Operating information-diagnostical system (IDS) BING-3 on the example of Andijan water reservoir

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Abstract. The article provides recommendations on the possibility of implementing an automated system of diagnostical control over the operational condition of a dam. Implementation of BING-3 allows to control the opening of cracks in concrete structures, take readings from piezometers and air temperature sensors in an automatic regime. The article gives an analysis of instruments used for diagnostics and reasons for the failure of certain devices. It has been established that further use of morally out-of-date devices reduces dam safety observation volumes.

1 Introduction

The majority of earth-fill and concrete dams in the republic were built in the middle of the last century. Correct technical solutions, implemented in the design of these dams, allowed to operate them for over fifty years [1, 2]. However, nowadays, the control over the dams is carried out by manual measurements of two or three coordinate crack measurers, pressure and non-pressure piezometers, reverse plumbs [19, 20]. Also, earth-fill and concrete structures of hydrosystems have many marks installed, whose positions are controlled relative to reference points using geodetical equipment. Such a system of control-measurement instrument management does not meet current requirements [1]. Time requires reequipping of all average and high pressure dams with modern instruments. When implementing automated systems of diagnostical control, several problems of financial origin may come out, including personnel training, etc.

In this article, we consider the issues concerning technical solutions for implementing automated systems of diagnostical control at the Andijan water reservoir (Figure 1).

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The goal of the work is to justify the practicability of implementing the system of diagnostical control over the operational condition of a concrete dam.

The task of improving the control over earth-fill and concrete dam conditions is determined with the necessity of providing the safety of operation of very important and technically complex facilities [3, 4, 10, 11, 15].

The main task of monitoring is to control the operational condition of hydrosystems. Monitoring is carried out using both inset control and measurement equipment, installed in the process of construction, geodetic, seismometric, other instrumental methods, and visual observations [21-36].

3 Methods

The research was carried out using the traditional method of conducting field research of structures.

There is a big experience accumulated throughout the world on implementing automated systems of diagnostical control over the technical condition of dams, for example, BING-3 [7,8,9,13,14].

BING-3 system operates in the automatic regime and carries out control over the opening of cracks in concrete structures, records piezometer and air temperature sensor readings. The system has successfully recommended itself at Orto-Tokoy water reservoir in Kirgizstan, being used since 2014 [13].
4 Results and Discussion

All the control and measurement equipment listed in table 1 must be replaced in Andijan water reservoir.

Table 1. Amount of instrumentation requiring reequipment. Static control and measurement equipment.

| Static control-measuring instrumentation: | Amnt.  |
|------------------------------------------|--------|
| String and semiconductor transformers    | 1119 ea. |
| *Filtration Control Measurement Instrumentation:* |        |
| Pressure piezometers                     | 108 ea |
| Nonpressure piezometers                  | 100 ea. |
| Including inside the dams                | 100 ea |
| Measuring weirs                          | 22 ea. |
| Springs at the dam tailrace              | 5 ea.  |
| *Geodetic Control Measurement Instrumentation:* |      |
| Fundamental reference marks             | 6 ea.  |
| - Operation reference marks              |        |
|   - Direct plumbs                        | 8 ea.  |
|   - Reverse plums                        | 16 ea. |
| Range signs in galleries at levels 817, 845, 885 | 103 ea. |
| Hydrostatic elevation meter (level) (at 4 sections) | 48 ea. |
| Uniaxial and triaxial crack meters       | 44 ea. |
| *Seismic Control Measurement Instrumentation:* |       |
| Seismic detectors                        | 53 ea. |
| *Hydraulic Control Measurement Instrumentation:* |     |
| Concrete failure sensors, including:     | 39 ea. |
|   at 1st tier waterways                  | 10 ea. |
|   at water outlet stilling basin         | 15 ea. |
|   at spillway stilling basin             | 14 ea. |
| Sensors of wearing of metal, including:  | 20 ea. |
|   at section №16 waterways              | 10 ea. |
|   at section №21 waterways              | 10 ea. |
| Pressure pulsation sensors               | 34 ea. |
| Cavitation sensors                       | 18 ea. |
| Inserts at section №21 and cable for measurement of: |       |
|   pressure and aeration                  | 4 ea.  |
|   velocity and aeration                  | 4 ea.  |
| Vibration sensors, including:           | 32 ea. |
|   in the body of sections №16, №17, №21 and №22 | 18 ea |
|   at spillway stilling basin             | 14 ea. |

