Background

The structural engineering component of a typical civil engineering curriculum entails: Statics, Mechanics of Materials, Structural Analysis, and Design courses. Those with a strong interest in Structures may take in addition: Advanced Mechanics of Materials, Matrix Structural Analysis. Those courses tend to be dry, uninspiring, challenging to relate to, and limited to rectilinear structural components. Some find them “boring”.

This course will seek to motivate students by examining the intersection of Structural Analysis/Design with Architecture, combining rigor with beauty.

This is best examined through iconic structures of a type seldom taught in undergraduate curriculum (arches, cables, shells), three-dimensional frames. Those may be bridges, towers, stadiums, cathedrals, museums, or large civic structures.

Whereas in modern days, many will immediately attempt to use complex finite element models, this course will place heavy emphasis on hand calculations rooted in the fundamentals of mechanics.

Description

This course will thus take us beyond the rectilinear realm of classical structural analysis, and lead us to explore the beauty of curvilinear or more complex iconic shapes. Emphasis will be placed on a rigorous, mechanics based, development of theory. Then, simplified analysis methods will be developed and applied.

As a vehicle for this development, we will focus on iconic structures. Students will be using exclusively analytical solutions (i.e. no finite element analysis).

What this course is not about: philosophical, societal, historical considerations governing design and architecture. It is not either a “light course” to visit Paris.

This will be a demanding and high level short course on structural analysis (about xx hours of lectures) for highly motivated students.
Format

We will start with a one day long meeting in Boulder to discuss coverage, expectations, format and pre-departure reading assignment. We will have a brief review of Matlab, and Mathematica. The “Art & Science” of structural engineering will be discussed, followed by a brief discussion of the Morandi bridge collapse in Genova.

On most days, there will be 4 or 6 hours lectures in a classroom setting, followed by afternoon site visits. On some occasions, lectures or site visits will be all day. There will be in class supervised exercises focusing on the topic covered. Students should be able to complete them in class, if not later that night. There will be no “homeworks” per se.

Students will be expected to maintain a day by day journal (OneNote format) that includes technical notes (from lectures), worked in class exercises, and report on site visits.

The reading list is long and exhaustive. Students will be expected to summarize 2-3 papers of each topic in about 10 slides.

Each student will be working on a project related to an *iconic* structure (structural analysis), and will make a presentation on the last day.

Students should come to class with their laptop preloaded with the required software. At least two weeks before, student shall receive detailed instructions on how to install software and related tutorials.

When and Where

This course is likely to be offered during the Maymester of 2018 (3 weeks in May) in Paris with the collaboration with the at the *École Spéciale des Travaux Pratiques* (ESTP) in Cachan & Paris.

Prerequisites

- Statics (CVEN 2121) and Structural Analysis (CVEN 3525), B and above.
- Mathematica* (most of the calculation will entail lengthy algebraic operations).
- One Note*
- Matlab*
- Familiarity with a “good” drafting (vector based) program such as Visio, AutoCad, SolidWork, Adobe Illustrator.
- VPN to CU.
- Ability to draw clear free body diagrams, and to sketch structures to highlight load paths.

* Students are expected to bring their laptop with this software preloaded. The University has a site license for students.

Site Visits (tentative)

- Alexandre III Bridge
- Eiffel Tower
- Passerelle Simone de Beauvoir
- CNIT (SETEC)
- Pont de Normandie (Eiffage)
- Notre Dame
- La Grande Arche
- Sainte Chapelle
- Centre Pompidou
- Passerelle Leopold Senghor
- ESTP; (bouygues) Louvre Entrance
- Forum des Halles
- Bouygues
Invited Speakers (tentative)

- Bernard Vaudeville
- Michel Virlogeux
- Marc Miram
- Bruno Godart
- Pre; STETC

Cultural sites close to technical visits

Not exhaustive.

- Louvre Museum
- Pompidou Museum
- Musee d’Orsay
- Musee Quai Branly
- Omaha Beach;
- Mont St Michel
- Versailles

Coverage

Most or required reading documents are available from the instructor in pdf format.

This is a preliminary draft, coverage, references need to be finalised.

