Course Administration

- Class attendance is not mandatory, but is strongly encouraged.
- Lecture notes will be posted to my web page.
- Completion of the assigned reading is recommended prior to each lecture. (See the attached syllabus and reading list.)
- Homework assignments are due on the following Monday from the day they are assigned.
- Collaboration with other students on the homework assignments is permitted.
- Homework assignments will be returned one week after they are collected.
- Please do not ask the grader to solve homework problems for you. He/she will, however, solve problems similar to your homework problems.
- Neatness counts. Straight lines should be drawn with a straight edge. Homework assignments should be stapled, and pages numbered.
- There will be two exams and numerous homework assignments. (See the attached syllabus.) The second exam is not comprehensive.
Course Goals

The goal of this course is to expand your analytical skills relative to framed structures and their subcomponents. Specifically you will learn how to determine internal forces and moments as well as corresponding deflections and rotations throughout complex structures using matrix methods.

You will use the skills acquired here in your design courses (CVE 322 Steel Design and CVE 422 Reinforced Concrete Design) and later in practice to help determine the appropriate geometry of structural elements in accordance with applicable building codes.

In Structural Analysis I (CVE 311) a number of “classical” methods were presented that are by and large intended for hand calculations. Only relatively simple structural elements (i.e., truss members, beams, and simple frames) were addressed in that course.

In CVE 511 we will revisit elements of CVE 311 and ESC 211 (Strength of Materials) as needed and then concentrate on “matrix” methods of analysis. The fundamental relationships of equilibrium, compatibility and the contribution that subcomponents in a structure make to the overall stiffness of a structure will be expressed in the form of matrix equations, which are easily adaptable for computer solution.
Lecture 1: INTRODUCTION

Course Objectives

• After successfully completing this course you should have an understanding of the theory behind the methods to analyze linear elastic framed structures using the knowledge of mathematics (linear algebra), engineering (mechanics and material behavior), and computer science (MATLab, Excel, Visual Analysis, RISA)

• In this class you begin laying a foundation of experience relative to how structures behave under load. This is accomplished primarily through an understanding of the flexibility method of solution.

• You will also develop an appreciation for the effective use of computational algorithms that rely on the stiffness methods of solution.

• This course provides the underlying theory for matrix analysis of two dimensional plate or shell structures. The analysis of these types of structures is a natural extension of the analysis used for three dimensional machine components. Hence this course begins the process of appreciating and understanding the finite element method of analysis.
Course Outcomes

You will be expected to show proficiency in both the theory and practical application of matrix based structural analyses. You will understand the use of software in analyzing realistic civil engineering structures. You will have the ability to:

1. Ascertain appropriate geometry and boundary conditions;

2. Choose correct modeling elements and the correct load representation;

3. Apply the appropriate software options to assess forces and displacements; and

4. Be able to interpret output and validate results using simplified models and hand calculations.
**Course Assessment**

In this course I will measure your progress in meeting the previously mentioned objectives by requiring you to:

- Calculate the forces within members of trusses, beams, and frames using analytical and computer based techniques;

- Understand and use the principle of superposition in simplifying the analysis of statically indeterminate structures;

- Apply the stiffness method to determine the behavior of plane truss, beams, and frames subject to various loads; and

- Extend the planar analysis to include three-dimensional trusses and frames;

This assessment is done through the use of exams and homework.
**Brief History of “Matrix Analysis” Methods (see article posted to web page)**

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850-75</td>
<td>Interaction concepts by Castigliano (force-deflection principles), Maxwell (reciprocal work theorem), and Mohr (moment area theorems) are introduced.</td>
</tr>
<tr>
<td>1875-1920</td>
<td>No significant progress due to obvious limitations in solving large numbers of equations.</td>
</tr>
<tr>
<td>1920</td>
<td>Ostenfeld and Maney (slope deflection method) propose utilizing joint displacements as unknowns in the analysis of trusses.</td>
</tr>
<tr>
<td>1932</td>
<td>Solutions for internal moments are available through the use of the moment distribution method developed by Hardy-Cross. Method helps in “visualizing” the interactions between structural subcomponents.</td>
</tr>
<tr>
<td>1930’s</td>
<td>Aeroelastic research at England’s National Physical Laboratory (NPL) extends previous efforts.</td>
</tr>
<tr>
<td>1950’s</td>
<td>Computers become available.</td>
</tr>
</tbody>
</table>
Brief History of “Matrix Analysis” Methods (continued)

1956 Turner, Clough, Martin and Topp make a landmark contribution when they succeed in deriving the stiffness of a triangular plate element. Clough observes later that this paper represents earlier work at the Boeing Summer Faculty Program. This effort as well as the work by Argyris and Kelsey mark the birth of modern finite element analysis.

