Spring 2018

FRACTURE MECHANICS

CVEN-6831/7161

T-Th 2:00-3:15 ECCE-1B47

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ECOT450; 2-1622

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Target This course addresses the need of students interested in: a) Fundamental understanding of fracture mechanics starting from continuum mechanics; b)Understanding failure and size effects; c)role of fracture mechanics in understanding design and analysis of flawed or potentially flawed components; d) forensic engineering.

Open to M.S. and PhD students.

Course description: In most structures (Civil, Mechanical, Aerospace), failure is directly or indirectly related to fracture. This course will blend theoretical (50%) computational (20%), and material (30%) aspects into a course geared for students interested in exploring the analysis of fracture based failures. Very heavy emphasis will be placed on independent work/project/presentations.

Meeting prerequisites: Mechanics of Materials, Finite element. The course will start with a brief review of continuum mechanics and elasticity. Mathematica will be extensively used throughout the course.

Schedule: T-Th: 3:30-4:45

Textbooks: Recommended, (but not required):
Anderson, T.L., *Fracture Mechanics; Fundamentals and Applications*, CRC Press, third Edition. Lecture notes will be provided.

Assignments: There will be approximately 5 homework assignments, a term paper, a term project and one exam. The term paper and project may be related to a student research interest or industrial application. Examples of past projects.

Instructor: Has been involved in theoretical, numerical and experimental fracture mechanics for over 30 years. His research has been applied to dams, nuclear reactors, solid-rocket propellants, and metal fatigue. He is past President of the international Association of Fracture Mechanics of Concrete FraMCoS. This course has been offered in Boulder, Milan, Barcelona, Lausanne and Paris.

Enrollment: Only students registered for the course could attend the lectures (sorry no auditing)

Outcome After completion of this course, you would have strengthen your basic understanding in Mechanics (and Mathematica), acquired the knowledge to conduct forensic studies in the investigation of failures/accidents and to understand the true strength of many materials.

Tentative Course Outline (not necessarily in this order)

Following is the *tentative* course outline. Coverage may vary depending on student interests.

I Introduction

1. Historical Overview
2. Stress based failure theories
3. Design Philosophies

II Review of Mechanics ($\sim$ 1-2 weeks) Review of the fundamental relations in Mechanics using tensor (indicial) notation: Strain, Strain, Equilibrium, Compatibility, Hooke's Law, Airy Stress Function, Complex Functions using Mathematica.

III Linear Elastic Fracture Mechanics: ($\sim$ 2 weeks)

1. Elastic Crack Tip Stress Field: Stress around an Elliptical Hole (Inglis, 1913), Complex Stress Functions (Westergaard, 1939), Bi-Material (Williams, 1959).
2. Stress Intensity Factors (Irwin, 1957): Elliptical Cracks, Design Philosophy (Example)
3. Energy Principles (Griffith, 1921): Ideal Fracture Strength (?), Griffith's Theory (Griffith, 1924), Energy Release Rate, G_c and R Curves, Compliance Calibration Method (Mostovoy, 1967).
4. Fracture of Anisotropic Bodies: Basic Equations of Anisotropic Elasticity (Lekhnitskii), Stress Analysis (Sih, Paris, and Irwin, 1965).
5. Mixed Mode Crack Propagation: Maximum Circumferential Tensile Stress (Erdogan, 1963), Maximum Strain Energy Release Rate (Hussain et al. 1974), Minimum Strain Energy Density (Sih, 1974), Anisotropic Materials (Saouma, Ayari, Leavell, 1986).

IV Elasto-Plastic Fracture Mechanics: ($\sim$ 1 Week)

1. The Crack Tip Plastic Zone: First and second Order Approximation (Irwin), Dugdale and Barenblat's models, Multiaxial Stress Based (Von-Mises, Tresca); Plane Stress versus Plane Strain.
2. Crack Tip Opening Displacements (Wells)
3. Energy Methods: J Integral Derivation (Rice); Variations on Original J Formulation, J-R Concept, EPRI method.