For measurements of deformations and temperature at the base and in concrete, openings of deformation joints and cracks, measurement of filtration pressure, string and semiconductor transformers of static control, and measurement instrumentation were installed in the dam [1]. The frequency of alternating voltage at transformer outlet or active
resistance of semiconductor thermoresistor serves as information parameter of the electrical signal [11,12]. Types of these transformers and their measuring limits are given in Table 2.

**Table 2.** Types of string transformers used for observations

| №  | Transformer type                                      | Abbreviation | Unit of measurement | Range of values | Function                                      |
|----|-------------------------------------------------------|--------------|---------------------|-----------------|-----------------------------------------------|
| 1  | Linear displacement transformers, string type         | PLPS         | mm                  | 0-1, 0-3, 0-6   | Measurement of the amount of joint and crack opening |
| 2  | Linear deformation transformers                       | PLPS         | mm                  | 0.1; 0.22; 1    | Measurement of relative linear deformations   |
| 3  | Force transformers, string type                       | AD           | kN                  | 80              | Measurement of tensile and compressive forces in rebar |
| 4  | Pressure transformers, string type                    | PD           | MPa                 | 3, 10           | Measurement of hydrostatic pressure in concrete and joints |
| 4  | Transformers for temperature measurement, string type | PTS-60       | degrees             | from -20 to +60 | Temperature measurement                       |
| 5  | Thermoresistor temperature transformers               | MMT-4        | degrees             | from 0 to +60   | Temperature measurement                       |

**Fig. 2.** Location of crack meters at the axis of right buttress section 18, 24.
In 2015 observations by static control measurement instrumentation were carried out every 10 days. Monthly checks of the number of sensors, which transmitted data, showed that their amount has decreased compared to 2014.

Table 3 shows data on the number of transformers used to take measurements in 2014-2015 and the decrease of the number of transformers used for observation in December of 2015 compared to June of 2014.

Table 3. The number of transformers used for observations.

| Transformer description | 2010r. | 2014 20 - VI | 2014 30-XII | 2015 30-VI | 2015 20-XII | Decrease |
|-------------------------|--------|--------------|-------------|------------|-------------|----------|
| 1                       | 79     | 79           | 79          | 78         | 79          | 0        |
| Semiconductor thermometers (T) | 27     | 26           | 25          | 25         | 25          | 1        |
| String type thermometers (TS) | 9      | 6            | 5           | 6          | 6           | 0        |
| Concrete-rock contact sensors | 44     | 44           | 39          | 42         | 41          | 3        |
| String type crack meters (C, CS) | 12     | 12           | 11          | 11         | 11          | 1        |
| Rebar dynamometers (RD) | 8      | 8            | 8           | 8          | 8           | 0        |
| Piezometer dynamometers (PD) | 70     | 70           | 70          | 69         | 69          | 1        |
| Reduction of sensors used for measurement from 20.06.2014 to 20.12.2015, ea | 5 |

It is seen from the given data that the number of transformers used for diagnostics decreased by 9 units in 2015 compared to 2014. The main reason for the reduction of observations is the failure of generator-frequency meter ІЦ – 5m. This device has morally aged and taken out of production. Frequency meters and period meters produced nowadays don’t have the same sensitivity as ІЦ – 5m. That is why it will be possible to recommence observations with a specified group of devices will be possible only after obtaining second-order devices with the required sensitivity.

