and bottom of the beam. Therefore, parallel to the load, if more of the object's mass is placed farther from the neutral axis, the harder it is to bend the 2x4 (Measurement 1998). The quantitative method for measuring resistance to bending is known as

moment of inertia. If two cross-sections are examined, the specimen with the higher moment of inertia is harder to bend. Figures 3.4.2 (a) and (b) help to demonstrate the concept of moment of inertia.

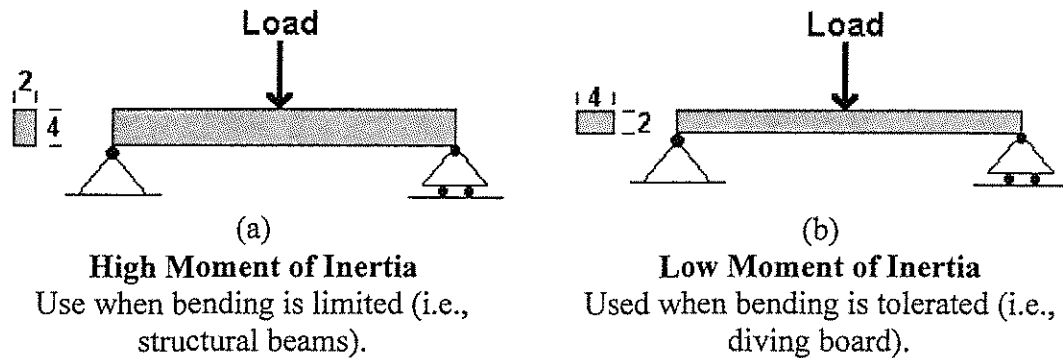


Figure 3.4.2 Effect of Beam Orientation on Moment of Inertia

3.4.3 Background

Moment of inertia is best introduced by bending beams with significantly different cross sections (i.e., a wooden yardstick and a three foot long 2x4). Using these members will give the students a feeling for the resistance to bending, or the moment of inertia, associated with a cross section. Once every student has had the opportunity to get a feeling for the moment of inertia of the samples, a simple voting process should be used to rank the bending resistance of the beams. Afterwards, the ballot results can be justified by calculating the moments of inertia for each sample using the equations on the laboratory worksheet.

Using the equations will demonstrate the accuracy of the ballot results while helping the students improve their math skills. A list of equations for the moment of inertia of common shapes is attached to the worksheet.

3.4.4 What You Will Need

- 1 – moment of inertia equation sheet (per student)
- 1 – yardstick
- 1 – three foot long 2x4

3.4.5 Schedule

Day 1: Introduce moment of inertia while letting the students try bending objects with different cross-sections. Introduce moment of inertia equations and practice calculating bending resistance for different common cross-sections.

Day 2: Review the problems on the moment of inertia worksheet.

3.4.6 Procedure

(Day One)

1. Let the students experiment with the two “beams.”
2. Have the students vote on the cross section that is the hardest and easiest to bend.
3. Introduce the moment of inertia equations and have the students calculate the moments of inertia after measuring the dimensions of the yardstick and 2x4.
4. Compare the calculated results with the rankings obtained earlier by the students. Were the assumptions about the moments of inertia correct? Justify why their assumptions were correct or incorrect and allow the

students to retest their theories. Afterwards, allow the students to solve the worksheet problems.

(Day Two)

5. Review worksheet solutions with students.

3.4.7 Observations

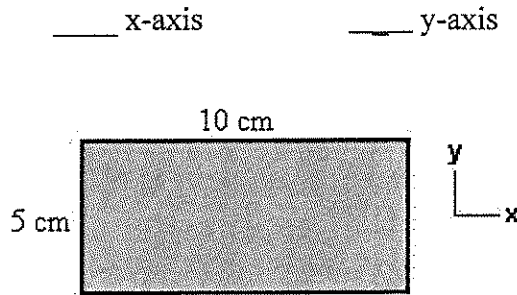
Students should become familiar with the concept of moment of inertia.

3.4.8 Summary

Students should be able to grasp the meaning of moment of inertia and know which shapes will have the most resistance to bending. This experiment should also help students recognize that members deeper in the direction parallel to the load will be able to provide more resistance to bending. This concept should be reemphasized during the design process of the bridge building competition (Experiment Number Six).

3.4.8 Worksheet Solutions

- 1) Guess if bending about the x-axis or y-axis produces the greater resistance. Then, calculate the moment of inertia for each axis to see if your assumption is correct.



** Bending about the y-axis will provide more resistance because the shape is deeper in that direction.

$$I_x = \frac{1}{12} b h^3$$

$$I_y = \frac{1}{12} b h^3$$

$$I_x = \frac{1}{12} (10 \text{ cm})(5 \text{ cm})^3$$

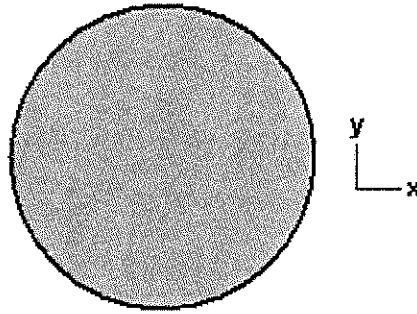
$$I_y = \frac{1}{12} (5 \text{ cm})(10 \text{ cm})^3$$

$$I_x = 104.17 \text{ cm}^4$$

$$I_y = 416.67 \text{ cm}^4$$

- 2) Calculate the moment of inertia for each axis. Will there be a difference between the axes?

