

**Modulhandbuch**  
**Studiengang Master of Science Computational**  
**Mechanics of Materials and Structures**  
Prüfungsordnung: 921-2016

Wintersemester 2017/18  
Stand: 19. Oktober 2017

Universität Stuttgart  
Keplerstr. 7  
70174 Stuttgart

## Kontaktpersonen:

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Studiengangsmanager/in:

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## 100 Compulsory Modules

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|---------------------|-------|---------------------------------------------------|
| Zugeordnete Module: | 23850 | Engineering Materials I (COMMAS C7)               |
|                     | 30060 | Optimization of Mechanical Systems                |
|                     | 55880 | Continuum Mechanics                               |
|                     | 55900 | Computational Mechanics of Materials              |
|                     | 55920 | Computational Mechanics of Structures             |
|                     | 68760 | Discretization Methods and Scientific Programming |
|                     | 68810 | Summer School and Seminar Lecture                 |

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**Modul: 23850 Engineering Materials I (COMMAS C7)**

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|-----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021500231                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 3 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Jan Hofmann                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 9. Dozenten:                                        | Siegfried Schmauder<br>Jan Hofmann<br>Christian Moormann                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 1. Semester<br>→ Compulsory Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 11. Empfohlene Voraussetzungen:                     | Bachelor degree                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 12. Lernziele:                                      | <p><b>Metals:</b><br/>The students are familiar with the theoretical background of the crystal structure and the deformation processes in metals on the atomistic level. The different hardening procedures, and their metallographic mechanisms are understood. The students know the main influence factors on the mechanical behaviour.</p> <p><b>Concrete:</b><br/>The students get a deep understanding of the behaviour of concrete, a very heterogeneous and rather brittle material, under compression and tension loading. They understand the influence of test conditions, light weight aggregates and fibres on concrete properties.</p> <p><b>Soils:</b><br/>The students understand the effective stresses and pore pressures. They also understand Hooke's law of linear elasticity, exponential compression law, the preconsolidation pressure and the stress-strain curves from drained triaxial test. The measurement of shear strength in direct shear tests, uniaxial compression tests and standard drained triaxial tests is also clarified.</p> |                |                |
| 13. Inhalt:                                         | <p><b>Metals:</b></p> <ul style="list-style-type: none"> <li>• Fundamentals of dislocation theory</li> <li>• Plastic deformation of metals</li> <li>• Possibilities of strengthening</li> <li>• Influences on behaviour of material</li> </ul> <p><b>Concrete:</b></p> <ul style="list-style-type: none"> <li>• Properties of concrete</li> <li>• The behaviour of concrete under compressive loading</li> <li>• The behaviour of concrete under tensile loading</li> <li>• Time dependent behaviour</li> <li>• Special concretes</li> </ul> <p><b>Soils:</b></p> <ul style="list-style-type: none"> <li>• Stresses in soils</li> <li>• Stiffness of soils</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |

- Strength of soils

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14. Literatur:

Metals:

- Lecture notes.
- Smallman, R., Bishop, R.: Metals and Materials. Butterworth-Heinemann Ltd., 1995.

Concrete:

- Lecture notes.
- Illston, J., Domone, P.: Construction Materials. CRC Press, 4th edition, 2010.
- Neville A.: Properties of Concrete. John Wiley und Sons, 4th edition, 1996.

Soils:

- Lecture notes.
  - Soil Mechanics, an elementary textbook that is available in the internet under <http://geo.verruijt.net/software.html>
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15. Lehrveranstaltungen und -formen:

- 238501 Vorlesung Engineering Materials I (COMMAS C7)
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16. Abschätzung Arbeitsaufwand:

Attendance time: 28 h  
Homework: 22 h  
Private study: 40 h

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17. Prüfungsnummer/n und -name:

23851 Engineering Materials I (COMMAS C7) (BSL), Schriftlich, 120 Min., Gewichtung: 1

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18. Grundlage für ... :

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19. Medienform:

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20. Angeboten von:

Befestigungstechnik und Verstärkungsmethoden

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## Modul: 30060 Optimization of Mechanical Systems

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|-----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 072810007                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 3 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Peter Eberhard                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 9. Dozenten:                                        | Peter Eberhard                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 1. Semester<br>→ Compulsory Modules                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 11. Empfohlene Voraussetzungen:                     | Basics in Applied Mechanics and Mathematics                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 12. Lernziele:                                      | Knowledge of the basics of optimization in engineering systems, Independent, confident, critical and creative application of optimization techniques to mechanical systems                                                                                                                                                                                                                                                                                                                            |                |                |
| 13. Inhalt:                                         | <p>○ <b>Formulation of the optimization problem:</b> optimization criteria, scalar optimization problem, multicriteria optimization</p> <p>○ <b>Sensitivity Analysis:</b> Numerical differentiation, semianalytical methods, automatic differentiation</p> <p>○ <b>Unconstrained parameter optimization:</b> theoretical basics, strategies, Quasi-Newton methods, stochastic methods</p> <p>○ <b>Constrained parameter optimization:</b> theoretical basics, strategies, Lagrange-Newton methods</p> |                |                |
| 14. Literatur:                                      | <p>○ Lecture notes</p> <p>○ Lecture materials of the ITM</p> <p>○ D. Bestle: Analyse und Optimierung von Mehrkörpersystemen, Berlin: Springer, 1994</p> <p>○ R. Haftka and Z. Gurdal: Elements of Structural Optimization. Dordrecht: Kluwer Academic Publishers, 1992</p> <p>○ L. Harzheim: Strukturoptimierung. Frankfurt, Verlag Harry Deutsch, 2007</p>                                                                                                                                           |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 300601 Lecture Optimization of Mechanical Systems                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Präsenzzeit: 21 Stunden<br>Selbststudium: 69 Stunden<br>Summe: 90 Stunden                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 17. Prüfungsnummer/n und -name:                     | 30061 Optimization of Mechanical Systems (BSL), Schriftlich oder Mündlich, 90 Min., Gewichtung: 1<br>schriftlich 90min oder mündlich 20min                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 20. Angeboten von:                                  | Technische Mechanik                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |

## Modul: 55880 Continuum Mechanics

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|-----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | Commas                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Holger Steeb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 9. Dozenten:                                        | Wolfgang Ehlers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 1. Semester<br>→ Compulsory Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 12. Lernziele:                                      | The students are able to apply continuum-mechanical methods to the description of solid mechanical problems.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 13. Inhalt:                                         | <p>Continuum-mechanical knowledge is the fundamental basis for the computation of deformation processes of solid materials. Based on the methods of tensor calculus, the lecture offers the following content:</p> <p>Vector and Tensor Algebra: symbols, spaces, products, specific tensors and definitions</p> <p>Vector and Tensor Analysis: functions of scalar-, vector- and tensor-valued variables, integral theorem (e. g., after Gauss or Stokes)</p> <p>Foundations of Continuum Mechanics: kinematics and deformation, forces and stress concepts: Cauchy's lemma and theorem, Cauchy, Kirchhoff and Piola-Kirchhoff stress tensors</p> <p>Fundamental Balance Laws: master balance, axiomatic balance relations of mechanics (mass balance, momentum and angular momentum balances)</p> <p>Related Balance Laws and Concepts: balance of mechanical energy, stress power and the concept of conjugate variables, d'Alembert's principle and the principle of virtual work</p> <p>Numerical Aspects of Continuum Mechanics: strong and weak formulation of the boundary-value problem</p> <p>The Closure Problem of Mechanics: finite elasticity of solid mechanics (as an example), linearization of the field equations</p> |                |                |
| 14. Literatur:                                      | <p>P. Chadwick [1999], Continuum Mechanics, Dover Publications.</p> <p>W. Ehlers [each WT, ST], Introduction to Vector- und Tensor Calculus, <a href="http://www.mechbau.uni-stuttgart.de/ls2/lehre/uebungen/index.php/#begleitmaterialien">http://www.mechbau.uni-stuttgart.de/ls2/lehre/uebungen/index.php/#begleitmaterialien</a>.</p> <p>M. E. Gurtin [1981], An Introduction to Continuum Mechanics, Academic Press.</p> <p>P. Haupt [2002], Continuum Mechanics and Theory of Materials, 2.nd Edition, Springer.</p> <p>G. H. Holzapfel [2000], Nonlinear Solid Mechanics, John Wiley und Sons.</p> <p>L. E. Malvern [1969], Introduction to the Mechanics of a Continuous Medium, Prentice-Hall.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 558801 Vorlesung Continuum Mechanics</li> <li>• 558802 Übung Continuum Mechanics</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |



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|---------------------------------|-------------------------------------------------------------------------|
| 16. Abschätzung Arbeitsaufwand: | Time of Attendance: ca. 52 h<br>Private Study: ca. 128 h                |
| 17. Prüfungsnummer/n und -name: | 55881 Continuum Mechanics (PL), Schriftlich, 120 Min., Gewichtung:<br>1 |
| 18. Grundlage für ... :         |                                                                         |
| 19. Medienform:                 |                                                                         |
| 20. Angeboten von:              | Mechanik II                                                             |

## Modul: 55900 Computational Mechanics of Materials

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|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | Commas                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 9. Dozenten:                                        | Christian Miehe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 1. Semester<br>→ Compulsory Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 12. Lernziele:                                      | <p>The students have a working knowledge of the behavior and modeling of</p> <p>elastic and inelastic materials in the one dimensional context. The</p> <p>students are further capable of performing numerical implementations</p> <p>of the classical material models of elasticity and inelasticity in the</p> <p>framework of the finite element method by using canonical algorithmic</p> <p>schemes.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 13. Inhalt:                                         | <p>Introduction to discrete and continuous modeling of materials (microstructures, homogenization techniques and multi-scale approaches),</p> <p>fundamental theoretical concepts (basic rheology, classification of the</p> <p>phenomenological material response, elements of continuum thermodynamics), fundamental numerical concepts (discretization techniques for evolution systems, linearization techniques and iterative solution of nonlinear systems), linear and nonlinear elasticity, damage mechanics, viscoelasticity (linear and nonlinear models, stress update algorithms and consistent linearization), rate-independent plasticity (theoretical formulations, return mapping schemes, incremental variational formulations, consistent elastic-plastic tangent moduli), viscoplasticity (classical approaches and overstress models).</p> |                |                |
| 14. Literatur:                                      | Complete notes on black board, exercise material will be handed out in the exercises.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 559001 Vorlesung Computational Mechanics of Materials</li> <li>• 559002 Übung Computational Mechanics of Materials</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | <p>Time of Attendance: approx. 52 h</p> <p>Self-study: approx. 128h</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |

17. Prüfungsnummer/n und -name: 55901 Computational Mechanics of Materials (PL), Schriftlich, 120 Min., Gewichtung: 1

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18. Grundlage für ... :

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19. Medienform:

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20. Angeboten von: Mechanik I

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## Modul: 55920 Computational Mechanics of Structures

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| 2. Modulkürzel:                                     | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Manfred Bischoff                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 9. Dozenten:                                        | Manfred Bischoff                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 1. Semester<br>→ Compulsory Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 12. Lernziele:                                      | The students know the fundamental theories and models in linear structural mechanics, in particular trusses, beams, plates and solids. They understand the basic concepts, algorithms and mathematical elements of the finite element method within the context of elasticity problems. In view of practical application of computational methods in structural mechanics the students are aware of their character as an approximation method and their convergence properties. They are able to critically check and interpret numerical results. The students have the theoretical background for the skilful modelling of structures with finite elements and other computational methods. They have learned the fundamentals for advanced courses on structural mechanics and finite elements. |                |                |
| 13. Inhalt:                                         | <p>The module combines fundamental topics of structural mechanics and finite element theory in their respective context.</p> <ul style="list-style-type: none"> <li>• direct stiffness method</li> <li>• isoparametric concept</li> <li>• variational formulation of finite elements, mixed variational principles, shape functions, approximation spaces and mathematical convergence requirements</li> <li>• finite elements for trusses, beams, plates and solids</li> <li>• locking, reduced integration, mixed and hybrid finite element methods</li> <li>• modelling in structural mechanic, mathematical model and numerical model (discretization)</li> <li>• interpretation of numerical results</li> </ul>                                                                                |                |                |
| 14. Literatur:                                      | lecture notes „Computational Mechanics of Structures“, Institut für Baustatik und Baudynamik                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 559202 Übung Computational Mechanics of Structures</li> <li>• 559201 Vorlesung Computational Mechanics of Structures</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 16. Abschätzung Arbeitsaufwand:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 17. Prüfungsnummer/n und -name:                     | 55921 Computational Mechanics of Structures (PL), Schriftlich, 120 Min., Gewichtung: 1<br>Prerequisite: 3 approved, not graded assignments                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |

20. Angeboten von: Baustatik und Baudynamik

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## Modul: 68760 Discretization Methods and Scientific Programming

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|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 074040610                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr. Remco Ingmar Leine                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 9. Dozenten:                                        | Andre Schmidt<br>Martin Bernreuther                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 1. Semester<br>→ Compulsory Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 12. Lernziele:                                      | <p>Discretization Methods :</p> <p>The students understand different concepts how partial differential equations in time and in space can be solved numerically. They are familiar with the strengths and weaknesses of the different methods and have a deeper understanding of selected aspects.</p> <p>Introduction to Scientific Programming:</p> <ul style="list-style-type: none"> <li>• knowledge transfer of programming basics in the field of scientific computing</li> <li>• put across the functionality of modern computers</li> <li>• development of algorithms, implementation through a (Python) program and evaluation of the efficiency</li> <li>• different fundamental data structures to efficiently store and manage data for diverse application fields are known</li> <li>• knowledge of computer numerics basics</li> <li>• implementation for elementary scientific computing applications, like solving a system of linear equations or polynomial interpolation</li> <li>• students should obtain the skills to develop software to solve numerical problems with modern programming languages (especially with Python)</li> </ul> |                |                |
| 13. Inhalt:                                         | <p>Discretization Methods :</p> <p>The lecture deals with the numerical treatment of differential equations which arise from different mechanical and thermodynamical problems. Contents are:</p> <ul style="list-style-type: none"> <li>• deduction of differential equations based on the principles of mechanics and thermodynamics and their classification</li> <li>• the Finite Difference Method</li> <li>• the method of weighted residuals: method of subdomains, collocation method, least squares method, and Galerkin's method</li> <li>• the Finite Element Method</li> <li>• different time integration schemes</li> <li>• convergence and stability</li> </ul> <p><i>Introduction to Scientific Programming:</i><br/><i>lecture:</i></p>                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |

*part I: layout of a computer*

- 1) *von Neumann architecture*
- 2) *design of modern microprocessors, memory hierarchy , parallelism*
- 3) *programming languages*

*part II: algorithms and data structures*

- 1) *complexity, Bachmann-Landau notation*
- 2) *example sorting algorithms (sub-topic: recursion)*
- 3) *arrays, lists, hashtables, trees (binary, KD, Quadtree, Octree), Heap*
- 4) *graphs (exemplary algorithms Cuthill McKee, Dijkstra)*

*part III: numerics*

- 1) *number representation integer and floating point*
  - 2) *rounding and rounding errors*
  - 3) *condition and stability*
  - 4) *matrices and linear mappings (demonstrative meaning, effect on geometric objects)*
  - 5) *solving of linear systems of equations (Gaussian elimination, LU-decomposition, Pivoting, Cholesky decomposition)*
  - 6) *polynomial interpolation (different bases and algorithms: Lagrange, Newton, Aitken-Neville, divided differences, error estimation, condition)*
  - 7) *spline interpolation und parametric curves (B-spline, Bezier)*
- Tutorials:*

*(practical) programming with Python (hands-on within a computer lab)*

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14. Literatur:

Discretization Methods:

Manuscript, all the examples in the lecture notes and exercises will be provided online as Matlab-Files, additional literature:

B. A. Finlayson. The Method of Weighted Residuals and Variational Principles, Academic Press, New York, 1972

M. N. Özisik. Finite Difference Methods in Heat Transfer. CRC Press, Boca Raton, 1994

Quarteroni and F. Saleri. Scientific Computing with MATLAB and Octave. Springer, Berlin, 2006

Introduction to Scientific Programming:

Cormen, Thomas H., Leiserson, Charles E., Rivest, Ronald L. (2000): Introduction to algorithms, MIT Press

Stoer, Josef, Bulirsch, Roland (2002): Introduction to numerical analysis, Springer

Bungartz, Hans-Joachim (2003): Lecture notes - "Introduction to Scientific Programming"

Bernreuther, Martin (2015): Lecture and Tutorial slides - "Introduction to Scientific Programming"

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15. Lehrveranstaltungen und -formen:

- 687601 Vorlesung Diskretisierungsmethoden
- 687602 Übung Diskretisierungsmethoden
- 687603 Vorlesung Einführung in die wissenschaftliche Programmierung

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16. Abschätzung Arbeitsaufwand:

Discretization Methods, lecture: 54 h (attendance: 14 h, self-study: 40 h)

Discretization Methods, exercise: 36 h (attendance: 9 h, self-study: 27 h)

Introduction to Scientific Programming lecture: 54 h (attendance: 14 h, self-study: 40 h)

Introduction to Scientific Programming exercise: 36 h (attendance: 9 h, self-study: 27 h)

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17. Prüfungsnummer/n und -name:

- 68761 Discretization Methods (PL), Schriftlich, 120 Min., Gewichtung: 1
  - 68762 Introduction to Scientific Programming (PL), Schriftlich, 90 Min., Gewichtung: 1
  - 68763 Discretization Methods (USL), Sonstige, Gewichtung: 1
- successful participation at the exercises  
Introduction to Scientific Programming: optional homeworks for the "Introduction to Scientific Programming" tutorial

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18. Grundlage für ... :

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19. Medienform:

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20. Angeboten von:

Nichtlineare Mechanik

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**Modul: 68810 Summer School and Seminar Lecture**

