Załącznik /Appendix 4

Autoreferat dotyczący działalności naukowo-badawczej, dydaktycznej i organizacyjnej w języku angielskim / Summary of professional accomplishments

Contents:

1. Name and surname

Michał Nitka

2. Diplomas held, scientific degrees with the indication of the name, place and year in which they were acquired, as well as the title of the doctoral dissertation

1. 16.12.2004. Master of Science, discipline: Civil Engineering, specialization: Structural Engineering. Gdańsk University of Technology, Faculty of Civil Engineering. Diploma title: “Sport Palace in Tbilisi with concrete spherical dome”. Supervisor: Prof. dr hab. inż. Tadeusz Godycki-Ćwirko.

2. 09.11.2010. PhD Degree in Technical Sciences, discipline: materials engineering, mechanics, civil engineering, electrochemistry. Grenoble Institute of Technology Grenoble I. Dissertation's title: “Multi-scale modelling of granular media” (French: “*Modelisation multi-echelles des milieu granulaires*”). Supervisors: Prof. Jacques Desrues, Prof. Cristian Dascalu and dr Gaël Combe; reviewers: Prof. Jean-Noël Roux and Prof. Jean Sulem.

3. Information about employment in academic/research institutions

1. 01.02.2007-30.04.2010: Grenoble Institute of Technology Grenoble, Laboratory 3S-R – PhD student scholarship.
2. 01.07.2010-30.06.2011: Gdańsk University of Technology, Faculty of Civil and Environmental Engineering – assistant (full time).
3. From 01.07.2011: Gdańsk University of Technology, Faculty of Civil and Environmental Engineering – assistant Professor (full time).

4. Indication of the achievement resulting from article 16, paragraph 2 of the Act of 14 March 2003 on academic degrees and title and degrees and title in the arts

a. Title of the scientific achievement

Model of concrete at the meso-scale level using the discrete element method (DEM).

b. Publications included in the scientific achievement

1. **Nitka M.**, Tejchman J. 2013. Modelling of behaviour of plain concrete using DEM. *Particle-based methods III: Fundamentals and Applications,* 649-658 (on the Web of Science list, MNiSW $^{(2016)}$: 15).

2. **Nitka M.**, Tejchman J. 2014. Discrete modeling of micro-structure evolution during concrete fracture using DEM. *Euro-C, Computational modelling of concrete structures (1),* 345-354 (on the Web of Science list, MNiSW$^{(2016)}$: 15).

3. **Nitka M.**, Tejchman J. 2014. Discrete Element Method used for describing fracture process in concrete during uniaxial compression and tension (in Polish). Inżynieria Morska i *Geotechnika 5,* 527-536 (MNiSW $^{(2016)}$: 6).

4. **Nitka M.**, Tejchman J. 2015. Modelling of concrete behaviour in uniaxial compression and tension with DEM. *Granular Matter 17(1),* 145-164 (a journal from the list "Web of Science", IF: 1.740, MNiSW $^{(2016)}$: 30).

5. Skarżyński Ł., **Nitka M.**, Tejchman J. 2015. Modelling of concrete fracture at aggregate level using FEM and DEM based on x-ray microCT images of internal structure. *Engineering Fracture Mechanics 147,* 13-35 (a journal from the list "Web of Science", IF: 2.024, MNiSW $^{(2016)}$: 35).

6. **Nitka M.**, Tejchman J. 2015. Modelling of concrete at aggregate level using DEM based on x-ray microCT images of internal structure. *Particle-based methods IV – Fundamentals and Applications,* 343-354 (on the Web of Science list, MNiSW $^{(2016)}$: 15).

7. **Nitka M.**, Skarżyński Ł. Tejchman J. 2015. Simulations of fracture in concrete beams under bending using a continuum and discrete approach. *Computational plasticity XIII: Fundamental and Applications,* 1065-1076 (on the Web of Science list, MNiSW $^{(2016)}$: 15).

