Self-report (in English)

Appendix no 2b

Piotr Mackiewicz

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Piotr Mackiewicz

Wrocław, 24.03.2016

Self-report

1. **First name and last name**

   Piotr Mackiewicz

2. **Diplomas and degrees with the name, place and year of obtaining them and the title of the doctoral dissertation**

1995 **M.Sc.**
Faculty of Civil Engineering, Wroclaw University of Technology
Title thesis: "The project of roads for single family houses in the village of Bielany Wrocławskie"

2001 **doctor of technical sciences**
Institute of Civil Engineering, Faculty of Civil Engineering, Wroclaw University of Technology
Thesis title: "The influence of rheological properties of asphalt mixtures for pavement deformation"

3. **Information on previous employment in scientific institutions**

1995–2001 **assistant** in the Department of Roads and Airports at the Institute of Civil Engineering at the Faculty of Civil Engineering, Wroclaw University of Technology

since 2001 **assistant professor** in the Department of Roads and Airports at the Institute of Civil Engineering at the Faculty of Civil Engineering, Wroclaw University of Technology

4. **Achievements under paragraph 16 section 2 of the Act from the 14th March 2003 on Academic Degrees and Titles and on Degrees and Titles in Art (Dz. U. No. 65, item. 595 as amended.)**

a) Title of the scientific / artistic achievement

„Fatigue life of asphalt mixtures used in pavements".

b) (author / authors, title / titles of publication, year of publication, name of publisher)

Piotr Mackiewicz, monograph: „Fatigue life of asphalt mixtures used in pavements", 2016, University of Technology Press ISBN 978-83-7493-932-4.

c) Summary of the scientific / artistic work and the achieved results, together with the discussion of their possible usage and application

Purpose and scientific achievement

The main goal of this work is research, identification and analysis of parameters describing the fatigue cracks and their developments in the asphalt mixtures. Analyses of the microcracks and macrocracks were carried out in variable temperatures, load levels and different compositions of asphalt mixtures. I perfomed laboratory tests on prismatic samples subjected to cyclic bending.

The main objectives of the work were realized by formulating equations of cracking kinetics and fatigue characteristics for criteria of the emergence of macrocracks (N_c) and changes in energy $N_{\Delta wN}$). Then I have shown their usefulness in the predicting fatigue life. I showed that the use of fracture mechanics and the corresponding numerical model is effective in the analysis and evaluation of the crack propagation in mixtures used in the pavement, which is not possible in the case of conventional methods.

To achieve this objective I realized the following detailed subtasks:

1. Preparation of the test procedures which allow the registration of the speed of development and propagation of microcracks and macrocracks in the various conditions of temperature and load level, taking into account the samples of the notches.
2. Identification of the ratio in the energy change allowing to characterize the appearance of microcracks and macrocracks for the various temperatures and load level.
3. Development of criteria for predicting fatigue cracks in the tested mixtures and pavement models.
4. Identification of viscoelastic parameters and analysis of variability in the fatigue process.
5. Development of numerical models of fatigue tests allowing determination of the fracture parameters and equation of crack propagation kinetics.
6. Carrying out the measurement of air void in the asphalt mixtures using tomographic and microscopic studies allowing analysis of changes in the microstructural fatigue.
7. Developing of the pavement model including the origin of cracks and using the parameters describing the crack propagation and material properties.

The past practice shows that unambiguous criteria related to micro- and macrocracks does not apply in the assessment of the fatigue life of asphalt mixtures. In addition, the fatigue tests do not identify

reliable parameters related to mechanical cracking. That is why, it is justified to develop appropriate methods and criteria describing the phenomenon of cracking in asphalt mixtures.

Characteristics of the monograph

The monograph covers extensive subjects relating to fatigue phenomena occurring in asphalt mixtures. It is the result of studies carried out by many years on this phenomenon. I have distinguished research and modeling issues separately because of the extensive subject about fatigue. The diagram of the work is shown on Figure 1.

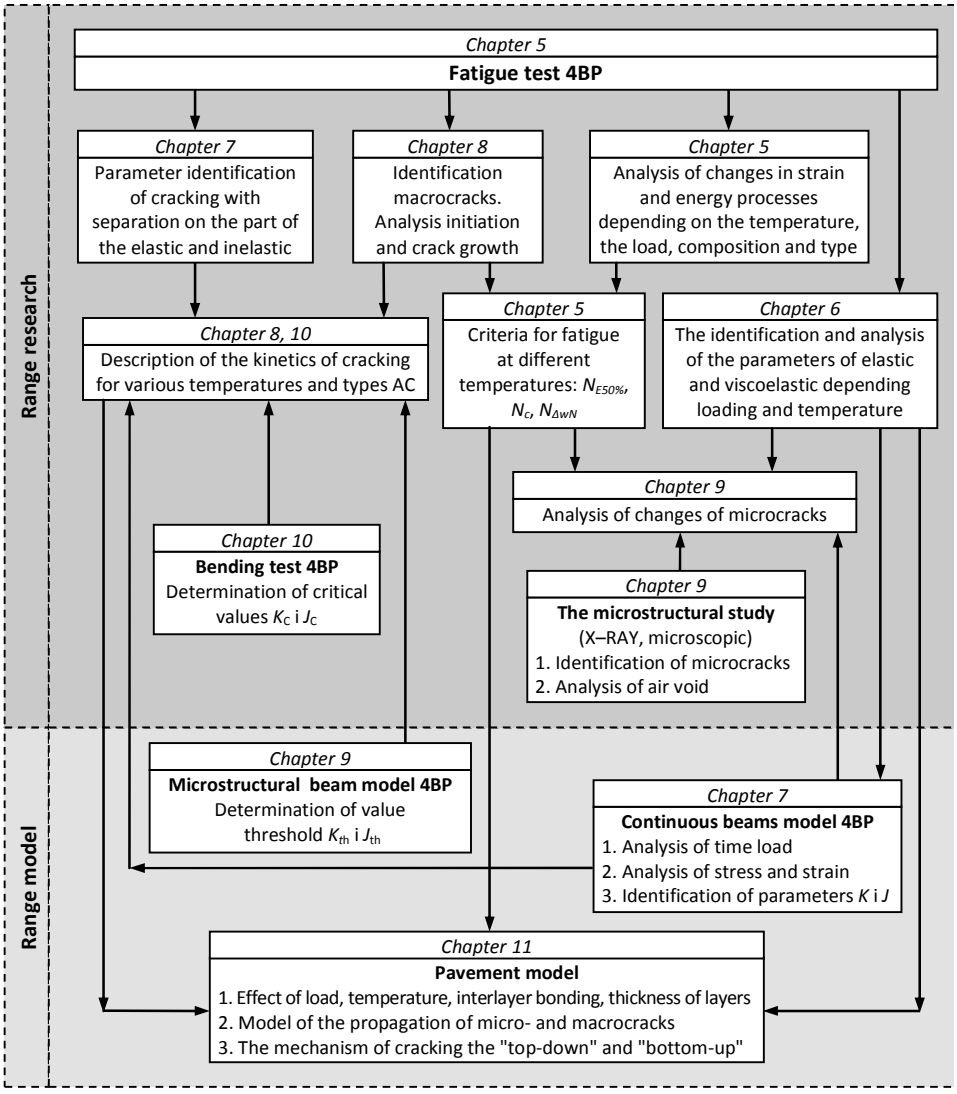

Figure 1. Diagram of the scope and problems discussed in the work

The research part includes dynamic fatigue and static bending tests. Based on their results, the criteria of fatigue parameters (classic $N_{E50\%}$ criterion, criterion macrocracks N_c, the criterion of energy change energy $N_{\Delta wN}$) and fracture critical parameters (critical stress intensity factor K_C, critical integral Rice J_C) were determined for selected mixtures devoted to the wearing, binder and base layers.. The criterion of

energy was linked with the accumulation and development of microcracks. In terms of macrocracks, I identified their initiation and development using the method of image capture. On this basis, I defined the criterion of the appearance of macrocracks.