V Fracture Toughness Testing: ($\sim$ 1 week)

1. Fracture toughness (ASTM E399)
2. Fracture Energy (RILEM, ISRM)

VI Subcritical Crack Growth: ($\sim$ 1 week)

1. Fatigue Models: Paris Law (Paris, 1963), Forman Law (Forman, 1967), Walker's Law, Table Look-Up.
2. Other: Mixed Mode Fatigue Crack Growth, Fatigue Life Prediction, Variable Amplitude Loading,
3. Load Interaction, Retardation Model: Wheeler, Generalized Willenborg
4. Corrosion

VII Numerical Methods: ($\sim$ 2 weeks)

1. Isoparametric singular element: Original Formulation (Barsoum), Subsequent Extensions, Assesment of Singular Isoparametric Elements (Fawkes et al.).
2. Extraction of SIF: Nodal Displacement Based: Without Singular Elements (Displacement Extrapolation) With Singular Elements (Displacement Correlation Method), Energy Based Methods: Energy Release Rate, Virtual Crack Extension (Park), Virtual Crack Extension (Sha), J_1 and J_2 Integrals (Hellen and Blackburn), Mutual Potentials (Stern & Becker), Surface Integral (Babuska)
3. Elasto-Plastic Analysis, J Integral
4. Fracture of cementitious materials: Fictitious Crack Model, (Hillerborg 1976), Size Effect Law (Bazant, 1984), ICM (Červenka and Saouma, 1994), Crack Band Model (Bažant, LEFM and NLFM (Fictitious Crack Model), (Reich 1992)

5. Lattice Model.

VIII Applications And Case Studies: (∼ 4 weeks)

1. Concrete: Applications to nuclear power containment vessels: Creep fracture, Transport (gas and liquid) in porous media, permeability, hydro-mechanical behavior.
2. Rock: Blasting; Hydro-fracturing.
3. Metals (connections under seismic excitation).
4. Solid rocket propellants (polymers).

Past Term Projects

Can be viewed here.

- Analysis Of Butt Welded Joints
- Cohesive Crack Models
- Cohesive Cracks For Interfaces
- Concrete Under High Temperatures
- Concrete Fracture
- Crack Between 2 Dissimilar Materials
- Crack Detection Location With White Noise Vibration
- Crack Propagation In Draw Cylinder
- Crack Propagation In Aluminium Panels
- Dynamic Fracture Mechanics
- Fatigue Crack Propagation With Retardation
- Fatigue Crack Propagation
- Fracture Mechanics Based Simulation Of Anchors
- Fracture And Fractals
- Fracture In Solid Rocket Propellants
- Fracture Mechanics Of Bond In reinforced concrete
- Fracture Mechanics Partition Unity Method
- Fracture Steel Connection Under Earthquake Load
- Fracture Testing Of Concrete
- Indentation Of Rock; Numerical Simulation
- Numerical Fracture Simulation Of Porous Sintered Steels
- Size Effects On Shear Strength
- Slope Stability
- Fracture and flow (liquid and/or gas).

Selected Bibliography

1. Anderson, T.L., *Fracture Mechanics; Fundamentals and Applications*, CRC Press, 1995.
2. Atkins, A.G., and Mai, Y.W., *Elastic & Plastic Fracture*, John Wiley, 1985.
3. Broek D., *The Practical Use of Fracture Mechanics*, Kluwer Academic Publishers, 1989.
4. Broek D., *Elementary Engineering Fracture Mechanics*, 4th Revised Edition, Martinus Nijhoff Publishers, 1986.
5. Cherepanov G.P., *Mechanics of Brittle Fracture*, McGraw Hill, 1979.
6. Hertzberg, *Deformation and Fracture Mechnaics of Engineering Materials*, Fifth Ed., J. Willey.
7. Hudson, C.M. and Rich, T.P. (Eds.) *Case Histories Involving Fatigue and Fracture Mechanics*, ASTM STP918, American Society for Testing and Materials, Philadelphia, 1986.
8. Kanninen, M.F., and Popelar, C.H., *Advanced Fracture Mechanics*, Oxford Engineering Science, Series 15, 1985.
9. Knott, J.F., *Fundamentals of Fracture Mechanics*, Halsted Press/John Wiley & sons 1973.
10. Liebowitz (Ed.), *Fracture -An Advanced Treatise*, Academic Press, 1968.
11. Owen, D.R., and Fawkes, A.J., *Engineering Fracture Mechanics Numerical Methods and Applications*, Pineridge Press, 1983.
12. Suresh, S., *Fatigue of Materials*, Cambridge University Press, 1991.
13. Tada and Irwin, *Stress Analysis of Cracks*, Del Research Corp.
14. Journals: Engineering Fracture Mechanics, International Journal of Fracture, Fatigue.

COMPUTER PROGRAMS AVAILABLE

Extensive usage of the Bechtel Lab will be made through the following computer programs:

1. Mathematica, Matlab
2. Merlin (Saouma's group)
3. Abaqus