** The inertia values will not be different, due to the symmetrical geometry.



Diameter = 20 cm

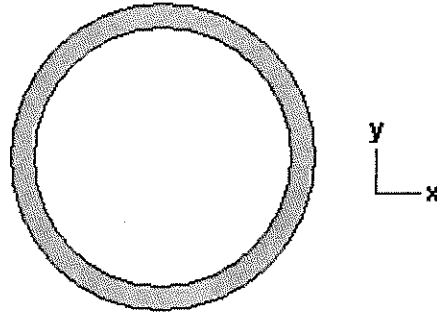
$$I_x = I_y = \frac{1}{4} \pi r^4$$

$$I_x = I_y = \frac{1}{4} (\pi) (10 \text{ cm})^4$$

$$I_x = I_y = 7853.98 \text{ cm}^4$$

Please STOP Here Until Everyone has Caught Up

3) Calculate the moment of inertia for this shape.



Diameter = 20 cm
Thickness = 2 cm

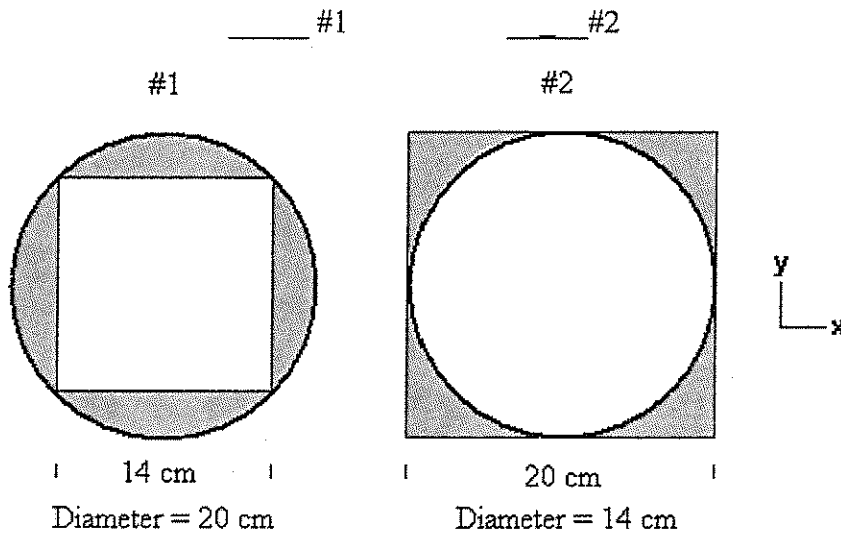
$$I_x = I_y = I_{\text{solid circle}} - I_{\text{inner circle}}$$

$$I_x = I_y = \frac{1}{4}(\pi)(10 \text{ cm})^4 - \frac{1}{4}(\pi)(8 \text{ cm})^4$$

$$I_x = I_y = 7853.98 \text{ cm}^4 - 3216.99 \text{ cm}^4$$

$$I_x = I_y = 4636.99 \text{ cm}^4$$

- 4) Please guess and place a checkmark on which shape (#1 or #2) possesses a greater resistance (higher moment of inertia) to bending. Then calculate the moment of inertia for each shape.



** Shape #2 will encounter more resistance because the shape is deeper in the axis parallel to the load.

#1

#2

$$\bullet \quad I_x = I_y = I_{\text{solid circle}} - I_{\text{inner square}}$$

$$\bullet \quad I_x = I_y = \frac{1}{4}\pi \cdot (10 \text{ cm})^4 - \frac{1}{12}(14 \text{ cm})(14 \text{ cm})^3$$

$$\bullet \quad I_x = I_y = 7853.98 \text{ cm}^4 - 3201.33 \text{ cm}^4$$

$$I_x = I_y = 4652.65 \text{ cm}^4$$

$$\bullet \quad I_x = I_y = I_{\text{solid square}} - I_{\text{inner circle}}$$

$$\bullet \quad I_x = I_y = \frac{1}{12}(20 \text{ cm})(20 \text{ cm})^3 - \frac{1}{4}\pi \cdot (7 \text{ cm})^4$$

$$\bullet \quad I_x = I_y = 13333.33 \text{ cm}^4 - 7853.90 \text{ cm}^4$$

$$I_x = I_y = 5479.35 \text{ cm}^4$$

Date: _____

Name: _____

Experiment Number 4 Worksheet**E4.0 Moment of Inertia****E4.1 Purpose**

This experiment illustrates the concept of moment of inertia. This laboratory should be completed, along with an introduction to bending moment (Experiment Number Five), to prepare the students for the bridge building competition (Experiment Number Six).

E4.2 Moment of Inertia Background

Moment of inertia represents the ability of an object to resist bending about an axis. This concept is best demonstrated by examining a 2x4 that spans between two supports (Fig E4.1), with a load placed at midspan.

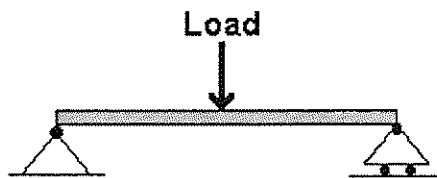


Figure E4.1 Beam Loaded at Midspan

To limit bending deflection, the most efficient way to place the 2x4 would be on edge so the load is parallel to the wider portion of the cross-section (Fig. E4.2a). Under this condition, the compression and tension forces are largest at the top and

bottom of the beam. Therefore, parallel to the load, if more of the material is placed farther from the neutral axis, the harder it is to bend the 2x4. The quantitative method for measuring resistance to bending is known as moment of inertia. If two cross-sections are examined, the specimen with the higher moment of inertia is harder to bend. Figures E4.2 a and b help to demonstrate the concept of moment of inertia.