A separate study was associated with the microstructural analysis of air voids. Using tomographic measurements and microscopic, I registered changes in free space of the selected mixture in the course of fatigue. I showed the effectiveness of the applied energy criterion analyzing the distribution of fatigue damage in the beam and tied them with a change of free space.

In the model part, I described models based on the four point beam test 4BP (continuous and microstructural models) that I used, among others, to identify the parameters used to develop equations to determine the kinetics of cracking and threshold parameters (K_{th}, J_{th}). I presented the pavement model taking into account the changing load conditions and appropriate material parameters depended on the temperature.,I set the stability of the pavement due to propagation of cracks based on the determined criterion of crack formation and crack kinetics equations based on the integral of Rice *J*..

The work was divided into twelve chapters. In the initial part of the work (Chapter Two), I made the overview the state of knowledge about fatigue. I pointed to the extensive subject of the fatigue in the pavement. In the review of methods for fatigue testing asphalt mixtures, I described the significant influence of research on the test results, including the type of load. Based on the review of the various criteria used in the assessment of fatigue asphalt mixtures, I found that there is no agreement for the critical point at which the blend is destroyed. In addition, I characterized energy methods allowing the description of the microstructure processes during fatigue. I found that the appropriate models using fracture mechanics should assist in the description of the phenomena of fatigue occurring in asphalt mixtures. Describing the problem of fatigue in the pavement I emphasized the significant problem of the distribution of deformations and contact of tire with the subgrade. An overview of the current state of knowledge helped to formulate the aim of work and subtasks characterized above in the introduction of the Self-report.

In the chapter four describing the different types of damage occurring in the pavement, I focused attention on fatigue cracks and pointed to their connection with other types of fractures. The purpose of the chapter was to discuss ways of formation of cracks and their identification in the pavement. I showed that there is no uniform method describing the state of fatigue cracks. Of many methods identifying the state of the pavement, the effective one is a dynamic method of deflections measurements. I pointed out that along with the procedure of identification modules stiffness it should be expanded to include additional parameters associated with the dissipated energy during fracture.

The fifth chapter contains the original modified fatigue tests in the four-point bending test under the controlled strain. These analyses were conducted at various temperatures, load and mixture composition. I included a sample of notches and registered the course of their cracking. The use of notches in the case of endurance test for asphalt mixtures is necessary in order to determine the parameters of cracking (stress intensity factor *K* and *J* integral). This applies to both a general description of stable crack propagation and the critical parameters corresponding to the resistance to cracking unstable crack

growth. The notches allow modelling a discontinuity material, creating favorable conditions to concentrate stress in the crack tip and controlling the crack initiation site.

By analyzing changes in strain and energy associated with the processes of fatigue, I proposed a way to determine the point of accumulation of cracks on the basis of their rate of energy change terms of fatigue cycles. Using this factor could determine when the critical accumulation of microcracks and draw the boundary between the formation of micro- and macrocracks. I found that the border area is significantly dependent on the value of a given strain corresponding to the appropriate temperature intervals. The change of energy relative to the cycle can more accurately indicate the critical moment of accumulated microcracks in the sample, compared to other methods determining the critical point. This factor was used to determine the energy change.

The current classic criterion of fatigue related to changes in the modulus can reliably indicate the emergence of structural changes, mainly macrocracks in the process of fatigue mixtures. Based on the research, I found that it can be helpful in estimating the initial stability, especially in the temperature range from 0°C to 10°C. Also other criteria based on the coefficients of energy (by ASU and Hopman) do not characterized well the studied mixtures in terms of the temperature and the length of the notch and can be difficult in the designation. Therefore, it was necessary to develop new criteria.

In the assessment of the fatigue life of asphalt mixtures, I propose to apply the criterion of change of energy. It illustrates the change in energy during fatigue which is linked to changes in the structure of the mixture (with viscous and elastic features). This criterion is more objective than the traditional criterion. According to the criterion of change in energy at higher temperatures (25°C) I got the durability almost two times longer compared to the classical criterion. In contrast, at lower temperatures (-5 °C), the criterion energy changes indicates the accumulation of microdamage before the module drop to 50%. In this case, the stability criterion with respect to the classical is about 1.5 times smaller. Description of the fatigue life on the pavement reflections of energy is effective due to the nature of asphalt mixtures.

I presented the second criterion determined by observing macrocracks. The criterion of appearing macrocracks may be useful to assess the stability of mixtures for the extreme conditions in which macrocracks develop and microcracks are stabilized. It provides durability tens of times larger than the classic criterion. However, in the extreme cases, i.e. low temperature (-5°C) for samples having a long notches (20 mm), the stability are reduced and cracks occur even before the moment when the modulus change reaches 50% (as for the criterion energy changes).

In the next section of the fifth chapter, I analyzed the change in the composition of the mixture on the wearing (AC11S), binding (AC16W) and base (AC22P) layers in their fatigue life. In the case of increasing asphalt content in the range of 4.0% to 5.3%, the fatigue life is increased by several times (at -5°C) to several tens of times (at 25°C). In the case, the increase of 1% void content reduces the service life of a few to several times. I found the greater durability of mixtures with finer grain size in the durability test for the selected mixtures for the wearing and base layers. The endurance test is useful in the selection of the composition of mixtures but attention must be paid to other features to ensure the proper density and resistance to deformation.

At the end of the fifth chapter, I compared fatigue characteristics found in the laboratory with the fatigue criterion used in pavement AASHTO 2004. Without their calibration, there is an approximately 10-fold difference in stabilities. The bigger mistake is burdened with the classic criterion. I used shift factors in the equations of fatigue dependent on the temperature and the content of the asphalt, which helped to minimize the error determining strains in laboratory criteria below $5x10^{-6}$. The determined relationships with the coefficients can be useful in estimation of the stability conditions depending on the asphalt content and temperature.

The characteristics of fatigue split on some elastic and inelastic are an important achievement of the work. This approach provides information on the conditions under which the type of deformation determines the fatigue. On this basis, I described the nature of cracking asphalt mixtures: brittle or ductile. Inelastic energy change dominates in higher temperatures from 10°C and 25°C..The intermediate state occurs in temperature between 10°C and 25°C. However, for the temperature from -5°C to 0°C, the energy dissipated on inelastic deformation is clearly smaller than the elastic one. For this range, it is sufficient to employ a model of elastic linear fracture mechanics principles. In other cases, a ductile fracture should be used nonlinear models taking into account the zone of plastic deformation and viscous in the tip crack.

