Fall 2012

CEE 421L. Matrix Structural Analysis

Instructor:	Henri P. Gavin, 162 Hudson Annex, `Henri.Gavin@Duke.edu`
Class Time:	Tu Th 11:45–1:00, Room 216 Hudson
Recitations:	We 4:40–5:55, Room 207 Hudson
T.A.:	Jenni Rinker, `Jennifer.Rinker@Duke.edu`
Office Hours:	H.P.G.: Mo 1:30-3-00, Rm 162; J.R.: We 1:30-3:00 Rm 132 Hudson and by appointment
Textbook:	A. Kassimali, *Matrix Analysis of Structures, 2nd ed.,* Brooks/Cole, 2012.
Course Website:	http://www.duke.edu/~hpgavin/cee421/
Prerequisite:	EGR 201L (EGR 75L). Solid Mechanics,
Corequisite:	Math 216 (Math 107). Linear Algebra and Diff. Eq'ns
Academic Integrity:	*The Duke Community Standard* applies.
Short Term Illness:	http://trinity.duke.edu/academic-requirements
Grading:	Homeworks(11) 30%; Tests(3) 40%; Final(1) 25%; Participation 5%

BULLETIN DESCRIPTION

Development of stiffness matrix methods from first principles. Superposition of loads and elements. Linear analysis by hand and computer of plane and space structures comprising one-dimensional truss and beam elements.

LEARNING OBJECTIVES

The objectives of this course are to teach students how to:

- Understand the difference between energy-based flexibility approaches and matrix-based stiffness approaches to structural analysis;
- Determine deflections and forces in statically determinate and indeterminate structures using strain-energy methods.
- Determine deflections and forces in statically determinate and indeterminate structures using the matrix stiffness method;
- Use a physical interpretation of stiffness matrices to assemble stiffness matrices analytically;
- Write and use computer programs which implement the matrix stiffness method;
- Apply knowledge of mathematics (linear algebra), science and engineering (material behavior), and computer programming;
- Consider professional and ethical responsibility in the design of public infrastructure; and
- Recognize the need for, and an ability to engage in life-long learning.

MEASURABLE OUTCOMES

This course measures students' progress in meeting the above objectives by requiring them to:

- Apply the matrix stiffness method to model the behavior of planar trusses, beams, and frames;
- Calculate deflections, reactions, and internal forces for planar trusses, beams, and frames using analytical and computer-based methods; and
- Extend the scope of linear static analysis to include geometric stability and dynamic effects.

GENERAL REQUIREMENTS

- **The Duke Community Standard**
  Duke University is a community dedicated to scholarship, leadership, and service and to the principles of honesty, fairness, respect, and accountability. Citizens of this community commit to reflect upon and uphold these principles in all academic and non-academic endeavors, and to protect and promote a culture of integrity.

  To uphold the Duke Community Standard:

  - I will not lie, cheat, or steal in my academic endeavors;
  - I will conduct myself honorably in all my endeavors; and
  - I will act if the Standard is compromised.

  The Duke Community Standard is described in detail in the document, *Duke Community Standard in Practice: A Guide for Undergraduates*. Each member of the Duke Community is expected to understand their obligations with respect to this standard. The section on cheating is excerpted below:

  > Cheating is the act of wrongfully using or attempting to use unauthorized materials, information, study aids, or the ideas or work of another in order to gain an unfair advantage. It includes, but is not limited to:
  >
  > - plagiarism on any assignment;
  > - giving unauthorized aid to another student or receiving unauthorized aid from another person on tests, quizzes, assignments or examinations;
  > - using or consulting unauthorized materials or using unauthorized equipment or devices on tests, quizzes, assignments or examinations;
  > - altering or falsifying any information on tests, quizzes, assignments or examinations;
  > - using any material portion of a paper or project to fulfill the requirements of more than one course unless the student has received prior faculty permission to do so;
  > - working on any examination, test, quiz or assignment outside of the time constraints imposed;
  > - the unauthorized use of prescription medication to enhance academic performance;
  > - submitting an altered examination or assignment to an instructor for re-grading; or
  > - failing to adhere to an instructor's specific directions with respect to the terms of academic integrity or academic honesty.

- **Reading:** Completion of the assigned reading is recommended prior to each lecture. (See the course schedule and reading list on page 4.)

- **Attendance:** Please be on time and please participate during class. Please keep your cell phones and computers off. Please be attentive. Silent and listen have the same letters. (Do I really need to write this?)

- **Communication:** We will use e-mail for out-of-class communication.

- **Extra-curricular and co-curricular activities:** In most cases extra-curricular and co-curricular activities conflicting with course commitments can be resolved easily. Just let me know beforehand.

