UDC 626/627
IRSTI 67.21.21
RESEARCH ARTICLE

MULTIFACTOR ASSESSMENT OF HYDRAULIC STRUCTURES IN SEISMICALLY ACTIVE ZONES: A CASE STUDY OF THE TASOTKEL RESERVOIR, REPUBLIC OF KAZAKHSTAN

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Abstract. *This article presents a multifactor assessment of the technical condition of the Tasotkel Dam, located in the seismically active zone of southern Kazakhstan. With the increasing frequency and intensity of earthquakes in the region - including the March 28, 2025, earthquake near the village of Merke in the Zhambyl region - there is a growing need for a systematic approach to evaluating the seismic safety of hydraulic structures. The investigation employed a range of modern techniques, including visual inspection, instrumental monitoring, geodetic surveying, non-destructive testing of concrete structures, as well as laboratory and in-situ analysis of the physical and mechanical properties of the dam body and its foundation soils. The assessment revealed localized defects in the facing, signs of erosion, reduced piezometric levels compared to design values, and high filtration activity of the foundation. Geodetic data confirmed the absence of critical deformations but identified areas of potential instability. Based on the collected engineering data, a numerical model of the dam was developed using the Plaxis 2D software package. Slope stability calculations were performed for two key cross-sections (PK 5+00 and PK 12+00) under seismic loading scenarios corresponding to intensities of 7 and 8 on the MSK-64 scale. As a result, safety factors, potential failure surfaces, filtration flow directions, and pore pressure distributions were identified. The study revealed the necessity for reconstruction and seismic strengthening of certain dam sections. The findings underscore the importance of implementing a multifactor approach as a reliable diagnostic tool in conditions of elevated seismic risk.*

Keywords: *hydraulic structures, seismic stability, dam, multifactor assessment, numerical modeling.*

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https://doi.org/10.51488/1680-080X/2025.2-08
Received April 30, 2025; Revised May 21, 2025; Accepted June 10, 2025

ӘОЖ 626/627
ҒТАМР 67.21.21
ҒЫЛЫМИ МАҚАЛА

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Аңдатпа. *Бұл мақала Қазақстанның оңтүстігінде орналасқан сейсмикалық қауіпті аймақтағы Тасөткел су торабының техникалық жағдайына көпфакторлы зерттеу жүргізуге арналған. Аймақта жер сілкіністерінің жиілігі мен қарқындылығының артуына, соның ішінде 2025 жылғы 28 наурызда Жамбыл облысындағы Мерки ауылына жақын жерде болған жер сілкінісіне байланысты, гидротехникалық құрылымдардың сейсмикалық тұрақтылығын бағалауға жүйелі тәсілдің қажеттілігі артып отыр. Зерттеу барысында заманауи әдістер кешені қолданылды: көзбен шолу, аспаптық бақылау, геодезиялық өлшеулер, бетон құрылымдарын бұзбайтын сынау, сондай-ақ су торабының бойындағы мен негізіндегі топырақтардың физика-механикалық қасиеттеріне зертханалық және дала жағдайындағы талдау. Зерттеу нәтижелері бойынша беткі қабаттың жергілікті ақаулары, эрозия белгілері, жобалық мәндермен салыстырғанда пьезометриялық деңгейлердің төмендеуі және іргетастың жоғары сүзгілік белсенділігі анықталды. Геодезиялық деректер айтарлықтай деформациялардың жоқ екенін растады, бірақ әлеуетті орнықсыздық аймақтары белгіленді. Инженерлік деректер негізінде Plaxis 2D бағдарламалық кешенінде су торабының сандық моделі жасалды. Есептеулер негізгі екі қимада (ПК 5+00 және ПК 12+00) 7 және 8 балдық сейсмикалық әсер сценарийлері үшін жүргізілді (MSK-64 шкаласы бойынша). Нәтижесінде тұрақтылық коэффициенттері, ықтимал опырылу беттері, сүзгілік ағындардың бағыты мен қысым таралуы анықталды. Бұл зерттеу су торабының кейбір учаскелерін қайта құру және сейсмикалық нығайту қажеттілігін көрсетті. Жоғары сейсмикалық қауіптілік жағдайында сенімді диагностикалық әдіс ретінде көпфакторлы тәсілді енгізудің маңыздылығы дәлелденді.*