In the sixth chapter, I conducted the identification of rheological parameters in dynamic conditions. I pointed to the significant contribution of the characteristics of sticky asphalt mixtures and developed relationship of changing parameters of viscoelastic model Burgers' model during fatigue. Based on the known hysteresis obtained in the study of fatigue and the conditions of the compliance phase angle and the modulus, I showed how the rheological parameters of the Burgers' model can be effectively determined. In the field of applied cycles, temperatures and loads, I got good compatibility between the studies and the model, the maximum error did not exceed 4.5%. The accuracy of determining the parameters is affected by the presence of the notch, temperature and load value.

Dynamics of changes in rheological parameters reflect changes in fatigue occurring in the mixture. However, these parameters are more suitable for description of changes in the entire temperature range than the modulus. I found that a good correlation between changes in the rheological parameters and changes of the modulus in the fatigue process is observable only at low temperatures (below 0°C) and with the Burgers' parameters E_1, E_2, η_1. I found that in the numerical models for positive temperatures and longer times of load (below 10 Hz) the viscoelastic properties of the material must be taken into account to its description.

I included the determined rheological parameters in numerical models described in the Chapter seven. I conducted the analysis of stresses and strains in beams with notches and without notches. Using the finite element method (FEM) I described an algorithm to determine the fracture parameters: K and the integral J.

The eighth chapter describes the methods of macrocracks, on the basis of which I have set the parameters K and J for different conditions and then the kinetics of cracking asphalt mixtures. For

different load conditions and temperature, I showed that the endurance test with registration of macrocracks is useful in determining the speed of propagation of cracks in the asphalt mixtures. For low temperature (-5°C and 0°C), it is sufficient to use low loading levels ($\Delta\varepsilon = 130x10^{-6}$) to initiate the crack. For higher temperatures (25°C), up to 10-fold higher load level is required to develop the crack. The timing macrocrack for small power levels ($\Delta\varepsilon < 300x10^{-6}$) corresponds to the modulus in the range of 26% to 44%. In contrast, for high power levels it occurs before the drop unit to 50%.

The chapter nine presents a procedure that uses tomographic X-ray and microscopic studies. I carried out them to analyze structural changes in the study of fatigue. I connected them with the fatigue damage, changes in the modulus and rheological parameters. The method of measurement of air voids in asphalt mixtures with the use of tomographic studies is effective in assessing the microcracks. There is a correlation (for the analyzed temperature from 0°C to 10°C) between the change in air void and change of the modulus but the stronger correlation was found for some rheological parameters (E_2, η_1, η_2). The determined fatigue damage in the numerical model of the beam using rheological parameters and the energy criterion correlates well with the change of free space. Expanding air voids are potential concentrators of stress favoring accumulation of microcracks. The process of change in the air voids during fatigue cycles is linear and the largest variation occurres when the modulus varies from 65% to 50%. In this step, the number of large voids with the volume greater than 6.0 mm^3 increases. However there is no initiation of new microcracks, which corresponds to the formation of additional voids with small volumes (0.5 - 5.0 mm^3) but they develop or are already in existing, greater microcracks. It can be considered that the tomography study are effective in monitoring structural changes in the mixtures resulting from fatigue and should be developed. I perfomed also the surface microscopic examination. However, this measurement method gives less accurate results and poorly distinguished mixtures due to the temperature and the length of the notch. Microstructure measurements in asphalt mixtures during fatigue testing should provide a further phase of work and can be useful to develop criteria for fatigue with the use of changes in the content of air void.

In a further step of microstructural analysis, using a numerical microstructural and FEM model, I set threshold parameters used in fracture mechanics: coefficient K_{th} and integral J_{th}. However, in the tenth chapter in the four-bending test, I set critical parameters: coefficient K_C and J_C. These parameters allowed supplementing the developed dependence on the speed of fracture based on the stress intensity factor K and the integral J.

Characteristics of crack propagation by the factor K depends essentially from strain peak to peak, while the description of the propagation of using the integrals of J is more independent of the load. The equation using the integral J is a better characteristics of material and fatigue suitable for the labeling compound in the range of cracking in nonlinearelastic and plastics conditions, i.e. in the positive temperatures.

The eleventh chapter concerns cracking occurring in the pavement. I pointed out that an important element in the analysis of crack propagation is a way to transfer the load to the pavement. In order to carry out effective methods of modelling the behavior of the pavement in terms of fatigue, I used the impact of dynamic interaction of the tire contact with the pavement, the equation describing the speed of

the rupture and the criteria defining the critical points of the emergence of macrocracks. I found that the use of positive temperatures and frequencies below 10 Hz is advisable to use modelling taking into account the rheological parameters.

I presented the usefulness of the model of fatigue in the mechanistic design of pavement with the occurrence of the phenomenon of cracking. In various variants of the pavement model with a slot, I carried out the numerical analysis FEM considering the different thickness of layers and temperature conditions. The criteria for fatigue cracking and the designated parameters of the equation in the model of propagation allowed the development of micro- and macrocracks in the pavement. I analyzed the strains and stresses emerging in different places of pavement layers. The essential points of the pavement due to fatigue are the bottom fields of the asphalt layers and at the edge of the load, which are associated with cracks "top down". The crack in the initial stage of the initiation and development phenomena are determined by stretching. In the further stage, the propagation of cracking under shear is important. On the basis of numerical calculations, I found that cracking at the edges of the load zone occurs intensively in thicker asphalt layers.

The work is ended with conclusions which summarize the theoretical analysis and research. In the conclusions of the work I indicated also the further scope of research referring to the need of analysis healing process, rest, closing of cracks and internal thermal effects occurring in the process of fatigue.

Summary monograph

The main achievement and contribution to the discipline of the monograph is to develop a method to identify the parameters associated with the fracture mechanics of the microstructure and on the propagation of macrocracks occurring in the asphalt mixtures.

The monograph is a scientific achievement containing the original equation of the kinetics of cracking and fatigue characteristics, which are important practical aspect of the work. On this basis, you can better choose mixtures due to fatigue and forecast the development and propagation of micro- and macrocracks in the pavement. Current experimental fatigue tests asphalt mixtures seem very promising and should be further developed. With the test procedures which I developed it is possible to record the speed of development and propagation of cracks in different conditions of temperature and load. Using a four point bending method under conditions of controlled deformation I showed on the example of selected mixtures using samples notches that it is possible to identify the fatigue processes. In order to determine the rate of fatigue crack growth, the testing should be modified using different test conditions. I suggest fatigue tests to be carried out on samples in the four-point scheme with notches (5 mm - 20 mm) in positive and negative temperatures (-5°C to 25°C).

To identify the development of macrocracks, the method recording images should be used and to determine for them equations propagation, the energy approach with the use of the integral *J*, which is promising for the inelastic materials to which asphalt mixtures belong. To describe the stable propagation step, the parameters of fracture may be determined numerically or on the basis of hysteresis in this study. In order to complement the analysis, the methodology of fatigue should include the

parameters of fracture toughness. It can be achieved by static bending test on samples with at least two lengths of the notches (e.g. 10 mm and 20 mm).

I suggest in the descriptions of the model for positive temperatures to include rheological parameters that truly reflect structural changes and energy occurring in the mixtures during the fatigue and are identifiable in the fatigue test. I think that we should apply the criterion of change of energy in identification of microstructural changes and the stability of mixtures.

