GEOMATICS AND ENVIRONMENTAL ENGINEERING • Volume 9 • Number 3 • 2015

http://dx.doi.org/10.7494/geom.2015.9.3.15

Stanisław Barycz*, Karol Firek*, Wojciech Kocot*

The Role of Testing Technical Features of Concrete to Assess Predicted Durability of Massive Reinforced Concrete Structures on the Example of Turbine Set Foundations**

1. Introduction

In the mid-90s, in connection with the modernization of one of the power plants, the possibility of using two existing reinforced concrete framework foundations for new turbine sets was considered. It was necessary to answer the question whether, assuming similar loads, it was possible to count on a reliable use of the existing foundations throughout the anticipated period of their usability, i.e. for at least another 40 years.

The answer called for testing the technical condition of both foundations and checking the mechanical and physico-chemical properties of the concrete from which they were made.

The foundations were designed and constructed in the early 60's of the twentieth century.

While the condition of the above-ground part did not raise any major objections, it was unknown in what condition are massive bottom plates, after about 40 years of their utilization, recessed below the basement floor. Already in the course of their construction, the issue was raised whether exothermic processes of setting and hardening of concrete did not lead to a reduction in its strength. The strength tests of the concrete of the foundation no. 2, conducted at the end of 1962 [1] showed large discrepancies of the results obtained both by the sclerometric non-destructive testing and the use ultrasonic flaw detector.

On the basis of the first ones it was found that the average former class of the concrete at the surface of the block was approximately R_w = 170 kG/m², while the other ones indicated that it was not more than 120 kG/m².

* AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Krakow, Poland

** This article was prepared within the scope of the AGH statutory research no. 11.11.150.005

In order to predict further life of the reinforced concrete bottom plates of turbine unit foundations, their technical condition was assessed (visual inspection of the exposed concrete surfaces) and a detailed study of the technical properties of the concrete was carried out, including [2]:

– assessment of compressive strength, based on destructive testing of the collected core samples,
– specification of strength distributions based on non-destructive testing,
– determination of static elastic modulus,
– determination of mass absorbability,
– determination of bulk density,
– determination of carbonation depth,
– specification of the binder content,
– determination of the content of ions,
– indication of changes in the phase composition and morphology of cement paste and concrete,
– assessment of the severity of corrosion of reinforcing steel.

The paper presents methods for the implementation of the above studies and summarizes their results, which were the basis for determining the technical condition of the bottom plates and for predicting a further period of their use. Moreover, an assessment of the accuracy of the conclusions formulated on the basis of periodic technical inspections of these foundations was made.

2. Description of the Foundation Structure

The studied foundations were designed as twin reinforced concrete structures (Fig. 1) of a spatial frame construction, made up of six single-span transverse frames and two four-span longitudinal frames [3]. The load of the frame foundation was transferred to the substrate through the bottom plate.

The dimensions of its horizontal projection were as follows:

– length 31.92 m,
– width 9.50 m,
– height 2.00 m.

The plate was at a depth of 5.0 m below ground level, on a 20-centimeter-thick layer of lean concrete and a damp proof layer. The vertical walls of the bottom plate were insulated against moisture.

According to the preserved project documentation [1, 2] as well as the conducted studies [3], Portland cement 350 from “Chełm Lubelski” Cement Plant was used to produce concrete, in a relatively large amount (from 450 to 513 kg/m^3). The chemical composition of the cement used has been presented in Table 1. The documentation assumed to obtain concrete of the former class R_w = 200 kG/m^2. The foundation was reinforced with carbon steel of standard quality of St0 type.

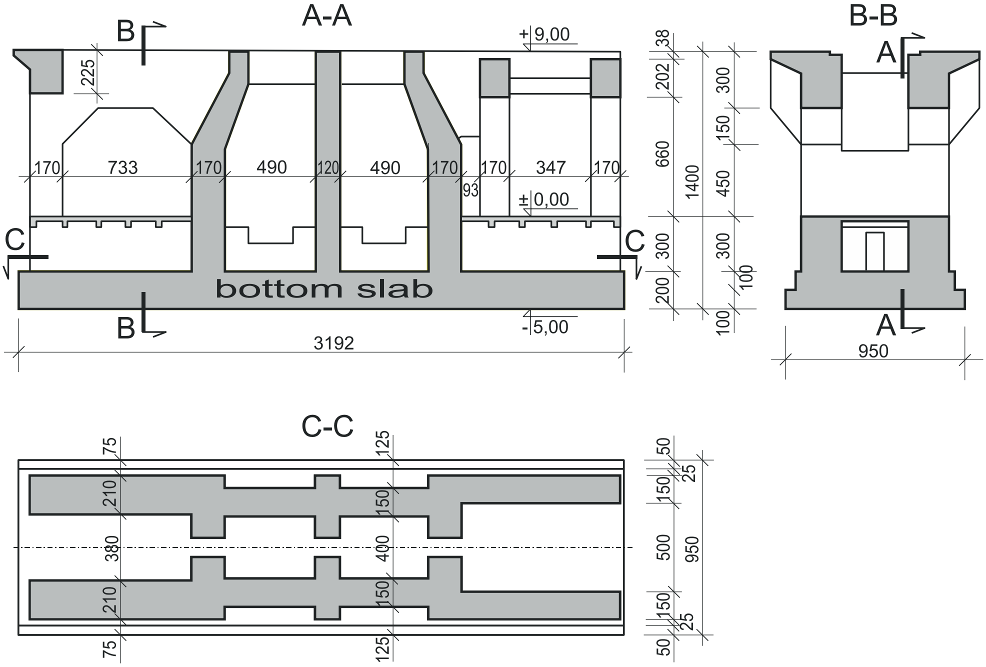

Fig. 1. Supporting structure geometry of the foundation no. 2

Source: [2]

Table 1. Characteristics of Portland cement 350 used to make the studied foundations

Chemical composition [%]		Modules	
CaO	67.73	Kind	0.92
MgO	0.90	MK	2.91
SiO_2	22.27	MG	1.82
Al_2O_3	4.94	MH	2.25
Fe_2O_3	2.73	Computational mineralogical composition [%]	
SiO_3	0.55	C_3S	66.96
CaO_n	0.96	C_2S	13.72
Insoluble matter	0.19	C_3A	8.69
Ignition loss	0.10	C_4AF	8.10

Source: [2, 3]

3. Concrete Cores for Laboratory Tests

To collect concrete cores, drilling machine Hilti DCM-1.5 was used, equipped with core diamond drill bits, having a diameter of ϕ = 108 mm, with water cooling. The location of the places where the cores were collected from are shown in Figure 2. In the case of the side walls of the bottom plate, the cores were drilled horizontally (Fig. 3), and the others were drilled vertically downwards. Each core was assigned a number corresponding to the place from which it was collected, as marked in the figure. In total, 7 cores were collected from the foundation no. 1, and as many as 11 cores from the foundation no. 2.

