NATIONAL COUNCIL OF STRUCTURAL ENGINEERS ASSOCIATIONS

NATIONAL COUNCIL OF STRUCTURAL ENGINEERS ASSOCIATIONS RECOMMENDED STRUCTURAL ENGINEERING CURRICULUM

The National Council of Structural Engineers Associations (NCSEA) recommends that structural engineering students receive instruction on the twelve courses listed below as part of their education. The NCSEA structural engineering curriculum was developed by practitioners and educators to improve the quality of structural engineering education.

NCSEA RECOMMENDED STRUCTURAL ENGINEERING CURRICULUM:

1. Structural Analysis I: Determinate Analysis
2. Structural Analysis II: Indeterminate Analysis
3. Structural Analysis III: Matrix Analysis
4. Steel Design I
5. Steel Design II
6. Concrete Design I: Reinforced Concrete
7. Concrete Design II
    a. Concrete Design IIA: Advanced Reinforced Concrete
    or
    b. Concrete Design IIB: Prestressed Concrete
8. Wood Design
9. Masonry Design
10. Foundation Design/Soil Mechanics
11. Structural Dynamics
12. Technical Communications

NCSEA RECOMMENED STRUCTURAL ENGINEERING SKILL TOPICS:

1. Load Path/Load Flow in Structural Systems

   (Load Path/Load Flow skills and an understanding of overall structural building and bridge behavior were identified as fundamental knowledge desirable for entry level structural graduates based on feedback obtained from the 2016 NCSEA Practitioner Survey.)

The National Council of Structural Engineers Associations values your opinion concerning the NCSEA Recommended Structural Engineering Curriculum. Please provide your input to the NCSEA Basic Education Committee by contracting Kevin Dong, NCSEA Basic Education Committee Chair, at kdong@calpoly.edu

NCSEA RECOMMENDED STRUCTURAL ENGINEERING CURRICULUM COURSE CONTENT:

STRUCTURAL ANAYSIS I – DETERMINATE ANALYSIS:

An introductory course focusing on fundamental structural analysis and mechanics concepts. Course material may be covered in a single class or a combination of classes. The course content includes, but is not limited to, concepts related to statics for determinate systems (stability, equilibrium, forces, moments and couples) and topics associated with mechanics (stress, strain, material properties, internal stresses and deformations). Upon completion of the course, students should be able to:

a. Use examples to illustrate, describe, and associate building/bridge conditions to structural design/engineering.
b. Identify stable structural systems and develop equations of equilibrium.
c. Quantify forces and force components and identify the application of moments and force couples on building/bridge elements.
d. Evaluate the internal actions (axial) in planar determinate trusses using the method of joints and method of sections.
e. Evaluate the internal actions (shear, bending, and axial) in planar determinate frames and multiple span beams which are idealized with internal hinges or pins.
f. Develop and use free-body diagrams to draw shear and moment diagrams.
g. Calculate section properties for simple cross sections and solve for internal stresses based on moments and axial forces.
h. Draw qualitative deflected shapes based on the applied loads and relate to shear and moment diagrams.
i. Introduce the concepts of stress and strain and develop the stress-strain relationship for building materials.

Use of sample buildings, bridge systems, and building components which highlight key structural analysis concepts are recommended for example and homework problems so that students would also be able to:

- Relate structural analysis and mechanics problems to individual building components.
- Describe how material properties affect component deformation.
- Identify the types of boundary conditions (e.g., pinned, fixed, or roller) that are used throughout the building and verbally describe how those connections influence the building or component behavior. Use of photographs, sketches, or free body diagrams may be used to demonstrate a concept.