8. Suchorzewski J., **Nitka M.**, Tejchman J. 2015. Modelling of uniaxial tension and compression of concrete at the aggregate level (in Polish). *Przegląd Budowlany 11,* 22-25 (MNiSW $^{(2016)}$: 5).

9. **Nitka M**, Tejchman J. 2017. DEM analysis of effect of interfacial transitional zones on fracture in concrete. *Particle-based methods – Fundamentals and Applications,* 249-260 *(*on the Web of Science list, MNiSW $^{(2016)}$: 15).

10. Suchorzewski J, **Nitka M.**, Tejchman J. 2018. Discrete elements method simulations of fracture in concrete under uniaxial compression based on its real internal structure. *International Journal of Damage Mechanics 27(4),* 578-607 (a journal from the list “Web of Science”, IF: 1.761, MNiSW $^{(2016)}$: 35).

11. **Nitka M.**, Tejchman J. 2018. A three-dimensional meso-scale approach to concrete fracture based on combined DEM with x-ray CT images. *Cement and Concrete Research 107,* 11-29 (a journal from the list “Web of Science”, IF: 5.430, MNiSW $^{(2016)}$: 45).

12. Suchorzewski J, **Nitka M.**, Tejchman J. 2018. Experimental and numerical investigations of concrete behaviour at meso-level during quasi-static splitting tension. *Theoretical and Applied Fracture Mechanics 96,* 720-739 (a journal from the list “Web of Science”, IF: 2.215, MNiSW $^{(2016)}$: 30).

13. Suchorzewski J., Tejchman J., **Nitka M**., Bobiński J. 2019. Meso-scale analyses of size effect in brittle materials using DEM. *Granular Matter 21 (9),* https://doi.org/10.1007/s10035-018-0862-6 (a journal from the list “Web of Science”, IF: 1.658, MNiSW $^{(2016)}$: 30).

14. **Nitka M.**, Tejchman J. 2018. Effect of interfacial transitional zones on concrete behaviour in DEM analyses. *Proceedings of the 6th European Conference on Computational Mechanics (Solids, Structures and Coupled Problems),* 1534-1543 (reported on the Web of Science list, MNiSW $^{(2016)}$: 5).

Summary Impact Factor for above publications is 14.828 (according to the year of publication). The total number of MNiSW points (according to 2016): 296 points (own contribution is 120.10 points).

c. Discussion of the above mentioned scientific work and the obtained results, including evaluation of their potential use

Fracture is a basic phenomenon in concrete elements and structures. Its understanding is very important for the safety of concrete structures and optimization of the concrete behaviour. Fracture is characterized by complex mechanical processes such as nucleation, formation, propagation and coalesce of micro-cracks that leads to strain localization and discrete macro-cracks. Cracking causes the decrease in strength and stiffness and finally leads to the destruction of the part or the entire structure. Fracture is a very complex process due to a heterogeneous structure of concrete over many different length scales (from the few nanometres for hydrated cement up to the millimetres for aggregate particles). Fracture depends mostly on e.g. number, size, shape and roughness of the aggregate and the cement matrix porosity. Therefore, the material meso-structure should be taken into account when realistically modelling the material behaviour. Concrete at the mesoscale level may be described as 4-phases material consisting of aggregate, cement matrix, macro-voids and interfacial transition zones (ITZs). Attention has to be paid to very porous interfacial transition zones, where micro-cracks are initiated. Their width depends on the shape and roughness of the aggregate and on the direction of concrete mixing.

Most concrete models use significant simplifications in calculations, such as material homogeneity, a simplified constitutive model or lack of scale effect. Even more advanced scientific models often ignore the microstructure of concrete, what impact on the global stiffness and durability of the element. The failure of the engineering structures made of concrete (or reinforced concrete) is a consequence of their damage and cracks at the mesoscale. Thus, in order to realistically describe the concrete behaviour, its microstructure should be taken into account. Two main approaches exist for concrete modelling at the meso level: continuous and discrete. The first approach is based on calculations with the finite element method (FEM) using constitutive laws for concreted enriched by a characteristic length. The second approach uses discrete methods (e.g. lattice or discrete element method (DEM)). In the discrete approach, the material is considered as naturally discontinuous, since particles are modelled as bonded elements. Under external forces they can be separated, what naturally allows to obtain cracks. The main advantage of these models is that they directly simulate microstructure and can be used to study local phenomena at the micro level, such as the mechanism of initiation, growth and the formation of locations and cracks, what affect the behaviour of concrete on a macro scale.