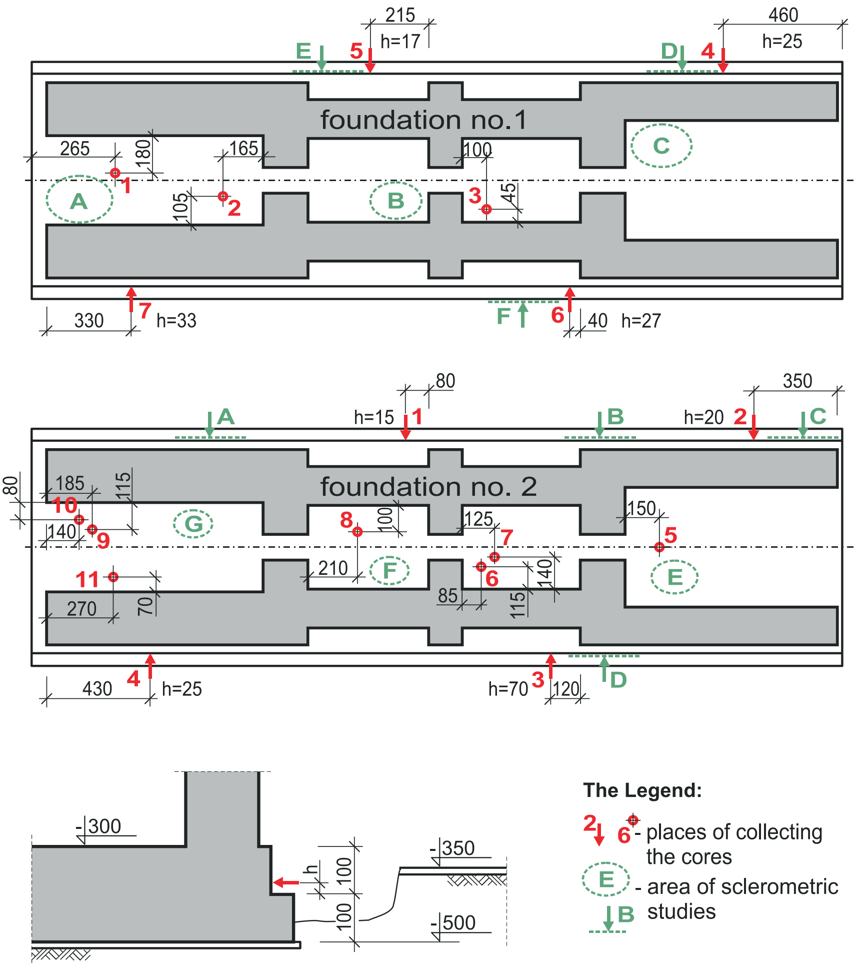

Fig. 2. Location of the places of collecting the concrete cores, and the areas of the sclerometric studies of the bottom plates of foundations no. 1 and 2

Source: [3]

Fig. 3. Drilling the core no. 7 from the bottom plate of the foundation no. 1

Source: [3]

The cores were cut into three types of samples (Fig. 4), and so [3]:

- samples for chemical tests from both ends of each core and from the middle part, with a height of about 10–60 mm,
- samples for testing compressive strength, with a height (length) of approximately equal to their diameter,
- samples for testing the elastic modulus of the concrete, with a height equal to twice their diameter.

Fig. 4. The cores from the bottom plate of the foundation no. 1 cut into samples

Source: [3]

4. Laboratory Test Results

Table 2 summarizes the results of laboratory tests of the concrete cores collected from the bottom plates of both of the analyzed foundations, of the scope stated in Section 1. These studies were carried out in the years 1995–1996, in accordance with the then applicable standard PN-88/B-06250 [4].

Table 2. Test results of the concrete cores collected from the bottom plates of the foundations no. 1 and 2

Type of tests			Foundation	
			no. 1	no. 2
Study of the mechanical properties	average strength $\overline{R}$ [MPa]		28.8	36.0
	guaranteed durability R_B^G [MPa]		19.6	27.6
	standard deviation S_R [MPa]		5.6	5.12
	index of variation Z_R [%]		19.4	14.2
	static elastic modulus E_b [MPa]		21 000	28 500
Study of the physical properties	bulk density ρ_o [kg/dcm^3]	on average	2248	2000
		from – to	2214–2272	1869–2131
	mass absorbability n_w [%]	on average	4.78	10.3
		from – to	3.5–6.4	8.7–12.3
Analysis of the concrete composition	aggregate content in the concrete [Mg/m^3]		1.594	1.434
	cement content in the concrete [Mg/m^3]		0.513	0.454
Chemical analysis of the concrete	the content of SO_3 in the calcined cement [%]		1.54	1.28
	the content of CO_2 in the concrete [%]	on average	1.7	1.4
		from – to	1.0–2.6	1.0–2.0

Source: [3]

The obtained results allowed us to draw the conclusions which are presented below, as to the mechanical and physico-chemical properties of the concrete of the bottom plates of the studied foundations.

During the strength tests, the bottom plate of the foundation no. 2 exhibited a higher compressive strength, as compared to the foundation no. 1, namely:

- a higher average strength $\overline{R}$, by approximately 25%,
- a higher guaranteed durability of the concrete R_B^G, by up to circa 40%.

This is confirmed by the 36.6% lower index of variation and the 9.3% lower value of standard deviation.

Moreover, for the concrete of the bottom slab of the foundation no. 2, a higher by as much as 35.7% value of the static elastic modulus E_b was obtained. This result is consistent with the static elastic modulus E_b provided in the standard [4] and in the technical literature.

While examining the physical properties, it was found that the higher value of the strength in the case of the bottom plate of the foundation no. 2, is accompanied by the mass absorbability higher by as much as 11.5%, and by approximately 11% lower bulk density. Additionally, a macroscopic evaluation of the presence of defects and abnormalities (honeycombing, delamination, capillary pores) in the structure of the collected cores was performed. In the case of two samples cut out from the foundation no. 2, larger capillary pores were found in the concrete structure at a depth of 295 and 650 mm from the outer surface.

While analyzing the composition of the concrete, it was found that the higher porosity and water absorbability of the concrete of the bottom plate of the foundation no. 2 should be explained by the concreting carried out in the summer, when more water was added to the concrete mix. The exothermic reaction of setting and hardening resulted in the occurrence of relatively large capillary pores. On the other hand, in the case of the bottom plate of the foundation no. 1, due to the low sand content, more cement was used. This resulted in the concrete with a lower porosity and absorbability, and higher bulk density, but in lower durability, by approximately 30%.

Chemical tests of the SO_3 and CO_2 content revealed no threat in this respect. This was due to the location of the foundations below the ground level and protection of their surface with suitable waterproof insulation, and thus protection against the influence of the external environment. In addition, phenolphthalein indicator test was performed on the surface of the collected borehole to determine the advancement of carbonation of the concrete. This test did not show the presence of processes of concrete carbonation.

5. Results of Non-Destructive Tests of Concrete Durability Distribution

To study the durability distribution of the concrete in the bottom plates of both foundations, a medium sclerometer of N type (to estimate the durability at the subsurface, i.e., to a depth of about 10–20 cm) and a heavy sclerometer of M type (to estimate the in-depth durability, i.e, to a depth of about 20–80 cm) were used. In the studied research areas, the measurements with both instruments of the values of rebound numbers were carried out at the same time. In total, 7 areas of study for each of the bottom plates were identified, marked in Figure 2 with uppercase letters A–G. When calculating the values of the instruments (for the range of values L = 20–50) regarding the local strength, the scaling curve was used for the sclerometer N, determined in parallel with the destructive studies of the samples cut from the structure.

On the other hand, for the heavy sclerometer (model M), the scaling equation was determined using the indirect method. Both dependences met the standard condition of the boundary error value of the approximation function [5, 6]. The summary of durability values in the research areas, determined with both instruments for the foundations no. 1 and 2 have been presented in Table 3.

The results obtained using both medium sclerometer (N) and the heavy one (M) exhibited higher durability of the concrete of the bottom plate of the foundation no. 2. Assuming that the heavy sclerometer (M) has a greater ability to identify the durability of the deep-seated area, the results presented in Table 3 gave rise to qualify the concrete class of the bottom plate of the foundation no. 1 to a reliable value of B20, and of the foundation no. 2 to the value of B25 [3]. This is fully consistent with the results of the destructive tests.

Slightly lower values obtained in the tests carried out with the medium sclerometer (N) should be attributed to its greater sensitivity to the roughness of the test surfaces of the foundations and a higher degree of moisture at the surface of the concrete.