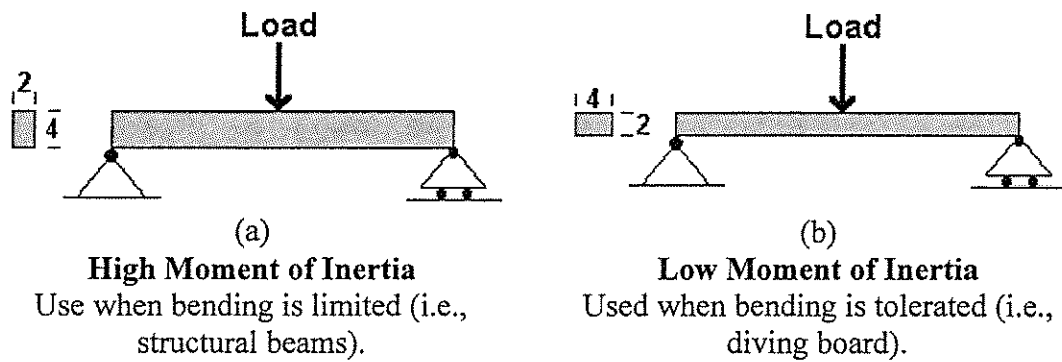
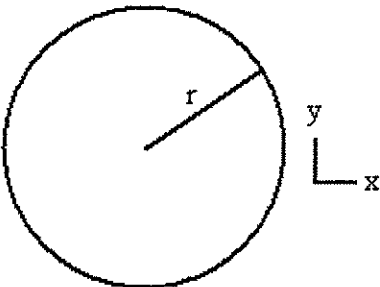
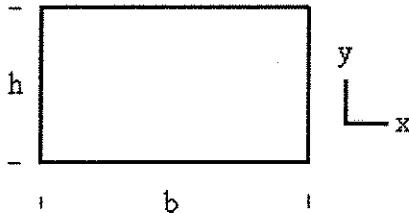
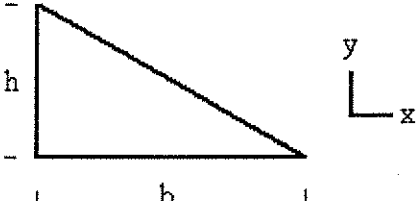
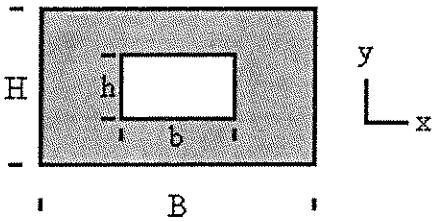


Figure E4.2 Effect of Beam Orientation on Moment of Inertia

E4.3 Moment of Inertia Equations

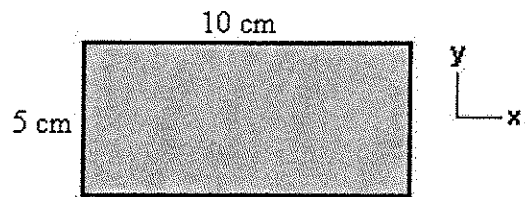
<p style="text-align: center;">Circle</p>  $I_x = I_y = \frac{1}{4} \pi \cdot r^4$	<p style="text-align: center;"><i>Square/Rectangle</i></p>  $I_x = \frac{1}{12} b \cdot h^3 \quad I_y = \frac{1}{12} h \cdot b^3$
<p style="text-align: center;">Triangle</p>  $I_x = \frac{1}{36} b \cdot h^3 \quad I_y = \frac{1}{36} h \cdot b^3$	<p style="text-align: center;">Special Condition</p>  $I_x = (\text{outer rect.}) - (\text{inner rect.})$ $I_x = \left(\frac{1}{12} B \cdot H^3 \right) - \left(\frac{1}{12} b \cdot h^3 \right)$ <p>(solution for x axis; for y-axis, just switch variables)</p>

E4.4 Moment of Inertia Questions

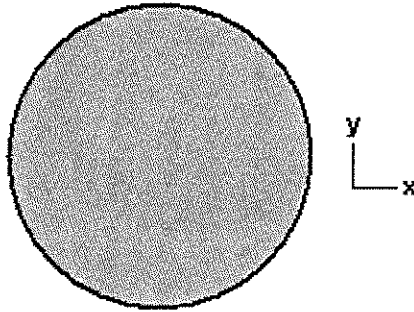
- 1) Guess if bending about the x-axis or y-axis produces the greater resistance. Then, calculate the moment of inertia for each axis to see if your assumption is correct.

____ x-axis

____ y-axis



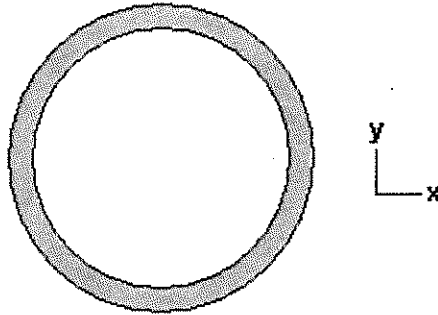
- 2) Calculate the moment of inertia for each axis. Will there be a difference between the axes?



