UDK 621.311.25-78(497.4):621.039.73:528.482.02
Stručni članak

Stability of the Krško Nuclear Power Plant

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ABSTRACT. The Krško Nuclear Power Plant (NEK) is of strategic importance for the Republic of Slovenia, producing electricity for users in Slovenia and Croatia. It generates over five billion kWh of electrical energy per year, which represents approximately 40% of the total electricity produced in Slovenia and approximately 17% in Croatia. The high level of security in NEK is of high importance; therefore a comprehensive supervision of structures is carried out. A special attention is given to the security systems, including the measurements of vertical displacements of benchmarks and measurements of horizontal displacements of the dam on the Sava River. Periodic geodetic observations are carried out on important technological structures comprising the nuclear island, the Sava River dam and the nuclear waste storage. The article aims at representing the results of geodetic observations for determination of stability and operational security of this important structure.

Key words: nuclear power plant, electricity, nuclear safety, security systems, geodetic technical observations, benchmarks, control points, vertical and horizontal displacements, stability.

1. Introduction

The first research in the Krško plain was carried out by the working group of the Business Association of the Energy Sector of Slovenia in the period 1964–1969, when the area was chosen as the potential location for a nuclear power plant. The investors of the first nuclear power plant were Savske elektrarne Ljubljana company and Elektroprivreda Zagreb, which, jointly with a group of investors, carried out the preparation works, the tender and selected the most advantageous bidder. In August 1974 the investors signed the contract specifying the purchase of

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equipment and building of nuclear power plant of net electrical output of 696 MW with the US company Westinghouse Electric Corporation; design engineering was performed by Gilbert Associates Inc., the contractors on the building sites were domestic Slovenian and Croatian companies Gradis and Hidroelektra, and the assembly was performed by Hidromontaža and Đuro Đaković. The foundation stone for the Krško Nuclear Power Plant (in continuation referred to as NEK) was laid on December 1, 1974. In January 1984 NEK acquired the full operation permit (URL 1).

NEK has been in commercial operation for more than 20 years. In this time the basic expectations, safety and stability objectives have been fulfilled, as well as those related to competitiveness of electricity production as compared to other energy sources, and public acceptability. Regarding the standards of nuclear safety and stability, NEK is today in the top 25% of operational nuclear power plants in the world (URL 1).

Energy has been a key factor in human life and development. One of the most important forms of energy is electricity. All over the world, electricity consumption has increased in line with the level and speed of socioeconomic development. Over the last ten years, electricity consumption in the European Union countries has increased by an average of two percent per year. Slovenia and Croatia are no exception and they currently register an average annual growth in consumption of 3 percent (URL 1). Electricity is produced in power plants using different sources, such as fossil fuels, nuclear fuels, water, biomass and solar energy.

The available sources of primary energy used to produce electricity are running out or have largely been used up. It is therefore reasonable to exploit all available sources. The environmental requirements in electricity production in conventional thermal power plants are becoming more and more demanding. Air pollution has become a global problem. The reliability of the electricity supply is also becoming an increasingly serious issue for national economies. Electricity cannot be imported in unlimited quantities and a high degree of independence in the energy supply is vital.

In NEK the high level of nuclear safety is important. An overall supervision of facilities, equipment and systems is performed, with a special emphasis on the security systems. Part of the security systems comprises technical observations performed by different contractors. These works include (Skube 2006):

– observation of damages and ruptures on structures,
– measurements of ruptures and their impact,
– dilatation measurements,
– geotechnical report,
– coordination of observation program,
– *measurements of vertical displacements of benchmarks, and*
– *measurements of horizontal displacements of the dam.*

2. Technical observations of security facilities

As early as during the design and the construction of NEK, the design for stabilisation of benchmarks on the structures of the nuclear island, turbine building and cooling tower was made, as well as a scheme of the observation of vertical and horizontal displacements. The observations are performed on important technological structures. However, the program of technical observations also includes other structures which are considered important and demanding as to their function and construction, and are therefore in need of close systematic monitoring (Kogovšek 1990).

The observations of vertical displacements are performed in the following structures of the technological part of NEK: nuclear island, diesel generator, turbine building, the Sava River dam, the cooling water pumping facility, the cooling water outflow facility, cooling towers, essential services pump house and fire service, essential service water discharge structure, water decarbonisation building, demineralised water reservoir, reactor feedwater reservoir, condenser reservoir, neutralisation pool, radiological protection building, radioactive waste storage, decontamination area, and transformer foundation. The observations of horizontal displacements are performed, in the line with the Regulation of technical monitoring of large dams, on the Sava River dam only.

