R A K E N T E I D E N   M E K A N I I K K A

Journal of Structural Mechanics

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Special issue for the Journal of Structural Mechanics 50 years anniversary seminar 24-25.8.2017, University of Vaasa

Edited by Tero Frondelius, Reijo Kouhia, Marko Matikainen, Jari Mäkinen, Antti Niemi, Jarkko Niiranen, Tero Tuovinen and Lauri Uotinen

SISÄLTÖ

Rakenteiden Mekaniikka – Journal of Structural Mechanics, Vol. 50, 2017, No 3.

Preface

This issue contains papers of lectures presented at the journal's 50-years anniversary seminar, at Vaasa University on 24-25 August 2017. The objective of this conference is to stimulate and promote research and applications within the area of solid mechanics, fluid mechanics and mathematical problems related to mechanics and especially to strengthen the collaboration between industry and academia. This kind of a seminar provides an ideal forum for researchers, designers, teachers and other professionals to network, discuss and share ideas and information.

Sincere thanks go to all of the authors and participants for making the meeting a stimulating occasion. This issue contains abstracts of the five invited plenary talks and 57 peer reviewed extended abstracts. As a total, 72 talks will be given at the conference. The five invited plenary speakers are Dr. Pauli Jumppanen, the founding editor of the journal, Professor Claes Johnson from The Royal Institute of Technology, Sweden, Professor Anders Klarbring, Linköping University, Sweden, Professor Aki Mikkola, Lappeenranta University of Technology and General Manager, Analysis, Hannu Tienhaara, Wärtsilä Finland Oy. Especially, thanks to all of our collaborators: Wärtsilä Finland Oy, ABB Oy, AGCO POWER, Avant Tecno Oy, Comsol Oy, EDR&Medeso, Federation of Finnish Learned Societies, FEMdata, Finnish Association of Civil Engineers RIL, Global Boiler Works Oy, Pressus Oy, Ramboll Finland Oy, Valmet Oyj and Vertex Systems Oy, whose support was indispensable for the organisation of this conference. Finally, we thank all the reviewers for their important anonymous contribution under a very strict time constraint.

August 2017

Editors

Organizing committee

This seminar celebrating the fifty years history of the journal *Rakenteiden Mekaniikka - Journal of Structural Mechanics* is organized by the Finnish Association for Structural Mechanics together with Aalto University, Lappeenranta University of Technology, Tampere University of Technology, University of Jyväskylä and University of Oulu. The members of the organizing committee are:

- Reijo Kouhia, Tampere University of Technology, chairman
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Rakenteiden Mekaniikka (Journal of Structural Mechanics)
Vol. 50, No 3, 2017

Historical aspects and milestones in the development of structural mechanics in Finland

Pauli Jumppanen

Summary. Engineering education began in Finland by the establishment of the Technical School of Helsinki in 1849. In 1879, the School was renamed the Polytechnic Institute, and made in 1908 a university-level institute called the Technological University of Finland. In the early 19th century, chemical and mechanical engineering, architecture, surveying, and water construction were important topics in the education. Teaching of bridge building and building statics started in 1920's, and were developed into a top level by the scientific staff of the state airplane industry unit after the Second World War. This made statics of buildings and strength of materials to become popular fields of technology among the students and researchers, which resulted in the establishment of the Journal of Structural Mechanics in 1968, followed by foundation of the Finnish Association for Structural Mechanics two years later. Since then, structural mechanics has found a large number of new applications in various fields of engineering. This has extended, correspondingly, the list of scientific topics discussed in the Journal of Structural Mechanics, such as thermo-mechanics, rock mechanics, biomechanics, intelligent structures, etc. Requirements on increased safety of structures and systems, sustainable use of resources, and the use of innovative technologies will continue to create future challenges and opportunities for the development of new applications in structural mechanics for several decades to come.