STRUCTURAL ANALYSIS II – INDETERMINATE ANALYSIS:

A course focusing on structural analysis for indeterminate structural systems and advanced mechanics concepts. Course material may be covered in a single class or a combination of classes. The course content includes, but is not limited to methods for evaluating indeterminate systems (e.g. moment-area, virtual work, slope deflection, moment distribution) and topics associated with mechanics (e.g. buckling, torsion, stress transformation, combined stresses, and plasticity). Upon completion of the course, students should be able to:

a. Extend and transfer concepts and principles introduced in Structural Analysis I – Determinate Analysis.
b. Evaluate axially loaded members, including indeterminate conditions, for stress and deformation.
c. Formulate, comprehend, and apply the Euler buckling formula to compression elements.
d. Evaluate the effects of torsion on building members and components, including indeterminate conditions.
e. Formulate, comprehend, and apply stress transformations to principal stresses and maximum in-plane shear stress; (e.g. Mohr's circle).
f. Compute shear flow and location of shear center for thin-wall cross-sections.
g. Evaluate determinacy (including degrees of indeterminacy) and stability for articulated beams and frames and analyze articulated beams and frames.
h. Determine the stability of and analyze statically determinate two- and three-dimensional structural systems.
i. Draw deformed shapes and calculate displacements and rotations for beams and frames.
j. Compute deformations (axial, shear, and bending) in statically determinate structures using virtual work, double integration, and moment area methods.
k. Compute member actions (rotation, displacement, reactions) in statically indeterminate structures using moment-area, virtual work, slope-deflection, and moment distribution methods.
l. Distinguish between different analysis methods and decide which method is appropriate for a given situation.
m. Determine the appropriate use of approximate methods and apply in statically determinate and indeterminate structures.
n. Use approximate methods to verify computer analysis results.
o. Draw influence lines for statically indeterminate structures and determine critical loading combinations.

Use of sample buildings, bridge systems, and building components, which highlight key structural analysis concepts, are recommended for examples and homework problems so that students would also be able to:

- Explain how a variety of building systems respond to different load conditions, such as gravity and lateral loads, and how this translates into loading for structural systems; then analyze using techniques for determinate or indeterminate systems.
- Determine the loading on building/bridge systems and the individual building/bridge components, analyze the components for forces, moments, and deflections using analysis methods noted above.
- Identify the types of connections (e.g., pinned or fixed) that might be used throughout the building/bridge and verbally describe how those connections influence the building/bridge analysis / behavior. Use of photographs, sketches, or free body diagrams maybe used to demonstrate a concept.

STRUCTURAL ANALYSIS III – MATRIX ANALYSIS:

A course focusing on analyzing framed and truss structures using matrix flexibility and stiffness methods. Students achieve a basic understanding of matrix algebra and stiffness methods in order to become effective users of structural analysis software and understand results. Introduction to commercially available software or computer programming is encouraged during the curriculum to help the student bridge the gap between theory and implementation. Upon completion of the course, students should be able to:

a. Apply virtual work and matrix algebra.
b. Compare and contrast the concepts of flexibility and stiffness in structural analysis.
c. Explain, show the application of, and analyze building systems using the flexibility method.
d. Explain, show the application of, and analyze trusses, beams, frames, and 3-D structures using stiffness methods.
e. Demonstrate and apply the stiffness method for thermal displacements, support settlements, etc.

A course design project may be implemented into the curriculum with the comparison of a structure, frame or truss, which is analyzed using both hand matrix methods and computer software. The hand method would be simplified, with the computer model showing increasing accuracy as the model is refined. Use of a real world structure or example is encouraged so that students would also be able to:

- Link the theoretical and foundational background of matrix methods to modern structural analysis software and finite element analysis methods.
- Demonstrate how to formulate the structural analysis in matrix form.
- Model and analyze real-world structures appropriately (e.g. boundary conditions, simplification of systems).
- Identify and discuss how advanced analysis methods such as finite element analysis and nonlinear analysis may be incorporated into structural design.

STEEL DESIGN I:

Introduction to steel as a building material may be covered in a single class or a combination of classes. The course content includes, but is not limited to the historical development of steel, overview of production and industry practices, and component design (e.g., beams, columns, rods). All design topics incorporate specifications and design references such as the *AISC Specification for Structural Steel Buildings* and the *AISC Steel Construction Manual*. Upon completion of the course, students should be able to:

a. Describe the use of steel as a building material; properties, processing, and its advantages and limitations.
b. Identify lateral and gravity load resisting systems in a building.
c. Recognize, analyze and design tension members, beams, and compression elements.
d. Recognize, analyze, and design combined stress elements.
e. Recognize and describe types of connections (e.g., shear, moment), their components, and where different connections might be used in a typical steel frame building.