The Diagnostic center receives data from Andijan water reservoir in the form of transformer string oscillation periods (microseconds) or thermoresistor resistance values (Ohm). Measurements on about 1250 transformers are taken in one cycle. 26 measurement cycles are carried out in a year. Work on these data starts with their initial processing, which lies in the conversion of transformer electrical signals into physical values [11]. Depending on the characteristics of the transformer output signal, the physical value being
measured is calculated using the following relationships:
- logarithmic relationship for thermoresistor transformers

\[ Y = \frac{A}{\ln(X-B)} - 273.15 \]

- parabolic relationship for string transformers

\[ Y = A(X^2 - C^2) + B(X - C), \]

Where

- \( Y \) is value being measured
- \( A, B, C \) are graduated relationship coefficients
- \( X \) is transformer output signal.

These calculations are carried out for each of 1250 transformers of static control measurement instrumentation. Table 4 with measurement data, carried out in March of 2015 and the results of their initial processing, is given as an example of information obtained from the water reservoir.

Table 4. Measurement data

| Device number | Data, transmitted from water reservoirs for processing | Transformers | Results of conversion of electrical signals into physical values |
|---------------|-----------------------------------------------------|-------------|---------------------------------------------------------------|
|               | Date of measurement (microsecond, Ohm)              |             | Measurement dates                                             |
|               | 10/01/15 5                                         |             | 10/01/15 5                                                   |
| 0             | 6423 6424 6423                                      | БТ-7        | -4.194 -4.2535 -4.194                                       |
| 1             | 5908 5909 5909                                     | БТ-8        | -2.198 -2.2828 -2.2828                                      |
| 2             | 6246 6243 6243                                     | БТ-9        | -1.834 -1.6322 -1.6322                                      |
| 3             | 6282 6282 6282                                     | БТ-10       | 3.0462 3.0462 3.0462                                        |
| 4             | 6466 6467 6468                                     | БТ-12       | -0.1084 -0.1661 -0.2239                                     |
| 5             |                                                     | БТ-13       |                                                             |
| 6             | 6248 6249 6250                                     | БТ-14       | -3.2085 -3.2741 -3.3396                                     |
| 7             | 6565 6585 6564                                     | БТ-15       | -2.0848 -2.0848 -2.0298                                     |
| 8             | 6380 6380 6381                                     | БТ-7        | 4.2659 4.2659 4.2017                                        |
| 9             | 7033 7033 7032                                     | БТ-16       | 9.9307 9.9307 9.9531                                        |
| 10            | 6086 6083 6084                                     | ТС-31       | 1.3304 1.5415 1.4711                                        |
| 11            | 6083 6085 6082                                     | БТ-11       | 1.7619 1.6241 1.8308                                        |
| 12            | 6240 6241 6241                                     | БТ-17       | -0.3769 -0.4443 -0.4443                                     |
| 13            | 6362 6626 6631                                     | БТ-18       | -8.9753 -8.6583 -8.9225                                     |
| 14            | 6337 6338 6339                                     | БТ-19       | -3.7545 -3.8166 -3.8788                                     |
| 15            | 6267 6281 6268                                     | БТ-20       | -5.7628 -6.6733 -5.8280                                     |
| 16            | 6355 6354 6355                                     | БТ-21       | 5.3308 5.3925 5.3308                                        |
| 17            | 6415 6413 6412                                     | БТ-22       | -9.4542 -9.3352 -9.2757                                     |
| 18            | 6220 6219 6219                                     | БТ-24       | -7.5873 -7.5210 -7.5210                                     |
| 19            | 77892 7788 7787                                   | БТ-25       | -1.7655 -1.6312 -1.5976                                     |
| 20            | 6543 6543 6543                                     | БТ-26       | -1.1296 -1.1296 -1.1296                                     |
| 21            | 7145 7149 7157                                   | БТ-27       | 9.5034 9.4291 9.2809                                        |
| 22            | 6016 6015 6015                                   | ТС-38       | 0.5907 0.6638 0.6638                                        |
| 23            | 6064 6064 6063                                   | БТ-28       | -3.6407 -3.6407 -3.5699                                     |
| 24            | 6232 6231 6231                                   | БТ-31       | -5.1491 -5.0811 -5.0811                                     |
| 25            | 6236 6235 6232                                   | БТ-32       | -0.6328 -0.5653 -0.3625                                     |
| 26            | 6132 6132 6133                                   | БТ-33       | -4.0200 -4.0200 -4.0899                                     |
Table 4. Measurement data (continuation)

