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F – literature search

Interpretation of the results of monitoring of the piezometric measurements of the Chańcza dam in 2014–2017

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Abstract

The occurrence of a hydraulic connection between piezometers is identified based on similar changes in water levels. Some piezometers react to changing upper or lower water levels, some may also react to atmospheric precipitation. If the reaction to variable upper water levels is significant, then leakage of seepage control devices is identified and the dam is subjected to repair works. The aim of this research paper is to present and analyse the dynamics of variability of water levels in open piezometers of the Chańcza dam, located at the 36 km of the Czarna Staszowska River in the town of Korytnica in Świętokrzyskie province (Poland). Before the analysis of the piezometric data was commenced, the Grubbs statistical test was used to identify and reject the outliers. The scope of the research includes the data captured between January 14, 2014 and January 13, 2017. A hypothesis was formulated that the change in the trend occurred after the spring of 2015 when the water level in the reservoir was reduced by approx. 1.5 m. Two trend lines were adapted for the water levels of each piezometer using the least squares method – the first one for the period from January 2014 to May 2015, and the second one from June 2015 to January 2017. In this way, two slopes of the linear function were obtained together with an estimation of their errors. These slopes were compared using a statistical parallelism test.

Key words: *earth-fill dam, open piezometer, safety of hydraulic structures, trend line*

INTRODUCTION

The construction of dams and the existence of water reservoirs which they form are of great importance to the local society. Reservoirs enable the storage of excess water and then its use when the shortage occurs. Dams, on the other hand, make it possible to prevent the effects of floods by modifying the course of the flood wave and, to a large extent, reduce its peak. Hydraulic structures, being massive objects, require the use of continuous diagnostic methods and are subject to constant monitoring. Because monitoring and diagnosis report about the technical condition of the facility, these processes help in formulating appropriate assessments, especially the assessment of the safety of hydraulic structures [GAMSE, OBERGUGGENBERGER 2017; KLEDYŃSKI 2011a; b]. Due to the fact that the intended purpose of dams is to impound water, these facilities can pose a serious threat to the surroundings. In order to ensure proper operation and safety of impounding structures, permanent monitoring is carried out, aimed at recording and predicting changes that occur in the foundation and structure of the facility, as well as at assessing its technical state [LACH, OPYRCHAŁ 2017; MOLSKI 2012]. Monitoring is usually a continuous, long-term and organized manner of observation of a specific structure or process. Therefore, monitoring of a facility determines systematic observations, measurements and model tests used to assess its technical state and safety [FELL *et al.* 2003; HU *et al.* 2011; SU *et al.* 2016]. The basic forms of monitoring dams include, e.g. piezometric measurements, which allow for measurements of water levels in open piezometers, or measurements of water pressure in closed piezometers. These measurements enable to control seepage through an impounding structure, and thus to assess structure's performance [LACH 2018a].

MATERIAL AND METHODS

Table 1 demonstrates the basic parameters of the Chańcza reservoir.

Table 1. Basic parameters of the Chańcza reservoir

Parameter	Value
Normal water level	217.80 m a.s.l.
Maximum water level	220.20 m a.s.l.
Minimum working water level	212.00 m a.s.l.
Total capacity	$23.78 \cdot 10^6$ m^3
Flood capacity	$9.57 \cdot 10^6$ m^3
Active storage	$12.19 \cdot 10^6$ m^3

Source: WOJTAS *et al*. [2015], modified.

Due to topographic and geological conditions, the dam was constructed as a homogeneous earth-fill structure from local fine sands and gravels (Figs. 1, 2). It has 412 m in length, 13.8 m of maximum height, 10.0 m of the crest width and 1:3 slope. The slope protection of the right frontal dam is a curtain made of 20 cm thick reinforced concrete slabs, connected with a horizontal seepage control blanket, which reaches 100 m into the reservoir. The sealing of the left frontal dam is a seepage control barrier constructed to the bedrock as a diaphragm wall. Water drainage from the shell dam ensures pipe drainage in the fleece discharged to the toe drains.

