Short presentation of research projects supported by the Croatian Science Foundation.

- **Research projects that are running at the Faculty of Engineering, University of Rijeka**

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Principal Investigator: Gordan Jelenic
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Principal Investigator: Ivica Kozar
∗9068 - MULTI-SCALE CONCRETE MODEL WITH PARAMETER IDENTIFICATION

Principal Investigator: Dragan Ribaric
*4775 - ASSUMED STRAIN METHOD IN FINITE ELEMENTS FOR LAYERED PLATES AND SHELLS WITH APPLICATION ON LAYER DELAMINATION PROBLEM

This research has been fully supported by Croatian Science Foundation under the project 6876.

ASSESSMENT OF STRUCTURAL BEHAVIOUR IN LIMIT STATE OPERATING CONDITIONS – *STRUBECON*

Principal investigator

Prof. Josip Brnić, D. Sc., Faculty of Engineering, University of Rijeka, Croatia

Team members

From Faculty of Engineering, University of Rijeka, Croatia: Prof. Goran Turkalj, D. Sc.; Prof. Marko Čanađija; Prof. Domagoj Lanc; Assist. Prof. Marino Brčić, D. Sc.; Assoc. Prof. Goran Vukelić, D. Sc.; Assist. Prof. Igor Pešić, D. Sc.; Assist. Prof. Sanjin Kršćanski, D. Sc.; Neven Munjas, D. Sc.; Damjan Banić, D. Sc. Student; Sandra Kvaternik, D. Sc. Student; Edin Merdanović, D. Sc. candidate, Euro Façade Tech, Kuala Lumpur, Malaysia.

Project summary

The project aims to determine the response of the structures operating in limit state conditions. In this sense, an assessment of structure behaviour, by comparing of the parameters such as stress, strain, crack occurrence, etc., caused by certain load level and temperature at this unexpected limit state are comparing with those allowed by material properties. Although many journal papers were published, only some of them are mentioned here and that those published in Current Contents indexed journals.

Some of journal papers related to CC published in 2015./2016./2017.

1. Torić, N., Brnić, J., Boko, I., Brčić, M., Burgess, I. W., Uzelac- Glavinić, I.; Development of a high temperature material model for grade S275JR steel, **Journal of Constructional Steel Research 137** (2017), 161–168.
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7. Brnic, J, Turkalj, G., Krscanski, S., Vukelic, G., Canadija, M.: Uniaxial Properties versus Temperature, Creep and Impact Energy of an Austentic Steel, **High temperature materials and processes, 36** (2017), 2, 135-143.
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13. Vukelić, G., Brnić, J.: Analysis of Austenitic Stainless Steels (AISI 303 and AISI 316Ti) Regarding Crack Driving Forces and Creep Responses, **Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 230** (2016), 3, 699-704.
14. Brnić, J., Turkalj, G., Krscanski, S., Niu, J., Li, Q.: Changes in the Material Properties of Steel 1.4762 Depending on the Temperature, **High temperature materials and processes,** 35 (2016), 8, 761-767.
15. Brnic J., Turkalj G., Canadija M., Krscanski S., Brcic M., Lanc D.: Deformation Behavior and Material Properties of Austenitic Heat - Resistant Steel X15CrNiSi25-20 Subjected to High Temperatures and Creep, **Materials and Design, 69** (2015), 219-229.
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17. Vukelic G., Brnic J.:Prediction of Fracture Behavior of 20MnCr5 and S275JR Steel Based on Numerical Crack Driving Force Assessment, **Journal of Materials in Civil Engineering, 27** (2015), 3, 04014132-1 - 04014132-5 .
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This research has been fully supported by Croatian Science Foundation under the project 4982.

DEVELOPMENT OF EVOLUTIONARY PROCEDURES FOR CHARACTERIZATION OF BIOLOGICAL TISSUES BEHAVIOR-BIOMAT

Principal investigator

Assoc. Prof. Marina Franulović, D. Sc., Faculty of Engineering, University of Rijeka

Team members

Assoc. Prof. Robert Basan, D. Sc., Kristina Marković, D. Sc. (postdoc), Tea Marohnić, D. Sc. (postdoc), Faculty of Engineering, University of Rijeka

Prof. Ivan Prebil †, D. Sc., Ana Trajkovski, D. Sc. (postdoc), Senad Omerović, PhD student, Simon Krašna, D. Sc. (postdoc), Faculty of Mechanical Engineering, University of Ljubljana

BIOMAT in the second year of research

The second year of the research activities on the project BIOMAT were oriented to set up an inverse problem, based on the selected material model suitable for modeling the behavior of biological materials, as well as to establish the material behavior research in the field of innovative materials - focus on biological materials, with the expansion of cooperation, obtaining laboratory equipment and recruitment of doctoral students.