| Device number | Data, transmitted from water reservoirs for processing | Transformers | Results of conversion of electrical signals into physical values |
|---------------|------------------------------------------------------|-------------|---------------------------------------------------------------|
|               | Date of measurement                                   |             | Measurement dates                                             |
|               | Date of measurement                                   |             | Physical values (mm, grad, kg/cm²)                           |
|               | 10/01/5                                              | TC-33       | 10/01/15                                                      |
|               | 20/01/15                                             | TC-36       | 20/01/15                                                      |
|               | 10/01/5                                              | TC-35       | 10/01/15                                                      |
| 27            | 6794                                                 | 6802        | 6811                                                          |
| 28            | 6619                                                 | 6620        | 6618                                                          |
| 29            | 6513                                                 | 6511        | 6510                                                          |
| 30            | 6265                                                 | 6265        | 6262                                                          |
| 31            | 6524                                                 | 6518        | 6514                                                          |
| 32            | 6145                                                 | 6145        | 6146                                                          |
| 33            | 7448                                                 | 7461        | 7476                                                          |
| 34            | 6329                                                 | 6330        | 6329                                                          |
| 35            | 6450                                                 | 6448        | 6442                                                          |
| 36            | 6317                                                 | 6318        | 6317                                                          |
| 37            | 6787                                                 | 6798        | 6825                                                          |
| 38            | 6218                                                 | 6214        | 6212                                                          |
| 39            | 6423                                                 | 6422        | 6423                                                          |
| 40            | 6062                                                 | 6059        | 6056                                                          |
| 41            | 5961                                                 | 5960        | 5961                                                          |
| 42            | 6974                                                 | 6990        | 7011                                                          |
| 43            | 6250                                                 | 6248        | 6247                                                          |
| 44            | 6931                                                 | 6928        | 6926                                                          |
| 45            | 6267                                                 | 6266        | 6267                                                          |

4 Discussion

Principles of building the automated system of diagnostic control over the condition of hydraulic structures (ASDC HS) [13] is in the following (Figure 3):
- ASDC system includes in itself an automated system of sensor query (ASQ CMI) and information-diagnostical system (IDS) BING-3, operating in a common computer network (local or corporate) and integrated at the software level.
- ASQ CMI carries out open-end transfer of data from initial sensors to central data collection server. At the data collection server outlet ASQ SMI is integrated with IDS BING-3. Besides, overall ASDC HS is an “open” type AS, which provides stage-by-stage system development, interchangeability of hardware and software means, and compatibility with ASM of other levels.
- ASQ CMI is a distributed system of remote control, which is built according to “industrial network” technology, which provides reliable protection from interferences, reduction in price, and simplification of works in mounting and operation of automated systems.
ASDC HS structurally includes the following elements:
- lower level – control-measurement instrumentation (CMI): sensors, measuring devices;
- medium level – the system of telecommunication, transformation, and transmitting of information in digital code to central data collection block ASQ CMI;
- higher level - program-technical complex, including in itself central automated query block ASQ CMI and information-diagnostic system of control over structure safety (IDS) with corresponding computer hardware and software.
Fig. 3. Simplified structural scheme for data collection system network CMI “BING-3”.

At the lower level ASDC directly uses measuring devices with sensors, registering physical processes and impacts on the structure. This automatization system uses water level sensors, sensors of excess pressure in pressure and nonpressure piezometers, discharge meters at drainage wells and measuring weirs, displacement sensors in crack meters, plumbs, string ranges, temperature sensors. The general requirement to sensors is their unified analogue, a digital or radiofrequency outlet of standard type, and interchangeability.

