The University of Western Ontario - Faculty of Engineering
Department of Civil and Environmental Engineering

CEE 9720 – Introduction to Pipeline Design and Assessment
Course Outline – 2021/2022

Objectives:

Pipelines are the safest and most economical means to transport large quantity of hydrocarbons. There are about 500,000 km and 100,000 km of onshore natural gas transmission pipelines in the US and Canada, respectively. The safe operation of these vast pipeline networks is the top priority for the pipeline operators in the US and Canada, and has significant social and economic implications. The design and integrity assessment of pipelines is a multi-disciplinary undertaking and involves a broad spectrum of engineering knowledge such as basic structural mechanics, elasticity and plasticity, soil mechanics, fracture mechanics, fatigue, reliability and risk assessments, and corrosion.

The objective of the course is to introduce the basic principles and methodologies employed in the design and assessment of onshore pipelines. Students who successfully complete this course should be able to perform the basic technical tasks carried out by pipeline integrity engineers. In particular, the students should be able to

- categorize pipelines based on their geographic locations, materials, function, and product carried;
- know the key material properties of line pipe steels;
- grasp the basic principles of plasticity and fracture mechanics;
- identify the class location of an onshore natural gas pipeline and use the design factor approach to determine the wall thickness of the pipeline;
- understand the basic tools and technologies used to conduct pipeline inline inspections;
- carry out integrity assessment of pipelines that contain metal-loss corrosion defects and planar defects, and
- understand the basic principles and methodologies of pipeline risk assessments.

Topics:

1. *Introduction (Weeks 1 – 2).* At the end of this section, the students should be able to
    a. distinguish various pipeline categories;
    b. know the basic pipeline construction methods, and
    c. know the basic material properties of line steel pipe including yield strength, tensile strength, engineering and true stress-strain relationships, Charpy v-notch toughness, and ductile-to-brittle transition temperature
2. *Pipeline Design (Weeks 3-4).* At the end of this section, the students should be able to
    a. know commonly used pipeline design standards in the US and Canada;
    b. identify the location class for an onshore gas pipeline according to the Canadian pipeline standard CSA Z662-19, and
    c. apply the design factor approach to determine the wall thickness for onshore pipelines.

3. *Introduction to Theory of Plasticity (Weeks 5-7).* At the end of this section, the students should be able to

a. understand and derive stress-strain relationships for an elastic continuum;

b. understand Cauchy's Formula and apply the formula to derive the governing equations for principal stresses and directions, and know how to solve for the principal stresses and directions by using the eigen value analysis;

c. know the basic concepts and principles of theory of plasticity for continuum under uniaxial and multi-axial stress states including the yield criterion (e.g. the von Mises and Tresca yield criteria), plastic flow rule and hardening rule;

d. know the difference between the plastic responses for elastic-perfectly plastic materials and elastic-strain hardening materials under multi-axial stress state as well as load-controlled and displacement-controlled conditions;

e. apply the incremental theory of plasticity to derive the burst capacity of pristine thin-walled steel pipes, and

f. apply the incremental theory of plasticity to calculate the stress and strain in pipelines due to internal pressure and/or axial load under different boundary conditions;

4. *Introduction to Fracture Mechanics (Weeks 8-9)*. At the end of this section, the students should be able to

a. know the basic concepts of linear-elastic and elastic-plastic fracture mechanics (LEFM and EPFM);

b. know the crack-tip stress-strain fields under LEFM and EPFM, and associated key concepts including the stress intensity factor (K), J-integral (J), crack tip opening displacement (CTOD) and small-scale yielding (SSY) conditions;

c. know how to determine the fracture toughness of pipeline steels using small-scale test specimens including the single-edged bending/tension specimens and compact tension specimen (SE(B), SE(T) and C(T) specimens) and the crack-tip constraint effect on the fracture toughness;

d. know different fracture failure criteria.

5. *Pipeline Integrity Assessment (Weeks 10-12)*. At the end of this section, the students should be able to

a. have basic knowledge of mechanism of corrosion on pipelines and know the commonly-used pipeline corrosion protection and inspection techniques;

b. apply the ASME B31G, B31G Modified and RSTRENG methods to determine the acceptability of a given metal-loss corrosion defect on a pipeline;

c. apply the Battelle model (i.e. Log-secant approach), CorLAS and failure assessment diagram (FAD) approach to evaluate the integrity of pipelines containing cracks or planar defects;

d. know the basic concepts and principles related to fatigue including Paris law, S-N curve, Miner's rule, variable amplitude loading and cycle counting method (e.g. rainflow counting), and

e. apply the fatigue principles to evaluate the remaining life of pipelines containing planar defects.

