CEE 598 – Reliability Analysis
Spring 2019

Instructor Paolo Gardoni, Ph.D.
Office 3118 Newmark
Email gardoni@illinois.edu
Office Hours Tu. and Th. 11:45 AM – 12:30 PM

TA Hao Xu
Office 1239 Newmark
Email haoxu3@illinois.edu
Office Hours Mon. and Wed. 3:00 PM – 4:00 PM in 1233 Newmark

Lecture Tu. and Th. 12:30 PM – 1:50 PM in 2311 Newmark

Prerequisites CEE 491

Course Description

Introduction to applied probability theory and random processes, Bayesian analysis of model uncertainties. Formulation of reliability for components and systems. Exact solutions for special cases. Approximate solutions by second-moments, first- and second-order reliability methods (FORM and SORM), the response surface method, simulation methods. Reliability-based optimal design and probabilistic design codes. Time- and space-variant reliability formulations.

Course Objectives

To offer a comprehensive and in-depth review of modern methods for reliability assessment, analysis of the propagation of uncertainties, probabilistic design codes, and the probabilistic basis for performance-based design. Students will use computer codes to apply the concepts learned to example problems. Students completing this course should be able to read and understand the large and growing literature in the field of reliability and risk analysis, as well as be able to make use of existing reliability analysis codes, such as CalREL, FERUM, OpenSees, NESSUS, PROBAN and STRUREL. Although some examples will emphasize structural engineering applications, methods discussed in this course have broad applicability and can be used in many disciplines where probabilistic analysis is needed.

Suggested Textbook

Ditlevsen, O., and H.O. Madsen (1996). *Structural reliability methods*. J. Wiley & Sons, New York, NY.
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.121.3682&rep=rep1&type=pdf

Additional resources on probability, Bayesian statistics, uncertainty analysis, and model estimation

Benjamin, J.R., and C. A. Cornell (1970). *Probability, statistics and decision for civil engineers*. McGraw-Hill, New York, NY.

Bard, Y. (1974). *Nonlinear parameter estimation*. Academic Press, Orlando, Florida.

Ditlevsen, O. (1981). *Uncertainty modeling*. McGraw-Hill, New York, NY.

Rubenstein, R. Y. (1981). *Simulation and the Monte Carlo method*. J. Wiley, New York, NY.

Box, G. E. P., and Tiao, G. C. (1992). *Bayesian inference in statistical analysis*. Addison-Wesley, Reading, Mass.

Stone, J. C. (1996). *A course in probability and statistics*. Duxbury Press, Belmont, California.

Ang, A. H-S., and W-H Tang (2007). *Probability Concepts in Engineering: Emphasis on Applications to Civil and Environmental Engineering*. John Wiley, New York, NY.

Additional resources on structural reliability

Hart, G. C. (1982). *Uncertainty analysis, loads, and safety in structural engineering*. Prentice-Hall, Englewood Cliffs, NJ.

Thoft-Christense, P., and M. Baker (1982). *Structural reliability theory and its applications*. Springer-Verlag, Berlin, Germany.

Augusti, G., A. Baratta and F. Casciati (1984). *Probabilistic methods in structural mechanics*. Chapman and Hall, London, UK.

Thoft-Christense, P., and Y. Murotsu (1986). *Applications of structural system reliability theory*. Springer-Verlag, Berlin, Germany.

Madsen, H. O., S. Krenk and N. C. Lind (1986). *Methods of structural theory and its applications*. Prentice-Hall, Englewood Cliffs, NJ.

Wen, Y. K. (1990). *Structural load modeling and combination for performance and safety evaluation*. Elsevie, Amsterdam, The Netherlands.

Ayyub, B. M., and R. H. McCuen (1997). *Probability, statistics & reliability for engineers*. CRC Press, New York, NY.

Melchers, R.E. (1999). *Structural reliability: analysis and prediction*. 2nd Edition, John Wiley, New York, NY.

Haldar A. and Mahadevan S. (2000). *Probability, Reliability and Statistical Methods in Engineering Design*. John Wiley & Sons, New York, NY.

Gardoni, P., (Ed.) (2017). *Risk and Reliability Analysis: Theory and Applications*, Springer.

Gardoni, P., (Ed.), (2019). Routledge Handbook of Sustainable and Resilient Infrastructure, Routledge.

Computer Programs

Several computer programs for reliability analysis are available. Selection of software will be discussed in class.