Түйін сөздер: *гидротехникалық құрылыстар, сейсмикалық тұрақтылық, бөгет, көпфакторлы зерттеу, сандық модельдеу.*

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https://doi.org/10.51488/1680-080X/2025.2-08
Алынды 30 сәуір 2025; Қайта қаралды 21 мамыр 2025; Қабылданды 10 маусым 2025

УДК 626/627
МРНТИ 67.21.21
НАУЧНАЯ СТАТЬЯ

MULTIFACTOR ASSESSMENT OF HYDRAULIC STRUCTURES IN SEISMICALLY ACTIVE ZONES: A CASE STUDY OF THE TASOTKEL RESERVOIR, REPUBLIC OF KAZAKHSTAN

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Аннотация. *Статья посвящена многофакторному обследованию технического состояния Тасоткельской плотины, расположенной в сейсмически активной зоне юга Казахстана. В условиях увеличения частоты и интенсивности землетрясений в регионе, включая землетрясение 28 марта 2025 года вблизи села Мерке Жамбылской области, возрастает потребность в системном подходе к оценке сейсмостойкости гидротехнических сооружений. Обследование выполнено с применением комплекса современных методов: визуального осмотра, инструментального контроля, геодезических наблюдений, неразрушающего контроля бетонных конструкций, а также лабораторного и натурного анализа физико-механических свойств грунтов тела плотины и её основания. По результатам обследования установлены локальные дефекты облицовки, признаки эрозии, снижение пьезометрических уровней по сравнению с проектными значениями и высокая фильтрационная активность основания. Геодезические данные подтвердили отсутствие критических деформаций, однако зафиксированы зоны потенциальной нестабильности. На основе полученных инженерных данных была построена модель плотины в программном комплексе Plaxis 2D, в рамках которой проведены численные расчёты устойчивости низового откоса на двух ключевых поперечниках (ПК 5+00 и ПК 12+00). Моделирование выполнено для различных сценариев сейсмической нагрузки (7 и 8 баллов по шкале MSK-64). В результате определены коэффициенты устойчивости, потенциальные поверхности обрушения, направления фильтрационных потоков и распределение фильтрационного давления. Проведённое исследование выявило необходимость реализации мероприятий по реконструкции и сейсмоусилению отдельных участков плотины.*

Ключевые слова: *гидротехнические сооружения, сейсмическая устойчивость, плотина, многофакторное обследование, численное моделирование.*

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https://doi.org/10.51488/1680-080X/2025.2-08
Поступило 30 апреля 2025; Пересмотрено 21 мая 2025; Принято 10 июня 2025

ACKNOWLEDGEMENTS/SOURCE OF FUNDING

The research was carried out with the financial support of the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan within the framework of the scientific project No. AP23487624.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу Қазақстан Республикасы Ғылым және жоғары білім министрлігі Ғылым комитетінің № AP23487624 ғылыми жобасы аясында қаржылық қолдауымен орындалды.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ екенін растайды.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование выполнено при финансовой поддержке Комитета науки Министерства науки и высшего образования Республики Казахстан в рамках научного проекта № AP23487624.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы подтверждают, что конфликта интересов нет.

1 INTRODUCTION

Dams are among the most critical and complex hydraulic structures built across rivers to create reservoirs that serve essential functions such as flow regulation, flood control, water supply for domestic and industrial needs, irrigation of agricultural lands, and hydroelectric power generation. The safety and reliability of dams depend directly on their resistance to external loads, including hydrostatic pressure, wind forces, and seismic activity-especially in regions with high seismic risk.

In recent years, the frequency and intensity of earthquakes have increased globally, including in Kazakhstan. A particularly alarming event occurred on March 28, 2025, when an earthquake struck near the village of Merke in the Zhambyl Region, near the Tasotkel Reservoir. This incident has underscored the urgent need to reassess seismic safety strategies and initiate comprehensive investigations of hydraulic structures located in seismically active zones.

The analysis of the technical inspection report on the Tasotkel Reservoir revealed serious deficiencies in the existing practice of inspecting hydraulic structures in Kazakhstan. Many inspections are carried out superficially and formally, without the use of modern methods, computational models, or scientifically grounded approaches. This has raised valid concerns within the scientific community and highlights the need to revise the current regulatory framework and technical guidelines governing the assessment and maintenance of dams and reservoirs. The development of new methodological standards that ensure comprehensive and reliable evaluations is now more crucial than ever.