Diameter = 20 cm

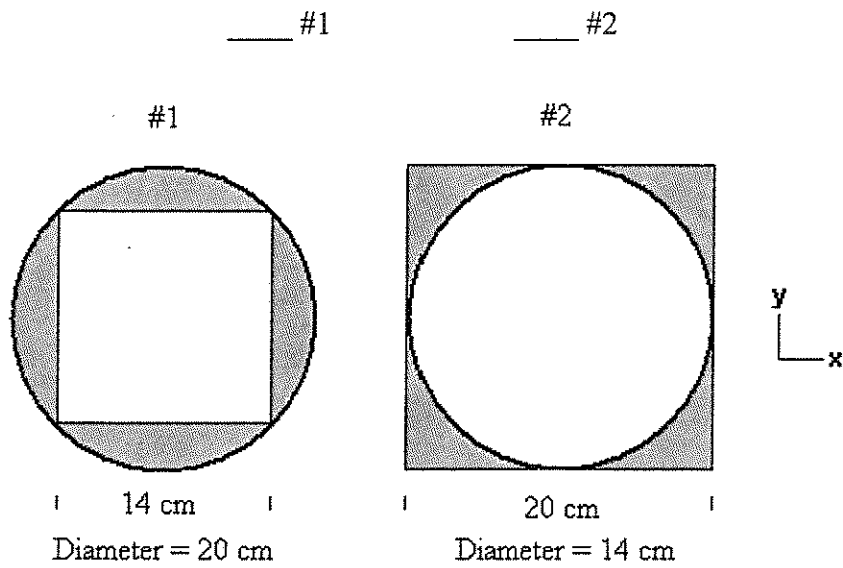
Please STOP Here Until Everyone has Caught Up

- 3) Calculate the moment of inertia for this shape.



Diameter = 20 cm
Thickness = 2 cm

- 4) Guess and place a checkmark on which shape (#1 or #2) possesses a greater resistance (higher moment of inertia) to bending. Then calculate the moment of inertia for each shape.



3.5 CALCULATING END REACTIONS (2 CLASS PERIODS)

EXPERIMENT NUMBER 5

3.5.1 Purpose

To successfully calculate the end reactions of a simply supported beam subjected to point loads perpendicular to the neutral axis.

3.5.2 Introduction

In most highway bridges it is common to find large I-shaped beams supporting the bridge deck. The weight that each I-beam carries is transferred to the bridge columns where opposing forces are exerted to support the beam. These forces are known as end reactions (Fig. 3.5.1).

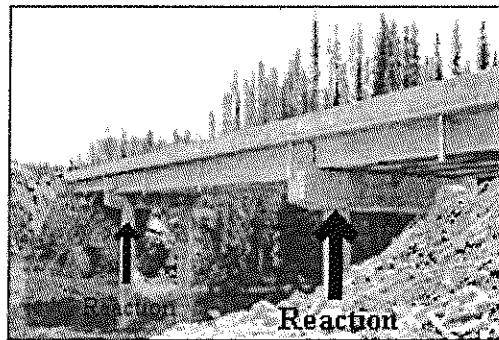


Figure 3.5.1 Bridge Reactions

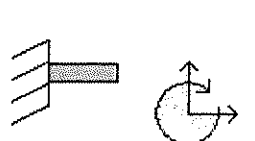


If a vehicle stopped at the center of the beam, the reactions at each end would equal half the weight of the vehicle. Although the reactions from this centrally loaded beam are easy to determine without mathematics, how would the reactions of a beam with more complex loading patterns be found? This experiment will focus on

mathematically determining the end reactions of beams with randomly placed point loads.

3.5.3 Background

To encourage group work and peer instruction, this laboratory works best after dividing the class into groups of four. Afterwards, a brief introduction should be given to summarize the three main types of supports associated with beams: fixed, hinge, and roller.

Table 5.1 Descriptions of the Primary Support Conditions

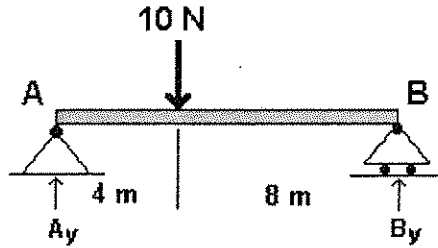
 <p>Fixed</p>	<ul style="list-style-type: none"> • Example: Airplane Wing • This connection will not move in any direction. • Resists: <ol style="list-style-type: none"> 1. Rotation 2. Vertical Movement 3. Horizontal Movement
 <p>Hinge</p>	<ul style="list-style-type: none"> • Example: Door Hinge • This connection has the ability to rotate but will not move in the vertical or horizontal directions. • Resists: <ol style="list-style-type: none"> 1. Vertical Movement 2. Horizontal Movement
 <p>Roller</p>	<ul style="list-style-type: none"> • Example: Car Wheel • This connection will rotate and move from side to side but will not move in the vertical direction. • Resists: <ol style="list-style-type: none"> 1. Vertical Movement

When explaining the purpose of each support condition, it is important not to discount the significance of the fixed support. Although the fixed support is not used

in a simply supported beam, it is a very common support condition and the rotational resistance it provides should be emphasized. Once the explanations of the support conditions have been completed, the students should be ready to learn about calculating the reactions.

