

**CE 595: FINITE ELEMENTS IN ELASTICITY**

School of Civil Engineering  
Purdue University

**Instructor:** Arun Prakash  
**E-mail:** [arunprakash@purdue.edu](mailto:arunprakash@purdue.edu)  
**Office Hours:** 4119, Civil Engineering building  
 Mondays & Fridays 2:30-4:30pm;  
 Or email for an appointment.

**Class Webpage:** <http://www.itap.purdue.edu/tlt/blackboard>

**Lecture Time and Location:** M-W-F 1:30pm-2:20pm, FRNY-G124

**Course Description:**

Fundamentals of theory of elasticity; variational principles; one-, two-, and three-dimensional elasticity finite elements; interpolation methods; numerical integration; convergence criteria; stress interpretation. (See the list of topics for details).

**Prerequisite:** CE-474 Structural Analysis II (or equivalent)  
**Recommended Prerequisite:** CE-570 Advanced Structural Mechanics (or equivalent)  
 Vector Calculus, Solid and Structural Mechanics  
 Computer Programming (MATLAB)

Students will be expected to complete programming assignments in MATLAB and gain some experience with Finite element software programs such ABAQUS, ANSYS, LS-DYNA etc. The choice of software is up to the student.

**Note:** ABAQUS student version is available FREE at the following link:

<http://campus.3ds.com/simulia/FreeSE/>

**Grading Basis:**

- |                |             |                                                                        |
|----------------|-------------|------------------------------------------------------------------------|
| • Homeworks    | 30%         |                                                                        |
| • Midterm - 1  | 20%         | 6:30pm – 7:30pm, Mon <b>February 18</b> , Location <b>MSEE B-012</b> . |
| • Midterm - 2  | 20%         | 6:30pm – 7:30pm, Mon <b>March 25</b> , Location <b>MSEE B-012</b> .    |
| • Final Exam   | 30%         | To be announced.                                                       |
| • <b>Total</b> | <b>100%</b> |                                                                        |
| • Bonus        | 5%          | For in-class activities, online forum participation                    |

Students should notify the instructor about conflicts with the scheduled exams allowing sufficient time to verify the conflict and arrange an alternate time. Make-up exams for absences will **not** be given except under extremely unavoidable situations.

**Academic Integrity**

- All work (assignments and exams) that you submit must be strictly **your own work**.
- Obtaining solutions from another student or from any other external source (and/or letting others copy from you) is **absolutely not** allowed. Collaboration in the form of giving and receiving help on concepts is allowed and encouraged.

**Emergency Procedures**

In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances. Information regarding these changes will be posted on the course webpage and you will be intimated using the class email list.

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**List of Topics:**

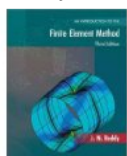
- Introduction to problems in Structural Engineering, Finite Element History  
(Ref: Reddy Ch 1, Z&T Vol 1 Ch 1)
- Basic Review of Solid/Structural Mechanics / Theory of Elasticity  
(Ref: Hjelmstad Ch 1-4; Timoshenko & Goodier)
  - Concept of Cauchy stress, Equilibrium, Notation: using coordinates; indices; vectors & tensors
  - Deformation, Strains, Compatibility, Hyper-elasticity
- 1D Boundary Value Problem (Ref: Hjelmstad Ch5, 6; Reddy Ch 2, 3; Hughes Ch 1)
  - Governing Differential Equation (*Strong Form*)
  - Principle of Virtual Work (*Weak form*), Method of weighted residuals, Raleigh-Ritz
  - Energy method, Variational Approach (*Alternative Weak form*), Calculus of Variations
  - Finite Element Discretization (*Galerkin Form*), Notation
  - 1D Quadrature, Equation solving, Boundary Conditions
  - 1-D FE Code structure (MATLAB)
  - Applications
- 2D & 3D Problems (Ref: Reddy Ch 8, 9, 11; Hughes Ch 2; Z&T Vol 1 Ch 2, 3, 4, 5)
  - Strong Form, Weak form, Integral Theorems, Principle of Virtual Work,
  - Finite Element – CST, Q4, Voight notation, Calculation of edge loads,
  - 2D Quadrature, Area coordinates
  - Iso-parametric formulation, Jacobian, Element Quality
  - Boundary conditions & Constraints
  - Finite Element Families: Lagrange, Serendipity
  - Locking, Reduced Integration, Non-conforming modes
  - Convergence requirements, Patch Tests,
  - Post-processing, Stress recovery, Superconvergence, Error estimates
  - Axi-symmetric problems
  - 3D finite elements
  - Finite Deformation, Newton-Raphson
  - Dynamics: Hamilton's Principle, Euler Lagrange Equations, (Ref: Hughes Ch8, 9)
  - Discretization: Mass & Damping matrices, Time-stepping
- Beams & Frames (Ref: Hjelmstad Ch7; Reddy Ch5; Z&T Vol 2 Ch 10)
  - Bernoulli-Euler, Timoshenko
  - Hermite-cubic  $C^1$  shape functions
  - 3D Frame structures
- Plates & Shells (Ref: Hjelmstad Ch 8; Reddy Ch 12; Hughes Ch 5, 6; Z&T Vol 2 Ch 11 & 12)
  - Kirchhoff-Love,
  - Reissner-Mindlin
- Advanced Topics (if time permits)
  - Material Models – J2 Plasticity
  - Mixed Forms, Hu-Washizu, Hellinger-Reissner, LBB condition

## CE 595: FINITE ELEMENTS IN ELASTICITY

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### Text Books (required):

- JN Reddy, *An Introduction to the Finite Element method*, 3<sup>rd</sup> Edition, McGraw Hill



**An Introduction to the Finite Element Method (Engineering Series)** by J Reddy (**Hardcover** - Jan 11, 2005)

Buy new: ~~\$156.60~~ **\$156.60**

17 new from \$146.00 15 used from \$101.99

Get it by **Wednesday, Oct 21** if you order in the next **10 hours** and choose one-day shipping.

