FALL 2014
CE 414 – INTRODUCTION TO STRUCTURAL DYNAMICS

CE 414 Catalog Course Description:
This course considers the analysis and design of structures subjected to time-dependent loads. Included is the formulation of dynamic models for single and multiple degree of freedom systems. Deterministic and stochastic responses to shock and environmental loadings (earthquakes, winds, and waves) are developed. Emphasis is given to design applications using existing codes and commercially available structural software.

CE 414 Extended Course Description:
In structural dynamics we start by covering introductory topics of simple vibrations and dynamics of systems (similar to what you may have learned in Physics), then we look at the dynamic response of systems that are forced to move, especially those subjected to seismic ground motion. We will use what we learn about these topics to help us analyze more complex structures, such as multistory buildings, and explore what happens to these systems when "shaken". Towards the end of the semester we will be able to look at how buildings can be designed to safely resist ground motions and about base isolation and damping strategies. Structural dynamics requires learning how to analyze and understand the behavior of systems in motion (which is mainly shaking from side to side for CEEs) as a parallel track to what you know about how to analyze systems at rest with statics. During the semester we will also learn how to use several tools that make our calculations much, much easier. We will use MATLAB to graph solutions and test out different configurations; we will use Excel to solve general loading problems by implementing numerical step methods; and we will use SAP 2000 to look at results for frame applications. My assumption is that no one has used MATLAB, SAP 2000 or even Excel - we will learn these as part of the class work. We will see math in the form of differential ODEs because 2nd order ordinary differential equations are what we get when we sum forces for dynamic systems. However, this is not a problem since it is the same ODE form over and over again and we already know the solution to it. The focus, therefore, in the course is not on the math but on the applications. In addition, the focus of this course is on application of dynamic response theory to structural design, which is different from the focus of dynamics courses taught in other engineering disciplines. *This course will provide students with an understanding of the dynamic response of structures and how designers design structures to safely carry dynamic loads.*

Prerequisite: The background needed for this course is ES 230 Strength of Materials. You do not need to have taken CE 311 Introduction to Structures to take CE 414 Structural Dynamics.

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Lecture: MWF 1:10 pm – 2:00 pm, AEC 243
Office Hours: W & F 9:30 am – 10:30 am; M & W 2:00 pm - 3:00 pm; and T & R 3:00 pm- 4:30 pm
Other times, if the door to my office is open, feel free to stop by and ask questions

Textbook: Chopra, A.K., *Dynamics of Structures*, 4th Ed. (2012), Prentice Hall, ISBN-13: 9780132858038

Course Grade Components and Descriptions

Homework	20%	Exam 1	20%	Exam 3	20%
		Exam 2	20%	Final Exam	20%

Letter Grade Scale: A ≥ 92; 92 > A- ≥ 90; 90 > B+ ≥ 87; 87 > B ≥ 82; 82 > B- ≥ 80; 80 > C ≥70; 70 > D ≥ 60; F < 60

Homeworks:
All assignments should be completed in a professional manner and are due at the beginning of class on the due date. Unless a prior arrangement is made, late assignments will receive a grade of zero. Please attempt and try to solve homework problems on your own. See the instructor if you need assistance in understanding the concepts. Attending the class sessions should make completing the homework an easier task. Collaboration through discussion is permitted, but you have to provide your own solution. Do not duplicate another student's solution or use their solution as an

outline for completing your solution. It is recommended that you use the homework as your chance to test your level of understanding of the course material. Without a solid understanding of the material covered you may find the exam material difficult. Also you are too far along in your college career to have to meet the Dean of Students. You should also plan to tackle class work dealing with the use of Excel, MATLAB, numerical methods, and SAP2000 with same individual effort and spirit. Additional help sessions will be scheduled as needed in support of students who need help beyond the tutorials and instruction sessions.
The only exception to the individual work policy is when students work in groups to complete the two class labs. The groups will perform the lab and then work together to compile the lab results in report form.

Exams:
There will be three exams during the semester in addition to a comprehensive final exam. The three exams will be held out of class in the evenings from 7 – 9 pm. The exams are currently scheduled for Thursday, Sept. 18th, Thursday, Oct. 23, and Thursday, Nov. 20th. Any changes to these exam days will be announced in class.