Figure 1. Swept-back Box Wing Test Structure
Brief History of “Matrix Analysis” Methods (continued)

1960  Paper by Argyris and Kelsey introduces the concept that the
displacement-based method of structural analysis. This is the twin
methodology to the force-based of structural analysis.

1965-1969 In 1965 NASA issued a Request for a Proposal (RFP) to develop the
NASTRAN finite element software algorithm. The original (RFP)
called for the simultaneous development of displacement-based and
force-based versions. Two separate contracts were awarded to MSC
and Martin. The contract for the force-based version was cancelled
in 1969. The following year may be taken as the end of the force-
based methods as a serious contender for general purpose finite
element programs.
Lecture 1: INTRODUCTION

**Matrix Analysis of Structures**

In the class we will use matrix algebra to express the relationships that are key to the structural analysis. In previous classes you learned about

- Castigliano’s theorem
- Slope deflection methods, and
- Method of consistent deformations

The methods above typically yield exact solutions, but they are applied to relatively “small” problems. Matrix methods of analysis are applied to “large” structures and the solutions obtained are approximate and not exact. You will learn as the course unfolds that there are ways to minimize errors.

The subassemblies used in matrix methods include, but are not limited to:

- Truss and beam elements
- 2D and 3D continuum elements
- Plate and shell element

In this course we focus on truss and beam elements and build a fundamental knowledge.
Structural analyses of large complex structures utilizing matrix methods involve four key ingredients:

1. Basic mechanics relationships (stress-strain, compatibility, equilibrium)
2. Equation Formulation (algebraic system)
3. Equation Solution (algorithms to solve simultaneous equations)
4. Solution Interpretation (“answers”)

This class focuses on these issues as they relate to frame, beam and truss elements. Elasticity (CVE 604) and Advanced Strength of Materials (CVE 513) focuses on ingredient #1 in preparation for Finite Element Analysis (CVE 512) where the issues above are discussed relative to continuum elements.
Discretizing the Structure

Trusses, beams and frames can be defined as an assemblage of structural elements joined together at discrete points known as nodes. In an analysis external loads are usually applied to the structure at these nodes. If in an actual structure loads (distributed or other types of member loads) are acting between nodes they can be replaced with equivalent loads at the nodes.

Thus any structure can be divided into progressively smaller subcomponents, or in other words, a structure can be discretized. For example a truss can be considered an assembly of two force members (subcomponents) pin connected at their ends (nodes). A rigid frame may be taken as an assembly of three force members (subcomponents).

The behavior of the each subcomponent (discrete element) of the assembly as well as the structure itself must satisfy:

- Equilibrium,
- Compatibility of displacements, and
- Force displacement relationships specified by the geometric and elastic properties of each discrete element
Lecture 1: INTRODUCTION

Methods of Analysis Using Discrete Elements

Framed Structures RISA, STAADs, RAM

Assemblage of one and two dimensional structural elements

"Machine" Components ANSYS, COMSOL, ABAQUS, NASTRAN

Assemblage of 2- and 3-dimensional continuum elements
Lecture 1: INTRODUCTION
Lecture 1: INTRODUCTION
Essentially - all surfaces visible on the bottom view are ground surfaces. There is only three surfaces visible on the top view that are ground. All others are as-fired.
Lecture 1: INTRODUCTION

Finite element mesh used for the analysis of a single vane (axisymmetric model)

First principle stress (psi) from a cold start on Ingersoll-Rand’s ceramic microturbine vane
In this course we will focus on SMALL STRAIN, LINEAR ELASTIC, STATIC analysis. The analytical approach presented here can be extended to include more complex structural behavior including:

1. Geometric nonlinearity (large displacements, e.g., tip of an airplane wing)

2. Material nonlinearity
   - Plasticity
   - Creep
   - Viscous elasticity

3. Time dependent dynamic analysis including all of above.
Beyond Solid Mechanics

The analytical techniques developed in this class and courses beyond this class can be utilized to analyze components in other fields, e.g.,

**Computational Fluid Dynamics** - (CFD) is a branch of fluid mechanics that uses numerical methods to analyze problems that involve fluid flow. Field equations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions are solved with matrix methods. Complex simulation scenarios (transonic or turbulent) flows are examined.

**Heat Transfer** - a sub discipline of mechanical engineering that analyzes the transfer of thermal energy from one physical system to another. Field equations required to simulate the transfer are solved numerically with matrix methods. Heat transfer problems are categorized by the mechanisms that are transferring energy, e.g., thermal conduction (transfer by contact), thermal convection (fluid/gas transfer), thermal radiation (transfer through space), and phase-change (chemical) transfer.

**Computational Electromagnetics** - modeling the interaction of electromagnetic fields with physical objects and the surrounding environment. This type of analysis involves matrix methods to solve Maxwell's partial differential equations along with Lorenz’s force law.
Lecture 1: INTRODUCTION

References – Other Textbooks