

## Chapter 1 - Introduction to Experimental Methods in Structural Engineering

Experimental methods in structural engineering, as by its name, is a course of methods in structural engineering. However, different from theoretical methods in structural engineering, it emphasizes on experiments. Including how to understanding engineering mechanics, especially in civil engineering, by experimental tests and how to perform these tests.

The above-mentioned theoretical methods in structural engineering, here is a generalized term including statics, dynamics, mechanics of materials, mechanics of structures, etc. Let us try to simply use one phrase to describe what is the basic essence of theoretical methods in structural engineering. Theoretical methods in structural engineering, deals with equations. In most case, we try to find equations that stand for the balance of forces. We also cope with certain results of those forces, such as motions and/or deformations of objects, which is in form of equations, too. We may also need equations to describe properties of materials, properties of cross sections, etc. Here the basic concept is that in order to unveil unknown quantities, one has to find enough equations.

Experimental methods in structural engineering, also deals with equations. In most cases, it is basically to measure certain coefficients or parameters (or their functions) or solutions of equations. Those equations, however, are likely existing already. By measuring those coefficients or parameters, we can learn properties of materials and structures, we can verify validity of a certain theory in the form of equations.

To perform the measurement, there are issues on sensors, instrumentation, data management, signal processing and analyses. There are also problems on how to set up the tests, how to manage the experiments.

In this regard, experimental methods in structural engineering, is more close to an art, instead of pure science. Consider theoretical mechanics. To solve a certain problem, we first have to examine the given conditions including related physical laws. In most cases, the numbers of these conditions do exactly fit the numbers of equations. The rigorousness means science.

However, in experimental methods in structural engineering, since we have to deal with the real world, the numbers of quantities we measured can be quite different from the numbers of unknown coefficients or parameters. In many cases, the former can be much larger than the later. However, it can also be smaller than the later.

We then have to take statistical measures to deal with those numbers. In so doing, we may have to consider some weighting game, that is, among those measured quantities, which are more important, which are less important.

Furthermore, we would better to understand that, any quantity described by digits, must be not exact "correct". In theoretical mechanics, what we often meet is  $1 + 1 = 2$ . However, in experimental mechanics,  $1.0 + 1.0$  is quite likely not equals  $2.0$ , which is, however, used to verify the theoretical relation  $1 + 1 = 2$ . That is an art.

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## 1.1 Importance of Experimental Methods

Theoretical mechanics played by brain.

Experimental mechanics played by both brain and hands.

Using hands is very important. After a dozen more years in school where we mainly concentrate on brain exercise, we are getting used to think theoretically, to play logical analyses.

We now are facing somewhat different knowledge, skills, we are about to realize an extremely important methodology, which must be learnt by using our hands. This methodology is to conceive theories, to verify assumptions, to find out real world quantities, to discover new relations and new quantities, by experimental work.

Good students use their brains

Students who use their hands are better.

Confucius (Con-Fu) Chinese philosopher of middle ages said:

- **I read -> I see;**
- **I listen -> I understand;**
- **I do, -> I know**

It is only when you experience “it” you really know “it”

More specifically,

### 1.1.1 Backbone to Modern Applied Science and Engineering

Carefully designed experiments are definitely needed

to conceive and verify theoretical concepts;

to develop new methods and products;

to commission sophisticated new engineering systems;

to evaluate the performance and behavior of existing products.

### 1.1.2 Basic Skills as an Engineer

Not only knowing how to find things in handbook, but also be creative

One of the necessary ingredients in creativity is “hands-on”.

### 1.1.3 Necessary Measures as a Researcher

Graduate students in engineering major, performing experiments

Research to find new concepts, new quantities, new relations, etc.

## Overview of this Course

### 1.1.4 Objectives

The following are three basic objectives of this course, namely,

- Knowledge
- Skill
- Methodology

This course is intended to introduce students to experimental methods, test planning, model preparation, loading systems, instrumentation, data acquisition and data processing. The course covers aspects of static and structural dynamics problems. Advance methods of testing will include hybrid techniques for substructure testing. Elements of modal testing and nondestructive methods will be introduced. The course provides an overview of laboratory work and is complemented with several "hands-on" applications in laboratory using testing and computing equipment. The students will get acquainted with the following subjects:

- 1 Similitude, modeling and dimensional analysis (1wk)
- 2 Measurement systems, statistical and error analysis (1wk)
- 3 Test Planing, design and implementation - test protocols (2 wk)
- 4 Structural and Materials testing - steel, timber, plastics, concrete, etc.(1wk)
- 5 Loading Systems - set-ups, loading devices, actuators, control, etc. (2wk)
- 6 Instrumentation - mechanical, electrical, electronic (2wk)
- 7 Data Acquisition - analog and digital (1wk)
- 8 Computerized data processing - numerical and graphical (1wk)
- 9 Data archiving and curating- data quality control (1 wk)

The information in parentheses is the tentative duration of each subject

During the training in laboratories, students will also gain corresponding skills from "hands-on" experiments, including basically how to choose and install sensors, how to establish data acquisition systems, how to conduct test setups, how to use actuators, etc.

Besides the necessary knowledge and skills for experimental studies, this course also attempts to encourage student to gain deeper thoughts, or methodologies, for better understanding the art of experimental studies. In the following, also in specific chapters, we shall discuss this point repeatedly.

### 1.1.5 Methods for how to learn this course

The "methods" of gaining knowledge and skills, especially understanding useful methodologies for experimental studies, are rather unique and different than many other engineering courses. The students are encouraged to consider the following lists, although they look rather superficial, before and during the entire training of this course.

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1. Understanding the philosophy mentioned below of measurement and experimental testing

Science vs. art

Skill you learnt vs. methodology you gained

2. Willingness of “hands-on”

Basic concepts, logically vs. experimentally

Integrate the test procedure and instrumentation to serve your major purpose

More detailed discussion of the ideas and methods are further discussed as follows.

## 1.2 Philosophy of Measurements & Experimental Testing

### 1.2.1 Theory vs. Practice

Unlike many other courses, experimental mechanics deals with both theoretical analysis and experimental tests simultaneously. In fact,

Theoretician does not have to use his hands

Experimentalist must use his brain.

### 1.2.2 Laws in Experimental Studies

The following profound descriptions or "laws" for experimental studies unveils real-world projects. The students shall be trained to deal with the real-world problems not only based on their sufficient knowledge and skills, but also necessary psychological preparations.

**(1) Murphy’s Law: If something can go wrong, it will.**

**(2) O’toole’s Law: Murphy’s law is too optimistic.**

**(3) Reinhorn’s Law: Things are never as bad as they turn out to be.**

**(4) Bracci’s Law: Anything can be done given time and money**

### 1.2.3 Quality vs. Quantity

Any value described by digits and numbers is not exactly that quantity.

If you learn something qualitatively, you indeed march forward a big step

If you learn that thing quantitatively, you actually march forwards ten steps from the origin.

### 1.3.4 Concept of Convolution and Filtering

Any quantity you measured is actually a result of convolution of some original value. Since most measurement systems are linear, the corresponding transfer function, which describes the nature of convolution in the frequency domain, becomes one of the most important tools in the experimental studies.

### **1.2.4 Details and Generality**

The essence is always in details

However, the conclusion you extracted from your measurement is often generality

### **1.2.5 Testing, Verification and Discovery**

Many tests are designed to verify some existing theory or initial assumptions.

A sharp experimentalist hopes that the test will yield different results and he will discover new things from his test.

### **1.2.6 Types of testing**

Therefore there are three types of tests: (i) exploration and discovery; (ii) proof of concept and (iii) qualifications

### **1.3.7 Adjustable**

In order to be successfully performing a test, one of the key technologies is to make the test setup adjustable.

### **1.2.7 Art of integrating measurement systems**

A test setup has its integrity; you have to bring multi-disciplinary knowledge to achieve the goal. The test procedure is in series, one single ring of the entire chain is broken, the entire chain is broken. However, to successfully run a test, we often have to solve few key problems, we have to be able to grab the major issues.

### **1.2.8 Essence of testing**

The essence of testing however is obtaining reliable and repeatable results. This means a known quality of measurements. Most of this semester we shall learn about structures and materials, instruments, and methods to quantify the information with a known level of confidence. Please note accuracy is relative and is important as soon as you know its measure and its importance.