Table 3. The characteristics of the concrete durability distributions in the bottom plates of foundations no. 1 and 2, as determined by the non-destructive method with sclerometers N and M

Research area	Foundation no. 1				Foundation no. 2			
	Distribution parameters R_i			Guaranteed durability	Distribution parameters R_i			Guaranteed durability
	$\overline{R}$ [MPa]	S_R [MPa]	Z_R [MPa]	R_B^G [MPa]	$\overline{R}$ [MPa]	S_R [MPa]	Z_R [MPa]	R_B^G [MPa]
	Medium sclerometer (N)				Medium sclerometer (N)			
A	22.0	2.9	13.4	17.2	32.8	2.1	8.5	29.3
B	18.5	2.0	10.8	15.2	41.7	2.6	6.2	37.4
C	26.6	3.2	11.9	21.3	39.2	2.6	6.4	34.9
D	18.3	2.3	12.5	14.5	39.6	3.0	7.6	34.7
E	20.5	3.0	14.7	16.3	33.6	3.1	9.3	28.5
F	19.3	2.8	14.0	14.7	35.8	2.1	5.9	32.3
G	–	–	–	–	33.0	2.9	8.8	28.2
	Heavy sclerometer (M)				Heavy sclerometer (M)			
A	26.4	4.5	17.2	19.1	33.9	3.0	9.7	29.0
B	24.3	3.9	16.1	17.8	45.2	2.9	6.4	40.0
C	24.0	2.2	9.3	20.3	43.5	2.6	6.0	39.2
D	–	–	–	–	46.8	3.2	6.8	41.5
E	25.7	3.5	13.6	20.0	34.7	2.6	7.5	30.4
F	27.5	3.5	12.7	22.16	37.4	3.6	9.6	31.5
G	–	–	–	–	38.6	3.4	8.8	33.0

Source: [3]

6. Summary

Reconstruction and modernization of the existing building structures requires the prediction of further sustainability of their structural components. It is essential to determine how long they can continue to be used safely while fulfilling the assumed function.

The article presents a detailed study of the technical condition of the approximately 35-year-old reinforced concrete foundation slabs for turbine sets, conducted in the years 1995–1996. Based on the strength tests of the concrete cores cut out from the bottom plates of the foundations no. 1 and 2, it was found that the resulting compressive strength of the concrete corresponded to at least the B20 and B25 classes, which are required for this type of construction.

According to the currently binding standard PN-EN 206-1:2003 [7], it is equivalent to the C16/20 and C20/25 concrete classes. The results of the physico-chemical tests allowed to conclude that for the conditions which these two bottom plates were placed in (with appropriate waterproof insulation), their durability was not compromised.

The presented results of the research formed the basis for a decision to use both foundations as supports for the framework structure for new turbine sets, thus allowing for further 40 years of their utilization.

Now, after nearly 20 years of use, they show no signs of wear and properly perform their role. Current technical condition of the turbine set foundations confirms that the decision made in the mid-90s was a right one, and the scope of the research which was then carried out can serve as an example of the course of action adopted for similar cases.

References

[1] Fuksa M., Barycz S.: *Opinia w sprawie jakości betonu w masywnych elementach na podstawie badań termicznych fundamentu pod turbozespół 200 MW*. Kraków 1963 [unpublished].

[2] Barycz S., Gawlicki M., Mierzwa J.: *Badanie techniczne płyty dolnej fundamentu turbozespołu nr 1 i 2 w elektrowni*. AGH, Kraków 1995 and 1996 [unpublished].

[3] *Projekt deskowania fundamentu tg 200 MW (obiekt D-6423)*. Biuro Projektów Energetycznych ENERGOPROJEKT, Warszawa 1960 [technical documentation, unpublished].

[4] PN-88/B-06250 *Beton zwykły*.

[5] PN-B-06262:1974 *Nieniszczące badania konstrukcji z betonu – Metoda sklerometryczna badania wytrzymałości betonu na ściskanie za pomocą młotka Schmidta typu N*.

[6] Runkiewicz L., Brunarski L.: *Instrukcja stosowania młotków Schmidta do nieniszczącej kontroli jakości betonu w konstrukcji*. Instrukcja ITB nr 210, Instytut Techniki Budowlanej, Warszawa 1977.
[7] PN-EN 206-1:2003. *Beton. Część 1: Wymagania, właściwości, produkcja i zgodność*.
[8] PN-EN 13791:2008. *Ocena wytrzymałości betonu na ściskanie w konstrukcjach i prefabrykowanych wyrobach betonowych*.

GEOMATICS AND ENVIRONMENTAL ENGINEERING • Volume 9 • Number 3 • 2015

http://dx.doi.org/10.7494/geom.2015.9.3.87

Kornyliy Tretyak*, Petro Dvulit*, Lyubov Babiy*

About Accuracy of Calculating Deviations of Plumbing Lines in the Region of International Research Geodetic Polygon of the Western Alps

1. Introduction

At present considerable areas on continents, seas and oceans are covered with gravimetric survey. According to data of the International gravimetric bureau (Toulouse, France) gravimetric exploring of different Earth's regions on 1986 included 3 362 575 gravimetric points and was presented by anomalies of gravitational acceleration with a corresponding trapezium size 1° × 1°. Notice, that gravimetric exploring of the world until the middle of the nineties of the of the twentieth century. was very inhomogeneous, but during last decades degree of the Earth surface exploring became equalized considerably.

On the modern stage creation of the Earth's gravitation field models for the provision of determination of quasigeoid heights and components of deviations of plumbing lines with mean square errors correspondently 0.3–0.5 m and 0.5–1.0" is actual problem. Due to achievements in the field of space geodesy and gravimetry, considerable value of new and more precise and detailed information about the Earth's gravitational field was obtained. As a result there was achieved considerable progress on enhancement of accuracy and detailing of the Earth's gravitational field models and in the direction of development and realization of new forms of mathematical representation of gravitational anomalies.

A lot of publications of various researchers are devoted to the problem of practical calculations of gravimetric components of plumbing line deviations for the points of International research geodetic polygon in the region of the Western Alps [1–3, 5, 6]. Relief of the terrain on this polygon is quite complicated and diverse. Most gravimetric points are located on the heights 100–400 m. In the north and western north parts there are points with heights 2–3 km above sea level. Errors of determination of values of anomalies of gravitational acceleration Δg for gravimetric points are 2–3 mgal when the mean network density is 1 point per 100 km^2. On the

* National University "Lviv Polytechnic", Lviv, Ukraine

research territory there are large sites (up to 1600 km^2) for which gravimetric survey was not implemented. Amplitude of majority of local anomalies $|\Delta g|$ = 20–60 mgal. Pure errors of interpolation for research polygon are $\delta(\Delta g)$ = 1–3 mgal, $\delta(\xi,\eta)$ = 0.2–0.7'' correspondently to anomalies and deviations of plumbing lines. In whole for polygon area the error of pure interpolation is 4–6 mgal and error of calculating deviations of plumbing lines is 1.0–1.2''. Additionally for 20 astronomic points of the research polygon the astronomic-geodetic components of plumbing line deviations were determined.

The aim of this work is generalization of some methods for calculating deviations of plumbing lines from a perspective of accuracy of their value calculation and possibilities to use high accuracy models of geopotential for calculating deviations of plumbing lines. Firstly we will dwell on the analysis of the last research where this problem is solving.

In the works [7–9] there is presented an overview of methods which are recommended for use for calculating deviations of plumbing lines in mountains. Particular attention was paid to methods which make more precise the known formulas of F. Vening Meinesz in zeroth and first approximations. Here only those methods which were approved on the models or in mountain region are described.

The method of interpolation and transformation of potential fields [1, 2] is used for practical effective algorithm of calculations of gravimetric components of plumbing lines in central zone. A practical realization of this method is implemented in the system of program "Reduction-plumb"[3].

Authors [4, 6] showed that corrections of Molodensky for the zeroth approximation of anomalous potential impacts mainly not on the heights of quasigeoid but on deviation of plumbing lines in the points of the physical Earth surface. So for the practice the calculating deviations of plumbing lines in the first approximation are in the first place of importance.