The most important objects from the aspect of radioactive and nuclear safety are the nuclear island, the Sava River dam and the radioactive waste storage.

- *The Nuclear Island* includes the reactor and the auxiliary reactor building. The reactor is the central building of the major generating facilities, composed from the outer reinforced concrete shield structure, steel containment building, inner reinforced concrete building and the fundations. The auxiliary reactor building is made of shield, auxiliary building, annulus area, the control room, fuel building, and cooling system building. There are 29 benchmarks positioned on the nuclear island for the determination of vertical displacements.
- *The Sava River dam* has been built to ensure the minimum Sava River water level and thus enable the water pumping for cooling. The dam has six 15 m wide spillways. To ensure earthquake stability the dam is split into two large concrete frame structures. The structure height is 15.5 m and is therefore considered as large dam, as defined by international standards, and needs to be technically monitored. 19 benchmarks have been stabilised on the dam to determine vertical displacements, and 7 control points to determine horizontal displacements. Along the outlet, there were stabilised 5 reference observation points with concrete pillars.
- *Radioactive waste storage* is a one-storey reinforced concrete building for temporary storage of radioactive waste which is the product of the technological processes and maintenance of NEK. There are 6 benchmarks built in to determine vertical displacements of the building.

3. Point stabilisation and measurements

3.1 Height network

The reference benchmark R100 (Figure 1) at the radioactive waste storage is stabilised with a deep concrete pillar with a longitudinal plate, metal rod and a protective cover. To the east and west of the NEK plateau there are two reference benchmarks RII and RIV stabilised (Figure 2), which are built in horizontally into the reinforced concrete monitoring masts with deep underground foundations.

Figure 1. Stabilisation of benchmark R100.

Figure 2. Stabilisation of benchmark RIV.

The control points in the structures are stabilized in the centre of the structure, so that they move together with the structure. In the outside areas of NEK's structures, the low benchmarks were built into the walls, however, inside, the benchmarks were mostly stabilised on the ground.

The measurements were performed with the precision digital levelling instrument Leica 3003. We mostly used two 3 m GPCL3 invar code levelling rods, which are regularly calibrated. If, in the case of barriers, the GPCL3 rods were not applicable, we used the GPCL2, GWCL92 and GWCL182 invar code levelling rods or the GWCL60 invar code scale. Besides the instrument and rods, we used other equipment necessary to the measurements: tripod, two rod stands, footplates, scale, thermometer and flashlight.

The geometric levelling method using the levelling from the centre was performed. By tying the points to the benchmark having a known height in the absolute sense, the heights above sea level are determined for the points. The geometric levelling is considered as the most precise surveying method, since the measuring procedure is relatively simple, and the geometric levelling theory has been investigated in detail. The main advantage of levelling from the centre is that the distances between the instrument and the rod behind and in front are as equal as possible. This enables the elimination of the majority of systematic errors (non-horizontal line-of-sight, influence of levelling refraction and Earth's curvature). The errors due to subsidence or lifting of the tripod and the footplate were eliminated by this method as well, too (Skube 2006).

The temperature dependency of the graduation interval on the levelling rod is significant, especially in measurements of high precision. However, the error is small and of systematic character. The linear expansion coefficient of the invar scale of rod α is given by the manufacturer or determined separately by comparison. The temperature correction is defined by the following equation:

$$\Delta l_t = \alpha(T - T_0), \tag{1}$$

where

T is the actual temperature,

$T_0 = 20°$ is the reference temperature and

$\alpha = 0.6 \cdot 10^{-6}\ \mathrm{K}^{-1}$ is the linear extension coefficient of the invar scale.

The correction of the height difference due to the temperature correction and the correction of rod graduation (gained with comparison) had an insignificant impact to height differences, since their value was below 0.01 mm, being much less than the measurement accuracy, which is 0.2–0.5 mm. The cause of such minor corrections is the small height differences between the measured benchmarks in the power plant area and the relatively small differences between the actual temperatures and the reference temperature. The correction error of the fifth rod or error of the first line of the graduation is the systematic error that was eliminated so that in the initial and end benchmarks always the same rod was used (Skube 2006).