Against this backdrop, multifactor assessments gain particular importance. These assessments consider the full spectrum of influencing parameters: engineering-geological conditions, current technical state, deformation dynamics, filtration and sedimentation levels, as well as the seismic vulnerability of structures. Unlike one-time visual inspections, a multifactor approach involves the application of geophysical techniques, instrumented monitoring, engineering modeling, and digital technologies, allowing for a comprehensive and objective evaluation of a structure's condition.

Commissioned in 1974, the Tasotkel Reservoir is a strategically significant facility in the water management system of southern Kazakhstan. It provides irrigation for more than 35,000 hectares of agricultural land in the Shu and Moiynkum districts, supplies water to the Tasotkel Hydropower Plant and maintains ecological flow in the downstream section of the Shu River. The reliable operation of the dam is directly linked to regional food security, sustainable development of the agro-industrial sector, and overall social stability.

Figure 1 shows a satellite image fragment depicting the Tasotkel Reservoir area, including its boundaries, adjacent irrigation zones, and key hydraulic structures. The image was obtained using remote sensing technologies and provides a clear visualization of the reservoir's scale, hydrographic position, and spatial relationships with the surrounding infrastructure.

The region's harsh continental and arid climate, complex hydrogeology, and increasing seismic activity necessitate a reassessment of existing engineering solutions. According to the General Seismic Zoning Map (GSZ–475) and the national construction standard SP RK 2.03–30–2017*, the seismic hazard level at the site has been revised from 6 to 7–8 on the MSK scale, with a calculated horizontal ground acceleration of $a_g = 0.279g$ for soil conditions classified as Type II. Combined with the age of the structure and identified defects-such as the undermining of facing slabs on the upstream slope due to wind-driven waves in April 2023-this situation necessitates reconstruction and seismic strengthening measures.

Thus, conducting a scientifically grounded, multifactor comprehensive assessment of the Tasotkel Dam is not merely a technical necessity but a matter of national security, sustainable agricultural production, and disaster prevention. The findings of this study will provide the foundation for updating Kazakhstan's normative and technical documents and for developing new standards for the diagnosis and evaluation of hydraulic structures under increasing seismic threats.

Figure 2 presents a 3D situational plan of the Tasotkel Reservoir, illustrating its spatial position within the river valley, the shoreline configuration, the location of main hydraulic structures, irrigation canals, and infrastructure elements. The model provides a visual representation of the terrain and allows for the assessment of the engineering and geographical features of the study area.

Figure 1 – Satellite image of the Tasotkel Reservoir (https://earth.google.com/)