My research achievements after obtaining my PhD degree focused on creating a new reliable concrete model using DEM to study fracture at the meso-scale and to optimize the concrete properties with respect to the stiffness, strength and ductility.

The novel elements of my research included: a) implementation of a new concrete model to the discrete element method (DEM), b) realistic fracture analyses at the aggregate level by taking into account different properties of concrete components and c) extension of DEM by a reproduction possibility of the real meso-structure of concrete, based on 3D images from a x-ray micro-tomography system of a new generation. I performed extensive 2D and 3D numerical simulations for concrete specimens during compression, tension, splitting and bending that were compared directly with corresponding laboratory tests (own results or from the literature). Concrete specimens were monotonically loaded into a quasi-static regime. An open-source platform for discrete calculations YADE (developed at the University of Grenoble, France) was used for numerical calculations.

My research works were divided into three areas:

A. implementation of the DEM model for concrete at the meso-scale level on the YADE platform,

B. reproduction of a real meso-structure of concrete in DEM based on laboratory tests with the use of a new generation micro-tomography system,

C. analyses of various meso-structural phenomena occurring during concrete fracture.

A. Implementation of the DEM model for concrete at the mesoscale level on the YADE platform

My aim was to implement a new model for concrete at the aggregate level, by taking its meso-structure into account, including 4 different phases (aggregates, cement matrix, macro-voids and interfacial transition zones). Concrete models in world literature focus on the 1-phase material law, completely ignoring its internal structure. My task was to numerically reproduce the internal microstructure of concrete with the implementation of simple material laws (e.g. modified Mohr-Coulomb law). The current 4-phase concrete model requires solely five material constants: the Young's modulus of contact, the Poisson ratio of contact, the internal friction angle, the maximum cohesive force and the minimum tensile force between the elements. The behaviour of concrete depends mainly on the assumed geometry and internal structure of the specimen (size and number of aggregate, density of cement matrix, size and number of macro-voids etc.). The model for concrete does not include material softening. The new method of preparing of any initial micro-porosity of concrete was developed by myself. The introduced modifications on the YADE platform went beyond the standard usage. The 2D and 3D calculations were made for a 1-phase, 3-phase and 4-phase material. The influence of material constants and the size of discrete elements (aggregate and cement matrix) on fracture was deeply studied. The efficiency of the DEM model was checked with uniaxial compression and uniaxial tension tests of concrete. I compared both the macroscopic results and the fracture at meso-level for concrete elements. The introduction of interfacial transition zones (ITZ), significantly increases the similarity of numerical calculations to experimental ones.

The results of the numerical calculations were published in articles: I.B.1-4, I.B.8 (Appx. 5) and presented at international conferences e.g. *FraMCoS* (2013), *Particles* (2013) and *Euro-C* (2014) (Appx. 5: II.L).

[4] **Nitka M.**, Tejchman J. 2015. Modelling of concrete behaviour in uniaxial compression and tension with DEM. *Granular Matter 17 (1),* 145-164.

B. Reproduction of real meso-structure of concrete in DEM based on laboratory tests with the use of a new generation micro-tomography system

In the first step of the research, I performed extensive laboratory experiments including 3-point bending tests on concrete beams with a notch at the mid-length. Concrete mix was prepared as for typical constructions (maximum aggregate diameter was 16mm). Concrete specimens were cut out from the beams in the notch region after each test and inserted into the x-ray micro-tomography system Skyscan 1173. The 3D spatial meso-structure of the concrete was obtained (position and shape of the aggregate and macro voids, micro-porosity, location and shape of the crack). The irregular aggregate shapes were modelled as a cluster of rigid spheres. The width of interfacial transition zones (ITZ) on the concrete surface and its porosity was measured with the Hitachi TM3030 electron microscope. We wrote own algorithm for porosity measurement from images from the electron microscope. The average width of this phase was 20-50 μm and its porosity was 10-25% (the cement porosity was established as 3-5% due to micro tomograph analysis).