In the flow control block, there are spillways and bottom outlets. The spillway consists of 4 spans spaced every 7.0 m, equipped with gate valves with a height of 1.8 m with hydraulic drive. The bottom outlets of the weir consist of 6 channels with a diameter of 1400 mm and 2 channels with a diameter of 600 mm, built into concretes of the lower parts of the dump up barrier. Typical wedge with electric drive were adopted as gates of the outlets. The total flow capacity of the outlets and spillways at maximum water level is 274 m^3·s^{-1}. The structure of a four-span bridge with a width of 10 m, located within the public road running along the crest of the dam, is based on the abutments and pillars of the weir. The weir contains a water intake for fish ponds and a fish restocking center. Below the flow control block, there is a release trough with a width of 35 m, length of 19.5 m and a depth of 1.5 m, with a single row of chicanes to dissipate the energy of the water flowing out of the reservoir through bottom outlets or spillways.

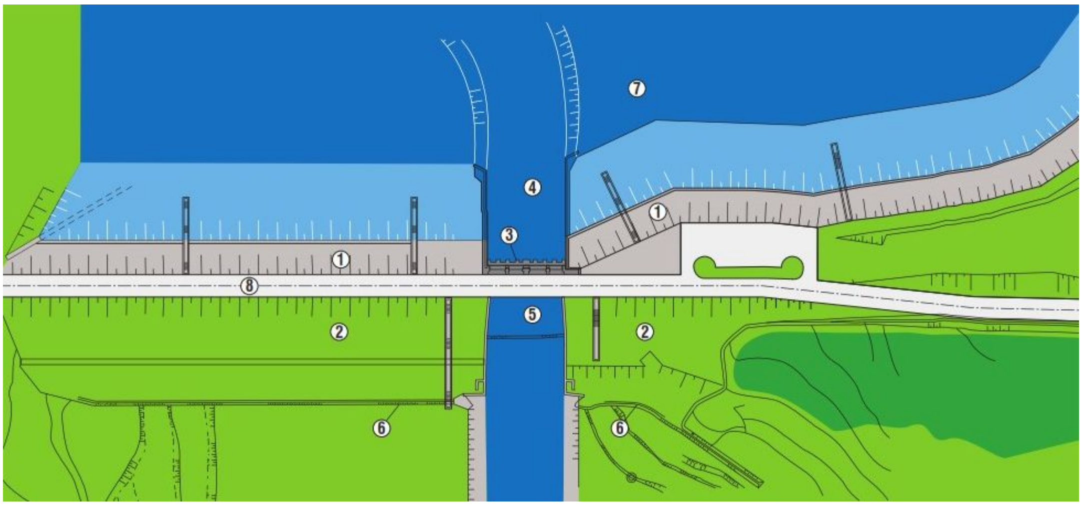

Fig. 1. Plan of the Chańcza dam; *1* = upstream slope, *2* = downstream slope, *3* = spillway channel, *4* = inlet channel, *5* = outlet basin, *6* = drainage trench, *7* = clay blanket, *8* = local road; source: materials from the Regional Water Management Authority in Krakow

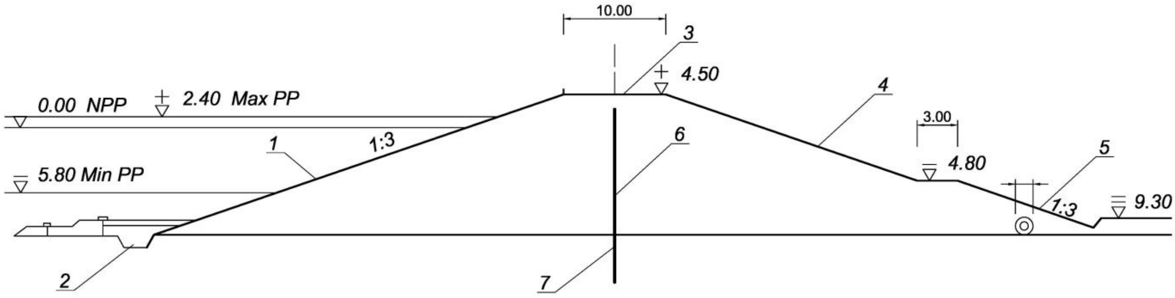

Fig. 2. Cross-section of the Chańcza dam; *1* = curtain made of 20 cm thick reinforced concrete slabs, laid on 10 cm thick stabilized layer, *2* = clay blanket, 50 cm thick, covered with Estrofol foil and protective layer, *3* = road along the crest, 10 m wide, *4* = vegetative cover (grass), *5* = pipe drainage system / 1.0 m in filtration gravel pack, *6* = seepage control barrier, *7* = grouted curtain;
Max PP = maximum pool level, Min PP = minimum pool level, NPP = normal water level;
source: own study based on materials from the Regional Water Management Authority in Krakow