3.2 Horizontal network

The reference points of the base network for performance of measurements are stabilised with concrete pillars, representing the conventional stabilisation of geodetic points for deformation measurements. The chosen stabilisation enables forced centring of the instrument and the reflector – *Leica Wild* system.

Stabilisation of control points on the dam also enables forced centring of the reflector – *Leica Wild* system. The control points were screwed into the concrete base, where the footplate can be fitted with the prism mount, which, in turn, enables horizontal alignment. Figure 3 shows the stabilisation and signalisation of the reference and control points.

In the Krško micro trigonometric network the classic terrestrial surveying was chosen. The measurements were performed with the precision of electronic total station Leica TC2003 intended for precise angle and distance measurements in precision terrestrial geodetic networks (Savšek-Safić et al. 2007). Forced centring of the instrument, signalisation of measuring points and measurement of meteorological parameters were performed by tested and calibrated supplementary equipment (reflectors, footplate with reflector mounts, psychrometer, barometer).

For determination of horizontal coordinates of reference and control points *triangulation/trilateration* methods were used. In this way a large number of redundant observations are obtained, ensuring higher accuracy and reliability of control point position. For reduction of distances, the trilateration method uses

Figure 3. Stabilisation and signalisation of the reference and control points.

the levelled above-sea-level heights of reference and control points. The coordinates of reference points are determined in order to establish their positional stability and determination of the geodetic datum of the network. The horizontal angles are measured according to the sets of angles method, both ways between the reference points and in one-way to the control points. Slope distances and zenith angles were measured simultaneously. The method enables the identification of statistically significant horizontal displacements of control points on the dam.

4. Determination of the geodetic datum and adjustment

4.1 Height network

The geodetic datum of the height network is realized by reference benchmarks R100, RII and RIV, which have a known above-sea-level heights. In four years, a displacement occurred between the reference benchmarks of the order of 1 mm, which was too large considering the 0.1 mm accuracy requirement.

To solve this problem the adjustment proceeded in two steps. Firstly, based on the given benchmark R100, we adjusted the remaining reference benchmarks RII and RIV. In this way a better global estimate of accuracy was obtained. Then, as a second step, benchmark R100 and both adjusted reference benchmarks RII and RIV were taken as given values and the entire height network could be adjusted. With the procedure of two-step adjustment we obtained information on relative displacements between reference benchmarks and their applicability in future measurements.

4.2 Horizontal network

The geodetic datum of the horizontal network is determined by two given assumingly stable points – reference points O1 and O5. To preserve the identical network geometry, as well as measurement and observation methods, the reference points were first tested for stability. The comparison of changes in coordinates between the last campaigns indicated that pillars O1 and O5 were statistically stable. In this way, the determination of the datum in the network enables us to determine the statistically significant displacements of control points with a higher probability (Savšek-Safić et al. 2007).

The horizontal coordinates are calculated into the existing local co-ordinate system of the network to the level of the lowest point (reference point O4). The observations are tested for the potential presence of gross error, following the Danish method. The input data for the horizontal adjustment are the reduced averages of three sets of angles and the slope distances reduced to the chosen level. The reduction of distances took into account the instrumental, meteorological, geometric and projection corrections (Kogoj 2005). The zenith angles were observed to establish the height stability of the reference and control points. The observations in the horizontal network were adjusted following the method of indirect observations. First, the adjustment of the free network is performed, thus gaining an unbiased estimate of observations, then the network is adjusted as a constrained network, where the geodetic datum is determined by two statistically stable reference points O1 and O5. The results of the horizontal adjustment are the most probable values of horizontal coordinates of measuring points in the local system with the corresponding accuracy estimates.

5. Stability of safety buildings

5.1 Testing of vertical displacements

The basis to determine the displacement of a building is to determine the changes of position of points on the building. We can talk about the point displacements between two epochs, when the statistically significant displacements are identified for the identical points, measured in two epochs. After the two-epoch adjustment, we can determine point displacement using the corresponding displacement accuracy. In practice, a test for determination of statistical significance of the displacement is often used, as the relation between the displacement and the displacement accuracy. The test statistic can be written as:

$$T = \frac{dH}{\sigma_{dH}}, \tag{2}$$

where the vertical displacement is calculated as:

$$dH = H_{t+\Delta t} - H_t, \tag{3}$$

and the variance of the vertical displacement as:

$$\sigma_{dH}^2 = \sigma_{H_t}^2 + \sigma_{H_{t+\Delta t}}^2 . \tag{4}$$

The test statistic (2) is tested for the given null and alternative hypotheses:

$H_0 : dH = 0$; the point has not moved between the two epochs, and

$H_a : dH \neq 0$; the point has moved between the two epochs.