Expected Workload:
This course requires what is called "*old-fashioned gumption*", as many of your other engineering courses have. There is a lot of work assigned in the course. The work takes many forms, including reading the textbook, working on homework, participating in class and during labs, and studying for exams. The main purpose of individual homework is to help you learn the fundamental topics covered in class. The labs provide the opportunity to gain hands-on experience with experimental system identification methods. There is typically a strong correlation between time spent on individual work and grades on the exams. The amount of out-of-class work required will vary each week, but you should plan to spend between 8 to 10 hours each week solving homework problems, reading course material, or studying for exams. Engineers are known for their intellectual curiosity and their willingness to work and these skills allow engineers to rise to positions of leadership.

Learning Objectives:
Specific learning objectives are defined for each topic to clearly identify the knowledge and skills the student is expected to have learned and mastered. Full understanding of a learning objective is accomplished through in-class and out-of-class work (i.e. notes, discussion, labs, reading assignments, homework, and exams). Individual assignments will assess the acquisition of the identified knowledge and skills for each student.

Class Participation: Your learning will take place both during and outside of formal class times. You are expected to participate during class discussions in addition to asking and answering questions and working effectively with your peers on in-class activities.

CE 414 Student Outcomes:
Upon completion of this course, students will:
1. Describe underlying assumptions in dynamic analysis and idealize (model) structural properties, geometry and loading for the purpose of analysis.
2. Solve simple dynamic problems, including those involving free fall, drag, and harmonic vibration, using dynamic equations of motion.
3. Model and analyze single degree of freedom (SDOF) undamped and damped systems in free vibration.
4. Describe the effect of damping on the dynamic response of SDOF systems.
5. Model and analyze SDOF undamped and damped systems that are subjected to forced vibrations, which include harmonic, step, impulse and general loads, using classical and numerical methods in order to predict displacement, velocity, and acceleration response as a function of time.
6. Model and analyze SDOF undamped and damped systems that are subjected to seismic ground motion time history using numerical methods in order to predict displacement, velocity, and acceleration response as a function of time.
7. Construct an elastic response spectrum for a given seismic ground motion time history and understand the behavior of SDOF systems subjective to seismic ground motions.
8. Demonstrate a basic understanding of numerical methods appropriate to solve linear and nonlinear 2nd order differential equations using MATLAB and Excel.
9. Describe nonlinear material behavior and the difference between linear and nonlinear response of structures.
10. Model multi-degree of freedom systems using mass, damping and stiffness matrices based on discrete formulation of equations of motion.

11. Solve eigenvalue problems using MATLAB to obtain the modal frequencies and mode shapes for MDOF systems in free vibration.
12. Demonstrate an understanding of how mode shapes and frequencies can be used to understand the dynamic response of a structure.
13. Describe the methods available to solve the equations of motion for MDOF systems, including coupled equation solvers, modal superposition methods and uncoupled equation solvers, and response spectrum methods.
14. Describe the process of modal superposition for MDOF systems and the property of orthogonality.
15. Model and analyze MDOF damped systems using modal superposition and elastic response spectrum methods in order to predict displacement, velocity, and acceleration response as a function of time.
16. Analyze MDOF damped systems using modal superposition and elastic response spectrum methods in order to predict story drifts, story shear, base shear, and overturning moments as a function of time.
17. Demonstrate a basic understanding of seismology and seismic ground motion, the influence of site characteristics on ground motions, and the influence of structural characteristics on structural response to ground motion.
18. Describe design strategies implemented to control the response of structures, including base isolation and passive mass dampers.
19. Model and analyze frame structures in SAP 2000 using time history analysis and response spectrum analysis and obtain design displacements, shears and moments.
20. Demonstrate the ability to acquire experimental data using accelerometers and force generators using data acquisition systems and to use the collected data to identify structural properties, including structural damping, mass and stiffness.
21. Demonstrate having acquired the background knowledge necessary to pursue graduate studies in structural engineering and/or contribute to the practice of structural engineering as an introductory consulting engineer.

Engineers Have Attitude:
In addition to focusing on picking up basic knowledge and developing technical skills required to solve engineering problems, such as problem solving, critical thinking, teamwork, and communication, there is another goal of all engineering courses. This is to promote an **"engineering attitude"**. The characteristics of having a solid engineering attitude are accepting mistakes, having common sense, patience, ethics, high standards, confidence, persistence, curiosity, flexibility, and understanding that there is not always a single right answer. Students with an engineering attitude possess a well-founded confidence in their ability to solve both routine and novel technical problems.