Rakenteiden Mekaniikka (Journal of Structural Mechanics)
Vol. 50, No 3, 2017

Structural mechanics of the atom

Claes Johnson

Summary. We present a new atom model in terms of classical continuum mechanics in three space dimensions as a system of Schrödinger equations for a collection of one-electron wave functions with non-overlapping supports, expressing stationarity of a total energy as the sum of potential and kinetic energies, combined with a Bernouilli free boundary condition asking continuity and vanishing normal derivative of electronic wave functions across inter-electron boundaries. The model is referred to as realQM signifying that it is (i) deterministic, (ii) computable, (iii) has a direct physical meaning in terms of distributed non-overlapping one-electron charge densities. We compute ground states as minimisers of the total energy and find good agreement with observations. We compare with standard text book quantum mechanics (stdQM) which is (i) probabilistic, (ii) uncomputable and (iii) non-physical.

https://dl.dropboxusercontent.com/u/26550356/realQMpresentation.pdf

Rakenteiden Mekaniikka (Journal of Structural Mechanics)
Vol. 50, No 3, 2017

Robust structural topology optimization and game theory

Carl-Johan Thore, Henrik Alm Grundström, Erik Holmberg and **Anders Klarbring**

Summary. Robust structural optimization can be formulated as a two(or more)-person mathematical game between a ”designer”, trying to achieve a structure which is optimal in some sense, and ”nature”, seeking the worst possible conditions to impose on the structure. For the special case of structural topology optimization (TO) under load uncertainty, the designer solves a standard TO problem for a fixed load – the ”design-problem” – while nature solves another optimization problem – the ”load-problem” – to find the worst load for a given design. Choosing the compliance as the objective function for both players one can consider either a min-max (or Stackelberg) formulation or a Nash game. The focus here is on the latter type, and in particular, we study the use of so-called decomposition methods to obtain numerical solutions. When applied to our Nash game, such methods solve the design- and the load-problem in an alternating sequence, hopefully converging to a Nash equilibrium (consisting of a load(s) and an optimized structure that is robust in the sense that it performs no worse for any other load realizable in the game). Decomposition methods for finding Nash equilibria are attractive since they are very easy to implement and may allow for straightforward parallelization. However, there are at least two major issues that must be dealt with: (i) existence of Nash equilibria, and (ii), when existence is assured, convergence to such points. We show here using numerical examples with trusses and discretized continuum structures that, when equilibria exist, convergence can be achieved, but sometimes requiring penalization of design and load variations to avoid oscillatory behavior of the decomposition method. We also give examples that seem to lack equilibria – or at least where the robust design obtained from the corresponding min-max formulation is not an equilibrium-design – leading to non-convergence of the algorithm.

Rakenteiden Mekaniikka (Journal of Structural Mechanics)
Vol. 50, No 3, 2017

SIM-platform - Sustainable product processes through real-time simulations

Aki Mikkola

Summary. The use of modern simulation techniques enables the description of complex products such as mobile machinery with a high level of detail while still solving the equations of motion in real-time. This technology has been utilized in user training and, more recently, in product development. For product development, real-time simulation makes it possible to account for the machine user and their needs early on in co-creation in the concept development phase.

SIM-platform, established in Lappeenranta University of Technology, takes simulator-driven design methodologies to the next level by developing and evaluating a number of community-based real-time simulator-driven processes. The primary focus of the evaluation efforts is to improve the effectiveness, customer value, and business potential of each process. By providing fully configurable, real-time, physics-based virtual prototyping environment, SIM-platform increases visibility and access to information in the areas of R&D, production planning, and customer services for all stakeholders.

Access of multiple actors along the product lifecycle to product or production related data which is produced during design, manufacturing or usage and maintenance phases, enhances the possibilities for creating new business models and for increasing the competitiveness of existing design and manufacturing processes. The integration of data, novel materials and virtual technologies enables utilization of knowledge to improve the development and traceability of processes, machines and end products to meet versatile customer demands as well as environmental and other requirements. The inclusion of customers and suppliers in different stages of the product lifecycle can have profound effects on the business models of the actors in the value network. Researching the business potential of the new proposed solutions and measuring the impact on productivity and value creation is a key activity of the platform.

