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KINEMATICS OF REFERENCE HEIGHT NETWORK ON THE TERRITORY OF RIVNE NPP

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Abstract

Rivne Nuclear Power Plant (NPP) is located in western Ukraine. Construction of the station began in 1976.Totally four power generating units are operating on the station. Complicated geological conditions and display of man-made karst led to the need for monitoring of sediments and deformations on Rivne NPP.Since 1984 on the Rivne NPP there were conducted geodetic observations on the conditions of height reference network consisting of nine deep fixed reference points, which are installed in basaltic rocks.Totally 110 cycles of observations were conducted. The heights of fixed reference points were determined by leveling of I-st class. It is necessary to assess the kinematics of the reference height network and implement zoning of station territory according to a speed of inclination of the earth's surface.An average annual rates of displacement which appear as a linear trend weredetermined on the results of measurements for each fixed reference point by the least squares method. Excluding these values the vertical displacements of fixed reference points were derived and only the periodic component that is changing according to the periodic law remained present there. For each fixed reference point it was determined amplitude and optimum oscillation period and the coefficients of regression equations. Using the annual velocity of displacement of fixed reference points it was done the zoning of the Rivne NPP. There were allocated areas, which were characterized by different rates of inclinations and frequency of oscillations.

Keywords: deformation, stability of fixed reference points, network kinematics, crustal movements, optimal oscillation period, annual rate of displacement

1. Introduction

Observations of subsidence and deformation of the energy complex objects and especially nuclear power plants (NPPs) have a significant place in the modern practice of engineering and surveying works. Thus the complexity of observations and requirements to the accuracy of their performance are permanently increasing (Baran et al., 1999; Ashraf, 2010; Ehigiator et al., 2012).

For observations of the vertical displacements of engineering structure foundations using the method of geometric levelling it is created reference height base consisting of deep fixed reference points, using which the sedimentations of engineering structures are periodically determined (Kuznetsov, 2013; Shekhovtsov, 2002). Experience of observations shows that due to various reasons (difficult geotechnical conditions, mechanical impact on the fixed reference points, etc.) the stability of fixed reference points can be broken (Dutchyn & Grytsiuk, 2013).

By this time, there are many methods for determining the stability of reference points. However, often when processing the same network different methods of stability evaluation can produce different results (Neumann & Kutterer, 2006; Vasilyev & Pankrushin, 1985; Aksamitauskas et al., 2010).

Analysis and prediction of deformation processes is essential to the safe operation of nuclear power plants (Acton & Hibbs,2012; Liu 1998). A reliable reference of deformation processes and determination of the reasons of their display is possible when to use method of processing kinematic geodetic networks and filtering effects of different physical nature of the manifestation of deformation processes which is theoretically justified from the standpoint of kinematics (Ganshin,1991; Tretyak, 2004). Therefore, continuous monitoring of deformations and numerous external influences is important to maintain the operation of NPP engineering structures. The method of geometric levelling provides information about condition of reference network for the time of measurement, i.e. with regular intervals. The position of fixed reference points between cycles of observations we do not know from the results of measurements. It is therefore necessary to conduct analysis of the condition of deep fixed reference points, which will allow to predict the deformation processes at the sites of observation.

2.1. Aim

Rivne Nuclear Power Plant (Rivne NPP) is located in the western Polyssia, near the River Styr. Construction of the station began in 1976. Totally four power generating units are operating on the station. Currently, the share of the Rivne NPP in the power of all nuclear power plants of Ukraine is 15.4 percent. Difficult geological conditions, the influence of man-made karsts and neighbourhood with tectonically unstable fracture zones in the valley of river Stir led to the need for monitoring of sediments and deformations on Rivne NPP. Since 1984 on the Rivne NPP they are conducted geodetic observations on the condition of height reference network (Fig. 1), which consists of nine deep fixed reference points (Rp3 - Rp11), located on the territory of power generating units № 1 - 4 and two deep fixed reference points (Rp1 , Rp2), placed on the territory of cooler. The depth of laying the fixed reference points is from 31m to 43m, and all reference points laid at least on 0.5m inside indigenous basalt rock. Laying period is from March 1980 to October 2000.