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|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021010025                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 9. Dozenten:                                        | Wolfgang Ehlers<br>Christian Miehe<br>Manfred Bischoff<br>Lothar Gaul<br>Peter Eberhard<br>Siegfried Schmauder<br>Christian Moormann<br>Jan Hofmann                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016,<br>→ Compulsory Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 12. Lernziele:                                      | <p>Summer School:</p> <p>The students possess a good understanding of current developments in computational mechanics, both in research and industrial application, through the direct interaction with internationally recognized researchers in this field. Through the exposure to the high-level course material, the students are able to make active use of the relevant literature in computational mechanics, which benefits them in their master thesis work as well as their later professional life.</p> <p>Seminar Lecture:</p> <p>The students are able to plan, prepare and present seminar lectures in an academic environment on previously unfamiliar topics. They know how to set and achieve necessary objectives and produce relevant deliverables. To this end the students are able to time-manage their work, use information resources and work in teams.</p> |                |                |
| 13. Inhalt:                                         | <p>Summer School:</p> <p>Advanced state-of-the art topics on continuum mechanics, numerical Methods, and engineering materials to be seen as enhancement of the courses in the first and second semester. These topics are given in the summer school by internationally recognized experts.</p> <p>Seminar Lecture:</p> <p>In connection to one of the modules chosen in the second semester, the students give a seminar lecture on a topic related to that module chosen in agreement with the module coordinator. The students present these lecture in front of a public audience, coinciding mostly with the students attending the same module.</p>                                                                                                                                                                                                                            |                |                |
| 14. Literatur:                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 688101 Vorlesung Sommerschule                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |

|                                 |                                                                                                                                     |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| 16. Abschätzung Arbeitsaufwand: | <i>Summer School: 90 h (attendance: 35 h, self-study: 65 h)</i><br><i>Seminar Lecture: 90 h (attendance: 2 h, self-study: 88 h)</i> |
| 17. Prüfungsnummer/n und -name: | 68811 Summer School and Seminar Lecture (BSL), Sonstige,<br>Gewichtung: 1<br>Presentation in "Seminar Lecture"                      |
| 18. Grundlage für ... :         |                                                                                                                                     |
| 19. Medienform:                 |                                                                                                                                     |
| 20. Angeboten von:              | Mechanik (Bauwesen)                                                                                                                 |

## 200 Elective Modules

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|                     |       |                                                                                   |
|---------------------|-------|-----------------------------------------------------------------------------------|
| Zugeordnete Module: | 16100 | Selected Topics in the Theories of Plasticity and Viscoelasticity                 |
|                     | 16110 | Elemente der nichtlinearen Kontinuumsmechanik                                     |
|                     | 16120 | Einführung in die Kontinuumsmechanik von Mehrphasenmaterialien                    |
|                     | 16130 | Erdbebenbeanspruchung von Bauwerken                                               |
|                     | 16150 | Geometrische Methoden der Nichtlinearen Kontinuumsmechanik und Kontinuumsmechanik |
|                     | 16160 | Micromechanics of Smart and Multifunctional Materials                             |
|                     | 16170 | Methoden der Parameteridentifikation und Experimentellen Mechanik                 |
|                     | 16180 | Theoretische und Computerorientierte Materialtheorie                              |
|                     | 18620 | Optimal Control                                                                   |
|                     | 25130 | Kontinuumsbiomechanik                                                             |
|                     | 30020 | Biomechanik                                                                       |
|                     | 30030 | Fahrzeugdynamik                                                                   |
|                     | 30100 | Nichtlineare Dynamik                                                              |
|                     | 33320 | Smart Structures                                                                  |
|                     | 33360 | Fuzzy Methoden                                                                    |
|                     | 33370 | Structure-Borne Sound                                                             |
|                     | 33630 | Boundary Element Methods in Statics and Dynamics                                  |
|                     | 34940 | Weiterführende Numerik partieller Differentialgleichungen                         |
|                     | 38240 | Simulation Methods in Physics for SimTech II                                      |
|                     | 40520 | Simulation Methods in Physics for SimTech I                                       |
|                     | 50090 | Environmental Fluid Mechanics I                                                   |
|                     | 50140 | Modeling of Hydrosystems                                                          |
|                     | 50170 | Environmental Fluid Mechanics II                                                  |
|                     | 50280 | Multiphase Modeling in Porous Media                                               |
|                     | 50290 | Numerical Methods for Differential Equations                                      |
|                     | 60210 | Implementation and Algorithms for Finite Elements                                 |
|                     | 67150 | Einführung in die Modellreduktion mechanischer Systeme                            |
|                     | 68740 | Advanced Computational Mechanics of Structures                                    |
|                     | 68750 | Computational Methods for Shell Analysis                                          |
|                     | 68770 | Metals and Computational Materials Science                                        |
|                     | 68780 | Micromechanics of Materials and Homogenization Methods                            |
|                     | 68790 | Numerical Modelling of Soils and Concrete Structures                              |
|                     | 68820 | Visualization in Science and Engineering                                          |
|                     | 68890 | Foundations of Continuum Thermodynamics for Single- and Multiphase Materials      |
|                     | 69460 | Computational contact mechanics                                                   |
|                     | 72120 | Modeling of connections between steel and concrete                                |
|                     | 72130 | Behavior and design of structures against natural and man-made hazards            |

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## Modul: 16100 Selected Topics in the Theories of Plasticity and Viscoelasticity

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021010012                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 7. Sprache:    | Englisch       |
|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 9. Dozenten:                                        | Christian Miehe<br>Wolfgang Ehlers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 11. Empfohlene Voraussetzungen:                     | B.Sc. degree in Bauingenieurwesen (Civil Engineering), in Maschinenbau (Mechanical Engineering), in Umweltschutztechnik (Environmental Engineering) or in related subject, as well as knowledge of basic concepts in continuum mechanics (comparable to HMI) and numerical mechanics (comparable to HMII)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 12. Lernziele:                                      | The students understand the concepts of plasticity and viscoelasticity as important classes of inelastic material response with a wide range of engineering applications. They have obtained a detailed understanding of selected aspects of the theories of plasticity and viscoelasticity, including specific algorithmic treatments.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 13. Inhalt:                                         | It is the superior goal of the lecture to foster the understanding of general inelastic material behavior with regard to the theoretical modeling and the numerical treatment based on selected model problems. As an example, the selected material models under consideration may cover (i) micromechanically motivated approaches to inelastic material response such as crystal plasticity or (ii) purely phenomenological formulations of an inelastic material response such as viscoelasticity. Contents: <ul style="list-style-type: none"><li>• Introduction to inelastic material behavior</li><li>• Micromechanical structure of solids</li><li>• Kinematics of inelastic deformations at finite strains</li><li>• Foundations of continuum-based material modeling for selected problems, e.g. finite crystal plasticity and viscoelasticity</li><li>• Integration algorithms of evolution systems, stress-update algorithms and consistent linearization of updating schemes</li></ul> |                |                |
| 14. Literatur:                                      | Complete notes on black board, exercise material will be handed out in the exercises.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"><li>• 161002 Übung Selected Topics in the Theories of Plasticity and Viscoelasticity</li><li>• 161001 Vorlesung Selected Topics in the Theories of Plasticity and Viscoelasticity</li></ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Time of Attendance:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 52 h           |                |
|                                                     | Self-study:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 128 h          |                |
|                                                     | Summary:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 180 h          |                |
| 17. Prüfungsnummer/n und -name:                     | 16101 Selected Topics in the Theories of Plasticity and Viscoelasticity (PL), Schriftlich, 120 Min., Gewichtung: 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |

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## Modul: 16110 Elemente der nichtlinearen Kontinuumsthermodynamik

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                  |
|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------------------|
| 2. Modulkürzel:                                     | 021020010                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 5. Moduldauer: | Einsemestrig     |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 6. Turnus:     | Unregelmäßig     |
| 4. SWS:                                             | 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 7. Sprache:    | Weitere Sprachen |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Holger Steeb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                  |
| 9. Dozenten:                                        | Wolfgang Ehlers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                  |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                  |
| 11. Empfohlene Voraussetzungen:                     | B. Sc.-Abschluß im Bauingenieurwesen, im Maschinenbau, in der Umweltschutztechnik oder einem vergleichbaren Fach sowie Kenntnisse der Technischen Mechanik und Grundkenntnisse der Kontinuumsmechanik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                  |
| 12. Lernziele:                                      | Die Studierenden verstehen die Anwendung der nichtlinearen Thermodynamik auf Probleme der Mechanik. Neben der Darstellung grundlegender Konzepte beherrschen sie Techniken, mit denen sich thermodynamisch zulässige Stoffgesetze für beliebige Materialien entwickeln lassen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                  |
| 13. Inhalt:                                         | <p>Kenntnisse der nichtlinearen Kontinuumsthermodynamik sind fundamentale Voraussetzung für die Beschreibung großer Deformationen von beliebigen Materialien mit nichtlinearen Stoffgesetzen. Die Vorlesung bietet eine systematische Darstellung der nichtlinearen Kontinuumsmechanik und der Grundlagen der Thermodynamik (Energiebilanz, Entropieungleichung). Auf der Basis der Grundprinzipie der Konstitutivtheorie und des zweiten Hauptsatzes der Thermodynamik werden die Mechanismen diskutiert, mit denen für beliebige Materialien thermodynamisch konsistente und damit zulässige Stoffmodelle entwickelt werden können. Alle Verfahren werden am Beispiel des nichtlinear deformierbaren, thermoelastischen Festkörpers diskutiert. Zusätzlich werden Aspekte der numerischen Behandlung nichtlinearer Prozesse in Zeit und Raum diskutiert. Im einzelnen wird der folgende Inhalt präsentiert:</p> <ul style="list-style-type: none"> <li>• Motivation und Einführung in die Problematik</li> <li>• Nichtlineare Kontinuumsmechanik: Kinematik, Transporttheoreme, nichtlineare Deformations- und Verzerrungsmaße in absoluter und konvektiver Notation</li> <li>• Spannungstensoren nach Cauchy, Kirchhoff, Piola-Kirchhoff, Biot, Mandel und Green-Naghdi</li> <li>• Bilanzrelationen der Mechanik: Massen-, Impuls- und Drallbilanz</li> <li>• Bilanzrelationen der Thermodynamik: Energiebilanz und Entropieungleichung (1. und 2. Hauptsatz der Thermodynamik)</li> <li>• Elemente der klassischen Thermodynamik: innere Energie und kalorische Zustandsgröße, thermodynamische Potentiale, Legendre-Transformationen</li> <li>• Thermodynamische Materialtheorie: Thermodynamische Prinzipie und Prozeßvariablen, materielle Symmetrie</li> <li>• thermoelastischer Festkörper: Auswertung des Entropieprinzips, Isotropie, das gekoppelte Problem der Thermomechanik,</li> </ul> |                |                  |

Thermoelastizität in Nominalform, Energie- und Entropieelastizität

- Numerische Aspekte: Schwache Form des Randwertproblems, Zeitintegration gekoppelter Probleme, Linearisierung der Feldgleichungen, Stabilitätskriterien

14. Literatur:

Vollständiger Tafelanschrieb, in den Übungen wird Begleitmaterial ausgeteilt.

- J. Altenbach, H Altenbach [1994], Einführung in die Kontinuumsmechanik, Teubner.
- E. Becker, W. Bürger [1975], Kontinuumsmechanik, Teubner.
- R. de Boer [1982], Vektor- und Tensorrechnung für Ingenieure, Springer.
- P. Chadwick [1999], Continuum Mechanics, Dover Publications.
- W. Ehlers [jedes WS, SS], Einführung in die Vektor- und Tensorrechnung <http://www.mechbau.uni-stuttgart.de/ls2/lehre/-uebungen/index.php#begleitmaterialien>.
- P. Haupt [2002], Continuum Mechanics and Theory of Materials, 2. Auflage Springer.
- G. H. Holzapfel [2000], Nonlinear Solid Mechanics, John Wiley und Sons.
- L. E. Malvern [1969], Introduction to the Mechanics of a Continuous Medium, Prentice-Hall.
- C. Truesdell, W. Noll [1965], The Non-linear Field Theories of Mechanics. In S. Flügge (Ed.): Handbuch der Physik, Band III/3, Springer.

15. Lehrveranstaltungen und -formen:

- 161101 Vorlesung Elemente der nichtlinearen Kontinuumsmechanik
- 161102 Übung Elemente der nichtlinearen Kontinuumsmechanik

16. Abschätzung Arbeitsaufwand:

Präsenzzeit: 52 h  
Selbststudium: 128 h  
Gesamt: 180 h

17. Prüfungsnummer/n und -name:

- 16111 Elemente der nichtlinearen Kontinuumsmechanik (PL), Schriftlich, 120 Min., Gewichtung: 1
  - V Vorleistung (USL-V), Schriftlich oder Mündlich
- Prüfung evtl. mündlich, Dauer 40 Min., Prüfungsvorleistung: Hausübungen

18. Grundlage für ... :

19. Medienform:

20. Angeboten von:

Mechanik II

## Modul: 16120 Einführung in die Kontinuumsmechanik von Mehrphasenmaterialien

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                  |
|-----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------------------|
| 2. Modulkürzel:                                     | 021020011                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 5. Moduldauer: | Einsemestrig     |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 6. Turnus:     | Unregelmäßig     |
| 4. SWS:                                             | 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7. Sprache:    | Weitere Sprachen |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Holger Steeb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                  |
| 9. Dozenten:                                        | Wolfgang Ehlers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                  |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                  |
| 11. Empfohlene Voraussetzungen:                     | B. Sc.-Abschluß im Bauingenieurwesen, im Maschinenbau, in der Umweltschutztechnik oder einem vergleichbaren Fach sowie Kenntnisse der Technischen Mechanik und Kontinuumsthermodynamik.<br>(B. Sc. degree in Civil Engineering, in Mechanical Engineering, in Environmental Engineering or a comparable discipline and basic knowledge in applied mechanics and continuum thermodynamics.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                  |
| 12. Lernziele:                                      | Die Studierenden begreifen die Anwendung kontinuumsmechanischer Methoden auf mehrphasige Materialien. Sie verstehen den Charakter stark gekoppelter Gleichungssysteme zur Beschreibung komplexer Phänomene bei Mehrkomponentenmaterialien und Mischungen.<br>(The students are able to apply continuum-mechanical methods to multiphase materials. They understand the character of strongly coupled equation systems for the description of complex phenomena in multi-component materials and mixtures.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                  |
| 13. Inhalt:                                         | <p>Poröse Festkörper mit fluiden Inhaltsstoffen fallen ebenso in die Kategorie der Mehrphasenmaterialien wie reale Mischungen von Flüssigkeiten oder Gasen. Mit der Kontinuumsmechanik von Mehrphasenmaterialien können die Bewegung oder die Strömung von Fluiden in deformierbaren porösen Festkörpern bei beliebigen Deformationen und bei beliebigem Materialverhalten der Festkörpermatrix beschrieben werden. Darüber hinaus lassen sich Phasenumwandlungen und elektrochemische Reaktionen in die Theorie integrieren. Damit steht ein Werkzeug zur Verfügung, mit dem eine große Klasse verschiedenster Materialien mathematisch beschrieben und numerisch analysiert werden kann, die von Geomaterialien über Polymer- oder Metallschäume bis zu biologischen Geweben reicht. Für die numerische Anwendung muss ein System stark gekoppelter, partieller Differentialgleichungen gelöst werden.</p> <ul style="list-style-type: none"> <li>• Kontinuumsmechanische Grundlagen zur Beschreibung von Ein- und Mehrphasenmaterialien: Bewegungszustand, Deformationsmaße, Spannungszustand</li> <li>• Bilanzrelationen für Mehrphasenmaterialien: Allgemeine Bilanzen, spezielle Bilanzen für Masse, Impuls, Drall, Energie und Entropie</li> <li>• Kalorische Zustandsvariablen und "freie" Energie</li> <li>• Grundlagen der Materialtheorie für Mehrphasenmaterialien:</li> <li>• Thermodynamik und Konstitutivgleichungen</li> </ul> |                |                  |



- der flüssigkeitsgesättigte, materiell inkompressibel deformierbare poröse Festkörper
- Elastisches Materialverhalten der Festkörpermatrix
- Plastisches Materialverhalten der Festkörpermatrix (optional)

(Porous solids with a fluid pore content as well as real mixtures of liquids and gases belong both to the class of multi-phase materials. With a continuum theory for multiphase media, the movement or flow of fluids in deformable porous solids can be described for arbitrary deformation processes and arbitrary material properties of the solid matrix. Moreover, it is possible to consider phase transitions and electrochemical reactions within such a theory. In this regard, a theoretical tool is provided that can be used to mathematically describe and numerically analyse a manifold of distinct materials, ranging from geomaterials over polymer and metal foams to biological tissues. For the numerical application, a system of strongly coupled partial differential equations has to be solved.

- Continuum-mechanical basics for the description of single- and multiphase materials: state of motion, deformation measures, stress states
- Balance relations for multi-phase materials: master balances, special balances for mass, momentum, moment of momentum, energy and entropy
- Caloric state variables and energy potentials
- Fundamentals of materials theory for multiphase media
- Thermodynamics and constitutive equations
- The fluid-saturated, materially incompressible deformable porous solid
- Elastic material properties of the solid skeleton
- Plastic behaviour of the solid skeleton (optional))

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#### 14. Literatur:

Vollständiger Tafelanschrieb, in den Übungen wird Begleitmaterial ausgeteilt (Comprehensive notes on blackboard, additional course materials will be distributed in the exercises).

- R. de Boer [1982], Vektor- und Tensorrechnung für Ingenieure, Springer.
- R. de Boer, W. Ehlers [1986], Theorie der Mehrkomponentenkontinua mit Anwendung auf bodenmechanische Probleme, Forschungsberichte aus dem Fachbereich Bauwesen der Universität-GH-Essen, Heft 40.
- R. M. Bowen [1976], Theory of Mixtures. In A. C. Eringen (ed.): Continuum Physics, Vol. III, Academic Press.
- W. Ehlers [1989], Poröse Medien - ein kontinuumsmechanisches Modell auf der Basis der Mischungstheorie, Forschungsberichte aus dem Fachbereich Bauwesen der Universität-GH-Essen, Heft 47.
- W. Ehlers [2002], Foundations of multiphase and porous materials. In W. Ehlers, J. Bluhm (eds.): Porous Media: Theory, Experiments and Numerical Applications, pp. 3-86, Springer.
- W. Ehlers [jedes WS, SS] Einführung in die Vektor- und Tensorrechnung, <http://www.mechbau.uni-stuttgart.de/ls2/lehre/uebungen/index.php#begleitmaterialien>.
- C. Truesdell [1984], Rational Thermodynamics, 2nd Edition, Springer.
- C. Truesdell, W. Noll [1965], The Non-linear Field Theories of Mechanics. In S. Flügge (ed.): Handbuch der Physik, Band III/3, Springer.

