Załącznik /Appendix 4

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

Contents:

1. **Name and surname**

   Jerzy Bobiński

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. 18.12.1997. Master of Science, discipline: Civil Engineering, specialization: Structural Engineering. Gdansk University of Technology, Faculty of Civil Engineering.
2. 15.02.1999. Bachelor of Science, discipline: Mathematics, specialization: Informatics. University of Gdansk, Faculty of Mathematics and Physics.
3. 20.12.2006. PhD Degree in Technical Sciences, discipline: Civil Enginering. Gdansk University of Technology, Faculty of Civil and Environmental Engineering. Dissertation's title: Implementation and application examples of nonlinear concrete's models with non-local softening. Supervisor: Prof. Andrzej Jacek Tejchman-Konarzewski. Reviewers: Prof. Zenon Mróz, Prof. Jacek Chróścielewski.

3. **Information about employment in academic/research institutions**

1. 01.01.1999-31.01.2007 – research assistant (full time): Gdansk University of Technology, Faculty of Civil and Environmental Engineering.
2. 01.02.2007-31.01.2015 – assistant professor (full time): Gdansk University of Technology, Faculty of Civil and Environmental Engineering.
3. od 01.02.2015 – senior lecturer (full time): Gdansk University of Technology, Faculty of Civil and Environmental Engineering.

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**

   Numerical simulations of cracks in concrete within continuous, discontinuous and coupled approach

b. **Publications included in the scientific achievement**

1. Marzec I., **Bobiński J.**, Tejchman J., 2007. Simulations of spacing of localized zones in reinforced concrete beams using elasto-plasticity and damage mechanics with non-local softening. Computers and Concrete**,** 4(5), 377-402.
2. Majewski T., **Bobiński J.**, Tejchman J., 2008. FE analysis of failure behaviour of reinforced concrete columns under eccentric compression. Engineering Structures, 30(2), 300-317.
3. **Bobiński J.**, Tejchman J., 2010. Continuous and discontinuous modeling of cracks in concrete elements. Computational Modelling of Concrete Structures, Proceedings of the EURO-C 2010 Conference, Rohrmoos/Schladming, Austria, 263-270, CRC Press, Taylor and Francis Group.

4. Syroka E., **Bobiński J.**, Tejchman J., 2011. FE analysis of reinforced concrete corbels with enhanced continuum models. Finite Elements in Analysis and Design, 47(9), 1066-1078.
5. **Bobiński J.**, Tejchman J., 2012. Application of eXtended Finite Element Method to cracked concrete elements – numerical aspects. Archives of Civil Engineering, 58(4), 409-431.
6. **Bobiński J.**, Tejchman J., 2011. Simulations of fracture in concrete elements using continuous and discontinuous models. Mechanics and Control, 30(4), 183-193.
7. Marzec I., Skarżyński Ł., **Bobiński J.**, Tejchman J., 2013. Modelling reinforced concrete beams under mixed shear-tension failure with different continuous FE approaches. Computers and Concrete, 12(5), 585-612.
8. **Bobiński J.**, Tejchman J., 2014. A constitutive model for concrete based on continuum theory with non-local softening coupled with eXtended Finite Element Method. Computational Modelling of Concrete Structures, Proceedings of the EURO-C 2014 Conference, St. Anton am Arlberg, Austria, Vol. 1, 117-126, CRC Press, Taylor and Francis Group.
9. **Bobiński J.**, Tejchman J., 2014. Numeryczne modelowanie betonu niezbrojonego dla mieszanego rodzaju zniszczenia przy zastosowaniu podejścia ciągłego i nieciągłego. Inżynieria Morska i Geotechnika, (5), 536-542.
10. **Bobiński J.**, Tejchman J., 2016. Comparison of continuous and discontinuous constitutive models to simulate concrete behaviour under mixed-mode failure conditions. International Journal for Numerical and Analytical Methods in Geomechanics, 40(3), 406-435.
11. **Bobiński J.**, Tejchman J., 2016. A coupled constitutive model for fracture in plain concrete based on continuum theory with non-local softening and eXtended Finite Element Method. Finite Elements in Analysis and Design, 114, 1-21.

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

Cracking is one of the most important features of concrete. It is responsible for the stiffness degradation and the strength decrease and it precedes the failure of the element or the entire structure. At the beginning a thin band of microcracks is created; it is called fracture process zone (FPZ). With the increase of loading, a single discrete macrocrack is formed. The proper choice of the description of cracking (fracture) is of major importance to obtain consistent with experiments proper results.

There are two basic approaches to describe cracks within continuum mechanics. The first one describes them in a smeared sense as a zone of strain localisation (microcracks) with a finite width. To define the behaviour of concrete, elasto-plastic constitutive laws, continuum damage mechanics or coupled models, which link both mentioned failure mechanisms, can be used. These formulations take into account the softening of the material, so they have to be equipped with an information about the characteristic length of the microstructure to restore the well-posedness of the boundary value problem and to obtain mesh independent results. Information about the characteristic length can be provided e.g. by using non-local theory, gradient approach or microplane constitutive laws. The alternative option introduces displacement jumps along cracks and it preserves the continuity of the displacement field in the remaining part. Older solutions used interface elements defined along finite elements' edges. Modern formulations allow for defining displacement jumps inside finite elements. One of such approaches is eXtended Finite Element Method (XFEM). Smeared (continuous) models better describe the process of creation of microcracks, while discrete (discontinuous) approach is more suitable to define the propagation of macrocracks. Usually only one method is chosen and it is applied to describe the whole process of cracks' propagation. In the simulations of reinforced concrete elements, the issue of defining reinforcement bars and the bond-slip law between concrete and steel should be also properly solved.

