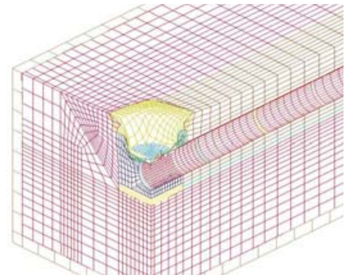
Geomaterial Modeling with LS-DYNA



A short course taught by **Len Schwer, Ph.D.**
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Course Description:
Constitutive models for geomaterials (rock, concrete, and soil) are typically based on the same mathematical plasticity theory framework used to model common metals. However, the constitutive behavior of geomaterials differs from that of metals in three important ways:

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

These basic differences between metals and geomaterials 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 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 geomaterial constitutive modeling, but will also be useful to those seeking a more in-depth explanation of the LS-DYNA 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 geomaterials. Unlike most metals, whose strength is characterized by a single value obtained from a simple uniaxial stress test, geomaterial characterization requires a matrix of laboratory tests. A 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 geomaterial constitutive model, is essential to becoming a successful geomaterial modeler.

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

Two application case studies will be covered:

1. Quasi-static soil penetration,
2. Quasi-static eccentric loading of reinforced concrete columns.

Instructor:
Len Schwer has worked on geomaterial applications, and developed geomaterial 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 so called Smooth 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 will be available in LS-DYNA v970 (Material Type 145). Since 1997 he has worked with Professors Belytschko and Liu of Northwestern University on applying their meshfree methods to reinforced concrete applications of interest to the Defense Threat Reduction Agency. Most recently, he contributed to a test and simulation program focused on non-standard loading of buried pipelines. Since 1999 he has been 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 Chair of a newly formed ASME Standards Committee on Verification and Validation in Computational Solid Mechanics.

COURSE OUTLINE – Class meets each day from 9 AM until 5 PM.

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
    - Determining the Plastic Strain
      - Consistency Condition
      - Flow Rule (a.k.a. Normality Rule)
      - Proportionality Factor
  - Tresca Yield Criterion

- 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

- 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

Using the LS-DYNA Material Model Driver

Exercise 1. Calibrating the Soil & Foam constitutive model (Material Type 5) to typical laboratory soil data.

Day 2

Case Study #1 - Quasi-static Soil Penetration.

Introduction to the LS-DYNA Cap-Type Models for Geomaterials
Pseudo-TENSOR (Material Type 16)
Geological Cap (Material Type 25)
Continuous Surface Cap Model (v970 Material Type 145)

Exercise 2. Using the Pseudo-TENSOR model (Response Mode I) to model limestone.

Exercise 3. Using the Pseudo-TENSOR model (Response Mode II) to model concrete.

Demonstration. Calibrating the Geological Cap model (Material Type 25) to Salem Limestone laboratory data.

Exercise 4. Calibrating the Geological Cap model (Material Type 25) to typical concrete laboratory data.

Day 3

Introduction to the LS-DYNA Cap-Type Models for Geomaterials (continued)
Pseudo-TENSOR (Material Type 16)
Geological Cap (Material Type 25)
Continuous Surface Cap Model (v970 Material Type 145)

Demonstration. Calibrating the damage model of the Three-Invariant Continuous Surface Cap Model to typical concrete data.

Case Study #2 - Quasi-static Eccentric Loading of Reinforced Concrete Columns.

Constitutive Model Verification and Validation.

Other LS-DYNA Material Models for Geomaterials (brief descriptions, time permitting)
Brittle Damage (Material Type 96)
Johnson Holmquist Concrete (Material Type 111)
Soil Concrete (Material Type 78)
Hysteretic Soil (Material Type 79)
Ramberg Osgood (Material Type 80)
Modified Drucker Prager (Material Type 193)
LS-DYNA Material Models for Geomaterials *not covered*:
Soil and Foam Failure (Material Type 14)
Orientated Crack (Material Type 17)
Honeycomb (Material Type 26)
Concrete Damage (Material Type 72)
Winfrith Concrete (Material Type 84)
Winfrith Concrete (Material Type 85)
Soil Brick (Material Type 192)
RC Shear Wall (Material Type 194)
Concrete Beam (Material Type 195)

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

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

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