A course design project or a theme building is recommended for examples and homework problems so that students would also be able to:

- Explain how the building system responds to different types of loads and combinations of loads, such as gravity and wind loads, and how this translates into loads for individual components.
- Determine the loading on the individual building components, analyze the components for the correct forces and moments, identify and utilize the equations needed to design those components.
- Identify the types of connections (e.g. shear, moment) that might be used throughout the building. Use of photographs, sketches, or models maybe used to demonstrate a concept or visually explain a condition.

STEEL DESIGN II:

Advanced topics describing the design and construction of steel structures are covered in subsequent courses beyond Steel Design I. Content in Steel Design II can vary widely by institution, due in part to regional needs and academic term (quarter or semester system). Course topics may include the integration of gravity and lateral load resisting systems into buildings, plate girder design, composite beam design, collapse mechanisms, and design of moment frames and braced frames, connections and detailing, and the development of construction documents and specifications. All design topics incorporate specifications and design references such as the *AISC Specification for Structural Steel Buildings* and the *AISC Steel Construction Manual*. Upon completion of the course, students should be able to:

a. Design partially and fully composite beams.
b. Design and detail plate girders, with consideration for shear buckling and tension field action.
c. Design and detail bolted and welded structural steel connections for moment resisting and braced frame systems.

Students may also be able to:

- Develop gravity and lateral load framing schemes for steel structures.
- Design moment and braced frame systems in accordance with the *AISC Seismic Provisions for Structural Steel Buildings*.

A course design project or a theme building is recommended to be used in examples and homework problems so that students would also be able to:

- Perform lateral and gravity analysis on a building. Design beams, columns, braced and moment resisting frames
- Design and detail connection(s) such as beam-to-beam, beam-to-column, brace-to-beam or column to foundation

CONCRETE DESIGN I – REINFORCED CONCRETE:

Introduction to concrete as a building material may be covered in a single class or a combination of classes. The course content includes, but is not limited to, the historical development of concrete, overview of production and industry practices, and component design (e.g., beams, columns, beam-columns). All design topics incorporate building codes and design references such as *ACI 318- Building Code Requirements for Structural Concrete*. Upon completion of the course, students should be able to:

a. Describe the use of reinforced concrete as a building material; composition and mechanical properties, construction processes, and its advantages and limitations.
b. Identify lateral and gravity load resisting systems in a building.
c. Recognize, analyze, and design flexural members (beams, one-way slabs) and compression elements (columns).
d. Recognize, analyze, and design combined stress elements.
e. Determine reinforcement development lengths and splice requirements.

A course design project or theme building is recommended for example and homework problems so that students would also be able to:

- Explain how the building system responds to different types of loads and combinations of loads, such as gravity and lateral loads, and how this translates into loads for individual components.
- Determine the loading on the individual building components, analyze the components for the correct forces and moments, identify and utilize the equations needed to design those components.

Hands-on activities including concrete beam fabrication and testing are recommended so that students would be able to describe how variations in concrete mix designs and reinforcement details can affect strength and ductility.

<u>CONCRETE DESIGN IIA – ADVANCED REINFORCED CONCRETE:</u>

Advanced topics describing the design and construction of reinforced concrete structures are covered in subsequent courses beyond Concrete Design I. Content in Concrete Design IIA can vary widely by institution, due in part to regional needs and academic term (quarter or semester system). Course topics may include the integration of gravity and lateral load resisting systems into buildings, two-way floor systems, collapse mechanisms, and design of moment frames and shear walls, including impact to foundations, formwork considerations, detailing, and the development of construction documents and specifications. Upon completion of the course, students should be able to:

a. Design and detail gravity load resisting systems to include the slab, beams, and columns.
b. Analyze and design two-way slabs for flexure, shear, and deflection.
c. Design and detail shear walls to include web reinforcement, shear friction, and boundary elements.
d. Identify, apply analysis models, and use design recommendations for corbels, members subject to torsion, deep beams, and strut and tie components.
e. Develop anchorage and complete the load path with connections into other elements and to other materials.