The aim of this research paper was to examine the changing trends in water table levels in 56 open piezometers of the Chańcza dam, covering the study period from 14th January 2014 to 13th January 2017. Figure 3 illustrates the distribution of the piezometers. For each piezometer, 78 piezometric measurements were analysed, which gave a total number of 4 368 observations. 20 piezometers, for which no measurements were carried out or the aim of this research paper was to examine the changing trends in water table levels in 56 open piezometers of the Chańcza dam, covering the study period from 14th January 2014 to 13th January 2017. Figure 3 illustrates the distribution of the piezometers. For each piezometer, 78 piezometric measurements were analysed, which gave a total number of 4 368 observations. 20 piezometers, for which no measurements were carried out or no full measurement sequences were available in the analysed period, were excluded from the analysis. Before the analysis of the piezo-

a)

b)

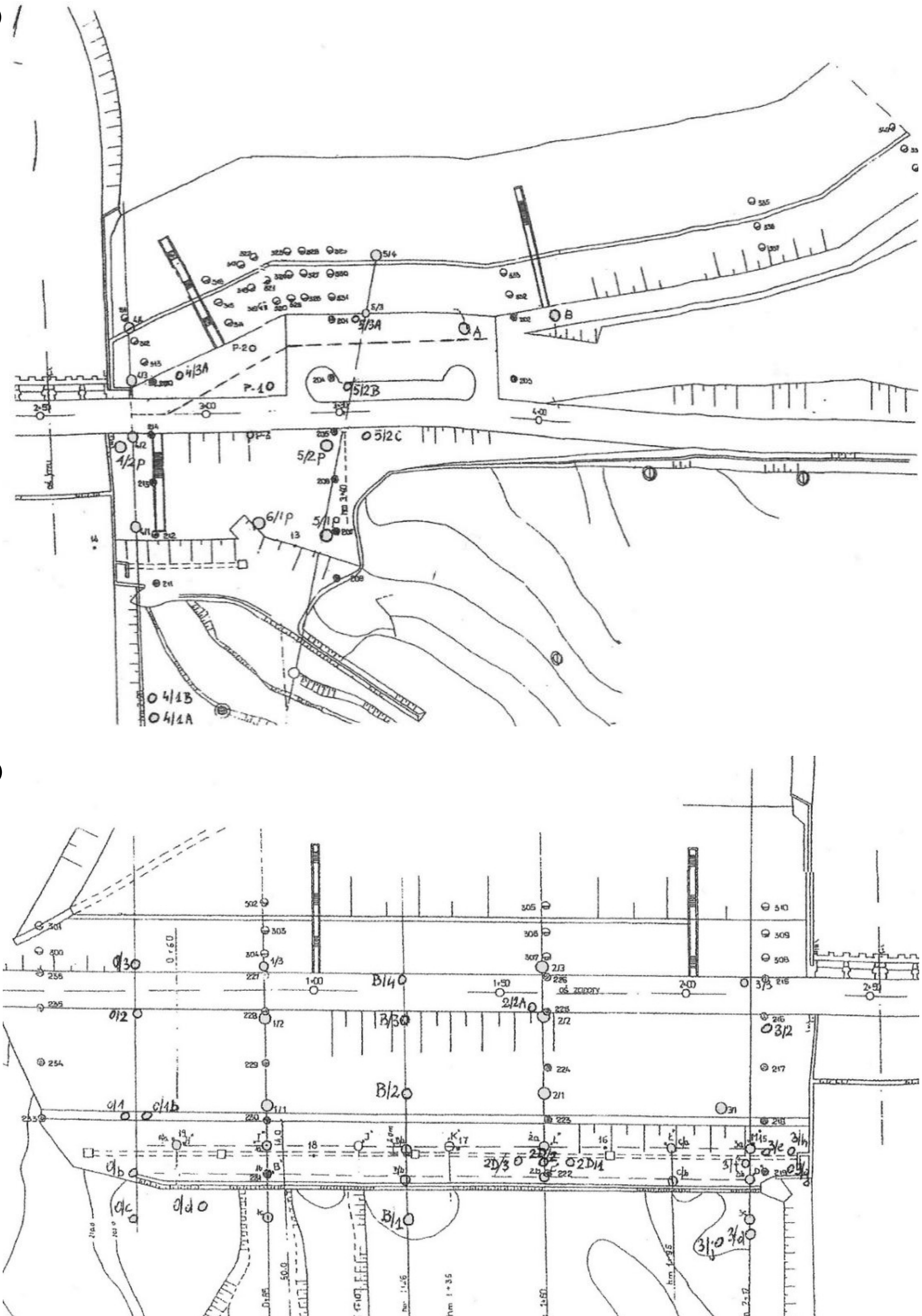

Fig. 3. Sketch of distribution of open piezometers: a) left abutment of the Chańcza dam, b) right abutment of the Chańcza dam; source: WOJTAŚ *et al*. [2015]

metric data was commenced, the Grubbs statistical test was used to identify and reject the outliers [LACH 2016; 2017; 2018b]. As a result, a total of 14 outliers were removed from the data set.

The methodology of the research study consisted in drawing graphs of changes of water table levels in the open piezometers of the Chańcza dam and then determining the trend line for each piezometer using the least-squares method. The method of least squares allowed to find a straight line, which would be the most "adjusted" to the measurement points collected on the graph. The parameters of the straight line were selected in such a way that the sum of the squares of the differences between the experimental values y_i and the calculated ones $a_i x + b_i$ was as small as possible. This resulted in obtaining the value of the slopes a and the constant term b. Graphs were obtained for 56 open