During the preparation of my Dissertation I performed numerical simulations of concrete elements under (mainly) uniaxial stress conditions. The aim of my scientific activity after obtain PhD degree was the further development of constitutive laws for concrete and its application in numerical simulations of various benchmarks, in which complex stress states in concrete were produced. In my research work I focused on elements loaded monotonically in a static regime. New aspects of my research were: execution of numerical simulations of reinforced concrete elements for different boundary value problems, modification of used so far continuous constitutive laws, application of the discrete description of cracks in concrete (cohesive elements and XFEM) and formulation of the constitutive law for concrete with coupled: continuous-discontinuous description of cracks. As a regularisation method for continuous material laws, a non-local theory in an integral format was chosen. Its application enables to obtain mesh independent results, both at the global level (e.g. force – displacement curves) and at the local level (e.g. strain of stress fields). So sophisticated regularisation techniques usually are not available in commercial software. All numerical calculations were performed with the aid of Abaqus program. Due to the wide spectrum of performed research, my scientific activities were divided into the following, discussed independently, topics:

A. application of constitutive laws with non-local softening to simulating the behaviour of reinforced conrete elements,
B. smeared and discrete modeling of cracks in concrete elements,
C. constitutive law for concrete with a smeared-discrete description of cracks.

A. *Application of constitutive laws with non-local softening to simulating the behaviour of reinforced conrete elements*

The group of publications described below contains results of numerical simulations of various reinforced concrete elements. The aim of the numerical calculations was to verify the ability of "relatively" simple constitutive laws describing concrete (and also a reinforcement steel and a slip between them) to simulate experiments and obtaining realistic results. To describe concrete constitutive laws formulated during the work on my Dissertation, with some extra modifications introduced during analyses, were used. Reinforcement steel was modelled as an elasto-plastic material (von Mises criterion). Numerical simulations described in this Section were performed by my colleagues from the Department: Dr. E. Korol, T. Majewski, Dr. I. Marzec and Dr. Ł. Skarżyński.

The first paper (item 4.b.1) contained results of simulations of reinforced concrete beams under bending with longitudinal reinforcement only (no stirrups) loaded symmetrically with two concentrated loads. To describe concrete, the elasto-plastic constitutive law with a Drucker-Prager criterion in compression and a Rankine criterion in tension with non-local softening for both conditions or continuum damage mechanics model was used. The stochastic distribution of the tensile strength using Box-Müller algorithm was assumed. The slip between concrete and reinforcement bars was described according to the bond-slip law proposed by Dörr. In the calculations the influence of the characteristic length, the fracture energy, the tensile strength, the reinforcement ratio, the position of concentrated forces and the initial stiffness of the bond-slip law was examined. Simulations have shown the crack spacing increases with increasing the characteristic length, but it decreased with increasing the fracture energy and the initial stiffness of the bond-slip relationship. Obtained crack spacing values were smaller than values obtained from analytical formulas. Calculated load bearing capacities were close to experimental outcomes by Walraven [1]. The size effect in shear for beams with different dimensions was also properly reproduced.

The second article (item 4.b.2) concerned of numerical simulations of reinforced concrete columns under eccentric compression. To describe concrete, the elasto-plastic constitutive law with a Drucker-Prager criterion in compression and a Rankine criterion in tension with non-local softening for both conditions was used. The slip between concrete and reinforcement bars was described according to the bond-slip law proposed by Dörr. 2D and 3D simulations were performed. The influence of the slenderness, the reinforcement ratio, the characteristic length, the initial stiffness of the bond-slip law and the fracture energy was investigated. Obtained crack spacing values were close to values from analytical formulas. A good agreement with results from experiments by Kim and Yang [2] was achieved.

The next publication (item 4.b.4) presented results of numerical simulations of short reinforced concrete corbels. Concrete behaviour was described with the one of three constitutive laws. The first option was to use the elasto-plastic law with a Drucker-Prager criterion in compression and a Rankine criterion in tension. The second alternative was based on isotropic damage mechanics. The last one utilises an anisotropic model with orthotropic smeared cracks (fixed or rotating formulation). To take into account the slip between concrete and reinforcing bars, I implemented a formulation from CEB-FIB Code (Dörr relationship was also used). Numerical results were compared with experimental outcomes obtained by: Campione et all. [3], Mehmel and Freitag [4] and Fattuhi [5]. In the case of simulations with the elasto-plastic constitutive law, a good agreement of load bearing capacities and crack patterns was achieved. The choice of the bond-slip law or the perfect bond assumption between concrete and reinforcement had no effect on force-displacement curves. Numerical calculations with isotropic and anisotropic damage models resulted in worse agreement with experimental results.