Medium level of ASDC HS includes in itself sensor communication means, transformations of the analogue signal into digital codes, and communication lines for signal transmission from sensors to the central block of automated query system ASQ. Data collection modules, located in the maximum concentration of measuring devices, are used to connect sensors to a communication line with an industrial interface.

Higher level of ASDC HS system is a program-technical complex, including data input-output controller, central block based on data collection industrial server, base specialized software for management of automated query of sensors and automated work areas with the complex of programs as part of IDS safety control of HS.

4 Conclusions

The main results of the work consist of the following:

1. Collected and analyzed field observation data from Andijan water reservoir concrete dam indicate of their safe operation at its long operation state.
2. Based on the analysis of available data, the main requirements to hydraulic structure operational control systems were determined, i.e., composition and types of field observations, device control means, observation periodicity, and initial data processing seismic monitoring and registering of earthquakes.
3. Permanent control over CMI operational efficiency in the process of monitoring HS
condition is provided.
4. Use of IDS BING-3 at Andijan hydrosystem allows for automatization of monitoring the condition of all structures at water level, piezometer pressures, discharge measurements, displacement, and temperature.

References

1. Bakiev M.R., Rahmatov N., Ibraymov A. «Control measurement devices of hydraulic structures» Textbook, p.263, Tashkent, (2019)
2. Bakiev M.R., Rahmatov N., Ibraymov A. Operation of hydraulic structures in canals. Textbook, T, p.280, (2018)
3. Methods for determining safety criteria of hydraulic structures. RAO «GES Russia», M., p.18, (2000)
4. Regulations on hydraulic structure sites, RD 254. 073-98. Minenergo RUz, Tashkent.
5. M. Malahanov. «Technical diagnostics of earthfill dams» M,(1990)
6. Basic rules on operation of water reservoirs with capacity of 10 mln. m³ and over. RD 33-3. 02.08-87. Official publ. M., (1987)
7. Kuzmin N.G., Raszkazhikov V.A., Ulyashinski V.A. Strength and deformation properties of concrete and strength properties of rock base of Krasnoyarssk GPS dam after 40 years of operation period. Info VNIIG of B.E.Vedeneev., T. 276. pp. 46-55, (2014)
8. Kuzmin N.G. Particularities of condition concrete dam of Krasnoyarsk HPS at long-term operation stage. Info VNIIG of B.E.Vedeneev. T. 276. pp. 24-32. (2015)
9. Lyutsko E.A. Monitoring the condition of Chirkey HPS dam. Info VNIIG of B.E.Vedeneev. T.237. pp.40-44. (2001)
10. Mayorova M.A., Sokolovski I.K. Methods for choosing the frequency of field observations. Info VNIIG of B.E.Vedeneev. T. 241. pp.137-143, (2002)
11. Mayorova M.A. Methods of initial Способы pre-processing of field observation data. Info VNIIG of B.E.Vedeneev. T. 237. pp.40-44, (2000)
12. Kuzmin N.G. C.t.s. dissertation «Improving the system of control of Krasnoyarsk HPS concrete dam condition (on the example of Krasnoyarsk HPS).» (2010)
13. Sherbina. Presentation in Almati city, «Installation in Orto-Tokoy hydrosystem of computer-diagnostic system to control safe condition of hydrotechnical structures (BING-3).» (2010)
14. Melnikov E., Morozov V., Krasnoshekov I. «Developing the system of control over condition of hydrotechnical structures of shipping lock »
15. Nosova O.N. Basic rules of processing observation results of piezometers for field observations of filtration». Info VNIIG. T.81.(1966)
16. KMK 2.06.01-96 Hydraulic structures. Basic design rules.
17. Rosanov N.P. and others «Hydraulic structures» (1985)
18. Bochkaryov Ya.V., Ovcharov E.E. Principles of automatics and automatization of production processes in hydromelioration. -M.: Kolos, - p.332, (1981)
19. Goncharov L.A., Komarov V.A., Lentyaev L.D. and others. – Complex field hydraulic observations of spillway structures. Research works Gidroproekt. – M. – Ed. 91. – pp.9-20, (1983)
20. Methodical recommendations to developing of arrangement design of control measurement devices in concrete structures. pp.41-70 Minenergo, - L.: VNIIG, - p.102, (1971)
21. Bazarov D., Vatin N., Obidov B., and Vokhidov O. Hydrodynamic effects of the flow on the slab of the stand in the presence of cavitation. IOP Conf. Ser. Mater. Sci. Eng.
22. Bazarov D., Markova I., Norkulov B. and Vokhidov O. Hydraulic aspects of the layout of head structures during water intake from lowland rivers. IOP Conf. Ser. Mater. Sci. Eng. 1015, 012041 (2021).