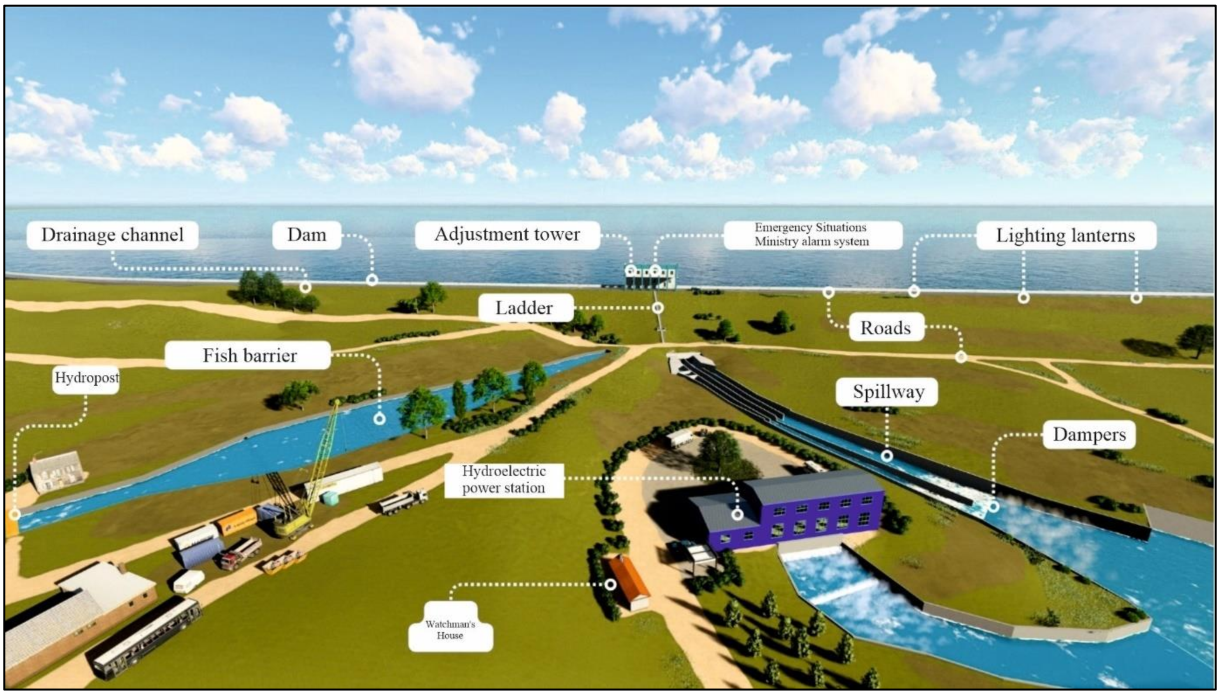

Figure 2 – Situational Plan of the Tasotkel Reservoir

2 LITERATURE REVIEW

The issue of ensuring the reliability of hydraulic structures, especially under seismic conditions, has been addressed in several recent studies. The rapid advancement of digital technologies has significantly improved the accuracy of diagnostics and the ability to predict dam behavior under dynamic loads.

For instance, **Antonovskaya et al. (2015); Antonovskaya et al. (2019)** emphasizes the importance of visual inspection using unmanned aerial vehicles (UAVs), computer vision systems, and artificial intelligence to assess the technical condition of dams. These technologies enable the early detection of hidden defects, cracks, and signs of deformation.

Bathymetric surveys are also becoming an essential element of dam assessments. **Simão Sêco e Pinto (2015)** evaluated sedimentation rates and accumulation patterns at the Obruk Dam in Turkey, allowing them to identify high-risk zones of siltation with precision.

Bonazzi et al. (2025); Gupta (2018) investigated the behavior of coarse-grained materials under seismic loading and developed a numerical method for analyzing residual deformations in rockfill dams-an approach that is critical for predicting long-term structural stability.

Historical events have demonstrated the high vulnerability of hydraulic structures to seismic impacts. Earthquakes in Bhuj (India, 2001), Sichuan (China, 2008), Iwate–Miyagi (Japan, 2008), and the devastating 2011 tsunami that damaged coastal embankments at the Fukushima Nuclear Power Plant illustrate the consequences of insufficient structural diagnostics.

Particular attention must be paid to the series of destructive earthquakes between 2023 and 2025 in Turkey, China, Peru, and Chile, which revealed serious structural damage to dams and reservoirs, including cracks in dam bodies, displacement of slabs, crest loss, and the emergence of groundwater. These incidents highlight the pressing need for international collaboration in the field of dam diagnostics, monitoring, and seismic strengthening.

Hinks (2023); Yiadom et al. (2009) proposed an innovative method of seismic isolation for earth dams using recycled steel-cord tires filled with a rubber-bitumen mix ("gumbrin"), which significantly reduces seismic wave amplitudes.

Green et al. (2023) and **Latrubesse et al. (2020)** applied non-destructive testing and engineering geophysics methods to assess the condition of earth dams at the Shapsug Reservoir. Their findings helped identify zones of potential filtration and led to the development of foundation reinforcement recommendations.

Adamo (2020) presented long-term observation data from the Akdarya Reservoir in Uzbekistan, combining leveling surveys and mathematical modeling. This allowed for a substantiated analysis of structural stability and the calculation of required reconstruction volumes.

A broad range of works by authors such as **Xiang et al. (2022); Gorai et al. (2021); Suwatthikul et al. (2021); Xiang et al. (2023) and Moldamuratov et al. (2021)** are dedicated to the topics of dam reconstruction, seismic resistance, and structural adaptation to evolving environmental conditions.

Using dipole electrical sounding, **Jakiyayev et al. (2023)** identified a reduction in apparent resistivity in the reservoir bed area of the Chirkey Dam, attributed to water saturation processes. These findings have substantial implications for evaluating the filtration status of dam foundations.

Thus, the accumulated scientific and practical experience clearly indicates the need for regular, multifactor, and comprehensive assessments of hydraulic structures, considering the combined impact of natural and anthropogenic processes-particularly in seismically active regions.