The last paper (item 4.b.7) was about numerical simulations of short reinforced concrete beams with longitudinal reinforcement only (without stirrup) under bending. As a starting point experiments conducted by Walraven i Lehwalter [6] were chosen, in which four geometrically similar (with different dimensions) specimens were tested. To describe concrete three constitutive laws used previously in simulations of short corbels and a coupled model linking isotropic damage degradation with elasto-plasticity formulated in the effective stress space were adopted. The slip between concrete and reinforcement bars was described according to the bond-slip law proposed by Dörr. All four material models produced similar maximum loads for different beam sizes comparing to experimental values. The size effect observed in experiment was also properly reproduced with all constitutive laws. Discrepancies occurred in the analysis of crack patterns. The best results were given by elasto-plastic and coupled models, medium – anisotropic smeared crack model and the worst – isotropic damage mechanics. Crack spacing values obtained in simulations and read from experimental data were significantly smaller than calculation from analytical formulas.

Results of numerical calculations were published in the following journals from the JCR list: Computers and Concrete (item 4.b.1 and 4.b.7), Engineering Structures (item 4.b.2) and Finite Elements in Analysis and Design (item 4.b.4). Short review of the constitutive laws for concrete and reinforced concrete was given in the paper [Appx 5, item II.E.12]. Obtained results and conclusions were also presented at the international conferences: WCCM 2006 (Appx. 5, item II.L.12), CMM 2007 (Appx. 5, item III.B.9) and CMM 2009 (Appx. 5, item III.B.13).

B. Smeared and discrete modeling of cracks in concrete elements

To verify the ability of different constitutive laws for to describe concrete's behaviour under complex stress states I executed numerical simulations of two known boundary value problems. First of them was Nooru-Mohamed test [7]. In this experiment the square concrete specimen with two notches located at the middle of the vertical edges is subjected to horizontal shear first. When a specified value of the horizontal force is attained, the specimen is subjected to a displacement controlled vertical tension (the value of the horizontal force is kept constant). Two less or more curved cracks are created in the element (their curvature depend on the level of the horizontal force). As a second benchmark I choose a beam with a notch under anti-symmetric loading (Schlangen test [8]). In the experiment a curved crack propagating from the vertical notch located in the middle of the top horizontal edge towards one of the bottom supports was observed. An extra difficulty in simulating this problem was a need to control the loading using an arc length control method.

I analysed the performance of the following continuum constitutive laws with non-local softening: elasto-plastic with a Rankine criterion, continuum damage mechanics with isotropic stiffness degradation (and different definitions of the equivalent strain measure) and anisotropic smeared crack model (with fixed or rotating cracks). I also executed simulations assuming discrete description of cracking and using interface cohesive elements. The elasto-plastic model allowed to obtain realistic force-displacement curves and good crack patterns (although cracks were too straight comparing to experiment). The performance of the damage model with isotropic stiffness degradation depended on the assumed equivalent strain measure definition. I obtained results consistent with experimental data with the modified von Mises definition, while the use of the strain equivalence of the Rankine criterion produced bad outcomes. The anisotropic smeared crack model (in both versions) did not allow to obtain proper results. The best agreement with experiment was achieved with the aid of cohesive elements.

Results of numerical calculations from the first stage were published in a peer-reviewed journal: Mechanics and Control (item 4.b.5). Obtained results and conclusions were presented and printed in the proceedings of the Euro-C 2010 conference (item 4.b.3 and Appx. 5, item II.L.23). They were also discussed during the international conferences: CFRAC 2007 (Appx. 5, item II.L.15), CMM 2007 (Appx. 5, item II.L.16), AMCM 2008 (Appx. 5, item II.L.17), WCCM 2008 (Appx. 5, item II.L.18), SolMech 2008 (Appx. 5, item II.L.19), ComGeo 2009 (Appx. 5, item II.L.20) and CMM 2009 (Appx. 5, item II.L.21).

After my return from PostDoc scholarship at the Delft University of Technology in the Netherlands (Appx. 5, item III.J.6) I applied eXtended Finite Element Method (XFEM) to cracks' simulations in concrete. There is available an implementation of this method in Abaqus program, but it allows for using only selected types of finite elements and does not allow the user for the full control over the cracks' propagation process. Therefore I decided to implement an author's version of XFEM. Due to the limitations in the access to the code, the implementation required:

1. identification of information about the topology of the defined finite elements' mesh (nodes' and elements' definitions) – it was necessary in defining the crack propagation in finite elements,
2. „take over control" on the convergence algorithm in Abaqus program (to detect iterations, in which addition of new crack segments is possible and to, eventually, restart calculations in the actual increment) – an extra code for independent calculation of maximum force residua and displacement corrections had to

defined,

3. formulation of the a standard finite element (without crack) and a cracked finite element with a discrete softening law in the crack,
4. definition of crack initiation/propagation criteria and the direction of its propagation,
5. preparation of extra procedures to visualise discrete cracks.

These modifications of Abaqus program were much more sophisticated than conventionally used extensions, as definitions of user's finite elements or material laws. The implemented algorithm was verified by executing several numerical tests. I investigated the effect of the size and the type of used finite element as well as the choice of the assumed integration scheme in cracked elements. Results from these tests verified the correctness of the implementation and they were independent on the FE mesh. They also showed a big influence of the crack direction propagation criteria on results.