## **1.4 Applications in Experimental Mechanics**

### **1.4.1 Measurement in Engineering Experimentation**

Material testing

Structural testing

Monitoring

Non-destructive evaluation

Earthquake/wind protective system

### **1.4.2 Measurement and Control in Operational Systems**

## 1.5 References

1. Dally and Riley, “Experimental Stress Analysis,” McGraw Hill, 1978
2. Harris and Sabnis, “Structural Modeling and Experimental Techniques” CRC Press 1999
3. Nachtigal, C.L., “Instrumentation and Control,” Wiley & Sons, 1990
4. Reese and Kawahara, “ Handbook of Structural Testing”, Prentice Hall / Fairmont Press 1993
5. Malhotra and carino, “Handbook of Nondestructive Testing of Concrete”, CRC Press, 1991
6. Instructor’s Handouts / Computer Manuals / Seewebsite

## ACCESS TO SEESL LABORATORY

1. Laboratory operation hours are 8:30am to 4:30 pm, when the University is officially open. Anyone can be in the laboratory during operation hours provided that safety rules are followed.
2. Access to the laboratory at times other than normal operation hours of 8:30am to 4:30pm is restricted as follows:
  - a. Only authorized personnel can enter.
  - b. Authorization can be provided only by the permanent staff of the laboratory and approved by either Dr. Reinhorn or Dr. Constantinou.
  - c. Students may work in the laboratory provided
    - i. they receive authorization,
    - ii. work in pairs, and
    - iii. are previously instructed on what exact machinery they may use.
  - d. Outside contractors may work in the laboratory provided
    - i. they receive authorization
    - ii. work in pairs, (or at least one other person is present in lab during work time) and
    - iii. have a valid certificate of insurance, or a clearly signed waiver of claims to the laboratory, laboratory staff and University. (Waiver can be obtained at Lab Management office).
3. Outside contractors may use equipment in the laboratory provided they are properly trained, are authorized by the permanent staff of the laboratory, and have a valid certificate of insurance, or waiver as indicated in 2d (iii) above.
4. The permanent staff of the laboratory and either of the co-directors may order any person to leave the laboratory if they determine that person poses a safety threat to him/her self or others.

Prof. M. C. Constantinou  
Department Chair and Co-Director SEESL

Prof A. M. Reinhorn  
Co-Director SEESL

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## **SAFETY RULES AT SEESL LABORATORY**

### **Failure to follow safety roles is grounds for suspension of laboratory privileges and/or removal from the laboratories**

1. All personnel working in the laboratory, including students, shall wear safety shoes.
2. All personnel working in the laboratory, including students, and visitors shall wear safety hats, helmets, except in areas marked otherwise.
3. Any time welding is being done, the operation shall be shielded so that it is not possible for visitors to view the welding. Any volatile materials shall be removed to a safe distance before welding is performed.
4. Grinding is covered by of the same rules of welding. In addition, a non-flammable shelter should be built around the grinding operation to contain sparks.
5. Safety belts shall be used when climbing. Climbing is defined as any activity, which results in the person being more than four feet above the floor. Safety belts on ladders are optional.
6. The overhead cranes are to be used for lifting and moving. They are not to be used for pulling or breaking. Only authorized personal can use crane.
7. Operation of overhead cranes, testing machines, machine tools or power equipment shall take place **ONLY** when member of the full-time staff, or authorized designated person is present in laboratory.
8. All personnel shall wear long pants and socks when using power tools or machine tools.
9. Personnel shall wear gloves if there is any possibility of abrasion or laceration. When in doubt, gloves shall be worn.
10. Personnel shall wear safety glasses when operating a machine tool or power equipment.

### **IN CASE OF EMERGENCY CALL 9-2222 AND NOTIFY MEMBER OF THE PERMANENT STAFF IN LABORATORY**

Prof. M. C. Constantinou  
Department Chair and Co-Director SEESL

Prof A. M. Reinhorn  
Co-Director SEESL

## Laboratory Safety Program

The Laboratory Safety Program of the Department of Civil, Structural & Environmental Engineering is intended to establish a framework of identifying and correcting workplace hazards, and preventing accidents within the Department. The safety program consists of:

- (a) Identification of responsibilities of the participants.
- (b) Establishing a program of periodic inspection of the laboratory areas identified in Table 1, correcting deficiencies identified in inspections, and issuing reports of the inspections.
- (c) Establishing periodic training seminars that include
  - (i) New York State “Right to Know” training,
  - (ii) Basic laboratory safety and waste handling training,
  - (iii) Operation of laboratory equipment, and
  - (iv) Basic fabrication shop training.
- (d) Updating faculty, staff and students on new safety regulations and requirements.
- (e) Conducting safety review of new equipment and experimental set-up when requested by laboratory directors or principal investigators.