The 2D calculations for beams were performed by myself. I assumed, that only the middle part of the beam was modelled with real microstructure (the rest of the specimen was modelled with larger, 1-phase elements). It significantly accelerated the calculations. Material constants in DEM numerical calculations were calibrated with the aid of uniaxial compression and uniaxial tension laboratory tests. Very good agreement between the DEM results and experiments with respect to the force-CMOD (Crack Mouth Opening Displacement) curve and the position and curvature of macro-crack was obtained. The effect of ITZ parameters on the strength curve and the shape of macro-crack was also investigated.

The results were presented in articles I.B.5-7 (Appx. 5) or during several international conferences, e.g. *CFRAC* (2015), *Particles* (2015), *FraMCoS* (2016), *EMMC15* (2016), *ECCOMAS* (2017) (Appx. 5: II.L).

[5] Skarżyński Ł., **Nitka M.**, Tejchman J. 2015. Modelling of concrete fracture at aggregate level using FEM and DEM based on x-ray microCT images of internal structure. *Engineering Fracture Mechanics 147*, 13-35.

Next, I performed comprehensive DEM calculations for uniaxial compression and splitting of concrete based on our own experimental tests on cubes (compression) and cylinders (splitting). The influence of the aggregate shape on the results was studied (e.g. the round aggregate from the see bottom so-called “Baltex” were used, which was characterized by very smooth surface). We found that the interfacial transitional zone was much thinner in comparison with crushed-stone aggregate. The influence of the boundary conditions and specimen size was also studied. A direct comparison of laboratory results with numerical calculations with aggregate modelled as spheres or clusters (with shapes based on images from a micro-tomograph system) clearly showed that the aggregate shape had a significant effect on both the force-displacement curve and the shape of a macro-crack. In experiments and in numerical calculations the splitting tests were controlled by the crack opening CMOD (the special algorithm was written by myself to control piston velocities due to crack opening during calculations). The numerical results were again in a very good agreement with the experimental results.

The results of laboratory tests and numerical calculations of DEM were described in articles I.B.10, I.B.12 and I.B.13 (Appx. 5) and presented on international conferences (Appx. 5: III.B).

[10] Suchorzewski J, **Nitka M.**, Tejchman J. 2018. Discrete elements method simulations of fracture in concrete under uniaxial compression based on its real internal structure. *International Journal of Damage Mechanics 27(4),* 578-607.

[12] Suchorzewski J, **Nitka M.**, Tejchman J. 2018. Experimental and numerical investigations of concrete behaviour at meso-level during quasi-static splitting tension. *Theoretical and Applied Fracture Mechanics 96,* 720-739.

[13] Suchorzewski J., Tejchman J., **Nitka M.**, Bobiński J. 2019. Meso-scale analyses of size effect in brittle materials using DEM. *Granular Matter 21 (9),* https://doi.org/10.1007/s10035-018-0862-6

The numerical calculations were performed for concrete beams under bending under 3D conditions. The aggregate was modelled as spheres or clusters based on scans from a micro-tomography system. For an automatic transfer of images of 3D aggregate after the reconstruction of scans from the micro-tomography system, a special program was written that created a density map of concrete specimens and converted it into a voxel map with coordinate data. Next, the voxels of the same density were replaced by discrete elements connected into rigid clusters. Thus, it was possible for a fast implementation of the real meso-structure of concrete in 3D conditions. The spatial shape of the crack in the bending beam was calculated in a very accurate manner as compared with the laboratory test. In the future, the 3D DEM calculations with the real meso-structure may replace expensive and time-consuming laboratory tests.