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|                                      | <ul style="list-style-type: none"> <li>• C. Truesdell, R. A. Toupin [1960], The Classical Field Theories. In S. Flügge (ed.): Handbuch der Physik, Band III/1, Springer.</li> </ul>                                                                                                                     |
| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"> <li>• 161202 Übung Einführung in die Kontinuumsmechanik von Mehrphasenmaterialien</li> <li>• 161201 Vorlesung Einführung in die Kontinuumsmechanik von Mehrphasenmaterialien</li> </ul>                                                                              |
| 16. Abschätzung Arbeitsaufwand:      | Präsenzzeit: 52 h<br>Selbststudium: 128 h<br>Gesamt: 180 h                                                                                                                                                                                                                                              |
| 17. Prüfungsnummer/n und -name:      | <ul style="list-style-type: none"> <li>• 16121 Einführung in die Kontinuumsmechanik von Mehrphasenmaterialien (PL), Schriftlich, 120 Min., Gewichtung: 1</li> <li>• V Vorleistung (USL-V), Schriftlich oder Mündlich</li> </ul> Prüfung evtl. mündlich, Dauer 40 Min., Prüfungsvorleistung: Hausübungen |
| 18. Grundlage für ... :              |                                                                                                                                                                                                                                                                                                         |
| 19. Medienform:                      |                                                                                                                                                                                                                                                                                                         |
| 20. Angeboten von:                   | Mechanik II                                                                                                                                                                                                                                                                                             |

## Modul: 16130 Erdbebenbeanspruchung von Bauwerken

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021020013                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 7. Sprache:    | Deutsch        |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Holger Steeb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 9. Dozenten:                                        | Wolfgang Ehlers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 11. Empfohlene Voraussetzungen:                     | B. Sc.-Abschluß im Bauingenieurwesen, im Maschinenbau, in der Umweltschutztechnik oder einem vergleichbaren Fach sowie Kenntnisse der Technischen Mechanik und Grundkenntnisse der Kontinuumsmechanik                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 12. Lernziele:                                      | Durch die Vorlesung beherrschen die Studierenden die Grundzüge erdbebensicherer Bauens. Darüber hinaus verstehen sie die Naturphänomene, die zu Erdbeben und den damit verbundenen katastrophalen Ereignissen führen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 13. Inhalt:                                         | <p>Erdbeben führen als unvermeidbare und derzeit nur schwer vorhersagbare Naturkatastrophen zu schwerwiegenden Folgen in den betroffenen Gebieten. Die Vorlesung gibt eine Einführung in die Technik des erdbebensicherer Bauens in theoretischen und konstruktiven Belangen. Insbesondere soll der Blick für den erdbebengerechten Entwurf von Hochbauten geschärft werden. Der Inhalt der Veranstaltung gliedert sich hierbei wie folgt:</p> <ul style="list-style-type: none"> <li>• Erdbebenentstehung, seismische Grundlagen (Plattentektonik, seismische Wellen, Erdbebenskalen), Erdbebenfolgen und Erdbebenbeanspruchung</li> <li>• Schwingungen mit einem Freiheitsgrad, freie ungedämpfte und gedämpfte Schwingung, erzwungene Schwingungen, Resonanz, Faltungsintegral</li> <li>• Schwingungen mit mehreren Freiheitsgraden, modale Koordinaten, Modalanalyse</li> <li>• Antwortspektren der Relativverschiebung, Relativgeschwindigkeit und Absolutbeschleunigung, Bemessungsgrundlagen nach DIN 4149 bzw. EC 8</li> <li>• Bauliche Aspekte, erdbebengerechter Entwurf, typische Schadensmuster, konstruktive Maßnahmen für erdbebensicheres Bauen (Grundriss, Aufriss, Gründung, Massenverteilung)</li> <li>• Modellbildung, Ersatzstabmodell, Modell der starren Stockwerksscheiben</li> <li>• Zeitverlaufsverfahren, numerische Integration der Schwingungsdifferentialgleichungen, Newmark-Verfahren</li> <li>• Ausblick: weitere Methoden zur Erdbebensimulation</li> </ul> |                |                |
| 14. Literatur:                                      | <p>Vollständiger Tafelanschrieb, Material für die Übungen wird in den Übungen ausgeteilt.</p> <ul style="list-style-type: none"> <li>• T. Paulay, H. Bachmann, K. Moser [1990], Erdbebenbemessung von Stahlbetonhochbauten, Birkhäuser Verlag.</li> <li>• R. W. Day [2002], Geotechnical Earthquake Engineering Handbook, McGraw-Hill.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |

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| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"><li>• 161301 Vorlesung Erdbebenbeanspruchung von Bauwerken</li><li>• 161302 Übung Erdbebenbeanspruchung von Bauwerken</li></ul>                     |       |
| 16. Abschätzung Arbeitsaufwand:      | Präsenzzeit:                                                                                                                                                                          | 52 h  |
|                                      | Selbststudium:                                                                                                                                                                        | 128 h |
|                                      | Gesamt:                                                                                                                                                                               | 180 h |
| 17. Prüfungsnummer/n und -name:      | 16131 Erdbebenbeanspruchung von Bauwerken (PL), Schriftlich, 120 Min., Gewichtung: 1<br>Prüfung evtl. mündlich, Dauer 40 Min., Prüfungsvorleistung<br>Teilnahme am Computer-Praktikum |       |
| 18. Grundlage für ... :              |                                                                                                                                                                                       |       |
| 19. Medienform:                      |                                                                                                                                                                                       |       |
| 20. Angeboten von:                   | Mechanik II                                                                                                                                                                           |       |

## Modul: 16150 Geometrische Methoden der Nichtlinearen Kontinuumsmechanik und Kontinuumsthermodynamik

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |              |
|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|--------------|
| 2. Modulkürzel:                                     | 021010010                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5. Moduldauer: | Einsemestrig |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 6. Turnus:     | Unregelmäßig |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7. Sprache:    | Deutsch      |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |              |
| 9. Dozenten:                                        | Christian Miehe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |              |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |              |
| 11. Empfohlene Voraussetzungen:                     | B.Sc.-Abschluss im Bauingenieurwesen, im Maschinenbau, in der Umweltschutztechnik oder einem vergleichbaren Fach sowie Grundkenntnisse der Kontinuumsmechanik (vergleichbar HMI) und der numerischen Mechanik (vergleichbar HMII)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |              |
| 12. Lernziele:                                      | Die Studierenden verstehen die grundlegenden Konzepte der nichtlinearen Kontinuumsthermodynamik als Basis für die phänomenologische, makroskopische Beschreibung ingenieurtechnischer Prozesse von Festkörpern und Fluiden bei endlichen (finiten) Deformationen und komplexen Materialverhalten unter Beachtung von Stabilitätsproblemen und Materialversagen. Durch die rigorose deduktive Darstellung in der Vorlesung haben die Studierenden somit einen direkten Zugang zur fortgeschrittenen Anwendung dieses elementar wichtigen Wissens- und Forschungsgebietes basierend auf Terminologien moderner Differentialgeometrie.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |              |
| 13. Inhalt:                                         | Kenntnisse der Kontinuumsmechanik und Kontinuumsthermodynamik sind fundamentale Voraussetzung für die theoretische und algorithmische Durchdringung geometrisch und physikalisch nichtlinearer Deformations-, Versagens- und Transportprozesse in Festkörpern aus metallischen und polymeren Werkstoffen sowie Geomaterialien. Die Vorlesung bietet eine Darstellung von Grundkonzepten der Kontinuumsmechanik und Materialtheorie großer elastischer und inelastischer Verzerrungen. Dabei erfolgt die Darstellung mit einem betont geometrischen Akzent basierend auf modernen Terminologien der Differentialgeometrie, u.a. auch in Hinblick auf die Beschreibung von Mehrfeldtheorien mit thermomechanischen Kopplungen. Parallel zu der theoretischen Darstellung werden algorithmische Aspekte der Computerimplementation von Modellen der nichtlinearen Kontinuumsmechanik behandelt. Inhalte:<br>Tensoralgebra und -analysis auf Mannigfaltigkeiten<br>Differentialgeometrie endlicher (finiter) Deformationen<br>Bilanzprinzipie der nichtlinearen Kontinuumsthermodynamik<br>Phänomenologische Materialtheorie endlicher Verzerrungen<br>Eindeutigkeit von Randwertproblemen und Stabilitätstheorie |                |              |
| 14. Literatur:                                      | Vollständiger Tafelanschrieb, Material für die Übungen wird in den Übungen ausgeteilt.<br>• J. E. Marsden, T. J. R. Hughes [1983], Mathematical Foundations of Elasticity, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |              |

- P. G. Ciarlet [1988], Mathematical Elasticity, Volume 1: Three Dimensional Elasticity, North-Holland.
- R. W. Ogden [1984], Non-Linear Elastic Deformations, Ellis Horwood Series Mathematics and its Applications.
- M. Silhavy [1997], The Mechanics and Thermodynamics of Continuous Media, Springer-Verlag.
- C. A. Truesdell, W. Noll [1965], The Non-linear Field Theories of Mechanics, Handbuch der Physik, Vol. III (3), S. Flügge (Ed.), Springer Verlag, Berlin.
- C. A. Truesdell, R. A. Toupin [1960], The Classical Field Theories, Handbuch der Physik, Vol. III (1), S. Flügge (Ed.), Springer Verlag, Berlin.

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|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"> <li>• 161501 Vorlesung Geometrische Methoden der Nichtlinearen Kontinuumsmechanik und Kontinuumsthermodynamik</li> <li>• 161502 Übung Geometrische Methoden der Nichtlinearen Kontinuumsmechanik und Kontinuumsthermodynamik</li> </ul> |
| 16. Abschätzung Arbeitsaufwand:      | <p>Präsenzzeit: 52 h<br/> Selbststudium: 128 h<br/> Gesamt: 180 h</p>                                                                                                                                                                                                      |
| 17. Prüfungsnummer/n und -name:      | <ul style="list-style-type: none"> <li>• 16151 Geometrische Methoden der Nichtlinearen Kontinuumsmechanik und Kontinuumsthermodynamik (PL), Mündlich, 40 Min., Gewichtung: 1</li> <li>• V Vorleistung (USL-V), Schriftlich oder Mündlich</li> </ul>                        |
| 18. Grundlage für ... :              |                                                                                                                                                                                                                                                                            |
| 19. Medienform:                      |                                                                                                                                                                                                                                                                            |
| 20. Angeboten von:                   | Mechanik I                                                                                                                                                                                                                                                                 |

**Modul: 16160 Micromechanics of Smart and Multifunctional Materials**

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021010013                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 7. Sprache:    | Englisch       |
|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 9. Dozenten:                                        | Christian Miehe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 11. Empfohlene Voraussetzungen:                     | B.Sc. degree in Bauingenieurwesen (Civil Engineering), in Maschinenbau (Mechanical Engineering), in Umweltschutztechnik                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 12. Lernziele:                                      | <p>The students possess a working knowledge of the behavior and modeling of smart and multifunctional materials, such as shape memory alloys or piezoelectric ceramics, which are used in the design of high-tech engineering applications with functional control. They are familiar with phenomenological and micromechanicsbased modeling approaches for the response of these materials, which rely on advanced continuum theories with multifieldcouplings, e.g. thermo-electro-magneto-mechanical interactions.</p> <p>The students are further capable of performing numerical implementations of coupled field problems which incorporate advanced constitutive models for functional materials based on specific algorithms for coupled problems such as staggered solution schemes and operator split techniques.</p> |                |                |
| 13. Inhalt:                                         | <p>The modeling approaches are rooted in micromechanics, mostly phenomenological, and build on the framework of continuum mechanics and the thermodynamically-consistent formulation of constitutive equations as taught in earlier courses. This framework, which accounts for thermomechanical coupling, is extended, where necessary, to include electric and magnetic coupling effects. The lecture covers the following topics:</p>                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 14. Literatur:                                      | Complete notes on black board, exercise material will be handed out in the exercises.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"><li>• 161601 Vorlesung Micromechanics of Smart and Multifunctional Materials</li><li>• 161602 Übung Micromechanics of Smart and Multifunctional Materials</li></ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Time of Attendance:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 52 h           |                |
|                                                     | Self-study:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 128 h          |                |
|                                                     | Summary:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 180 h          |                |
| 17. Prüfungsnummer/n und -name:                     | 16161 Micromechanics of Smart and Multifunctional Materials (PL), Schriftlich, 120 Min., Gewichtung: 1<br>Prüfung evtl. mündlich, Dauer 40 Min.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |

20. Angeboten von: Mechanik I

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## Modul: 16170 Methoden der Parameteridentifikation und Experimentellen Mechanik

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|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021010015                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 7. Sprache:    | Deutsch        |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 9. Dozenten:                                        | Christian Miehe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 11. Empfohlene Voraussetzungen:                     | B.Sc.-Abschluss im Bauingenieurwesen, im Maschinenbau, in der Umweltschutztechnik oder einem vergleichbaren Fach sowie Grundkenntnisse der Kontinuumsmechanik (vergleichbar HMI) und der numerischen Mechanik (vergleichbar HMII)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 12. Lernziele:                                      | Die Studierenden verstehen Methoden zur Bestimmung optimaler Parameter in komplexen Materialmodellen, welche eine der zentrale Voraussetzung für die Konstruktion prädiktiver, computerorientierter Simulationsmethoden darstellt und eine ganzheitliche Betrachtung von theoretischer Modellbildung, numerischer Implementation, Simulation und Vergleich mit Experimenten erfordert. Sie beherrschen somit die Konzepte der Parameteridentifikation und die Lösung inverser Problemstellungen der Mechanik auf der Grundlage nichtlinearer Optimierungsverfahren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 13. Inhalt:                                         | <p>Die Modellbildung phänomenologischen Materialverhaltens beinhaltet zwei wesentliche Schritte. Zunächst ist die Formulierung eines mathematischen Modells zur Erfassung der physikalischen Effekte erforderlich. Anschließend ist die Bestimmung der dem Modell zugrunde liegenden Materialparameter anhand von Versuchsergebnissen erforderlich. Die Bestimmung der Materialparameter führt somit auf inverse Problemstellungen, in der die Parameter die Unbekannten sind und optimal an Experimente angepasst werden müssen. Eine klassische Vorgehensweise zur Identifikation der Materialparameter ist die Fehlerminimierung zwischen Modellsimulationen und experimentellen Daten. Dieser Ansatz führt auf ein hochgradig nichtlineares Optimierungsproblem mit den Materialparametern als unabhängige Variablen, das man als Parameteridentifikation bezeichnet. Die Vorlesung bietet eine Einführung in Grundkonzepte der experimentellen Mechanik und Parameteridentifikation sowie der nichtlinearen Optimierung mit Anwendungen auf ausgesuchte Modellprobleme. Inhalte:</p> <ul style="list-style-type: none"> <li>• Grundkonzepte der experimentellen Materialmechanik</li> <li>• Die inverse Problemstellung der Parameteridentifikation</li> <li>• Nichtlineare Optimierungsmethoden und Sensitivitätsanalysen</li> <li>• Gradientenverfahren, Evolutionsstrategien, neuronale Netze</li> <li>• Finite Elemente Implementation inhomogener Probleme</li> <li>• Anwendung auf repräsentative Modellprobleme</li> </ul> |                |                |
| 14. Literatur:                                      | Vollständiger Tafelanschrieb, Material für die Übungen wird in den Übungen ausgeteilt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |

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|--------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"><li>• 161702 Übung Methoden der Parameteridentifikation und Experimentellen Mechanik</li><li>• 161701 Vorlesung Methoden der Parameteridentifikation und Experimentellen Mechanik</li></ul> |       |
| 16. Abschätzung Arbeitsaufwand:      | Präsenzzeit:                                                                                                                                                                                                                  | 52 h  |
|                                      | Selbststudium:                                                                                                                                                                                                                | 128 h |
|                                      | Gesamt:                                                                                                                                                                                                                       | 180 h |
| 17. Prüfungsnummer/n und -name:      | 16171 Methoden der Parameteridentifikation und Experimentellen Mechanik (PL), Mündlich, 40 Min., Gewichtung: 1                                                                                                                |       |
| 18. Grundlage für ... :              |                                                                                                                                                                                                                               |       |
| 19. Medienform:                      |                                                                                                                                                                                                                               |       |
| 20. Angeboten von:                   | Mechanik I                                                                                                                                                                                                                    |       |

## Modul: 16180 Theoretische und Computerorientierte Materialtheorie

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|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|--------------|
| 2. Modulkürzel:                                     | 021010011                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 5. Moduldauer: | Einsemestrig |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 6. Turnus:     | Unregelmäßig |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 7. Sprache:    | Deutsch      |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |              |
| 9. Dozenten:                                        | Christian Miehe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |              |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |              |
| 11. Empfohlene Voraussetzungen:                     | Geometrische Methoden der Nichtlinearen Kontinuumsmechanik und Kontinuumsthermodynamik                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |              |
| 12. Lernziele:                                      | Den Studierenden ist die Bedeutung einer qualitativ und quantitativ sicheren Beschreibung des Materialverhaltens als das zentrale Problem bei der Formulierung prädiktiver Simulationsmodelle ingenieurtechnischer Prozesse bewusst. Sie beherrschen moderne Konzepte der computerorientierten Materialtheorie komplexen reversiblen und irreversiblen Verhaltens von Festkörpern unter Beachtung von mikromechanischen Aspekten, Mehrskalenansätzen und Homogenisierungstechniken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |              |
| 13. Inhalt:                                         | <p>Die Vorlesung gibt einen vertieften Einblick in die Formulierung und algorithmische Durchdringung von Materialmodellen zur Beschreibung von physikalisch und geometrisch nichtlinearen Deformations- und Versagensmechanismen von Festkörpern. Behandelt werden Materialmodelle der Elastizität, Viskoelastizität, Plastizität sowie der Schädigungs- und Bruchmechanik bei endlichen (finiten) Deformationen. Dies beinhaltet auch nicht-mechanische Effekte wie thermo-mechanische oder elektro-mechanische Kopplungen. Auf verschiedenen Raum- und Zeitskalen werden neben Kontinuumsmodellen auch diskrete Modellansätze vorgestellt sowie die Grundkonzepte von Mehrskalenmodellen und mathematischen Homogenisierungstechniken behandelt. Die Vorlesung behandelt integriert theoretische und numerische Aspekte. Es werden u.a. modellspezifische Algorithmen zur Zeitintegration, globale Lösungsalgorithmen von gekoppelten nichtlinearen Feldgleichungen sowie verschiedene Finite Elemente Formulierungen zur räumlichen Diskretisierung von nichtlinearen Materialmodellen und Diskontinuitäten behandelt. Viele der dargestellten Entwicklungen und Methoden sind derzeit aktuelle Themen der Forschung. Eine Spezifizierung und Orientierung der breiten Thematik am Interesse der Hörer kann erfolgen. Inhalte:</p> <ul style="list-style-type: none"> <li>• Direkte Variationsmethoden finiter Elastizität und Eindeutigkeit</li> <li>• Anisotrope Finite Elastizität und isotrope Tensorfunktionen</li> <li>• Schädigungsmodelle und Elemente der Bruchmechanik</li> <li>• Finite Elasto-Visko-Plastizität von Metallen und Polymeren</li> <li>• Diskrete Modelle: Partikelmethode und Versetzungsdynamik</li> <li>• Mehrskalenmodelle und numerische Homogenisierungsmethoden</li> <li>• Materialinstabilitäten, Phasenübergänge und Mikrostrukturen</li> </ul> |                |              |