### 4.1 Responsibilities of Participants

#### 4.1.1 Chair of Department

The Department Chair has primary authority and responsibility to ensure departmental implementation of the laboratory safety program and to ensure the safety of the department’s faculty, staff and students. This is accomplished by communicating the University’s emphasis on safety, analyzing work procedures for hazard identification and correction, ensuring regular laboratory inspections, providing safety training, and encouraging prompt reporting of safety concerns without fear of reprisal.

#### 4.1.2 Department Safety Committee

The Department Safety Committee consists of representatives of faculty, staff and students. The committee has the responsibility to maintain and update the Laboratory Safety Program, to assess departmental compliance with applicable regulations and University policies, to evaluate reports of unsafe conditions, to schedule periodic laboratory inspections, to coordinate any necessary corrective actions, and to interact with the Department of Occupational and Environmental Safety (OES).

Specifically, the Department Safety Committee will:

- Review the results of periodic, scheduled laboratory inspections to identify any needed safety procedures or programs and to track specific corrective actions,
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- Review investigations of accidents and injuries to ensure that all causes have been identified and corrected,
- Where appropriate, submit suggestions to the Department Chair for the prevention of future incidents,
- Review alleged hazardous conditions brought to the attention of the Department, determine necessary corrective actions, and assign responsible parties and correction deadlines,
- When determined necessary by the Committee, the Committee may conduct its own investigation of accidents and/or alleged hazards to assist in establishing corrective actions.

Records of Department Safety Committee, including minutes of meetings, reports of unsafe conditions, hazard correction forms, laboratory inspection forms and safety training attendance records, must be maintained by the Department. Department Safety Committee minutes of meetings should be reported on Form CSEE 5.

#### **4.1.3 Department Safety Coordinators**

The Department has two Safety Coordinators, one responsible for the Ketter Hall areas and one responsible for the Jarvis Hall and Trailers C and D areas. The two coordinators are, respectively, the chair and vice-chair of the Department Safety Committee.

#### **4.1.4 Supervisors**

Supervisors are the Department Chair, Principal Investigators, instructors of courses with laboratory component and any employee who oversees the work of others. Supervisors are responsible for:

- Communicating to their staff and students the University's emphasis on safety,
- Ensuring periodic, documented inspection of workspaces under their authority,
- Promptly correcting identified hazards,
- Modeling and enforcing safe and healthful work practices,
- Providing appropriate safety training and personal protective equipment,
- Implementing measures to eliminate or control workplace hazards,
- Stopping any employee's work that poses an imminent hazard to either the employee or any other individual,
- Encouraging employees to report health and safety issues.

#### **4.1.5 All Employees**

It is the responsibility of all faculty and staff to comply with all applicable safety regulations, University policies, and established work practices. This includes but is not limited to:

- Observing safety-related signs, posters, warning signals and directions,
- Learning about the potential hazards of assigned tasks and work areas,
- Taking part in required safety training,
- Following all safe operating procedures and precautions,
- Using proper personal protective equipment,
- Warning coworkers about defective equipment and other hazards,
- Reporting unsafe conditions immediately to a supervisor, and stopping work if an imminent hazard is presented,
- Participating in workplace safety inspections.

## 4.2 Identifying Hazards

Regular, semi-annual workplace safety inspections of all departmental shops and laboratories must be conducted. The inspections should be noted on Form CSEE 3 and the Department must maintain copies of this documentation. The responsible PI, laboratory director or manager should be notified in writing using Form CSEE 6, which may include estimated enforcement penalties of infractions. Guidance on the details of inspections is provided in the document *Safety Inspection Guidance*. These regular inspections will be supplemented with additional inspections whenever new substances, processes, procedures, or equipment introduced into the workplace represent a new safety hazard or whenever supervisors are made aware of a new or previously unrecognized hazard.

Generally, supervisors are responsible for identification and correction of hazards that their staff and/or students face and should ensure that work areas they exercise control over are inspected at least semi-annually. Supervisors should check for safe work practices with each visit to the workplace and should provide immediate verbal feedback where hazards are observed.