3 MATERIALS AND METHODS

As part of the multifactor assessment of the Tasotkel Dam, modern methods were applied to evaluate the technical condition of the hydraulic structure. These included visual inspection, instrumental measurements, geodetic monitoring, non-destructive testing, as well as the analysis of the physical and mechanical properties of soils and the condition of reinforced concrete structures.

Visual inspection was carried out along the entire length of the dam crest (1,200 meters) to identify surface defects, breaches in structural integrity, and signs of deformation processes. Particular attention was given to the following elements:

- condition of the facing slabs on the upstream slope;
- presence of cracks, delamination, and settlements along the crest of the dam;
- integrity and functionality of the reinforced concrete parapet and warning barriers;
- signs of erosion and soil washout near the spillway and drainage components.

During the inspection, two local sections of damaged facing were identified, accompanied by soil washout to a depth of up to 40 cm due to wind wave action. Surface displacement of the turf layer was also observed on the downstream slope.

Instrumental measurements included:

- monitoring of piezometric levels in 13 observation wells (PK 5+5.0; PK 9+10; PK 13+00);
- determination of the position of the phreatic surface (depression curve) at various reservoir water levels;
- control of filtration water levels using drainage wells;
- temperature monitoring of concrete structures.

The results indicated that the actual piezometric levels at PK 5+5.0 and PK 9+10 were 5.0 to 7.2 meters below the design levels, indicating a high drainage capacity of the foundation soils.

Geodetic monitoring was conducted to assess potential vertical and horizontal displacements of the dam body. High-precision total stations and leveling instruments were used (measurement error not exceeding ±1.5 mm per 1 km of double-run leveling). The following activities were carried out:

- leveling of 12 benchmarks along the dam crest;

- repeated measurements of control points on the slopes;
- comparison of current coordinates with archival data from the period 2010–2023.

Non-destructive testing methods were used to evaluate the condition of concrete and reinforced concrete structures, including:

- Ultrasonic testing: measurement of longitudinal wave velocity in the concrete of the parapet and inlet section of the outlet works. Average velocity was 3600–4000 m/s, corresponding to concrete of at least grade B15.
- Schmidt hammer testing: rebound values ranged from 25 to 32 units, confirming the required concrete strength.
- Visual-instrumental defectoscopy: used to detect cracks, voids, and delamination in the protective concrete layer.

Assessment of the soil condition in the dam body and its foundation was based on engineering and geological investigations supplemented by targeted in-situ testing. The following parameters were evaluated:

- internal friction angle: from 24° to 36°;
- cohesion: from 0.01 to 0.4 kg/cm²;
- dry unit weight: 1.51–1.66 g/cm³;
- natural moisture content: over 20%;
- porosity coefficient: 0.699;
- permeability coefficient for loose detrital foundation soils: 35 m/day.

Figure 3 presents fragments documented during the visual and instrumental inspection of the Tasotkel Dam. The images illustrate characteristic defects in the facing slabs, areas of soil washout, and structural elements affected by surface erosion and filtration processes. This visual data confirms the necessity of implementing reconstruction measures and reinforcing specific sections of the dam.

Figure 3 – Inspection Fragmens

The physical and mechanical properties of the foundation and dam body soils used in the engineering calculations for strength and filtration stability are presented in Table 1. These parameters were obtained based on data from engineering and geological surveys, laboratory tests, and field observations, and represent the average values for the main engineering-geological elements of the soil profile.

Table 1
Physical and Mechanical Properties of Soils

Name	Designation	Unit of measurement	Soils of the dam body	Priming prism (gravel soil)	Sandy–gravel soil of the base	Gravel
The weight of the soil of natural moisture	$\gamma_{вл}$	g/cm³	2,03	1.91	1,91	2,3
The weight of the soil saturated with water	$\gamma_{нас}$	g/cm³	2,06	2.0	2,00	2,5
The modulus of deformation of the soil of natural humidity	E	kN/cm^2	39000	40000	40000	-
Modulus of deformation of soil saturated with water	E	kN/cm^2	20000	30000	30000	40000
Filtration coefficient	$к_ф$	m/day	0,41	32	35	75
The Poisson's ratio	v	-	0,35	0,27	0,27	0,27
Soil adhesion of natural moisture	C	kPa	31	1	-	-
Adhesion of soil saturated with water	C	kPa	24	-	2	1
The angle of internal friction of the soil of natural humidity	φ	°	25	31	-	-
The angle of internal friction of the soil saturated with water	φ	°	18	-	33	40

During the inspection of the Tasotkel Dam, measurements were taken of the water level in the reservoir and the position of the phreatic (depression) curve of the filtration flow.