In the work [5] calculating deviations of plumbing lines for the Earth's models using created for them gravimetric maps has been implemented. A comparison of calculation results with precise shows that they differ on the values to a tenth of a second.

The author [3] proposed a method of processing anomalies of gravitational acceleration for arbitrary surface of measurements. This method can be used for processing the anomalies in mountain regions, for the interpolation of values of different field characteristics, for the calculation of various field transformants including deviations of plumbing lines. It is shown that the accuracy of this method is close to optimal. The possibility of applying this method for calculating deviations of plumbing lines in the case of inhomogeneous and low-density networks of gravimetric measurements is established on the basis of a comparison with data obtained from astronomic observations and using other methods.

In the work [6] there was done an attempt to determine the order of the value of the first corrections of Molodensky into Stoke approximation of quasigeoid heights and deviations of plumbing lines in the mountain region of the International geodetic polygon. If calculations are done on formulas Stokes and Vening Meinesz using topographic maps and maps of anomalies in partial topographic reduction then we get the basic value of the first correction of Molodensky.

In work [7] the calculations of gravimetric components of deviations of plumbing lines for the points of International research geodetic polygon in the region of the Western Alps in zeroth approximation were done. Obtained divergences of gravimetric and astronomic-geodetic components of plumbing line deviations could be explained by principal errors of zeroth approximation formulas and errors of astronomic determinations. Additionally, authors underlined obvious shortage of gravimetric survey around some astronomic points.

2. Exposition of Basic Material

Solution of scientific and many applied problems of geodesy is connected with necessity of precise allowance of influence of such characteristics of the Earth's gravitational field as components of plumbing line deviations, quasigeoid heights and others.

Methods for calculation of quasigeoid heights and components of plumbing line deviations using gravimetric information can be divided on the following groups: methods of integral transformation, methods of parametric approximation, methods of statistic collocation and combined methods.

Methods of integral transformation are based on integral formulas of Stokes and Vening Meinesz:

$$\zeta = \frac{R}{4\pi\gamma}\iint_{\sigma} \Delta g \cdot S(\psi) \cdot d\sigma \tag{1}$$

$$\begin{Bmatrix} \xi \\ \eta \end{Bmatrix} = \frac{1}{4\pi\gamma}\iint_{\sigma} \Delta g \cdot \frac{dS(\psi)}{d\psi} \cdot \begin{Bmatrix} \cos A \\ \sin A \end{Bmatrix} d\sigma \tag{2}$$

where:

ζ – quasigeoid height,
ξ, η – components of plumbing line deviations in the plane of meridian and first vertical,
Δg – source (initial) anomaly of gravitational acceleration in the free air,
σ – Earth sphere,
R – radius of the Earth sphere,
γ – normal value of gravitational acceleration,
ψ – spherical distance between researched and running points,
$S(\psi)$ – Stokes function.

When modern requirements of science and practice concerning on determination of components of plumbing line deviations, the accuracy of formulas (1) and (2) is not sufficient and it is necessary to use more handy methods of calculation of L.P. Pellinen, which according to accuracy can be compared with formulas of Molodenskii in the first approximation [9]:

$$\begin{Bmatrix} \xi \\ \zeta \end{Bmatrix} = \frac{1}{4\pi\gamma} \iint_\sigma (\Delta g' + 2\pi GDH + \delta g) \frac{dS(\psi)}{d\psi} \cdot \begin{Bmatrix} \cos A \\ \sin A \end{Bmatrix} d\delta + \begin{Bmatrix} \Delta\xi \\ \Delta\eta \end{Bmatrix} \tag{3}$$

$$\begin{Bmatrix} \Delta\xi \\ \Delta\zeta \end{Bmatrix} = \frac{GDR^2}{4\pi\gamma} \iint_\sigma \frac{H - H_0}{r_0} \left(\frac{1}{r_0} - \frac{1}{r} \right) \begin{Bmatrix} \cos A \\ \sin A \end{Bmatrix} d\delta \tag{4}$$

$$\delta g = \frac{H_0 - H}{2\pi} R^2 \iint_\sigma \frac{\Delta g' - \Delta g_0}{r_0^3} d\delta \tag{5}$$

where:

$\Delta g'$ – anomaly of gravitational acceleration in partial topographic reduction,

$2\pi GDH$ – correction of Bouguer,

H, H_0 – heights of running and researched points,

r_0 – projection of on horizontal plane,

$\Delta\xi$, $\Delta\eta$ – corrections into components of plumbing line deviations for the influence of topographic mass.

Most useful in the case of calculating there is a method analytical continuation [4]. In this method the source (initial) anomalies are reduced from the physical Earth surface onto reference sphere of researched point using expansion in a Taylor series:

$$\begin{Bmatrix} \Delta\xi \\ \Delta\zeta \end{Bmatrix} = \frac{1}{4\pi\gamma} \iint_\sigma \Delta g \cdot \frac{dS(\psi)}{d\psi} \cdot \begin{Bmatrix} \cos A \\ \sin A \end{Bmatrix} d\delta + \sum_{n=1}^{\infty} \frac{1}{4\pi\gamma} \iint_\sigma g_n \cdot \frac{dS(\psi)}{d\psi} \cdot \begin{Bmatrix} \cos A \\ \sin A \end{Bmatrix} d\delta$$

$$g_0 = g_n,$$

$$g_n = -\sum_{m=1}^{n} (H - H_0)^m L_m(g_{n-m}) \tag{6}$$

$$L_0(\Delta g) = \frac{1}{n} L_1 \left| L_{n-1} \Delta(g) \right|$$

$$L_1(\Delta g) = \frac{1}{2} \iint_\sigma \frac{\Delta g' - \Delta g_0}{r^3} d\delta$$

Among methods of approximation for calculating components of plumbing line deviations the method of spherical harmonics based on known formulas of series expansion of the Earth's gravitational field characteristics according to spherical functions is most widespread:

$$\begin{aligned} \xi &= \frac{GM}{\gamma r^2}\sum_{n=r}^{N}\left(\frac{a}{r}\right)^n \sum_{m=0}^{n}(\bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\sin m\lambda)\frac{\partial \bar{P}_{nm}(\sin\varphi)}{\partial\varphi} \\ \eta &= -\frac{GM}{\gamma r^2\cos\varphi}\left(\frac{a}{r}\right)^n \sum_{m=0}^{n}(\bar{S}_{nm}\cos m\lambda - \bar{C}_{nm}\sin m\lambda)\frac{\overline{\partial P_{nm}}(\sin\varphi)}{\partial\varphi} \end{aligned} \tag{7}$$

where:

$\bar{C}_{nm}, \bar{S}_{nm}$ – completely normalized expansion coefficients,
$\bar{P}_{nm}(\sin\varphi)$ – completely normalized Lagrange functions,
n – harmonic degree,
m – harmonic order,
N – sum limit.

With the enhancement of the accuracy of global models, geopotential has got altimetric approach which is called "elimination – renovation". This approach is used for calculating quasigeoid heights and components of plumbing line deviations.

We implemented the following experimental research: for nine researched points of International research geodetic polygon in the region of the Western Alps there were determined the gravimetric components of plumbing line deviations from the models of the Earth's gravitational field EGM 2008; previously calculated gravimetric components of plumbing line deviations in zeroth approximation and in the first approximation were used for these points; difference in heights of the observation points was considered. Then astronomic-geodetic components of plumbing line deviations on these points were calculated and compared with their known values according to astronomic and geodetic coordinates. The results of the experimental research are shown in Tables 1–3. Table 1 displays the values of gravimetric and astronomic-geodetic components of plumbing line deviations.