Inverse modelling

Appropriate material model to simulate the behavior of biological materials takes into account the high nonlinearity of their behavior. This material model is extremely complex, and setting up an inverse problem requires the application of a complex mathematical formulation of the physical laws that need to be proposed. The material model consists of three parts, and the basic problem is expected in their proper connections together with definition of specific boundary conditions for this purpose. The objective function has been determined on the basis of the selected mathematical formulation to describe the physical processes in the material. Inverse modeling is used to describe the actual system as accurately as possible, by the affecting measurements results to the values of the parameters. The results relate to the laying of the foundations for the development of efficient complex genetic algorithm for the identification of material parameters.

Establishment of expanded research foundations

In order to establish foundation for extension of developed methodology to other materials and material models, project activities include acquiring of more published results and sources of information on material behaviour and material models. Analysis and systematization of acquired data is underway so that most apropriate datasets and their sources can be selected for attainment of access to more detailed results of experiments for which direct contacts will be established with research groups that produced these results. Report on constitutive models of material behaviour has been expanded in regard to elastic-plastic material behaviour and complemented with additional material models with special focus on hyperelastic material models suitable for non-metallic materials such as certain polymers, rubbers as well as bilogical materials and tissues.

Presentation

The working group members participated in prominent international conferences and also published research results in well-recognized journals, in order to promote the excellence of own research and thus ensure the continuation of their careers and international recognition.

This research has been fully supported by Croatian Science Foundation under the project UIP-2014-09-7945.

EVOLVING SOFTWARE SYSTEMS: ANALYSIS AND INNOVATIVE APPROACHES FOR SMART MANAGEMENT (EVOSOFT) – FIRST YEAR STATUS REPORT

Research summary

This installation research project led by the young researcher Tihana Galinac Grbac has the main goal to establish her independent research career and her own laboratory and research group. For this project she received institutional support of the Faculty of Engineering at the University of Rijeka. Detailed summary can be found at web page: http://www.seiplab.riteh.uniri.hr/?page_id=712&lang=en.

EVOSOFT accomplishments in the second year of research

This project brings together the skills of University of Rijeka in Croatia, Lund University in Sweden, IT University of Copenhagen in Denmark, and industrial partner Ericsson Nikola Tesla to provide a better understanding of the fault distributions and underlying influencing effects in *EVOlving complex SOFTware systems* (EVOSOFT) and to propose innovative solutions for smart EVOSOFT management. Faults are local system properties connected to particular line of code and are directly influencing some key global system quality properties such are reliability and availability. In EVOSOFT, properties of system that we refer as global are impossible to describe by using simple rule with collection of local properties. Another problem is that in engineering EVOSOFT there is limited understanding of local software properties. However, recent findings of several replications on fault distribution show fundamental behaviour that seems to apply to any EVOSOFT. In second year of the project we were working on replication studies aiming to confirm empirical principles and methods proposed and used in software engineering community and to define solid base to ground new theories and on experimental studies aiming to define structural dependencies between various empirical principles.

Selected research group's publications related to the project in 2016/2017.

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[2] Tanković, N; Galinac Grbac, T.; Žagar, M.: ElaClo: A Framework for Optimizing Software Application Topology in the Cloud Environment, *Expert systems with applications*, Vol. 30 (2017), pp. 62-86.

[3] Galinac Grbac, T.; Domazet, N.; On the Applications of Dijakstra's Shortest Path algorithm in Software Defined Networks , *11th International Symposium on Intelligent Distributed Computing*, Belgrade, Serbia, 2017.

[4] Galinac Grbac, T.; Runeson, P.; Huljenić, D.; Unit verification effects on reused components in sequential project releases, *43rd Euromicro Conference on Software Engineering and Advanced Applications* Vienna, Austria, 2017.

