Concrete & Geomaterial Modeling with LS-DYNA

A short course taught by

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Course Description:

Constitutive models for concrete & geomaterials (rock and soil) are typically based on the same mathematical plasticity theory framework used to model common metals. However, the constitutive behavior of concrete & geomaterials differs from that of metals in three important ways:

1. They are (relatively) highly compressible, i.e., pressure-volume response;
2. Their yield strengths depend on the mean stress (pressure), i.e. frictional response; and
3. Their tensile strengths are small compared to their compressive strengths.

These basic differences give rise to interesting aspects of constitutive modeling that may not be familiar to engineers trained in classical metal plasticity.

The course starts from the common ground of introductory metal plasticity constitutive modeling and successively builds on this base adding the constitutive modeling features necessary to model concrete & geomaterials. The LS-DYNA constitutive models covered are adequate for modeling most types of rock, all concretes, and a large class of soils. The course is intended for those new to concrete & geomaterial constitutive modeling, but will also be useful to those seeking a more in-depth explanation of the LS-DYNA concrete & geomaterial constitutive models covered.

A significant portion of the course is devoted to understanding the types of laboratory tests and data that are available to characterize concrete & geomaterials. Unlike most metals, whose strength is characterized by a single value obtained from a simple uniaxial stress test, concrete & geomaterial characterization requires a matrix of laboratory tests. Knowledge of how these tests are performed, the form and format of typical laboratory test data, and the interpretation of the data for use with a concrete or geomaterial constitutive model, is essential to becoming a successful concrete & geomaterial modeler.

The basic mathematics of the LS-DYNA concrete & geomaterials constitutive models are covered, with an emphasis on how the mathematics can aid the modeler in fitting constitutive models to the available laboratory data. The mechanics of the constitutive model are emphasized to provide the modeler with the insights necessary to easily separate cause and effect in these complicated constitutive models. Exercises in fitting the LS-DYNA concrete & geomaterial constitutive models to typical laboratory data are used to illustrate the data and the constitutive models.

Several application case studies are covered:

1. Quasi-static soil penetration,
2. Quasi-static eccentric loading of a reinforced concrete column
3. Penetration of a concrete target using Lagrange with erosion, Eulerian and SPH formulations.
4. Blast loading of a reinforced concrete slab modeled with several concrete models.

Photo credit: Professor William P. Manion   http://www.civil.umaine.edu/cie111/concrete/strength.htm
University of Maine Civil Engineering Materials Course Manual CIE 111. 14 September, 2009.

Course Materials:
The course notes consist of over 300 pages of descriptive text, presented in a narrative style, i.e. not a collection of presentation slides, arranged in more than 20 sections that include the exercises and their solution. Participants are offered the LS-DYNA input files for all examples, and Microsoft Excel workbooks containing the laboratory data for several materials including a sandy soil, Salem limestone, and two concretes.

Instructor:
Len Schwer has worked on concrete & geomaterial applications, and developed constitutive models, for the past 25 years; he has been a DYNA3D user since 1983 and an LS-DYNA user since 1998. His early work at SRI International included the development of a Mohr-Coulomb constitutive model for modeling the rock surrounding tunnels under very high pressure loadings. While at Lockheed Missile and Space Company he worked on high speed earth penetrators designed to penetrate reinforced concrete structures buried in soil. In the early 1990's, while working for APTEK, Inc., and as a consultant, he co-developed with Yvonne Murray the Continuous Surface Cap Model for application in the Underground Technology Program of the then-named Defense Nuclear Agency; this model is implemented in DYNA3D (Material Type 37) and in LS-DYNA Version 970 (MAT145). From 1997 - 2001 he worked with Professors Belytschko and Liu of Northwestern University on applying their meshfree methods to reinforced concrete problems of interest to the Defense Threat Reduction Agency. During 1999 - 2000 he contributed to a test and simulation program focused on non-standard loading of buried pipelines. From 1999 - 2002 he was a consultant to Sandia National Laboratories providing documentation, verification and validation for the constitutive models used by the Engineering & Manufacturing Mechanics Group. He has a strong interest in verification and validation in computational solid mechanics, and is the recent past Chair of the ASME Standards Committee on Verification and Validation in Computational Solid Mechanics.

Len Schwer is a Fellow of the American Society of Mechanics Engineers (ASME) and the United States Association for Computational Mechanics (USACM).

COURSE OUTLINE – Class starts at 9:00 AM and lectures end at about 4 PM. Additional time is allocated at the end of each day for one-on-one participant discussion with the instructor.

Day 1

> ***Introduction to Metal Plasticity***
> > Nomenclature
> > > Stress Tensor
> > > Principal Stresses
> > > Stress Invariants
> > > Spherical and Deviatoric Stress Tensors
> > > Deviatoric Stress Invariants
> > von Mises Constitutive Model (Material Type 3)
> > > Uniaxial Tension
> > > The Effective Stress or Mises Stress
> > Perfect Plasticity and Hardening
> > Overview of a Numerical Constitutive Model Algorithm
> > > Determining the Plastic Strain
> > > > The Principle of Maximum Plastic Resistance
> > > > Drucker's Postulate
> > > > Flow Rule (a.k.a. Normality Rule)
> > > > Consistency Condition
> > > Updating the Stress
> > Tresca Yield Criterion
> > Description of the Pi-Plane
> > Two Special Limiting Cases for the Lode Angle