The “Report of Unsafe Condition” (Form CSEE 1) should be filled out when a referral is made to the Safety Committee as a result of a condition discovered during an inspection for which the responsible supervisor could not determine an immediate remedy. The same form may be used by anyone wishing to report an unsafe condition to the Department Chair.

## 4.3 Correcting Hazards

Hazards discovered either as a result of a schedule periodic inspection or during normal operations must be corrected by the supervisor in control of the work area, or by cooperation between the department in control of the work area and the supervisor of the employees working in that area. Supervisors of affected employees are expected to correct unsafe conditions as quickly as possible after discovery of a hazard, based on the severity of the hazard.

Specific procedures that can be used to correct hazards include but are not limited to the following:

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- Locking out and tagging unsafe equipment “Do Not Use Until Repaired,” and providing a list of alternatives for employees to use until the item is repaired,
- Stopping unsafe work practices and providing retraining on proper procedures before work resumes,
- Reinforcing and explaining the need for proper personal protective equipment (PPE) and ensuring its availability,
- Barricading areas that have chemical spills or other hazards and reporting the hazardous conditions to a supervisor.

Supervisors should use the “Hazard Correction Report” (Form CSEE 2) to document corrective actions, including projected and actual completion dates. If necessary, supervisors can seek assistance in developing appropriate corrective actions by submitting a “Report of Unsafe Condition” to the Department Safety Committee. If the Department Safety Committee requires assistance from other campus resources such as OES, these resources should be contacted immediately. If an imminent hazard exists, work in the area should cease, and the appropriate supervisor must be contacted immediately. If the hazard cannot be immediately corrected without endangering employees or property, all personnel need to be removed from the area except those qualified and necessary to correct the condition. These qualified individuals will be equipped with necessary safeguards before addressing the situation.

#### **4.4 Safety Training**

Safety training shall be provided to all employees and students involved in laboratory work. Safety training may be presented by a knowledgeable supervisor, other department personnel, or by representatives from other relevant campus departments. Regardless of the instructor, all safety training must be documented using the “Safety Training Attendance Record” (Form CSEE 4). Safety training must meet applicable OSHA and EPA requirements.

All employees should receive Hazard Communications/Right-To-Know Training once per year. Information on this training is available at the following site:

<http://wings.buffalo.edu/services/fac/OES/rtk/RTKHome.htm>

All undergraduate students registered in the laboratory courses CIE 361 and CIE 362 must receive safety training in the first week of classes.

All graduate students must receive safety training before being allowed to start work in any laboratory.

Staff and faculty involved in laboratory work shall also receive training in special topics, including but not limited to the following:

- Fire prevention techniques and fire extinguisher use (contact Mr. Jim Guy, OES, 829-2401),

- Obtaining emergency medical assistance and first aid,
- Disaster preparedness and response, including building evacuation procedures (contact Mr. Jim Guy, OES, 829-2401),
- Back care, body mechanics, and proper lifting techniques,
- Chemical Hygiene Plan including training on Material Safety Data Sheets, chemical hazards and container labeling (contact Dr. Robert Najjar, OES, 829-2401),
- Proper housekeeping,
- Chemical spill reporting procedures,
- Proper hazardous waste handling, storage, and disposal.

#### 4.5 Ensuring Compliance

All department personnel have the responsibility for complying with safe work practices, including applicable regulations, University policies, and departmental safety procedures. Overall performance in maintenance of a safe work environment should be recognized by the supervisor and noted in performance evaluations. Employees will not be discriminated against for work-related injuries, and injuries will not be included in performance evaluation, unless the injuries were a result of an unsafe act on the part of the employee.

Standard progressive disciplinary measures in accordance with the applicable personnel policy or labor contract will result when employees fail to comply with applicable regulations, University policies, and/or departmental safety procedures. All personnel will be given instruction and an opportunity to correct unsafe behavior. Repeated failure to comply or willful and intentional non-compliance will result in disciplinary measures.

#### 4.6 Safety Resources

The following departments at the University at Buffalo may be contacted for information related to safety.

**Department of Public Safety** – The University police provide security on campus and services on crime prevention and personal safety. Call in case of emergency: 645-2222.

**Department of Occupational and Environmental Safety (OES)** – Develops safety and environmental compliance standards, policies and procedures.

Main Office: 829-2401, fax 829-2704

Radiation Safety Office : 829-2401, fax 829-2029

<http://wings.buffalo.edu/services/fac/OES/>

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