Rakenteiden Mekaniikka (Journal of Structural Mechanics)
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Fifty years of structural mechanics and simulation in Wärtsilä

Hannu Tienhaara

Summary. Wärtsilä has a long history of utilizing calculations and simulations for verifying structural durability of engine designs. This presentation discusses, with few examples, the main development steps of calculation methodologies and capabilities, as well as the main method development projects during the past decades. Some examples are shown on different Wärtsilä engines, starting from Vasa22 engine in early 1970's, and ending to the world record engine Wärtsilä 31 introduced in 2015. Also a review of the computing capacity is given, starting from 1980 when the first computer for structural calculations were bought. Since then Wärtsilä has invested regularly on simulation and been one of the simulation forerunners in Finland.

An important driver for the method development is the continuously increasing demand of higher performance and output power of engines, while the structures must be kept as light as possible still not sacrificing the reliability. Due to its complicated dynamic force system, a running reciprocating engine is a vibrating machine by nature. This in turn, has forced Wärtsilä to take a strong focus on developing engine dynamics simulation methods and fatigue calculation theories. Development has quite often been run through projects, either internal or publicly funded. Also different regulations for e.g. emissions, noise and vibration, have a role in guiding the development. Starting CFD-calculations in 1990's enabled the development of combustion simulation, which had a great influence on reaching higher performance and lower emissions levels.

Finally, a glance on the current development activities is given, and in order to cover the full 50 years, a view for the few coming years.

List of contributed papers

Thursday 24.8.2017

Plenary I 8:40-10:10

- **Pauli Jumppanen**; Historical aspects and milestones in the development of structural mechanics in Finland
- **Claes Johnson**; Structural mechanics of the atom
- **Anders Klarbring**; Robust structural topology optimization and game theory

Session 1A: Fatigue 1 – analysis and modelling 10:40-12:20

- **Asko Kumpula**, Joona Vaara, Anton Leppänen, Tero Frondelius; Nodular cast iron Onera fatigue model fitting
- **Anton Leppänen**, Asko Kumpula, Joona Vaara, Massimo Cattarinussi, Juho Könnö, Tero Frondelius; Thermomechanical fatigue analysis of cylinder head
- **Miikka Väntänen**, Joona Vaara, Jukka Aho, Jukka Kemppainen, Tero Frondelius; Bayesian sequential experimental design for fatigue tests
- **Joona Vaara**, Antti Mäntylä, Tero Frondelius; Brief review on high-cycle fatigue with focus on non-metallic inclusions and forming
- Joonas Jussila, Sami Holopainen, Terhi Kaarakka, **Reijo Kouhia**, Jari Mäkinen, Heikki Orelma, Niels Saabye Ottosen, Matti Ristinmaa, Timo Saksala, A new paradigm for fatigue analysis - evolution equation based continuum approach

Session 1B: Experimental mechanics 10:40-12:20

- **Jukka Aho**, Tero Frondelius; Analyzing 3 TB Field measurement data set
- **Pasi Halla-aho**, Antti Mäntylä, Tero Frondelius, Tommi Helander, Juha Hautala; Counterweight measurements device development
- **Diana Burdiel**, Carlo Pestelli, Moreno Almerigogna, Alan Pettirosso, Heikki Mikonaho, Teemu Kuivaniemi, Tero Frondelius; Matching simulated and measured eigen frequencies of medium speed diesel engine
- **Tommi Helander**; Pyörivien laitteiden etävalvonta/Remote condition monitoring of rotating machinery
- **Seppo Moilanen**, Ville Lehtinen; Suurikaliiperisten aseiden tuliputkien pyörrevirta-tarkastuksen ja ultraäänitarkastuksen mekanisoinnin kehitys ja toteutus