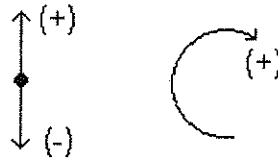
The methods used to determine the end reactions of a simply supported beam are best demonstrated by constructing a beam using two scales and two yardsticks. To avoid excessive deflection, the yardsticks should be stacked upon each other as the ends are placed on the scales. Once completed, the beam should be loaded with objects of known mass. The scales will measure the end reactions and the students can be challenged to calculate the same loads measured by the scales. Since the end supports have the ability to rotate, the resistance to rotation, or moment, at the ends will be equal to zero. Therefore, the end reactions can be found by summing the moments (distance \times load) about one end of the beam. Examples of this technique should be presented to the class prior to students attempting the calculations.

3.5.4 Step-By-Step Instruction to Calculating End Reactions (example)



A_y & B_y = End Reactions

- 1) Pick which end of beam to sum end reactions about (A or B)
 - For this example, we will pick end A.
- 2) Choose which directions the positive axis and moment are orientated.



- 3) Sum the moments about the A end (Moment = length x force).
 - Since the end supports are rollers and hinges, the ends of the beam will rotate. As a result, the moments will be equal to zero.

$$M_A = 0 = B_y(12 \text{ m}) - 10 \text{ N}(4 \text{ m})$$

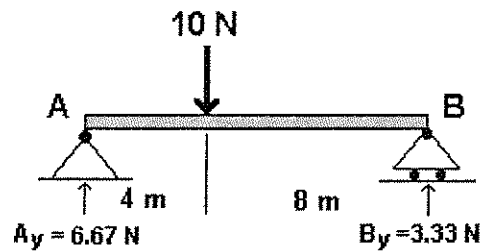
$$B_y = 3.33 \text{ N}$$

4) Sum the vertical forces to determine the end reaction at A_y .

- The sum of forces in the vertical direction (ΣF_y) is equal to zero because the beam is in equilibrium.

$$\Sigma F_y = 0 = 3.33 \text{ N} + A_y - 10 \text{ N}$$

$$A_y = 6.67 \text{ N}$$



A_y & B_y = End Reactions

3.5.5 What You Will Need (per group of four)

- 2 – scales (i.e., triple beam balance)
- 2 – yardsticks
- several objects of known mass

3.5.6 Schedule

Day 1: Introduce support conditions and explain the provided example on solving end reactions. Afterwards, students should calculate the end reactions for three different loading configurations on the yardstick beam.

Day 2: Review the end reaction homework problems.

3.5.7 Procedure

1. Place the yardsticks, using the scales as end supports.
2. Place weights at different locations on the yardstick beam.
3. Calculate the end reactions and compare to the readings on the scales.
4. Repeat this procedure two more times, placing the weights at different locations each time.

3.5.8 Summary

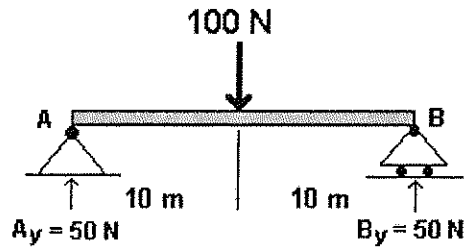
By the end of this laboratory, the students should feel comfortable with calculating end reactions of a simply supported beam.

3.5.9 Answers to Worksheet

Please refer to the attached worksheet solution guide.

3.5.10 Worksheet Solution Guide

- 1) Determine the forces experienced on each support.



Solve for B_y

$$\Sigma M_A = 0$$

$$0 = 100\text{ N} (10\text{ m}) - B_y (20\text{ m})$$

$$B_y (20\text{ m}) = 1000\text{ N} \cdot \text{m}$$

$$B_y = \frac{1000\text{ N} \cdot \text{m}}{20\text{ m}}$$

$$\underline{\underline{B_y = 50.0\text{ N}}}$$

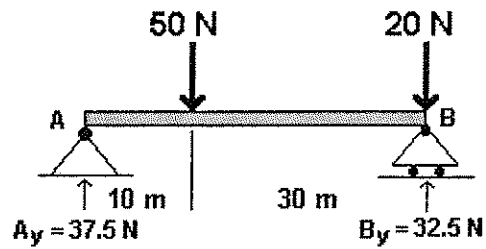
Solve for A_y

$$\Sigma F_y = 0$$

$$0 = A_y - 100\text{ N} + 50.0\text{ N}$$

$$\underline{\underline{A_y = 50.0\text{ N}}}$$

2) Determine the forces experienced on each support.



Solve for B_y

$$\Sigma M_A = 0$$

$$0 = 50 \text{ N} (10 \text{ m}) + 20 \text{ N} (40 \text{ m}) - B_y (40 \text{ m})$$

$$B_y (40 \text{ m}) = (500 \text{ N} \cdot \text{m}) + (800 \text{ N} \cdot \text{m})$$

$$B_y = \frac{1300 \text{ N} \cdot \text{m}}{40 \text{ m}}$$

$$\underline{\underline{B_y = 32.5 \text{ N}}}$$

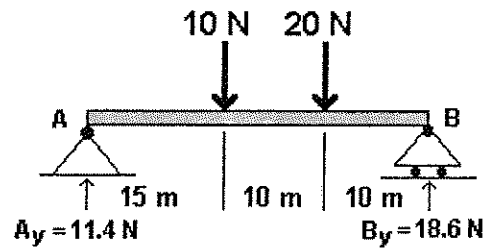
Solve for A_y

$$\Sigma F_y = 0$$

$$0 = A_y - 50 \text{ N} - 20 \text{ N} + 32.5 \text{ N}$$

$$\underline{\underline{A_y = 37.5 \text{ N}}}$$

3) Determine the forces experienced on each support.