23. Shokirov B., Norkulov B., Nishanbaev Kh., Khurazbaev M., Nazarov B. Computer simulation of channel processes. E3S Web of Conferences, 97, 05012, (2019)

24. Bazarov D., Markova I., Sultanov S. and Kattakulov F. Dynamics of the hydraulic and alluvial regime of the lower reaches of the Amudarya after the commissioning of the Takhiatash and Tuyamuyun hydrosystems. IOP Conf. Ser. Mater. Sci. Eng. 1030, 012110 (2021).

25. Bazarov D. and Vokhidov O. Extinguishing Excess Flow Energy in Spillway Structures. In book: Proceedings of EECE 2020, LNCE 150, pp. 535-545, (2021) DOI: 10.1007/978-3-030-72404-7_52

26. Krutov A., Choriev R., Norkulov B., Mavlyanova D. and Shomurodov A. Mathematical modelling of bottom deformations in the kinematic wave approximation. IOP Conf. Ser. Mater. Sci. Eng. 1030, 012147 (2021).

27. Bazarov D., Markova I., Norkulov B., Isabaev K., Sapaeva M. Operational efficiency of water damless intake. IOP Conf. Ser. Mater. Sci. Eng. 869(7), 072051, (2020)

28. Krutov A., Norkulov B., Uljaev F., and Jamalov F. Results of a numerical study of currents in the vicinity of a damless water intake. IOP Conf. Ser. Mater. Sci. Eng. 1030, 012121 (2021).

29. Obidov B., Vokhidov O., Tadjieva D., Kurbanova, U., Isakov A. Hydrodynamic effects on the flow elements of the downstream devices in the presence of cavitation. IOP Conf. Ser. Mater. Sci. Eng. 1030, 012114 (2021).

30. Krutov A., Norkulov B., Mavlyanova D. Simulation of spreading of non-conservative passive substances in water bodies. IOP Conf. Ser. Mater. Sci. Eng. 883(1), 012028 (2020)

31. Bazarov D., Norkulov B., Vokhidov O., Uljaev F., Ishankulov, Z. Two-dimensional flow movement in the area of protective regulatory structures. IOP Conf. Ser. Mater. Sci. Eng. 890, 012162 (2020)

32. Krutov A., Norkulov B., Nurmatov P., Mirzaev M. Applicability of zero-dimensional equations to forecast nonconservative components concentration in water bodies. IOP Conf. Ser. Mater. Sci. Eng. 883(1), 012028 (2020)

33. Uralov B., Rakhmatov N., Khidirov S., Uljaev F., Raimova I. Hydraulic modes of damless water intake. IOP Conf. Ser. Mater. Sci. Eng. 1030(1), 012123 (2021)

34. Krutov A., Norkulov B., Artikbekova F., Nurmatov P. Optimal location of an intake at a reservoir prone to salt diffusion. IOP Conf. Ser. Mater. Sci. Eng. 869(7), 072020, (2020)

35. Bazarov D., Markova I., Raimova I., Sultanov Sh. Water flow motion in the vehicle of main channels. IOP Conf. Ser. Mater. Sci. Eng. 883, 012025 (2020).

36. Matyakubov B., Begmatov I., Raimova I. and Teplova G. Factors for the efficient use of water distribution facilities. IOP Conf. Ser. Mater. Sci. Eng. 883, 012025 (2020).