piezometers of the Chańcza dam, illustrating the variability of the water table between 14th January 2014 and 13th January 2017 as well as the adjusted trend lines with variable slope a, accounting for the first period from January 2014 to May 2015 and the second one from June 2015 to January 2017. For each piezometer, $\widehat{y_1} = a_1 x + b_1$ and $\widehat{y_1} = a_2 x + b_2$were obtained, respectively. Then, the linear regression functions (of the trend line) were compared in both analysed periods of time, with different slopes a for individual piezometers. For this purpose, a significance test was used for the hypothesis of equality of two linear regression slopes, called the parallelism test. The hypothesis $H_0: a_1 = a_2$ was formulated against the alternative hypothesis $H_1: a_1 \neq a_2$. Then, for both tests, the sum of squares of the deviations from these simple regressions was calculated according to formula [LACH 2018c]:

$$\sum_{i=1}^{n_1}(y_{i1} - \hat{y}_{i1})^2 \text{ and } \sum_{i=1}^{n_2}(y_{i2} - \hat{y}_{i2})^2 \quad (1)$$

The value of the statistics was calculated according to formula:

$$t = \frac{a_1 - a_2}{S_{a_1 - a_2}} \quad (2)$$

Where:

$$S_{a_1-a_2} =$$

$$= \sqrt{\frac{\sum_{i=1}^{n_1}(y_{i1} - \hat{y}_{i1})^2 + \sum_{i=1}^{n_2}(y_{i2} - \hat{y}_{i2})^2}{n_1 + n_2 - 4} \cdot \left(\frac{1}{\sum_{i=1}^{n_1}(x_{i1} - \bar{x}_1)^2} + \frac{1}{\sum_{i=1}^{n_2}(x_{i2} - \bar{x}_2)^2}\right)}$$

Based on the assumption that the verified hypothesis H_0 is true, the above statistic has Student's t distribution with $n_1 + n_2 - 4$ degrees of freedom. From the table of this distribution for the predetermined significance level $\alpha = 0.05$ and for $n_1 + n_2 - 4$ degrees of freedom, such a critical value t_α was read, so that $P\{|t| \geq t_\alpha\} = \alpha$. When comparing the calculated value of the statistic t with the critical value t_α, the inequality $|t| \geq t_\alpha$ or $|t| < t_\alpha$ was obtained. In the first case, the hypothesis H_0 was rejected, in the second case, there were no grounds for rejecting the hypothesis H_0 [LACH 2018c].

