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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»
ЧФ «Халық»

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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
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GEODETIC MONITORING OF DEFORMATION PROCESSES AT KAPCHAGAY HYDROPOWER PLANT

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Abstract. *Study purpose* is to monitor deformation processes of hydraulic structures. *Object of the study* is the Kapchagay hydroelectric power station (HPS), located in the Almaty region of the Republic of Kazakhstan.

Research methodology - ensuring safe operation of such strategic and critical engineering structures is achieved by conducting geodetic monitoring using modern technologies (satellite technologies, electronic and laser devices). The required accuracy can be ensured by measuring elevations with automated high-precision tacheometers and observing several conditions.

Research results. The article provides recommendations for improving methods of geodetic monitoring of deformation processes at the Kapchagai hydroelectric station. In this regard, improved methodology for carrying out geodetic work and using modern measuring instruments in it has been proposed. Monitoring was

carried out using modern instruments, special attention was paid to use of high-precision trigonometric leveling.

Scientific novelty. As a result of research work carried out, following were created and put into production:

- diagram of the reference geodetic Kapchagai hydroelectric station;

-developed geodetic reference point of forced centering, allowing to increase productivity and accuracy of observations.

The novelty of the developed network and point design is confirmed by Patents and Certificates of the Republic of Kazakhstan.

Practical significance lies in use of the research results in the dissertations of master and PhD students, in the educational process of the Kazakh National Research Technical University named after K.I. Satpayev, and can also be used to increase level of industrial safety at other facilities and minimize risks caused by seismicity in the region.

Keywords: hydraulic structures, deformation processes, geodetic monitoring, modern geodetic instruments, satellite systems, trigonometric leveling, high-precision total stations, accuracy assessment.

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ҚАПШАҒАЙ СУЭЛЕКТР СТАНСАСЫНЫҢ ДЕФОРМАЦИЯЛЫҚ ПРОЦЕСТЕРІН ГЕОДЕТИЯЛЫҚ МОНИТООРИНГТЕУ

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Аннотация. *Зерттеудің мақсаты* - гидротехникалық құрылымдардың деформациялық процестерін бақылау. Зерттеу объектісі Қазақстан Республикасы Алматы облысының сейсмикалық жоғары аймағында орналасқан Қапшағай су электр станциясы (СЭС) болып табылады. *Зерттеудің әдістемесі* – осындай стратегиялық және маңызды инженерлік құрылымдардың қауіпсіз жұмыс істеуін қамтамасыз ету қазіргі заманғы технологияларды (спутниктік технологиялар, электронды және лазерлік қаспаптардыр) пайдалана отырып, геодезиялық мониторинг жүргізу арқылы қол жеткізіледі. Қажетті дәлдікті автоматтандырылған жоғары дәлдіктегі тахеометрлерді қолданумен биіктіктерді өлшеу және бірқатар шарттарды сақтау арқылы қамтамасыз етіледі

Зерттеудің нәтижелері. Мақалада Қапшағай су электр станциясындағы деформация процестерін геодезиялық бақылау әдістерін жетілдіру бойынша ұсыныстар берілген. Осыған байланысты геодезиялық жұмыстарды жүргізудің және онда заманауи өлшем құралдарын қолданудың жетілдірілген әдістемесі ұсынылды. Бақылау заманауи аспаптарды қолдану арқылы жүргізілді, жоғары дәлдіктегі тригонометриялық нивелирлеуді қолдануға ерекше көңіл бөлінді. *Ғылыми жаңалығы.* Жүргізілген ғылыми зерттеу жұмыстарының нәтижесіде:

- Капшағай суэлектр станциясының геодезиялық тірек торабы жасалынды;
- бақылаулардың өнімділігі мен дәлдігін арттыруға мүмкіндік беретін мәжбүрлеп центрлеудің геодезиялық тірек пункт әсірленді.

Әзірленген тірек торабы мен пункт конструкциясының жаңалығы Қазақстан Республикасының патент, куәліктерімен расталды.

Тәжірибелік маңыздылығы. Ғылыми-зерттеу нәтижелерін магистранттардың, докторанттардың диссертацияларында, Қ.И.Сәтбаев атындағы Қазақ ұлттық ғылыми-зерттеу техникалық университетінің оқу процесінде пайдалануында, сонымен қатар, осындай нысандарды пайдаланудағы өнеркәсіптік қауіпсіздітің деңгейін жоғарылату және аумақтағы сейсмикалық қауіптердің алдын алуында.

Түйін сөздер: гидротехникалық құрылыстар, деформация процестері, геодезиялық бақылау, қазіргі геодезиялық аспаптар, спутниктік жүйелер, тригонометриялық нивелирлеу, жоғары дәлдіктегі толық станциялар, дәлдікті бағалау.