Results of numerical calculations from the second stage were published in a peer-reviewed journal: Archives of Civil Engineering (item 4.b.6). Obtained results and conclusions were presented at internation conferences: CMM 2011 (Appx. 5, item II.L.24) and AMCM 2011 (Appx. 5, item II.L.25).

In the last part of my research I returned to simulations of Nooru-Mohamed test. I focused my attention on the definition of the material in the tension – compression regime. To evaluate the agreement of numerically obtained cracks trajectories I introduced the definition of the 'crack's height' measured as a distance between a horizontal line joining two notches and a most distant point on the crack. I extended Rankine plasticity condition by a linear dependence in a tension – compression regime (tensile strength linearly decreased with increasing the absolute value of the perpendicular compressive stress). Numerical calculations showed that this modification did not produce the results closer to experiments. I made the similar modification in the definition of the equivalent strain based on Rankine criterion. To obtain the results close to experimental outcomes, it was necessary to unphysically increase (not to decrease) the strength in the tension – compression regime. This observation also explains the correctness of calculated results when using continuum damage mechanics with the modified von Mises equivalent strain definition. It also suggests the necessity of using anisotropic relationships to describe concrete. Results obtained with XFEM were close to experiments, but obtained cracks were too 'high' comparing to averaged experimental crack heights.

Results of numerical calculations from the third stage were published in a journal from JCR list: International Journal for Numerical and Analytical Methods in Geomechanics (item 4.b.10) and in a peer-reviewed journal: Inżynieria Morska i Geotechnika (item 4.b.9). Obtained results and conclusions were also presented at the international conference: ECCOMAS 2012 (Appx. 5, item II.L.27).

C. *Constitutive law for concrete with a smeared-discrete description of cracks*

The application of smeared or discrete approach to describe the crack's behaviour from its initiation till the creation of a macrocrack is a simplification. More precise description should take into account both phases present in the cracking process. On the basis of these assumptions, I formulated a constitutive law coupling smeared (continuous) and discrete (discontinuous) crack's description. To simulate smeared cracks I used one of the two material models with non-local softening: elasto-plastic constitutive law with Rankine criterion or isotropic damage approach. To describe discrete cracks, eXtended Finite Element Method (XFEM) was used. The direction of the crack propagation was determined from the distribution of the softening variable at the front of the crack tip. Transition from continuous into discontinuous description can be defined for any point on the softening curve. I analysed the process of energy dissipation to guarantee the constant value of the total fracture energy, independently on the choice of the transition point from continuous into discontinuous description. In the case of isotropic damage model it requires the modification of the softening curve assumed for a discrete crack (independently for each crack's segment at the time of its creation). The definition of a crack segment in a finite element resulted in "turning off" non-locality in perpendicular (to this segment) finite elements with a band equal to the localization width to avoid double description of the softening process. The transition point between both formulations was the source of the convergence problems in numerical simulations. To overcome (partially) this issue, I introduced so called "mixed zone" at the crack tip with a length being a model parameter. Its presence delays non-locality "turning off" process. I proposed also some modifications of the standard algorithm used in solving FEM global system of equations, to take into account specific features of the formulated constitutive law. To verify the new material model, I performed numerical simulations of uniaxial tension, three point bending, Nooru-Mohamed [7] and Schlangen [8] tests. Numerical calculations confirmed the correctness of the formulated constitutive law, although they exhibited a slow convergence. Based on displacement fields obtained from experiment (performed by Dr. Ł. Skarżyński with the aid of Digital Image Correlation method – DIC), I tried to identify the transition point in the three point bending test. It was estimated for the tensile stress equal to 20% of the tensile strength. This topic was realised with the research program [Appx. 5, item II.J.2].

Problems with finding the convergence in numerical simulations with coupled model motivated me to improve it. The main idea was to replace a distinct jump between continuous and discontinuous description of cracking with a smooth and gradual transition (starting and ending points on the softening curve). Therefore I defined transfer/transition function ρ with values changing from 0 (no discrete description) to 1 (no smeared description) as a function of a softening variable or a distance from the crack tip. When a new crack segment is defined, finite elements and nodes located in a band perpendicular to this segment, are doubled. The width of this band should include the whole width of the localisation zone. Bottom layer of finite elements describes continuous cracks (with the weight 1-ρ) and the top one – discontinuous description (with the weight ρ). Such solution eliminates necessity of "turning off" non-locality and extra modifications of the FEM algorithm.

Results of numerical calculations obtained with the original formulation of the coupled model were presented in a journal from JCR list: Finite Elements in Analysis and Design (item 4.b.11). Obtained results and conclusions were presented and printed in the proceedings of the Euro-C 2014 conference (item 4.b.8 oraz Appx. 5, item II.L.32). They were also discussed during international conferences: FraMCoS 2013 (Appx. 5, item II.L.29) and CFRAC 2013 (Appx. 5, item II.L.30). The improved version of this constitutive law was presented at international conferences: CFRAC 2015 (Appx. 5, item II.L.34) and CMM 2015 (Appx. 5, item II.L.35). The lastest outcomes will be presented during the conference FramCoS 2016 in Berkeley (USA).