The results of laboratory tests and numerical calculations by DEM were presented in articles I.B.11, I.B.14 (Appx. 5) and on international conferences e.g. *Eccomas* (2017), *Particle* (2017), *Euro-C* (2018) and *ECCM-ECFD* (2018) (Appx. 5: II.L).

[11] **Nitka M.**, Tejchman J. 2018. A three-dimensional meso - scale approach to concrete fracture based on combined DEM with x-ray CT images. *Cement and Concrete Research 107*, 11-29.

Currently, the DEM model for concrete was extended by the presence of interfacial transition zones between aggregate and mortar of a certain width, with higher porosity. I invent a code that allows creating numerical samples with varying porosity near the aggregate, keeping the micro-porosity of the cement mortar. The porosity of the interfacial transition zone was determined based on the image from an electron microscope of the concrete surface (with the usage of own algorithm). The current model after coupling with Computational Fluid Dynamics (CFD) will be applied to calculate liquid and heat flow in concrete.

Numerical results of DEM were presented at the *ECCM-ECFD* conference (2018) (Appx. 5: I.B.14).

C. Analyses of various meso-structural phenomena occurring during concrete fractures

The discrete element method (DEM) allows for very realistic fracture analyses including the formation and development of micro-cracks and occurrence of discrete macro-cracks. During fracture various meso-structural phenomena were studied, such as force chains, normal contact forces, tangential contact forces, broken contacts, grain rotation, local porosity, local energies, crack width, etc. In numerical calculations, the bridging and branching around an aggregate of the crack were observed, similar as in experiments. In macro crack, the interlocking of elements was found and strong tensile forces were obtained.

Results were presented in articles I.B.1-12 (Appx. 5) and on international conferences (Appx. 5: III.L).

[4] **Nitka M.**, Tejchman J. 2015. Modelling of concrete behaviour in uniaxial compression and tension with DEM. *Granular Matter 17(1)*, 145-164.
[10] Suchorzewski J, **Nitka M.**, Tejchman J. 2018. Discrete elements method simulations of fracture in concrete under uniaxial compression based on its real internal structure. *International Journal of Damage Mechanics 27(4)*, 578-607.

[11] **Nitka M.**, Tejchman J. 2018. A three-dimensional meso - scale approach to concrete fracture based on combined DEM with x-ray CT images. *Cement and Concrete Research 107*, 11-29.

[12] Suchorzewski J, **Nitka M.**, Tejchman J. 2018. Experimental and numerical investigations of concrete behaviour at meso - level during quasi - static splitting tension. *Theoretical and Applied Fracture Mechanics 96*, 720-739.

The energy calculations were made for the entire concrete specimen or for cracked and non-cracked parts. I wrote an algorithm, which allows calculating internal energy from localized part of the specimen only. The calculations provided a better understanding of the size effect in concrete associated with the decrease of both strength and ductility in large elements.

Results were published in article I.B.13 (Appx. 5) and presented on international conferences (Appx. 5: III.L).

[13] Suchorzewski J., Tejchman J., **Nitka M.**, Bobiński J. 2019. Meso-scale analyses of size effect in brittle materials using DEM. *Granular Matter* 21 (9), https://doi.org/10.1007/s10035-018-0862-6

The DEM results showed also the possibility of early prediction of macro-cracks based on the contact strength capacity and current stress, e.g. using Griffith's energy criterion. The numerical results were published and presented on international conference *Powder and Grain* (2017) and *Euro-C* (2018) (Appx. 5: II.E.14, II.E.16).

Summary

The results of numerical simulations of concrete specimens showed the ability of the discrete DEM model based on the real meso-structure of concrete to reliably describe the behaviour of concrete specimens under load at both the macro-scale and meso-scale level. The model included 4 concrete phases: aggregate, cement matrix, macro-voids and interfacial transition zones between the aggregate and cement matrix. The DEM model was checked for various boundary problems (uniaxial compression, uniaxial tension, splitting, bending) and the results were directly compared with the results of own experimental or experiments in the literature. Excellent agreement of the DEM results with the experiments with respect to strength, ductility and fracture of concrete was obtained. Such an advanced model of concrete based on internal microstructure is not available in any commercial programs.