The measurements were conducted along three cross-sections - at PK 5+5.0, PK 9+10, and PK 13+00 - when the reservoir water level was recorded at 514.85 m (with the normal pool level, NPL, being 519.0 m). The results indicated a significantly low piezometric level, ranging from 5.0 to 7.2

meters below the design values. Only in the downstream toe did the actual position of the depression curve correspond closely to or match the design curve.

A detailed analysis showed the following: at PK 5+5.0, within the berm zone, the piezometric level did not exceed 497.49 m, compared to the design value of 505.80 m; at PK 9+10, the level remained below 498.8 m.

These findings indicate a high drainage capacity of foundation soils relative to the design assumptions. At the observed locations, the actual phreatic surface lies significantly lower than the projected line - by 3.1 to 7.2 meters.

Figure 4 shows the actual position of the phreatic surface at a reservoir level of 514.65 m, the expected profile at NPL 519.0 m, and the maximum allowable position of the depression curve.

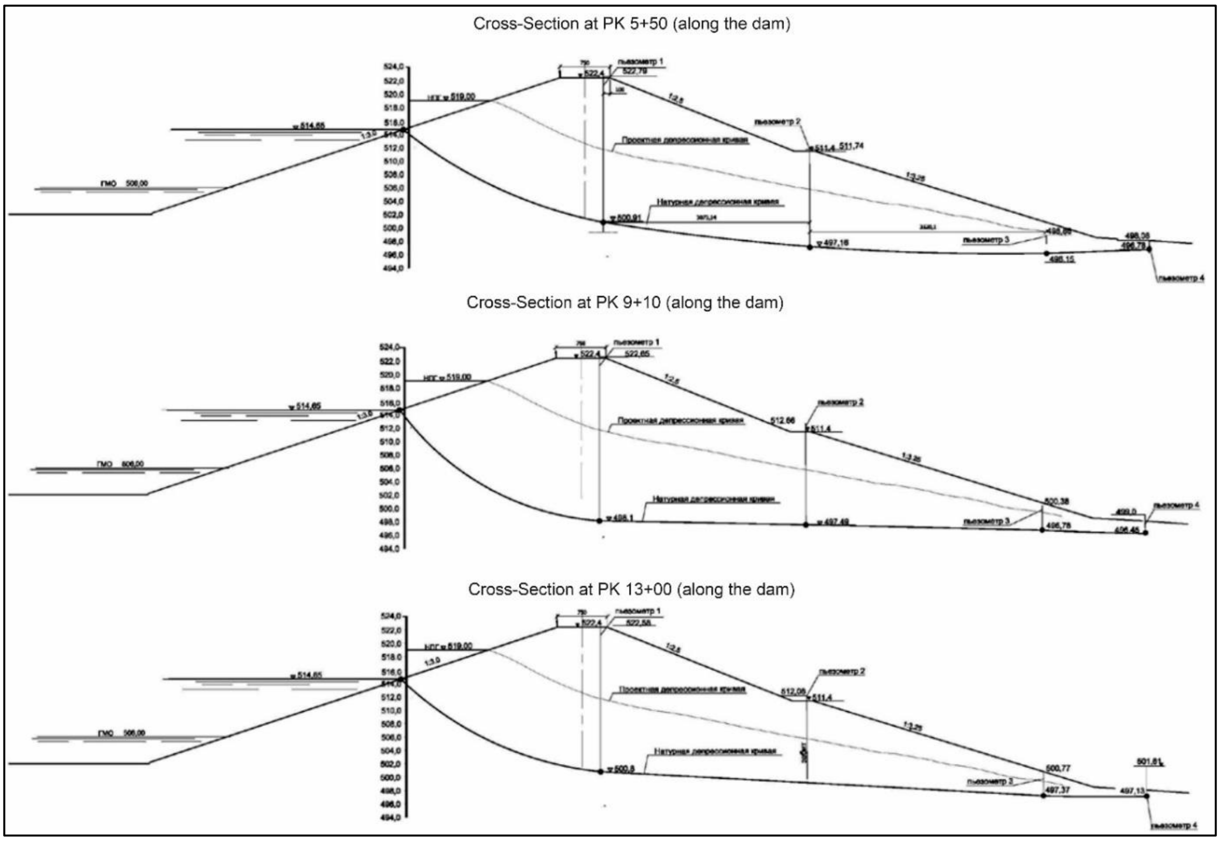

Figure 4 - Position of the Phreatic Surface

4 RESULTS AND DISCUSSION

As part of the engineering assessment, the overall and seismic stability of the downstream slope of the Tasotkel Dam was evaluated for two representative cross-sections - PK 5+00 and PK 12+00. The analysis was carried out using the specialized software Plaxis 2D, a finite element method-based program designed for geotechnical engineering applications, including deformation analysis, slope stability assessment, and groundwater flow modeling.

The modeling process accounted for the stratification of foundation soils, material properties, saturation conditions, and seismic loading. The physical and mechanical properties of soils used in the calculations were based on field and laboratory data obtained from engineering-geological investigations. Real-time measurements of the phreatic surface (depression curve), recorded during the site inspection, were also incorporated.

Figure 5 shows the calculation model for cross-section PK 5+00, including the slope geometry, water levels, outlines of reconstructed sections, the phreatic line at the upstream water level of 519.0 m, and the potential failure surface under seismic loading with an intensity of 8 on the MSK scale.

Figure 6 presents the corresponding model for cross-section PK 12+00, used for evaluating slope stability following the implementation of reinforcement and reconstruction measures. In both cases, seismic conditions were considered in accordance with SP RK 2.03–30–2017* for soil type II, with a design peak ground acceleration of ag = 0.279g.

The calculated safety factor (Fs) was determined for both static and seismic loading conditions. The results demonstrated that:

- Under static conditions, the safety factor exceeded 1.5, meeting regulatory requirements;
- Under seismic conditions with an intensity of 8, the safety factor ranged between 1.1 and 1.2, which is within acceptable limits and confirms the adequacy of the proposed stabilization measures.

These numerical modeling results validate the effectiveness of the design solutions for stabilizing the downstream slope and support the implementation of these technical measures as part of the comprehensive rehabilitation of the dam.