Summary

Results of numerical simulations of concrete and reinforced concrete elements described above proved the ability of constitutive laws used to reflect the behaviour of real specimens. This verification was performed on many various boundary value problems. Three method of describing cracking in concrete were taken into account: smeared, discrete and coupled. In the simulations with continuum constitutive laws, non-local theory confirmed its effectiveness in obtaining results independent from FE mesh.

The most important achievements, resulted from performed research, are:

1. formulation/modification and implementation of continuum constitutive laws with non-local softening; these constitutive laws allow for obtaining results independent from the FE mesh,
2. application of defined material models to execute series of numerical simulations of different reinforced concrete element and obtaining outcomes consistent with experimental data,
3. application of continuum constitutive laws for concrete to perform numerical simulations of concrete and reinforced concrete elements in Dissertations and other scientific activities by colleagues from the Department (E. Korol, T. Majewski, T. Małecki, I. Marzec, M. Ostaszewska, Ł. Skarżyński, M. Skuza, Ł. Widuliński),
4. implementation in Abaqus program author's code of eXtended Finite Element Method (XFEM) allowing for full control on modelling the process discrete

cracks' propagation in concrete,

5. analysis of continuous and discrete constitutive laws for concrete in complex stress states showing the importance of the proper definition of the material model in tension – compression regime,
6. formulation of the constitutive law for concrete with continuous-discontinuous description of cracking with the proper formulation (with respect to softening) for both phases and identification and solution of numerical issues.

Obtained results (material models) can be applied to:

1. perform numerical simulations of other concrete and reinforced concrete elements (e.g. splitting test, beams under torsion),
2. analysis of the influence of selected geometrical and material parameters on the behaviour of concrete and reinforced concrete specimens,
3. formulation of the constitutive laws to describe non-mechanical phenomena coupled with stress analysis (e.g. creep, concrete maturing, corrosion),
4. simulations of cracks propagation in concrete elements with taking into account the change of the cracking type (continuous-discontinuous law).

At the same time, performed numerical calculations indicated some new research topics, which could improve and extend capabilities of my algorithms. One of such issues is a problem of taking into account in solving the global system of equations of FEM interactions between integration points (finite elements), which are created in calculating non-local quantities for a given point (so called non-local stiffness matrix). Implementation of such stiffness matrix in Abaqus program is currently under preparation. The second task is the extension of capabilities of eXtended Finite Element Method (XFEM). The existing implementation allows for defining and propagating of many independent cracks, which have to start at the specimen's edges and they cannot join/intersect. The improved version of the algorithm will allow for initiating cracks in any points in the specimen and it will provide the possibility to join and intersect cracks. It will enable to perform numerical calculations of reinforced concrete elements. This algorithm will be also used to simulate cracks' creation and propagation with taking into account the mesostructure of concrete. Is topic is realised with the cooperation with W. Trawiński, PhD student from the Department.

[1] Walraven, J., 1978. The influence of depth on the shear strength of lightweight concrete beams without shear reinforcement. TU-Delft Report 5-78-4, Delft University.

[2] Kim J, Yang J., 1995. Buckling behaviour of slender high-strength concrete columns. Engineering Structures, 17(1), 39-51.

[3] Campione G., La Mendola L., Papia M., 2005. Flexural behavior of concrete corbels containing steel fibres or wrapped with FRP sheets. Materials and Structures. 38(6), 617-625.

[4] Mehmel A., Freitag W., 1967. Tragfahigkeitsversuche an Stahlbetonkonsolen. Bauingenieur. 42(10), 362-369.

[5] Fattuhi, N.I., 1990. Strength of SFRC corbels subjected to vertical load. Journal of Structural Engineering ASCE. 116(3), 701-718.
[6] Walvaren J., Lehwalter N., 1994. Size effects in short beams loaded in shear. ACI Structural Journal, 91(5), 585-593.
[7] Nooru-Mohamed M, B, 1992. Mixed-mode fracture of concrete: an experimental approach. PhD Thesis, Delft University of Technology, Delft.
[8] Schlangen E., 1993. Experimental and numerical analysis of fracture process in concrete, PhD Thesis, Delft University of Technology, Delft.

5. Description of other academic and research achievements

<u>Before obtaining PhD degree</u>

My first contact with scientific activity I owe to Dr. Piotr Korzeniowski from Gdansk University of Technology. When I was a student of Civil Engineering, he invited me to write a program which calculated the load bearing capacity of reinforced concrete columns under compression according to EuroCode 2 (Appx. 5, item III.B.1).

After starting my work as an assistant at the Gdansk University of Technology (January 1999) I began the cooperation with Prof. J. Techman. This cooperation is continued till today. At the beginning I was to examine the load bearing capacity of reinforced concrete beams under simultaneous bending, shear and torsion. This topic was modified and I focused my scientific attention on, generally speaking, numeric simulations of concrete (and reinforced) concrete elements. From the very beginning I was using Abaqus program. I spent three months in Karlsruhe within Socrates-Erasmus program, under the supervision of Prof. J. Eibl, to learn this software (Appx. 5, item III.L.2). Initially I was dealing with constitutive laws defined within continuum mechanics. These laws were defined with softening, so they had to be equipped with a regularisation method to obtain mesh independent results. In my case it was a non-local theory in an integral format. Next important internship took place at the Dortmund University (Appx. 5, item III.L.3). Information given by Dr. T. Maier accelerated and simplified my work on implementing non-local theory into Abaqus program.