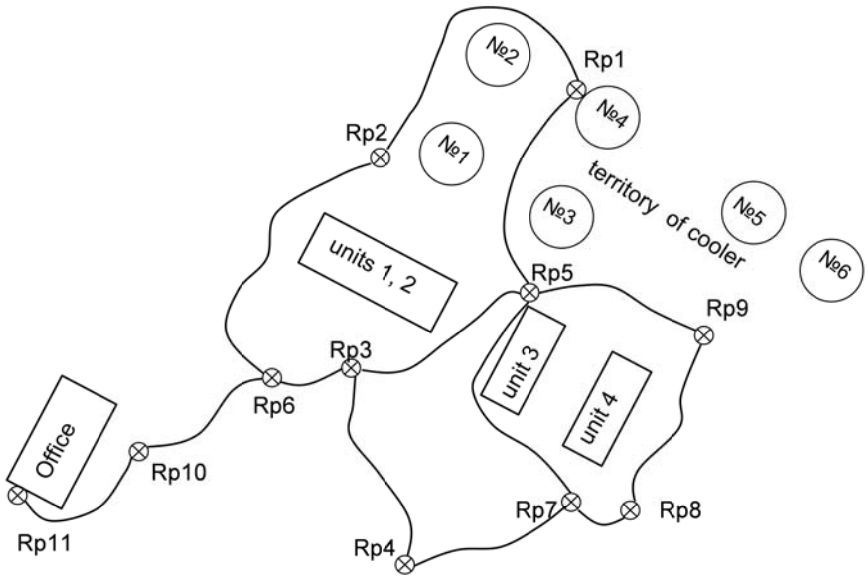

Fig. 1. Scheme of height reference network on the territory of Rivne NPP

It is necessary to assess the kinematics of the height reference network and on it's the basis to implement zoning of station territory.

2.2. Method

For the analysis of the condition of deep fixed reference points it is necessary to evaluate their kinematics. Model of vertical linear displacements and periodic oscillations of deep reference point can be described with the equation (Tretyak et al., 2012):

$$h = a \cdot t + b + c \cdot \cos\left[\frac{2\pi(t - t_0 - nT)}{T}\right] + s \cdot \sin\left[\frac{2\pi(t - t_0 - nT)}{T}\right] \quad (1)$$

where: *a*,*b* –coefficients of equation of regression of linear displacement of deep fixed reference point (*a*- an average annual velocity of displacement, *b*- initial height fixed reference point); *c*,*s* – harmonic coefficients, t_0, t– initial and current epoch of observations, *n* –number of periods of oscillation with duration *T*, which fits in the gap t-t_0.

In the formula (1) $a \cdot t + b$– equation of the strait line that actually describes the direction of displacement of deep fixed reference point, and the second part of the formula describes the frequency of the point position changing.

Based on the results of measurements for each fixed reference point the coefficients *a* i*b* of the regression equation (1) are determined by the method of least squares. Coefficient *a* characterizes a linear trend, so for the study of the oscillation frequency we apply the equation:

$$h = c \cdot \cos\left[\frac{2\pi(t - t_0 - nT)}{T}\right] + s \cdot \sin\left[\frac{2\pi(t - t_0 - nT)}{T}\right] \quad (2)$$

Since the harmonic oscillations depend on the length of the period, it is necessary to determine for each fixed reference point the length of oscillation period that describes these vertical displacements the best way.

For this purpose using software MathCad it was developed program for the selection of optimal harmonic curve to describe the kinematics of deep fixed reference points. For each deep fixed reference point the system of equations (2) is defined and after it's solving the optimal oscillation period is obtained. Each equation corresponds to the cycle of observations. The criterion for choosing the optimal harmonic functions describing the displacements of fixed reference points is the minimum of the expression.

$$\mathrm{M(T)} = c \cdot \cos\left[\frac{2\pi(t - t_0 - nT)}{T}\right] + s \cdot \sin\left[\frac{2\pi(t - t_0 - nT)}{T}\right] - H_i = min \qquad (3)$$

where H_i – the height of the fixed reference point in the relevant cycle of observations.