The original contribution to the study in terms of the microstructural analysis is the use of unique methods of measurement with computed tomography and microscopy. I showed that it is possible to evaluate fatigue processes based on changes of air voids in asphalt mixtures. These studies provide important information on the time and conditions when microcracks in the mix develop. In order to obtain reliable measurements, the use of minimum three samples from different stages of fatigue and different temperatures is required. It should be also analyzed areas of extreme bending in the beam and changes in different ranges of volume of air voids.

Although the mechanism of cracking is asphalt mixtures is a complex phenomenon, I carried out appropriate modeling processes occurring both in the laboratory and in the pavement. I found that the cracking is conditioned by rheological characteristics of asphalt materials dependent on temperature and load. A new feature was the inclusion rheological parameters in the course of fatigue obtained from hysteresis fatigue.

I showed in the work that a numerical model of four-point study (also at the level of microstructure) using FEM is useful to determine the parameters of cracking and to develop equations for the kinetics of propagation of asphalt mixtures. In turn, the originally developed pavement model is suitable for predicting the fatigue life in the micro- and macrocracks. It is possible on the basis of knowledge of the kinetics equations and criteria for fatigue obtained in laboratory tests. I showed that the pavement model takes into account the dynamic load and the correct way to transfer the load to the pavement allows to carry out forecasts cracks "top down", which have not yet been considered in detail previously. Additionally, the model allows taking into account the impact of connections, asphalt layers' thickness and the speed of the load also on the initiation and growth of cracks "bottom up."

The applied methodology is useful for the design of asphalt mixtures with structural defects affecting the cracking mixtures. The proposed analysis and the results should contribute to the development of issues on fatigue in pavement. Models, criteria and algorithms developed in the monograph can be useful in predicting fractures occurring in pavements containing asphalt mixtures, which in turn can increase the reliability of their design.

5. Discussion of the other achievements of scientific research (artistic)

5.1. The scientific activity

The remaining scientific activity I present in the further parts of the self-report referring to the publication from the list of published scientific papers – Appendix no 3. I distinguish the following thematic groups:

- *Research and modelling of rheological phenomena occurring in asphalt mixtures and pavement*
- *Research and numerical modelling of concrete pavement with regard to static and dynamic loads*
- *Research and numerical modelling of concrete pavement with regard to effects of temperature*
- *Research and modelling of the phenomena occurring in the subgrade under the pavement*
- *Impact load bearing capacity of the pavement*
- *Impact load on the fatigue of asphalt mixtures*
- *Issues related to the infrastructure of public transport, modelling and optimization of transport networks*

Research and modelling of rheological phenomena occurring in asphalt mixtures and pavement

I interested in issues related to the rheology of asphalt mixtures before obtaining the degree of doctor in technical sciences [L19]. This subject I developed further and the culmination of the research and scientific consideration was the dissertation: "The influence of rheological properties of asphalt mixtures for pavement deformation". Reports Inst. of Civil Eng. PWroc. 2001 Ser. PRE No. 1. (04.25.2001) Wroclaw University of Technology, Institute of Civil Engineering, Wroclaw. My supervisor was Prof. Antoni Szydło. The most important achievement of the study was development of a model for MMA studies in a device called rutting tester and identification of rheological parameters.

I built the model using the algorithms of finite element method (FEM) [E24], [L17]. Properties of asphalt mixture in this model described rheological parameters in the linear viscoelastic models by Maxwell, Zerner and Burgers. Identification of rheological parameters I carried out in the study of creep under compression for the third duty cycle [L16], [L13]. I showed that the smallest approximation error in determining the parameters was for the Burgers' model, and the largest fot Zerner's model. Using the model I developed and identified rheological parameters and predicted deep of ruts, which were then compared with the values obtained during the rut depth research with rutting tester [E28], [L15], [L12], [L11]. Eventually, I found that Burgers' and Maxwell's models give a good compliance of calculations with the results of the rutting tester [E25], [L14]. I found that for practical purposes, due to the small number of parameters, it is possible to use Maxwell's model.

Particular attention was turned to the fact that the effectiveness of the rut prediction is good when rheological parameters are determined in the third load cycle in the temperature range 50°C under the

load of 0.1 MPa to 0.5 MPa. I also established that the load time 1400 s in the study of creep is reliable to determine the parameters. For this time it is observed creep estabilishment, which correlates with a fixed rutting. At a later stage, I developed empirical relationships for the rut depth as a function of the composition of the mixtures and the number of load cycles [A7]. Analyses of the results made possible to determine crucial parameters of the rheological properties of mixtures and factors affecting rutting (temperature, time and load value). Using rheological parameters I developed the viscoelastic model of pavement and predicted the depth of the rut in different climatic conditions and periods of operation [A6].

Research and numerical modelling concrete pavement with regard to static and dynamic loads

In terms of mechanics of pavement, I dealt with the analysis of the stress state depending on the load [L22]. In the later stage of scientific development I became interested in computer applications in the numerical calculations mainly FEM [L20], which were then used in pavement models. Particular attention I devoted to the concrete pavement, dealing at first with technology and the requirements for the concrete pavement subjected to low traffic [E26] [E14] and next pavements for the other categories. I had a significant contribution to research and scientific development of "Catalogue of typical rigid pavement construction" [B1], [E8], [E6]. Earlier in this regard, along with co-authors, I carried out work on different catalogue solutions [B10] and new technologies of making concrete pavements, adjustment of the catalogue structures to the increased traffic load [B7]. At the later stage, I took part in determining the fatigue life for concrete pavements using advanced numerical pavement models with temperature impact [B5]. I dealt with specific issues relating to technology, among others, joints [B22], [B21], and damages arising as a result of various external factors. The publication [L7] with co-authors described traditional technologies used for strengthening the pavement and a new effective method using SAMI layer, preventing against reflected cracking.

An important scientific activity I devoted to the issue of stress concentration in the concrete around the steel dowels used in the concrete pavement [A2]. The transverse joint in concrete pavements are an important place where there is the most common structural damage. A special place is the area of concrete around the dowels. The concentration of stresses in these areas is the most common cause of cracks and damage limitation in cooperation of concrete plates. For the purposes of this subject I developed a special numerical model taking into account the cooperation of the concrete dowel in the form of GAP contact elements. Using this model I conducted an analysis of stress distribution around the dowel. I pointed to the dangerous tensile and compressive strains. Using FEM calculations with different diameters, spacing and length of the dowels in the pavement, I showed the efficacy of three-dimensional modeling in the assessment of the cooperation between the dowels and the concrete. The analysis used a typical load of the pavement corresponding to the load applicable in the dynamic test FWD (*falling weight deflectometer*). This study I used in the verification of the model chosen for concrete pavement motorway in Poland. On the basis of the analysis, I determined practical functional dependencies enabling to find the maximum stress in the concrete around the dowel in relation to variable parameters of dowels.

The confirmation of these analysis were laboratory tests carried out in collaboration with Andrea Zuzulova (Department of Transport Construction and Traffic (FCE) Bratislava) (app. 4 [F1]). In this

subject, I made the strain measurements in specific locations around the dowel, then contact stress analysis and numerical verification using FEM. I analyzed different levels of load and diameter dowels. The results indicated that the simulation model using the linear-elastic is effective in calculating the stress and consistent with studies with the selected load ranges. During the analysis I drew attention not only to the compressive stress on the dowels, but also tensile stress, whose concentration and high values can cause the development of cracks in the concrete. I found that for small diameter of dowels the destruction under high load exceeds the permissible value for the dowel, and for dowels with large diameters the destruction occurs in the concrete due to exceeding the permissible tensile stress. The analysis for the different load levels may be useful in the selection of spacing and diameter dowels in the pavement. In this subject I published one paper and prepared another for printing.