[5] Grbac Babić, S.; Galinac Grbac, T.; Network analysis of evolving software-systems, 25th International Conference on Software, Telecommunications and Computer Networks, Split, Croatia, 2017.

[6] Pita Costa, J., Galinac Grbac, T.: The Topological Data Analysis of Time Series Failure Data in Software Evolution. International Workshop on Autonomous Control for Performance and Reliability Trade-offs in Internet of Services, L'Aquila, Italy, 2017.

[7] Mauša G.; Galinac Grbac, T.; The Stability of Threshold Values for Software Metrics in Software Defect Prediction, 7th International Conference on Model and Data Engineering, Barcelona, Spain, 2017.

[8] Miletić M, Vukušić M., Mauša G., Galinac Grbac, T.: Relationship Between Design and Defects for Software in Evolution, 6th Workshop on Software Quality Analysis, Monitoring, Improvement, and Applications, Belgrade, Serbia, 2017.

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This research has been fully supported by Croatian Science Foundation under the project 8722.

GREENER APPROACH TO SHIP DESIGN AND OPTIMAL ROUTE PLANNING – GASDORP – (Principal investigator Prof. Jasna Prpić–Oršić)

Project summary

The accurate calculation of attainable ship speed at actual sea is essential from economical and also environmental aspects. Reliable ship speed loss estimation under real environmental conditions allows a more accurate prediction of the power increase and fuel consumption as well as gas emissions from ships. Nowadays this second issue becomes very important because of the problem of global warming. Following the increasing awareness of the environmental and human health concerns of shipping, legislative actions have been taken on global and national levels making mandatory (from January 1st 2013) that new ships over 400 gross tonnage, to comply with the regulations, should have emissions of CO_2 under limiting value. Technological enhancement to ships like improved hull designs as well as improvement in power and propulsion systems could potentially reduce CO_2 emission up to 35 %. These measures could effectively be combined with several other operational measures, such as weather routing and voyage planning, in order to ensure that fuel consumption and CO_2 emissions from ships are minimized on every voyage.

References of project third year

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2. J. Prpić-Oršić, O. M. Faltinsen, J. Parunov, Influence of operability criteria limiting values on ship speed, Brodogradnja, Vol. 67, No. 3, pp. 37-58, 2016.
3. K. Sasa, Li-Feng Lu, O. M. Faltinsen, W. Sasaki, J. Prpić-Oršić, M. Kashiwagi, T. Ikebuchi, Development and validation of speed loss for a blunt-shaped ship in two rough sea voyages in the Southern Hemisphere, Ocean Engineering, (prihvaćen za objavljivanje), 2017.
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ENHANCEMENT OF THE HEAT EXCHANGER ENERGY EFFICIENCY - HEXENER

Principal investigator: Prof. Anica Trp, D. Sc., Faculty of Engineering University of Rijeka
Team members:

Prof. Kristian Lenić, D. Sc., Prof. Branimir Pavković, D. Sc., Assoc. Prof. Igor Wolf, D. Sc., Assist. Prof. Paolo Blecich, D. Sc., Assist. Prof. Igor Bonefačić, D. Sc., Assist. Prof. Vladimir Glažar, D. Sc., Boris Delač, D. Sc. (postdoc), Assist. Mateo Kirinčić, Assist. Fran Torbarina, Faculty of Engineering University of Rijeka

Project summary

The research topic of the project is enhancement of the heat exchanger energy efficiency. Investigations will focus on the analysis of heat transfer and the enhancement of energy efficiency of various fin and tube heat exchangers, as well as of the latent heat storage unit as a special type of heat exchanger. Scientific research objectives include: numerical and experimental investigation of the influence of the heat exchanger geometry characteristics on the physical process of heat transfer and efficiency, numerical and experimental investigation of the influence of the heat exchanger operating conditions on the physical process of heat transfer and efficiency, numerical and experimental investigation of the influence of the latent heat storage operating conditions, geometry and phase change material characteristics on heat transfer and efficiency, as well as analysis of energy storing in the renewable energy system with the latent heat storage unit. The expected scientific contribution of the research is the increase of the existing scientific knowledge related to the energy efficiency of fin and tube heat exchangers, latent heat storage as a component of the system and the overall system of renewable energy sources with the latent heat storage.