- **Grading:** The TA will grade your solutions to homework assignments. I will grade the exams. See me (not the TA) about any grading errors.

HOMEWORK REQUIREMENTS

- **Assignments and due dates:** Homework assignments shown on the course schedule and are due at 5:00 pm Fridays. (See page 4.)
- **Collaboration:** You may work with other students and get help from the TAs and the instructor on homework assignments, but *do not* copy solutions (from any source). Carry out your solutions in a way that makes sense to you.

  Teaching assistants and fellow students *are not allowed* to solve homework problems for you. Questions like, "How did you do this problem?" or "What did you get for an answer to Problem 3?" are not appropriate. Don't ask questions like these, and don't answer questions like these. You are not allowed to get help from anyone on the exam. Violations will be forwarded to the Academic Integrity Council.

  You won't learn anything from copying solutions. It is a violation of the Duke Community Standard. Respect your integrity. Don't do it.
- **Matlab:** Three homework assignments require MATLAB programming abilities.
- **Short-term illness:** If you miss a due-date because you were sick, follow the university policy for submitting the missed assignment. http://trinity.duke.edu/academic-requirements
- **Extensions:** You are allowed *one no-questions-asked homework extension* (from Friday to Monday) during the semester. I will give each of you your own free-pass for a single HW extension, signed by yours-truly. To use your extension, simply staple your extension pass to the front of your HW when you hand it in to me in person. (Don't lose your HW extension pass.)
- **Neatness:** Take pride in your work.
  On homework assignments, 15 of the 100 points will be awarded for following these rules:
  - Use a pencil (so you can erase). Mechanical pencils are recommended.
  - Write neatly and clearly. Your TA may lose patience with illegible solution sets.
  - Write your first and last name, the course number, the assignment number and the due-date in the upper right corner of the first page. Write the page number on each page (e.g., 3/6, means page 3 of 6)
  - Write out each problem statement. (i.e., Given=. . . , Find=. . . , Collaborators=. . .)

    For "Collaborators:" list anyone who helped you with the solution. If there are no collaborators just write "none".
  - Use a straight edge (a ruler or a triangle) to draw straight lines.
  - Present solutions to problems in the same order as listed in the assignment, and begin every problem on a new page unless the next solution is so short that it can fit on the same page.
  - Partial credit will be awarded *only* if the solution leading to an incorrect answer describes your thinking in words.
  - Draw a box around your final answer and provide the units associated with your answer (e.g., mm, kN, psi).
  - Staple your solution set.
- **Submission of work:** Submit your on-time solution sets to the CEE 421L IN box in Room 118 Hudson. Do not submit your work to the TA. If your homework is late, or if you have used your extension, submit it to me after class or in my office.
- **Late work:** Grades for solutions to assignments turned in after the time they are due will be penalized ten points for each day late; late penalties are not accrued for weekends or University holidays. For example, if you submit your homework solution before 5:00 on the Monday after a 5:00 Friday due-date, the grade will be penalized 10 points. Assignments submitted after the the solution is posted get no credit. Submit late work to me or under my office door.
- **Grading:** The TA will grade each homework assignment out of 100 points.
- **Graded homework and answer keys:** Graded homework will be placed in the CEE 421L OUT box in Room 118 Hudson. Homework answer keys will be posted outside my office door when graded homework solution sets are returned.