To determine the optimal period of oscillations of each deep fixed reference point we investigate the change of mean square error of approximation by the first terms of the expansion Fourier series of height oscillations of fixed reference points relating to the length of the period (3).For each fixed reference point it is determined optimal oscillation period, which corresponds to the minimum value of mean square error of approximation of curve of height oscillation of deep fixed reference points by Fourier series. As a result of the optimal solution of equations (3) the regression equation coefficients *c* and *s* and oscillation amplitude of each fixed reference point are obtained.

2.3. Results

During the period from 1984 to 2013 there were carried out 110 cycles of observation. The heights of fixed reference points were determined by the I-st class levelling. Mean square errors for each kilometre of the levelling route according to closing errors and the adjustment results for the whole period of observations are within limits: μ_{km}=0,29mm i μ_{km}=0,24mm.

Initial data for calculation of stability of height base are heights of deep fixed reference points derived from the results of measurements performed during the period from 03.1984 to 11.2013 (Research and development in the field of geodesy and mining, 2013). Fixed reference point № 5 is taken as immovable. According to measurements the diagrams of change of the heights of the deep fixed reference points during the period of observations have been created (Fig. 2). The red line on Fig.2 shows the change in of height position of deep fixed reference points.

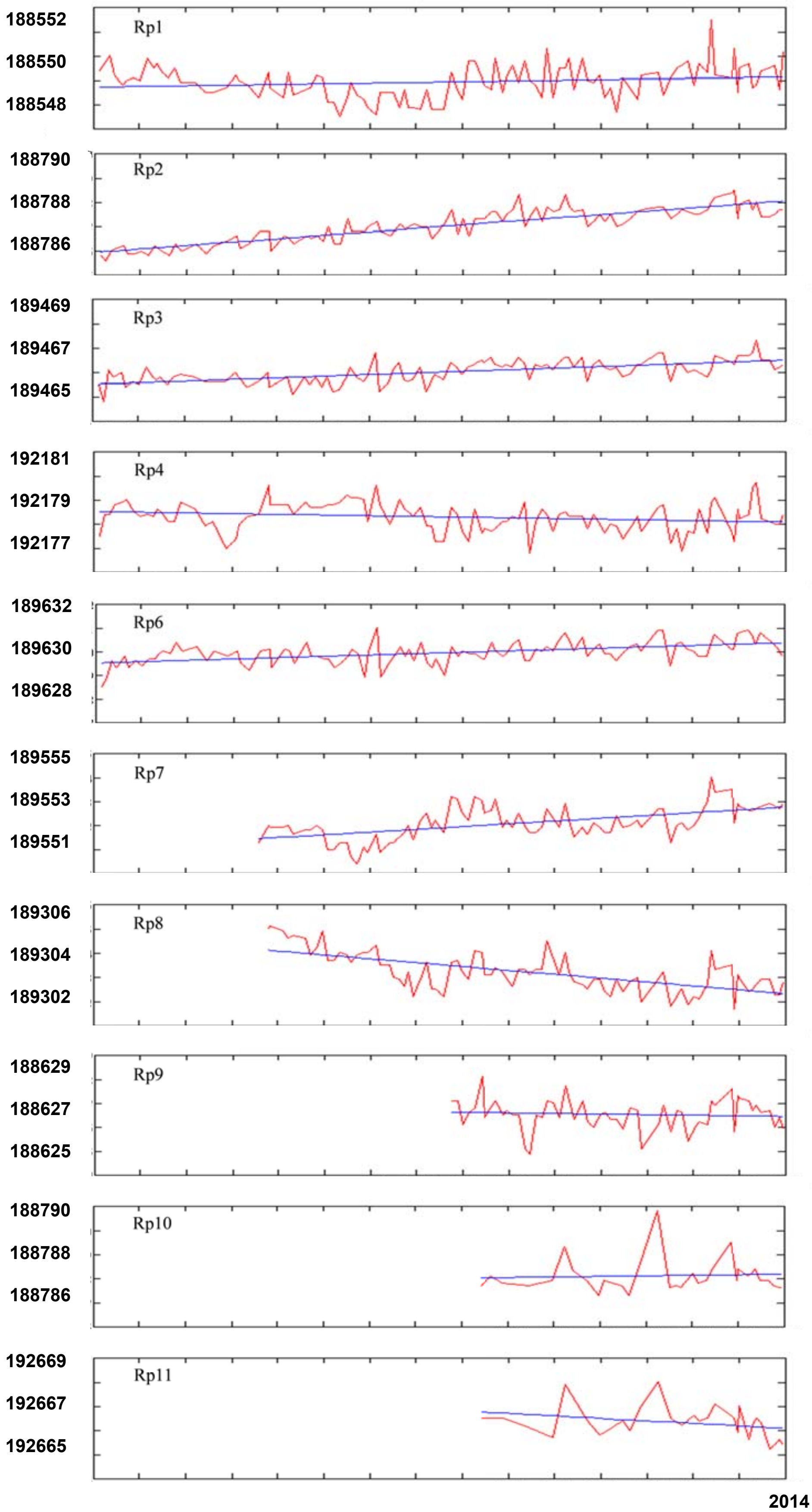

Fig. 2. The diagrams of change of the heights of the deep fixed reference points (mm)

Using equation (1) for each fixed reference point coefficients *a* and *b* were calculated. Since the coefficient *b* belongs to the initial height of the fixed reference point, we are interested only in coefficient *a*, therefore Table 1 shows the value of mean annual velocity of fixed reference points displacement and the average square error of their determination.

