ME:5159 FRACTURE MECHANICS

Spring 2020

Instructor: Professor Sharif Rahman, 2140 SC, 335-5679
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Lecture: 1:30 - 2:20 pm, MWF, 4030 SC

Office Hours: 2:30 - 3:30 pm at 2140 SC, MWF and by appointment

Website: http://user.engineering.uiowa.edu/~me159

Pre-/Co-reqs: ENGR:2750 (pre-req); ME:3052 or equivalents (co-req)

Textbook:

1. Rahman, S., Lecture Notes: Fracture Mechanics, 2020. (Available at Iowa Hawk Shop, IMU, (319) 335-3874)

References:

1. Anderson, T. L., Fracture Mechanics: Fundamentals and Applications, 3rd Edition, CRC Press, Boca Raton, FL, 2005. [Engrg. Library]
2. Hertzberg, R. W., Deformation and Fracture Mechanics of Engineering Materials, 5th Edition, John Wiley & Sons, Hoboken, NJ, 2013. [Engrg. Library]
3. Kanninen, M. F. and Popelar, C. H., Advanced Fracture Mechanics, Oxford University Press, New York, NY, 1985. [Engrg. Library]
4. Saxena, A., Nonlinear Fracture Mechanics for Engineers**,** CRC Press, Boca Raton, FL, 1998. [Engrg. Library]
5. Stephens, R. I., Fatemi, A., Stephens, R. R., and Fuchs, H. O., Metal Fatigue in Engineering, 2nd Edition, John Wiley & Sons, NY, 2000. [Engrg. Library]
6. Dowling, N. E., Mechanical Behavior of Materials: Engineering Methods for Deformation, Fracture, and Fatigue, 4th Edition, Boston, MA, 2013. [Engrg. Library]

Catalog Data: 3D stress states, definition and criteria for failure, nominal and local yield phenomena, linear-elastic and elastic-plastic fracture mechanics, plane stress and plane strain fracture toughness, J-integral, crack-opening displacement, environmental assisted cracking, fatigue crack growth, fail safe, and damage tolerant design.

Course Objectives

1. Students will have the knowledge of 2D and 3D field equations of elasticity, material yield criteria, stress concentrations, and introduction to the finite element method.

2. Students will have a fundamental understanding of linear-elastic fracture and will able to solve elementary linear-elastic fracture-related problems.

3. Students will be able to analyze stationary cracks and perform crack propagation in 2D linear-elastic mechanical components of arbitrary geometry using commercially available finite element software.

4. Students will have an understanding of crack-tip plasticity and elastic-plastic fracture and will able to solve practical elastic-plastic fracture problems using J-estimation methods.

5. Students will be able to analyze planar cracks in 3D elastic-plastic mechanical components using commercially available finite element software.

6. Students will have an elementary knowledge of fatigue crack growth and will be able to conduct fatigue life prediction of simple mechanical components under constant-amplitude loading.

Course Outline (44 Meetings)

1 Introduction

1. Relevance, Motivation, and Examples

2 Review of Elasticity Theory, Stress Concentration, and FEM

2. 3D Elasticity Equations in the Cartesian System
3. 2D Elasticity Equations in the Polar System and Yield Criteria
4. Stress Concentration in Mechanical Components
5. Formulation of 2D Finite Element Analysis
6. Introduction to CASCA/FRANC2D and Computer Project No. 1
7. Computer Project No. 1 (Contd.)
8. Computer Project No. 1 (Contd.)

3 Linear-Elastic Fracture Mechanics (LEFM)

9. Stress-Intensity Factors (SIFs), Crack-Tip Fields, and Energy Release Rate
10. SIFs for Common Fracture Specimens
11. Singular Finite Elements
12. Computational Methods for Evaluating SIFs
13. Fracture Toughness, SIF as a Failure Criterion, and Examples
14. 2D Fracture Analysis by CASCA/FRANC2D and Computer Project No. 2
15. Computer Project No. 2 (Contd.)
16. Computer Project No. 2 (Contd.)
17. Principle of Superposition in LEFM
18. Fracture Analysis of Fuselage Lap Joints: Aircraft Industry
19. Mixed-Mode Fracture Analysis and Crack Trajectory Prediction
20. 2D Crack Propagation by CASCA/FRANC2D and Computer Project No. 3
21. Computer Project No. 3 (Contd.)