COURSE SCHEDULE

Week	Dates	Topic	Reading
1	8/28 8/30	strain energy, Castigliano's theorems, superposition, examples;	hand out
		flexibility (force) method and stiffness (displacement) method; linearity;	Ch. 1-2
	due 9/7	HW 1: 2.4, 2.8, 2.18, and hand-out problems	hand out
2	9/4 9/6	meaning of flexibility matrix coefficients; introduction to stiffness methods;	hand out
		Maxwell reciprocity experiment and hypothesis test.	hand out
	due 9/14	HW 2: Castigliano theorem problems	hand out
		— PART I. TRUSSES —	
3	9/12 9/13	nodes; displacement and reaction coordinates;	3.1-3.5
		truss bar element stiffness matrix in local and global coordinates;	
		truss stiffness matrix assembly methods (element-wise and column-wise);	3.5-3.8
		partitioning $\mathbf{K_s}$ for displacement unknowns and force unknowns	9.1
	due 9/21	HW 3: 3.1, 3.5, 3.6, 3.9, 3.11, 3.15, 3.20, 3.21	
4	9/18 9/20	examples of the matrix method for truss problems;	3.5-3.8, 9.4
		Matlab implementation for 2-D trusses.	hand out
5	9/25 9/27	geometric stiffness effects in 2-D trusses.	hand out
		3-D trusses.	8.1, hand out
	due 10/5	HW 4: Matlab implementation for geometric stiffness in trusses	
6	** 10/2 **	TEST 1 - The Matrix Stiffness Method for 2D Trusses	
		— PART II. BEAMS —	
	10/4	element and structural coordinates for beams;	5.1-5.2
		shear deformation effects in beam elements;	hand out
		beam element stiffness matrix and column-wise assembly;	5.4-5.5
	due 10/12	HW 5: 5.8, 5.9, 5.12, 5.21, 5.23	
7	10/9	*Fall Recess*	
	10/11	superposition, fixed end forces, and equivalent load vector;	5.5-5.7
		nodal deflections, reactions, and internal forces;	
		beam element end forces, shear and moment diagrams;	
		examples of the matrix method for beam problems	
	due 10/19	HW 6: 5.26, 5.28, 5.34	
8	10/16 10/18	examples of the matrix method for beam problems	
		Matlab implementation for continuous beams	hand out
		eigen-values and eigen-vectors of stiffness matrices	hand out, 9.9
	due 10/26	HW 7: Matlab analyses for 2-D beams	
		— PART III. FRAMES —	
9	10/25 10/25	frame element stiffness matrix in local and global coordinates;	6.1-6.4
		stiffness matrix assembly, fixed-end forces, equivalent load vector,	
		deflections, reactions, and internal forces; temperature effects	
		examples of frames with vertical and horizontal beams	9.2
10	** 10/30 **	TEST 2 - The Matrix Stiffness Method for 2D Beams	6.5-6.6
	11/1	examples of frames with inclined beams:	
	due 11/5	HW 8: 6.7, 6.13, 6.18, 6.27, 6.31, 6.34	
11	11/6 11/8	Matlab implementation for 2-D frames	hand out
		2D frame element geometric stiffness matrix	hand out
		3D frames, coordinate transformations, and the Frame3DD program	8.3
	due 11/13	HW 9: Matlab implementation for 2-D frames	
	due 11/20	HW 10: 8.2, 8.4, 8.11, 8.17 using the Frame3DD program	
		— PART IV. STRUCTURAL DYNAMICS AND BUCKLING —	
12	11/13 11/15	review of single degree of freedom oscillations	hand out
		multi-degree of freedom systems and the generalized eigen-value problem	
13	11/20	natural frequencies, mode shapes, proportional damping	hand out
	11/22	*Thanksgiving Recess*	
	due 12/6	HW 11: Natural modes of vibration	
14	11/27	matrix condensation, shear, temperature, connections, test review	9.3,9.5-9.7
	** 11/29 **	TEST 3 - The Matrix Stiffness Method for 2D Frames	
15	12/4 12/6	buckling of 2D and 3D frames	hand out
	** 12/12 **	*** THE TAKE HOME FINAL IS DUE AT 12:00 PM (NOON) ***	

REFERENCES

Bostok Library Call Numbers: 624.17, 624.171.

1. Allen, H.G., and Bulson, P.S., *Background to Buckling,* McGraw-Hill, 1980. ⋆
2. Arbabi, F. *Structural Analysis and Behavior,* McGraw-Hill, 1991.
3. Dym, C.L., *Structural Modeling and Analysis,* Cambridge University Press, 2005. ⋆
4. Felton, L.P. and Nelson, R.B., *Matrix Structural Analysis,* Wiley,1997.
5. Gaylord, Jr., E.H., *Structural Engineering Handbook, 3rd ed.,* McGraw-Hill, 1990.
6. Hibbler, R.C., *Structural Analysis,* 5th ed., Prentice-Hall, 2002.
7. Kassimali, A., *Matrix Analysis of Structures, 2nd ed.* Brooks/Cole, 2012. ⋆
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10. McGuire, W., Gallagher, R.H. and Ziemian, R.D., *Matrix Structural Analysis,* 2nd ed. John Wiley, 2000.
11. Meek, J.L., *Matrix Structural Analysis,* McGraw-Hill, 1971.
12. Paz, M. and Leigh, W.E., *Integrated Matrix Analysis of Structures - Theory and Computation,* Kluwer Pub., 2001.
13. Przeminiecki, J.S., *Theory of Matrix Structural Analysis,* Dover Press, 1985. ⋆
14. Sack, R.L., *Matrix Structural Analysis,* Waveland Press, 1994.
15. Sennet, R.E., *Matrix Analysis of Structures,* Waveland Press, 2000.
16. Wang, C-K, *Matrix Methods of Structural Analysis,* International Textbook Co., 1970.