Mechanical phenomena occurring around the dowels have an effect on technological issues in implementing and maintaining gaps in concrete pavements. Knowledge about the distribution of contact stress between the dowels and the concrete is important for improving the LTE (*load transfer efficiency*). This subject was developed in [A1]. In this publication I stated that the load transfer between adjacent concrete slabs in the transverse joint is dependent on various parameters anchors. I analyzed the effect of different diameters and spacing of dowels for cooperation slabs. Currently, there are no new methods to ensure the proper selection of dowels ensuring proper the cooperation of slabs. I presented an original approach using 3DFEM. Verification of the model I carried out for the FWD dynamic tests on selected pavement. I presented a comprehensive range of calculations and determined concentrated stress around dowels for different parameters of dowels and effectiveness of load transfer. I showed how dowels with small diameter can increase the concentration of compressive stress and the limited cooperation (below 80%). The found functional dependence allows to determine the stresses in concrete dowels depending on the diameter and the effectiveness of load transfer.

Research and numerical modelling of concrete pavement with regard to effects of temperature

Undoubtedly, a major subject of my research was the issue of the impact of temperature on the concrete pavement. The study [E18] analyses the impact of climate phenomena associated with the deformation of the concrete slabs. I characterized changes in the temperature gradient in the concrete slabs according to national conditions based on meteorological data and own measurements of the temperature distribution in concrete pavements. Using the FEM I conducted thermal stress calculations depending on the dimensions of plates and their thickness. As a result of conducted studies, I found that the maximum stresses in the concrete slabs in Polish climatic conditions for a uniform temperature gradient (independent of the slab thickness) for plates with the lengths greater than 5 m does not depend on the thickness and virtually oscillate around the value of 1 MPa. However, in the slab, in which the thickness depends on the gradient, thermal stresses in the thicker slab are greater than the stresses in the thinner slab, but for the length greater than 3.5 m. The values of this force also oscillate around the value of 1 MPa. The advantage of thick slabs is that they are deformed less in their vertical plane and, therefore, lower stresses arise in them . The topic was presented in the conference [L5].

Studies on behavior of the concrete slabs under the influence of temperature was expanded into its impact on the base and the subgrade. Therefore, the thermal expansion and the influence of uneven

temperature make that the slab is deformed during the day causing deformation in the lower lying layers. In addition, because of the different types of layers and the subgrade on which it rests different stress are formed in them,, which should be taken into account in dimensioning the pavement. In Poland, due to the frequent variable air circulation concrete pavements are subjected to cyclic thermal and diverse influences in a year and a day. In the article [E12] I analyzed the impact of different types of base and subgrade on the condition of displacement and stress in the selected layout layer. Numerical calculations were conducted based on the variable daily temperature using FEA. Calculations show that due to the diurnal thermal variations in the area of transverse joint in the base, vertical displacement and tensile stresses may be accumulated resulting in damage to the base. I have shown that the use of rigid base leads to higher tensile stresses in the slab than in the flexible base. However, in the flexible base with low modulus and also with the small thickness accumulated displacement will appear. Furthermore, I showed the effect of changes in the value module base and the value on the thermal tensile stresses in the concrete slab. The conducted analysis can be helpful in the design of new concrete pavements as well as assessing the capacity of the existing pavement resting on a variety of subgrade.

Although in this article I included elastic material parameters, the analysis of the thermal load adopted for the selected day of July, helped identifying weak spots of pavement that may appear under the influence of both negative and positive difference in temperature between the upper and lower surface of the slab. Together with co-author in further studies, a numerical analysis will be carried out, taking into account the viscoelastic and plastic characteristics in the selected base.

The topic of the impact of variable climate was developed in the next publication [A8], which is currently after review. In this article, I included different climatic conditions occurring in Poland associated with variable air circulations within a year and a day. I showed the dependence of daily temperature fluctuations on the temperature difference occurring in the concrete slab and described an analysis of thermal stresses in the concrete slabs depending on their length and variable temperature difference corresponding to the respective seasons. Using detailed model 3DFEM, I made the numerical calculations. They show that in the case of long slab greater than 5 m and a positive temperature difference characteristic for years (10°C), stresses arise at approx. 1 MPa. In the case of incidental interactions (20°C), stress for the plates longer than 5 m can amount to more than 1.5 MPa. I compared the values of stress for the two slab thickness of 25 cm and 30 cm. I found that in the slab with a thickness of 25 cm and a length of less than 4.5 m, larger by about 5%.stress occurs than in the slab with the thickness of 30 cm In this model I also took into account the relevant characteristics of cooperation between the slab and the subgrade including friction slab with the subgrade and base.

Original and detailed analysis I carried out in [A3]. Here I focused attention on stress-induced deformation around the dowels in the concrete slab under the influence of temperature. Daily temperature variation results in the significant deformation if the slab is reflected in its adverse dowels joint. In this article, I analyzed the thermal stress according to the different diameters of dowels and thermal gradients. I conducted the analysis using FEA. The calculation showed that the use of plugs with small diameter increases the stress in the concrete. Particularly harmful is the concentration of tensile stresses in the concrete on the two sides of the dowels. These stresses may exceed the limit values in the case of accidental strong thermal gradients. In addition, they may increase as a result of the

impact load from the vehicle. The results obtained in this publication may be helpful in the design of new concrete pavements and assessing their sustainability in countries with large temperature amplitudes that are taking place in Central Europe.

Research and modelling of the phenomena occurring in the subgrade under the pavement

Another subject I deal with during my career is the study of phenomena occurring in the base and subgrade under static load and dynamic. The publication [E15] presents numerical analysis using FEA to assess the effects of subgrade strengthen on the pavement durability. For calculation I chose the pavement for parking spaces designed for heavy traffic. I described the material properties of the subgrade using elastic and elastic-plastic models. Then I evaluate the stability of the pavement using deformation criteria of the subgrade and analyzed the structural deformation. I found a significant effect of the thickness of the gain (stability) on durability and a considerable variety of results depending on the criterion used. The calculations show that the found values of the criteria for the axis reflecting pavement durability can classify different structures depending on the category of traffic. Reinforcements classify well the analysed structures KR1 (group G2 and G3) and KR2 (for enhanced subgrade G4). The biggest differences I noticed in the application of the criterion of French and Shell, while the lowest criterion for the Asphalt Institute and the University of Nottingham. Both the elastic subgrade model and elastic-plastic model similarly classified the analyzed pavement in terms of traffic categories. However, for the weakest base I registered a significant plastic deformation, and found that the nature of the "non-linear" subgrade using the elastic-plastic model, which includes additional subgrade parameters must be taken into account for the more difficult and varied subgrade conditions at depth (variable compaction, the degree of plasticity, humidity, etc.) and the detailed analysis.