Eligible for **FREE** Super Saver Shipping.

★★★★☆ (12)

Other Editions: Hardcover, Paperback, Unknown Binding

- KD Hjelmstad, *Fundamentals of Structural Mechanics*, Springer.

(Available **FREE** through Purdue Libraries)



**Fundamentals of Structural Mechanics** by Keith D. Hjelmstad (**Hardcover** - Nov 12, 2004)

Buy new: ~~\$104.00~~ **\$62.40**

24 new from \$50.53 15 used from \$50.55

Get it by **Friday, Jan 8** if you order in the next **9 hours** and choose one-day shipping.

Eligible for **FREE** Super Saver Shipping.

★★★★☆ (8)

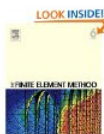
Other Editions: Hardcover

Excerpt - page 444: "... D. Hjelmstad, July 1, 2004 \*-----\* 8.. Set problem parameters, Chapter 12, ..."

Surprise me! See a random page in this book.

### Text Books (recommended):

- O.C. Zienkiewicz and R.L. Taylor, *The Finite Element Method*, Volumes I, II & III, 6<sup>th</sup> Edition Butterworth & Hinemann publishers. (Available **FREE** through Purdue Libraries)



**The Finite Element Method Set, Sixth Edition** by O. C. Zienkiewicz and R. L. Taylor (**Hardcover** - Sep 19, 2005)

Buy new: ~~\$290.00~~ **\$246.50**

11 new from \$246.49 2 used from \$339.87

Get it by **Friday, Jan 8** if you order in the next **9 hours** and choose one-day shipping.

Eligible for **FREE** Super Saver Shipping.

★★★★☆ (5)

Other Editions: Hardcover



**The Finite Element Method for Solid and Structural Mechanics, Sixth Edition** by O. C. Zienkiewicz and R. L. Taylor (**Hardcover** - Sep 20, 2005)

Buy new: ~~\$114.00~~ **\$85.27**

20 new from \$80.99 13 used from \$82.99

Get it by **Friday, Jan 8** if you order in the next **9 hours** and choose one-day shipping.

Eligible for **FREE** Super Saver Shipping.

Other Editions: Kindle Edition

Excerpt - Front Matter: "... The recipient of 27 honorary degrees and many medals, Professor Zienkiewicz is also a member of five academies + an honour ..."

Surprise me! See a random page in this book.



**The Finite Element Method for Fluid Dynamics, Sixth Edition** by O. C. Zienkiewicz, R. L. Taylor, and P. Nithiarasu (**Hardcover** - Sep 19, 2005)

Buy new: ~~\$114.00~~ **\$91.20**

15 new from \$77.69 9 used from \$77.40

Get it by **Friday, Jan 8** if you order in the next **9 hours** and choose one-day shipping.

Eligible for **FREE** Super Saver Shipping.

Other Editions: Kindle Edition

Excerpt - page 27: "... References 27 References 1. O.C. Zienkiewicz, R.L. Taylor and J.Z. Zhu. The Finite Element Method: Its ..."

Surprise me! See a random page in this book.

- TJR Hughes, *The Finite Element Method*, Dover Publication.



**The Finite Element Method: Linear Static and Dynamic Finite Element Analysis** by Thomas J. R. Hughes (**Paperback** - Aug 16, 2000)

Buy new: ~~\$29.95~~ **\$19.77**

21 new from \$16.53 14 used from \$12.00

Get it by **Friday, Jan 8** if you order in the next **9 hours** and choose one-day shipping.

Eligible for **FREE** Super Saver Shipping.

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Other Editions: Hardcover

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**Other Text Books**

- J. Fish and T. Belytschko, *A first course in Finite Elements*, Wiley & Sons. (ABAQUS student edition - Free CD)
- R.D. Cook, D.S. Malkus, M.E. Plesha and R.J. Witt, *Concepts & Applications of Finite Element Analysis*, 4<sup>th</sup> Edition, Wiley & Sons.
- R.D. Cook, *Finite Element Modeling for Stress Analysis*, Wiley & Sons.
- K.J. Bathe, *Finite Element Procedures*. Prentice Hall.
- D. Logan, *A first course in Finite Element Method*, Fourth Edition, Thomson Publishers.
- T.R. Chandrupatla and A. Belegundu, *Introduction to Finite Elements in Engineering*, Prentice Hall.

**FEM for Nonlinear Problems**

- J. Bonet and R. D. Wood. *Nonlinear continuum mechanics for finite element analysis*. Cambridge University Press, Cambridge, UK, 1997.
- T. Belytschko, W. K. Liu, and B. Moran. *Nonlinear Finite Elements for Continua and Structures*. John Wiley & Sons, 2000.
- J. T. Oden. *Finite Elements of Nonlinear Continua*. Dover Publications, 2006.

**Mathematical Theory of Finite Elements**

- B. Szabó and I. Babuska. *Finite Element Analysis*. John Wiley & Sons, 1991.
- P. G. Ciarlet. *The Finite Element Method for Elliptic Problems*. SIAM, 2002.
- G. Strang and G.J. Fix. *An Analysis of the Finite Element Method*, Wellesley-Cambridge.
- D. Braess, *Finite Elements*, Cambridge.
- S. C. Brenner and L. R. Scott. *The Mathematical Theory of Finite Element Methods*. Springer, 1994.

and many more ...