The test statistic (2) is compared related to the critical value calculated on the basis of the cumulative distribution function. It is calculated for the displacement of each point between the single campaigns, assuming that the point displacements are distributed normally. If the test statistic is lower than the critical value at the chosen significance level α, the risk to reject the null hypothesis is too high. In such case we can establish that the displacement is statistically non-significant. However, if the value of the test statistic is higher than the critical value, then it can be established that the risk to reject the null hypothesis is smaller than the chosen significance level α. The null hypothesis can be justifiably rejected and we can confirm that the displacement is statistically significant.

To support our decision, we calculate the actual risk of rejecting the null hypothesis. The actual risk α_T is calculated from the cumulative distribution function at the calculated value of the test statistic T. The actual risk of rejecting the null hypothesis is compared to the test significance level α. The user decides whether the risk is acceptable or not, according to the actual risk and consequences of making the wrong decision. According to the decision, a point displacement is considered as statistically significant or non-significant (Savšek-Safić et al. 2003).

We tested the significance of vertical displacements of control points on the Sava River dam between the epochs in the period between December 2003 and October 2007. During this period nine measurement campaigns have been completed.

Table 1. *Cumulative vertical displacements of control points on the Sava River dam between December 2003 and October 2007.*

Point	Displacement dH [mm]	s_{dH} [mm]	T	T_{crit} ($\alpha = 1\%$)	α_T (%)
H1	0.7	0.5	1.41	2.58	16.00
H2	1.3	0.5	2.72	2.58	0.65
H3	1.7	0.5	3.50	2.58	0.05
H4	0.6	0.5	1.23	2.58	21.81
H5	1.8	0.4	4.10	2.58	0.00
H6	2.0	0.4	4.83	2.58	0.00
H7	1.3	0.4	3.18	2.58	0.15

Between the respective campaigns between December 2003 and October 2007 there were statistically significant vertical displacements practically on all control points of the order of ± 3 mm. These displacements between the campaigns were of significant periodic character. For the period of 4 years cumulative vertical displacements weren't statistically significant for control points H1 and H4, since the test statistic in these two points did not exceed the critical value, as shown in Table 1. The dam is subjected to the great forces of the Sava River, therefore it seems logical that such considerable vertical displacements between campaigns occur, however, in a longer time period.

5.2 Time line of vertical displacements of control points on the Sava River dam

The function of change of the value of impact was shown with the deformation model. For all benchmarks in the height network, where we identified a displacement at a certain test significance level, the graph representing the change of the benchmark height as a function of time.

Control point H5 was chosen as the representative point of the construction. Other points on the Sava River dam behave similarly.

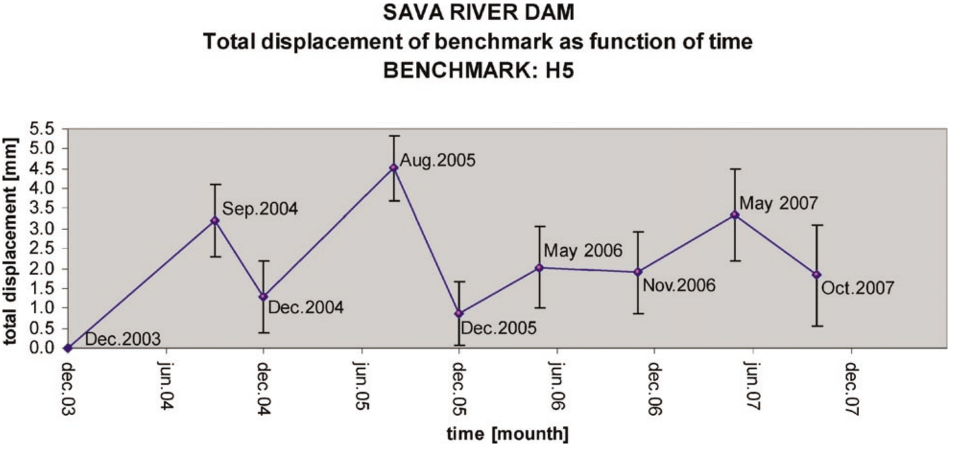

Figure 4. *Displacements of the benchmark H5 during period of 4 years.*

The displacement between two consecutive campaigns is interpolated by a linear function. The accuracy of displacement determination, calculated at the chosen test significance level $\alpha = 1\%$ (standard displacement deviation multiplied by 2.576), is shown by the vertical line.