Students may also be able to:

- Design and detail pan-joist systems.
- Design moment frame systems for earthquake resistant structures in accordance with ACI 318-*Building Code Requirements for Structural Concrete*.
- Develop structural drawings for regular reinforced concrete buildings.

A course design project or a theme building is recommended for examples and homework problems so that students would also be able to:

- Perform lateral and gravity analysis on a building. Design beams, columns, shear walls, and moment resisting frames.
- Design and detail connection(s) such as beam-to-beam, beam-to-column, and column to foundation.
- Associate construction sequencing and construct-ability with reinforcement placement, detailing, confinement and congestion (e.g., beam-column joint). Use of photographs, sketches, or models may be used to demonstrate a concept or visually explain a condition.

CONCRETE DESIGN IIB – PRE-STRESSED CONCRETE:

Introduction to pre-stressed concrete, both prestress and precast, as a building material may be covered in a single class or a combination of classes. The course content includes, but is not limited to the historical development of pre-stressed concrete, overview of manufacturing and industry practices, and component design (e.g., beams and slabs). All design topics incorporate building codes and design references such as the *ACI 318- Building Code Requirements for Structural Concrete*, and the *PCI Design Manual*. Upon completion of the course, students should be able to:

a. Describe the use of prestress and precast concrete as a building material; differences between reinforced concrete, composition and mechanical properties, construction processes, and its advantages and limitations.
b. Recognize, analyze, and design flexural members for service and strength force levels.
c. Analyze, and account for loss in prestress, anchorage, shrinkage, camber and deflection in member design.
d. Design and detail basic connections.

A course design project or a long-span theme building/bridge is recommended for examples and homework problems so that students would also be able to:

- Explain how the structural system responds to different types of loads and combinations of loads, such as prestress shrinkage, and how this translates into loads for individual components and detailing to accommodate the effects.
- Identify the impact of construction sequences and the associated loading, then utilize the equations needed to design the structural system and its components.
- Identify the types of connections (e.g. bearing, mixed materials) and structural performance criteria (ductile vs. non-ductile) that might be used throughout the building and verbally describe those connections with the aid of photographs or sketches of those connections.

WOOD DESIGN:

Introduction to wood as a building material may be covered in a single class or a combination of classes. The course content includes, but is not limited to the historical use of timber, material properties, industry practices, and component design (e.g., beams, columns, walls and connections). All design topics incorporate building codes and design references such as the *NDS for Wood Construction*. Upon completion of the course, students should be able to:

a. Describe building applications for wood in gravity and lateral load resisting systems, and explain how the material properties of wood in sawn lumber and engineered products influence structural design.
b. Design timber beams and posts.
c. Select appropriate connectors (nails, screws, bolts) and design and detail typical connections.
d. Design and detail timber trusses with nailed or bolted connections.
e. Identify lateral and gravity load resisting systems in a typical wood framed building.
f. Design wood shear walls for in-plane and out-of-plane wind and seismic forces in combination with floor/roof gravity forces.
g. Design wood diaphragms and distribute the forces to the lateral load resisting system
h. Design collectors, struts, and ties within a wood diaphragm.

The students may also be able to:

- Design heavy truss connections, shear plates, and split rings.
- Review and understand quality assurance and special inspection programs associated with timber construction for high wind and high seismic loading.
- Describe recent development or trends in wood construction such as cross laminated timber (CLT) or mass timber construction.

A course design project or a theme building is recommended to be used in examples and homework problems so that students would also be able to:

- Explain how the building system responds to different types of loads and combinations of loads, such as gravity and wind loads, and how this translates into loads for individual components.
- Determine the loading on the individual building components, analyze the components for the correct forces and moments, and identify and utilize the equations needed to design those components.
- Identify the types of connections (e.g., nailed, screwed, or bolted) that might be used throughout the building and verbally describe those connections with the aid of photographs, sketches or models of those connections.