Solve for B_y

$$\Sigma M_A = 0$$

$$0 = 10 \text{ N} (15 \text{ m}) + 20 \text{ N} (25 \text{ m}) - B_y (35 \text{ m})$$

$$B_y (35 \text{ m}) = (150 \text{ N} \cdot \text{m}) + (500 \text{ N} \cdot \text{m})$$

$$B_y = \frac{650 \text{ N} \cdot \text{m}}{35 \text{ m}}$$

$$\underline{\underline{B_y = 18.6 \text{ N}}}$$

Solve for A_y

$$\Sigma F_y = 0$$

$$0 = A_y - 10 \text{ N} - 20 \text{ N} + 18.6 \text{ N}$$

$$\underline{\underline{A_y = 11.4 \text{ N}}}$$

Date: _____

Name: _____

Experiment Number 5 Worksheet**E5.0 Solving End Reactions****E5.1 Purpose**

To successfully calculate the end reactions of a simply supported beam subjected to point loads perpendicular to the neutral axis.

E5.2 Introduction

In most highway bridges it is common to find large I-shaped beams supporting the bridge deck. The weight that each I-beam carries is transferred to the bridge columns where opposing forces are exerted to support the beam. These forces are known as end reactions (Fig. E5.1).

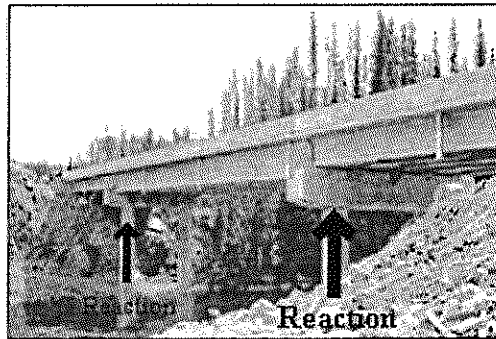


Figure E5.1 Bridge Reactions

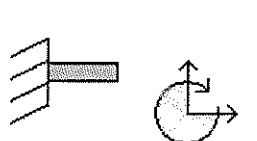
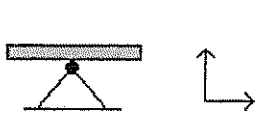

For example, if a vehicle stopped at the center of the I-beam, the end reactions would equal half the weight of the vehicle. Although the reactions from this centrally

loaded beam are easy to determine without mathematics, how would the reactions of a beam with more complex loading patterns be found? This experiment will focus on mathematically determining the end reactions of beams with randomly placed point loads.

E5.3 Background

When engineers design structural beams they primarily use three different support conditions. The most common are the fixed, hinge, and roller supports. Descriptions of these support conditions are summarized in Table E5.1.

Table E5.1 Descriptions of the Primary Support Conditions

 <p>Fixed</p>	<ul style="list-style-type: none"> • Example: Airplane Wing • This connection will not move in any direction. • Resists: <ol style="list-style-type: none"> 1. Rotation 2. Vertical Movement 3. Horizontal Movement
 <p>Hinge</p>	<ul style="list-style-type: none"> • Example: Door Hinge • This connection has the ability to rotate but will not move in the vertical or horizontal directions. • Resists: <ol style="list-style-type: none"> 1. Vertical Movement 2. Horizontal Movement
 <p>Roller</p>	<ul style="list-style-type: none"> • Example: Car Wheel • This connection will rotate and move from side to side but will not move in the vertical direction. • Resists: <ol style="list-style-type: none"> 1. Vertical Movement

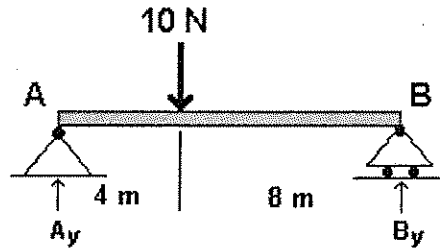
This experiment will consider end reactions produced on a simply supported beam. A simply supported beam exists with a hinge support at one end and a roller at the other.

The roller support allows for expansion and contraction as the temperature changes. Although not part of a simply supported structure, a fixed support condition also plays an important role in structural design. The fixed support is very popular because it can resist moving in any direction. This experiment will not consider end reactions on beams with fixed support conditions reaction because the calculations become too complex.

E5.4 Solving End Reactions

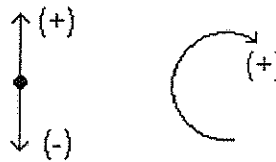
The methods used to determine the end reactions of a simply supported beam are best demonstrated by constructing a beam using two scales and two yardsticks. To avoid excessive deflection, the yardsticks should be stacked upon each other as the ends are placed on the scales. Once completed, the beam should be loaded with objects of known mass and the measured loads on the scales (end reactions) should be recorded. Since the end supports have the ability to rotate, the resistance to rotation, or moment, at the ends will be equal to zero. Therefore, the end reactions can be found by summing the moments (distance x load) about one end of the beam. An example of this technique is provided in the next section.

E5.5 Step-By-Step Instruction to Calculating End Reactions (example)



A_y & B_y = End Reactions

- 1) Pick which end of beam to sum end reactions about (A or B)
 - For this example, we will pick end A.
- 2) Choose which direction the positive axis and moment are orientated.