RESULTS AND DISCUSSION

Table 2 demonstrates the results obtained for the open piezometers of the Chańcza dam. Figure 4 illustrates changes in the water level in the reservoir and examples of water level changes in several selected piezometers in the study period 2014–2017. In addition, Figure 5 illustrates exemplary time series for the piezometers (piezometer B/a, for which the hypothesis H_0 was rejected, as well as the piezometer 5/2P, for which there were no grounds for rejecting the hypothesis H_0).

Table 2. Results obtained for open piezometers of the Chańcza dam in the study period 2014—2017

Piezometer	Period from January 2014 to May 2015		Period from June 2015 to January 2017		Value S	Value t	Critical value t_α	Result
	slope a	constant term b	slope a	constant term b				
1	2	3	4	5	6	7	8	9
0/c	–0.0103035	208.247	–0.0033884	207.856	0.00304	2.27111	1.6657	rejecting the hypothesis H_0
0/b	–0.0180417	208.467	–0.0028030	207.737	0.00302	5.05161	1.6657	rejecting the hypothesis H_0
0/1	–0.0196373	208.902	–0.0022599	208.177	0.00346	5.02810	1.6657	rejecting the hypothesis H_0
0/1b	–0.0153627	208.559	–0.0031266	207.937	0.00319	3.83389	1.6657	rejecting the hypothesis H_0
0/2	–0.0352608	209.792	–0.0045385	208.412	0.00475	6.46345	1.6657	rejecting the hypothesis H_0
0/3	0.1107730	208.683	–0.0071567	212.286	0.01634	–7.21808	1.6657	rejecting the hypothesis H_0
1/c	–0.0119488	207.925	–0.0026585	207.466	0.00255	3.63718	1.6657	rejecting the hypothesis H_0
1/b	–0.0159009	208.270	–0.0028931	207.658	0.00283	4.60166	1.6657	rejecting the hypothesis H_0
1/a	–0.0211166	208.598	–0.0000638	207.803	0.00183	11.49066	1.6657	rejecting the hypothesis H_0
1/1	–0.0264699	208.880	–0.0035582	207.846	0.00370	6.19230	1.6657	rejecting the hypothesis H_0
1/2	–0.0475913	209.769	–0.0024672	207.914	0.00507	8.89377	1.6657	rejecting the hypothesis H_0
1/3	0.1006420	208.673	–0.0051914	211.910	0.01509	–7.01561	1.6657	rejecting the hypothesis H_0
2/b	–0.0115410	208.217	–0.0042242	207.751	0.00363	2.01800	1.6657	rejecting the hypothesis H_0
2D/3	–0.0133476	208.352	–0.0036864	207.783	0.00367	2.63041	1.6657	rejecting the hypothesis H_0
2D/2	–0.0106686	208.181	–0.0041623	207.762	0.00345	1.88845	1.6657	rejecting the hypothesis H_0
2D/1	–0.0079848	207.911	–0.0034869	207.576	0.00326	1.38032	1.6657	no grounds for rejecting the hypothesis H_0
2/a	–0.0112186	208.387	–0.0045169	207.923	0.00376	1.78245	1.6657	rejecting the hypothesis H_0