In the later stage of scientific development in the field of this subject, I became interested in the analysis of the cyclic load with regard to permanent plastic and viscous deformation. Commonly used methods for evaluating the load of the subgrade using a Light Weight Deflectometer (LPD) assumes linear-elastic behavior of the material. In identifying the subgrade parameters are taken into account only the initial load cycles. It does not include changes in the parameters of the material under cyclic loads. The aim of the publication [E10] was to carry out periodic measurements of subgrade displacements using the LPD and confront the results of the numerical identification layers moduli. I showed variability of the identified parameters of subgrade depending on the number of load cycles in the study of antidepressants. To identify the parameters of the subgrade used a 3DFEM. The measurements indicate the limitations and errors commonly used in the identification procedure on the subgrade using the LPD, involving the improper taking of vertical displacements (deflections) registered in the 4th, 5th and 6th cycle load as a basis for identifying parameters (modules) base in the backcalculation. In the case of crushed stone layer on the home subgrade, the difference between modules equivalent of such a system, identifiable in the 4th, 5th and 6th cycle and the 30th cycle of the load is about 30%. It results in at least double underestimation of the fatigue life. In the case of the unreinforced subgrade, the differences range is from 20% to 60% depending on the load value. In the case of cement-bound material layer on the subgrade (due to the very high rigidity of the same stabilization), smaller equivalent change modules is observed. On this basis, I formulated the conclusion that the subgrade reinforced by stabilized cement realizes to a greater extent assumptions of the linear-elastic model, while successive cycles impact the

module equivalent for other types of strengthening and should be described by plastic and viscus models. These characteristics of the material I highlighted in [E9] analysing the influence of loading and unloading time in the study VSS recording vertical displacements and the estimated carrying capacity of the test subgrade. I included in the calculations the visco-plastic component, and then I showed significant differences in the results of displacements and values of primary and secondary modules depending on the time of the study.

I verified in actual field test the developed 3D model using FEA,. Analyses indicate the limitations of the commonly used procedures to identify the parameters of the subgrade in the study of VSS. I showed how important parameter during the subgrade test, especially with a limited capacity, is the time interval between loading and unloading. I pointed out that any long waiting time may not provide stabilization of the settlement for the very weak base. Thus, the use of "non-linear" model, taking into account the characteristics of the plastic and also creep under such conditions is reasonable, and the designated deformation moduli are no longer valid in such conditions, as it is common applied in assessing the elastic characteristics of the material. In addition, they cannot be identified with the Young's modulus of elasticity, which is one of the parameters used in the linear-elastic models of the pavement.

The subject of the study VSS along with co-authors I developed in the next publication of this series [E7]. On the basis of field test, I drew attention to the significant influence of the applied weight and the type of counterweights used in this study on the secondary modules deformation. In addition, on the basis of numerical calculations in a pre-established elastic medium, I analyzed basin deflection, allowing to explain the cause of these differences. I distinguished three different layouts layered subbase and subgrade. I showed the difference in the values of secondary modules identified in testing using VSS as a counterweight to a typical vehicle and the bucket of the excavator. Analysis of the shape of the basin deflection at different configurations sandwich in two cases the load explained the mechanism of overlapping bowls movements which affects overstating the results obtained during the test modules layers of VSS using the vehicle. Differences between the modules designated in studies using excavators and vehicle increase with stiffness test system layers and range from 14% in subgrade to 54% on a rigid structure with a layer of cement stabilization. This difference adversely affects the assessment of the capacity of the pavement. It is suggested to *in situ* studies of the vehicle wheel as a counterweight were located on the disc approx. 1.20 m in the case of the test subgrade and to aggregate on the subgrade at a distance of min. 1.5 m, while for systems with high stiffness min. 2.2 m. Undoubtedly, the more reliable way to obtain accurate results is the use as a counterweight bucket excavators.

Currently, in terms of this subject I prepared together with the co-authors another article (being sent to journal), which concerns the impact of the weight of the counterweight (vehicle) and load time on the parameters identified in the study of static plate, due to the ongoing visco-plastic phenomenon. I conducted extended research involving registration of vertical displacements of the three cycles of loading and unloading the static plate. Using the Drucker-Prager's model and Classical Law Creep by Bailey-Norton model, I pointed out the difference in the values of secondary modules designated strain, depending on the load in the study VSS. Further work relates to the impact of the layer thickness on the parameters identified in the study VSS and LPD.

Impact load bearing capacity of the pavement

I showed the first interest in bearing capacity of pavement before my doctorate. With the co-authors [L18] I analysed the problems that arise in assessment of bearing capacity and dimensioning reinforcements pavement based on recorded measurements of displacements in the dynamic tests. The conducted studies showed that the measurement of displacement (maximum) at one point does not allow for a precise assessment of the pavement capacity. The measurement of the so-called "basin deflection" allows for full identification of subgrade and layer modules and thus it is possible to determine the capacity expressed as the number of allowable loads. The subject of dynamic loads using FWD I developed with co-authors in a series of publications related to the research project Innowacyjna Gospodarka [J3]. I developed several reports and publications [L8], [L6], [L4] [E4] for the task: "Diagnosis of roads and airport pavement using advanced dynamic testing." Its main objective was to develop a method to identify the parameters of models for road and airport pavements using dynamic deflectometer FWD. The measurement of vertical displacements of the pavement using deflectometer FWD is currently the most effective study in non-destructive testing. In modern practice, however, it is not usually taken into account the dynamic nature of the load. Loads exerted by FWD have a short-term dynamic (impact) and recorded displacements of pavement are the result of these burdens. The most commonly used pavement models, however, are static models in the form of a layered elastic half-space. Therefore, parameters for the static model (modules) based on the displacements obtained in the dynamic load (as impulse force) are identified, which results in a definite conflict in methodology. Therefore, together with co-authors I developed an algorithm of transfer (transformation) from a dynamic test to a static test in the manner that allows for movements recorded in the dynamic test to identify the parameters of the static models, which are used today to multilayered elastic halfspaces. A series of FWD tests were carried out on pavements (both susceptible and rigid) with different structures.

The final stage of this project enriched significantly the current knowledge in the subject of dynamic measurements and models of roads and airport pavements. The most important achievement of the project can be regarded the development of correction factors for the typical pavement, which allows the use of dynamic measurements to identify the parameters of static models of pavement (by transforming the pavement deflection measurements obtained in the dynamic of their quasi-static equivalent). It was also shown that in the case of dynamic measurements, the adoption of the layered half-elastic models is the most appropriate, in view of the short pulse load - there is a linear relationship between displacement and load, and the visco-plastic phenomena (permanent deformation), unlike static measurements are practically absent.

In a further step of my activity in this topic, I dealt with the immediate impact of the vehicle wheels on the pavement. A significant development of knowledge I attained with co-authors in the task: "Examining the possibility of vehicle weighting in motion with scales working on the PAT network" [F55] [F57]. At selected locations using test vehicles, I have carried out an analysis of the accuracy of measurement scales for different pressures and speeds. In order to properly process the data, I was involved in developing the software collecting and archiving measurement results and supporting statistical analysis of the data obtained. The application uses the database *TruckStatistic* working under

the control of the *SQLExpress* system. The developed database allowed collecting data such as date and time of measurement and making automatic vehicle classification, taking into account the total weight of vehicle, axle (single axle, a group of axles, axle components in the group), spacing for each axis and the speed of vehicles. It was also possible to make a graphic presentation of spectra (distribution of axle) for different periods of measurement (and for different types of axes). After measurements I found that it is possible to precisely determine the aggressiveness of the movement in Poland based on the results of measurements obtained using the weights of the PAT working on the road network. The publication of [E23] closes these studies and states that the conversion factors set out in the manual measurement of individual profiles of a given category, without analyzing the occurring loads, may decrease the degree of harmful effects of passing vehicles on the pavement. This is most evident in the group of trucks with two-axle trailers. The final conclusions indicate that in order to determine the conversion factors groups of vehicles on the calculating (standard) axes in the most possible precise manner, it is necessary to install the scales of measurement for other representative roads and collecting data for the entire country, which in turn will help more accurately to determine the durability of the pavement.