W1-D1: Getting Started; Working tools (Boulder)

Coverage: a) Introduction, expectations, grading, logistic. b) A brief history of structural analysis. c) The art of structural engineering, how "form follows functions", architectural value of iconic structures designed by structural engineers (and not architects); b) Review of Mathematica and Matlab; b) Morandi bridge collapse (Genova 2018); c) Art and Science of structural Engineering.

Exercise In about 15 slides, discuss content of at least 5 of the papers listed below.

Reading: Morandi (1962), Beghini et al. (2014), Hines (2012), Bradshaw et al. (2002)


W1-D2; Straight Lines: Trusses

Coverage: Review of Truss analysis; Optimal Design.

Examples: Alexandre III bridge, Eiffel tower.

Exercise: Complete approximate analysis of Eiffel tower. Iterate toward an optimal design for a cantilevered structure.


Additional Reading: Sandaker and Eggen (1992, pp. 66-76:), Stromberg et al. (2012)

W1-D3: Shape and Form: Cable Structures

Coverage: Advantages and disadvantages of cable structures, how load dictates shape of cables, funicular, derivation of governing differential equation for both parabolic and catenary shapes.

Examples Dulles Airport (Saarinen), Alitalia Hangar (Morandi), Sagrada Familia (Gaudi)

Exercise Matlab code for the approximate analysis of Nervi’s Burgo paper mill in Mantua


W-1-D4: Cable structures: Bridges

Coverage: Suspension versus cable stayed bridges; Derivation of governing equations, Introduction to the concept of geometric nonlinearity,

Examples Dulles Airport (Saarinen), Alitalia Hangar (Morandi), Sagrada Familia (Gaudi)

W-1-D5; Pont de Normandy

Day trip

W-2-D1; Frames Revisited

Coverage: Shear, Moment, Torsion diagrams of 3D frames; Approximate analysis of frames.
Examples: la Grande Arche; and Magazzini Generali
Exercise Complete spreadsheet program for approximate analysis of frames.
Additional Reading: Chaslin and Lefebvre (1989)

W-2-D2: Soaring Structures: Gothic Cathedrals

Coverage: a) Stability of Gothic cathedrals, challenge in the transfer of the horizontal thrust caused by the vaults, roles of flying buttresses, b) Graphical method, thrust lines, load transfer; Impact of low tensile strength of masonry structures.
Examples: Notre Dame
Exercise: Matlab code to determine and plot lines of thrusts.

W-2-D3; The Mechanics of Arches

Coverage: Advantages of arches, three hinge arch, optimal shape of an arch, semi-circular vs parabolic.
Example generic
Exercise Analysis of 3 centered arch (Matlab), plot internal forces.
Reading: Sonavane (2014), Duflot and Taylor (2008)

W-2-D4; Arches for Bridges

Coverage: Two hinged statically indeterminate arch.
Example Salginatobel Bridge (Maillart), detailed analysis.
Exercise Complete Matlab code for the analysis of a two hinged arch.
Additional reading: Hauck (1986)

W-2-D5; Laboratory visits

W-3-D1; As Complex as Can be: Helicoidal Arch

Coverage: Review of three dimensional vector mechanics, 6 internal forces in a curved structure.
Example: Generic
Exercise: Complete class exercise.
Reading: Lecture Notes
W-3-D2; Domes

Coverage: Approximate analysis of domes.
Example: St Peter, Florence (Bruneleschi).
Exercise: Complete class exercises.
Reading: Lecture Notes; Lopez (2006)

W-3-D3; Perfect Shapes: Shell*

Coverage: a) Theory; free body diagram; highlight of the derivation of the eighth order PDE for shell. b) Simplifications; Membrane theory. c) Statically indeterminate dome/cylinder. full day lecture
Example Palazetto dello Sport by Nervi
Exercise Matlab assignment.
Additional Reading: Billington (1965)
Homework:

W-3-D4; Experimental Methods

Coverage: Derivation of shapes from experimental techniques.
Examples Gaudi, Nusmeci, Isler.
Exercise Write a brief report.

W-3-D5; Presentations; Final Exam

Presentation of each student project (AM); Final Exam (2 hrs) PM

Other references

Grades; Examinations

Grades will be based on: 30% Project and Presentation; 30% Field book; 40% Final Exam. The final grade will depend on the average of the two highest individual point totals (h) for the course. The final letter grade that you get is determined by taking your point total and putting it in one of these

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References