Table 1. Values of plumbing line deviations determined by different methods

Point number	Gravimetric components of plumbing line deviations						Astronomic-geodetic components of plumbing line deviations							
	model values		on Ostach		on Aronov		true values		model values		on Ostach		on Aronov	
	ξ″gr	η″gr	ξ″gr	η″gr	ξ″gr	η″gr	ξ″ag	η″ag	ξ″ag	η″ag	ξ″ag	η″ag	ξ″ag	η″ag
14	−25.5	21.5	−23.3	16.5	−20.5	15.3	−26.3	17.1	−25.2	21.5	−23.2	16.5	−19.9	15.3
20	−15.2	4.9	−15.9	1.6	−15.8	1.6	−20.9	1.0	−15.2	4.9	−15.9	1.6	−15.8	1.6
30	−20.5	28.4	−21.9	27.5	−20.4	26.3	−24.8	23.3	−20.4	28.4	−21.9	27.5	−20.3	26.3

Table 1. cont.

Point number	Gravimetric components of plumbing line deviations						Astronomic-geodetic components of plumbing line deviations							
	model values		on Ostach		on Aronov		true values		model values		on Ostach		on Aronov	
	ξ″gr	η″gr	ξ″gr	η″gr	ξ″gr	η″gr	ξ″ag	η″ag	ξ″ag	η″ag	ξ″ag	η″ag	ξ″ag	η″ag
33	−4.5	17.1	−4.2	17.0	−4.2	17.1	−8.3	14.4	−4.4	17.1	−4.2	17.0	−4.1	17.1
34	−8.1	27.0	−7.3	25.9	−7.0	24.2	−11.4	24.9	−8.0	27.0	−7.3	25.9	−6.9	24.2
37	4.0	4.8	1.1	4.6	1.1	3.2	−2.9	2.2	4.0	4.8	1.2	4.6	1.2	3.2
38	11.5	−0.1	9.5	−1.4	8.7	0.0	4.0	−8.9	11.6	−0.1	9.5	−1.4	8.7	0.0
43	12.2	17.2	12.3	18.9	10.6	17.9	13.4	23.2	12.2	17.2	12.3	18.9	10.6	17.9
45	−0.2	0.0	−2.6	−0.6	−3.4	−1.0	−5.6	−1.7	−0.1	0.0	−2.6	−0.6	−3.4	−1.0

Table 2 displays differences between real and calculated values of astronomic-geodetic deviations of plumbing line obtained by different calculation methods.

Table 2. Differences between real and calculated values of astronomic-geodetic deviations of plumbing line obtained by different calculation methods

Point number	Differences of true and model values		Differences of true values and calculated on Ostach		Differences of true values and calculated on Aronov	
	$\xi_{ag}^{true} - \xi_{ag}^{mod}$	$\eta_{ag}^{true} - \eta_{ag}^{mod}$	$\xi_{ag}^{true} - \xi_{ag}^{Ost}$	$\eta_{ag}^{true} - \eta_{ag}^{Ost}$	$\xi_{ag}^{true} - \xi_{ag}^{Ar}$	$\eta_{ag}^{true} - \eta_{ag}^{Ar}$
14	−1.1	−4.4	−3.1	0.6	−6.4	1.8
20	−5.7	−3.9	−5.0	−0.6	−5.1	−0.6
30	−4.4	−5.1	−2.9	−4.2	−4.5	−3.0
33	−3.9	−2.7	−4.1	−2.6	−4.2	−2.7
34	−3.4	−2.1	−4.1	−1.0	−4.5	0.7
37	−6.9	−2.6	−4.1	−2.4	−4.1	−1.0
38	−7.6	−8.8	−5.5	−7.5	−4.7	−8.9
43	1.2	6.0	1.1	4.3	2.8	5.3
45	−5.5	−1.7	−3.0	−1.1	−2.2	−0.7

Accuracy estimation of calculation results is shown in Table 3.

Table 3. Errors of calculated values of plumbing line deviations

Errors of model values of plumbing line deviations		Errors of plumbing line deviations calculated on Ostach		Errors of plumbing line deviations calculated on Aronov	
$m''\xi$	$m''\eta$	$m''\xi$	$m''\eta$	$m''\xi$	$m''\eta$
4.90	4.65	3.86	3.46	4.42	3.79

3. Conclusions

Discrepancies between true and calculated components of plumbing line deviations can mainly be explained by errors of astronomic determination as components of plumbing line deviations includes the influence of the zeroth and the first approximation of the field of anomalies.

Considering height differences considerably improves the accuracy of the gravimetric components of plumbing line deviations to 1″ if relief corrections using gravimetric maps of Bouguer anomalies are taken into account.

Differences between model end true components of plumbing line deviations can be explained by not considering the influence of the central and closed zone of the anomaly field.

References

[1] Aronov V.I., Gordin V.M.: *Ob odnom sposobe interpolyatsii anomalii i vychisleniy gravimetricheskikh ukloneniy otvesa v rayone Zapadnykh Al'p* [Об одном способе интерполяции аномалии и вычислений гравиметрических уклонений отвеса в районе Западных Альп]. Geofizicheskiy byulleten', 24, 1971, pp. 19–24.

[2] Aronov V.I., Gordin V.M., Beleykov N.Ye., Shirginova A.I.: *Programma dlya vychisleniya gravimetricheskikh ukloneniy otvesa v tsentral'noy zone* [Программа для вычисления гравиметрических уклонений отвеса в центральной зоне]. Izvestiye vuzov, Geodeziya i aerofotos'yemka, 4, 1971, pp. 41–45.

[3] Aronov V.I.: *Obrabotka na EVM znacheniy anomaliy sily tyazhesti pri proizvol'nom rel'yefe poverkhnostey nablyudeniy* [Обработка на ЭВМ значений аномалий силы тяжести при произвольном рельефе поверхностей наблюдений]. Nedra, Moskva 1976.

[4] Marich M.I.: *O vychislenii otvesa na fizicheskoy poverkhnosti Zemli* [О вычислении отвеса на физической поверхности Земли]. Geodeziya, kartografiya i aerofotos'yemka, no. 18, 1973, pp. 24–28.

[5] Marich M.I., Gudz I.N., Dvulit P.D.: *Opyt vychisleniya ukloneniy otvesa na modelyakh Zemli* [Опыт вычисления уклонений отвеса на моделях Земли]. Geodeziya, kartografiya i aerofotos'yemka, no. 18, 1973, pp. 29–33.

[6] Marich M.I., Gudz I.N.: *O vychislenii vysot kvazigeoida i ukloneniy otvesa v gornom rayone* [О вычислении высот квазигеоида и уклонений отвеса в горном районе]. Geodeziya, kartografiya i aerofotos'yemka, no. 34, 1981, pp. 65–68.

[7] Ostach O.M., Pellinen L.P.: *Vychisleniye gravimetricheskikh ukloneniy otvesa v nulevom priblizhenii v rayone Zapadnykh Al'p* [Вычисление гравиметрических уклонений отвеса в нулевом приближении в районе Западных Альп]. Geofizicheskiy byulleten', 24, 1971, pp. 13–18.
[8] Pellinen L.P.: *Comparison of different methods for computing the plumb-line deflections in the mountainous areas*. Bulletin géodésique, vol. 89, issue 1,1968, pp. 345–354.
[9] Pellinen L.P.: *O vychislenii ukloneniy otvesa i vysot kvazigeoida v gorakh* [О вычислении уклонений отвеса и высот квазигеоида в горах]. Trudy TSNIIGAIK, vyp. 176, 1969, pp. 99–112.

http://dx.doi.org/10.7494/geom.2015.9.3.95

Grażyna Wójcik*, Przemysław Leń**

Spatial Development of Agricultural Land Division throughout the Ages in Villages of the Opoczno County

1. Introduction

Development of agricultural land division over the centuries in the villages of the Opoczno County resulted in defective spatial structure of the region's rural areas. Numerous factors have influenced today's picture of the countryside in Central Poland. In this article the authors attempt to identify factors which have impacted the present spatial structure of the investigated area. The study was based on registration data acquired from the district geodetic and cartographic documentation centre in Opoczno as well as field research.