continue Tab. 2

1	2	3	4	5	6	7	8	9
2/1	–0.0166856	209.004	–0.0051623	208.304	0.00474	2.42959	1.6657	rejecting the hypothesis H_0
2/2	–0.0291252	209.749	–0.0058443	208.584	0.00580	4.01107	1.6657	rejecting the hypothesis H_0
2/A	–0.0206733	209.698	–0.0068921	208.903	0.00583	2.36333	1.6657	rejecting the hypothesis H_0
2/3	0.0651446	209.361	–0.0037392	211.350	0.01240	–5.55669	1.6657	rejecting the hypothesis H_0
3/j	–0.0065339	206.987	–0.0031829	206.767	0.00279	1.20035	1.6657	no grounds for rejecting the hypothesis H_0
3/d	–0.0045140	206.711	–0.0011914	206.529	0.00242	1.37520	1.6657	no grounds for rejecting the hypothesis H_0
3/c	–0.0045946	206.760	–0.0013415	206.570	0.00245	1.32969	1.6657	no grounds for rejecting the hypothesis H_0
3/b	–0.0026553	206.489	–0.0002946	206.344	0.00177	1.33378	1.6657	no grounds for rejecting the hypothesis H_0
3/f	–0.0040398	206.445	–0.0004062	206.236	0.00163	2.22819	1.6657	rejecting the hypothesis H_0
3/g	–0.0064106	207.351	–0.0018293	207.063	0.00293	1.56394	1.6657	no grounds for rejecting the hypothesis H_0
3/h	–0.0067900	207.472	–0.0021360	207.159	0.00314	1.48417	1.6657	no grounds for rejecting the hypothesis H_0
3/e	–0.0060432	207.431	–0.0021248	207.136	0.00310	1.26496	1.6657	no grounds for rejecting the hypothesis H_0
3/a	–0.0044571	207.088	–0.0016360	206.874	0.00250	1.12803	1.6657	no grounds for rejecting the hypothesis H_0
3/1	–0.0065410	208.211	–0.0035206	207.883	0.00419	0.72113	1.6657	no grounds for rejecting the hypothesis H_0
3/3	0.0434448	209.475	–0.00429456	210.729	0.01201	–3.97454	1.6657	rejecting the hypothesis H_0
A/a	–0.0170413	208.429	–0.00112195	207.735	0.00251	6.33761	1.6657	rejecting the hypothesis H_0
B/a	–0.0126577	208.366	–0.00430863	207.866	0.00342	2.44101	1.6657	rejecting the hypothesis H_0
B/b	–0.0145638	208.404	–0.00411069	207.817	0.00361	2.89728	1.6657	rejecting the hypothesis H_0
C/a	–0.00819346	207.933	–0.0033349	207.588	0.00362	1.34291	1.6657	no grounds for rejecting the hypothesis H_0
C/b	–0.00719061	207.639	–0.00285647	207.327	0.00309	1.40261	1.6657	no grounds for rejecting the hypothesis H_0
4/1	–0.00841868	207.534	0.0148433	206.256	0.00460	5.06143	1.6657	rejecting the hypothesis H_0
4/2	–0.00304884	207.924	0.00642777	207.347	0.00403	2.34922	1.6657	rejecting the hypothesis H_0
4/2P	–0.000903272	208.441	–0.000497186	208.046	0.00511	0.07954	1.6657	no grounds for rejecting the hypothesis H_0
4/3	0.00314841	217.042	–0.0197824	216.817	0.01908	–1.20161	1.6657	no grounds for rejecting the hypothesis H_0
4/3A	0.000412518	209.543	–0.00316792	209.082	0.00746	–0.48007	1.6657	no grounds for rejecting the hypothesis H_0
4/4	0.00416074	216.981	–0.0197617	216.744	0.01943	–1.23117	1.6657	no grounds for rejecting the hypothesis H_0
5/1P	–0.00925557	207.6	0.00570169	206.991	0.00350	4.27067	1.6657	rejecting the hypothesis H_0
5/2P	–0.00149597	212.853	0.000108818	212.811	0.00174	0.92322	1.6657	no grounds for rejecting the hypothesis H_0
5/2C	–0.00059744	213.333	–0.000559099	213.354	0.00154	0.02488	1.6657	no grounds for rejecting the hypothesis H_0
5/2B	–6.88E–05	208.992	–0.00453752	208.746	0.00582	–0.76733	1.6657	no grounds for rejecting the hypothesis H_0
5/3A	0.00102892	210.697	–0.00600188	210.359	0.00891	–0.78873	1.6657	no grounds for rejecting the hypothesis H_0
5/3	0.00134898	217.114	–0.018636	216.742	0.01985	–1.00695	1.6657	no grounds for rejecting the hypothesis H_0
5/4	0.00234234	217.161	–0.0174193	216.673	0.01901	–1.03938	1.6657	no grounds for rejecting the hypothesis H_0
A	0.0190019	214.223	–0.0270966	214.487	0.02185	–2.11010	1.6657	rejecting the hypothesis H_0
B	0.00321479	209.369	–0.00600281	209.226	0.00702	–1.31371	1.6657	no grounds for rejecting the hypothesis H_0
P–2	0.0112423	209.938	–0.00632458	209.527	0.01128	–1.55735	1.6657	no grounds for rejecting the hypothesis H_0
P–1	0.00947131	209.295	–0.00568386	209.106	0.00790	–1.91959	1.6657	rejecting the hypothesis H_0
P–3	0.00577051	209.001	–0.00534615	208.907	0.00583	–1.90774	1.6657	rejecting the hypothesis H_0
6/1P	–0.0083689	208.259	0.00136116	207.915	0.00333	2.91901	1.6657	rejecting the hypothesis H_0