Impact load on the fatigue of asphalt mixtures

In the topic of fatigue asphalt mixture, I developed the first publication [E21]. It concerned the laboratory tests, which can well simulate the fatigue phenomenon. I introduced a model of propagation of cracks on the basis of the endurance test under controlled load for four-beam bending test (4BP). Model tests with FEM allowed verifying the behavior of asphalt mixtures and assess the state of stress and strain in the tip crack. The study used a sample of the notch. Such an assumption allowed initially to simulate the problem of propagation of fatigue cracks occurring in the pavement. The subject of fatigue has been completed in [A4] with a broader scope of research, which in turn made possible to determine the fatigue criterion using "cracked" beams in the study of fatigue and compare it with the criteria of the Institute of Asphalt and Shell.

The presented research program is a valuable database of information and a good starting point for a broader assessment of the fatigue life of cracked asphalt mixtures. The test results clearly showed the impact of the slots on the decrease in modulus. For longer breaks it is non-linear. The presented criterion of fatigue using beams 4BP with the notch may be useful in predicting the fatigue life of cracked pavement. The better correlation of laboratory criterion of fatigue is for the Shell criterion. I found also that the numerical model containing a notch is promising in further analyses under different conditions of temperature and composition.

This subject has become my main scientific activity. I worked out the presented monograph in relation to it. Currently, I continue studies in this field. In [E2], I developed issues related to the rheology and fatigue outlining the procedure for identification of viscoelastic properties of materials in dependence on temperature and load conditions. I analyzed a static creep test and dynamic endurance test (10 Hz) based on the scheme 4BP. Based on these studies, I determined parameters in the Burgers' viscoelastic model. I got a similar variability of temperature in both tests but different absolute values. I showed that the parameters are significantly dependent on the duration of the load and temperature. I found that parameters should be determined from the creep curves for static tests with long-term load and for the

study of dynamic hysteresis. In further publications, I plan to verifiy examples of calculations using FEM for both studies including Burgers' model.

Issues related to the infrastructure of public transport, modelling and optimization of transport networks

Presented topics differ from my main interests but are also my scientific activity related with numerical analysis, modelling and measurements. In the first publication of this subject [L21], I drew attention to one of the most important problems which are parking in the downtown of the city. I presented various ways of programming including parking places using the satisfaction of needs related to accessibility and comfort of commuters. I presented various indicators (direct and indirect), allowing determine the parking needs. In the conclusions, I formulated rules required to design methods for determining the demand for parking. The next joint authorship publication [A5] dealts with the study of pedestrian traffic. Its attention is focused on the calculations of wasted time for pedestrians coming to pass. With co-authors, I assumed that the process of getting pedestrians to cross, has a significant impact on the loss of time by pedestrians that cross the street equipped with signaling. My significant contribution measurements were recording a loss of time, and then calculate the model. From the comparison of the calculations achieved compliance. It has been shown the usefulness of new models against used so far, not checking in all conditions.

In papers [E17] and [E16] I dealt with shaping and optimization of infrastructure in conjunction with the availability of terrain. I presented concrete solutions for two large areas called Aglomeracja Sudecka oraz Dolnośląski Zachodni Obszar Integracji analyzing railway infrastructure. Detailed studies of demographic and economic areas allowed to develop in my opinion, effective solutions to ensure the integration of these areas. I considered as much as possible of the existing network and included demographic needs and transgenic relationships. The extensive literature review was very helpful in this regard, in which I made a reference to social, economic and development strategies.

Due to the fact that many of the world urban areas faced currently with transport problems, as well as the city in which I live, in publications [E20] [E13], [L3] I presented an unconventional means of transport - rail car. I conducted extensive literature studies on this topic and referred to the existing ropeway functioning in the campus of the Wroclaw University of Technology. I discussed the classification, history and future development strategies of the country and the world. In the example of Wroclaw, I showed the possibility of the developing public transport in large cities. I drew attention to its technical parameters and stages of development. Since its inception, along with a team from the Department of Roads and Airports I continue motion studies. The first calculations showed a significant change in movement in the analyzed area. Their relationship to the size of travel and parking was determined depending on the different periods of rail use [L2]. Further work will be associated with the development of a traffic model for the study area.

Summary

My scientific activity in the presented field is quite extensive. My research interests and main research focus on problems using modern techniques of numerical modelling. In the calculations, I use FEM and

take into account the diverse nature of the load (static and dynamic). Analyses were performed both for different types of pavement, as well as its individual elements considering relevant material modelling and thermal influences. Currently, I develop a modelling technique using microstructures elements rheology and fracture mechanics. Contribution to the field of construction involves developing models, parameter identification of road materials and pavements as well as their verification.

In terms of scientific achievements, I realized: 37 publications (1 monograph, 7 JCR articles, 29 articles in peer-reviewed journals (including 1 chapter in a book, 1 book), 22 publications and participation in conferences. A detailed list of publications is given in Appendix no 3, and parametrics in section 7 of Self-report (Appendix no 2a). the number of individual publication in JCR database is 4, in other peer-reviewed journals, I realized 8 individual scientific publications.

5.2. Activity on the realized achievements in design, engineering and technological research, expertise, research projects

Studies related to this activity are listed in Appendix no 3 at points B, C, F, J. The milestone tasks refer to extensive subject and required the large involvement of all co-authors. My participation in this work is presented in Appendix no 3. In some cases, my contribution is limited to one or several chapters of the report, in others my contribution is distributed throughout the whole study.

One of the topics concerned the work on updating the catalogue of typical rigid pavement, for GDDKiA made in years: 2011 - 2014 [B10], [B7], [B5]. At first, based on extensive literature studies and other directory solutions, I analyzed the characteristics of different types of pavement, including some technological details. In the further step, I performed computational analysis taking into account the aggressiveness and the impact load on the concrete surface and the climatic influences occurring in the country. The final result was the development of the target version of the catalogue rigid pavement [B1].

Another activity I showed in the elaboration of safeguarding the slope of the road in the western bypass of the city of Legnica in the years 2010 - 2011 [B19], [B18], [B14]. Within the scope of this study, I conducted a detailed inventory of existing state, which pointed to the problems of stability associated with poor drainage. I worked out a situational-altitude project with construction details and elements of strengthening and drainage.

I had a large contribution in the multistage design work of the road sector for selected investments of Wroclaw University of Technology. They include: Parking at the building D2 (2004) [B34], the expansion of land and building H - 3 (2009, 2011), [B26], [B13] Educational Complex - Integrated Students Centre C13 (2004-2008) [B31], [B27], parking in the building C7 (2009-2010), [B25], the cable car on the Oder, PFU (2013-2014), [F33], the project (2004-2011), [B4], visualization [F21]. The final project was the realization of the concept, construction projects or regulations for the investments. Fo some studies I performed detailed measurements of capacity and motion study.

