Structural and Solid Mechanics

The field of Structural and Solid Mechanics is concerned with the study of deformation and failure of structural systems and solid materials. The field is intended to meet the needs of Ph.D. students whose primary objective is the Doctor of Philosophy Degree in Aerospace Engineering or Mechanical Engineering.

Summary of Major Field Body of Knowledge:

Students should master the major field body of knowledge covered in the following courses:
MAE M256A, 256B, 261A, 269A, and undergraduate material described in the **Syllabus** on the following page, and a selection of 2 courses from one of the following stems:
Structural Mechanics Stem: MAE 261B, 269B, 269D, CEE 233
Solid Mechanics Stem: MAE CM240, M256C, 256F, M257A, 258A, 262.

The written qualifying (preliminary) examination covers the following subset of the major field body of knowledge:
MAE M256A, 256B, 261A, 269A and undergraduate material described in the **Syllabus**.

More details concerning the major field body of knowledge can be found in the **Syllabus for the Major Field**, on the next page.

Minimum Requirements for Ph.D. Major Field Students:

The student must pass a written examination in the major field and satisfy other program requirements for the Ph.D. in the MAE Department besides completing all other formal University requirements.

Format of Written Qualifying Examination:

The exam consists of a 4-hour closed book part and a 4-hour open book part.

Timing of Written Qualifying Examination:

Offered every Fall and Spring.

Link to old exams:

http://stdntsvcs.mae.ucla.edu/exam/index.htm

Ph.D. Minor Field Requirements:

Students selecting Structural and Solid Mechanics as a minor field must complete any three of the following courses with a GPA of at least 3.33. At least two must be graduate (200 level) courses:

MAE 166C, 168, M256A, M256B, M256C, 256F, M257A, 258A, 261A, 262, M269A, 269B, 269D, CEE 233, CM 140/240.

It should be noted that students majoring in the Structures Major Field offered by the Civil Engineering Department can take only those courses offered by the MAE department which do not duplicate the material contained in their major field.

Syllabus for the Major Field in Structural and Solid Mechanics

Undergraduate Prerequisites:

The preparation for this field should cover the subjects of statics and dynamics of particles and rigid bodies, mechanics of deformable solids, structural analysis, mechanical vibrations and elementary structural dynamics, as they are normally taught to undergraduates in mechanical or aerospace engineering. A more detailed description of the undergraduate preparation is presented in Appendix A.

Core:

Students majoring in Structural and Solid Mechanics are expected to have a thorough knowledge of the "core" material described below and shown in the summary of requirements (Appendix B).

(1) Linear Elasticity (Course MAE M256A, Refs. 10, 17).

Equations of linear elasticity; uniqueness of solution; Betti/Rayleigh reciprocity; Saint-Venanit's principle; simple problems involving spheres and cylinders; special techniques for plane problems. Airy stress function, complex variable method, transforms method; three-dimensional problems, torsion, entire space and half-space problems; boundary integral equations.

(2) Mechanics of Deformable Solids (Course MAE M256B, Ref. 10).

Kinematics of deformation; the deformation gradient tensor, polar decomposition, finite Eulerian and Lagrangian strain tensors, principal strains, infinitesimal strains, compatibility. Balance laws. Analysis of stress and equations of motion. Boundary and interface conditions. Constitutive Equations; fundamental postulates, the strain energy function, nonlinear stress-strain relationships, Hooke's law, isotropy and anisotropy, viscoelastic materials, thermal stress. Exact solutions of linear and non linear elasticity problems.

(3) Energy and Computational Methods in Structural Mechanics (Course MAE 261A)

Review of theory of linear elasticity and reduced structural theories (rods, plates, and shells). Calculus of variations. Virtual work. Minimum and stationary variational principles. Variational approximation methods. Weighted residual methods, weak forms. Static finite element method. Isoparametric elements, beam and plate elements. Numerical quadrature.

(4) Dynamics of Structures (Course MAE M269A, Refs. 5, 6, 8, 11)

Hamilton's principle, Lagrange's equations. The structural dynamic eigenvalue problem and its solution. Beam type finite elements in structural dynamics. Rayleigh's quotient. Approximate methods -Rayleigh-Ritz, Galerkin and Collocation methods. Proportional damping. Normal mode and frequency response methods. Displacement driven structural dynamics.

In addition to the "core", students are also responsible for certain portions of the material contained in the structural mechanics or solid mechanics stems as described below and in Appendix B.

Structural Mechanics Stem:

(A) Computational Mechanics of Solids and Structures (Course MAE 261B, Ref. 2)

Variational formulation and computer implementation of linear elastic finite element method. Error analysis and convergence. Methods for large displacements, large deformations, and other geometric nonlinearities. Solution
techniques for nonlinear equations. Finite element method for dynamics of solids and structures. Time integration algorithms.