The most important achievements of my research works are:

- introduction of a novel DEM mode to describe the concrete behaviour at the meso-scale level by taking fracture into account. The model includes 4 basic concrete phases: aggregate, cement matrix, macro-voids and interfacial transition zones,
- extensive numerical DEM calculations with the real meso-structure of concrete, based on spatial images from a x-ray micro-computed tomography system (micro-CT),
- detailed analyses of fracture in concrete at the aggregate level,
- creation of an original program for building various 3D shapes of aggregate grains based on images from a micro-tomography system (using voxels with similar densities).

The obtained DEM results may be applied to:

- improvement of constitutive laws for concrete in the case of continuous models (e.g. regarding the damage evolution, characteristic length, instant of macro-crack formation etc.),
- optimization of the concrete about stiffness, strength and ductility based on the density, shape, roughness of aggregate and the presence of various additives during simple experimental tests,
- prediction of a crack path in concrete.

In the next stage of my research works, the DEM model for concrete will be extended by aggregate breakage, interfacial transition zones with a defined width, steel fibres and micro-sphere. The DEM model will be coupled with the Computational Fluid Dynamics (CFD) to model moisture and heat flow in concrete.

5. Description of other academic and research achievements

<u>Before obtaining PhD degree</u>

After I have terminated my doctoral course at the Gdańsk University of Technology, I started my research work at the 3S-R laboratory at the University of Grenoble in France, receiving a doctoral scholarship from the Ministry of France (from 02.2007). Initially, I made familiar with research works and literature on modelling of granular materials using the finite element method (FEM) and the discrete element method (DEM). Under the supervision of Prof. C. Dascalu I have learned on numerical homogenization and FEM and under the supervision of dr. G. Combe, I have learned DEM and programming (FORTRAN, Matlab and C ++). Prof. J. Desrues introduced for me different geotechnical experiments and multi-scale problems.

The subject of my doctoral thesis was the multi-scale modelling of granular materials, by combining DEM calculations at the grain level with FEM calculations at the global level. The stiffness matrix at the global level was determined based on DEM calculations. Together with my supervisor, I modified his numerical discrete code for working in multi-scale domain. The periodic limit conditions (PLC) were implemented by myself, due to eliminating boundary influence (smaller specimens could be used, with no influence on the results). In the DEM calculations, a detailed analysis of acoustic tensor stability was also carried out. After numerical homogenization, the data from the DEM scale were transferred to the FEM scale. The DEM calculations were performed at each integration point. In FEM, strains of mesh nodes were calculated that were transferred next to DEM

Both DEM and FEM were coupled into one calculation program. It was possible for parallel calculations on many CPUs after my changes in the main code, what significantly accelerated calculations. The numerical simulations were performed for typical geotechnical tests (odometer, shear, biaxial shear with and without volume change) and were compared with single-scale numerical calculations. The doctoral thesis titled "Multi-scale modelling of granular media" was written in English and defended on November 9, 2010 in Grenoble.

The results were presented in 1 article from the JCR journal II.A.1 (Appx. 5) and on international conferences e.g. *Powder and Grains* (2009), *ComGeo* (2009), *Multiscale Modeling* (2010), *IWBDG* (2011).

[Appx. 5: II.A.1] **Nitka M.**, Combe G., Dascalu C., Desrues. J. 2011. Two-scale modeling of granular materials: a DEM-FEM approach. *Granular Matter 13(3)*, 277-281.