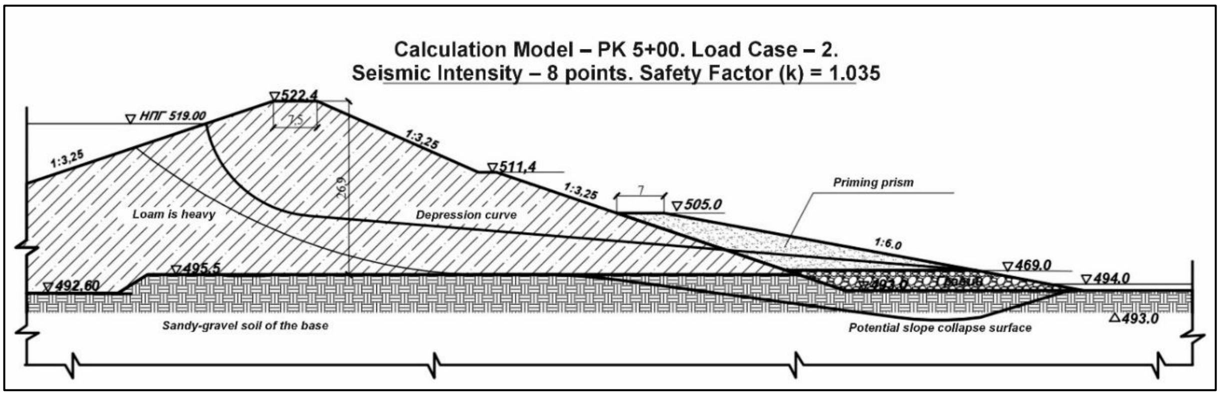

Figure 5 - Calculation Model at Cross-Section PK 5+00

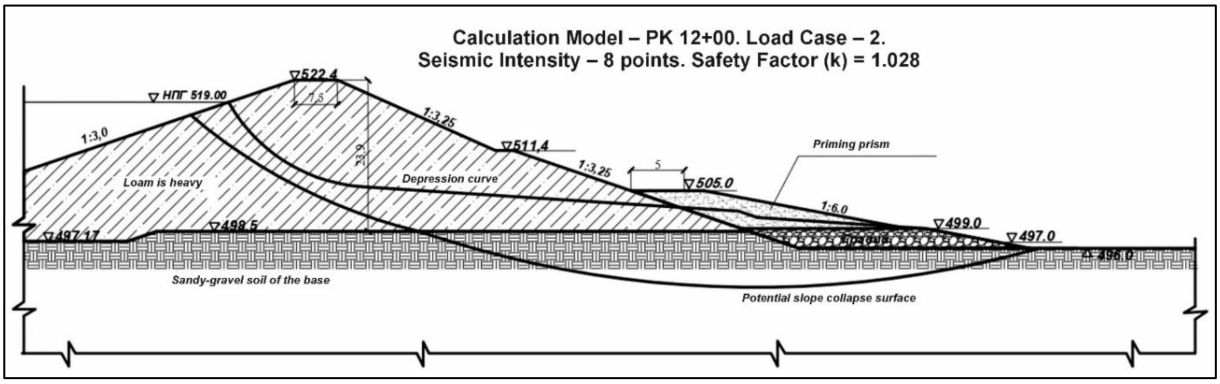

Figure 6 - Calculation Model at Cross-Section PK 12+00

The **Figures 7-18** present the results of numerical modeling performed using the Plaxis 2D software for cross-sections PK 5+00 and PK 12+00, considering seismic loads with intensities of 7 and 8 on the MSK-64 scale.

The models include:

- the geometric configuration of the slopes after reconstruction;

- current data on the position of the phreatic surface at the upstream water level of 519.0 m;
- calculated potential slip (failure) surfaces of the downstream slope;
- values of the safety factor (Fs) under static and seismic loading conditions;
- directions and magnitudes of filtration flow within the dam body.

The simulation results illustrate the slope behavior under different seismic scenarios, including displacements, stress distribution, and critical zones of potential instability. Filtration flows within the dam body and foundation are visualized using a vector field, which allows for the identification of areas with concentrated seepage pressure and the assessment of groundwater movement directions.

Figure 7 presents the calculation schemes for the cross-section at PK 5+00, developed using the Plaxis 2D software under two seismic scenarios. In Load Case 1, with a seismic intensity of 7 points on the MSK-64 scale, the calculated safety factor was k=1.227, indicating a stable slope. In Load Case 2, under 8-point seismic loading, the safety factor decreased to k=1.035, approaching the limit of stability and indicating the need for seismic reinforcement of the downstream slope.

Figure 8 illustrates the phreatic surface position at an upstream water level of 519 m. The configuration of the seepage line allows for the assessment of hydrogeological behavior and the effectiveness of the drainage system under operational conditions.