The illustrated displacement and corresponding standard deviations of displacements between December 2003 and October 2007 show that the displacements are statistically significant at the chosen significance level. Due to the obvious periodicity of displacements, however, the cumulative displacements are not statistically significant. After December 2005 it can be established that the displacements and cumulative displacements are statistically non-significant.

5.3 Testing the horizontal displacements

In the area of NEK the horizontal stability of the Sava River dam is investigated based on nine consecutive epochs. In December 2003, the transition to a new way of measurements (measurement method, instrument, network geometry) and the determination of a new geodetic datum in the micro network of Krško enabled a higher reliability of determination of statistically significant displacements. After the adjustment of at least two epochs, it is possible to determine the displacement of point d and displacement variance σ_d^2 by the following equations

$$d = \sqrt{\Delta y^2 + \Delta x^2} = \sqrt{(y_{t+\Delta t} - y_t)^2 + (x_{t+\Delta t} - x_t)^2}, \tag{5}$$

$$\sigma_d^2 = \left(\frac{\Delta y}{d}\right)^2 (\sigma_{y_t}^2 + \sigma_{y_{t+\Delta t}}^2) + 2\frac{\Delta y}{d}\frac{\Delta x}{d}(\sigma_{y_t x_t} + \sigma_{y_{t+\Delta t} x_{t+\Delta t}}) + \left(\frac{\Delta x}{d}\right)^2 (\sigma_{x_t}^2 + \sigma_{x_{t+\Delta t}}^2), \tag{6}$$

where $\sigma_{y_t}^2$, $\sigma_{y_{t+\Delta t}}^2$, $\sigma_{x_t}^2$, $\sigma_{x_{t+\Delta t}}^2$ are elements of covariance matrix of coordinates of identical points in time t and $t + \Delta t$.

Similar to testing of vertical subsidence, both values are used to form the test statistic:

$$T = \frac{d}{\sigma_d}. \tag{7}$$

It is important to note that the calculated displacement is not a linear function of variables Δy and Δx, therefore the test statistic (7) is not normally distributed. The probability function for the test statistic (7) is determined empirically with simulations, and then compared to the critical value considering the chosen significance level α. Displacements can be identified as statistically significant according to the distribution of test statistic and chosen significance level α (Savšek-Safić 2002).

The null and alternative hypotheses are tested by the test statistic:

$H_0 : d = 0$; the point has not moved between the two epochs, and

$H_a : d \neq 0$; the point has moved between the two epochs.

The test statistic (7) is compared against the critical value calculated from the simulated distribution function. If the test statistic is smaller than the critical value at the chosen significance level α, the risk to reject the null hypothesis is too high. In such case, we assume that the displacement is statistically non-significant. If the test statistic is higher than the critical value, the risk to reject the null hypothesis is smaller than the chosen significance level α. Therefore, the hypothesis is justifiably rejected and we can confirm the statistical significance of the displacement.

The significance of horizontal displacements of control points on the Sava River dam between the campaigns performed from December 2003 to October 2007 was tested. Therefore nine consecutive epochs are investigated.

Table 2. *Cumulative horizontal displacements of control points on the Sava River dam between December 2003 and October 2007.*

Point	Displacement d [mm]	σ_d [mm]	T	T_{crit} ($\alpha = 1\%$)	α_T (%)
H1	4.8	0.9	5.60	2.96	0.00
H2	0.4	0.5	0.67	2.88	76.26
H3	0.8	0.8	0.98	2.87	56.39
H4	0.6	0.9	0.65	2.87	77.40
H5	0.4	0.6	0.77	2.84	69.74
H6	1.2	0.6	2.15	2.82	6.21
H7	1.4	0.9	1.58	2.80	21.08

It has been established that in the campaigns performed between December 2003 and October 2007 in most cases points H1 and H7 show significant displacements, on average between 4 and 7 mm, with the standard deviation of 1–1.5 mm. When the cumulative displacement in a period of four years is observed, we can see that the actual cumulative displacements are much smaller than the periodic seasonal displacements, that is, between the spring and autumn campaigns. Table 2 shows that, at the chosen significance level $\alpha = 1\%$, only point H1 can be regarded as having a significant displacement. The displacement is statistically significant (4.8 mm). The displacements in other points cannot be considered as statistically significant, since the displacements are too small.