Table 1. Mean annual velocity of fixed reference points displacement and the average square error of their determination

№ point	*a*, mm/year	m_a,mm/year
1	0,014	0,008
2	0,070	0,004
3	0,033	0,004
4	-0,015	0,006
5	0,000	0,000
6	0,028	0,004
7	0,058	0,009
8	-0,080	0,010
9	-0,012	0,019
10	0,012	0,032
11	-0,052	0,029

According to the Table 1 the linear change of height position of fixed reference points is created (blue line in Fig.2). The graphs show that the maximum uplift there are for deep fixed reference points №2 and №7, and the maximum drawdown is recorded at a deep fixed reference point №8. As a result of calculating the velocity of displacement of fixed reference points the schematic map of distribution of annual vertical crustal velocities on the Rivne NPP was created (Fig. 3).

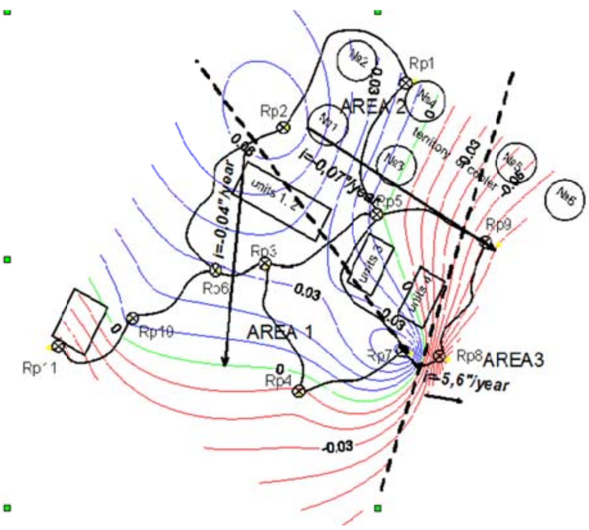

Fig. 3. Schematic map of distribution of annual vertical crustal velocities and the annual rate of inclination of the earth's surface on the Rivne NPP (isolines are at intervals of 0.01 mm / year)

— — — · boundaries of areas; → the direction and value of inclination velocity of the earth's surface; —— isolines of surface uplift; —— isolines of surface drawdown.

Analyzing presented schematic map it should be noted about the anomalous velocity of displacements of relative position of fixed reference points №7 and №8 comparing with other reference points

In displacements without a linear trend only periodic component of deep fixed reference points remained present (Fig. 4, red line). The diagrams on Fig. 4 show that the values of the displacement of fixed reference points have periodic regularity.

In order to determine the optimal period of oscillation of each deep fixed reference point it was researched the change of mean square error of Fourier series approximation of height oscillations of fixed reference points depending on the length of period (3).