> ***Introduction to Geomaterials***
> > Compressibility the Pressure – Volume Response
> > > Metals
> > > Geomaterials
> > Pressure Enhanced Shear Strength – Frictional Materials

Unconfined Compressive Strength
Tri-Axial Compressive Strength
Mohr Circles
Mohr-Coulomb Failure Criteria
Mohr-Coulomb Tri-Axial Compression
Mohr-Coulomb Tri-Axial Extension
Soil and Foam Model (Material Type 5)
Shear Failure Criterion
Pressure-Volume Specification
Two Surface Model Representation
Other Soil and Foam Model Parameters
Relation to Drucker-Prager Model
Appendix: Engineering and True Stress-Strain

Material Characterization - Laboratory Tests & Data
Hydrostatic Compression Testing
Tri-Axial Compression Testing
Unconfined Compression Testing
Elastic Material Property Determination
Typical Tri-Axial Compression Test Data
Other Useful Material Tests
Uniaxial Strain Compression Test Data
Elastic Material Property Determination
Tri-Axial Extension Test
Mohr-Coulomb Failure Criteria in Tri-Axial Extension

Exercises - Calibrating the Soil & Foam constitutive model (MAT005) to low and high pressure soil data.

Case Study - Quasi-static Soil Penetration.

Pseudo-TENSOR (MAT016)

Day 2

Simple Input Concrete Models
The following single parameter (unconfined compression strength) models are compared with laboratory data:
*MAT_PSEUDO_TENSOR (Mode II Concrete)
*MAT_CONCRETE_DAMAGE_REL3
*MAT_WINFRITH_CONCRETE
*MAT_CSCM_CONCRETE
*MAT_RHT
*MAT_CDPM

Case Study – Reinforced Concrete Column Eccentric Loading
Case Study – Brick Wall Performation
Case Study – Concrete Target Perforation using Lagrange with erosion, Eulerian & SPH Formulations.
Case Study – Reinforced concrete slab under blast loading – Blind Blast Simulation Contest

Modeling reinforcement

Winfrith Cobcrete Model – Crack Patterns

Strain Rate Effects – Much Ado About Nothing?

Introduction to the LS-DYNA Cap- Models – x Calibrating the Geological Cap Model (MAT025)

Other LS-DYNA Material Models for Concrete & Geomaterials (*not covered*):
> Soil and Foam Failure (Material Type 14)
> Orientated Crack (Material Type 17)
> Honeycomb (Material Type 26)
> Soil Concrete (Material Type 78)
> Hysteretic Soil (Material Type 79)
> Ramberg Osgood (Material Type 80)
> Brittle Damage (Material Type 96)
> Johnson Holmquist Concrete (Material Type 111)
> Modified Drucker Prager (Material Type 193)
> Soil Brick (Material Type 192)
> RC Shear Wall (Material Type 194)
> Concrete Beam (Material Type 195)

Comments from Class Participants:

"Really a great course and one I would highly recommend to others. I feel like I'm starting to understand my way around CAP models. I think your course material and explanation is the kind of instructive material that leads to better productivity and understanding."

"I really enjoyed your short course myself. This is because that this course not only cover the mathematical formulations of these geomaterial models, but also a lot of physical insights behind the various components in these models plus your wealthy experiences of using them."

"I thought that it was very helpful in presenting the specific geomaterial data, but I also appreciated the background in simple plasticity because I have a fluid mechanics and heat transfer background."

Useful Reference Books:

Soil Plasticity: Theory & Implementation, Developments in Geotechnical Engineering Series #38
Authors: Chen, Wai-Fah and Baladi, G. Y.
Elsevier Science, December 1985, Hardcover, 234 Pages
ISBN: 0444424555

Nonlinear Analysis in Soil Mechanics: Theory & Implementation, Developments in Geotechnical Engineering Series #53
Authors: Chen, Wai-Fah and Mizuno, E.
Elsevier Science, December 1990, Hardcover, 672 Pages
ISBN: 0444430431

Experimental Soil Mechanics
Author: Bardet, Jean-Pierre
Prentice Hall, July 1996, Hardcover, 583 Pages
ISBN: 0133749355

Reinforced Concrete Design
Authors: Chu-Kia Wang and Charles G. Salmon
Harper Colins Publishers
ISBN: 0-06-046887-4

Soil Behaviour and Critical State Soil Mechanics
Author: David Muir Wood
Cambridge University Press, January 1990, 462 pages
ISBN: 0521337828

Finite Element Analysis in Geotechnical Engineering: Application
Authors: David M. Potts and Lidija Zdravkovic

Thomas Telford, August 2001, Hardcover, 427 Pages
ISBN: 0727727834

Finite Element Analysis in Geotechnical Engineering: Theory
Authors: David M. Potts and Lidija Zdravkovic
Thomas Telford, 1999, Hardcover, 440 Pages
ISBN: 0727727532

CEB-FIP Model Code 1990: Design Code
American Society of Civil Engineers, August 1993, Hardcover, 437 Pages
ISBN: 0727716964

Computational Inelasticity
Authors: Juan C. Simo and Thomas J. Hughes
Publication Date: December 1997
ISBN: 0387975209

Nonlinear Finite Elements for Continua and Structures
Authors: Ted Belytschko, Wing Kam Liu, & Brian Moran
Publication Date: June 2000
ISBN: 0471987735