

**Title of Course**  
**CGN 6905 (class number 11340) Computational Poromechanics**  
**Class Periods:** Tuesday and Thursday, Period 8-9 (3:00 PM – 4:55 PM)  
**Location:** Weil Hall (Zoom)  
**Academic Term:** Spring 2022

**Instructor:**

Name: Xiaoyu Song – PhD, Associate Professor

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Office Phone Number: 352 294-3656

Office Hours: Tuesday and Thursday, 1:00 pm – 2:00 pm

Office: Weil Hall 480C

**Teaching Assistants:**

- N/A

**Course Description**

The course is designed for 3 credit hours, and is offered every other spring semester since 2018 (first offered in spring 2015). Porous media are relevant to many areas of engineering, science and medicine, including geo-hazards engineering, hydrology, subsurface flow, biomechanics, physical chemistry, materials science, geomechanics, geosciences, and petroleum engineering. Some applications include containment transport, piping in soils, scouring and erosion, dynamics of landslides, CO<sub>2</sub> sequestration, shale gas production, 3D printing of smart/biomimicry porous materials, and human tissue repair/transplant.

The course will cover (1) brief review of tensorial analysis in poromechanics, (2) fundamental principles and concepts in poro-elastoplasticity theory, (3) Interfacial physics in unsaturated poromechanics, (4) Balance laws for saturated and unsaturated porous media under isothermal and non-isothermal conditions, (5) Development of the weak and matrix forms for mixed finite element implementation, (6) Numerical stability analysis – consistency, stability and convergence in time and space domain, (7) Stabilized low-order mixed finite elements, (8) Benchmark problems in computational poromechanics – Mandel-Cryer effect etc, (9) Case studies of computational poromechanics applications – industrial CO<sub>2</sub> sequestration projects etc, and (10) Advanced topics: Nano and Micro-poromechanics with/without bio-electro-chemical reaction and advanced numerical methods such as nonlocal meshfree methods for modeling discontinuities in porous media, deep learning, digital twins, big data and high-performance computing.

**Course Pre-Requisites / Co-Requisites**

**N/A**

**Course Objectives**

The course aims to introduce students the fundamental principles and concepts in continuum poromechanics, the numerical implementation of poromechanics through the stabilized mixed finite element method, and basic structure of the nonlinear finite element code, numerical stability analysis in time and space domain for coupled poromechanical problems, case studies of the application of computational poromechanics in science, engineering and medicine, and advanced topics such as nano- and micro - poromechanics with/without bio-electro-chemical reactions, as well as advanced numerical methods for modeling poromechanics problems with discontinuities (i.e., cracks and shear bands) through high-performance computing.

Those objectives will be accomplished via (i) the fundamental theory and mathematical formulation as well as robust numerical algorithms covered in lectures, (ii) 3 Case studies on CO<sub>2</sub> sequestration, dynamics of landslides and mud flow, shale gas production, (iii) 6 homework assignments including 2 computational assignments, (iv) templates for numerical implementation of classical poromechanics problems designed for computational assignments, and (v) 1 final course project on computational modeling of a coupled/uncoupled poromechanics problem in engineering and science chosen by students.

## **Materials and Supply Fees**

N/A

## **Required Textbooks and Software**

N/A

## **Recommended Materials**

1. *Computational Geomechanics with Special Reference to Earthquake Engineering* by O. C. Zienkiewicz, A. H. C. Chan, M. Pastor, B. A. Schrefler and T. Shiomi, Wiley, Chichester, 1999, No. of pages: 398, ISBN 0-471-98285-7
2. *Poroelasticity* by Alexander H-D, Cheng. Springer, 2016.
3. *Poromechanics*, by O. Coussy, Wiley, 2004

## **Course Schedule (tentative)**

Week 1:

*Tuesday (1/6) Introduction, pore scale, continuum scale, concept of volume fraction, Homogenization and upscaling, nonlocality*