After obtaining PhD degree

In July 2010 I started work at the Gdańsk University of Technology as a full-time assistant at the Department of Building and Materials Engineering, and then from July 2011, I continued my work as an assistance Professor (full-time). My main research activity was related to meso-scale modelling of various meso-structural phenomena occurring concrete using DEM. The remaining research achievements after obtaining the PhD degree constituted an extension of my basic research activity. Those research works can be divided into four main groups:

A. continuation of two-scale modelling for granular and concrete materials,

B. numerical analyses of shear zones in granular materials using DEM,

C. methods for early detection of cracks in concrete,

D. fracture model of rocks under hydraulic pressure during hydro-fracturing using a coupled DEM/CFD approach.

A. Continuation of two-scale modelling for granular and concrete materials

After obtaining my PhD degree, I continued the development of the multi-scale model. The attention was directed laid to improve the discrete code. My research work focused more on concrete materials, thus I modified the discrete code for this material. The two-scale results were presented in the articles (Appx 5: II.E.6-7, II.E.10) and at international conferences e.g. *FraMCoS* (2013) and *Euro-C* (2014).

B. Numerical analyses of shear zones in granular materials using DEM

The DEM calculations were carried out for passive earth pressure problems of a moving rigid wall in granular material. Good agreement was obtained with experimental outcomes and numerical results using the finite element method (FEM). The discreet method allowed for obtaining many interesting data due to modelling of the material meso-structure (e.g. the presence of local dilatant and contractant regions and so-called vortex structures in the shear zones). The vortex corresponds to a rigid motion of a group of particles around one middle point, which can be seen after plotting displacement fluctuations map. The vortices proved to be a very good indicator for early detection of shear zones. Future analysis of vortex structures was done by Prof. Kozicki, who developed Helmholz’a-Hodge decomposition method.

The results were described in one article from the JCR list (Appx 5: II.A.2) and presented at some international conferences e.g. *Particles* (2013, 2015), *IWBDG* (2015) and *Geomechanics from Micro to Macro* (2015).

[Appx. 5: II.2] **Nitka M.**, Tejchman J., Kozicki J., Leśniewska D. 2015. DEM analysis of micro-structural events within granular shear zones under passive earth pressure conditions. *Granular Matter 17(3),* 325-343.

The research works on the problem of earth pressure in granular materials resulted in a close co-operation with Prof. D. Leśniewska (Koszalin University of Technology) and participation in the NCN grant under her supervision (Appx. 5: II.J.2). Currently, I perform DEM simulations for active earth pressure of a rigid wall in granular material. The attention is laid on the distribution of contact forces in grains. My own numerical algorithm was written to obtain dense samples (porosity ratio below 0.5). The numerical results were compared with the experiments, where the polarized light was used.

The comparison of experimental and numerical calculations was presented at the *IWBDG* (2017) conference.

C. Methods for early detection of cracks in concrete using DEM

Together with the University of Melbourne, Australia (Prof. A. Tordesillas), we have developed a method for early detection of cracks in concrete based on the distribution and evolution of contact forces, by taking into account the contact strength and current contact forces in the DEM model. This method was extended with the energy criterion of Griffith.

The results of calculations for concrete were presented at two international conferences: *Powder and Grains* (2017) and *Euro-C* (2018).

D. Fracture model of rock under hydraulic pressure during hydro-fracturing using a coupled DEM/CFD approach

The recent area of my research interests is the modelling fracture in natural rocks under hydraulic pressure during a hydro-fracturing process. The scientific work began two years ago with the cooperation with the National Geological Institute in Warsaw within the BLUE GAS - POLISH SHALE GAS grant. Together with colleagues from our department under the supervision of Prof. J. Tejchman, we have extended the DEM model by the presence of fluid based on CFD. The novelty of the program was the exact meshing of geometric and topological changes of rocks to accurately track the pressure changes in pores. I carried out a number of calculations with the DEM/CFD coupled model for rocks with different internal structure. Then we continued the research program by extending and improving the model (e.g. an additional gas phase was added). Our research works resulted in obtaining the NCN grant in 2019 by Prof. J. Tejchman (Appx. 5: II.J.5) in which I now take a part.

The results on hydro-fracturing were discussed in the article from the JCR list that is under review and during international conferences: *YADE Workshop* (2018), *ComGeo* (2018) and *ECCM-ECFD* (2018).