- 3) Sum the moments about the A end (Moment = length x force).
 - Since the end supports are rollers and hinges, the ends of the beam will rotate. As a result, the moments will be equal to zero.

$$M_A = 0 = B_y(12 \text{ m}) - 10 \text{ N}(4 \text{ m})$$

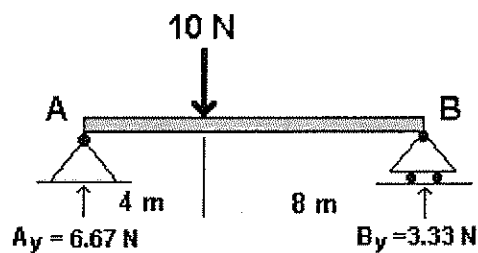
$$B_y = 3.33 \text{ N}$$

4) Sum the vertical forces to determine the end reaction at A_y .

- The sum of forces in the vertical direction (ΣF_y) is equal to zero because the beam is in equilibrium.

$$\Sigma F_y = 0 = 3.33 \text{ N} + A_y - 10 \text{ N}$$

$$A_y = 6.67 \text{ N}$$



A_y & B_y = End Reactions

E5.6 What You Will Need (per group of four)

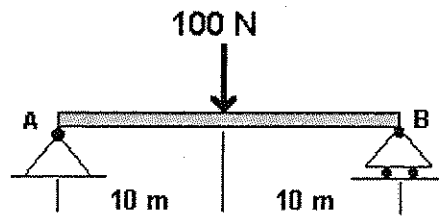
- 2 – scales (i.e., triple beam balance)
- 2 – yardsticks
- several objects of known mass

E5.7 Procedure

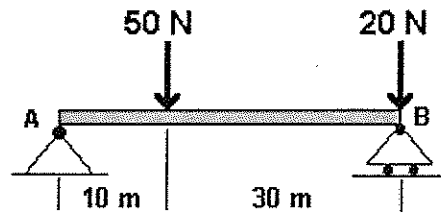
- Place the yardsticks, using the scales as end supports.
- Place weights at different locations on the yardstick beam.
- Calculate the end reactions and compare to the readings on the scales.
- Repeat this procedure two more times, placing the weights at different locations each time.

E5.8 End Reaction Questions

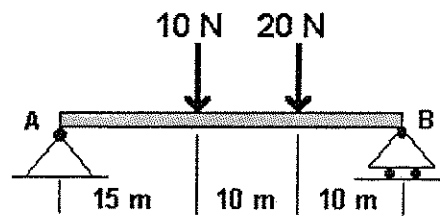
- 1) Determine the forces experienced on each support.



2) Determine the forces experienced on each support.



3) Determine the forces experienced on each support.



3.6 BRIDGE BUILDING COMPETITION (10 CLASS PERIODS)

EXPERIMENT NUMBER 6

3.6.1 Purpose

To enhance the students' recently acquired structural design skills and allow them to participate in a bridge building competition. The students will have the opportunity to calculate the moment of inertia and end reactions of their original bridge designs as they consider the factors on which the bridges will be judged. These factors include strength, aesthetics, cost, and weight.

3.6.2 Introduction

To eliminate any confusion, a set of guidelines has been established to provide a foundation to begin the competition. These suggestions were developed after conducting a similar bridge building contest.

3.6.3 Competition Rules

3.6.3.1 Bridge Dimensions

The bridge should span twenty inches and be supported at each end. School desks work well as bridge supports. The bridge should be two inches wide and will be loaded at the center of the span.

3.6.3.2 Bridge Materials

Wooden popsicle sticks and/or tongue depressors should be used to construct the bridges. Pasta was used once, but many problems were encountered when gluing

pieces together and cutting them into the desired shapes. Using wood alleviates most of the difficulties experienced with pasta. The pieces of wood should be attached to each other using Elmer's glue—it is inexpensive, dries relatively quickly and is easy to clean up.

3.6.3.3 Cost

As the students are designing their bridges, the “cost” of materials and labor should be considered to create a realistic design environment. Considering the cost associated with each structural member and the overall construction time will encourage the students to acknowledge the effects that each decision will have on the final cost. This is done to demonstrate that the best bridges are not always made of the biggest and strongest members—the best bridges are constructed by optimizing the strength and cost of each structural member.

Labor costs are set high to encourage the students to build their bridges as quickly and as efficiently as possible. Likewise, the structural member costs are suggested to encourage the students to use smaller, lighter members in their structural designs. For a wooden popsicle stick bridge, the suggested costs are listed below:

- Popsicle Stick: \$100.00
- Tongue Depressor: \$400.00
- Labor Costs: \$100.00/hour

3.6.3.4 Judging

The bridges are judged based on strength, weight, cost, and aesthetics. Using strength, weight, and cost encourages the students to explore different designs. The total cost of the bridge design includes the cost of materials plus labor. The cost of materials should be calculated by multiplying the cost of each member by the total number of members used. The labor costs should be calculated by multiplying the cost per hour by the total number of hours devoted to constructing the bridge. Bridge aesthetics will be judged by the graduate student and head teacher and will encourage the students to foster a creative construction environment.

3.6.3.5 Loading

The bridge should be weighed before it is loaded. Once the weight has been recorded, loading the bridge can be accomplished using a plastic bucket, a 3 foot long piece of wire, and sand. Simply, hang the wire over the bridge, with the center of the wire at the center of the bridge. Connect the ends of the wire to the bucket through handles or by drilling holes in the side of the bucket. Once the bucket has been rigged, sand can be placed in the bucket until the bridge fails. The bucket and sand should then be weighed to determine the maximum load carried by the bridge.