5.4 Time line of horizontal displacements of control points on the Sava River dam

The time line of horizontal displacements of points on the Sava River dam was represented with the displacements of control points and corresponding relative displacement ellipsoids referring to the two-epoch displacements. The relative displacement ellipsoids are calculated form the point determination accuracy in a single epoch.

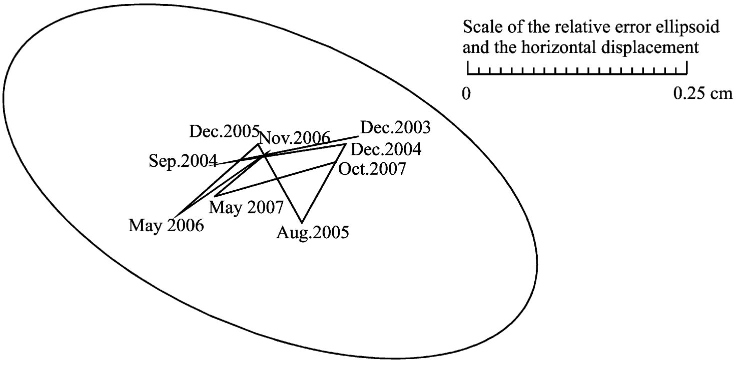

Figure 5. *Illustration of control point H5 displacement in a period of four years.*

Figure 5 shows the displacement of the control point H5 in time. The displacements between different campaigns are between 0.5 mm and 1.8 mm. In the analysis of horizontal displacements, the periodicity of point displacements on the Sava River dam is observed. Figure 5 shows the relative displacement ellipsoid between two campaigns (Dec. 03 and Sept. 04), calculated at the chosen significance level $\alpha = 1\%$ (the axis lengths of the standard ellipsoid multiplied by 3.035), which was the smallest of all relative displacement ellipsoids, so we drew it in the centre of control point displacements. The figure shows that the displacement of control point H5 is not statistically significant at the chosen significance level.

6. Conclusions

Due to its strategic importance, NEK is subjected to detailed estimates of building stability and its operational security. Periodic geodetic measurements take place on the NEK grounds, determining the vertical and horizontal displacements of benchmarks and control points on structures and devices. The most important structures regarding radiation and nuclear safety are the nuclear island, the dam on the Sava River and the radioactive waste disposal facility. Due to the changes in measurement techniques and a more comprehensive approach to defining displacements, the measuring campaigns of the last four years were used, since they can be quantified ensuring a high level of reliability in terms of displacement determination. The results acquired were included in annual reports which are part of mandatory technical observations done on NEK structures. The interpretation of displacement trends has been, from the safety standpoint, of importance and interest for the general public.

On most structures involved in all nine campaigns, periodic displacement changes were found, meaning that the vertical displacements were positive as well as negative. In the summer months the benchmarks were usually positive, and in winter months they were negative.

In the last four years, a large vertical displacement (up to 5 mm) occurred at least once on all three structures. A large displacement (up to 5 mm) occurred on the nuclear island in the August 2005 campaign, but in the next compaign in December 2005 benchmarks returned to their previous level. The displacement has not been entirely explained. The situation is not a critical one, since no damage was found on the structures, also, already in the next campaign it was recorded that the benchmarks moved back by approximately the same value.

The Sava River dam has a specific place among NEK buildings, since it is subjected to the great force of the Sava River flow and to the differences in filling and emptying the reservoir, i.e. the difference between high flow and low flow. Periodically larger displacements of the entire dam are to be expected. The vertical displacements are of highly periodic character and are quite considerable compared to benchmark displacements on other structures. The largest vertical displacements are recorded during consecutive measurements exceeded 3 mm. When estimating the cumulative vertical displacements of the benchmarks on the dam in a period of four years, it is established that the displacements are not statistically significant. Similarly, the outermost control points H1 and H7 on the dam in consecutive campaigns show periodic horizontal displacements from 4 to 7 mm, while the displacementc of other control points cannot be regarded as statistically significant. By taking into consideration the cumulative horizontal displacements of control points in the period of four years, it can be concluded that the displacements are very small. Only the cumulative displacement of point H1, nearly exceeded 5 mm, which is, from the aspect of permissible displacement deviations for nuclear power plant structures, negligible.