Students with Disabilities**:** The Americans with Disabilities Act (ADA) is a federal anti-discrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all students with disabilities be guaranteed a learning environment that provides for reasonable accommodation of their disabilities. If you believe you have a disability requiring an accommodation or require assistance with academic concerns/accommodations, please contact the Office of the Dean of the College, 200 Scott Hall (610-330-5080). The college policy regarding student disabilities can be found at this website: http://attic.lafayette.edu/disability-services/ and will be adopted in this course.

Academic Integrity Statement**:** "Students are expected to be honorable, ethical, and mature in every regard"
Just as ethical conduct is an essential part of the engineering profession, academic integrity is essential to ensure a fair and positive learning environment. No form of scholastic misconduct will be tolerated. Academic dishonesty includes cheating, fabrication, falsification, plagiarism, copying homework from other students (even if you have received their permission) or from a solution, etc. It is the student's responsibility to comply with the *Lafayette College Student Handbook* (http://studentlife.lafayette.edu/resources/) and to be familiar with the *Principles of Intellectual Honesty* (http://fye.lafayette.edu/academics/). Violations will be handled in accordance with the Procedural Standards in Disciplinary Proceedings outlined in the *Student Handbook*.

> *"I give you two examinations, one in trigonometry and one in honesty. I hope you pass them both, but if you must fail one, let it be trigonometry for there are many good people in this world today who cannot pass an examination in trigonometry, but there are no good people in the world who cannot pass an examination in honesty"*
> *- Vanderbilt Univ. past-Chancellor Madison Sarratt*

Course Topics:

The topics listed below are tentative and may be modified by the instructor during the semester. Students will be advised in a timely manner of assignments, due dates, required readings, and any help sessions offered. If you have questions during the semester, please ask me during class, stop by my office and/or email me (raicha@lafayette.edu).

Class		Date	Tentative Topic (Subject to Change)	Reading
1	M	8/25	Intro/Syllabus/Motivation/Statics vs. Dynamics	
2	W	8/27	Newton's Laws and Equations of Motion/Free Fall and Drag	
3	F	8/29	If Free Fall is a Drag, How About Bungee Jumping? Approx. Methods	
4	M	9/1	Numerical Methods – Solving Free Fall, Drag, Bungee Problems	
5	W	9/3	Modeling of Dynamic Problems – Loads, Models, Equation of Motion	
6	F	9/5	Modeling of SDOF Systems – Mass, Stiffness and Equation of Motion	All of Chapter 1
7	M	9/8	Free Vibration of SDOF Systems – Undamped	2.1
8	W	9/10	Free Vibration of SDOF Systems - Damped	2.2
9	F	9/12	MATLAB 101 – SDOFs: Plotting, ODEs and You	
10	M	9/15	System ID – Characterization of SDOF System Properties (k, m, and ξ)	
11	W	9/17	Forced Vibration - Harmonic Loading and SDOF Systems - Undamped	3.1
	R	9/18	Exam I from 7 - 9 pm	
12	F	9/19	Forced Vibration - Harmonic Loading and SDOF Systems - Damped	3.2
13	M	9/22	Force Transmitted to Foundation and Response to Support Motion	3.5, 3.6
14	W	9/24	Impulse Loading and Rectangular or Step Loading and SDOF Systems	4.1-4.9
15	F	9/26	General Loading (Ramp, Triangle, Half Sine, Periodic) and SDOF	4.1-4.9
16	M	9/29	Seismic Hazards and Risk & Seismic Response of Buildings	6.1
17	W	10/1	Base Excitation (Ground Motion) and SDOF Systems	4.12, 6.2
18	F	10/3	Numerical Methods and Solving Base Excitation SDOF Systems	5.1, 5.4
19	M	10/6	Numerical Methods and Solving Base Excitation SDOF Systems - Excel	5.5
20	W	10/8	Response Spectrum Construction	6.3-6.6
21	F	10/10	Design Spectrum and Seismic Building Codes	
	M	10/13	*Fall Break*	
22	W	10/15	Numerical Methods & Solving General Excitation SDOF Systems-Excel	6.7-6.9
23	F	10/17	MATLAB 202 – Solving SDOFs with Numerical Methods	
24	M	10/20	Nonlinear Materials and Inelastic Response of SDOF Systems	5.7, 7.1, 7.3, 7.4
25	W	10/22	Generalized Systems – from SDOF to MDOF	8.3, 8.4
	R	10/23	Exam II from 7 – 9 pm	
26	F	10/24	Modeling of MDOF Systems – Mass, Stiffness and Eqns. of Motion	9.1, 9.2
27	M	10/27	Modeling of MDOF Systems – **M**, **K**, EOMs, Mode Shapes,	10.1-10.5
28	W	10/29	MATLAB 303 –Eigenvalues and Eigenvectors	
29	F	10/31	Mode Shapes and Frequencies – What Do They Tell Us?	10.6, 10.7
30	M	11/3	Modal Superposition – Uncoupling of Coupled Equations	12.3,12.4
31	W	11/5	Free Vibration of MDOF Systems	10.8
32	F	11/7	Classical Damping and MDOF Systems – **c** and ξ	10.9,11.1-11.4
33	M	11/10	Modal Response Contributions	12.8-12.11
34	W	11/12	Forced Vibration of MDOF Systems	
35	F	11/14	Base Excitation and MDOF Systems –Time History	13.1, 13.2
36	M	11/17	Base Excitation and MDOF Systems –Time History	
37	W	11/19	Base Excitation and MDOF Systems –Response Spectrum	13.7,13.8,12.5,12.6
	R	11/20	Exam III from 7 – 9 pm	
38	F	11/21	Base Excitation and MDOF Systems – Shear and Moment Calcs	
39	M	11/24	MATLAB 404 – MDOF Coupled Equations Numerical Methods	
	W/F	11/26&28	*Thanksgiving Break*	
40	M	12/1	System ID – Characterization of MDOF System Properties	
41	W	12/3	SAP2000 - SDOF/MDOF Systems and Time History/Response	
42	F	12/5	Impact of Retrofit Strategies/Base Isolation/Tuned Mass Damper	12.2, 21.1-21.4
			Final TBD	