Finally the title of my Dissertation was "Implementation and application examples of nonlinear concrete models with non-local softening". Dissertation was defended with distinction on 20 December 2006. Its main aim was the application of the non-local theory into different constitutive laws defined within continuum mechanics to perform numerical simulations of concrete (and reinforced concrete) elements under various two-dimensional quasi-static boundary problems. Detailed aims (achievements) were:

1. implementation of non-local algorithms into commercial program Abaqus/Standard in coupling with various constitutive laws,
2. investigation of the influence on results of different non-local parameters,
3. comparison of correctness and effectiveness of different non-local algorithms in elasto-plasticity,

Dissertation contained:

1. description of concrete properties, phenomenon of strain localisation and regularisation methods,
2. basic equations forming Finite Element Method and constitutive laws used to describe the behaviour of concrete, steel and slip between them,
3. presentation of the implementation method of the non-local approach into Abaqus/Standard program, with the special attention paid to data gathering from neighbour integration points, symmetry and barriers in non-local averaging,
4. numerical simulations for various boundary problems as a verification of a non-local models used with different constitutive laws for concrete.

Set of used constitutive laws for concrete contains an elasto-plastic law with a Rankine criterion and non-local softening, an elasto-plastic law with a Drucker-Prager criterion and non-local softening and model with isotropic stiffness degradation defined within continuum damage mechanics. Verification process consists of numerical simulations of uniaxial compression, uniaxial tension and three-point bending tests. In all calculations obtained results were independent from FE mesh. These results were presented in a journal from JCR list: Computers and Concrete (Appx. 5, item II.A.1) and in peer-reviewed journals: TASK Quarterly (Appx. 5, item II.E.4) and Archives of Hydro-Engineering and Environmental Mechanics (Appx. 5, item II.E.6). Obtained results and conclusions were also presented and printed in the proceedings of the conferences: in Karlsruhe in 2004 (Appx. 5, item II.E.5 and item III.B.2) and Powders and Grains 2005 (Appx. 5, item II.E.7 and item III.B.4). They were also discussed during international conferences: CMM 2003 (Appx. 5, item II.L.7), SEMC 2004 (Appx. 5, item III.B.3) and AMCM 2005 (Appx. 5, item III.B.5) and national conferences: in Zielona Góra in 2001 (Appx. 5, item II.L.1), Gdańsk-Sobieszewo in 2001 (Appx. 5, item II.L.4) and in Wisła in 2002 (Appx. 5, item II.L.6).

In the Dissertation the ability of the non-local theory to simulating the deterministic size effect was also examined. Uniaxial tension, uniaxial compression and three-point bending of beams with notches tests of elements of different sizes were numerically simulated. In all calculations the elasto-plastic material with the appropriate criterion and isotropic damage model were used. Numerical simulations confirmed the ability of non-local models to reflect the size effect phenomenon. They were published in peer-reviewed journals: Archives of Civil Engineering (Appx. 5, item II.E.8), TASK Quarterly (Appx. 5, item II.E.9) and in the paper [Appx. 5, item II.E.11]. Obtained results and conclusions were also presented at international conferences: Cure 2004 (Appx. 5, item II.L.8), CMM 2005 (Appx. 5, item II.L.9), AMCM 2005 (Appx. 5, item III.B.6) and at national conference in Krynica in 2005 (Appx. 5, item II.L.10).

One of the last topics analysed in my Dissertation was the formulation and the implementation of the constitutive law dedicated to simulating the behaviour of concrete elements under cyclic loading. A coupling between elasto-plastic law with Rankine and Drucker-Prager criteria (defined in effective stress space) without softening with a non-local version of the isotropic damage model. The verification was performed for the four-point bending test of the concrete beam with a notch under cyclic loading. Good agreement with experimental data by Hordijk was achieved. Numerical results were presented in a journal from JCR list: Journal of Theoretical and Applied Mechanics (Appx. 5, item II.A.2). Obtained results and conclusions were presented and printed in the proceedings of the Euro-C 2006 conference (Appx. 5, item II.E.10 and item II.L.11). They were also discussed during international conferences: WCCM 2006 (Appx. 5, item II.L.13) and SolMech 2006 (Appx. 5, item II.L.14). Next the problem of numerical simulations of concrete under cyclic loading has been examined by my colleague from the Department, Dr. I. Marzec.

My additional activity, not connected with PhD research, concerned practical aspects of application FEM in engineering problems and it was a consequence of making projects and technical opinions. Applied numerical methods and obtained results during the designing of the foundation slab (Appx. 5, item II.B.1) were presented at the conference in Wenecja (Poland) in 2001 (Appx. 5, item II.E.1 and item II.L.2). During the same conference results of calculations of reinforced concrete slabs-column floors, with the attention paid to defining loads from interior walls were shown (Appx. 5, item II.E.2 and item II.L.3). Results from report about calculating internal forces in a reinforced concrete tank due to the thermal loading (Appx. 5, item III.M.4) were discussed at the conference in Łańsk in 2002 (Appx. 5, item II.L.5).