3.6.4 What You Will Need (per class)

- 1000 – popsicle sticks
- 100 – tongue Depressors
- 5 – bottles of glue
- 5 – pairs of scissors
- 1 – plastic bucket

- 1 – piece of three ft. long wire
- 2 – desks
- 1 – scale

3.6.5 Schedule

Day One: Summarize contest rules and encourage the students to suggest different appearances and designs for their bridges. Take the suggestions and record them on the chalkboard. Emphasize the relevance of moment of inertia and how it can be used to orientate a beam for optimum bending resistance. As homework, the students should develop a preliminary structural design.

Day Two: Students should present their bridge designs to the class. This step allows the graduate student and teacher to suggest changes (if needed) and to help students having problems developing the structural designs.

Days Three through Eight: Construct the wooden bridges.

Days Nine and Ten: Judge the bridges based on strength, weight, cost, and aesthetics.

3.6.6 Procedure

1. The students should design the bridge on paper considering the dimensions and appearance and the competition rules (Section 3.6.3).
2. The students should build the bridge.
3. Once the bridges have been completed, the students can calculate the moment of inertia for the main span supporting the bridge.
4. The instructor and graduate student will judge the bridge competition based on strength, weight, cost, and aesthetics.

3.6.7 Summary

At the conclusion of this laboratory, the students will gain some insight into the field of structural design. The students should be asked to perform moment of inertia calculations on their bridges and calculate the end reactions in their bridges at the maximum load. Comparing the moments of inertia and end reactions may help explain how the winning bridge was able to hold the most weight before failure.

Date: _____

Name: _____

Experiment Number 6 Worksheet**E6.0 Bridge Building Competition****E6.1 Purpose**

To enhance the students' recently acquired structural design skills and allow them to participate in a bridge building competition. The students will have the opportunity to calculate the moment of inertia and end reactions of their original bridge designs as they consider the factors on which the bridges will be judged. These factors include strength, aesthetics, cost, and weight.

E6.2 Bridge Building Background**E6.2.1 Dimensions**

- Length = 20 inches
- Deck Width = 2 inches

E6.2.2 Cost of Labor and Bridge Materials

- The costs will be summed at the end of the competition and will be used as one of the criteria for selecting the winning design competition.
- Popsicle sticks - *\$100.00/stick*
- Tongue Depressors - *\$400.00/depressor*
- Labor Costs - *\$100.00/hour*

E6.2.3 Loading

- The load will be placed at the center of the bridge until the bridge breaks.

E6.2.4 Judging

- Judging will be based on three different categories:
 1. Aesthetics
 2. Cost
 3. Strength-to-weight ratio

E6.3 Procedure

1. The students should design the bridge on paper considering the dimensions and appearance and the competition rules (Section E6.2).
2. The students should build the bridge.
3. Once the bridges have been completed, the students can calculate the moment of inertia for the main span supporting the bridge.
4. The instructor and graduate student will judge the bridge competition based on strength, weight, cost, and aesthetics.

CHAPTER 4

SUMMARY AND CONCLUSION

4.1 SUMMARY

In February 1999, the National Science Foundation approved a \$7.5 million program that placed graduate students in kindergarten through grade twelve (K-12) classrooms. The National Science Foundation's GK-12 Fellowship program was developed to assist in addressing science, mathematics, engineering, and technology (SMET) weaknesses found in the nation's public schools. As part of the program, graduate students from the University of Kansas developed experiments to interest high school students in their respective fields of study and to educate teachers in various fields of science and technology. Presenting experiments to the K-12 classes assisted in science and mathematics instruction and enriched the students' and teachers' knowledge and understanding of SMET.

Other universities have offered programs in which graduate students have promoted science and technology and introduce K-12 teachers and students in SMET. One program, coordinated by the University of Kansas, involves thousands of K-12 students in a project that tracks the migration habits of the Monarch Butterfly. Similarly, graduate students from the University of Wisconsin have visited GK-12 classrooms to familiarize K-12 students with the major influences that professional engineers have had on society. The University of Wisconsin also developed a program that placed graduate students in local classrooms to lead discussions based on theoretical science problems. This program also hosted several teaching seminars for instructors in kindergarten through twelfth grade, to spark interest in space science and technology.

The graduate students participating in the GK-12 program developed experiments, relating to their respective fields of study, that encouraged learning about SMET for the students and instructors in the K-12 community. The author, a civil engineering graduate, wrote six experiments directed towards teaching students and instructors about important aspects of civil engineering. The experiments include the following topics:

1. the process of corrosion,
2. developing concrete mix designs,
3. graphing with Microsoft Excel,
4. calculating moment of inertia,
5. calculating end reactions of simply supported beams, and
6. designing and building a bridge to be entered in a classroom bridge building competition.

4.2 CONCLUSIONS

The experiments within this report can be used as a valuable tool for teaching students in grades kindergarten to twelve (K-12) about science, mathematics, and engineering related technology. The six experiments presented in this report sparked the interest of high school students in civil engineering. The students enjoyed the experiments because (1) they offered hands-on activities, which encouraged students to learn about science, math and engineering related technology normally not taught in grades K-12, and (2) the students had the opportunity to learn from and to help their peers while completing group work required in each exercise.

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