(B) Advanced Structural Dynamics (Course MAE 269B, Refs. 8, 12).

Structural dynamics of two and three dimensional structures using approximate and finite element methods. Dynamic stress calculations. Non proportional damping. Vibrations of Timoshenko beams. Structural dynamics of rotating systems. Vibrations of plates. Parametric excitation. Linear and nonlinear response calculations.

(C) Aeroelastic Effects in Structures (Course MAE 269D, Refs. 3, 7).

Classical and computational methods in aeroelasticity. Static aeroelasticity. Unsteady subsonic, supersonic, and transonic aerodynamics. Flutter of wings and panels. Nonlinear flutter and divergence in transonic flow; computational aeroelasticity. Aeroelastic problems in turbomachines; helicopter rotor blade flutter. Flutter of suspension bridges.

(D) Mechanics of Composite Material Structures (Course CE 233, Ref. 19)

Elastic, anisotropic stress-strain-temperature relations. Analysis of prismatic beams by three-dimensional elasticity. Analysis of laminated anisotropic plates and shells based on classical and first-order shear deformation theories. Elastodynamic behavior of laminated plates and cylinders.

Solid Mechanics Stem:

(A) Plasticity (Course MAE M256C, Refs. 13).

Incremental plastic stress-strain relations. Time dependent stress-strain relations commonly used in structural analysis. Unified treatment of plastic strain, creep strain, and thermal strain. Elastic-plastic and creep analysis of beams, columns, shafts, frames, and plates.

(B) Analytical Fracture Mechanics (Course MAE 256F, Refs. 4, 9).

Review of modem fracture mechanics, analytical and numerical methods for crack tip stress intensity factors. Engineering applications in stiffened structures, pressure vessels, plates and shells.

(C) Elastodynamics (Course MAE M257A, Refs. 1, 10).

Equations of linear elasticity, Cauchy equation of motion constitutive relations, boundary and initial conditions, principle of energy. Sources and waves in unbounded isotropic, anisotropic, and dissipative solids. Half-space problems. Guided waves in layered media. Applications to dynamic fracture, nondestructive evaluation (NDE), structural health monitoring, mechanics of earthquakes.

(D) Nanomechanics and Micromechanics. (Course MAE 258A, Refs. 20, 21)

Analytical and computational modeling methods to describe mechanics of materials at scales ranging from atomistic through microstructure or transitional and up to continuum. Discussion of atomistic simulation methods (e.g., molecular dynamics, Langevin dynamics, and kinetic Monte Carlo) and their applications at nanoscale. Developments and applications of dislocation dynamics and statistical mechanics methods in areas of nanostructure and mircostructure self-organization, heterogeneous plastic deformation, material instabilities, and failure phenomena. Presentation of technical applications of these emerging modeling techniques to surfaces and interfaces, grain boundaries, dislocations and defects, surface growth, quantum dots, nanotubes, nanoclusters, thin films (e.g., optical thermal barrier coatings and ultrastrong nanolayer materials), nano-identification, smart (active) materials, nanobending and microbending, and torsion.

(E) Mechanics of Intelligent Material Systems (Course MAE 262)

Constitutive relations for electro-magneto-mechanical materials. Micro\macro analysis, including classical lamination theory, shear lag theory, concentric cylinder analysis, hexagonal models, and homogenization techniques as they apply to active materials. Active System design, inch-worm, and bimorph.

(F) Introduction to Biomechanics (Course CM 240)

Introduction to mechanical functions of human body; skeletal adaptations to optimize load transfer, mobility, and function. Dynamics and kinematics. Fluid mechanics applications. Heat and mass transfer. Power generation. Laboratory simulations and tests.

Breadth Requirements:

In addition to completing the graduate coursework and written examination described, the student must satisfy a breadth requirement. The requirement can be met by either of the following options:

(i) Satisfactory completion of any two established minor fields (other than the structures field offered by the Civil Engineering Department) offered in the School of Engineering and Applied Science.

(ii) Satisfactory completion of one established minor field and three courses from either the **Solid Mechanics Stem** or the **Structural Mechanics Stem**. Students with **Solid Mechanics** concentration must select the three courses from the **Structural Mechanics Stem** and students with **Structural Mechanics** concentration must select the three courses from the **Solid Mechanics Stem**.

References:

The references provided below indicate where most of the material associated with the syllabus can be found. The numbers in brackets after the reference indicate the pertinent course.