<u>After obtaining PhD degree</u>

The remaining scientific and research accomplishments after obtaining PhD degree were the supplement or the extension of my basic scientific activity. Some of them were the continuation of analyses presented in my Dissertation while the others were about completely new topics. These accomplishments were grouped into three topics:

D. analysis of crack spacing in reinforced concrete elements under tension,
E. size effect in concrete elements under bending,
F. numerical simulations of shear zones in soils.

In addition, results of the majority of my numerical simulations, including also the description of constitutive laws presented in my Dissertation and formulated after obtaining PhD degree (topics A, B, D and E), were collected in the monography published by Gdansk University of Technology Publishing House (Appx. 5, item II.E.15). Its improved and extended version (e.g. results of numerical simulations of discrete cracks in concrete) was published by Springer (Appx. 5, item II.E.16).

Additional topics, not covered in points A-F, concerned numerical aspects of application of the non-local theory. Methods of implementation of constitutive laws with non-local softening were presented at the conference MHM 2007 (Appx. 5, item III.B.10), while comparison of different algorithms used in non-local plasticity was discussed at the conference COMPLAS 2009 (Appx. 5, item II.L.22).

D. Analysis of crack spacing in reinforced concrete elements under tension

In my Dissertation the bar under the tension was the only one numerical test simulating the behaviour of a reinforced concrete element. Original calculations were performed with elasto-plastic constitutive law using the Rankine criterion with non-local softening and the bond-slip law by Dörr. Box-Müller algorithm was used to define the stochastic distribution of the tensile strength in the specimen. To investigate the influence of the bond-slip on the results, I implemented advanced formulation proposed by den Uijl and Bigaj. Numerical simulations, performed by T. Małecki, Dr I. Marzec and Ł. Widuliński, have shown that only the initial stiffness of the bond-slip law influences the results in this problem. In the simulations the influence of the reinforcement ratio and the characteristic length was also examined. Numerical calculations have shown that the crack spacing increases with increasing the characteristic length, but it decreased while increasing the reinforcement ratio, fracture energy and initial stiffness of the bond-slip law. No impact of the cross section area and confining pressure was observed. Cracks spacing obtained from numerical calculations was compared with analytical relationships. The best agreement was achieved for the CEB-FIB formula.

Results of numerical calculations were published in a journal from the JCR list: Mechanics Research Communications (Appx. 5, item II.A.3) and in a peer-reviewed journal: Archives of Civil Engineering (Appx. 5, item II.E.13). Obtained results and conclusions were also presented at the international conference: WCCM 2006 (Appx. 5, item II.L.12).

E. Size effect in concrete elements under bending

Size effect in concrete elements was the second topic I started to analyse while preparing my Dissertation. After obtained my PhD degree, first I performed numerical simulations of geometrically similar concrete beams with a notch under bending. I used elasto-plastic constitutive law with a Rankine criterion and non-local softening. Spatially correlated tensile strength random fields were prepared by Dr J. Górski from Gdansk University of Technology. In the analysis of the stochastic size effect, the influence of the correlation length was examined. Its change does not influence on averaged beams' load bearing capacities, but the decrease of the correlation length causes the decrease of the scatter of calculated maximum loads. In the second stage, concrete beams without notches were analysed. Numerical calculations were performed by Dr E. Korol, my colleague from the Department. The stronger stochastic size effect was obtained for beams without notches, comparing to results obtained for beams with notches. It was caused by a difference in a crack propagation pattern and its possible non-symmetric position (with a respect to a symmetry axis).

The topic of the deterministic and stochastic size effect in concrete (and reinforced concrete) beams under bending was undertaken by Dr E. Korol and it is successfully continued till today. Actually I analyse the problem of the deterministic size effect in axially loaded concrete specimens with notches/holes in the cooperation with Prof. Z. Mroz from Institute of Fundamental Technological Research Polish Academy of Sciences as a part of the research project [Appx. 5, item III.J.3].

Results of numerical calculations were published in a journal from the JCR list: Archives of Mechanics (Appx 5, item II.A.4). Obtained outcomes and conclusions were presented and printed in the proceedings of the Euro-C 2010 conference (Appx. 5, item II.E.14 and item III.B.16). They were also discussed during the international conferences:
CFRAC 2007 (Appx. 5, item III.B.8), AMCM 2008 (Appx. 5, item III.B.11), SolMech 2008 (Appx. 5, item III.B.12), CMM 2009 (Appx. 5, item III.B.14) and COMPLAS 2009 (Appx. 5, item III.B.15).

F. Numerical simulations of shear zones in soils.

Knowledge about assumptions and implementation methods of the non-local theory resulted in starting the cooperation with Dr W. Minkley from Institut für Gebirgsmechanik GmbH in Leipzig. The cooperation lasted in years 2006 and 2009 and it concerned the extension by the non-local theory of the selected constitutive laws used to simulate the behaviour of soils. Within this collaboration I implemented the non-local theory into the programs FLAC and UDEC created by ITASCA Group company. The non-local extension was added to an elasto-plastic constitutive law with a Mohr-Coulomb criterion and to an elasto-visco-plastic material description formulated by Minkley. As a result, a series of reports were written, in which the process of the implementation and results of numerical simulations performed for verification were described (Appx. 5, item II.B.2).