Week 2:

*Thursday (1/11) Elements of tensorial analysis, symbolic and index notations*

*Tuesday (1/13) Deformation gradient and transport formulae, Eulerian and Lagrangian coordinate systems, strain tensor*

Week 3:

*Thursday (1/18) Deformation gradient and transport formulae, Eulerian and Lagrangian coordinate systems, strain tensor (HW1-due in 1 week)*

*Tuesday (1/20) Cauchy and Piola-Kirchhoff stress tensors, and stress partition concept*

Week 4:

*Thursday (1/25) Flow through porous media, general conservation laws, constitutive assumptions, Darcy's law, Richards equations I*

*Tuesday (1/27) Flow through porous media, general conservation laws, constitutive assumptions, Darcy's law, Richards equations II (HW2-due in 1 week)*

Week 5:

*Thursday (2/1) Fluid conduction: Parabolic systems, review of mathematical theory of the finite element method*

*Tuesday (2/3) Strong and weak forms, Galerkin approximation, matrix form*

Week 6:

*Thursday (2/8) **Case study 1: CO2 injection and sequestration and associated micro-seismic activities** (HW3 – coding – due in 2 weeks)*

*Tuesday (2/10) Solution of elliptic and parabolic system, time-integration algorithms-stability and accuracy I*

Week 7:

*Thursday (2/15) Solution of elliptic and parabolic system, time-integration algorithms-stability and accuracy II*

- Tuesday (2/17) **Mixture theory, first law of thermodynamics – internal energy for a solid-fluid porous material, effective stress concept**
- Week 8: Thursday (2/22) **Mixed variational principle, time integration of “mixed” parabolic systems- stability and accuracy**
- Tuesday (2/24) **Stabilized low-order mixed finite elements – formulation**
- Week 9: Thursday (3/1) **Stabilized low-order mixed finite elements –implementation**
- Tuesday (3/3) **Case study 2: Shale gas production: solved problems and open questions.**
- Week 10: **Spring Break**
- Week 11: Thursday (3/15) **Mandel and Cryer problems, Mandel-Cryer’s effect (HW4 – due in 1 week)**
- Tuesday (3/17) **Isothermal unsaturated poromechanics (I): Interfacial physics, capillary pressure, effective stress concept in unsaturated porous media, generalized Darcy’s law and effective permeability**
- Week 12: Thursday (3/22) **Isothermal unsaturated poromechanics (II): Stabilized mixed finite element formulation for unsaturated fluid flow under the isothermal condition**
- Tuesday (3/24) **Non-isothermal unsaturated poromechanics (I): energy balance equation, water retention surface (HW5 – due in 1 week)**
- Week 13: Thursday (3/29) **Non-isothermal unsaturated poromechanics (II): Permeability and matrix deformation under non-isothermal conditions, field equations**
- Tuesday (3/31) **Non-isothermal unsaturated poromechanics (III): stabilized mixed finite element formulation and implementation**
- Week 14: Thursday (4/5) **Case study 3: Dynamics of landslides (HW6 – coding – due in 2 weeks)**
- Tuesday (4/7) **Nano and Micro-poromechanics – theory and application**
- Week 15: Thursday (4/12) **Nano and Micro-poromechanics with bio-electro-chemical processes**
- Tuesday (4/14) **Advanced computational techniques for poromechanics: deep learning, digital twins, big data, high-performance computing etc.**
- Week 16: Thursday (4/19) **Advanced computational techniques for poromechanics: deep learning, digital twins, big data, high-performance computing etc.**
- Week 17: **No class (Final Course Project Due on 4/28)**

**Attendance Policy, Class Expectations, and Make-Up Policy**

Attendance is required, and the instructor will monitor attendance for each lecture. Late homework will receive a 10% penalty per day it is late. No cell phone/laptop use is allowed in class (except consent of instructor). These

rules apply unless advance written request has been submitted to the instructor and approved. Illegible homework is subject to being rejected by the instructor. Make-up Quiz, Exam/Late Assignment Policy: Do not miss an exam. Make-up exams will only be given if prior approval is granted by the instructor and the student must make a reasonable attempt to take the exam before the scheduled exam date. Exams can be reviewed at any time in the instructor's office but will not be returned to keep. The instructor will discuss any exam or homework within one week (excluding holidays) after return. After this time, grades are final.