"If you like challenges, there's no greater time to be alive"- Lester Brown

Federal Credit Hour Compliance:
The student work in this course is in full compliance with the federal definition of a four credit hour course. Please see the Registrar's Office website for the full policy and practice statement.
http://registrar.lafayette.edu/files/2013/04/Federal-Credit-Hour-Policy-Web-Statement.doc

Assignment Policies:
Assignments will be collected at the beginning of class on the date due. Late work will be accepted **only** by making a **prior** arrangement with the instructor either during office hours or by email, subject to Lafayette College Dean's Excuse Policy outlined in section 7.3.2 of the Faculty Handbook under the heading Class Attendance

- This class emphasizes developing skills in problem solving. All homework involving calculations should be submitted on engineering paper (one side only) in a professional manner, which includes neat handwriting and organization. Therefore, neatness, clarity, and the ease that others have in understanding your work is important and will considered as part of your grade. The following should be provided in the homework:
    - Provide a description of the problem being solved and any assumptions made.
    - Provide clearly drawn figures and FBDs that include dimensions and necessary labels. Use some type of straight edge when drawing figures and FBDs.
    - Clearly identify the analysis steps you are taking and the calculations you are making in each step. Include units on all calculated values and make sure to check your units throughout the analysis process.
    - Provide a summary of your final answers and make a statement as to whether your answer(s) seems reasonable, i.e. 12 inches is not a velocity; 1" is a reasonable displacement for this system; 2 million kips of force is probably not correct, but I don't know where my mistake is.
- Unless otherwise stated, all homework in this class are expected to be individual work. Copying the work of others, including homework, is in violation of the College's Principles of Intellectual Honesty, which can be accessed at http://www.lafayette.edu/academics/honesty.pdf. You may discuss the homework assignments with other students. All work submitted, however, must be your own and it is your responsibility to properly acknowledge the source of ideas and facts received from others, including other students. A student who commits academic dishonesty is subject to a range of penalties, including suspension or expulsion. The primary purpose of homework is to facilitate learning about behavior not just having a solution to turn in.
- Discussions about re-grading of assignments are not conducted in person or by email. If you would like to request re-grading, attach a signed statement to your work that details where you feel you lost points and submit it to the professor within one week after the assignment or lab has been returned.

Software Used for this Class:
The CE Lab computers have Microsoft Excel, MATLAB, and SAP2000 installed, which you can use to complete the homework assignments and labs. Over the course of the semester you will learn how to make pretty decent plots, how to find eigenvalues and eigenvectors of matrices, how to solve ordinary differential equations (ODEs), and how to solve systems of ODEs with MATLAB. All of these will turn out to be quite simple to do with MATLAB.