<u>MASONRY DESIGN:</u>

Introduction to masonry as a building material may be covered in a single class or a combination of classes. The course content includes, but is not limited to, the historical use of masonry, material properties, industry practices, and component design (e.g., beams, columns and walls). All design topics incorporate building codes and design references such as the *ACI 530/TMS 402 Building Code Requirements for Masonry Structures*. Upon completion of the course, students should be able to:

a. Describe the use of masonry as a building material; properties, processing, and its advantages and limitations.
b. Assess governing codes and specifications and distinguish the differences between Allowable Stress Design and Strength Design.
c. Recognize, analyze and design masonry beams, and compression elements such as columns, piers, and wall elements.
d. Apply code requirements regarding proper construction techniques and detailing; such as reinforcement clearances, development length, and confinement.
e. Design masonry walls for in-plane and out-of-plane wind and seismic forces in combination with floor/roof gravity forces.
f. Identify and/or develop lateral and gravity load resisting systems in a building using masonry shear walls.

Students may also be able to:

- Develop lateral force load path skills and technical knowledge in designing Lateral Force Resisting Systems.
- Review and determine the differences between quality assurance and special inspection programs associated with masonry construction.

A course design project or a theme building is recommended to be used in examples and homework problems so that students would also be able to:

- Explain how the building system responds to different types of loads and combinations of loads, such as gravity and lateral loads, and how this translates into loads for individual components.
- Determine the loading on the individual building components, analyze the components for the correct forces and moments, and identify and utilize the equations needed to design those components.
- Identify the types of connections which incorporate multiple materials (such as wood to masonry collectors) that might be used throughout the building and verbally describe those connections with the aid of photographs, sketches, or models.

FOUNDATION DESIGN/SOIL MECHANICS:

Introduction to foundation design assumes soil mechanics is a pre-requisite course and the material may be covered in a single class or a combination of courses. A basic understanding of geologic principles and soil properties, exploration methods, soil profile preparation, index properties and void description prior to the foundation design class is required. The foundation design course includes the introduction to soil subsurface bearing materials, lateral earth pressure, design for both shallow spread and deep foundation systems, soil mechanics and stability. Upon completion of the course, students should be able to:

a. Describe and examine soil properties and soil strata and relate to foundation design.
b. List field exploration techniques and explain how data is incorporated into a geotechnical report.
c. Recognize sources for lateral earth pressure and the effects of active and passive restraints.
d. Recognize conditions where slope stability is a design issue and determine failure planes and factors of safety.
e. Interpret soil conditions and highlight the benefits and applicability of shallow versus deep foundation systems.
f. Compare footings, rafts, or mats and choose the appropriate system when designing shallow foundations.
g. Compare piles to caissons (piers) and choose the appropriate system when designing deep foundations.
h. Analyze and design retaining walls for strength and stability.

A course design project which includes an example geotechnical engineering report is recommended so that students would also be able to:

- Select an appropriate foundation system given the soil profile or characteristics.
- Design a foundation system for bearing, stability, and settlement.
- Design a retaining wall and associated footing.
- Develop a basic understanding of soil properties in order to converse with Geotechnical Engineers and interpret soils reports, soil boring logs, standard penetration test and other soil characteristics with respect to structural engineering design.
- Demonstrate knowledge of material properties of soils.
- Identify the relationship between in-situ foundation bearing materials and allowable foundation and lateral pressure values presented in Building Codes.
- Use the empirical strength for in-situ bearing material and design an appropriate deep or shallow foundation.

STRUCTURAL DYNAMICS:

Introduction to structural dynamics assumes rigid body dynamics is a pre-requisite course and the course material may be covered in a single class or a combination of courses. The course content includes the dynamic response of structures modeled as single degree of freedom systems, multi-degree of freedom systems, or as shear buildings. Multiple techniques are used to estimate seismic building behavior such as time history and response spectrum. Analysis techniques are compared and contrasted with methods described in building codes and design references, such as the *International Building Code, ASCE 7, and ASCE 41*. Upon completion of the course, students should be able to:

a. Explain dynamic loading characteristics from various sources such as: seismic, blast, pedestrian, equipment, etc.
b. Describe the characteristics of earthquakes including causes, faults, seismic waves, plate-tectonics, magnitude and intensity; strong ground motion, etc.
c. Analyze free and forced vibration response of single degree of freedom and multi-degree of freedom systems.
d. Estimate the response of single degree of freedom structural systems to earthquake ground motion using response spectra, design spectra, damping, and damping ratios.
e. Demonstrate the concepts of mode shapes, frequencies, and conduct (seismic) analysis using modal superposition for multi-degree of freedom systems.
f. Conceptually understand inelastic seismic behavior and ductility concepts and how these concepts are incorporated into structural system design.
g. Describe behavior of lateral force resisting systems (LFRS) due to earthquake loading and identify the advantages or limitations of reinforced concrete, prestressed concrete, steel, masonry and timber as building materials for LFRS.