Excused absences are consistent with university policies in the undergraduate catalog (<http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020#attendance>) and require appropriate documentation.

### ***Evaluation of Grades***

<b>Assignment</b>	<b>Total Points</b>	<b>Percentage of Final Grade</b>
Homework Sets (6)	100 each	60%
Course Project	100	40%
		100%

### ***Grading Policy***

<b>Percent</b>	<b>Grade</b>	<b>Grade Points</b>
90.0 - 100.0	A	4.00
87.0 - 89.9	A-	3.67
84.0 - 86.9	B+	3.33
81.0 - 83.9	B	3.00
78.0 - 80.9	B-	2.67
75.0 - 79.9	C+	2.33
72.0 - 74.9	C	2.00
69.0 - 71.9	C-	1.67
66.0 - 68.9	D+	1.33
63.0 - 65.9	D	1.00
60.0 - 62.9	D-	0.67
0 - 59.9	E	0.00

More information on UF grading policy may be found at:  
<http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020#grades>

### ***Students Requiring Accommodations***

Students with disabilities requesting accommodations should first register with the Disability Resource Center (352-392-8565, <https://www.dso.ufl.edu/drc>) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodation. Students with disabilities should follow this procedure as early as possible in the semester.

### ***Course Evaluation***

Students are expected to provide feedback on the quality of instruction in this course by completing online evaluations at <https://evaluations.ufl.edu/evals>. Evaluations are typically open during the last two or three weeks of the semester, but students will be given specific times when they are open. Summary results of these assessments are available to students at <https://evaluations.ufl.edu/results/>.

### ***University Honesty Policy***

UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or

implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (<https://www.dso.ufl.edu/sccr/process/student-conduct-honor-code/>) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

### **Software Use**

All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

### **Student Privacy**

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: <http://registrar.ufl.edu/catalog0910/policies/regulationferpa.html>

### **Campus Resources:**

#### Health and Wellness

##### **U Matter, We Care:**

If you or a friend is in distress, please contact [umatter@ufl.edu](mailto:umatter@ufl.edu) or 352 392-1575 so that a team member can reach out to the student.

**Counseling and Wellness Center:** <http://www.counseling.ufl.edu/cwc>, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

##### **Sexual Assault Recovery Services (SARS)**

Student Health Care Center, 392-1161.

**University Police Department** at 392-1111 (or 9-1-1 for emergencies), or <http://www.police.ufl.edu/>.

#### Academic Resources

**E-learning technical support**, 352-392-4357 (select option 2) or e-mail to [Learning-support@ufl.edu](mailto:Learning-support@ufl.edu).  
<https://lss.at.ufl.edu/help.shtml>.

**Career Resource Center**, Reitz Union, 392-1601. Career assistance and counseling. <https://www.crc.ufl.edu/>.

**Library Support**, <http://cms.uflib.ufl.edu/ask>. Various ways to receive assistance with respect to using the libraries or finding resources.

**Teaching Center**, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring.  
<https://teachingcenter.ufl.edu/>.

**Writing Studio, 302 Tigert Hall**, 846-1138. Help brainstorming, formatting, and writing papers.  
<https://writing.ufl.edu/writing-studio/>.

**Student Complaints Campus:** [https://www.dso.ufl.edu/documents/UF\\_Complaints\\_policy.pdf](https://www.dso.ufl.edu/documents/UF_Complaints_policy.pdf).

**On-Line Students Complaints:** <http://www.distance.ufl.edu/student-complaint-process>.