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ГЕОДЕЗИЧЕСКИЙ МОНИТОРИНГ ДЕФОРМАЦИОННЫХ ПРОЦЕССОВ КАПЧАГАЙСКОЙ ГИДРОЭЛЕКТРОСТАНЦИИ

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Аннотация. *Цель исследования* – мониторинг деформационных процессов гидротехнических сооружений. *Объект исследования* – Капчагайская гидроэлектостанция (ГЭС), находящаяся в Алматинской области Республики Казахстан.

Методика исследования – обеспечение безопасной эксплуатации таких стратегических и ответственных инженерных сооружений достигается проведением геодезического мониторинга с использованием современных технологий (спутниковые технологии, электронные и лазерные приборы). Необходимая точность может быть обеспечена при измерении превышений автоматизированными высокоточными тахеометрами и соблюдении ряда условий.

Результаты исследования. В статье приведены рекомендации по совершенстованию методов геодезического мониторинга дефоромационных процессов Капчагайской ГЭС. В связи с этим предложена совершенстованная методика проведения геодезических работ и использования в них современных средств измерений. Проведен мониторинг с использованием современных

приборов, особое внимание обращено применению высокоточного тригонометрического нивелирования.

Научная новизна. В результате проведенных научно-исследовательских работ, созданы и внедрены в производство:

- схема опорной геодезической Капчагайской ГЭС;
- разработанный опорный геодезический пункт принудительного центрирования, позволяющий повысить производительность и точность наблюдений;

Новизна разработанной сети и конструкции пункта подтверждены Патентами и Свидетельствами РК.

Практическая значимость заключается в использовании результатов исследовании в диссертационных работах магистрантов, докторантов, в учебном процессе Казахского национального исследовательского технического университета имени К.И. Сатпаева, а также могут быть использованы для повышения уровня производственной безопасности на других объектах и минимизации рисков, вызванных сейсмикой региона.

Ключевые слова: гидротехническое сооружение, деформационные процессы, геодезический мониторинг, современные геодезические приборы, спутниковые системы, тригонометрическое нивелирование, высокоточные тахеометры, оценка точности.

Introduction. Hydropower is significant sector of Kazakhstan's strategy to diversify country's entire energy sector. In this context, the Kapchagay Hydroelectric Power Station named after Sh. Chokin is of particular interest - the only hydroelectric power station on the Ili River. Construction of main structures of the hydroelectric complex began in 1966, the Ili River was blocked on September 29, 1969, the first hydroelectric unit of the station was launched on December 22, 1970, the last - on December 22, 1971. In 1980, construction of the hydroelectric power station was finally completed.

Fig. 1 - General view of the Kapchagai hydroelectric station

Construction of the Kapchagay hydroelectric power station was necessary to provide developing city of Almaty and its satellite cities with unexpensive electricity. At present it has become important factor in development of the Kunayev city contributing to formation of communal, educational, medical and cultural infrastructure (Zholtaev, Nalibayev, 20218). Intensive development of Kunayev city expressed in the plan change, emergence of new large objects and structures, as well as the safe operation of such strategic and important engineering structures as the Kapchagay hydroelectric power station, is achieved by conducting geodetic monitoring.

In this regard, study of the geodynamic state of urbanized territories by traditional methods is labor-intensive and therefore for such areas geodetic monitoring with high-precision instruments is extremely necessary and they are of significant practical interest.

Methods and materials. The work uses a comprehensive approach, including: analysis of current scientific and technical information in the form of scientific papers and studies of predecessors; natural conditions, location of reference points around observed object, assessment monitoring and its accuracy.

Literature review. Today, wide variety of measurement methods and tools are used in geodetic monitoring of hydraulic structures. Satellite technologies, electronic tacheometers, sensors, etc. are successfully used to control planned displacements (Genike and Chernenko, 2010; Nikonov, 2013; Marfenko, 2014; Jiang et al,2018).). Moreover, control can be carried out by conducting cycles of geodetic measurements with a set frequency, as well as continuously, by using various types of sensors and based on automated tacheometers or satellite equipment (Bazaluk et al.,2021; ,Hiller et al., 2015; Salnikov et al., 2018; Nurpeisova et al., 2021).

Geometric leveling is traditionally used to control vertical displacements of structures. It should be noted that at operating industrial enterprises, due to influence of several factors reducing measurements accuracy, use of digital levels or levels with compensator for geometric leveling does not always ensure required measurement accuracy. Measurement methods that consider influence of factors reducing accuracy, as a rule, significantly increase period of work performance (Aitkazinova et al, 2020; Nurpeissova et al. 2023; ; Zhe et al. 2023).