4 Elastic-Plastic Fracture Mechanics (EPFM)

22. Crack-Front Process Zone and Limitations of LEFM
23. The *J*-integral, HRR Singularity Fields, and Validity of *J*
24. Pipe Fracture Evaluations by the GE/EPRI Method
25. Fracture Analysis of Ductile Piping: Nuclear Industry
26. Pipe Fracture Evaluations by Limit-Load Analysis
27. 3D Fracture Analysis by ABAQUS/CAE and Computer Project No. 4
28. Computer Project No. 4 (Contd.)
29. Computer Project No. 4 (Contd.)
30. Computer Project No. 4 (Contd.)
31. Crack-Opening-Area (COA) Analysis by the GE/EPRI Method
32. Leak-Rate Analysis and NRC Leak-Before-Break Concept
33. An Example on Leak-Before-Break Analysis

5 Fatigue Crack Propagation

34. Subcritical Crack Propagation and Various Crack-Growth Equations
35. Life Prediction under Constant Amplitude Loading
36. Crack Closure, Variable Amplitude Loading, and Crack-Tip Plasticity
37. Life Prediction by CASCA/FRANC2D and Computer Project No. 5
38. Computer Project No. 5 (Contd.)
39. Computer Project No. 5 (Contd.)
    + **[1 class for video on experimental fracture]**
    + **[2 classes for examinations]**
    + **[2 classes for reviews]**

Performance Evaluation Criteria

A. Homework and Project Assignments

- The assigned homework problems and computer projects should be worked out and submitted to the instructor in a professional format at the beginning of the lecture period. Include your name, course title, assigned homework/project problem numbers in the heading of your paper. The dates of assignments and their due dates are given in the attached assignment sheet (Page 5).

- Your homework/project solution must be submitted individually. No group submission or copies are permitted. If a copy is detected, a zero score will be assigned to all papers in question. You are advised to obtain help from the instructor or the TA.

- Unless appropriate reason(s) is (are) given, late submission will not be accepted.

B. Examination Policy

- There will be two examinations (Examinations 1 and 2) in this course. Both will be closed-book examinations. The tentative schedules for the examinations are:

  Examination 1: 1:30-2:20 pm, March 13, 2020, Fri at 4030 SC
  Examination 2: 1:30-2:20 pm, May 08, 2020, Fri at 4030 SC

  (The exact date/time/place will be confirmed or revised during the semester)

- If any of these examinations is missed, the instructor will use his discretion in choosing alternative means to evaluate student's performance. This can be a make-up examination, oral examination, or both.

C. Grading Policy

- A student must turn in all HW/CP solutions to receive a passing grade.

- The letter grade for this course will be based on the student's overall performance on homework assignments and computer projects; midterm; and final examinations. The distribution of points is as follows:

1.	Homework Assignments	25 percent
2.	Computer Projects	25 percent
3.	Examination 1	25 percent
4.	Examination 2	25 percent

- The final grade will be posted on the web at the end of the semester.

Assignment Sheet for ME:5159 Fracture Mechanics (Spring 2020)

Wk.	Mtg. (Lec.)	Date	Topics/Reading[(a)]	HW/CP	Due Date
1	1 (1)	Jan 22, Wed	Introduction (1-12)		
	2 (2)	Jan 24, Fri	Review of Elasticity Theory (88-91)		
2	3 (3)	Jan 27, Mon	Review of Elasticity/Yield Criteria		
	4 (4)	Jan 29, Wed	Stress Concentration	HW1	Feb 10, Mon
	5 (5)	Jan 31, Fri	FEM – 2D Elasticity Problems (554-556)		
3	6 (6)	Feb 03, Mon	CP1 – Stress Concentration (27-28)	CP1	Feb 17, Mon
	7 (7)	Feb 05, Wed	CP1		
	8 (8)	Feb 07, Fri	CP1/HW1		
4	9 (9)	Feb 10, Mon	Stress Analysis of Cracks (42-48, 72-75)		
	10 (10)	Feb 12, Wed	SIFs for Fracture Specimens (48-53)		
	11 (11)	Feb 14, Fri	Singular Finite Elements (587-591)		
5	12 (12)	Feb 17, Mon	Numerical Evaluation of SIFs (558-586)	HW2	Feb 28, Fri
	13 (13)	Feb 19, Wed	SIF as a Failure Criterion (58-61, 69-79)		
	14 (14)	Feb 21, Fri	CP2 – 2D Mode-I Fracture Analysis	CP2	Mar 06, Fri
6	15 (15)	Feb 24, Mon	CP2		
	16 (16)	Feb 26, Wed	CP2/HW2		
	17 (17)	Feb 28, Fri	Principle of Superposition (54-57)		
7	18 (18)	Mar 02, Mon	Applications – Aircraft Industry	HW3	Mar 11, Wed
	19 (19)	Mar 04, Wed	Mixed-mode Fracture (80-85)		
	20 (20)	Mar 06, Fri	CP3 – 2D Mixed-Mode Fracture Analysis	CP3	Mar 25, Wed
8	21 (21)	Mar 09, Mon	CP3/HW3		
	22	Mar 11, Wed	Review		
	23	Mar 13, Fri	**Examination 1**		
9	Spring Break (Mar 16-20)				
10	24 (22)	Mar 23, Mon	Fracture Process Zone (61-71)		
	25 (23)	Mar 25, Wed	EPFM, J-integral, HRR (103-133)	HW4	Apr 03, Fri
	26 (24)	Mar 27, Fri	Pipe Fracture Evaluation		
11	27 (25)	Mar 30, Mon	Applications – Nuclear Industry (398-401)		
	28 (26)	Apr 01, Wed	Limit-Load Analysis/HW4		
	29 (27)	Apr 03, Fri	CP4 – 3D Pipe Crack Analysis	CP4	Apr 13, Mon
12	30 (28)	Apr 06, Mon	CP4		
	31 (29)	Apr 08, Wed	CP4		
	32 (30)	Apr 10, Fri	CP4/HW5		
13	33 (31)	Apr 13, Mon	Crack-Opening-Area Analysis	HW5	Apr 20, Mon
	34 (32)	Apr 15, Wed	Crack-Opening/NRC LBB		
	35 (33)	Apr 17, Fri	Design Example based NRC LBB		
14	36 (34)	Apr 20, Mon	Fatigue Crack Propagation (451-457)	HW6	Apr 27, Mon
	37 (35)	Apr 22, Wed	Fatigue Life Prediction (451-459)		
	38 (36)	Apr 24, Fri	Crack Closure, etc./HW6 (457-459)		
15	39 (37)	Apr 27, Mon	CP5 – Fatigue Crack Growth Analysis	CP5	May 04, Mon
	40 (38)	Apr 29, Wed	CP5		
	41 (39)	May 01, Fri	CP5		
16	42 (40)	May 04, Mon	Experimental Fracture (Video)		
	43	May 06, Wed	Review		
	44	May 08, Fri	**Examination 2**		