A course design project or a theme building is recommended to be used in examples and homework problems so that students would also be able to:

- Apply building code principles to seismic analysis both empirical (static analysis) and modal analysis methods.
- Develop a computer model using commercial software and compare to hand analysis for single degree of freedom systems or multi-degree of freedom systems for regular buildings.
- Explain how the building or lateral force resisting system resists different types of lateral loads and how this translates to building performance and/or building response, i.e. an introduction to seismic engineering.

TECHNICAL COMMUNICATIONS:

Technical communications may be covered in a single class, a combination of classes, or formally integrated into the entire recommended structural engineering curriculum. Technical communications prepare engineering students to communicate individually and collaboratively through effective technical writing and oral communications while considering audience and purpose. Upon completion of the course, students would be able to:

a. Understand the characteristics of technical communications and the importance of purpose, audience, and subject matter.
b. Research, analyze, synthesize, and apply information to create technical written and oral reports.
c. Plan, draft, revise, edit, and critique technical and professional documents through individual and collaborative writing.
d. Write technical and business documents using proper grammar and style to articulate complex engineering ideas for both nontechnical and technical audiences.
e. Prepare and deliver professional technical presentations using effective oral and graphic communications that articulate complex engineering ideas for both nontechnical and technical audiences.
f. Recognize ethical implications of technical communications in professional contexts.

The following course projects are recommended to reinforce the course learning outcomes and to equip students to critically evaluate their own and others' writing:

- Construct typical business correspondence and documents using common mediums such as email, job site observation reports, condition surveys, project proposals, and building narratives.
- For group projects, evaluate external and internal team communications through peer evaluation of papers, reflective essay, and project documentation.

SKILL TOPIC: LOAD PATH / LOAD FLOW in STRUCTURAL SYSTEMS

Load path/load flow and structural system behavior concepts may be covered in a single class or as modules in a series of classes. This is not considered one of the primary 12 recommended structural courses, however information obtained from the NCSEA Practitioner Survey expressed a greater need for this material. The content includes the development of structural systems and associated behavior, plus defining and developing load paths for those systems. The course topics incorporate building codes (IBC), building references (ASCE 7), and construction drawings. Analysis techniques reference supporting courses such as Analysis I or Analysis II, but also provide a link to design courses for steel, concrete, wood, and masonry. Upon completion of the course, students should be able to:

a. Define the concept of load path, describe the importance of load path, and develop load paths for vertical and lateral load resisting systems for buildings
b. Introduce the concept of grid spacing, bay size, and patterning as they relate to space and structural systems
c. Understand the influence of rigid and flexible characteristics of structural components on load path and systems behavior
d. Recognize the effect of and differences between stiffness and strength on load path
e. Understand the behavior of different structural systems, elements, and boundary conditions such that the design loads may be determined; for example rigid versus flexible diaphragms, moment frames versus braced frames, pin versus fixed connections, etc.
f. Translate load flow concepts into free body diagrams and 3D-modeling to determine diaphragm and collector forces, building displacements, and building reactions
g. Perform a computational check using computer modeling to confirm the load path in the design process
h. Use case studies to identify common problems associated with load path

A course design project or a theme building is recommended for examples and homework problems so that students would also be able to:

- Explain how a variety of building systems respond to different load conditions, such as gravity and lateral loads, and how this translates into loading for structural systems and individual components
- Determine the loading on building systems and the individual building components, analyze the components for the correct forces and moments, identify and utilize the equations needed to design those components
- Identify the types of connections (e.g., shear, moment) that might be used throughout the building and verbally describe how those connections influence the building or component behavior. Use of photographs, sketches, or models may be used to demonstrate a concept or visually explain a condition