For each curve the optimal oscillation period (on Fig. 4 blue line), which corresponds to the minimum value of mean square error is determined (in Fig. 5 shown with arrows).Fig. 5 shows the change of mean square error of Fourier series approximation of height oscillation curve of each deep fixed reference points without a linear trend, depending on the value of the period of harmonic functions.

As a result of determining the optimal period of oscillations from the solution of the equations system (2) the coefficients *c* and *s* are determined. Table 2 shows the optimal oscillation periods, oscillation amplitude and coefficients (*c, s*) of regression equation for each deep fixed reference point.

Table 2. Optimal period and oscillation amplitude and coefficients (*c, s*) of regression equation for each deep fixed reference point.

№ point	T,years	Oscillation amplitude, mm	*c*	*s*
1	26,5	0,868	0,4341	0,0032
2	26	0,303	-0,0821	-0,1275
3	14	0,331	0,0226	0,1642
4	9	0,580	0,1680	0,2366
6	4	0,318	-0,1583	-0,0185
7	11	0,914	0,4254	-0,1677
8	10	0,857	0,1463	0,4026
9	4	0,783	-0,3852	0,0715
10	3,5	1,084	0,1195	0,5301
11	3,5	0,903	-0,3650	0,2680

Based on the obtained kinematic characteristics of the network it can be argued that the fixed reference points № 1 and № 2 have a period of oscillation 26 years, which corresponds almost to the duration of observations. Long-period component indicates their stability. Long-period component indicates their stability. However, for fixed reference point № 1 the deviations from the harmonic curve and the oscillation amplitude is much larger than the fixed reference point № 2 (Fig. 4). For the fixed reference points №№ 3,4,7,8 oscillation period is in the range from 9 to 14 years. This group of fixed reference points undergoes mean periodic oscillations, and minimal oscillation amplitude there is on the points № 3 (Fig. 4). Fixed reference points № 6,9,10,11 undergo periodic oscillations with short duration 3.5 - 4 years. And fixed reference points № № 9,10,11 have a large oscillations amplitude from 0.7 to 1.0 mm, and the № 6 only 0.3 mm, that indicates about stability of the height position of this point.