2. Location of the Investigated Area

The Opoczno County is situated between two rivers, the Vistula and the Pilica. Opoczno, the district capital, is located at a distance of 100 km from Warsaw and 90 km from Łódź (Fig. 1).

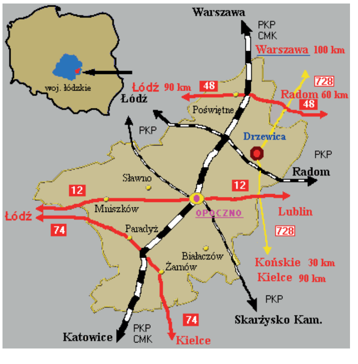

Fig. 1. Location of the Opoczno County

Source: http://archiwalna.drzewica.pl, accessed on 20.03.2015

* Jan Kochanowski University in Kielce, Kielce, Poland

** Rzeszów School of Engineering and Economics, Institute of Cadastral Surveying and Geodetic Engineering, Rzeszów, Poland

Opoczno is located along the Drzewiczka River, a right-bank tributary of the Pilica. The Opoczno County comprises an area within the Opoczyńskie Hills, which run along the north-western border of the Kielce Upland, and comprise areas encircled by the large arch of the Pilica, from Przedbórz to Smardzewice and from Końskie as far as Drzewica. This is an area of approx. 1460 km^2. In the east the county borders on the Gielniowski Hump, in the south-east it adjoins the Suchedniów Plateau, and in the south the Łopuszańskie Hills as well as the Przedborsko-Małogoskie Range. The northern and western boundary of the region is also a border of the Małopolska Upland and the Central Polish Lowlands. Opoczno is located in the north-western outskirts of the Kielce-Sandomierz Upland, i.e. between the Małopolska Upland and the Mazovian Lowland [1].

3. History of Settlements in the Opoczno Region

Human settlements appeared here as early as the 10–11th century, mainly in the areas with terrain and natural conditions convenient for this purpose. Other favourable factors included important traffic routes, rivers and fertile soils. These conditions enabled establishment of such settlements as: Opoczno, Drzewica, Odrzywół, Inowłódz. A trade route passing through Drzewica, Odrzywół and northward via Nowe Miasto was part of the Amber Road from Cracow to Warsaw and further to the Baltic Sea. Another important route ran through Opoczno and Inowłódz. This location contributed to the development of these places and the growing wealth of their populations. The factors of vital importance for the development of civilization included: easy access to water from the rivers Pilica and Drzewiczka as well as the soils which yielded good crops for consumption by the local people and for trade [2].

Villages situated away from traffic routes and rivers did not have such convenient conditions for growth. The lands were owned by families with a status of nobility; they established large landed estates, were endowed with privileges and had authority over peasants. This system survived until the mid-19th century.

In the following centuries the Opoczno region witnessed a systematic development of new settlements which were established as colonies. Over 70 perpetual colonies were founded during 1812–1862. These were mainly established within large and medium-size landed estates, in areas cultivated by land owners, in areas formerly occupied by serfs, and in deforested areas (as many as 60%). Farming lands designated for parcelling out for the new colonies were frequently of poor quality; these were plots of fields and forests, pastures, thickets, wilderness and wasteland. Most frequently the colonies comprised an area of 200–300 morgens and settlers would receive farms of 15-30 morgens. Names of colonies most commonly were derived from the first names of owners or members of their families, e.g. Emilianów – Emilia, Stanisławów – Stanisław, Wandzinów – Wanda, or, less frequently, from their last names or names of coats of arms. Within the Opoczno County in 1859 there were 310 rent based settlements, 1220 rent and tribute based settlements as well as 5626 tribute based settlements [2].

4. Legal Property Rights

Property rights in the area reflected the conditions which were predominant over the ages throughout Poland.

From the times of early settlements, in Poland and in the area of Opoczno there were two types of agricultural operations: those maintained by landowners and peasants. Landed estates comprised the most fertile soils, while peasants were most often left to manage poor soils, unprofitable for manor owners. Peasants faced double load of work. They cultivated their own plots and had to pay tribute to the lord of the manor by working in his estate. The latter duty was varied, depending on the times and circumstances. It ranged from a few days in a year to a few days per week (even 5 days a week). Another important aspect, leading to overpopulation of rural areas, was the limited personal freedom of peasants. During the reign of King Casimir the Great, only two peasant families were allowed to leave the village in a given year. In the 1400s, the times of King John Albert, only one person from a peasant family was allowed to leave the village. If permitted by the lord of the manor, only one son of peasants from a given village could go to town to get education or learn a craft. This situation continued during the times of foreign authority. Changes occurred only in the 1860s, as a result of peasants' resistance which contributed to a greater awareness of problems faced by the rural population in Poland [2].

The rebellion of Polish peasants against serfdom kept growing and gained impetus after the agrarian reform of 3 March 1861, introduced in the Russian Empire. The reform in fact did not apply to peasants living in Congress Poland; this led to strong protests, especially in early April 1861. In May 1861 peasant riots spread to 1076 villages. As a result the authorities introduced the so-called redemption payments. In autumn of 1861 large number of villages (95%) adopted the redemption payment system. Other related developments included the ordinance of statutory rent, issued on 5 June 1862 which continued the process of replacing serfdom with redemption payment. These provisions were only implemented after the outbreak of the January Uprising in 1863. Ordinances related to granting property rights were issued on 2 March 1864. After that peasants gained ownership of approx. 7.8 million morgens of land; including the plots owned by townsmen, the figure amounted to 8.3 million [3].

Imperial ordinance granted peasants with the property rights for plots of land cultivated by them. They no longer had to work for the lord of the manor; instead they were required to pay land value tax to the state treasury. Yet, rural population continued to vary in status; there were farmers, semi-farmers, croft holders, cottage holders and shed holders. Importantly, peasants were now allowed to move away.

Some set off "for bread", seeking jobs in towns or abroad. The fact that peasants gained property rights contributed to a change in their worldview and mentality. This social group, oppressed for ages by Polish nobility, gradually changed its subservient attitude to their overlords. Emancipated, the peasant became the master of his land. He also desired more independence and education, which would enable him e.g. to make better use and retain the ownership of the land. Peasants were driven by the need (or even desire) to own as much land as possible; that led to "craving for land". Yet, divided between family members (bequests to children), peasants' farms were more and more fragmented. Due to this the average size of peasants' farms kept decreasing [2]; that adversely affected financial situation of rural populations, frequently resulting in poverty and even deprivation, particularly during periods preceding the new harvest.

5. Agrarian Reforms in the Period from 1918 to 1950

After Poland regained independence in 1918 challenges related to agriculture continued to exist. They resulted from the defective system of bondage and subordination. Two thirds of all farms in Poland in those days were small, comprising no more than 5 ha; their profits were lower than those yielded by large farming estates. In addition to the small farms there were also large landed estates, accounting for approx. 1% of the total number, and these comprised nearly half of the agricultural land of the country. Agrarian problems became more pronounced in the latter half of the 1800s and in the early 1920s. These were still caused by peasants' poverty, which contributed to the so-called "craving for land". Agrarian issues were the main political and economy related problems in Poland after its liberation, and were particularly pronounced in the areas formerly subjected to Austrian and Russian authority, where peasants rebelled against their masters. In the times of the Second Republic there was an awareness of the need for agrarian reform because of the growing peasant movement. The government announced an intention to nationalize large and medium size landed estates to be further transferred, by the state, to smallholders and landless peasants [4].