The main factors reducing accuracy in relation to measurements conditions at hydraulic structures (HS) include: vibration from operating hydraulic units and water flow; electromagnetic fields from operating hydraulic units and high-voltage power lines; air turbulence due to operating equipment, etc.

Main content.

Previously, geodetic base was created to carry out construction works on the territory of the Kapchagshayskaya hydroelectric power station, i.e. planned-altitude base of several points, which turned out to be of little avail for organizing observation sessions with satellite receivers, since they were laid out for carrying out observations using traditional methods, especially this concerns reference points.

With advent of high-precision satellite technologies and electronic tacheometers, angular measurements are supplemented by linear measurements. Accuracy of calculating coordinates in the network increases. Percentage of accuracy increase depends on network shape including sides lengths in the network. Further increase in network accuracy is impossible without changing of network shape, number of starting points, and reducing lengths of the lines. To determine deformation state of hydraulic structures and ensure their trouble-free operation, whole range of field observations are carried out using geodetic methods. At the same time, methodology for performing geodetic measurements is constantly being improved, especially with advent of satellite technologies.

However, there are three factors that in many cases do not allow obtaining required measurement accuracy. This is explained by the fact that*, firstly*, it is necessary for the reference points to be in the alignmen*t, secondly*, ensuring open radio horizon during entire measurement session for enough GNSS satellites and, *thirdly*, construction of the reference benchmarks do not meet requirements of regulatory literature. In such cases, accuracy of coordinates determining of points, for example, during horizontal displacements determination of hydraulic structures can be ensured, in our opinion, by combined use of satellite geodetic receivers and high-precision automated electronic tacheometers.

Therefore, to realize advantages of satellite technologies, in particular, absence of need for direct visibility between points in network, existing network schemes can be reconstructed as follows. To perform measurements, three-four-point ranges are laid out, with mutual visibility between them.

Figure 2 shows diagram of measurements at the State Geodetic Network (SGN) points Kapchagay and Iliysk during determination of coordinates of reference points RP-I, RP-2, RP-3 and RP-4, located in places that provide the most favorable conditions for satellite measurements. In this case, the most favorable option is considered, when high-quality satellite measurements can be performed at previously established reference points of the alignment.

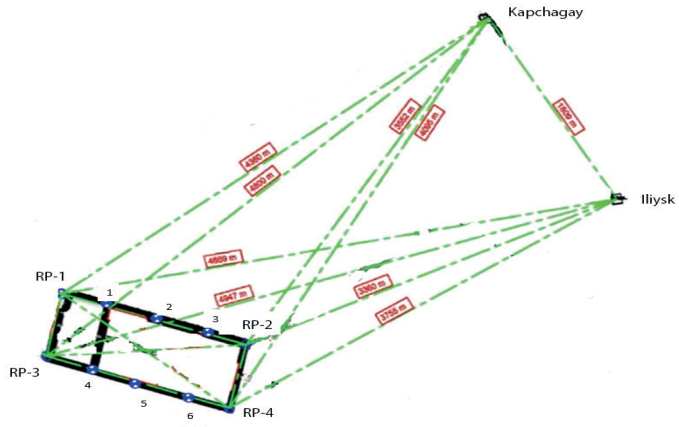

Fig. 2 -Diagram for determining coordinates of HPP reference points

To obtain the most equal accuracy of determining baselines, it is recommended to perform measurements with satellite receivers at all network points simultaneously. From points RP-I, RP-2, RP-3, RP-4, coordinates transfer to reference points 1, 2, 3 and 4, 5, 6 of alignment is performed using high-precision electronic tacheometers.

In this measurement scheme, error in coordinates determination of reference points of alignment depends on measurements accuracy by satellite receivers and by electronic taeometers (Kasymkanova et al.,2018; Nurpeisova et al., 2021). Stability control of points can be easily performed by repeated measurements. Accuracy of determining relative position of starting points is increased by using the *trilateration* method (Instruction, 1976).

All work was carried out by GPS system and for results comparison electronic tachometer TCR1201 of the firm «Leica Geosystem» was used. Measurements of base distances were made from points of the state geodetic network Kachagai and Ilisk. Coordinates of the geodetic base are defined in the local system, and the altitude coordinates - in the Baltic system.

During deformation monitoring of the Kapchagay hydroelectric power station, new design of geodetic points of forced centering (GPFC) was proposed as permanent supports, which meets standards of regulatory literature (SNiP 3.03.01-87, 1987). GPFC is reinforced concrete pile, 12 meters long (Fig. 3), installed in a selected location on the industrial site.