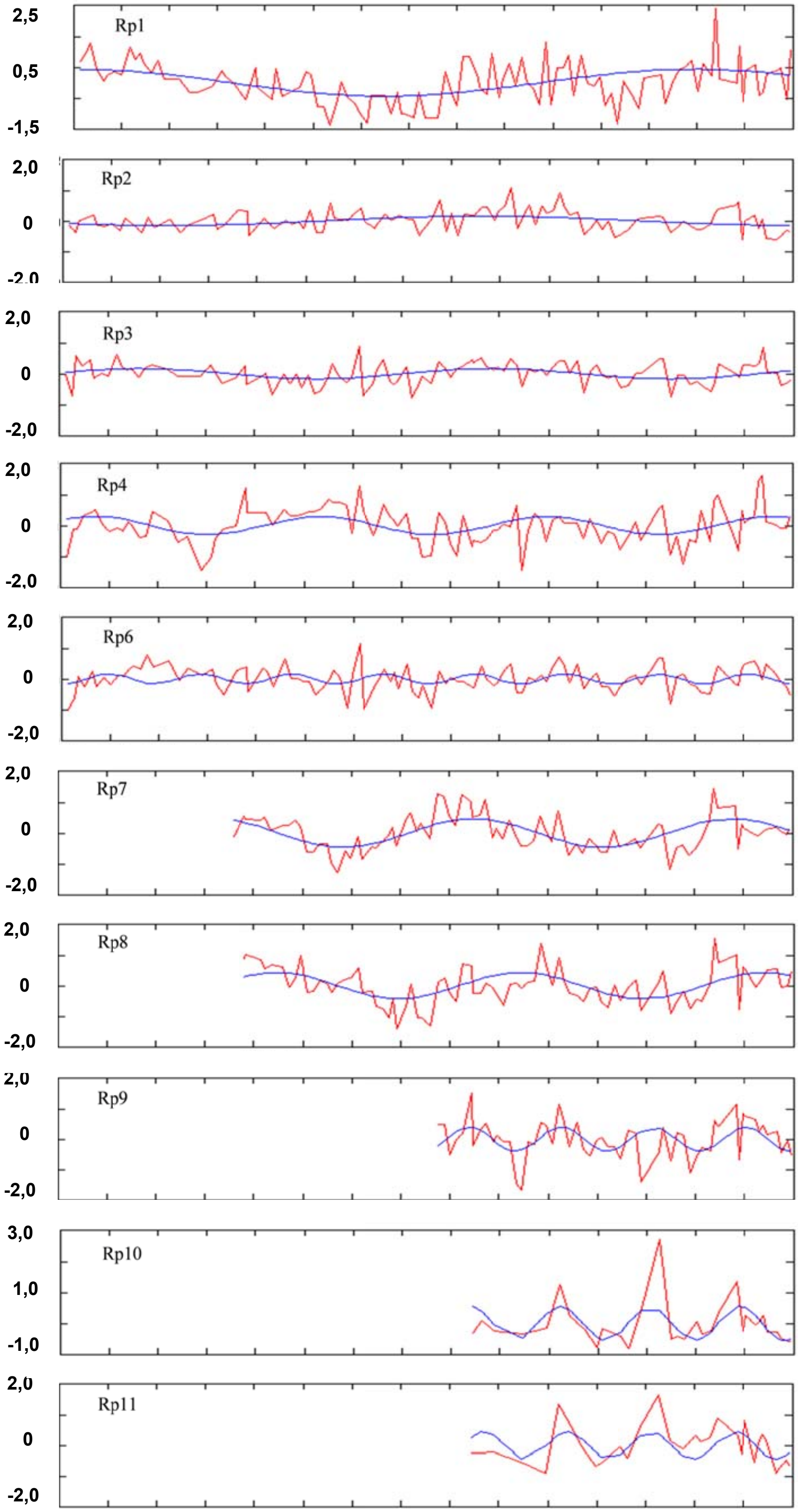

Fig. 4. The diagrams of vertical displacement of the deep fixed reference points without a linear trend (mm)