Under pressure from peasants' parties the Legislative Parliament passed a resolution on 10 July 1919 concerning the rules of implementing an agrarian reform [5]. The agrarian reform act was adopted on 15 July 1920 [6]. Accordingly, for the purpose of implementing the agrarian reform the following categories of land were defined: land owned by the state, purchased by the state from land owners, estates owned by the ruling dynasties of the countries formerly in control of Poland, the so-called *mortua manus* estates (owned by churches and monasteries) and estates owned by various public institutions. It was also determined that the Main Authority for Landed Estates was entitled to buy out land and excess plots in accordance with defined criteria. The rules and prices were defined for enforced buyout and parcelling out. The act stipulated: a plan of parcelling, potential buyers, buyout fund and other rules [6]. Unfortunately, due to the noncompliance of the act with the Constitution, only 19,000 ha of land were parcelled out in 1919–1920.

On 28 December 1925 the parliament passed another agrarian act [7]. It was most favourable for large landowners. The process of parcelling out was very slow and by 1939 it was only completed at the level of 58%. In 1933 the agrarian act was amended. The total of 2.6 million ha of land was parcelled out during 1919–1939.

Agrarian reforms were interrupted by World War II. A new decree on agrarian reform was issued on 6 September 1944 by the Polish Committee of National Liberation [8]. The document specified the types of farming land subject to the reform, the results of expropriation without damages, or the level of damages or compensation paid to owners of estates subject to parcelling out [9]. The parliament passed the act of 20 March 1950 on nationalization of landed estates owned by the Church and religious communities and on establishing the Church Fund [10] and following the decree of 12 December 1944 some forests became a property of the State Treasury [11].

6. Analysis of Spatial Structure of Rural Areas in the Opoczno County

As a result of developments related to settlements in the area of Opoczno, the county comprises 216 land register units. In terms of administration they belong to 8 communes; this is illustrated by data in Table 1 and by Figure 2.

Fig. 2. Spatial distribution of the communes in the Opoczno County
Source: www.archiwum.opocznopowiat.pl, accessed on 20.03.2015.

The largest is the Commune of Opoczno, which comprises 36 villages with a total area of 19,064.0 ha, accounting for 18.3% of the total county area. The second largest is the Commune of Żarnów. It comprises 43 villages, and a total area of 14,106.0 ha, i.e. 13.6% of the total county area. The next one in terms of size is the

Commune of Poświętne, with 17 villages, and an area of 14,081.0 ha, accounting for 13.5% of the total area of the county. It is followed by the Commune of Sławno, located west of Opoczno, which comprises 34 villages and an area of 12,931.0 ha. i.e. 12.4% of the total county area. The areas of the next 3 communes: Mniszków, Drzewica and Białaczów are in the range from 11.0% to 11.9% of the total area of the county. The smallest Commune of Paradyż comprises 26 villages and a total area of 8,139.0 ha, i.e. 7.8% of the total area of the Opoczno County.

Table 1. Spatial structure of the communes in the Opoczno County

No.	Name of commune	Commune villages		Total area of the commune	
		number	[%]	[ha]	[%]
1	Białaczów	14	6.5	11,463.0	11.0
2	Drzewica	17	7.9	11,819.0	11.4
3	Mniszków	29	13.4	12,416.0	11.9
4	Opoczno	36	16.7	19,064.0	18.3
5	Paradyż	26	12.0	8,139.0	7.8
6	Poświętne	17	7.9	14,081.0	13.5
7	Sławno	34	15.7	12,931.0	12.4
8	Żarnów	43	19.9	14,106.0	13.6
Total:		216	100.0	104,019.0	100.0

6.1. Population Density in the Relevant Area

The largest in terms of population is the urban commune of Opoczno, which is inhabited by 35,461 people, i.e. 45.2% of the total population of the county. This number includes 22,188 residents of the town of Opoczno. With the rate of 186 people per 1 km^2 this commune is most densely populated; the second in terms of population is the Commune of Drzewica, with 94 people per 1 km^2.

The remaining communes of the Opoczno County are characterized by low population density, ranging from 38 people per 1 km^2 in the Commune of Mniszków to 57 people per 1 km^2 in the Commune of Sławno (Tab. 2). The findings show that population density in the villages of the Opoczno County is quite low, with an average of 75 people per 1 km^2. For comparison, the average population density in the villages of the Brzozów County in the Podkarpackie Province amounts to 124 people per 1 km^2, with the rate for Brzozów, the county capital, at the level of 262 people per 1 km^2 [12].

Table 2. Demographic rates in the Opoczno County

No.	Name of commune	Commune villages		Population		Population density per 1 km²
		number	[%]	number	[%]	
1	Białaczów	14	6.5	5,952	7.6	52
2	Drzewica	17	7.9	11,076	14.1	94
3	Mniszków	29	13.4	4,754	6.1	38
4	Opoczno	36	16.7	35,461	45.2	186
5	Paradyż	26	12.0	4,434	5.7	54
6	Poświętne	17	7.9	3,273	4.2	23
7	Sławno	34	15.7	7342	9.4	57
8	Żarnów	43	19.9	6,181	7.9	44
Total:		216	100.0	78,473	100.0	75

6.2. Structure of Ownership and Land Use in the Opoczno County

The conducted analyses (Tab. 3) show that, in the villages of the Opoczno County 75,699.0 ha of land belong to owners of individual farms; this accounts for 72.8% of the total county area. 'State Forests' National Forest Holding owns 19,904.0 ha, i.e. 19.1% of the total county area. Communal lands constitute 2%, and other lands account for 6.1% of the total rural area.

Table 3. Legal property rights

No.	Name of group	Area	
		[ha]	[%]
1	Land owned by private farms	75,699.0	72.8
2	'State Forests' National Forest Holding	19,904.0	19.1
3	Communal land	2,101.0	2.0
4	Other land	6,315.0	6.1
Total:		104,019.0	100.0

The data in Table 4 show that the county is characterised by a large proportion of agricultural land, which comprises an area of 65,829.0 ha, i.e. 63.3% of the total county area. More specifically, arable land comprises an area of 49,559.0 ha, accounting for 47.6% of the total county area. The region in question is characterised by a large proportion of forests. The findings show that forests comprise an area of 32,509.0 ha, i.e. 31.3% of the total county area.

Table 4. Structure of agricultural land

Type of land	Area	
	[ha]	[%]
Arable land	49,559.0	47.6
Orchards	982.0	0.9
Permanent grassland	6,072.0	5.8
Permanent pastures	6,261.0	6.0
Built-up agricultural land	2,427.0	2.3
Areas of ponds	149.0	0.1
Areas of ditches	379.0	0.4
Total agricultural lands:	65,829.0	63.3
Forests	32,509.0	31.3
Wooded land	583.0	0.6
Total forests and wooded land	33,092.0	31.8
Built-up and developed land	3749.0	3.6
Areas of watercourses	883.0	0.8
Ecological sites	37.0	0.0
Wasteland	421.0	0.4
Various areas	8.0	0.0
Total:	104,019.0	100.0

The findings related to the structure of land use show that farming land and forests constitute a majority in the county. Yet, the data presented in Table 5 show varied distribution of the types of land in the specific communes.

Table 5. Proportion of farming land (FL) and forests in the communes of the Opoczno County

No.	Name of commune	Number of villages in commune	Total area of commune [ha]	Including	
				farmland [%]	forests [%]
1	Białaczów	14	11,463.0	53.0	37.0
2	Drzewica	17	11,819.0	60.0	33.0
3	Mniszków	29	12,416.0	59.0	33.0
4	Opoczno	36	19,064.0	69.0	19.0
5	Paradyż	26	8,139.0	78.0	16.0
6	Poświętne	17	14,081.0	38.0	57.0
7	Sławno	34	12,931.0	76.0	15.0
8	Żarnów	43	14,106.0	70.0	22.0
Total:		216	104,019.0	–	–

The percentage of farming land ranges from 38.0% in the commune of Poświętne, to 78% in the commune of Paradyż. Percentage of forests ranges from 15.0% in the commune of Sławno to 57% in the commune of Poświętne.