Explanations: piezometers as in Fig. 3
Source: own study.

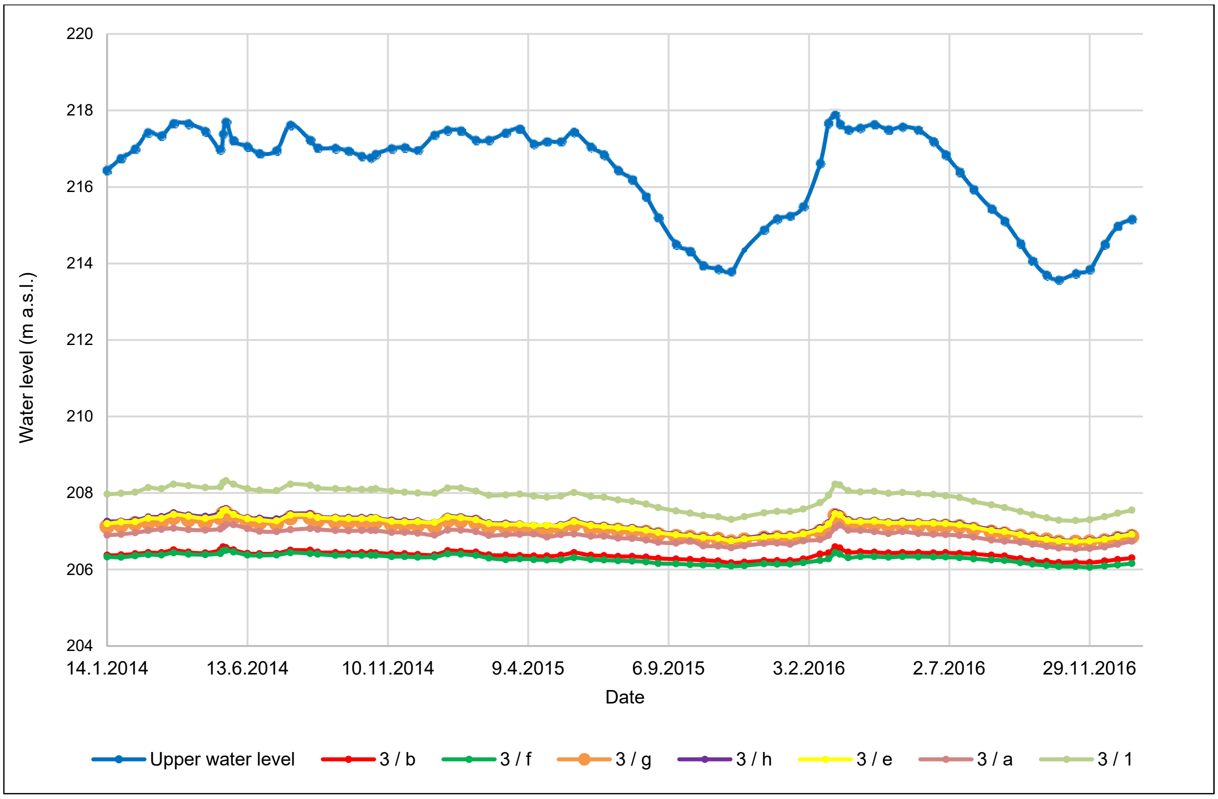

Fig. 4. Changes in the water level in the reservoir and examples of water level changes in several selected piezometers in the study period 2014–2017 source: own study