1. Achenbach, J.D. *Wave Propagation in Elastic Solids,* North Ho1land, 1973 (MAE M257A).
2. Bathe, K. *J, Finite Element Procedures in Engineering Analysis.* Prentice Hall, 1982 (MAE 261B).
3. Bisplinghoff, R.L. and Ashley, *H., Principles of Aeroelasticity, W*iley and Sons, Inc., Dover (MAE 269D).
4. Broek, D., *Elementary Engineering Fracture Mechanics,* Martinus Nijhoff, Fourth Edition, 1986 (MAE 256F).
5. Clough, R W. and Penzien. J., *Dynamics of Structures,* McGraw-Hill, Second Edition, 1943 (MAE M269A).
6. Craig, R.R., *Structural Dynamics: An Introduction to Computer Methods,* John Wiley, 1981 (MAE M269A).
7. Dowell, E.H., et all, *A Modern Course in Aeroelasticity,* Kluwer Academic Publisher, Third Edition, 1995 (MAE 269D).
8. Geradin, M., and Rixen, D., *Mechanical Vibration -Theory and Application to Structural Dynamics,* Wiley, 1994 (MAE M269A and MAE 269B).
9. Kanninen, M.J., and Popelar, C.H., *Advanced Fracture Mechanics,* Oxford University Press, 1985 (MAE 256F).

10. Mal, A.K. and Singh, S.J., *Deformation of Elastic Solids,* Prentice Hall, 1991, (MAE M256A, B; MAE M257A).
11. Meirovitch, L., *Analytical .Methods in Vibrations,* McMillian Co., 1967 (MAE M269A).
12. Meirovitch L., *Computational Methods in Structural Dynamics,* Sijthoff and Noordhoff, 1980 (MAE 269B).
13. Mendelson, A., *Plasticity: Theory and Application,* McMillian, 1968 (MAE M256C).
14. Peery, D.J., and Azar, J.J., *.4ircraft Structures,* McGraw Hill, 1982 (MAE 166A).
15. Rao, S.S., *Mechanical Vibrations,* Addison-Wesley, 1984 (MAE M169A).
16. Rivello, R.M., *Theory and Analysis of Flight Structures,* McGraw Hill, 1969 (MAE 166A).
17. Sokolnikoff, I.S., M*athematical Theory of Elasticity*, McGraw-Hill, 1956 (MAE M256A).
18. Ugural, A.C., and Fenster, S.K., *Advanced Strength and .4ppl'ied Elasticity,* American Elsevier, 1975 (MAE 156A).
19. Whitney, J.M., *Structural Analysis of Laminated Anisotropic Plates*, Technomic Publisher, 1987 (CE 233).
20. Rob Phillips*, Crystals, Defects and Microstructures : Modeling Across Scales*, Cambridge University Press, 2001 (MAE 258A)
21. Nasr Ghoniem and Daniel Walgraef, Instabilities and Self-Organization in Materials, Oxford University Press, 2006 (MAE 258A)

Appendix A

Topical description of undergraduate prerequisites

I. Mechanics of Solids (Refs. 8, 12, 40)
   1. Deformation, the strain tensor, linear strain displacement relations.
   2. Stress vector, equations of equilibrium, Cauchy's stress tensor.
   3. Constitutive relations for linear elasticity and thermoelasticity, bulk modulus. Young's modulus. Poisson's ratio.
   4. Field equations of elasticity, boundary conditions.
   5. Plane stress and plane strain. Solution of simple boundary value problem of elasticity.
   6. Failure criteria for fatigue and plastic yielding.
   7. Torsion of prismatic bars

II. Structural Analysis (Refs. 8, 31, 35)
   1. Analysis of simple frames
   2. Bending of beams
   3. Torsion of beams and warping
   4. Shear flow
   5. Combined bending and torsion of thin-walled structures
   6. Buckling of columns

III. Mechanical Vibrations (Ref. 32)
   1. Fundamentals of vibration theory and its applications
   2. Free, forced and transient vibration analysis of systems having one and two degrees of freedom, including damping.
   3. Normal modes, coupling and normal coordinates

4. Structural dynamics of beams

Appendix B

Requirements and suggested course preparation for structural and solid mechanics field

I. Core classes: MAE 256A; M256B; MAE 261A; M269A

II. 8-hour written exam

III. Major field courses:

Structural Mechanics stem

Select Two Courses:
MAE 261B
MAE 269B
MAE 269D
CEE 233

Solid Mechanics stem

Select Two Courses:
MAE M256C
MAE 256F
MAE M257A
MAE 258A
MAE 262
MAE CM 240

IV. Breadth requirements (see syllabus)

In addition, the following post exam requirements apply:

(a) Structural Mechanics Stem
Take two courses from the group: MAE 261B, MAE 269B, MAE 269D, CEE 233.

(b) Solid Mechanics Stem
In addition to the core courses, it is recommended that students who select this stem take two courses from: MAE M256C, MAE 256F, MAE M257A, MAE 258A, MAE 262, MAE CM240.