Session 1C: Optimization 10:40-12:20

- **Timo Turkkila**; Topology optimization of cast iron parts
- **Joni Keski-Rahkonen**; Probabilistic framework for product design optimization
- **Evgeniya Kiseleva**, Juho Könnö, Niclas Liljenfeldt, Teemu Kuivaniemi, Tero Frondelius; Topology optimisation of In-line engine turbocharger bracket
- **Károly Jármai**; Optimum design of welded structures
- **Teemu Tiainen**, Kristo Mela; Kaksivaiheinen menettely epälineaarisen diskreetin teräsrakenteiden optimointitehtävän ratkaisemiseksi

Plenary 2 13.20 – 14.30

- **Aki Mikkola**; SIM-platform - Sustainable product processes through real-time simulations
- **Hannu Tienhaara**; Fifty years of structural mechanics and simulation in Wärtsilä

Session 2A: Computational methods in industry 15:00-16:20

- **Antti Korpela**, Marko Jokinen, Teemu Kuivaniemi, Tero Frondelius; W4L20 VEBIC genset dynamics baseframe design
- **Jussi Göös**, Antti Mäntylä, Anton Leppänen, Tero Frondelius; Large bore connecting rod simulations
- **Ilkka Väisänen**, Antti Mäntylä, Antti Korpela, Tero Frondelius; Medium speed engine crankshaft analysis
- **Teemu Kuivaniemi**, Antti Mäntylä, Ilkka Väisänen, Antti Korpela, Tero Frondelius; Dynamic gear wheel simulations using multibody dynamics

Session 2B: Fretting fatigue modeling and measurements 15:00-16:20

- Jouko Hintikka, Janne Juoksukangas, **Arto Lehtovaara**, Tero Frondelius, Antti Mäntylä; Non-idealities in fretting contacts
- **Antti Mäntylä**, Jussi Göös, Anton Leppänen, Tero Frondelius; Large bore engine connecting rod fretting analysis
- **Jouko Hintikka**, Arto Lehtovaara, Tero Frondelius, Antti Mäntylä; Tangential traction instability in fretting contact below fully developed friction load
- **Juho Niva**; Fretting-säröjen etenemisen tutkiminen murtumismekaniikan avulla

Session 2C: Models, methods and applications of structural analysis 1 15:00-16:20

- **Timo Björk**, Niko Tuominen, Antti Ahola; X-liitoksen vinoutumisnurjahdus
- **Markku Raiskila**, Joona Tuikka; IFC- tiedostomuodon käyttö FEM- mallinnuksessa
- **Jouni Freund**; Two-scale Reissner-Mindlin plate model
- **Jarkko Niiranen**, Sergei Khakalo, Viacheslav Balobanov; Isogeometric finite element analysis of mode I cracks within strain gradient elasticity

Friday 25.8.2017

Session 3A: Models, methods and applications of structural analysis 2 8:40-10:20

- **Tero Frondelius**, Jukka Aho; JuliaFEM - open source solver for both industrial and academic usage
- **Jarno Jokinen**, Mikko Kanerva; Sensitivity analysis for simulated testing of composites: mapping via Isight and Abaqus
- **Mika Malinen**; Shell finite elements: implementation with Elmer software
- **Marja Rapo**, Jukka Aho, Tero Frondelius; Natural frequency calculations with JuliaFEM
- **Timo Saksala**; Numerical modelling of rock materials with polygonal finite elements

Session 3B: Mathematical methods in mechanics 8:40-10:20

- **Mikael Nyberg**, Antti Mäntylä, Tero Frondelius; Explosion simulation of pressurized components
- **Juhani Taipale**; Rakennejärjestelmän toisen asteen tekijöiden luotettavuusteoreettinen yhteisvaikutusanalyysi
- **Juuso Nänimäinen,** Structural simulation as a part of a whole product's systems level simulation
- **Juuso Nänimäinen,** IoT-Based Predictive Maintenance with Digital Twins Using Engineering Simulatio
- **Reijo Karvinen**, Effects of non-uniform heat transfer in a tempering process on glass quality