6.3. Analysis of Land Layouts in the Investigated Area

Development of settlements in the Opoczno region occurred as a result of establishing new colonies. Each owner received a land of a few morgens, including one large piece of land and a so-called "annex". As a rule, the annex would comprise an area of several ares of land, such as a forest or meadow. The spatial structure of lands in rural areas evolved as a result of an extremely complex process influenced by a diversity of interrelated phenomena. The division of the rural areas was and still is greatly impacted by the form of land ownership. This in turn has depended on a number of factors.

Population density was the primary factor contributing to the changes in the spatial structure of land in the countryside; it was closely related to factors linked with the natural environment as well as structure of economy and production [13]. The statement by Noga aptly explains the state of the spatial land structure in the investigated region. Overpopulation and lack of possibility to migrate resulted in the fact that relatively large farms of 15–30 morgens were constantly divided between family members (all children inherited the land). Due to this the mean size of peasants' farms became lower and lower.

The consecutive property division led to significant land fragmentation and most importantly, to the resulting ribbon-type patchwork of fields, which is so typical for the region (Fig. 3).

Fig. 3. Part of the village of Strzyżów in the commune of Drzewica
Source: www.geoportal.gov.pl, accessed on 25.03.2015

The present findings show that practically the entire area of the county is characterized by the ribbon-type patchwork of land, and plots range in width from 2 m to several metres, yet the very narrow plots of land are most common. Such defective layout is in fact even more pronounced in areas of private forests, where the width of specific plots does not exceed a few metres (Fig. 4).

Field inspection of a selected farm showed other irregularities. In order to have access to the entire land, this particular owner had to delineate a road through his farm, which is shown in Figure 5. The road is 2.5 m wide. In total, the plots (329, 330, 331) are 27 m wide, and the farm has a length of 1,330 m, including a section of 110 metres, which is fenced and holds the house and farm buildings. Hence, a 2.5 metre wide road has been sectioned off along a distance of 1,220 m, comprising a total area of 0.3050 ha, i.e. 8.5% of the total land adjoining the buildings. The same situation can be seen in other farms. Therefore, the necessity to section off a road leads to significant loss in the size of the farm.

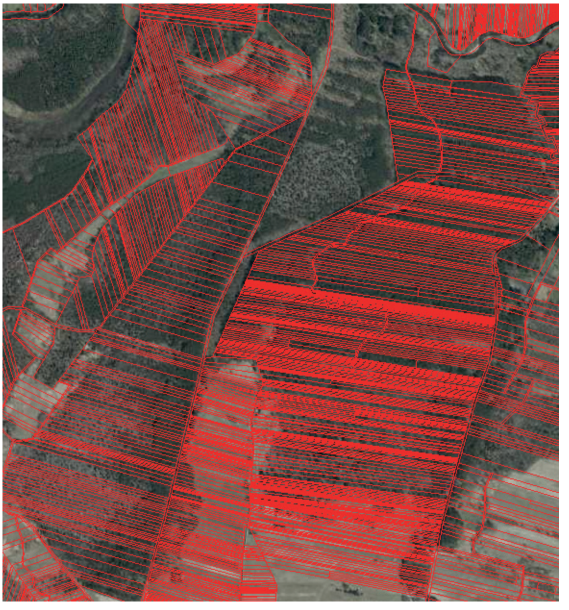

Fig. 4. Part of a forest in the village of Brzustowiec, commune of Drzewica

Source: www.geoportal.gov.pl, accessed on 25.03.2015

Fig. 5. Area of a farm in the village of Brzustowiec, plots no. 329,330,331

7. Conclusions

The present study has shown that rural areas in central Poland are characterized by high proportion of lands belonging to individual farms. In terms of structure, land property is dominated by agricultural areas, and in particular arable land. Similarly, forests constitute a significant percentage of the area, and their proportional share in specific communes of the Opoczno County is greatly varied. The analysis also shows that the spatial division of land throughout the ages negatively impacted the current spatial structure of rural areas in Central Poland. Overpopulation in the rural areas, as well as lack of possibility for people to migrate to towns resulted in the fact that peasants' farms were more and more fragmented, which in the investigated area, contributed to the development of ribbon-type patchwork of land. The present situation presents great disadvantages and hinders development of agriculture in the region. Therefore, it is necessary to initiate works aimed at consolidation of farming land in the area. Adequately performed land consolidation enables effective organization of farms, also contributing to the conservation of the natural environment. It creates adequate conditions for sustainable and multifunctional development of rural areas by reducing the harmful effects of intensive farming for the natural environment and results in better living and working conditions enjoyed by rural populations.

References

[1] Żarnowiecki G., Olszewski J.L.: *Warunki geograficzno-przyrodnicze Opoczna*. [in:] Meducka *M.* (red.), *Opoczno. Studia i szkice z dziejów miasta*, Kieleckie Towarzystwo Naukowe, Kielce 2003, pp. 15–30.

[2] Sroka J.: *Nasze Brudzewice 1321–2000: monografia*. Tomaszów Mazowiecki 2002.

[3] Groniowski K.: *Uwłaszczenie chłopów w Polsce: geneza – realizacja – skutki*. Wiedz Powszechna, Warszawa 1976.

[4] Kostrowicka I., Landau Z., Tomaszewski J.: *Historia gospodarcza Polski XIX i XX wieku*. Książka i Wiedza, Warszawa 1978.

[5] Roszkowski W. [pseud. Andrzej Albert]: *Najnowsza historia Polski 1914–1993. T. 1, 1914–1945.* Świat Książki, Warszawa 1995.

[6] *Ustawa z dnia 15 lipca 1920 r. o wykonaniu reformy rolnej* [*Act on the performance of agrarian reform, dated 15 July 1920*]. Dz.U. 1920 nr 70, poz. 462.

[7] *Ustawa z dnia 28 grudnia 1925 r. o wykonaniu reformy rolnej* [*Agrarian Act dated 28 December 1925*]. Dz.U. 1926 nr 1, poz. 1.

[8] *Dekret Polskiego Komitetu Wyzwolenia Narodowego z dnia 6 września 1944 r. o przeprowadzeniu reformy rolnej* [*Decree on the agrarian reform implementation, dated 6 September 1944*]. Dz.U. 1944 nr 4, poz. 17.

[9] Słabek H.: *Dzieje polskiej reformy rolnej 1944–48*. Wiedza Powszechna, Warszawa 1972.

[10] *Ustawa z dnia 20 marca 1950 r. o przejęciu przez Państwo dóbr martwej ręki, poręczeniu proboszczom posiadania gospodarstw rolnych i utworzeniu Funduszu Kościelnego* [*Act on nationalization of mortua manus estates, dated 20 March 1950*]. Dz.U. 1950 nr 9, poz. 87.

[11] Suchoń A., Kowalczyk M.: *Analiza przepisów dekretu PKWN z 6 września 1944 r. o przeprowadzeniu reformy rolnej wraz z późniejszymi zmianami oraz innych aktów prawnych, na podstawie których nastąpiło przejęcie nieruchomości ziemskich i lasów*. [in:] Borkowska-Bagieńska E., Szafrański W. (red.), *Reformy rolne w Polsce międzywojennej i powojennej,* Wydawnictwo Naukowe Uniwersytetu im. Adama Mickiewicza, Poznań 2008, pp. 63–138.

[12] Leń P.: *Sposób określenia pilności potrzeb scalenia i wymiany gruntów*. Akademia Górniczo-Hutnicza, Kraków 2013 [Ph.D. thesis].

[13] Noga K.: *Metodyka programowania i realizacji prac scalenia i wymiany gruntów w ujęciu kompleksowym*. Akademia Rolnicza, Kraków 2001.