The original development of construction carried out with co-authors refers to the technical design of

Wroclaw road plate for MPWiK, intended for use in excavation works in the roads and streets. Its task was to cover the excavation and relocation of traffic at the stage of renovation. The used board was designed to provide relevant safety for traffic without restrictions, and therefore also for heavy vehicles. Initially, I developed various concepts of the construction [B9], and in the further step were carried out laboratory tests and field [B8]. The final result was the shape of the board in various sectional schemes [B6]. The project was submitted to the Patent Office, 2012 - 2015 [C1]. I developed several publications [E11], [E3] [E1] and realized the occurrence conference [L1] related to the project and implemented solutions in the streets of Wroclaw.

Other studies, in which I took part are related to the design of concrete pavements with dowels [B22], [B21] and continuous reinforcement [B20]. I developed graphic and calculation of selected structural elements of concrete pavement. The analysis of asphalt stability I did with co-authors in the multistage project (2013-2015) for the A2 [F9], [F6] [F3], the A4 motorway [F10], [F5], [F2] and S3 expressway [F11], [F7], [F4].

I showed the activity in research and design with modelling transport networks in studies of traffic for the city of Radom in 2008-2009. I realized several reports including, among others detailed measurements and inventory of public transport elements of the city [F43] [F42] to develop a traffic model for different variants of rebuilt network [F38] and specific design solutions for selected crosswords and streets of the city [F37].

I would like to mention works on comprehensive analysis of traffic for some of the planned investments in Wrocław (2008-2009), [F45] - [F51] [F41] [F40]. I conducted detailed measurements of traffic and its modelling in different time horizons indicating the degree of investments' profitability.

Other studies listed in Appendix no 3 (position [B] and [F]) were devoted to infrastructure from road sector including construction projects, implementing projects of target and substitute traffic, cost estimates, technical specifications, measurements opinions, analysis and research on evaluation capacity of the pavement, visualization and computer animations and applications and computer programs for road investments, as well as laboratory and field analysis and operability. The total number of all studies in the field of design, engineering and research ([B] and [F]) is 137.

So far, I participated in a European research program EUREKA 2004-2006, "Improving the quality of operational air transport infrastructure" (Appendix no 4 [A1]), and a national research project Innovative Economy 2010-2014 (Appendix no 3 [J3]). In this project, I participated in the development of several reports and publications in Appendix no 3: [L8], [L6], [L4] [E4] for the task: "Diagnosis of paving roads and airport using advanced dynamic testing." Currently, I attend (from 2016) in two national projects Innovation Development Road on protection against road noise (Appendix no 3 [J1]) and the use of recycled materials (Appendix no 3 [J2]). This is connected with my participation in research consortia presented in Appendix no 4 [E1] - [E3]. I directed a project in collaboration with scientist from the Department of Transport Construction and Traffic (FCE) Bratislava in 2013-2014 for research concrete pavement with dowels (Appendix no 4 [F1]).

6. Information about achievements in education, scientific cooperation, foreign and national traineeships and activity popularizing science

As a researcher and teacher at the Faculty of Civil Engineering and water Wroclaw University of Technology I realize classes: Roads, streets, road junction, Roads and streets-base, highways, roads technological infrastructure, The road in urban areas, Dimensioning theory of pavement, Computer-aided design of roads, airports, Diploma seminar. The range of teaching hours significantly exceeds the required teaching load (by 180% in year), the number of engineering graduates promoted and graduate reach 200.

Additional information I collected in Appendix no 4. I participated in organization of 8 national conferences [C1] - [C8] collecting and reviewing papers. I was once a member-secretary. I got 19 awards [D1] - [D9] and the Bronze Medal of the President of Poland. Since 2010 I am a secretary of the journal Review of Communications (SITK-RP, list B MNiSW - 8 p.) [G1]. I am or was a member of the 5 national scientific organizations [H1] - [H5]. I would like to emphasize my participation in the popularization of science in the Faculty of Civil Engineering Wroclaw University of Technology, mainly at the Science Festival [I2], University for children and fair [I6], I also participated in competitions [I4], [I7] as well as workshops and lectures in the field of road [I1] [I3], [I5]. I participated in other activities for the home department and university in teaching and administration which I presented in Appendix no 4 [Q].

I am auxiliary promoter of one PhD student at the Faculty of Civil Engineering Wroclaw University of Technology as a [K1]. I had three practices, internships in the field of road construction [L1] - [L3]. I am a member of three expert or competition teams (PWr, SITK-RP, NCBiR) [N1] - [N3]. For the National Centre for Research and Development, from 2012, I reviewed 17 applications and projects about construction and transport infrastructure [O1]. I am a reviewer in four magazines: Studies Geotechnica et Mechanica [P1], Drogownictwo [P2], Roads and Bridges [P3] Przegląd Komunikacyjny [P4] and five international conferences [Q2] - [Q7]. Until then, I have reviewed 29 journal articles and 19 papers for international conferences.

7. Parametric summary of scientific achievements

Parametric list of scientific achievements and research developed by the list in Appendix no 3 and I listed in Table 1.

Table 1. Parametric statement of total output (according to Appendix no 3)

Type of achievement	Labelling Appendix no 3	Number
Monographs habilitation		1
Scientific publications in the database JCR	[A]	7
Other scientific publications in peer-reviewed journals	[E]	29
Design, construction and technological achievements	[B]	36
Patent	[C]	1
Research expertise	[F]	101
Participation in national projects	[J]	3
Publications and participation in conferences	[L]	22
The number of publications on national databases by Dona PWr	-	38
The number of publications on international database by Dona PWr	-	13
Book (guide), chapters in books	-	2
Total number of works [A]+[E]+[B]+[C]+[F]+[J]+[L]	200	
The number of points by MNiSW and criteria for the evaluation of research units (monographs, Ch. Books and patent)	150 (JCR) + 167 = 317	
Total Impact Factor	[G]	6,273
Number of citations by Web of Science	[H]	23
The Hirsch index by Web of Science	[I]	3
Number of citations by Scopus	44	
The Hirsch index by Scopus	3	
Number of citations by Google Scholar	88	
The Hirsch index by Google Scholar	5	

The number of works executed before PhD is:
- Scientific publications in international journals or national [E]: 1,
- Research, expertise [F]: 21,
- Publications and participation in conferences [L]: 5.

8. Summary of the educational and popularizing achievements

Educational and popularizing achievements are preensted in Table 2. It was worked out on the basis of the list in Appendix 4.

Table 2. Educational and popularizing achievements (according to Appendix no 4)

Type of achievement	Labelling Appendix no 4	Number
Participation in European projects	[A]	1
Participation in conference organizing committees	[C]	8
Received awards and prizes (including the Rector of Wroclaw University of Technology - 11)	[D]	19
Participation in consortia and research networks	[E]	3
Project management in collaboration with other scientists	[F]	1
Participation in committees of scientific journals	[G]	1
Member organizations and scientific societies	[H]	5
Achievements in the field of education and popularization of science	[I]	8
Scientific supervision of students	[J]	2
Scientific care for PhD students (promoter auxiliary)	[K]	1
National internships	[L]	3
Expertise or other reports on request	[M]	13
Participation in expert teams and competition	[N]	3
Reviewing national projects (for NCBiR)	[O]	17
Reviewing publications in journals	[P]	29
Reviewing the publications for international conferences	[Q]	19