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|--------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 14. Literatur:                       | <p>Vollständiger Tafelanschrieb, Material für die Übungen wird in den Übungen ausgeteilt.</p> <ul style="list-style-type: none"> <li>• J. E. Marsden, T. J. R. Hughes [1983], Mathematical Foundations of Elasticity, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.</li> <li>• R. W. Ogden [1984], Non-Linear Elastic Deformations, Ellis Horwood Series Mathematics and its Applications.</li> <li>• M. Silhavy [1997], The Mechanics and Thermodynamics of Continuous Media, Springer-Verlag.</li> <li>• C. A. Truesdell, W. Noll [1965], The Non-linear Field Theories of Mechanics, Handbuch der Physik, Vol. III (3), S. Flügge (Ed.), Springer Verlag, Berlin.</li> <li>• Arnold Krawietz [1986], Materialtheorie, Mathematische Beschreibung des phänomenologischen thermomechanischen Verhaltens, Springer-Verlag.</li> <li>• J. C. Simo, T. J. R. Hughes [1997], Computational Inelasticity, Springer, New York</li> </ul> |
| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"> <li>• 161801 Vorlesung Theoretische und Computerorientierte Materialtheorie</li> <li>• 161802 Übung Theoretische und Computerorientierte Materialtheorie</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 16. Abschätzung Arbeitsaufwand:      | <p>Präsenzzeit: 52 h<br/>Selbststudium: 128 h<br/>Gesamt: 180 h</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 17. Prüfungsnummer/n und -name:      | <ul style="list-style-type: none"> <li>• 16181 Theoretische und Computerorientierte Materialtheorie (PL), Schriftlich oder Mündlich, 120 Min., Gewichtung: 1</li> <li>• V Vorleistung (USL-V), Schriftlich oder Mündlich</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 18. Grundlage für ... :              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 19. Medienform:                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 20. Angeboten von:                   | Mechanik I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

## Modul: 18620 Optimal Control

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|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 074810120                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Christian Ebenbauer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 9. Dozenten:                                        | Christian Ebenbauer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 11. Empfohlene Voraussetzungen:                     | B.Sc.-Abschluss in Technischer Kybernetik, Maschinenbau, Automatisierungstechnik, Verfahrenstechnik oder einem vergleichbaren Fach sowie Grundkenntnisse der Regelungstechnik (vergleichbar Modul Regelungstechnik)                                                                                                                                                                                                                                                                                                                           |                |                |
| 12. Lernziele:                                      | The students learn how to analyze and solve optimal control problems. The course focuses on key ideas and concepts of the underlying theory. The students learn about standard methods for computing and implementing optimal control strategies.                                                                                                                                                                                                                                                                                             |                |                |
| 13. Inhalt:                                         | <p>The main part of the lecture focuses on methods to solve nonlinear optimal control problems including the following topics:</p> <ul style="list-style-type: none"> <li>• Nonlinear Programming</li> <li>• Dynamic Programming</li> <li>• Pontryagin Maximum Principle</li> <li>• Model Predictive Control</li> <li>• Applications, examples</li> </ul> <p>The exercises contain student exercises and mini projects in which the students apply their knowledge to solve specific optimal control problem in a predefined time period.</p> |                |                |
| 14. Literatur:                                      | <p>D. Liberzon: Calculus of Variations and Optimal Control Theory, Princeton University Press,<br/> A. Brassan and B. Piccoli: Introduction to Mathematical Control Theory, AMS,<br/> I.M. Gelfand and S.V. Fomin: Calculus of Variations, Dover,<br/> D. Bertsekas: Dynamic Programming and Optimal Control, Athena Scientific,<br/> H. Sagan: Introduction to the Calculus of Variations, Dover,</p>                                                                                                                                        |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 186201 Vorlesung Optimal Control                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Präsenzzeit: 42 h<br>Selbststudiumszeit / Nacharbeitszeit: 138 h<br>Gesamt: 180 h                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 17. Prüfungsnummer/n und -name:                     | 18621 Optimal Control (PL), Schriftlich oder Mündlich, 90 Min., Gewichtung: 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 20. Angeboten von:                                  | Computations in Control                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |

## Modul: 25130 Kontinuumsbiomechanik

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|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------------------|
| 2. Modulkürzel:                                     | 021010012                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 5. Moduldauer: | Einsemestrig     |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 6. Turnus:     | Wintersemester   |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 7. Sprache:    | Weitere Sprachen |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Holger Steeb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                  |
| 9. Dozenten:                                        | Wolfgang Ehlers<br>Oliver Röhrle                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                  |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                  |
| 11. Empfohlene Voraussetzungen:                     | B. Sc.-Abschluß im Bauingenieurwesen, im Maschinenbau, in der Umweltschutztechnik oder einem vergleichbaren Fach sowie Kenntnisse der Technischen Mechanik und Grundkenntnisse der Kontinuumsmechanik<br>(B. Sc. degree in Civil Engineering, in Mechanical Engineering, in Environmental Engineering or a comparable discipline and basic knowledge in applied mechanics and continuum thermodynamics.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                  |
| 12. Lernziele:                                      | <p>Die Studierenden sind in der Lage, kontinuumsmechanische Methoden zur Beschreibung harter und weicher biologischer Gewebe einzusetzen. Ausgehend vom Kalkül mehrphasiger Materialien können die Studierenden Deformations- und Transportprozesse analysieren und in einem System gekoppelter Gleichungen darstellen. Die Studierenden haben ein Gefühl für die Komplexität lebender Systeme entwickelt und gelernt, biologische Gewebe zu verstehen und zu berechnen.</p> <p>(The students are able to apply continuum-mechanical methods to the description of hard and soft biological tissues. Based on the calculus of multiphasic materials, the students master the analysis of deformation and transport processes and to handle these problems within a system of coupled equations. The students have a feeling for the complexity of living systems. They understand to describe and calculate biological tissues.)</p>                                      |                |                  |
| 13. Inhalt:                                         | <p>Kenntnisse der Biomechanik sind fundamentale Voraussetzung zur Berechnung von Vorgängen im lebenden Organismus (in vivo) und außerhalb des lebenden Organismus (in vitro). Im Rahmen der Vorlesung stehen weiche biologische Gewebe (z. B. Bandscheiben) im Vordergrund. Harte biologische Gewebe (z. B. Knochen) können als Sonderfall weicher Gewebe dargestellt werden. Für weiche Gewebe muß das gekoppelte Deformations- und Strömungsverhalten des Festkörperskeletts aus Proteoglykanen (Aggrecan) und Kollagenfasern mit der interstitielle Porenflüssigkeit (Porenwasser und darin gelöste Stoffe) dargestellt werden. Zusätzlich werden Quell- und Schrumpfvorgänge beschrieben, die durch chemisch gelöste Stoffe (z. B. NaCl) verursacht werden. Im einzelnen wird der folgende Inhalt präsentiert:</p> <ul style="list-style-type: none"> <li>• Motivation und Einführung in die Problematik</li> <li>• Kontinuumsmechanik gekoppelter Systeme</li> </ul> |                |                  |

- Modellierung weicher biologischer Systeme (finite Viskoelastizität)
- Einbeziehung von Transportprozessen (Fluidströmung, Diffusion chemisch gebundener Stoffe)
- Einbeziehung elektrochemischer Gleichungen (Elektroneutralität, 1. Maxwell-Gleichung, Donnan-Gleichgewicht, van't Hoffsche Osmose)
- Schwache Form des gekoppelten Gleichungssatzes
- Ansatzstruktur für die Finite-Elemente-Methode gekoppelter Systeme

(Biomechanical knowledge is the fundamental basis for the computation of processes inside (in vivo) and outside (in vitro) of living organisms. The lecture especially concerns soft biological tissues such as intervertebral discs. Hard biological tissues such as bones can be described as a special case of soft tissues. In case of soft tissues, the solid deformation and pore-fluid flow of the complete system consisting of the solid skeleton matrix of proteoglycans (aggrecan) and collagen fibres and an interstitial fluid of pore water and dissolved matter (e. g., NaCl) has to be handled. In addition, swelling and shrinking processes have to be described. In particular, the lecture offers the following content:

- Motivation and introduction to the problem
- Continuum mechanics of coupled systems
- Modelling of soft biological tissues (finite viscoelasticity)
- Consideration of transport processes (fluid flow, diffusion of chemically active matter)
- Consideration of electro-chemical equations (electro-neutrality, 1st Maxwell equation, Donnan equilibrium, van't Hoff osmosis)
- Weak form of the governing set of coupled equations
- Basic structure of the Finite Element Method of coupled systems)

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#### 14. Literatur:

Vollständiger Tafelanschrieb, in den Übungen wird Begleitmaterial ausgeteilt (Comprehensive notes on blackboard, additional course materials will be distributed in the exercises).

- R. de Boer, W. Ehlers [1986], Theorie der Mehrkomponentenkontinua mit Anwendung auf bodenmechanische Probleme, Forschungsberichte aus dem Fachbereich Bauwesen der Universität-GH-Essen, Heft 40.
- R. M. Bowen [1976], Theory of Mixtures. In A. C. Eringen (ed.): Continuum Physics, Vol. III, Academic Press.
- W. Ehlers [1989], Poröse Medien - ein kontinuumsmechanisches Modell auf der Basis der Mischungstheorie, Forschungsberichte aus dem Fachbereich Bauwesen der Universität-GH-Essen, Heft 47.
- W. Ehlers [2002], Foundations of multiphase and porous materials. In W. Ehlers, J. Bluhm (eds.): Porous Media: Theory, Experiments and Numerical Applications, pp. 3-86, Springer.
- W. Ehlers [jedes WS, SS] Einführung in die Vektor- und Tensorrechnung, <http://www.mechbau.uni-stuttgart.de/ls2/lehre/uebungen/index.php#begleitmaterialien>.
- W. Ehlers, B. Markert (eds.) [2005], Proceedings of the 1st GAMM Seminar on Continuum Biomechanics, Report No. II-14, Institut für Mechanik (Bauwesen), Universität Stuttgart.
- Y. Fung [1981], Mechanical Properties of Living Tissues, Springer.

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|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|------|----------------|-------|---------|-------|
|                                      | <ul style="list-style-type: none"> <li>• J. D. Humphrey, S. L. Delange [2004], An Introduction to Biomechanics, Springer.</li> <li>• V. C. Mow, W. C. Hayes (eds.) [1997], Basic Orthopaedic Biomechanics, 2nd Edition, Lippincott-Raven.</li> <li>• C. Truesdell [1984], Rational Thermodynamics, 2nd Edition, Springer.</li> </ul> |              |      |                |       |         |       |
| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"> <li>• 251301 Vorlesung Kontinuumsbiomechanik</li> <li>• 251302 Übung Kontinuumsbiomechanik</li> </ul>                                                                                                                                                                                             |              |      |                |       |         |       |
| 16. Abschätzung Arbeitsaufwand:      | <table> <tr> <td>Präsenzzeit:</td><td>52 h</td></tr> <tr> <td>Selbststudium:</td><td>128 h</td></tr> <tr> <td>Gesamt:</td><td>180 h</td></tr> </table>                                                                                                                                                                               | Präsenzzeit: | 52 h | Selbststudium: | 128 h | Gesamt: | 180 h |
| Präsenzzeit:                         | 52 h                                                                                                                                                                                                                                                                                                                                 |              |      |                |       |         |       |
| Selbststudium:                       | 128 h                                                                                                                                                                                                                                                                                                                                |              |      |                |       |         |       |
| Gesamt:                              | 180 h                                                                                                                                                                                                                                                                                                                                |              |      |                |       |         |       |
| 17. Prüfungsnummer/n und -name:      | <p>25131 Kontinuumsbiomechanik (PL), Schriftlich, 120 Min.,<br/>Gewichtung: 1</p> <p>Prüfung evtl. mündlich, Dauer 40 Min., Prüfungsvorleistung:<br/>Hausübungen (Prerequisites: Assignments)</p>                                                                                                                                    |              |      |                |       |         |       |
| 18. Grundlage für ... :              |                                                                                                                                                                                                                                                                                                                                      |              |      |                |       |         |       |
| 19. Medienform:                      |                                                                                                                                                                                                                                                                                                                                      |              |      |                |       |         |       |
| 20. Angeboten von:                   | Mechanik II                                                                                                                                                                                                                                                                                                                          |              |      |                |       |         |       |



## Modul: 30020 Biomechanik

|                                                     |                                                                                                                                                                                                                                                                                                                          |                |                |
|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 072810008                                                                                                                                                                                                                                                                                                                | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 3 LP                                                                                                                                                                                                                                                                                                                     | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 2                                                                                                                                                                                                                                                                                                                        | 7. Sprache:    | Deutsch        |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Peter Eberhard                                                                                                                                                                                                                                                                                      |                |                |
| 9. Dozenten:                                        | Albrecht Eiber                                                                                                                                                                                                                                                                                                           |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                |                |                |
| 11. Empfohlene Voraussetzungen:                     | Grundlagen in Technischer Mechanik                                                                                                                                                                                                                                                                                       |                |                |
| 12. Lernziele:                                      | Kenntnis und Verständnis biomechanischer Grundlagen, selbständige, sichere, kritische und kreative Anwendung mechanischer Methoden in der Biomechanik                                                                                                                                                                    |                |                |
| 13. Inhalt:                                         | <ul style="list-style-type: none"> <li>○ Einführung und Übersicht</li> <li>○ Skelett</li> <li>○ Gelenke</li> <li>○ Knochen</li> <li>○ Weichgewebe</li> <li>○ Biokompatible Werkstoffe</li> <li>○ Muskeln</li> <li>○ Kreislauf</li> <li>○ Beispiele</li> </ul>                                                            |                |                |
| 14. Literatur:                                      | <ul style="list-style-type: none"> <li>○ Vorlesungsmitschrieb</li> <li>○ Vorlesungsunterlagen des ITM</li> <li>○ Nigg, B.M., Herzog, W.: Biomechanics of the Musculo-Skeletal System. Chichester: Wiley, 1999</li> <li>○ Winter, D.A.: Biomechanics and Motor Control of Human Movement. Hoboken: Wiley, 2005</li> </ul> |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 300201 Vorlesung Biomechanik                                                                                                                                                                                                                                                                                           |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Präsenzzeit: 21 Stunden<br>Selbststudium: 69 Stunden<br>Summe: 90 Stunden                                                                                                                                                                                                                                                |                |                |
| 17. Prüfungsnummer/n und -name:                     | 30021 Biomechanik (BSL), Schriftlich oder Mündlich, 60 Min., Gewichtung: 1                                                                                                                                                                                                                                               |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                          |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                          |                |                |
| 20. Angeboten von:                                  | Technische Mechanik                                                                                                                                                                                                                                                                                                      |                |                |

**Modul: 30030 Fahrzeugdynamik**

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|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 072810009                                                                                                                                                                                                                                                                                                                                                                                               | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 3 LP                                                                                                                                                                                                                                                                                                                                                                                                    | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 2                                                                                                                                                                                                                                                                                                                                                                                                       | 7. Sprache:    | Deutsch        |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Peter Eberhard                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 9. Dozenten:                                        | Peter Eberhard<br>Pascal Ziegler                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                               |                |                |
| 11. Empfohlene Voraussetzungen:                     | Grundlagen in Technischer Mechanik                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 12. Lernziele:                                      | Kenntnis und Verständnis fahzeugdynamischer Grundlagen,<br><br>selbständige, sichere, kritische und kreative Anwendung mechanischer Methoden in der Fahrzeugdynamik                                                                                                                                                                                                                                     |                |                |
| 13. Inhalt:                                         | <ul style="list-style-type: none"> <li>○ Systembeschreibung und Modellbildung</li> <li>○ Fahrzeugmodelle</li> <li>○ Modelle für Trag- und Führsysteme</li> <li>○ Fahrwegmodelle</li> <li>○ Modelle für Fahrzeug-Fahrweg-Systeme</li> <li>○ Beurteilungskriterien</li> <li>○ Berechnungsmethoden</li> <li>○ Longitudinalbewegungen</li> <li>○ Lateralbewegungen</li> <li>○ Vertikalbewegungen</li> </ul> |                |                |
| 14. Literatur:                                      | <ul style="list-style-type: none"> <li>○ Vorlesungsmitschrieb</li> <li>○ Vorlesungsunterlagen des ITM</li> <li>○ Popp, K. und Schiehlen, W.: Ground Vehicle Dynamics. Berlin: Springer, 2010.</li> </ul>                                                                                                                                                                                                |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 300301 Vorlesung Fahrzeugdynamik                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Präsenzzeit: 21 Stunden<br>Selbststudium: 69 Stunden<br>Summe: 90 Stunden                                                                                                                                                                                                                                                                                                                               |                |                |
| 17. Prüfungsnummer/n und -name:                     | 30031 Fahrzeugdynamik (BSL), Mündlich, 20 Min., Gewichtung: 1                                                                                                                                                                                                                                                                                                                                           |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 20. Angeboten von:                                  | Technische Mechanik                                                                                                                                                                                                                                                                                                                                                                                     |                |                |