During my scientific work, I was the co-author of ***8*** *articles in the JCR journals: Granular Matter (4), Engineering Fracture Mechanics (1), International Journal of Damage Mechanics (1), Theoretical and Applied Fracture Mechanics (1) and Cement and Concrete Research (1).*

6. Didactic activities

Since my employment at Gdańsk University of Technology (July 2010), I conducted didactic activities in Civil Engineering, Environmental Engineering and Geodesy. For last years, I had classes from the following subjects (Appx. 5: III.J):

- Construction Materials (undergraduate studies) – laboratory classes,
- Basic Building Engineering I (undergraduate studies) – tutorials and projects,
- Basic Building Engineering II (undergraduate studies) – tutorials and projects,
- Basics of Construction Technology (undergraduate studies) – lectures and projects (the person responsible for the subject),
- Strengthening of Basic Building Structures (graduate studies) – projects,
- Municipal and Industrial Structures (undergraduate studies) – lectures and tutorials (the person responsible for the subject),

- Master Seminar (graduate studies) – in English.

Since 2010 I was the supervisor of 36 and the reviewer of 39 bachelor theses and the supervisor of 7 and the reviewer of 20 master theses on stationary and non-stationary studies (Appx. 5: III.J).

7. Organization activities, scientific cooperation and popularisation of science

During my scientific work, I cooperated not only with Gdańsk University of Technology or the University of Grenoble. I cooperated also with Koszalin University of Technology (with Prof. D. Leśniewska) in the research grant of the National Science Centre (NCN) (Appx. 5: II.J.2). The results from that cooperation were published in the paper in the journal from the JCR list (Appx. 5: II.A.1) and presented in the international conferences e.g. *Powder and Grains* (2013), *Geomechanics from Micro to Macro* (2014), *IWBDG* (2017) (Appx. 5: II.L and III.B). Since January 2016, I also started a cooperation with University of Melbourne (Prof. A. Tordesillas) to develop a method for early detection of cracks in concrete elements under tension (presentations at *Powder and Grains* (2017) and *Euro-C* (2018)).

During my research works (after PhD) I fully participated in 3 scientific grants of the National Science Center NCN (one under the supervision of Prof. D. Leśniewska in 2013-2016 and two under the supervision of Prof. J. Tejchman in 2018-till now and 2019-till now). In addition, I participated for nine months in the NCBiR Blue-Gas grant (2017), for two years in the NCN grant on the deterministic and statistical size effect in brittle materials under the direction of Prof. J. Tejchman (2017) and 3 years in European grant (2011-2014) (Appx. 5: II.J.2).

Since November 2016 I am an administrator of the website of the Department of Building and Material Engineering. I am also co-responsible for the powerful computers used by all researchers in our department.

I have participated in several scientific conferences (Appx. 5: II.L and III.B). I have taken part in 14 national conferences (French and Polish) and 16 international conferences wherein I had in total 25 oral presentations. The most important conferences which I attended after the PhD defence in France are: “Computational Modelling of Concrete and Concrete Structures” *EURO-C* (2014, 2018), “Fracture Mechanics of Concrete and Concrete Structures” *FraMCoS* (2013, 2016), “Particle-based Methods: Fundamentals and Applications” *Particles* (2013, 2015, 2017), “Computational Modelling of Fracture and Failure of Materials and Structures” *CFRAC* (2015) and “Powder and Grains” *P&G* (2017).

In May 2016, 2017 and 2018, I actively participated in the Baltic Science Festival held at the Gdańsk University of Technology where I presented the lecture "*Everything consists of the grains*" (Appx. 5: III.A.1).

Since 2017 I prepared 3 reviews of papers submitted to the international journals from JCR list: *Engineering Fracture Mechanics, Cement and Concrete* and *Soils and Foundations* (Appx. 5: III.P).

My Hirsch index and the number of citations are (on 20.02.2019):
Web of Science (*All Databases*): ***h=5***, number of citation - 130 (without self-citation - 107),
Web of Science (*Core Collection*): ***h=5***, number of citation - 125 (without self-citation - 102),
Scopus: ***h=6***, number of citation - 177.