(a) Parenthetical values are page nos. of the *Anderson* book; HW = homework; CP = computer project

Regulations Dealing with Academic Misconduct
August 1980

The College of Engineering endorses the policies and rights of students as printed in the "Policies and Regulations Affecting Students" of The University of Iowa. Under Section 1 in the Code of Student Life, which appears in the above publication and has been adopted by the College of Engineering Faculty, the College has the authority to handle acts of academic misconduct, which are defined in Section 1 as:

"Academic dishonesty, including the acquisition of honors, awards, certification or professional endorsements, degrees, academic credits, or grades by means of cheating, plagiarism, or falsification with respect to any examination, paper, project, application, recommendation, transcript, or test, or by any other dishonest means whatsoever, or aiding or abetting another student to do so."

The following regulations provide a procedure for dealing with students who are alleged to have committed an act of academic misconduct:

1. Guidelines for Disciplinary Action by an Instructor

Exams: In cases of cheating on hourly or final exams, it is recommended that the instructor reduce the student's grade, including the assignment of the grade of "F" in the course. When a course grade has been reduced to an "F", the student may not drop the course, nor use the Second Grade Option procedure to eliminate the failing grade from semester and cumulative GPA values that appear on the permanent record card (i.e., the grade transcript.) It is recommended that cheating on quizzes be considered as serious a violation as on exams and that the penalty be similar. The instructor shall send a written report of any disciplinary action to the Office of the Dean and the report shall be placed in the student's file.

Homework, Lab Reports, etc.: Each instructor shall announce at the beginning of each course the acceptable policies on student collaboration in each of the graded course requirements. When the policy is clearly violated, a zero shall be assigned for the total portion of the course grade allocated to the requirement in which the violation occurred (e.g., a zero for all homework assignments if cheating occurred on a homework assignment.) A written report of this action shall be sent by the instructor to the Office of the Dean and placed in the student's file.

2. Student Appeal

When a written report of disciplinary action by an instructor is received by the Office of the Dean, the student shall be notified in writing of the action. If the student feels that the finding of cheating is in error or the penalty is unjust, the student may request a hearing by notifying in writing the associate dean of the College, who will in turn appoint a committee to review the incident. If the student is not satisfied with the results of the hearing, the student may request a review by the Office of the Vice President for Academic Affairs.

3. Disciplinary Action by the Dean

In cases of flagrant or a second offense, the dean of the College may impose the following or other penalties as the offense may warrant: cancellation of the student's registration, disciplinary probation, suspension from the College, or recommendation of expulsion from the University by the President. If the student feels that the penalty imposed by the dean is unjust, the student may request a review by the Office of the Vice President for Academic Affairs.

4. Record of Disciplinary Action

Reports of academic misconduct received by the Office of the Dean shall be placed in the involved student's file maintained in the Office of the Dean. The Office of the Dean shall notify the student of each report and the right of the student to request a hearing for review of the case. The reports shall be destroyed when the student graduates or within two years after the student leaves the University.

(These regulations are based on the recommendations of the Ad-Hoc Committee on Student Academic Conduct which were approved by the Faculty on April 29, 1980.)