6. *Pipeline Risk Assessment (13-14)*. At the end of this section, the students should be able to

a. know the common integrity threats for pipelines and basic steps for carrying out a pipeline risk assessment;

b. estimate the average pipeline failure statistics using the pipeline failure databases in the US and Europe including the DOT, EGIG and CONCAWE databases;

c. evaluate the failure consequences of onshore gas pipelines using the simplified pipeline ignition and thermal radiation models, and

d. know various risk measures in the pipeline risk assessment such as the societal and individual risks, and various risk criteria such as the as low as reasonably practicable (ALARP) criterion.

Learning Outcomes

Degree Level Expectation	Weight	Assessment Tools	Outcomes
Depth and breadth of knowledge	40%	• Assignments • Critique • Final exam	• Understanding of advanced concepts and theories • Awareness of important current problems in the field of study • Understanding of computational and/or empirical methodologies to solve related problems
Research & scholarship	15%	• Assignment • Critique	• Ability to conduct critical evaluation of current advancements in the field of specialization • Ability to conduct coherent and thorough analyses of complex problems using established techniques/principles and judgment
Application of knowledge	30%	• Assignments • Final exam	• Ability to apply knowledge in a rational way to analyze a particular problem
Communication skills	15%	• Critique and presentation	• Ability to communicate (oral and/or written) ideas, issues, results and conclusions clearly and effectively

Prerequisite:
This course is intended for graduate students enrolled in civil or mechanical engineering with an interest in the design and assessment of energy pipelines. It is expected that students will have basic understanding of structural mechanics obtained by taking suitable courses at either the undergraduate or graduate level. Students without a suitable background in structural mechanics should discuss this with the instructor prior to registering for the course.

Corequisite:
None

Antirequisite:
None
Note: It is the **student's responsibility** to ensure that all Prerequisite and Corequisite conditions are met or that special permission to waive these requirements has been granted by the Faculty. It is also the **student's responsibility** to ensure that they have not taken a course listed as an Antirequisite. The student may be dropped from the course or not given credit for the course towards their degree if they violate the Prerequisite, Corequisite or Antirequisite conditions.

Instructor:
Dr. Wenxing Zhou, P. Eng.
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Administrative support: Mr. E. Sviridenko, SEB3010

Contact Hours:
Lecture from 11:30 am to 1:30 pm on Thursday every week starting September 16, 2021 delivered in-person in ACEB1450.
Contact policy:

- Contact instructor via email (above) or through messages in OWL.
- Weekly office hours – exact time to be determined with the students during the first lecture – are held at Dr. Zhou's office.

Course Materials:
Prepared lecture notes will be posted on the course OWL site at the beginning of the course. Some suggested, non-mandatory references include:

1. Anderson, T.L. 1995. *Fracture Mechanics: Fundamentals and Applications. 2nd Ed*. CRC Press, Boca Raton.
2. Barsom, J. and Rolfe, S.T. 1999. *Fracture and Fatigue Control in Structures: Application of Fracture Mechanics*. ASTM, PA.
3. Broek, D. 1988. *The Practical Use of Fracture Mechanics*. Kluwer Academic Publishers, Dordrecht.
4. Chen, W.-F. and Han, D.-J. 2007. *Plasticity for Structural Engineers*. J. Ross Publishing, Fort Lauderdale, FL.
5. Neto, E.d.S., Peric, D. and Owen, DRJ. 2008. *Computational Methods for Plasticity: Theory and Application*. John Wiley & Sons., Chichester, UK.
6. Canadian Standard Association (CSA). 2019. *Oil and Gas Pipeline Systems, CSA Z662-19*. CSA, Mississauga.
7. Hutchinson, J.W. 1979. *A Course on Nonlinear Fracture Mechanics*. Technical University of Denmark.
8. Kiefner, J.F. and Clark, E.B. 1996. *History of Line Pipe Manufacturing in North America*. CRTD-Vol. 43, American Society of Mechanical Engineers, New York.

Computing:
Assignments will require the use of computing software such as Matlab and Excel (access to such software is available through Western's campus licences), and students will be assumed to be proficient in the use of the software of their choice.