Homework Problems

Homework problems will be given every Thursday. They will be assigned for the first seven consecutive weeks of the semester starting from Thursday, January 24. They will be due by 12:30 PM of the following Thursday submitted as hard copies at the beginning of class. The homework statements and solutions will be posted on Compass2g.

Students are encouraged to use MATLAB, Mathematica, Mathcad, Python or Excel in preparing their solutions.

The homework assignments will count 20% towards the course grade.

Exams

There will be one midterm examination on Thursday, March 28. This exam will count 35% towards the course grade.

Term Project

Each student is required to submit an individual term project. The term project will count 45% towards your course grade. The topic should be selected based on your personal interest and discussed with me for approval. You should receive my approval before proceeding with the work.

An abstract of the term project is due on Thursday, March 14. The abstract has to state the title of the project, the name of the investigator, and a 200-word description of the proposed work including its main objectives, the technical approach to be used, and the expected results.

A progress report describing your weekly <u>progress</u> on the project is due each Thursday after the due date of the last homework. A term paper is due by 5:00 PM on Sunday, May 5. It should be in a typed form and in sufficient detail to allow evaluation of its merits (a template will be provided).

Grading

- Homework 20%
- Midterm Examination 35%
- Term Project 45%

Course Topics

Motivation: The need to take uncertainties into account, the use of reliability methods in engineering practice

Types of uncertainty: A review of various types of uncertainties, classified as either "aleatory" or "epistemic" in nature

Elementary set theory: Random events, Venn diagrams, union and intersection of events

Elementary rules of probability: The three basic axioms of probability, total probability theorem, Bayes' rule, and the inclusion-exclusion rule

Partial descriptors of random variables: The concept of random variable, probability distributions, mean, standard deviation, measures of skewness, and the concept of moments

Univariate probability distribution models: Normal, lognormal, uniform, exponential, gamma, etc.

Data analysis: Mean and standard deviation of observations, assessment of probability distribution based on observations, goodness of fit, Bayesian statistics

Multiple random variables: Correlation, multivariate distribution functions, multivariate probability models

Functions of random variables: How to obtain the probability distribution for the function, exact cases, first- and second-order approximations

Formulation of the reliability problem: Limit-state functions, capacity and demand safety format, component vs. system reliability problems

The first-order second-moment method (FOSM): Geometrical reliability index, early developments of reliability methods, the invariance problem

The first-order reliability method (FORM): Solution of the invariance problem, the generalized reliability index, determination of the most likely failure point, linearization of the limit-state surface

Parameter importance measures: Ranking of the random variables according to relative importance, identification of "resistance" and "load" variables

The second-order reliability method (SORM): Approximation of the limit-state surface by a paraboloid, determination of curvature

Sampling methods: Mean-centered Monte Carlo sampling, importance sampling, other sampling techniques

Response surface methods

System reliability problems: The case of multiple limit-state functions, formulation and solution of system reliability problems, series and parallel system bounds

Reliability analysis under parameter uncertainties

Fragility analysis

Response sensitivity analysis: The need for sensitivities, review of the direct differential method

Random fields

Random processes: Environmental loads, elementary concepts of random vibrations

Time and space-variant reliability problems

Reliability-based optimization: Formulation of objective function and constraints, solution techniques

Probability-based design: Introduction to codes and RBD, uncertainty modeling, target reliabilities, code calibration

Topics may vary based on time and interest of the students

Academic Integrity

- The University of Illinois at Urbana-Champaign requires all students to adhere to the Student Code [see Part 4 on Academic Integrity, Part (d) on Plagiarism] www.admin.uiuc.edu/policy/code/index.html
- It is NOT acceptable to copy another student's work and represent it as your own.
- It is NOT acceptable to work problems as a group unless specifically authorized in the written assignment.
- You MAY speak with other students about the problem and methods of solutions, sticky points, etc.
    - But you MUST create-write your own solutions independently of others.
    - Solutions with similar appearance will receive a 0 score followed by consideration of other disciplinary actions.

Copyright Statement

The handouts used in this course are copyrighted. By "handouts," it is meant all materials that have been generated for this course. Such materials include but are not limited to syllabi, quizzes, exams, problem sets, worked problems, materials posted on Compass2g, in-class materials, review sheets, additional problem sets, and solutions. Because these materials are copyrighted, you do not have the right to copy them, or possess copies of them outside of the normal course uses for which they were intended. Certain violations of these copyrights could be treated as violations of academic integrity.

American with Disabilities Act

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. To obtain disability-related accommodations for this class, students with disabilities are advised to contact me and the Division of Rehabilitation-Education (DRES) as soon as possible.