HEXENER accomplishments during the first year of research

The first year of the research activities on the HEXENER project has been mainly oriented to planning the procurement of experimental equipment and computer hardware. This activity included writing specifications of equipment needed for experimental investigations of geometry characteristics and of the influence of operating conditions on heat transfer inside the microchannel heat exchanger and the fin and tube heat exchanger, respectively. Moreover, the equipment needed for experimental investigation on the latent heat storage have been specified. Computer hardware, as well as software packages for CFD simulations have been determined. For all the equipment, offers were collected and reports on the selected equipment were done. The software package for numerical simulations, *ANSYS Academic Research CFD,* has been installed.
State of the art in the area of optimal geometry characteristics of the microchannel heat exchanger has been investigated using relevant scientific literature.
Test system, with built-in measuring sensors and emitters for experimental investigation of the influence of geometry on heat transfer, has been established. Technical documentation of the test system has been made.

More information about HEXENER is available on the project web page http://www.riteh.uniri.hr/en/science/existing-projects/hexener/

This research has been fully supported by Croatian Science Foundation under the project 5371.

OPTIMISATION AND MODELLING OF THERMAL PROCESSES OF MATERIALS (OMOTPOM) – THIRD YEAR REPORT

Principal investigator

Prof. Božo Smoljan, D. Sc. / Assist. prof. Dario Iljkić, D. Sc., Faculty of Engineering, University of Rijeka

Summary of the third year of Optimisation and Modelling of Thermal Processes of Materials

In development of models and computer simulations of thermal processes and optimizing the application of tools and dies in thermal processing of materials, in the third year of research, focus was on heat treatment, casting and welding as well as on development of electroless Ni-P coatings on substrates made of stainless steel. Extensive research has been done regarding the mentioned thermal processes. Computer models and programs for simulation of mechanical properties and microstructure distribution after thermal processing have additionally been developed. Electroless Ni-P coating has successfully been applied to substrate made of X5CrNiMo17-12-2 stainless steel. Further research of electroless Ni-P coating will be focused on increasing the adhesiveness and on characterization of surface layers of the coating and the substrate.
Research results have been published in the following scientific journals:

- Smoljan, B.; Iljkić, D.; Maretić, M.; Adhesivity of electroless Ni-P layer on austenitic stainless steel; Archives of Materials Science and Engineering, (1897-2764) 80, 2016., 53-58,
- Smoljan, B.; Iljkić, D.; Maretić, M.; Computer simulation of hardness and microstructure of casted steel 100Cr6; Archives of Materials Science and Engineering, (1897-2764) 78, 2016., 23-28,
- Smoljan, B.; Iljkić, D.; Štic, L.; Kolumbić, Zvonimir; Mathematical modelling of steel quenching; Materials Science Forum, (1662-9752) 879, 2017., 1813-1818,
- Smoljan, B.; Maretić, M.; Iljkić, D.; Heat treatment of electroless Ni-P layers on an austenitic stainless-steel substrate; Materiali in tehnologije, (1580-2949) 51, 2017., 413-417,

and on 12 conferences and their proceedings. Some of them are:

- Smoljan B., Iljkić D., Štic L., Smokvina Hanza S., Borić A., Tomašić N.; Numerical modelling of heat treated welded joint; Proceedings of the 24th IFHTSE Congress 2017; 2017; Nice, France,
- Smoljan B., Iljkić D., Maretić M., Smokvina Hanza S., Štic L., Borić A.; An analysis of properties of electroless Ni-P layer on stainless steel; Proceedings of the ESSC & DUPLEX 2017; 2017.; Bergamo, Italy,
- Smoljan B., Iljkić D., Smokvina Hanza S., Štic L., Borić A.; Computer simulation of cast steel properties; Proceedings of the 16th International Foundrymen Conference, IFC17; 2017., Opatija.

Conclusion

Models for prediction of mechanical properties of specimens after heat treatment, casting and welding have additionally been developed and improved. Electroless Ni-P coatings have successfully been applied on stainless steel substrate. All accomplished results have been published in three scientific journals and several conference proceedings. Next step in optimisation and modelling of thermal processes of materials is additional development of models as well as their verification. Electroless Ni-P coatings will be further optimised with main goal to increase their adhesiveness and improve their mechanical properties.