Units:
SI units will be used in lectures and examinations

Evaluation:
The final course mark will be determined as follows:

Assessment Type	Material Covered	Due Date	Weight
Assignments (4)	Topics 2 - 6	TBD	50%
Written critique of suggested references	Topics 1- 6	TBD	10%
Presentation and discussion of reference critique	Topics 1 - 6	TBD	10%

Final exam – written component	Topics 1- 6	TBD	20%
Final exam – oral component	Topics 1- 6	After the written component, exact time TBD	10%

1. Students must work alone on all the assessments listed in the table above. No collaboration is allowed.
2. The written component of the final exam will be 3 hr long, open-book and delivered through OWL.
3. The oral component of the final exam will be a one-on-one discussion of the course contents with the instructor through Zoom. Each discussion will be approximately 20 minutes long.

Use of English
In accordance with Senate and Faculty Policy, students may be penalised up to 10% of the marks on all assignments, tests, and examinations for the improper use of English. Additionally, poorly written work with the exception of the final examination may be returned without grading. If resubmission of the work is permitted, it may be graded with marks deducted for poor English and/or late submission.

Course Content
The lecture notes and online lecture videos are copyrighted to the instructor and legally protected. Do not post these videos and lecture notes on any other website or online forums. The recording of the live/synchronous sessions of the course without the permission from the instructor is prohibited. The illegal posting and sharing of the copyrighted course content could be subjected to legal actions.

Cheating, Plagiarism/Academic Offences
Academic integrity is an essential component of learning activities. Students must have a clear understanding of the course activities in which they are expected to work alone (and what working alone implies) and the activities in which they can collaborate or seek help; see information above under “Assessments” and ask instructor for clarification if needed. Any unauthorized forms of help-seeking or collaboration will be considered an academic offense. University policy states that cheating is an academic offence. If you are caught cheating, there will be no second warning. Students must write their essays and assignments in their own words. Whenever students take an idea or a passage of text from another author, they must acknowledge their debt both by using quotation marks where appropriate and by proper referencing such as footnotes or citations. Plagiarism is a major academic offence. Academic offences are taken seriously and attended by academic penalties which may include expulsion from the program. Students are directed to read the appropriate policy, specifically, the definition of what constitutes a Scholastic Offence (see Western's scholastic discipline regulations for graduate students).

Synchronous Learning Activities
Students are expected to participate in synchronous learning activities as outlined in the course syllabus and/or described by the instructor. If you have issues that will impede your ability to participate in synchronous activities, please discuss with the course instructor at the beginning of the course.

Conduct
Students are expected to follow proper etiquette during synchronous and asynchronous activities to maintain an appropriate and respectful academic environment. Any student who, in the opinion of the instructor, is not appropriately participating in the synchronous and asynchronous learning activities and/or is not following the rules and responsibilities associated with the online learning activities, will be reported to the Associate Dean (Graduate) (after due warning has been given). On the recommendation of the Department concerned,

and with the permission of the Associate Dean (Graduate), the student could be debarred from completing the assessment activities in the course as appropriate.

Health/Wellness

As part of a successful graduate student experience at Western, we encourage students to make their health and wellness a priority. Western provides several health and wellness related services (remotely accessible) to help you achieve optimum health and engage in healthy living while pursuing your graduate degree. Information regarding health- and wellness-related services available to students may be found at http://www.health.uwo.ca/.

Students seeking help regarding mental health concerns are advised to speak to someone they feel comfortable confiding in, such as their faculty supervisor, their program director (graduate chair), or other relevant administrators in their unit. Campus mental health resources may be found at http://www.health.uwo.ca/mental_health/resources.html https://www.uwo.ca/health/psych/index.html

Sickness

Students should immediately consult with the Instructor (for a particular course) or Associate Chair (Graduate) (for a range of courses) if they have problems that could affect their performance. The student should seek advice from the Instructor or Associate Chair (Graduate) regarding how best to deal with the problem. Failure to notify the Instructor or the Associate Chair (Graduate) immediately (or as soon as possible thereafter) will have a negative effect on any appeal. Obtaining appropriate documentation (e.g., a note from the doctor) is valuable when asking for accommodation due to illness.

Accessibility

Please contact the course instructor if you require material in an alternate format or if any other arrangements can make this course more accessible to you. You may also wish to contact Accessible Education at 661-2111 x 82147 or http://academicsupport.uwo.ca/accessible_education/index.html, for any specific question regarding an accommodation.