Session 3C: Fatigue 2 - structural and testing 8:40-10:20

- **Ilkka Valkonen**, Antti Valkonen: Tuotantokäyttöön soveltuva edullinen menetelmä hitsin juuren puolen väsymiseliniän arvioimiseksi
- **Antti Ahola**, Heli Mettänen, Timo Björk; Kuormitustavan ja symmetrisyyden vaikutus kuormaa kantamattomien hitsausliitosten väsymiseen – tehollisen lovijännityksen ja murtumismekaniikan menetelmien vertailu
- **Jussi Korhonen**, Antti Mäntylä. Juho Könnö, Tero Frondelius; Full scale fatigue testing of crankshaft
- Jussi Korhonen, **Juha Kuoppala**, Miikka Väntänen, Joona Vaara, Mikko Turunen, Panu Kämäräinen, Jarkko Laine, Aulis Silvonen, Tero Frondelius: QT steel high cycle fatigue testing with ultrasonic

Session 4A: Multi scale modelling of materials 10:50-12:10

- Tomas Their, **Luc St-Pierre**, Stiffness and strength of a semi-regular lattice
- **Stefania Fortino**, Merja Sippola, Tom Andersson, Kirsi Immonen, Arttu Miettinen, Petr Hradil; X-ray micro-tomography based FEM modelling of hygroexpansion in PLA composites reinforced with birch pulp fibers
- Merja Sippola, **Anssi Laukkanen**, Tom Andersson, Matti Lindroos; Microstructural modelling of materials
- **Anssi Laukkanen**, Matti Lindroos, Tom Andersson, Tuukka Verho, Tatu Pinomaa; Micromechanical modeling of failure behavior of metallic materials

Session 4B: Dynamics 10:50-12:10

- **Liang Bai**, Teemu Kuivaniemi, Pasi Halla-aho, Tero Frondelius; Elastohydrodynamic simulation of the slider bearing
- **Matti Lindstedt**; Combined mesh and frame motion for fast transient CFD simulation of rotating machines
- Tapani Kukkola, **Pentti Varpasuo;** Fortum contribution to the Iris phase 3 benchmark study
- Pekka Salmenperä, Robert Hildebrand, **Riku Varis**; Ratapenkereen värähtelyriski nopeuden noustessa

Session 4C: Structural mechanics 1 10:50-12:10

- **Antti-Jussi Vuotikka**, Mikael Nyberg, Heikki Karhinen and Tero Frondelius; Contact sealing simulation of high pressured diesel injector
- **Antti H. Niemi**, Jani Koskela, Filip Fedorik; Evaluation of some harmonic load models for the vibration analysis of footbridges.
- **Tuomo Poutanen**, Rakenteiden mekaniikka Eurokoodeissa

Session 5A: Design approaches 13:00-14:40

- **Kai Katajamäki**; Automatic simulation platform to support product design and optimization
- **Erin Kom**i, Petteri Kokkonen; Design approaches for additive manufactured components, with a focus on selective laser melting
- **Massimo Cattarinuss**i, Anton Leppänen, Juho Könnö, Tero Frondelius; Cylinder head design of experiment by using the Wärtsilä Digital Design Platform
- **Johannes Heilala**, Teemu Kuivaniemi, Juho Könno, Tero Frondelius; Calculation tool for dynamics of generator set common baseframe
- **J. Könnö**, H. Tienhaara, T. Frondelius; Wärtsilä digital design platform

Session 5B: Electromechanics 13:00-14:40

- **Anouar Belahcen**; Stress Effect on magnetostriction measurement in electrical sheets under rotational magnetization
- **Janne Keränen**, Pavel Ponomarev, Sabin Sathyan, Juhani Kataja, Anouar Belahcen; Magneto-structural simulation of an induction motor start-up using nodal magnetic forces in Elmer
- Juan Chowdhury, Gaurav Kumar, **Karuna Kalita**, Kari Tammi, Sashindra K. Kakoty; A brief overview on linear switched reluctance Motor
- Deepak Singh, Kati Mökkönen, Jarmo Poutala, **Paavo Rasilo**, Anouar Belahcen, Reijo Kouhia; Preliminary results on the effect of plastic deformation on magnetic properties
- **Siavash Danaee**, Reijo Kouhia, Paavo Rasilo, Anouar Belahcen, Deepak Singh, Matti Ristinmaa; A model for magneto-elastic behaviour