This research has been fully supported by Croatian Science Foundation under the project 1631.

CONFIGURATION-DEPENDENT APPROXIMATION IN NON-LINEAR FINITE-ELEMENT ANALYSIS OF STRUCTURES

Project summary

This research project has at its centre the concept of *configuration-dependent interpolation*, in which the shape functions depend on the problem unknowns. The design principle for such interpolation is two-pronged: (i) in the linear limit the interpolation should coincide with the exact solution or a known reference solution, and (ii) in general, it is to be designed to preserve one or more of the underlying physical properties. The project is organized in work-packages dealing with micro-polar continuum including straight and curved 3D beams (WP1), plates and shells (WP2) and layered structures involving cracking (WP3), while a particular strand of the research project addresses a configuration-dependent integration of the equations of motion including non-smooth systems (WP4).

Principal investigator and team members (University of Rijeka, Faculty of Civil Engineering)

Principal investigator:	Gordan Jelenić
Academic staff:	Dragan Ribarić, Edita Papa Dukić, Paulo Šćulac, Leo Škec, Maja Gaćeša
Research Associates/Assistants:	Jean-Francois Camenen, Nina Čeh, Sara Grbčić, Miran Tuhtan

Research outcome:

Investigation of dual-mode delamination in layered structures has shown that geometrically non-linear effects may become significant even in relatively small-displacement regime and a detailed comparison with the related results in the geometrically linear analysis has been presented in an article published in a reputable international journal [1] and a couple of international conferences. A thorough analysis of interpolation sensitivity in the 3D-beam non-linear fixed-pole approach has been conducted and presented on an international conference [2]. Analytical, numerical and experimental analysis of rocking of a rigid block subject to constant ground acceleration has also been presented at an international conference [3], while more work has also been conducted on single- and dual-block systems subject to free rocking and harmonic ground excitation lying on rigid and deformable bases. Additional work on fixed-pole approach, linked interpolation in spatially curved beams, micro-polar continua and simple continua with rotational degrees of freedom, rate-dependent delamination and dynamics of discontinuous systems is under-way and planned to be submitted for publication soon. All the above results have also been presented at a national conference of the Croatian Society of Mechanics, held in Osijek in July 2017 in eight separate papers.

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1. Leo Škec, Gordan Jelenić: Geometrically non-linear multi-layer beam with interconnection allowing for mixed-mode delamination. Engineering Fracture Mechanics 169 (2017) 1-17

2. Maja Gaćeša, Gordan Jelenić, Objective fixed-pole approach in geometrically exact 3D beams: Implementational aspects, Proceedings of 25th UKACM Conference on Computational Mechanics, 12 - 13 April 2017, University of Birmingham, 2017, UKACM, 224-227

3. Gordan Jelenić, Nina Čeh, Nenad Bićanić, Rocking of single and dual rigid-block systems subject to ground excitation: Experimental and computational analysis of overturning conditions, Proceedings of 25 th UKACM Conference on Computational Mechanics, 12 - 13 April 2017, University of Birmingham, 2017, UKACM, 244-247

This research has been fully supported by Croatian Science Foundation under the project 9068.

MULTI-SCALE CONCRETE MODEL WITH PARAMETER IDENTIFICATION – *CONCRETEMUSCID*

Principal investigator : Prof. Ivica Kožar, D. Sc., Faculty of Civil Engineering, University of Rijeka.

Objective

The project goal is development of the new numerical model for steel-fiber reinforced concrete under static and dynamic loading. The material under consideration is a composite material consisting of high performance concrete matrix with embedded (steel) fibers. In order to make an effective model, parameters have to be identified from experiments, e.g., using inverse procedures.