The second contact with soil mechanics occured during my one-year PostDoc scholarship at Delft University of Technology in the Netherlands (Appx. 5, item III.L.6). My supervisors were Dr R. Brinkgreve and Prof. L. Sluys. The stay in the Netherlands let me to gain knowledge about the theory assumptions and implementation methods of the eXtended Finite Element Method (XFEM). I participated in the research project [Appx. 5, item II.J.1] and I was responsible for the implementation of this method into the program Plaxis. To describe the shear in soils an elasto-plastic constitutive law was used with the Mohr-Coulomb criterion in a continuous format (without softening) and in a discrete format (with softening). As a result of my scholarship, a report was created (Appx. 5, item II.F.1), in which the main assumptions of XFEM, implementation details and results of several numerical simulations were described. Numerical calculations included e.g. uniaxial compression test, the direct shear test and the wall retaining problem. The topic of shear zones in soils was continued after my returning to Poland. The discrete model of shear zones for soils was implemented into Abaqus program. Results of numerical simulations were presented at the conference IWBDG 2014 (Appx. 5, item II.E.17 and item II.L.33).

6. Didactic activities

Since the start of my employment at Gdansk University of Technology (in 1999) I have classes on full-time studies in Civil Engineering (in the past also in Environmental Engineering). Currently I have classes from the following subjects (Appx. 5, item III.J):

1. Building Construction I (undergraduate studies) – tutorials and projects,
2. Building Construction II (undergraduate studies) – tutorials and projects,
3. Wooden Structures (undergraduate studies) – lectures and projects (person responsible for the subject),
4. Modern Wooden Structures (graduate studies) – lectures and tutorials (person responsible for the subject),
5. Design of Complex Engineering Structures (graduate studies) – tutorials and projects (person responsible for the subject),
6. Complex Concrete Structures (graduate studies) – tutorials and projects (classes conducted in English).

I prepared the program of the following subjects: Modern Wooden Structures and Design of Complex Engineering Structures. In the past I had project classes from Concrete Structures and Building Construction III (graduate studies) and classes from Building Construction in Environmental Engineering studies.

Since the year 2008 I have been the supervisor of 31 and the reviewer of 35 bachelor thesis and I have been the supervisor of 16 and the reviewer of 58 master thesis on full-time and part-time studies (Appx. 5, item III.J).

In the year 1999 I visited City University in Londyn (one-week short stay), within the TEMPUS program. Its purpose was to get knowledge about teaching methods used in the Great Britain (Appx. 5, item III.L.1).

I was the co-author of the auxiliary materials for the subject Building Construction I (together with my colleagues from the Department: M. Niedostatkiewicz, T. Majewski and M. Skuza). They were published by Gdansk University of Technology Publishing House in the year 2006 (Appx. 5, item III.I.1).

For my didactic achievements I was awarded by Rector of the Gdansk University of Technology with the individual award of the second degree (academic year 2000/2001), the individual award of the second degree (academic year 2001/2002) and the team award of the third degree (year 2006).

7. Organisation activities, scientific cooperation and populatisation of science

In years 2005-2008 I was a member of the Board of Faculty of Civil and Environmental Engineering. I was a participant of the team, which formulated the development strategy of the Faculty (years 2008-2009). I am involved in several tasks in my Department. I was responsible for preparing information about classes and office hours of all Department employees (till the year 2009). I am responsible for buying new computer software and hardware in the Department. Since the year 2001 I have been working in Academic Computer Centre in Gdansk (CI TASK), where I am a consultant of software used in mechanics and civil engineering (Abaqus, MSC software and, recently, Ansys).

I am an active participant of scientific conferences (Appx. 5, item II.L and III.B). I took part in 9 national conferences and 26 international conferences; I had (in total) 35 oral presentations. The most important cyclic conferences I attend are: Computational Modelling of Concrete Structures EURO-C (2006, 2010, 2014), Conference on Computer Methods in Mechanics CMM (2003, 2005, 2007, 2009, 2011, 2015) and Conference on Computational Modeling of Fracture and Failure of Materials and Structures CFRAC (2007, 2013, 2015). I was also a participant of the cyclic conferences Analytical Models and New Concepts in Concrete and Masonry Structures AMCM (2005, 2008, 2011) and Solid Mechanics Conference SolMech (2006, 2008).

I spent 3 months at Karlsruhe University under the supervision of Prof. J. Eibl within Socrates-Erasmus program (Appx. 5, item III.L.2). I also had scientific interships at Dortmund University and University of Kaiserslautern (Appx. 5, item III.L.3 and III.L.4). I took part in the course on modelling localisations of deformations run by Prof. M. Jirásek at Czech Technical University in Prague (Appx. 5, item III.L.5). The most important internship I attended was a one-year PostDoc scholarship at Delft University of Technology under the supervision of Dr R. Brinkgreve and Prof. L. Sluys (Appx. 5, item III.L.6). I also collaborated with Dr W. Minkley from Institut für Gebirgsmechanik GmbH in Leipzig (Appx. 5, item II.B.2).

Since they year 2009 I have prepared 6 reviews for papers submitted to international journals. Three of them were made for journals from the Journal Citation Reports (JCR) list: Journal of Civil Engineering and Management, Archives of Civil and Mechanical Engineering and Materials and Design (Appx. 5, item III.P).