Session 5C: Structural mechanics 2 13:00-14:40

- Marsel Garifullin, Jarmo Havula, Sami Pajunen, Kristo Mela, **Markku Heinisuo**; Initial in-plane rotational stiffness of welded rectangular hollow section T joints with axial force at the main member
- **Mohammad Dabir**i, Mehran Ghafouri, Timo Björk; Estimation of stress concentration factors in butt and T-welded joints using artificial neural network-based models
- **Teemu Peltoniemi**; Ultralujan teräksen hitsiliitoksen äärikestävyys
- **Pentti Varpasuo**, Timo Kirkkomäki; Imatran vesivoimalaitos, koneisto nro 7, generaattorin perustusten korjaus

RM50 Seminar – Program at glance

Wednesday, 23.8.2017

18:00-21:00	**Pre-registration and get-together party, restaurant Wazaca,** Hovioikeudenpuistikko 18

Thursday, 24.8.2017

8:00-8.30	**Registration**		
8:30-8:40	**Avaus – Opening Erkki Antila,** Professor emeritus, University of Vaasa		
8:40-10:10	Plenary I Chair: **R. Kouhia**		
10:10-10:40	**Coffee**		
10:40-12:20	1A: Fatigue 1 Chair: **T. Björk** Asst: S. Abe	1B: Experimental mech. Chair: **M. Heinisuo** Asst: S. Danaee	1C: Optimization Chair: **T. Tuovinen** Asst: M. Pressacco
12:20-13:20	**Lunch at restaurant Mathilda,** Tervahovi building		
13:20-14:30	Plenary II Chair: **J. Mäkinen**		
14:30-15:00	**Coffee**		
15:00-16:20	2A: Comp. meth. industry Chair: **T. Frondelius** Asst: S. Abe	2B: Fretting fatigue Chair: **A. Lehtovaara** Asst: M. Pressacco	2C: Structural analysis 1 Chair: **J. Niiranen, A. Niemi** Asst: S. Danaee
16:40-	**Excursion to VEBIC**		
20:00-24.00	**Banquet at restaurant Bacchus-Swedish Club,** Rantakatu 4		

Friday, 25.8.2017

8:40-10:20	3A: Structural analysis 2 Chair: **J. Niiranen, A. Niemi** Asst: M. Pressacco	3B: Mathematical Methods Chair: **H. Orelma** Asst: S. Danaee	3C: Fatigue 2 Chair: **R. Kouhia** Asst: S. Abe
10:20-10:50	**Coffee**		
10:50-12:10	4A: Multiscale modelling Chair: **A. Laukkanen, S. Fortino** Asst: S. Abe	4B: Dynamics Chair: **T. Saksala** Asst: M. Pressacco	4C: Structural mechanics 1 Chair: **J. Könnö** Asst: S. Danaee
12:10-13:00	**Lunch at restaurant Mathilda,** Tervahovi building		
13:00-14:40	5A: Design approaches Chair: **J. Hintikka** Asst: S. Abe	5B: Electromechanics Chair: **A. Belahcen, K. Tammi** Asst: S. Danaee	5C: Structural mechanics 2 Chair: **J. Heinonen** Asst: M. Pressacco
14:40-14:50	**Closing - T. Frondelius**		
14:50-15:20	**Coffee**		
15:20	Bus to the railway station		

Plenaries and A Sessions (White Sessions) in F118 Syrenius F = Fabriikki
B Sessions (Blue Sessions) in F250 LähiTapiola
C Sessions (Yellow Sessions) in F251 OP-Pohjola