Numerical model

Numerical model is based the lattice model applied on the Voronoi tessellation as presented in Fig.1

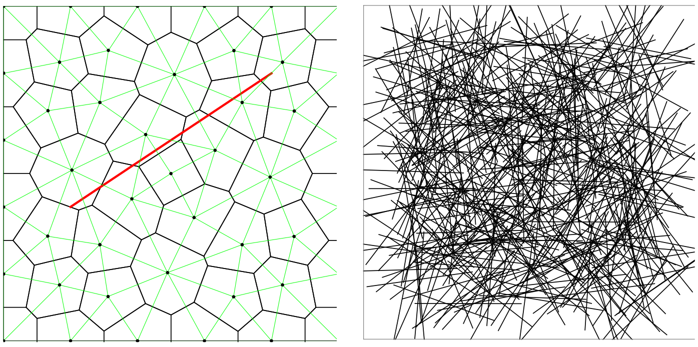

Figure 1.: a) Voronoi tessellation representing concrete matrix with an overlaid fiber, b) fiber distribution inside concrete matrix – numerical simulation, c) example of real steel fibers.

Parameter Identification

One of the important model parameters is the bonding force between steel fiber and concrete matrix. It could be determined from fiber pullout experiments but increased accuracy could be obtained with specially designed three-point bending tests as depicted in Fig.2.

Figure 2.: Three-point bending test. a) experimental setup, b) test result.

Additional aspects

In addition, the aspects of corrosion in concrete will be dealt with. The corrosion is described using transport equations but coupled with mechanical equations so that the damage of concrete cover due to expansion of corrosion products and transport of rust through concrete pores and cracks could be computed.

Doctoral student working on the project is also taking part in the project of French – Croatian collaboration (”cotutelle”) under two doctoral thesis supervisors: Prof. A. Ibrahimbegovic for Université de Technologie de Compiègne / Sorbonne Universités and Prof. I. Kozar for University of Rijeka, Faculty of Civil Engineering and will acquire doctoral degree on both institutions.

This research has been fully supported by Croatian Science Foundation under the project IP-2016-06-4775.

ASSUMED STRAIN METHOD IN FINITE ELEMENTS FOR LAYERED PLATES AND SHELLS WITH APPLICATION ON LAYER DELAMINATION PROBLEM

Project summary

This is a research project in basic technical sciences concerning the numerical analysis of the Mindlin type moderately thick plates and shells by the finite element method. On the basis of already designed quadrilateral and the triangular plate elements (with various number of nodes) by the assumed strain interpolation in the element stiffness formulation and good performances, we want to extend our research to the layered plates in 2D space and the layered facet or curved shells in 3D space.

The material connecting the layers will be modeled at first with a simple elastic constitutive law, but following our successful numerical experiments on the layered beams, the interfaces between layers will be further modeled by a mixed-mode cohesive-zone damage-type constitutive law. This kind of interconnection behavior will be then applied to all kinds of structural models - plates, facet and curved shells. The numerical results will be compared with the other models and the experimental results from literature.

At the same time, experimental research will be performed using the equipment in our laboratories. We shall carry out experiments with delamination of the real layered models and also compare them with the appropriate numerical models.

Principal investigator and team members (University of Rijeka, Faculty of Civil Engineering)

Academic staff:	Dragan Ribarić, Gordan Jelenić and Leo Škec
Post-doctoral Research Associate:	will be included in the third year of the project
Doctoral students / Research Assistants:	not yet included in the project

Project work objectives

O1: Development of novel lower- and higher-order triangular and quadrilateral plate finite elements based on linked-interpolation and assumed-strain concepts

O2: Development of layered plate elements involving rigid and elastic connection between layers

O3: Development of layered plate elements with a mixed-mode cohesive-zone damage-type constitutive law for interfaces between layers

O4: Development of the experimental setup to validate performance of the layered plate elements in delamination

O5: Development of layered facet shell elements with a mixed-mode cohesive-zone damage-type constitutive law for interfaces between layers

O6: Development of layered curved facet shell elements with a mixed-mode cohesive-zone damage-type constitutive law for interfaces between layers

Outline of the 1st year project results

The project begun on the 1st of March this year and after 6 month of work the project activities are still at the beginning.

Until this moment a four-node assumed strain plate element has been developed, tested for typical problems of moderately thick and extremely thin plate models and compared with similar known elements from the literature. Currently we are enhancing this element for the “membrane effects” to get a good facet shell four-node element.

At the same time we are studying 2D curved beam FEM formulations and programing 2D curved beam elements for both out-of-plane and in-plane actions. Some good results have emerged and two journal articles are prosperous. The curved beam formulations will be used to generate curve-shaped shell elements.