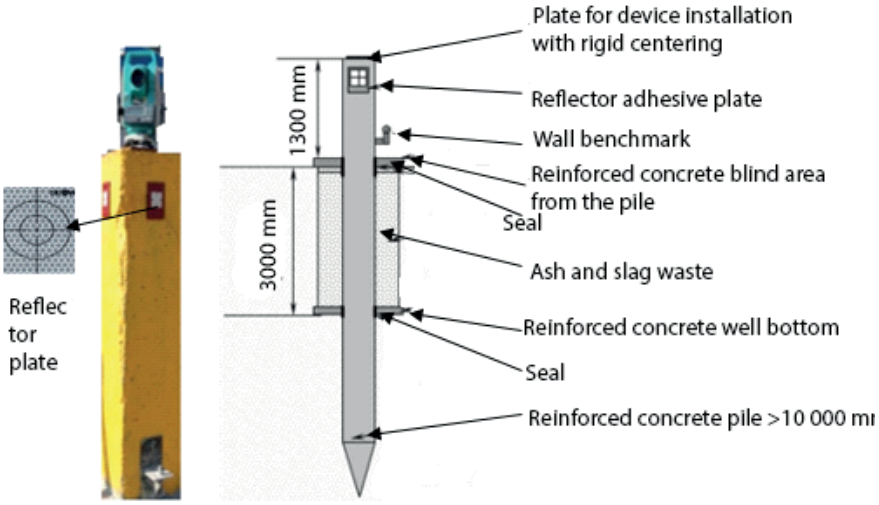

Fig. 3 - Diagram of pile support of geodetic point of forced centering (FC)

During creating of geodetic control points (GCP), following requirements must be met. The pile height must be approximately 1,3 m higher than planned vertical layout of landscaping, with its installation in a vertical position using spacers and jack frames. Hole at least 3,2 m deep is drilled around pile with a diameter of

0,6 m to install casing pipe. To ensure stability of the pile, the bottom of the hole must be compacted and filled with concrete approximately 50 mm thick. After this, a casing pipe approximately 0,5 m in diameter and 3 m long is installed on the concrete, so that the pile is in the center of this structure. To eliminate influence of temperature and rainfall, layer of ash and slag waste is placed on top, followed by the construction of formwork and blind area. To ensure installation of geodetic device, table measuring 0,2 × 0,2 m with a set screw is mounted on top of the pile. To ensure visibility from all directions, on each rectangular metal plates are installed on the side of the pile, to which reflective plates are glued

To ensure visibility from all directions, rectangular metal plates are installed on each side of the pile, to which reflective plates are glued. If the reflective film is destroyed, it is glued again by aligning its edges with the drawn lines (Patent of the Republic of Kazakhstan № 35798, 2022).

Study of meteorological factors on accuracy of geodetic measurements

Atmospheric pressure. Changes in atmospheric pressure can affect accuracy of geodetic measurements. High atmospheric pressure can increase density of the atmosphere, which can lead to distortion of trajectory of laser radiation or radio waves used in geodetic measurements. Therefore, it is important to consider current atmospheric pressure and its changes over time.

Humidity. Air humidity can affect optical measurements and laser measurements. Humid air can cause dispersion of the laser beam or change optical properties of the medium, which can lead to distortion of measurement data. This is especially important during using laser rangefinders and theodolites, where measurements accuracy depends on the properties of the atmosphere.

Temperature. Temperature changes can cause deformations in surveying instruments. This can affect expansion or contraction of reference points and markers, which in turn can add measurements errors. The accuracy of height and angle measurements can also be affected by temperature, as temperature changes can cause distortions in optical systems. To prevent this, surveying umbrella should be used during high-precision measurements.

Meteorological factors can significantly affect accuracy of geodetic measurements. Therefore, to achieve high accuracy and reliability of geodetic measurements, it is necessary to consider and correct these atmospheric factors during measurement process. Usually, problem with this type of monitoring is that atmospheric parameters are measured only at the station, although the beam can pass over the water surface and other objects where meteorological data differ. Solution to the problem can be measurement of meteorological data at different points, for example, in the middle of beam and near the target, then these corrections are entered into tacheometer. In this way, gross errors in measurements can be avoided.

According to the Kapchagay HPP deformation monitoring program, in 2023, monitoring was carried out with a frequency of 1 month during the year, then, according to measurement results, no critical deformations were detected, accordingly, frequency was reduced (Certificate RK № 39036, 2023). The above

methods and techniques were tested when monitoring the Kapchagay HPP.

Conclusion

Geodetic monitoring is a key tool for ensuring safety and efficient operation of berthing facilities. It allows monitoring deformations and movements of structures in real time, detecting possible threats and risks associated with their condition, and taking timely measures to prevent emergency situations. Geodetic monitoring systems allow saving money and resources, eliminating need for expensive repairs and restoration. They also help extend the service life of structures, which is important for the sustainability of infrastructure and the development of the region's economy.

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