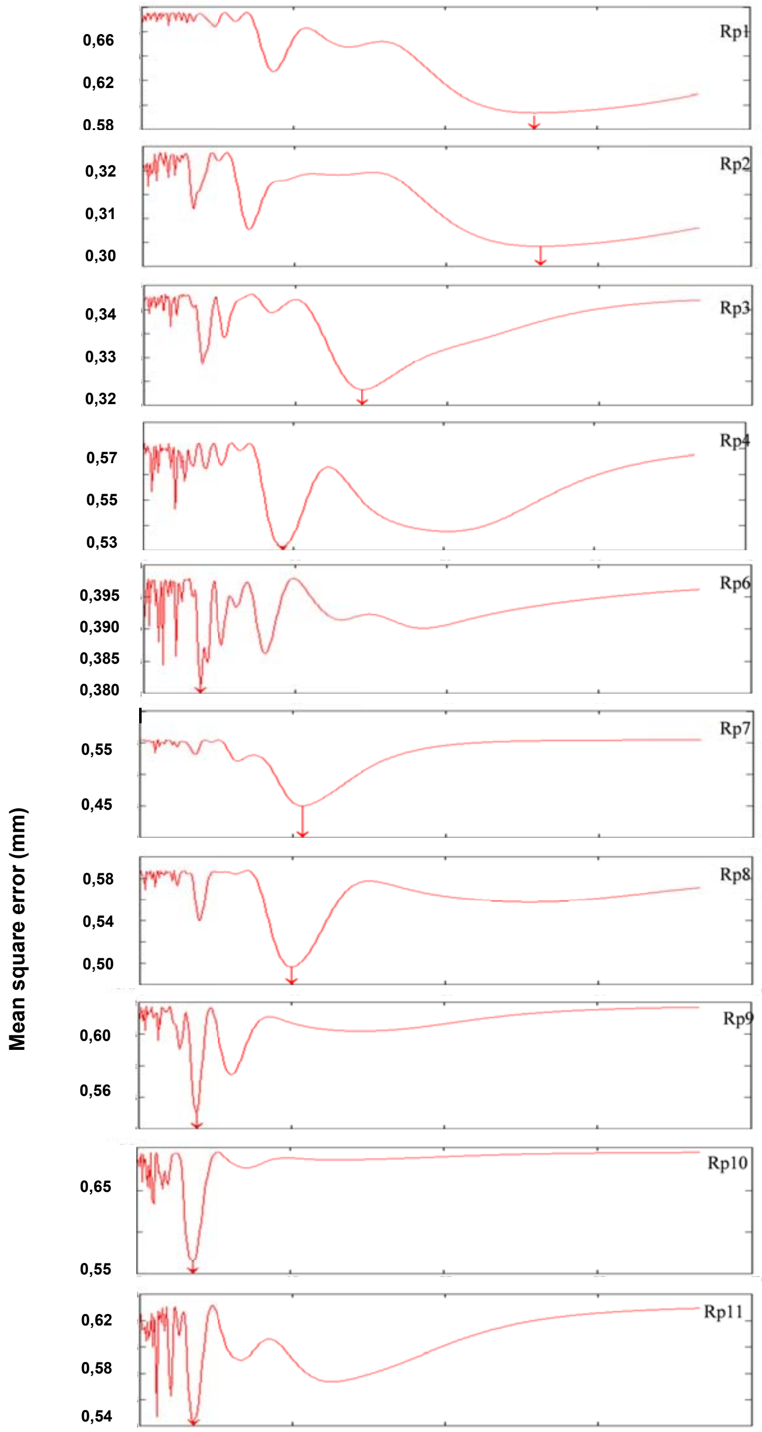

Fig. 5. Diagram of determining the optimal oscillation period of deep fixed reference points(in years).

Based on the created isolines of annual vertical crustal velocities (Fig. 3), the territory of Rivne NPP can be conditionally divided onto three areas.On the territory of the first area there are power generating units № 1-2. On the territory of the second area there are power generating unit № 3 and the cooling towers 1 - 4. On the territory of the third area there is the power generating unit № 4.

I area (where the fixed reference points № 3,4,6,10,11 are located) is characterized by a constant inclination velocity towards the south direction with value of 0.04"per year and the period of oscillation 5 - 8 years.

II area (where the fixed reference points № 1,2,5 are located) is characterized by the inclination towards the southeast direction with value of 0.07" per year and the period of oscillation of 15 - 25 years.

III area (where the fixed reference points № 7,8,9 are located)undergoes the inclination in the east direction with abnormal 5,6" per year and the period of oscillation 4 - 10 years.

2.4. Scientific novelty and practical significance

The proposed method of determining the stability of the fixed reference points allows analyze the stability of the fixed reference points of height network and implement zoning of territory where these points are located.

This method of processing the results of observations can be used for further efficient observations planning, zoning of territory according to earth's surface inclination velocity, and for prediction the kinematics of the reference height base.

3. Conclusions

Analyzing the research results, the following conclusions can be made:

1. There was developed method, which using the precision leveling allows to determine vertical displacements, and periodic components (length of period and the oscillation amplitude of fixed reference points), that enables to carry out zoning of the territory according to their kinematic characteristics.
2. Using results of110 cycles of I-st class leveling on the territory of Rivne NPP it was implemented investigation of kinematics of deep fixed reference points of the reference height base and were determined values of linear trend, length of period and the oscillation amplitude of each point.
3. Zoning of the territory of Rivne NPP was done and three areas were allocated which are characterized with stable velocity of surface inclination, linear velocity of movement of fixed reference points,period and the oscillation amplitude.Maximum velocity of inclination is 5,6" per year (area III). Period of oscillations is within limit from 3,5 years (points 10, 11) till 26 years (points 1 and 2). Oscillation amplitude is within limit from 1,084 mm (point 10) till 0,303 mm (point 2).
4. Proposed method allows to increase accuracy of processing geodetic measurements for the networks which are based on height reference network. Application of this method increases the reliability of determination of kinematic processes during observation of deformations of buildings and constructions that allows implement zoning of the territory according to these characteristics.

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