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Pedagogical Material in MyCourses

0. **INTRODUTION**
1. **ELASTICITY**
2. **VISCOELASTICITY** (+ basics of creep)
3. **PLASTICITY**

Reading – **Textbooks:**

- Lemaitre and Chaboche – *Mechanics of Solid Materials*
- Ottosen & Ristinmaa – *The Mechanics of Constitutive Modeling*
- W.F. Chen, D.J. Han – *Plasticity for Structural Engineers* (only *chapters* 1-5)

Lemaitre & Chaboche textbook as an **e-book**:
http://proquestcombo.safaribooksonline.com.libproxy.aalto.fi/book/physics/9781107384712

Course of **materials modelling** in other universities

TECHNISCHE UNIVERSITÄT DARMSTADT

Technische Universität Darmstadt

9.10.2016

13-02-0003-vl Werkstoffmechanik

Veranstaltungsdetails

Lehrende: Prof. Dr.-Ing. Michael Vormwald; Dipl.-Ing. Melanie Fiedler

Veranstaltungsart: Vorlesung

Orga-Einheit: FB13 Bau- und Umweltingenieurwissenschaften

Anzeige im Stundenplan: Werkstm. (V)

Fach:

Anrechenbar für:

Semesterwochenstunden: 3

Unterrichtssprache: Deutsch

Min. | Max. Teilnehmerzahl: - | -

Lehrinhalte:

- Klassifizierung der Phänomene des Deformations- und Festgk
- Lineare Elastizität
- Isotropie, Anisotropie (Orthotropie, transversale Isotropie)
- Elastoplastizität
- Idealplastizität, Isotrope und kinematische Verfestigung
- Viskoelastizität, Viskoplastizität
- Werkstoffgesetze für Stahl, Beton, Glas, Holz, Kunststoffe und Geomaterialien
- Numerische Umsetzung

Today subject

… for comparison of the courses contents at **two universities to show the relevance of such course content for CIV-engineers**

Aalto-university,
summer 2016

Content:

Djebar BAROUDI, PhD
Aalto-University

- **Elasticity – kimmoisuus tai elastisuus**
  (linear, hyper-elasticity, isotropy, anisotropy, orthotropy)
- **Viscoelasticity - viskoelastisuus**
- **Viscoplasticity** or creep – **viskoplastisuus** … viruminen
- **Failure hypotheses - lujuushypoteesit**
- **Plasticity - plastisuus**
  associative, non-associative
- **Damage - vauriotuminen**
  damage-plasticity *ex.* Concrete Damage Plasticity, Model in Abaqus

If time…

Ref: thanks go to an exchange student for providing the course content-list above

CONTENT

1. INTRODUTION
2. **ELASTICITY**
3. VISCOELASTICITY
4. PLASTICITY

Elasticity in Solids

Definitions

Thermodynamical framework

Elastic Solids

Isothermal Cauchy-elastic material

Green-Elastic or Hyper-elastic Materials

Examples of Non-Linear Elasticity

Hysteresis during loading and unloading

Equations of Elasticity

Material Symmetries

Degree of symmetry

Linear Elasticity – Matrix Formulation

Anisotropy

Isotropy

Limits on Elastic Parameters Values

Orthotropy

Transversal isotropy

Limits on Elastic Parameters Values

Nonlinear isotropic Hooke formulation

Generalized Hooke's Law – Examples of problems

Orthotropic case – A worked example

Good to know: layered composite (transverse orthotropy)

Transformation of Stress and Strain Components

Example exercises for training

...

Minimum Master level

Minimum L-level

Nonlinear isotropic Hooke formulation

Some general aspects

Why splitting volumetric and deviatoric (shearing)?

Thermo-elasticity

Hyperelasticity

Rubber or rubber-like Elasticity

Terminology and some definitions

Thermodynamics of rubber – enthalpic and entropic forces

Some classical models

Neo-Hookean model

Mooney-Rivlin model

Yeoh model

Ogden model

Example of Rubber Elasticity In Abaqus

W. Gilbert's experiment

On thermodynamics of elastomers

Homework

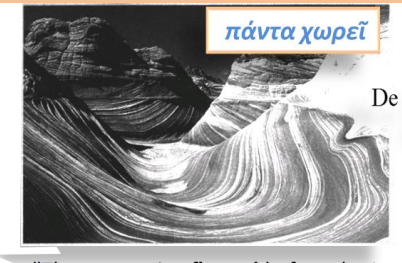
Appendix 1

Stress invariants (Recall)

Appendix 2

On Thermodynamics of Rubber

Enthalpic and Entropic forces



"The mountains **flowed** before the Lord"
(The Song of **Deborah**, Bible)
דְּבוֹרָה

1. INTRODUTION
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Civil Engineering Department

22.4.2017

Otaniemi, February 2017

Viscoelasticity

$$\mathcal{F}(\sigma, \dot{\sigma}, \varepsilon, \dot{\varepsilon}, T, \dot{T}) = 0$$

Content

- **Experimental observations: evidence of viscoelastic behavior**
- **Stress relaxation at constant strain**
- **Creep at constant stress**
- **Strain-rate dependence**
- **Constitutive models in the rate form**:
  - Maxwell model
  - Kelvin-Voight model
  - Standard linear solid model
  - Burgers model
  - Generalized Maxwell model
  - Kelvin chain model

Reading: Textbooks

- Lemaitre and Chaboche – *Mechanics of Solid Materials*. **Chapter 4.3**
- Ottosen & Ristinmaa – *Introduction to time-dependent material behaviour.* **Chapter 14**

Lemaitre & Chaboche textbook as an **e-book**:
http://proquestcombo.safaribooksonline.com.libproxy.aalto.fi/book/physics/9781107384712

Primary creep:

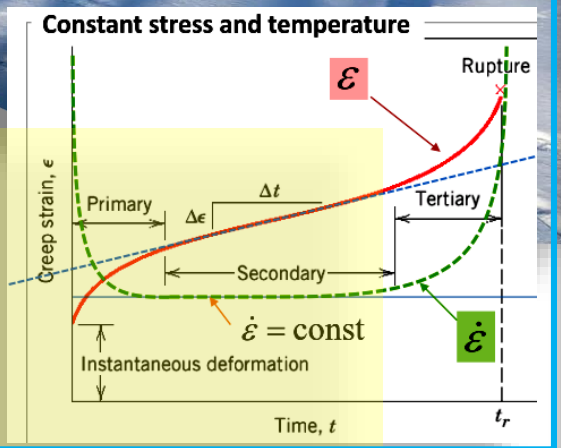
$$\varepsilon = A(\sigma)\cdot t^{1/\beta},$$

$$2 < \beta < 4$$

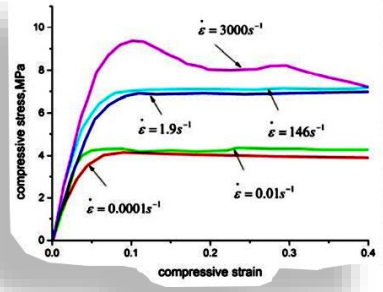
$$\varepsilon = A(\sigma)\cdot \left[t / t_{\mathrm{REF}}\right]^{1/\beta},$$

Secondary creep:

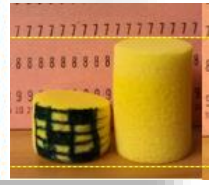
$$\dot{\varepsilon} = K_2 \left[\frac{\sigma}{\sigma_{\mathrm{Ref}}}\right]^n \exp\left(-\frac{Q_c}{RT}\right)$$



Experimental: Compressive responses of balsa wood at static, intermediate, and high strain rate

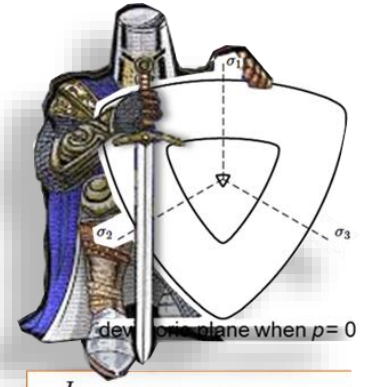


Partial recovery



Content

Engineering Plasticity



Motivation

- Course of materials modelling in other universities
- Literature & textbooks
- Some historical notes on engineering plasticity
- Motivation: How engineering Plasticity is seen in Abaqus, Ansys, Lusas?
- Stress invariants
- Examples of Failure of Structures
- What is failure? Types of failures, failure envelopes and failure criteria

Plasticity

Failure hypothesis or Yield criteria

Plasticity Isotropic & Isothermal Rate-Independent

- Examples
- Some basic physics for Engineering Plasticity
- Plastic basic behavior in simple tension & compression

Modelling of uniaxial behavior in plasticity – simplified models

- Elastic-Perfectly Plastic Model
- Elastic-Linear Work-hardening model
- Elastic-Exponential Hardening model
- Ramberg-Osgood model
- **Tangent- and plastic modulus**
- **Hardening rules**
- **Elastic-plastic behaviour – cyclic loading**
  - ➢ **Worked uniaxial example – analytical & Abaqus**
- Loading history dependency and **strain hardening effects**
- Homework: Uniaxial Elastic-plastic behaviour : ex #1, ex #2
- Some examples of solved problems in Plasticity
  - ✓ **Plastic limit load and displacement-force relation in bending**

Continued…

Engineering Plasticity

Classical theory – fundamentals

The three ingredient of the classical plasticity theory

- **Yield criteria**
- **Flow rule**
- **Hardening rule**

Yield Criteria

Pressure independent Yield criteria

- Tresca yield Criterion
- Von Mises yield Criterion

Pressure dependent Yield criteria

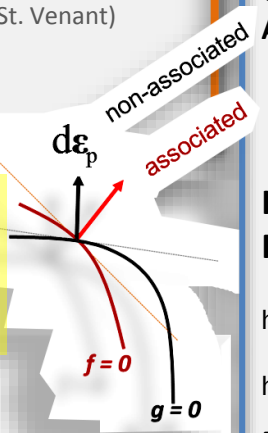
- Mohr-Coulomb Criterion
- Drucker-Prager Criterion
- Ottosen (1977) developed a 4-parameters failure criterion for concrete
- Hoek–Brown failure criterion
- Mohr-Coulomb yield criterion
- The Cam-Clay model

(good to know) Example of material Behavior of Clay and Silt in Otaniemi

Other types of failure criteria

- Maximum Principle Stress Criteria (Rankine)
- Maximum Principal strain (St. Venant)

Anisotropic yield criteria



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Appendices

Appendix 1: Stress invariants

Appendix 2: Recommended compulsory reading

Continued

$$A\frac{J_2}{\sigma_c} + \Lambda\sqrt{J_2} + BI_1 - \sigma_c = 0,$$

Hardening – notions

- Hardening Rules
- Examples of simple rheological models for Rate-independent plasticity
- Examples of hardening rules in Abaqus – how they looks like?

Flow rules

Flow rule & Consistency condition

Plastic strain increment

Principle of maximum plastic work

Normality rule

Consistency Condition

Associative and Non-associate Plasticity

Convexity of the criterion

Normality of the plastic flow

Some application examples of associated and non-associated plasticity

Incremental Stress-Strain Relationships

Example of a flow rule for isotropic hardening

Examples of hardening rules in Abaqus – how it looks like?

EOL