## Modul: 30100 Nichtlineare Dynamik

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|-----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 074810240                                                                                                                                                                                                                                                                                                                                                                                                                                | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                     | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 6                                                                                                                                                                                                                                                                                                                                                                                                                                        | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Christian Ebenbauer                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 9. Dozenten:                                        | Christian Ebenbauer                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                |                |                |
| 11. Empfohlene Voraussetzungen:                     | Systemdynamische Grundlagen der Regelungstechnik                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 12. Lernziele:                                      | This course provides the necessary background for students to understand and solve engineering problems involving nonlinear dynamical systems. The main focus of this course is on differential geometric methods. Applications will include problems from nonlinear control, optimization and mechanics.                                                                                                                                |                |                |
| 13. Inhalt:                                         | <ul style="list-style-type: none"> <li>• Basic facts about nonlinear differential equations, vector fields, flows</li> <li>• Stability and bifurcation</li> <li>• Lie brackets, nonlinear controllability, integrability</li> <li>• Manifolds, calculus on manifolds, optimization on manifolds</li> <li>• Extremum seeking</li> <li>• Advanced stability analysis and center manifolds</li> <li>• Oscillations and averaging</li> </ul> |                |                |
| 14. Literatur:                                      | <ul style="list-style-type: none"> <li>• Arnol'd: Ordinary Differential Equations</li> <li>• Moser, Zehnder: Notes on Dynamical Systems</li> <li>• Bloch: Nonholonomic Mechanics and Control</li> <li>• Isidori: Nonlinear Control Systems I</li> <li>• Guckenheimer, Holmes: Nonlinear Oscillations, dynamical systems, and bifurcations</li> </ul>                                                                                     |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 301001 Vorlesung Nichtlineare Dynamik</li> <li>• 301002 Übung Nichtlineare Dynamik</li> </ul>                                                                                                                                                                                                                                                                                                   |                |                |
| 16. Abschätzung Arbeitsaufwand:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 17. Prüfungsnummer/n und -name:                     | 30101 Nichtlineare Dynamik (PL), Schriftlich oder Mündlich, Gewichtung: 1                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 20. Angeboten von:                                  | Computations in Control                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |

## Modul: 33320 Smart Structures

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|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 074010710                                                                                                                                                                                                                                                                                                                                                                                        | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                             | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                | 7. Sprache:    | Deutsch        |
| 8. Modulverantwortlicher:                           | Prof. Dr.-Ing. Lothar Gaul                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 9. Dozenten:                                        | Helge Sprenger                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                        |                |                |
| 11. Empfohlene Voraussetzungen:                     | Regelungstechnik I                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 12. Lernziele:                                      | Die Studierenden kennen die mechanischen und regelungstechnischen Grundlagen von adaptiven Strukturen, Wirkprinzipien der typischen Aktuatoren und Sensoren, sowie Anwendungen von adaptiven Strukturen                                                                                                                                                                                          |                |                |
| 13. Inhalt:                                         | <ul style="list-style-type: none"> <li>• Dynamik intelligenter Strukturen (Modellierungsmethoden, Wellenausbreitung, Schwingungen)</li> <li>• Materialgesetze intelligenter Materialien(elektrostriktive, magnetostriktive, piezoelektrische Materialien, etc.)</li> <li>• Messtechnik und Sensoren</li> <li>• Signalverarbeitung</li> <li>• Regelungskonzepte</li> <li>• Anwendungen</li> </ul> |                |                |
| 14. Literatur:                                      | Skript                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 333201 Vorlesung Smart Structures</li> <li>• 333202 Übung Smart Structures</li> </ul>                                                                                                                                                                                                                                                                   |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Präsenzzeit: 42 Stunden<br>Selbststudium: 138 Stunden<br>Summe: 180 Stunden                                                                                                                                                                                                                                                                                                                      |                |                |
| 17. Prüfungsnummer/n und -name:                     | 33321 Smart Structures (PL), Schriftlich, 120 Min., Gewichtung: 1                                                                                                                                                                                                                                                                                                                                |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |
| 20. Angeboten von:                                  | Akustik                                                                                                                                                                                                                                                                                                                                                                                          |                |                |

## Modul: 33360 Fuzzy Methoden

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|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 072810017                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                          | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7. Sprache:    | Deutsch        |
| 8. Modulverantwortlicher:                           | apl. Prof. Dr.-Ing. Michael Hanss                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 9. Dozenten:                                        | Michael Hanss                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                     |                |                |
| 11. Empfohlene Voraussetzungen:                     | Regelungstechnik 1 und 2                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 12. Lernziele:                                      | Die Studierenden sind vertraut mit der Theorie der unscharfen Mengen (Fuzzy-Mengentheorie) und ihrer Anwendung zum Aufbau von Expertensystemen und Fuzzy-Regelungen sowie zur Modellierung und Simulation von Systemen mit unsicheren Parametern.                                                                                                                                                                                             |                |                |
| 13. Inhalt:                                         | Einführung: Motivation, Beispiele. Grundlagen der Fuzzy-Theorie: Fuzzy-Mengen, linguistische Variablen, Fuzzy-Relationen, Fuzzy-Logik, unscharfes Schließen. Fuzzy-Systeme: Fuzzyifizierung, Inferenz (Aggregation, Implikation, Komposition), Defuzzyifizierung. Fuzzy-Regelung: Werkzeuge, Anwendungen, Fallstudien. Fuzzy-Arithmetik: Fuzzy- Zahlen, Erweiterungsprinzip, Transformationsmethode. Fuzzy-Clustering: Fuzzy-c-Means-Methode. |                |                |
| 14. Literatur:                                      | Bothe, H.-H.: Fuzzy Logic. Springer-Verlag, Berlin 1995.<br>Hanss, M.: Applied Fuzzy Arithmetic - An Introduction with Engineering Applications. Springer-Verlag, Berlin 2005.                                                                                                                                                                                                                                                                |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 333601 Vorlesung + Übungen Fuzzy Methoden                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Präsenzzeit: 42 Stunden<br>Selbststudium: 138 Stunden<br>Summe: 180 Stunden                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 17. Prüfungsnummer/n und -name:                     | 33361 Fuzzy Methoden (PL), Schriftlich oder Mündlich, 90 Min.,<br>Gewichtung: 1                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 20. Angeboten von:                                  | Technische Mechanik                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |

**Modul: 33370 Structure-Borne Sound**

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|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 074010610                                                                                                                                                                                                                                                                                    | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 3 LP                                                                                                                                                                                                                                                                                         | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 2                                                                                                                                                                                                                                                                                            | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Prof. Dr.-Ing. Lothar Gaul                                                                                                                                                                                                                                                                   |                |                |
| 9. Dozenten:                                        | Lothar Gaul<br>Max Kraus                                                                                                                                                                                                                                                                     |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                    |                |                |
| 11. Empfohlene Voraussetzungen:                     | Technische Schwingungslehre                                                                                                                                                                                                                                                                  |                |                |
| 12. Lernziele:                                      | Die Studierenden sind vertraut mit den Grundlagen der Entstehung und Ausbreitung von Körperschall. Sie kennen Strategien, um Körperschallprobleme zu vermeiden oder zu minimieren.                                                                                                           |                |                |
| 13. Inhalt:                                         | Grundgrößen zur Beschreibung von Körperschall, Übersicht über Wellenarten, Übertragung von Körperschall, Impedanzen, Reflexionen, Schallleistung, Dämmung von Körperschall durch elastische Zwischenlagen, Sperrmassen, Abstrahlung von Körperschall, Dämpfung in Materialien und Bauteilen. |                |                |
| 14. Literatur:                                      | Skript                                                                                                                                                                                                                                                                                       |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 333701 Vorlesung Körperschall                                                                                                                                                                                                                                                              |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Präsenzzeit: 21 Stunden<br>Selbststudium: 69 Stunden<br>Summe: 90 Stunden                                                                                                                                                                                                                    |                |                |
| 17. Prüfungsnummer/n und -name:                     | 33371 Structure-Borne Sound (BSL), Mündlich, 20 Min., Gewichtung: 1                                                                                                                                                                                                                          |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                              |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                              |                |                |
| 20. Angeboten von:                                  | Akustik                                                                                                                                                                                                                                                                                      |                |                |

## Modul: 33630 Boundary Element Methods in Statics and Dynamics

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|-----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 074010720                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Prof. Dr.-Ing. Lothar Gaul                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 9. Dozenten:                                        | Lothar Gaul                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 11. Empfohlene Voraussetzungen:                     | HM I-III, TM I-IV                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 12. Lernziele:                                      | Die Studierenden kennen die Grundlagen der Randelemente Methode (Boundary Element Method, BEM). Sie sind in der Lage, einfache analytische Berechnungen durchzuführen und verstehen Stärken und Schwächen der Methode im Vergleich zu anderen numerischen Verfahren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 13. Inhalt:                                         | <p>Das Konzept der BEM: Vergleich mit der Finiten Elemente Methode (FEM), Grundlagen der BEM, Prinzip der gewichteten Residuen, Reziprozitäts- Theorem, Transformation auf den Rand, eindimensionale Beispiele, Balken und Stäbe.</p> <p>Formulierung der Laplace und der Poisson Gleichungen in zwei und drei Dimensionen mit Hilfe der direkten Methode: Wärmeleitung, gemischte Randwert-Probleme, Fundamentallösungen, Randintegral-Gleichung, numerische Lösung durch Punktkollokation, Behandlung von Gebietsintegralen, orthotropes Materialverhalten, Substruktur Technik.</p> <p>BEM in der Akustik: Wellen- und Helmholtzgleichungen, fundamental Lösungen im Frequenz und Zeitbereich, Kirchhoff- und Somigliana- Integralgleichungen. Anwendungen: ausbreitende und stehende Schallwellen.</p> <p>BEM in der Elastomechanik: Lamé-Navier- Gleichungen, statische und dynamische Fundamentallösungen, Randintegral-Gleichung, Somigliana- Identität, numerische Lösung durch Punktkollokation. Anwendungen: Ausbreitung von Körperschall, Spannungsberechnung mit der BEM.</p> <p>Ausblick auf fortgeschrittene Themengebiete: dual reciprocity BEM, hybride BE Formulierungen, Kopplung zwischen BEM und FEM.</p> |                |                |
| 14. Literatur:                                      | Gaul, Fiedler: Methode der Randelemente, Vieweg (1997)<br>Gaul, Kögl, Wagner: Boundary Element Methods, Springer (2003)<br>Steinbach: Numerische Näherungsverfahren, Teubner (2003)<br>100 online lecture: <a href="http://www.bem.uni-stuttgart.de">www.bem.uni-stuttgart.de</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 336301 Vorlesung Boundary Element Methods in Statics and Dynamics</li> <li>• 336302 Übung Boundary Element Methods in Statics and Dynamics</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Präsenzzeit: 42 Stunden<br>Selbststudium: 138 Stunden<br>Summe: 180 Stunden                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |

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|---------------------------------|--------------------------------------------------------------------------------------------------|
| 17. Prüfungsnummer/n und -name: | 33631 Boundary Element Methods in Statics and Dynamics (PL),<br>Mündlich, 40 Min., Gewichtung: 1 |
| 18. Grundlage für ... :         |                                                                                                  |
| 19. Medienform:                 | Beamer, Tafel, PC, Internet                                                                      |
| 20. Angeboten von:              | Akustik                                                                                          |



**Modul: 34940 Weiterführende Numerik partieller Differentialgleichungen**

|                                                     |                                                                                                                                                                                                                                                                                                                                                    |                |              |
|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|--------------|
| 2. Modulkürzel:                                     | 080803802                                                                                                                                                                                                                                                                                                                                          | 5. Moduldauer: | Einsemestrig |
| 3. Leistungspunkte:                                 | 9 LP                                                                                                                                                                                                                                                                                                                                               | 6. Turnus:     | Unregelmäßig |
| 4. SWS:                                             | 6                                                                                                                                                                                                                                                                                                                                                  | 7. Sprache:    | Deutsch      |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr. Kunibert Gregor Siebert                                                                                                                                                                                                                                                                                                            |                |              |
| 9. Dozenten:                                        | Christian Rohde<br>Kunibert Gregor Siebert<br>Bernard Haasdonk                                                                                                                                                                                                                                                                                     |                |              |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                          |                |              |
| 11. Empfohlene Voraussetzungen:                     | empfohlen: Einführung in die Numerik partieller Differentialgleichungen                                                                                                                                                                                                                                                                            |                |              |
| 12. Lernziele:                                      | Die Studenten verfügen über Kenntnis weiterführender Konzepte, Algorithmen und Methoden zur Lösung von partiellen Differentialgleichungen, sie erwerben die Fähigkeit, mit den erlernten Kenntnissen selbständig Methoden zu entwickeln, zu analysieren und umzusetzen, mit denen anwendungsorientierte Probleme effizient und genau gelöst werden |                |              |
| 13. Inhalt:                                         | Vertiefende Themen der Numerik für PDEs, beispielsweise aus dem Bereich der Spektralmethoden, Finite Volumen, Continuous und Discontinuous Galerkin, schnelle Löser für dünnbesetzte Systeme, Mehrgitter und Multilevelverfahren, Anwendungen in der Kontinuumsmechanik, hierarchische Ansätze                                                     |                |              |
| 14. Literatur:                                      | D. Braess, Finite Elemente: Theorie, schnelle Löser und Anwendungen in der Elastizitätstheorie.<br>D. Kröner, Numerical Schemes for Conservation Laws.                                                                                                                                                                                             |                |              |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 349402 Übung Weiterführende Numerik partieller Differentialgleichungen</li> <li>• 349401 Vorlesung Weiterführende Numerik partieller Differentialgleichungen</li> </ul>                                                                                                                                   |                |              |
| 16. Abschätzung Arbeitsaufwand:                     | Insgesamt 270 h, wie folgt:<br>Präsenzzeit: 42 h (V), 21 h (Ü)<br>Selbststudium: 207                                                                                                                                                                                                                                                               |                |              |
| 17. Prüfungsnummer/n und -name:                     | <ul style="list-style-type: none"> <li>• 34941 Weiterführende Numerik partieller Differentialgleichungen (PL), Mündlich, 30 Min., Gewichtung: 1</li> <li>• V Vorleistung (USL-V), Schriftlich oder Mündlich</li> </ul>                                                                                                                             |                |              |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                    |                |              |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                    |                |              |
| 20. Angeboten von:                                  | Angewandte Mathematik/Numerik für Höchstleistungsrechner                                                                                                                                                                                                                                                                                           |                |              |

**Modul: 38240 Simulation Methods in Physics for SimTech II**

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| 2. Modulkürzel:                                     | 082300666                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Ph.D. Christian Holm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 9. Dozenten:                                        | Christian Holm<br>Maria Fyta                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 4. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 11. Empfohlene Voraussetzungen:                     | Contents of the Module "Simulationsmethoden in der Physik für SimTech I                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 12. Lernziele:                                      | <ul style="list-style-type: none"> <li>• Thorough understanding of the methods for the simulation of physical phenomena of classical and quantum-mechanical systems</li> <li>• Competence to autonomously use various simulation software</li> <li>• The lab sessions also supports the students' media competence</li> </ul>                                                                                                                                                                                                    |                |                |
| 13. Inhalt:                                         | Homepage (SS 2016): <a href="http://www.icp.uni-stuttgart.de/~icp/Simulation_Methods_in_Physics_II_SS_2016">http://www.icp.uni-stuttgart.de/~icp/Simulation_Methods_in_Physics_II_SS_2016</a> <ul style="list-style-type: none"> <li>• Ab-initio MD</li> <li>• Advanced MD Methods</li> <li>• Implicit Solvent Models</li> <li>• Methods for Hydrodynamic Interactions</li> <li>• Methods for Electrostatic Interactions</li> <li>• Coarse-graining</li> <li>• Advanced MC Methods</li> <li>• Computing Free Energies</li> </ul> |                |                |
| 14. Literatur:                                      | <ul style="list-style-type: none"> <li>• Frenkel, Smit, "Understanding Molecular Simulations, Academic Press, San Diego, 2002.</li> <li>• Allen, Tildesley, "Computer Simulation of Liquids. ,Oxford Science Publications, Clarendon Press, Oxford 1987.</li> </ul>                                                                                                                                                                                                                                                              |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 382401 Lecture Simulation Methods in Physics for SimTech II</li> <li>• 382402 Tutorial Simulation Methods in Practice</li> </ul>                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | <ul style="list-style-type: none"> <li>• Lecture: Simulation Methods in Physics II: 28h Attendance, 56h Self-studies</li> <li>• Tutorial Simulation Methods in Practice: 28h Attendance, 68h Tasks</li> </ul> <p>Sum: 180h</p>                                                                                                                                                                                                                                                                                                   |                |                |
| 17. Prüfungsnummer/n und -name:                     | <ul style="list-style-type: none"> <li>• 38241 Simulation Methods in Physics for SimTech II (PL), Mündlich, 40 Min., Gewichtung: 1</li> <li>• V Vorleistung (USL-V), Schriftlich oder Mündlich 50% der Punkte in den Übungen</li> </ul>                                                                                                                                                                                                                                                                                          |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |
| 20. Angeboten von:                                  | Computerphysik                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |

## Modul: 40520 Simulation Methods in Physics for SimTech I

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| 2. Modulkürzel:                                     | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Ph.D. Christian Holm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 9. Dozenten:                                        | Christian Holm<br>Maria Fyta                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 11. Empfohlene Voraussetzungen:                     | <ul style="list-style-type: none"> <li>• Fundamental Knowledge of theoretical and experimental physics, in particular Thermodynamics and Statistical Physics.</li> <li>• Unix basics</li> <li>• Basic Programming skills in C and Python</li> <li>• Basics of Numerical Mathematics</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 12. Lernziele:                                      | The goal is to obtain a thorough understanding of numerical methods for simulating physical phenomena of classical and quantum systems. Afterward, the participants shall be able to autonomously apply simulation methods to a given problem. The tutorials also support media- and methodological skills.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 13. Inhalt:                                         | <b>Simulation Methods in Physics 1 (2 SWS Lecture + 2 SWS Tutorials in Winter Term)</b><br>Homepage (Winter Term 2016/2017):<br><a href="https://www.icp.uni-stuttgart.de/~icp/Simulation_Methods_in_Physics_I_WS_2016/2017">https://www.icp.uni-stuttgart.de/~icp/Simulation_Methods_in_Physics_I_WS_2016/2017</a> <ul style="list-style-type: none"> <li>• History of Computers</li> <li>• Finite-Element-Method</li> <li>• Molecular Dynamics (MD) <ul style="list-style-type: none"> <li>• Integrators</li> <li>• Different Ensembles: Thermostats, Barostats</li> <li>• Observables</li> </ul> </li> <li>• Simulation of quantum mechanical problems <ul style="list-style-type: none"> <li>• Solving the Schrödinger equation</li> <li>• Lattice models, Lattice gauge theory</li> </ul> </li> <li>• Monte-Carlo-Simulations (MC)</li> <li>• Spin Systems, Critical Phenomena, Finite Size Scaling</li> <li>• Statistical Errors, Autocorrelation</li> </ul> |                |                |
| 14. Literatur:                                      | <ul style="list-style-type: none"> <li>• Frenkel, Smit, "Understanding Molecular Simulations", Academic Press, San Diego, <b>2002</b>.</li> <li>• Allen, Tildesley, "Computer Simulation of Liquids. <i>Oxford Science Publications</i> , Clarendon Press, Oxford, <b>1987</b> .</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 405201 Lecture Simulation Methods in Physics for SimTech I</li> <li>• 405202 Exercise Simulation Methods in Physics for SimTech I</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | <ul style="list-style-type: none"> <li>• Lecture Simulation Methods in Physics 1:<br/>28h Attendance, 56h Home work</li> <li>• Tutorials Simulation Methods in Physics 1:<br/>28h Attendance, 68h Doing the Exercises</li> </ul> <p><b>Total: 180h</b></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |

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| 17. Prüfungsnummer/n und -name: | <ul style="list-style-type: none"><li>• 40521 Simulation Methods in Physics for SimTech I (BSL), Mündlich, 40 Min., Gewichtung: 1</li><li>• V Vorleistung (USL-V), Sonstige 50% der Punkte aus den Übungen</li></ul> |
| 18. Grundlage für ... :         |                                                                                                                                                                                                                      |
| 19. Medienform:                 |                                                                                                                                                                                                                      |
| 20. Angeboten von:              | Computerphysik                                                                                                                                                                                                       |

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## Modul: 50090 Environmental Fluid Mechanics I

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| 2. Modulkürzel:                                     | 021420012                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | apl. Prof. Dr.-Ing. Holger Class                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 9. Dozenten:                                        | Holger Class<br>Jürgen Braun<br>Sergey Oladyshkin                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 11. Empfohlene Voraussetzungen:                     | <p>Technical Mechanics</p> <ul style="list-style-type: none"> <li>• Introduction to the statics of rigid bodies</li> <li>• Introduction to elastostatics</li> <li>• Introduction to the mechanics of incompressible fluids</li> </ul> <p>Higher Mathematics</p> <ul style="list-style-type: none"> <li>• Partial differential equations</li> <li>• Vector analysis</li> <li>• Numerical integration</li> </ul> <p>Fundamentals of Flow Mechanics</p> <ul style="list-style-type: none"> <li>• Conservation equations for mass, momentum, energy</li> <li>• Navier-Stokes, Euler, Reynolds, Bernoulli equation</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 12. Lernziele:                                      | Students have fundamental knowledge of flow in various natural hydrosystems and its application in civil and environmental engineering.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 13. Inhalt:                                         | <p>The lecture deals with flow in natural hydrosystems with particular emphasis on groundwater / seepage flow and on flow in surface water / open channels. Groundwater hydraulics includes flow in confined, semi-confined and unconfined groundwater aquifers, wells, pumping tests and other hydraulic investigation methods for exploring groundwater aquifers. In addition, questions concerning regional groundwater management (z.B. recharge, unsaturated zone, saltwater intrusion) are discussed. Using the example of groundwater flow, fundamentals of CFD (Computational Fluid Dynamics) are explained, particularly the numerical discretisation techniques finite volume und finite difference. The hydraulics of surface water deals with shallow water equations / Saint Venant equations, unstationary channel flow, turbulence und layered systems. Calculation methods such as the methods of characteristics are explained. The contents are:</p> <ul style="list-style-type: none"> <li>• Potential flow and groundwater flow</li> <li>• Computational Fluid Dynamics</li> <li>• Shallow water equations for surface water</li> <li>• Charakteristikenmethode</li> <li>• Examples from civil and environmental engineering</li> </ul> |                |                |
| 14. Literatur:                                      | <p>Lecture notes: Hydromechanics, Helmig and Class</p> <p>Lecture notes: Ausbreitungs- und Transportvorgänge in Strömungen, Cirkpa</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |

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|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|
|                                      | White, F.M.: Fluid Mechanics, WCB/McGraw-Hill, New York, 1999<br>Freeze, R.A. and Cherry J.A.: Groundwater, Prentice Hall, 1979 |
| 15. Lehrveranstaltungen und -formen: | • 500901 Lecture and Exercise Environmental Fluid Mechanics I                                                                   |
| 16. Abschätzung Arbeitsaufwand:      | Sum 180 h                                                                                                                       |
| 17. Prüfungsnummer/n und -name:      | • 50091 Environmental Fluid Mechanics I (PL), Schriftlich, 120 Min.,<br>Gewichtung: 1<br>• V Vorleistung (USL-V), Schriftlich   |
| 18. Grundlage für ... :              | Environmental Fluid Mechanics II                                                                                                |
| 19. Medienform:                      | Fundamentals will be developed using the blackboard and<br>presentation tools.                                                  |
| 20. Angeboten von:                   | Hydromechanik und Hydrosystemmodellierung                                                                                       |

## Modul: 50140 Modeling of Hydrosystems

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| 2. Modulkürzel:                                     | 021420011                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Rainer Helmig                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 9. Dozenten:                                        | Bernd Flemisch<br>Rainer Helmig                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 11. Empfohlene Voraussetzungen:                     | <p>Recommended background knowledge:</p> <p>Higher Mathematics:</p> <ul style="list-style-type: none"> <li>• Partial differential equations</li> <li>• Numerical integration</li> </ul> <p>Fundamentals of fluid mechanics:</p> <ul style="list-style-type: none"> <li>• Conservation equations for mass, momentum, energy</li> <li>• Mathematical descr</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 12. Lernziele:                                      | Students can select suitable numerical methods for solving problems from fluid mechanics and have basic knowledge of implementing a numerical model in C.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 13. Inhalt:                                         | <p>Discretisation methods:</p> <ul style="list-style-type: none"> <li>• Knowledge of the common methods (finite differences, finite elements, finite volume) and the differences between them</li> <li>• Advantages and disadvantages and of the methods and thus of their applicability</li> <li>• Derivation of the various methods</li> <li>• Use and choice of the correct boundary conditions for the various methods</li> </ul> <p>Time discretisation:</p> <ul style="list-style-type: none"> <li>• Knowledge of the various possibilities</li> <li>• Assessment of stability, computational effort, precision</li> <li>• Courant number, CFL criterion</li> </ul> <p>Transport equation:</p> <ul style="list-style-type: none"> <li>• Various discretisation possibilities</li> <li>• Physical background</li> <li>• Stability criteria of the methods (Peclet number)</li> </ul> <p>Clarification of concepts: model, simulation</p> <p>Application of the finite element method to the stationary groundwater equation</p> <p>Setting-up of a simulation programme for modeling groundwater:</p> <ul style="list-style-type: none"> <li>• Programme requirements</li> <li>• Programming individual routines</li> </ul> <p>Fundamentals of programming in C:</p> <ul style="list-style-type: none"> <li>• Control structures</li> <li>• Functions</li> <li>• Arrays</li> </ul> |                |                |

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|                                      | <ul style="list-style-type: none"> <li>• Debugging</li> </ul> <p>Visualisation of the simulation results</p>                                                                                             |
| 14. Literatur:                       | Lecture notes: Modeling of Hydrosystems, Helmig<br>Helmig, R.: Multiphase Flow and Transport Processes in the Subsurface, Springer Verlag, 1997                                                          |
| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"> <li>• 501401 Lecture and Exercise Modeling of Hydrosystems 1, Fundamentals</li> <li>• 501403 Lecture and Exercise Modeling of Hydrosystems 2, Applications</li> </ul> |
| 16. Abschätzung Arbeitsaufwand:      | Sum: 180h                                                                                                                                                                                                |
| 17. Prüfungsnummer/n und -name:      | 50141 Modeling of Hydrosystems (PL), Schriftlich, 120 Min., Gewichtung: 1                                                                                                                                |
| 18. Grundlage für ... :              |                                                                                                                                                                                                          |
| 19. Medienform:                      | Fundamentals will be developed using the blackboard and presentation tools. Group exercises help in understanding the obtained theoretical basis.                                                        |
| 20. Angeboten von:                   | Hydromechanik und Hydrosystemmodellierung                                                                                                                                                                |



**Modul: 50170 Environmental Fluid Mechanics II**

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|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021420013                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Rainer Helmig                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 9. Dozenten:                                        | Wolfgang Nowak<br>Rainer Helmig                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 4. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 11. Empfohlene Voraussetzungen:                     | Recommended background knowledge:<br>Mechanics of incompressible and compressible fluids, fundamentals of numerical methods in fluid mechanics, fundamentals of exchange and transport processes in technical and natural systems (e.g. groundwater and surface water, pipelines).<br>Contents of Environmental Fluid Mechanics I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 12. Lernziele:                                      | Students have the necessary grasp of hydrodynamic, physical and chemical processes and systems to be able to answer environmentally relevant questions concerning water and air quality in natural and technical systems.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 13. Inhalt:                                         | The lecture deals with the heat and mass budget of natural and technical systems. This includes transport processes in lakes, rivers and groundwater, heat and mass transfer processes between compartments as well as between various phases (sorption, dissolution), conversion of matter in aquatic systems and the quantitative description of these processes. In addition to classical single fluid phase systems, multiphase flow and transport processes in porous media will be considered. On the basis of a comparison of single- and multiphase flow systems, the various model concepts will be discussed and assessed.<br>In the accompanying exercises, example problems present applications, extend the lecture material and help prepare for the exam. Computer exercises improve the grasp of the problems and give insight into the practical application of what has been learned. |                |                |
| 14. Literatur:                                      | Lecture notes: Fluidmechanics II, Helmig<br>Helmig, R.: Multiphase Flow and Transport Processes in the Subsurface. Springer, 1997                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 501701 Lecture and Exercise Environmental Fluid Mechanics II                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Sum: 180h                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 17. Prüfungsnummer/n und -name:                     | 50171 Environmental Fluid Mechanics II (PL), Schriftlich, 120 Min., Gewichtung: 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 19. Medienform:                                     | Fundamentals will be developed using the blackboard and presentation tools. Process understanding will be improved using movies and experiments. Small exercises will help to to deepen the knowledge.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |

20. Angeboten von: Hydromechanik und Hydrosystemmodellierung

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## Modul: 50280 Multiphase Modeling in Porous Media

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|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021420014                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | apl. Prof. Dr.-Ing. Holger Class                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 9. Dozenten:                                        | Holger Class<br>Rainer Helmig                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 11. Empfohlene Voraussetzungen:                     | Theory of multiphase systems in porous media: <ul style="list-style-type: none"> <li>• Phases / components</li> <li>• Capillary pressure</li> <li>• Relative permeability</li> </ul> Contents of Environmental Fluid Mechanics I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 12. Lernziele:                                      | Students have the basic theoretical and numerical knowledge to model multiphase systems in porous media.<br>Furthermore, they have basic skills to practically work with numerical software, programming languages, etc.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |
| 13. Inhalt:                                         | Using complex models in engineering practice requires well-founded knowledge of the characteristics of discretisation techniques as well as of the capabilities and limitations of numerical models, taking into account the respective concepts implemented and the underlying model assumptions. The contents are:<br>Theory of multiphase flow in porous media <ul style="list-style-type: none"> <li>• Derivation of the differential equations</li> <li>• constitutive relations</li> </ul> Numerical solution of the multiphase flow equation <ul style="list-style-type: none"> <li>• Box method</li> <li>• Linearisation</li> <li>• Time discretisation</li> </ul> Multicomponent systems <ul style="list-style-type: none"> <li>• Thermodynamic fundamentals and non-isothermal processes</li> </ul> Application examples: <ul style="list-style-type: none"> <li>• Thermal remediation techniques</li> <li>• CO<sub>2</sub> storage in geological formations</li> <li>• Water / oxygen transport in gas diffusion layers of fuel cells</li> <li>• Freshwater / saltwater interaction</li> </ul> |                |                |
| 14. Literatur:                                      | Lecture notes: Multiphase Modeling, Class<br>Helmig, R.: Multiphase Flow and Transport Processes in the Subsurface. Springer, 1997<br>Class, H.: Models for Non-Isothermal Compositional Gas-Liquid Flow and Transport in Porous Media, Habilitation, Universität Stuttgart, 2008                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 502802 Exercise Multiphase Modeling in Porous Media</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |

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|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                 | • 502801 Lecture Multiphase Modeling in Porous Media                                                                                                                                                                                                                      |
| 16. Abschätzung Arbeitsaufwand: | Lectures: 55 h<br>Self-study: 125 h<br>Total: 180 h                                                                                                                                                                                                                       |
| 17. Prüfungsnummer/n und -name: | 50281 Multiphase Modeling in Porous Media (PL), Schriftlich, 120 Min., Gewichtung: 1                                                                                                                                                                                      |
| 18. Grundlage für ... :         |                                                                                                                                                                                                                                                                           |
| 19. Medienform:                 | Fundamentals will be developed using the blackboard and presentation tools. Group exercises help in understanding the obtained theoretical basis. Practical computer exercises for different problems are carried out with the help of an interactive multi-media system. |
| 20. Angeboten von:              | Hydromechanik und Hydrosystemmodellierung                                                                                                                                                                                                                                 |

## Modul: 50290 Numerical Methods for Differential Equations

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|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 080310506                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr. Kunibert Gregor Siebert                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 9. Dozenten:                                        | Claus-Justus Heine                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 12. Lernziele:                                      | <ul style="list-style-type: none"> <li>• basic knowledge about the theory of ordinary and/or partial differential equations</li> <li>• overview about numerical solution methods for these problems</li> <li>• ability to link a given problem and the appropriate method</li> <li>• ability to program solution methods in MATLAB</li> </ul>                                                                                                                                                                      |                |                |
| 13. Inhalt:                                         | <p>In the first part of the semester, we will discuss algorithms for the numerical integration of ordinary differential equations (ODEs). In the second part, an introduction to partial differential equations (PDEs) and its solution by the use of the Finite Element (FE) method will be given. While the lecture focuses on the treatment of the required mathematical theory, the tutorial will place emphasis on the implementation of the developed schemes within the Matlab programming environment.</p> |                |                |
| 14. Literatur:                                      | Stoer, Bulirsch: Introduction to numerical Analysis                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 502901 Lecture Numerical Methods for Differential Equations</li> <li>• 502902 Tutorial Numerical Methods for Differential Equations</li> </ul>                                                                                                                                                                                                                                                                                                                            |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | <p>Time of attendance: approx. 33=21(L)+12(T) hours<br/>         Private Study: approx. 70 hours<br/>         Preparation of exercises: 33 hours<br/>         Coding: approx 40 hours</p>                                                                                                                                                                                                                                                                                                                          |                |                |
| 17. Prüfungsnummer/n und -name:                     | 50291 Numerical Methods for Differential Equations (PL), Schriftlich, Gewichtung: 1                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 20. Angeboten von:                                  | Angewandte Mathematik/Numerik für Höchstleistungsrechner                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |

## Modul: 60210 Implementation and Algorithms for Finite Elements

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|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 020300006                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Dr.-Ing. Malte von Scheven                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 9. Dozenten:                                        | Malte von Scheven                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 11. Empfohlene Voraussetzungen:                     | "Computational Mechanics of Structures" or "Finite Elemente für Tragwerksberechnungen"                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 12. Lernziele:                                      | The students know the numerical methods and algorithms for implementation of the finite element method. They are able to understand the individual components of complex finite element packages and they can produce their own finite element code. For that purpose, the students have basic knowledge of a scientific programming language. Furthermore, the students understand the most important methods of numerical mathematics and know how to implement it within a computer code. |                |                |
| 13. Inhalt:                                         | <ul style="list-style-type: none"> <li>• principal structure of a finite element code</li> <li>• pre- and post-processing, software engineering in the context of finite element programs</li> <li>• integration of element stiffness matrices and load vectors, implementation of boundary conditions</li> <li>• assembly of stiffness matrices</li> <li>• solution of linear systems of equations</li> <li>• storage formats for sparse matrices</li> </ul>                                |                |                |
| 14. Literatur:                                      | lecture notes "Implementation and Algorithms for Finite Elements", Institut für Baustatik und Baudynamik                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 602101 Vorlesung Implementation and Algorithms for Finite Elements</li> <li>• 602102 Übung Implementation and Algorithms for Finite Elements</li> </ul>                                                                                                                                                                                                                                                                                             |                |                |
| 16. Abschätzung Arbeitsaufwand:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 17. Prüfungsnummer/n und -name:                     | 60211 Implementation and Algorithms for Finite Elements (PL), Schriftlich, 120 Min., Gewichtung: 1<br>Prerequisite: 3 approved, not graded assignments                                                                                                                                                                                                                                                                                                                                       |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 20. Angeboten von:                                  | Baustatik und Baudynamik                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |

## Modul: 67150 Einführung in die Modellreduktion mechanischer Systeme

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|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------------------|
| 2. Modulkürzel:                                     | 021020015                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 5. Moduldauer: | Einsemestrig     |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 6. Turnus:     | Wintersemester   |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 7. Sprache:    | Weitere Sprachen |
| 8. Modulverantwortlicher:                           | Dr.-Ing. Felix Oliver Fritzen                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                  |
| 9. Dozenten:                                        | Wolfgang Ehlers<br>Felix Oliver Fritzen                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                  |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016,<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                  |
| 11. Empfohlene Voraussetzungen:                     | Grundkenntnisse der Kontinuumsmechanik,<br>Kenntnisse numerischer Methoden für partielle Differentialgleichungen (insbesondere Finite-Elemente-Methode, Finite-Differenzen-Methode),<br>Grundkenntnisse in MATLAB,<br>basic knowledge of continuum mechanics,<br>knowledge in numerical methods for partial differential equations (in particular: finite element method, finite difference method),<br>basic knowledge in MATLAB,                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                  |
| 12. Lernziele:                                      | <p>Durch die Vorlesung erlernen die Studierenden Grundkenntnisse aus dem Bereich der Modellreduktionsverfahren zur numerisch effizienten Behandlung parametrisierter partieller Differentialgleichungen. Dabei werden theoretische Grundlagen und anwendungsorientierte Aspekte vermittelt, die in praktische Problemstellungen und akademischen Fragestellungen eingesetzt werden können.</p> <p>Withing the course the students attain basic knowledge in the field of model order reduction for the computationally efficient treatment of parameterized partial differential equations. Both theoretical foundations and application oriented aspects will be covered, thus providing tools for use in either practical problem settings or in an academic environment.</p>                                                                                                                   |                |                  |
| 13. Inhalt:                                         | <p>Die Vorlesung gibt eine Einführung in Modellreduktionsverfahren, insbesondere in Verfahren, die eine Reduktion linearer Funktionenräume durch sogenannte Reduzierte Basen realisieren. Die Veranstaltung gliedert sich wie folgt:</p> <ul style="list-style-type: none"> <li>• Motivation: Notwendigkeit der Modellreduktion für numerische Studien, Eigenschaften parametrisierter mechanischer Probleme (mit Beispielen)</li> <li>• Kontinuumsmechanische Grundlagen:</li> </ul> <p>Wärmeleitung (stationär, instationär)<br/>Diskrete mechanische System (Feder-Massen-Systeme)<br/>Elastostatik</p> <ul style="list-style-type: none"> <li>• Matrixalgebra (inkl. EIG/SVD, ), formale Definition von Funktionenräumen</li> <li>• Substrukturtechniken</li> <li>• Definition lokaler und globaler Maße für Approximationsfehler</li> <li>• Proper Orthogonal Decomposition (POD)</li> </ul> |                |                  |

- Reduzierte Basis Methoden für lineare, zeitunabhängige Probleme  
(RB for LTI systems)
- Reduzierte Basis Methoden für lineare, zeitabhängige Probleme
- Einführung in die Modellreduktion nichtlinearer Systeme
- Numerische Aspekte der Modellreduktion für nichtlineare Probleme

The lecture gives an introduction to model order reduction, more specifically for methods aiming at a reduction of linear function spaces by using a reduced basis. The course is partitioned as follows:

- Motivation: necessity for model order reduction in numerical studies, properties of parameterized mechanical systems (with examples)
- Continuum mechanical foundations:

Heat conduction (stationary, instationary)

Discrete mechanical systems (spring-mass-systems)

elasto statics

- matrix algebra (eigenproblems/SVD, ), formal definitions of function spaces
- substructuring techniques
- definition of local and global measures of the approximation error
- proper orthogonal decomposition (POD)
- reduced basis methods for linear time invariant problems (LTI)
- reduced basis methods for linear time dependent problems
- introduction to model order reduction of nonlinear systems
- numerical aspects of model order reduction for nonlinear problems

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14. Literatur:

Digital lecture notes including digital material for the course preparation will be provided

Supplementing literature:

J. Fehr: "Automated and error controlled model reduction in elastic multibody systems", Dissertationsschrift, Shaker Verlag, 2011

F. Fritzen: "Microstructural modeling and computational homogenization of the physically linear and nonlinear constitutive behavior of micro-heterogeneous materials", Dissertationsschrift, KIT Scientific Publishing, 2011

F. Fritzen, M. Leuschner: "Reduced basis hybrid computational homogenization based on a mixed incremental formulation", Computer Methods in Applied Mechanics and Engineering 260, 143-154, 2013

D. Wirtz, Dissertationsschrift "Model reduction for nonlinear systems: kernel methods and error estimation", Universität Stuttgart, 2013

F. Fritzen, M. Hodapp, M. Leuschner: "GPU accelerated computational homogenization based on a variational approach in a reduced basis framework", Computer Methods in Applied Mechanics and Engineering 278, 186-217, 2014

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15. Lehrveranstaltungen und -formen:

- 671501 Vorlesung Einführung in die Modellreduktion mechanischer Systeme

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16. Abschätzung Arbeitsaufwand:

Präsenzzeit Vorlesung 21 h

Nachbereitung Vorlesung 56 h

Präsenzzeit Übung/Rechnerpraktika 32 h





## Modul: 68740 Advanced Computational Mechanics of Structures

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|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 020300005                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Manfred Bischoff                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 9. Dozenten:                                        | Manfred Bischoff<br>Anton Tkachuk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 11. Empfohlene Voraussetzungen:                     | Computational Mechanics of Structures (55920)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 12. Lernziele:                                      | The students have an overview of computational methods for the non-linear analysis of structures with an emphasis on the finite element method. They are prepared for self dependent work on a scientific level. At the same time they have practical skills, particularly in view of computational modelling of non-linear structural behaviour and critical review of the results. They have gained insight into aims and methods of scientific work in an international environment.                                                                                                      |                |                |
| 13. Inhalt:                                         | <p>The course covers the theory of non-linear structural mechanics and corresponding discretization methods and algorithms with a focus on the finite element methods.</p> <ul style="list-style-type: none"> <li>• basic principles, phenomena and concepts of structural mechanics</li> <li>• non-linear strain measures and stress measures</li> <li>• large deformations, stability problems</li> <li>• methods and algorithms of non-linear structural mechanics</li> <li>• iteration methods and path following techniques</li> <li>• stability analysis, buckling problems</li> </ul> |                |                |
| 14. Literatur:                                      | <ul style="list-style-type: none"> <li>• T. Belytschko, W.K. Liu, B. Moran: Nonlinear Finite Elements for Continua and Structures, Wiley 2001.</li> <li>• M.A. Crisfield: Non-linear Finite Element Analysis of Solids and Structures, Essentials: 1, Wiley 1996.</li> <li>• lecture notes "Advanced Computational Mechanics of Structures", Institut für Baustatik und Baudynamik</li> </ul>                                                                                                                                                                                                |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 687401 Vorlesung Advanced Computational Mechanics of Structures</li> <li>• 687402 Übung Advanced Computational Mechanics of Structures</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 16. Abschätzung Arbeitsaufwand:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 17. Prüfungsnummer/n und -name:                     | <ul style="list-style-type: none"> <li>• 68741 Advanced Computational Mechanics of Structures (PL), Schriftlich, 120 Min., Gewichtung: 1</li> <li>• V Vorleistung (USL-V), Sonstige</li> </ul> <p>Prerequisite: 3 approved, not graded assignments</p>                                                                                                                                                                                                                                                                                                                                       |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 20. Angeboten von:                                  | Baustatik und Baudynamik                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |

## Modul: 68750 Computational Methods for Shell Analysis

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|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 020300007                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Manfred Bischoff                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 9. Dozenten:                                        | Manfred Bischoff                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 11. Empfohlene Voraussetzungen:                     | Computational Mechanics of Structures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 12. Lernziele:                                      | <p>The students understand the mechanical properties and load carrying behaviour of plates and shells. They know the concepts of membrane theory and shell theory involving bending. They are able to adequately check and interpret computational results and know how to handle the discrete quantities involved in shell finite elements. The students know the most important shell models (Kirchhoff/Love, Reissner/Mindlin) and corresponding finite element formulations along with their respective advantages and drawbacks. The students have some insight into the peculiar behaviour of shells in view of their imperfection sensitivity and their critical non-linear behaviour (snap-through and buckling). They know how to apply general purpose finite element packages to non-linear analysis of shells. Beyond specific knowledge on shells the students increase their awareness about the general necessity to master classical theories when utilizing modern computational methods.</p> |                |                |
| 13. Inhalt:                                         | <p>The course covers design and analysis of shells, membrane and shell theory as well as mathematical and computational models for analysis of shells. The theoretical contents is supplemented and exemplified with applications of commercial finite element software.</p> <ul style="list-style-type: none"> <li>• historical overview of shell theory</li> <li>• geometrical basics and load carrying behaviour</li> <li>• shell models, prerequisites and assumptions§ membrane theory, basic equations and analytical solutions for shells of revolution</li> <li>• computation of stress resultants and displacements§ bending theory, analytical solutions for cylindrical shells</li> <li>• computational models for shells with arbitrary geometry, shear deformable (Reissner/Mindlin) shell finite elements</li> <li>• non-linear analysis and stability</li> <li>• application of shell elements using commercial codes</li> </ul>                                                                |                |                |
| 14. Literatur:                                      | <ul style="list-style-type: none"> <li>• C.R. Calladine: Theory of Shell Structures. Cambridge University Press 1983.</li> <li>• H. Kraus: Thin Elastic Shells. Wiley, 1967.</li> <li>• P. Csonka: Theory and Practice of Membrane Shells. VDI Verlag, 1987.</li> <li>• M. Bischoff, K.-U. Bletzinger, W.A. Wall, E. Ramm: Models and Finite Elements for Thin-walled Structures. Encyclopedia of Computational Mechanics, Wiley, 2004.</li> <li>• lecture notes "Computational Methods for Shell Analysis", Institut für Baustatik und Baudynamik</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |

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|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"><li>• 687501 Vorlesung Computational Methods for Shell Analysis</li><li>• 687502 Übung Computational Methods for Shell Analysis</li></ul>                                                            |
| 16. Abschätzung Arbeitsaufwand:      |                                                                                                                                                                                                                                        |
| 17. Prüfungsnummer/n und -name:      | <ul style="list-style-type: none"><li>• 68751 Computational Methods for Shell Analysis (PL), Schriftlich, 120 Min., Gewichtung: 1</li><li>• V Vorleistung (USL-V), Sonstige</li></ul> Prerequisite: 3 approved, not graded assignments |
| 18. Grundlage für ... :              |                                                                                                                                                                                                                                        |
| 19. Medienform:                      |                                                                                                                                                                                                                                        |
| 20. Angeboten von:                   | Baustatik und Baudynamik                                                                                                                                                                                                               |

## Modul: 68770 Metals and Computational Materials Science

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|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr. Siegfried Schmauder                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 9. Dozenten:                                        | Siegfried Schmauder                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 11. Empfohlene Voraussetzungen:                     | Optimization of Mechanical Systems and Engineering Materials                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 12. Lernziele:                                      | <p><b>Metals</b><br/>The students are familiar with the macroscopic deformation behavior of metals. They are able to calculate the deformation behavior of simple structures. For the above mentioned calculations, they will also learn how to account the influential factors, e.g., notches, static and cyclic loadings and creep. The students will have fundamental knowledge to make a safety analysis of metal components.</p> <p><b>Computational Materials Science</b><br/>The students are familiar with the most common simulation techniques in material science. They will have the theoretical background to perform simulations on the atomistic, the microscopic and the macroscopic size level. The main applications of the simulation methods with respect to the different material groups are known by the students.</p>                                                                                                                                                                                                                                                                                  |                |                |
| 13. Inhalt:                                         | <p><b>Metals</b><br/>The first part is about the mechanical behavior, including strength calculation, loading modes and cyclic loading of materials. The second part is focused on stress states of materials under different deformation modes. The third part considers the notch effect on the stress calculations and the creep based on the visco-elastic material behavior. The last part describes the damage accumulation, the failure modes and the strength condition for the safety of structures.</p> <p><b>Computational Materials Science</b><br/>The theoretical foundations of Monte Carlo (MC), Molecular Dynamics (MD) and other advanced simulation techniques with respect to atomistic phenomena in computational materials science, such as, e.g., precipitation strengthening in steels. Another focus is put on dislocation theory including the dislocation dynamics and the applications for the understanding of the local deformation processes in metallic materials. Finite-Element-methods, crystal plasticity and damage mechanical modelling are further essential topics in this course.</p> |                |                |
| 14. Literatur:                                      | <p><b>Metals</b><br/>- Lecture specific manuscript and additional information given in internet (ILIAS).<br/>- Smallman, R. E., Bishop, R. J.: Metals and Materials - Science, Processes, Applications, Butterworth-Heinemann, Oxford (1995).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |

Computational Materials Science

- Lecture specific manuscript and additional information given in the internet (ILIAS).
- Raabe, D., Computational Materials Science, The Simulation of Materials Microstructures and Properties, Wiley-VHC, Weinheim (1998).
- Schmauder, S., Mishnaevsky Jr., L., Micromechanics and Nanosimulation of Metals and Composites, Advanced Methods and Theoretical Concepts, Springer-Verlag, Berlin-Heidelberg-New York (2009).

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| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"> <li>• 687701 Vorlesung Metalle</li> <li>• 687702 Übung Metalle</li> <li>• 687703 Vorlesung Computerorientierte Materialkunde</li> <li>• 687704 Übung Computerorientierte Materialkunde</li> </ul>                                                   |
| 16. Abschätzung Arbeitsaufwand:      | <p>Metals, Lecture und Exercise: 90 h (attendance: 28 h, self-study: 62 h)</p> <p>Computational Materials Science, Lecture und Exercise: 90 h (attendance: 28 h, self-study: 62 h)</p>                                                                                                 |
| 17. Prüfungsnummer/n und -name:      | <ul style="list-style-type: none"> <li>• 68771 Metals and Computational Materials Science (PL), Schriftlich, 120 Min., Gewichtung: 1</li> <li>• 68772 Computational Materials Science (USL), Sonstige, Gewichtung: 1</li> <li>• 68773 Metals (USL), Sonstige, Gewichtung: 1</li> </ul> |
| 18. Grundlage für ... :              |                                                                                                                                                                                                                                                                                        |
| 19. Medienform:                      |                                                                                                                                                                                                                                                                                        |
| 20. Angeboten von:                   | Materialprüfung, Werkstoffkunde und Festigkeitslehre                                                                                                                                                                                                                                   |

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## Modul: 68780 Micromechanics of Materials and Homogenization Methods

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|-----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021010021                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 9. Dozenten:                                        | Christian Miehe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 11. Empfohlene Voraussetzungen:                     | Computational Mechanics of Materials                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 12. Lernziele:                                      | The students have a working knowledge of the behavior and modeling of elastic and inelastic materials in the three dimensional context. They are familiar with phenomenological and micromechanics-based modeling approaches for the response of these materials. The students are further capable of performing numerical implementations of such models in the framework of the finite element method by using specific algorithmic schemes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 13. Inhalt:                                         | <p><i>The course advances the topics of the core course "Computational Mechanics of Materials". It is structured into the parts</i></p> <ul style="list-style-type: none"> <li><i>• computational mechanics of three-dimensional material models at small strains,</i></li> <li><i>• micro-mechanically-based material models,</i></li> <li><i>• homogenization methods,</i></li> <li><i>• computational mechanics of solid materials at large strains.</i></li> </ul> <p><i>Basic contents are thermodynamics of a general internal variable formulation of inelasticity at small strains, linear and nonlinear elasticity, finite element implementation of nonlinear elasticity, viscoelasticity, rate-independent and rate-dependent plasticity, micro-mechanically-based models of plasticity for crystalline solids, introduction to homogenization methods and micro-to-macro transitions, a general internal variable formulation of inelasticity at large strains, approaches to the modeling and numerics of finite elasticity and finite viscoelasticity.</i></p> |                |                |
| 14. Literatur:                                      | <p>Holzapfel, G. (2000): Nonlinear Solid Mechanics: A Continuum Approach for Engineering, Wiley und Sons.</p> <p>Wriggers, P. (2008): Nonlinear Finite Element Methods, Springer.</p> <p>Belytschko, T., Liu, W. K., Moran, B., Elkhodary, K. (2013): Nonlinear Finite Elements for Continua and Structures, Wiley und Sons.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 687801 Vorlesung Micromechanics of Materials and Homogenization Methods</li> <li>• 687802 Übung Micromechanics of Materials and Homogenization Methods</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | <p>Lecture: 108 h (attendance: 42 h, self-study: 66 h)</p> <p>Exercise: 72 h (attendance: 28 h, self-study: 44 h)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 17. Prüfungsnummer/n und -name:                     | <ul style="list-style-type: none"> <li>• 68781 Micromechanics of Materials and Homogenization Methods (PL), Schriftlich, 120 Min., Gewichtung: 1</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |

- 68782 Micromechanics of Materials and Homogenization Methods (USL), Sonstige, Gewichtung: 1
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18. Grundlage für ... :

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19. Medienform:

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20. Angeboten von:                      Mechanik (Bauwesen)

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## Modul: 68790 Numerical Modelling of Soils and Concrete Structures

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|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 020600013                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Christian Moormann                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 9. Dozenten:                                        | Christian Moormann<br>Josko Ozbolt                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 12. Lernziele:                                      | <p><b>Numerical Modelling of Soils</b><br/>The student knows about the elasto-plastic soil models and their use in FE analyses of geotechnical engineering. The first group of models to be considered consists of perfect-plasticity models, e.g. Drucker-Prager, Mohr-Coulomb and the failure model by Lade. In all these models the use of a non-associated flow rule is shown to be essential. The second group of models are Isotropic Hardening models that involve an expanding yield surface. Moreover, the time effect is included via introducing a creep model. Advantages and limitations will be clear as well as the selection of suitable input parameters from laboratory tests. The student knows fundamental information about viscous effects in soft soils and large deformations in soil mechanics.</p> <p><b>Numerical Modelling of Concrete Structures</b><br/>In the framework of the course the computational material models for detailed three dimensional numerical analysis of quasi-brittle materials, such as concrete, are discussed. Starting with a general introduction into linear and nonlinear fracture mechanics, material models such as damage, plasticity, smeared and discrete crack and microplane are discussed. Strong emphasis is placed on the application of these models to concrete and reinforced concrete structures. The topics of regularization techniques and adaptive remeshing are also presented. Finally, modeling of concrete under extreme loading conditions, such as impact and fire, and basic of durability mechanics, i.e. the interaction between mechanical and non-mechanical processes in concrete are discussed.</p> |                |                |
| 13. Inhalt:                                         | <p><b>Numerical Modelling of Soils</b></p> <ul style="list-style-type: none"> <li>- Perfect plasticity and density hardening of soils,</li> <li>- the density hardening cam clay model,</li> <li>- friction hardening of soils,</li> <li>- friction hardening with non-associated flow rule,</li> <li>- viscous effect and creep model,</li> <li>- hypoplastic model for granular materials,</li> <li>- large deformation formulation by MPM, CEL and ALE.</li> </ul> <p><b>Numerical Modelling of Concrete Structures</b><br/><i>Introduction and course organization</i></p> <ul style="list-style-type: none"> <li>- Course organization</li> <li>- Quasibrittle materials und motivation for nonlinear analysis</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |

*Concrete material properties*

- Review of concrete behavior in tension and compression
- Extension to 3D

*Modeling of concrete*

- Thermodynamic principles
- Basic frameworks for modeling of quasibrittle materials, Continuum/Combination continuum-discontinuum/Discrete

*Fracture mechanics*

- Linear Elastic Fracture Mechanics (LEFM), Griffith und Irwin
- Nonlinear Fracture Mechanics (NLFM), Discrete crack concept/ Smeared crack concept
- Size effect

*Plasticity models for concrete*

- Associated and non-associated flow
- Failure surfaces for quasibrittle materials

*Damage mechanics*

- Simple isotropic damage
- Mazar's damage model for concrete
- Other damage models

*"The Smeared Crack Models"*

- Fixed / Multi-direction fixed / Rotating
- Stress locking

*Microplane theory*

- Concept and fundamental equations
- Relaxation of kinematic constraint/Anisotropy/Model validation

*Objective modeling (regularization) and new developments*

- Crack band and higher order methods
- Adaptive meshing/Embedded discontinuity elements/X-FEM (Partition of Unity)

*Modeling steel and bond*

- Smeared vs. discrete bond

*Modeling of concrete under extreme conditions - impact and fire*

- Dynamic fracture
- Concrete exposed to high temperature

*Durability mechanics*

*Modeling steel and bond (optional)*

- Smeared vs. discrete bond

*Course summary*

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14. Literatur:

- Numerical Modelling of Soils
- Lecture notes can be downloaded from the internet (ILIAS)
- Numerical Modelling of Concrete Structures
- Jirasek, M. und Bazant, Z. P.: Inelastic Analysis of Structures, J. Wiley and Sons, New York, 2002
  - Karihaloo, B. L.: Fracture Mechanics und Structural Concrete, Concrete Design and Construction Series, Longman Scientific und Technical, 1995
  - Shah, S. P., Swartz, S. E. und Ouyang, C.: Fracture Mechanics of Concrete: Applications of Fracture Mechanics to Concrete, Rock and Other Quasi-Brittle Materials, J. Wiley und Sons, New York, 1995

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15. Lehrveranstaltungen und -formen:

- 687901 Vorlesung Numerische Modellierung von Böden
- 687902 Übung Numerische Modellierung von Betonstrukturen

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16. Abschätzung Arbeitsaufwand:

- Numerical Modelling of Soils: Lecture: 90 h (attendance: 28 h, self-study: 62 h)
- Numerical Modelling of Concrete Structures: Lecture: 90 h (attendance: 28 h, self-study: 62 h)
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17. Prüfungsnummer/n und -name:
- 68791 Numerical Modelling of Soils and Concrete Structures (PL), Schriftlich, 120 Min., Gewichtung: 1
  - 68792 Numerical Modelling of Soils (USL), Sonstige, Gewichtung: 1
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18. Grundlage für ... :

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19. Medienform:

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20. Angeboten von: Geotechnik

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## Modul: 68820 Visualization in Science and Engineering

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|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 051900015                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr. Daniel Weiskopf                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 9. Dozenten:                                        | Thomas Ertl<br>Daniel Weiskopf                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 3. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 12. Lernziele:                                      | <p>Students obtain a general overview of, and some basic knowledge about, visualization techniques, algorithms, and data structures as well as visual literacy and acquaintance with practical applications of visualization in science and engineering. Students become proficient with practical aspects in a hands-on fashion by using existing visualization tools and applying them to example data from typical science and engineering disciplines (e.g. computational fluid dynamics, scanning devices, etc.).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                |                |
| 13. Inhalt:                                         | <p>Visualization deals with all aspects that are connected with the visual representation of data sets from scientific experiments, simulations, medical scanners, and the like in order to achieve a deeper understanding or a simpler representation of complex phenomena. To achieve this goal, both well-known techniques from the field of interactive computer graphics and completely new methods are applied. This course covers basic knowledge and practical applications of visualization by discussing the following topics:</p> <ul style="list-style-type: none"> <li>• Introduction, historical remarks, visualization pipeline</li> <li>• Data acquisition and representation (sampling and reconstruction, grids and data structures)</li> <li>• Basic mapping concepts</li> <li>• Visualization of scalar fields (isosurface extraction, volume rendering)</li> <li>• Visualization of vector fields (particle tracing, texture-based methods, vector field topology)</li> <li>• Tensor fields, multi-attribute data, multi-field visualization</li> </ul> <p>Throughout the course, visualization methods are applied to practical examples from science and engineering, such as volumetric visualization of 3D data, flow data from computational fluid dynamics, scanner data, etc.</p> |                |                |
| 14. Literatur:                                      | <p>Course slides will be provided. Material and assignments for the exercises will be provided.</p> <p>Recommended books:</p> <ul style="list-style-type: none"> <li>• C.D. Hansen, C.R. Johnson (eds.): The Visualization Handbook, Elsevier, 2005.</li> <li>• C. Ware: Information Visualization, Morgan Kaufmann, 2nd edition, 2004.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |

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|--------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                      | <ul style="list-style-type: none"><li>• H. Schumann, W. Müller: Visualisierung. Grundlagen und allgemeine Methoden, Springer, 1999.</li></ul>                                                                                |
| 15. Lehrveranstaltungen und -formen: | <ul style="list-style-type: none"><li>• 688201 Vorlesung Visualization in Science and Engineering</li><li>• 688202 Übung Visualization in Science and Engineering</li></ul>                                                  |
| 16. Abschätzung Arbeitsaufwand:      | Lecture: 90h (attendance: 28h, self-study: 62h)<br>Excercises: 90h (attendance: 21h, self-study: 69h)                                                                                                                        |
| 17. Prüfungsnummer/n und -name:      | <ul style="list-style-type: none"><li>• 68821 Visualization in Science and Engineering (PL), Schriftlich oder Mündlich, Gewichtung: 1</li><li>• V Vorleistung (USL-V), Sonstige written (90 min), or oral (30 min)</li></ul> |
| 18. Grundlage für ... :              |                                                                                                                                                                                                                              |
| 19. Medienform:                      |                                                                                                                                                                                                                              |
| 20. Angeboten von:                   | Visualisierung und Interaktive Systeme                                                                                                                                                                                       |

## Modul: 68890 Foundations of Continuum Thermodynamics for Single- and Multiphasic Materials

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
|-----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021020021                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 6. Turnus:     | Sommersemester |
| 4. SWS:                                             | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Univ.-Prof. Dr.-Ing. Holger Steeb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                |                |
| 9. Dozenten:                                        | Wolfgang Ehlers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, 2. Semester<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 11. Empfohlene Voraussetzungen:                     | Continuum Mechanics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 12. Lernziele:                                      | The students are able to apply continuum-thermodynamical methods to the description of single- and multiphasic materials                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 13. Inhalt:                                         | <p>The lecture offers the following content:</p> <p>Foundations of Thermodynamics for Singlephasic Materials:</p> <ul style="list-style-type: none"> <li>• Thermodynamic Balance Laws: Balance of energy, entropy inequality, thermodynamic potentials, application to finite thermoelasticity</li> <li>• Geometrically Linear Thermoelasticity: Linearisation of the finite problem, inversion of the linear law of thermoelasticity, determination of material parameters</li> <li>• Geometrically Linear Viscoelasticity: Motivation and basic model rheology, the standard model of viscoelasticity (Poynting-Thomson model), Clausius-Planck inequality and internal dissipation, the viscoelastic solid</li> <li>• Geometrically Linear Elasto-Plasticity: Motivation and basic model rheology, metal plasticity, generalised and geomaterials plasticity</li> </ul> <p>Foundations of Thermodynamics for Multiphasic Materials:</p> <ul style="list-style-type: none"> <li>• Hydraulics in Porous Materials: Basic concepts, mechanical balance relations, constitutive equations, Darcy's filter law</li> </ul> |                |                |
| 14. Literatur:                                      | <p>P. Chadwick [2012], Continuum Mechanics: Concise Theory and Problems, Dover Publications.</p> <p>W. Ehlers [each WT, ST], An Introduction to Vector and Tensor Calculus, <a href="http://www.mechbau.uni-stuttgart.de/ls2/Downloads/vektortensorskript_eng_ws1314.pdf">http://www.mechbau.uni-stuttgart.de/ls2/Downloads/vektortensorskript_eng_ws1314.pdf</a>.</p> <p>M. E. Gurtin [1981], An Introduction to Continuum Mechanics, Academic Press.</p> <p>P. Haupt [2013], Continuum Mechanics and Theory of Materials, Science and Business Media.</p> <p>G. H. Holzapfel [2000], Nonlinear Solid Mechanics, John Wiley und Sons.</p> <p>L. E. Malvern [1969], Introduction to the Mechanics of a Continuous Medium, Prentice-Hall.</p>                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 688901 Vorlesung Grundlagen der Kontinuumsthermodynamik für Ein- und Mehrphasenmaterialien</li> <li>• 688902 Übung Grundlagen der Kontinuumsthermodynamik für Ein- und Mehrphasenmaterialien</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |

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|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 16. Abschätzung Arbeitsaufwand: | Lecture: 108 h (attendance: 42 h, self-study: 66 h)<br>Exercise: 72 h (attendance: 28 h, self-study: 44 h)                                                                                                                                                                                                                                                                                                                            |
| 17. Prüfungsnummer/n und -name: | <ul style="list-style-type: none"><li>• 68891 Foundations of Continuum Thermodynamics for Single- and Multiphasic Materials (PL), Schriftlich, 120 Min., Gewichtung: 1</li><li>• 68892 Foundations of Continuum Thermodynamics for Single- and Multiphasic Materials (USL), Schriftlich, Gewichtung: 1</li></ul> written examination (120 minutes) in "Foundations of Continuum Thermodynamics for Single- and Multiphasic Materials" |
| 18. Grundlage für ... :         |                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 19. Medienform:                 |                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 20. Angeboten von:              | Mechanik II                                                                                                                                                                                                                                                                                                                                                                                                                           |

## Modul: 69460 Computational contact mechanics

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 6 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Anton Tkachuk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 9. Dozenten:                                        | Anton Tkachuk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016,<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 11. Empfohlene Voraussetzungen:                     | Computational Mechanics of Structures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |
| 12. Lernziele:                                      | This course describes formulations, methods and algorithms of contact mechanics. It covers penalty, Lagrange and Nitsche formulations for weak forms, Node-to-Node, Node-to-Segment and Segment-to-Segment spatial discretization of contact terms, local and global search algorithms, friction and application to quasi-static and dynamic problems. The students learn to solve contact problems, how to skilfully choose the solution methods, interpret results of contact simulations and avoid problems with convergence. Furthermore, the students understand details of the implementation and performance of contact algorithms. |                |                |
| 13. Inhalt:                                         | <ul style="list-style-type: none"> <li>• Introduction to kinematics of contact, Signorini conditions</li> <li>• Weak and strong forms of a contact problem</li> <li>• Spatial discretization</li> <li>• Global and local contact search</li> <li>• Global solution algorithms: active set and complementarity algorithms</li> <li>• Treatment of contact for explicit time integration</li> <li>• Treatment of contact with implicit time integration</li> <li>• Mesh tying techniques</li> </ul>                                                                                                                                          |                |                |
| 14. Literatur:                                      | <ul style="list-style-type: none"> <li>• slides</li> <li>• additional material (Maple worksheets, Ansys examples)</li> <li>• textbook (Wriggers, "Computational contact mechanics")</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 694601 Vorlesung Computational contact mechanics</li> <li>• 694602 Übung Computational contact mechanics</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 16. Abschätzung Arbeitsaufwand:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 17. Prüfungsnummer/n und -name:                     | <ul style="list-style-type: none"> <li>• 69461 Computational contact mechanics (PL), Schriftlich, 120 Min., Gewichtung: 1</li> <li>• V Vorleistung (USL-V), Schriftlich oder Mündlich</li> </ul> Prerequisite: 3 approved, not graded assignments                                                                                                                                                                                                                                                                                                                                                                                          |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 20. Angeboten von:                                  | Baustatik und Baudynamik                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |



## Modul: 72120 Modeling of connections between steel and concrete

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|-----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | 021500631                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 3 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 7. Sprache:    | Englisch       |
| 8. Modulverantwortlicher:                           | Akanshu Sharma                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 9. Dozenten:                                        | Akanshu Sharma                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016,<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                |                |
| 11. Empfohlene Voraussetzungen:                     | Reinforced concrete design                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                |                |
| 12. Lernziele:                                      | <p>The students will learn the basic principles as well as methods for modeling the connection between steel and concrete.</p> <p>The two categories will be targeted: (i) bond between reinforcement and concrete, and (ii) Anchorage in concrete construction</p>                                                                                                                                                                                                                                                                                                                                                                            |                |                |
| 13. Inhalt:                                         | <p>The following topics will be covered:</p> <ul style="list-style-type: none"> <li>• Bond between reinforcement and concrete (Behavior of bond between reinforcement and concrete, Analytical methods and models in International standards, Spring based models and applications, 3D Finite Element models and applications)</li> <li>• Anchorage in concrete construction (Basic principles of load transfer from anchorage to concrete, Analytical methods and models in International standards, Anchorages with supplementary reinforcement, Spring based models and applications, 3D Finite element models and applications)</li> </ul> |                |                |
| 14. Literatur:                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 15. Lehrveranstaltungen und -formen:                | <ul style="list-style-type: none"> <li>• 721201 Vorlesung Modeling of connections between steel and concrete</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | <p>Attendance time: 42 h</p> <p>Private study: 48 h</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                |                |
| 17. Prüfungsnummer/n und -name:                     | 72121 Modeling of connections between steel and concrete (BSL), ,<br>Gewichtung: 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 20. Angeboten von:                                  | Befestigungstechnik und Verstärkungsmethoden                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |

## Modul: 72130 Behavior and design of structures against natural and man-made hazards

|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
|-----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| 2. Modulkürzel:                                     | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 5. Moduldauer: | Einsemestrig   |
| 3. Leistungspunkte:                                 | 3 LP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 6. Turnus:     | Wintersemester |
| 4. SWS:                                             | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 7. Sprache:    | Englisch       |
|                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 8. Modulverantwortlicher:                           | Akanshu Sharma                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 9. Dozenten:                                        | Akanshu Sharma                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016,<br>→ Elective Modules                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                |                |
| 11. Empfohlene Voraussetzungen:                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 12. Lernziele:                                      | The students will learn advanced aspects of the behavior and design of reinforced concrete structures against natural and man-made hazards namely, earthquakes, impact and fire.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                |                |
| 13. Inhalt:                                         | <p>The following topics will be covered:</p> <p>Important aspects in hazard engineering applied to reinforced concrete structures</p> <p>Behavior and design against seismic loads: Basics of structural dynamics, inelastic behavior of structures, seismic demand, structural capacity, performance based analysis and design of structures</p> <p>Behavior and design against impact loads: Dynamic fracture behavior of concrete, concept of inertia and rate sensitivity, dynamic behavior of structural elements</p> <p>Behavior and design against fire loads: Temperature dependent material behavior of concrete and reinforcement, bond behavior under fire, behavior and design of structural elements under fire, structural fire rating, explosive spalling</p> |                |                |
| 14. Literatur:                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 15. Lehrveranstaltungen und -formen:                | • 721301 Vorlesung Engineering Concrete Structures against Hazards                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                |                |
| 16. Abschätzung Arbeitsaufwand:                     | Attendance time: 42h<br>Private study: 48h                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                |                |
| 17. Prüfungsnummer/n und -name:                     | 72131 Engineering Concrete Structures against Hazards (BSL), Schriftlich oder Mündlich, 60 Min., Gewichtung: 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                |                |
| 18. Grundlage für ... :                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 19. Medienform:                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| 20. Angeboten von:                                  | Befestigungstechnik und Verstärkungsmethoden                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                |                |

**Modul: 81460 Masterarbeit COMMAS**

|                                                     |                                                                         |                |                                   |
|-----------------------------------------------------|-------------------------------------------------------------------------|----------------|-----------------------------------|
| 2. Modulkürzel:                                     | 073100103                                                               | 5. Moduldauer: | Zweisemestrig                     |
| 3. Leistungspunkte:                                 | 30 LP                                                                   | 6. Turnus:     | Wintersemester/<br>Sommersemester |
| 4. SWS:                                             | 0                                                                       | 7. Sprache:    | Deutsch                           |
| 8. Modulverantwortlicher:                           | Jun.-Prof. Dr.-Ing. Marc-André Keip                                     |                |                                   |
| 9. Dozenten:                                        |                                                                         |                |                                   |
| 10. Zuordnung zum Curriculum in diesem Studiengang: | M.Sc. Computational Mechanics of Materials and Structures, PO 921-2016, |                |                                   |
| 11. Empfohlene Voraussetzungen:                     |                                                                         |                |                                   |
| 12. Lernziele:                                      |                                                                         |                |                                   |
| 13. Inhalt:                                         |                                                                         |                |                                   |
| 14. Literatur:                                      |                                                                         |                |                                   |
| 15. Lehrveranstaltungen und -formen:                |                                                                         |                |                                   |
| 16. Abschätzung Arbeitsaufwand:                     |                                                                         |                |                                   |
| 17. Prüfungsnummer/n und -name:                     |                                                                         |                |                                   |
| 18. Grundlage für ... :                             |                                                                         |                |                                   |
| 19. Medienform:                                     |                                                                         |                |                                   |
| 20. Angeboten von:                                  | Mechanik (Bauwesen)                                                     |                |                                   |