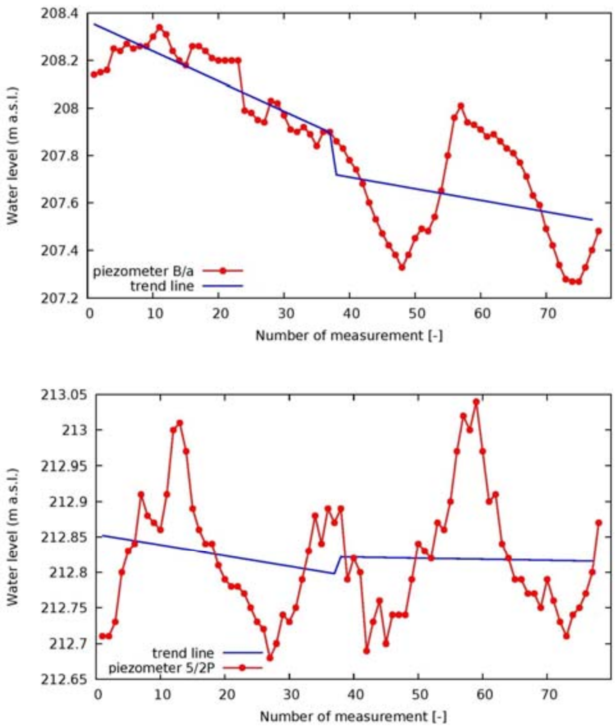

Fig. 5. Time series of changes in water levels in open piezometers together with trend line for Chańcza dam in the study period 2014–2017: a) piezometer B/a, b) piezometer 5/2P; source: own study

CONCLUSIONS

Out of the 56 analysed open piezometers of the Chańcza dam, in 24 cases there were no grounds for rejecting the hypothesis of equality of linear regression slopes, taking into account the period between January 2014 and May 2015, as well as between June 2015 and January 2017. This means that the trend of water levels has changed for 57.14% of piezometers. In most cases (95.83%) the trend is a declining one, which will lead to a decrease in filter gradients. Only for the piezometer 5/2P located on the downstream slope of the dam trend between June 2015 and January 2017 demonstrated an upward direction. The reasons for the noted changes in the trends of water levels and increase in filter pressure in these piezometers must be further clarified. Continuous monitoring of water levels, as well as possible model studies are necessary to explain this phenomenon.

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Interpretacja wyników pomiarów piezometrycznych uzyskanych dla zapory Chańcza w latach 2014–2017

STRESZCZENIE

Występowanie kontaktu hydraulicznego między piezometrami stwierdza się na podstawie podobieństwa zmian stanów wody. Część piezometrów reaguje na zmiany stanu wody górnej lub na zmiany stanu wody dolnej, część może także reagować na opady atmosferyczne. Jeżeli reakcja na zmiany stanu wody górnej jest znacząca, wówczas stwierdza się nieszczelność zabezpieczeń przeciwfiltracyjnych i przystępuje do remontu zapory. Celem artykułu jest przedstawienie oraz przeanalizowanie dynamiki zmian stanów wody w piezometrach otwartych zapory Chańcza zlokalizowanej w 36. km rzeki Czarnej Staszowskiej w miejscowości Korytnica w województwie świętokrzyskim. Przed przystąpieniem do analizy danych piezometrycznych wykorzystano test statystyczny Grubbsa, dzięki któremu możliwe było zidentyfikowanie oraz odrzucenie obserwacji odstających. Zakres badań obejmuje dane uzyskane od 14.01.2014 r. do 13.01.2017 r. Postawiono hipotezę, że zmiana trendu nastąpiła po okresie wiosennym w 2015 r., po którym nastąpiło obniżenie poziomu wody w zbiorniku o ok. 1,5 m. Metodą najmniejszych kwadratów dla każdego piezometru do jego stanów wody dopasowano dwie linie trendu – pierwszą dla okresu od stycznia 2014 do maja 2015 r. oraz drugą, od czerwca 2015 r. do stycznia 2017 r. W ten sposób uzyskano dwa współczynniki kierunkowe funkcji liniowej wraz z oszacowaniem ich błędów. Współczynniki te zostały porównane za pomocą statystycznego testu równoległości.

Słowa kluczowe: *bezpieczeństwo budowli hydrotechnicznych, linia trendu, piezometr otwarty, zapora ziemna*