The displacements of benchmarks on the radioactive waste disposal facility are highly periodic, and the values are from –2.8 mm to 3 mm at the most critical benchmark R49. A considerable displacement occurred in the campaign of August 2005. The cause, considering the lack of damage on the building, remains unknown. In the next campaign it was recorded that the benchmark returned to its previous level. The displacements of the remaining benchmarks are within ± 2.2 mm. Statistically significant vertical displacements were identified between the first and last campaigns, and their value was, compared to that between the consecutive campaigns, much smaller.

Another possible explanation of the recorded periodic displacement changes of the benchmarks is the groundwater level of the Krško polje. This could be monitored with piesometers. Additionally, the periodic displacement changes could be determined more reliably if the height network, i.e. reference benchmarks, were tied to the stable surroundings.

The values of maximum permissible displacements are defined based on the type of construction and land type, and they are from 7.5 cm for brick buildings to 30 cm for heavy concrete buildings (Kogovšek 1990). Since the displacements are, with the rare exceptions, smaller than ± 2.0 mm, the displacements were identified as non-significant. In general, the buildings in the NEK grounds are stable, considering the maximum permissible displacements of benchmarks and control points.

Acknowledgements: We greatly acknowledge the help of IBE d.o.o. company, and specifically Mr. Božo Kogovšek, the expert responsible for NEK technical monitoring, for allowing to use the data for research purposes, and Mr. Matej Ključevšek, who performed most of the levelling measurements.

References

Kogoj, D. (2005): Merjenje dolžin z elektronskimi razdaljemeri, UL-FGG, Ljubljana.

Kogovšek, B. (1990): Projekt tehničnega opazovanja Nuklearne elektrarne Krško, Inženirski biro elektroprojekt, Ljubljana.

Savšek-Safić, S. (2002): Optimalna metoda določanja stabilnih točk v deformacijski analizi, UL-FGG, Doktorska disertacija, Ljubljana.

Savšek-Safić, S., Ambrožič, T., Stopar, B., Turk, G. (2003): Ugotavljanje premikov točk v geodetski mreži, Geodetski vestnik, 47/1&2, 7–17.

Savšek-Safić, S., Kogoj, D., Marjetič, A., Jakljič, S. (2007): 49. geodetska izmera horizontalnih premikov geodetskih točk NEK, UL-FGG, Tehnično poročilo.

Skube, K. (2006): Vertikalni premiki reperjev na objektih NE Krško med leti 2002 in 2006, UL-FGG, Diplomska naloga, Ljubljana.

URL 1: Nuklearna elektrarna Krško, http://www.nek.si/sl/, (12/11/2007).

Stabilnost nuklearne elektrane Krško

SAŽETAK. Nuklearna elektrana Krško (NEK) je za državu Sloveniju objekt od izuzetnog strateškog značaja, koji snabdijeva korisnike u Sloveniji i Hrvatskoj. Godišnja proizvodnja iznosi preko 5 milijardi kWh električne energije, što predstavlja približno 40% ukupne proizvodnje električne energije u Sloveniji i 17% u Hrvatskoj. U NEK se zahtjeva iznimno visok stupanj sigurnosti, stoga se izvodi cjelovit nadzor pojedinih objekata i postrojenja. Posebna pozornost je namijenjena sigurnosnim sustavima, među koje ubrajamo i mjerenja vertikalnih pomaka repera i horizontalnih pomaka brane na Savi. Periodična geodetska opažanja se izvode na objektima, koja po kategorizaciji spadaju u najviši sigurnosni razred koji obuhvaća nuklearni otok, branu na Savi i skladište radioaktivnih otpadaka. U radu želimo prikazati važnost geodetskih mjerenja za utvrđivanje stabilnosti i sigurnosti rada tog važnog objekta.

Ključne riječi: *nuklearna elektrana, električna energija, sigurnosni sustavi, geodetska mjerenja, reperi, kontrolne točke, vertikalni i horizontalni pomaci, stabilnost.*

Prihvaćeno: 2008-02-29