Figures 9, 10, and **11** show three critical load cases representing the potential failure surfaces of the downstream slope under increasing seismic intensity. **Figure 9** depicts the most probable slip surface formed under moderate saturation and dynamic loading conditions. **Figure 10** highlights stress redistribution within the dam body and potential deformation development in weakened zones. **Figure 11** models a worst-case scenario involving full saturation, maximum seepage, and peak seismic intensity. In all three cases, the safety factors approach minimally acceptable values, requiring further analysis and design measures.

Figure 12 visualizes the seepage flow field within the dam body at PK 5+00. Flow vectors illustrate the direction and magnitude of water movement, allowing the identification of zones with concentrated seepage pressure and potential internal erosion.

Figure 13 presents the calculation schemes for the cross-section at PK 12+00. In Load Case 1 (7-point seismic intensity), the safety factor was k=1.209. Under Load Case 2 (8-point seismic intensity), the safety factor decreased to k=1.028, again indicating the need for slope stabilization under seismic action.

Figure 14 displays the phreatic surface for PK 12+00 at an upstream water level of 519 m. The results highlight specific features of the seepage regime and help evaluate the performance of drainage elements in this section. **Figures 15, 16,** and **17** illustrate additional special seismic load cases at PK 12+00. Each model varies the saturation and seismic intensity parameters to simulate structural behavior under critical combinations of loads. The results identify areas of potential local instability, providing a foundation for future strengthening measures.

Figure 18 presents the distribution of seepage flows within the dam body at PK 12+00. The vector field helps identify zones of increased water inflow and material migration, which can impact on the structural integrity and long-term reliability of the dam.

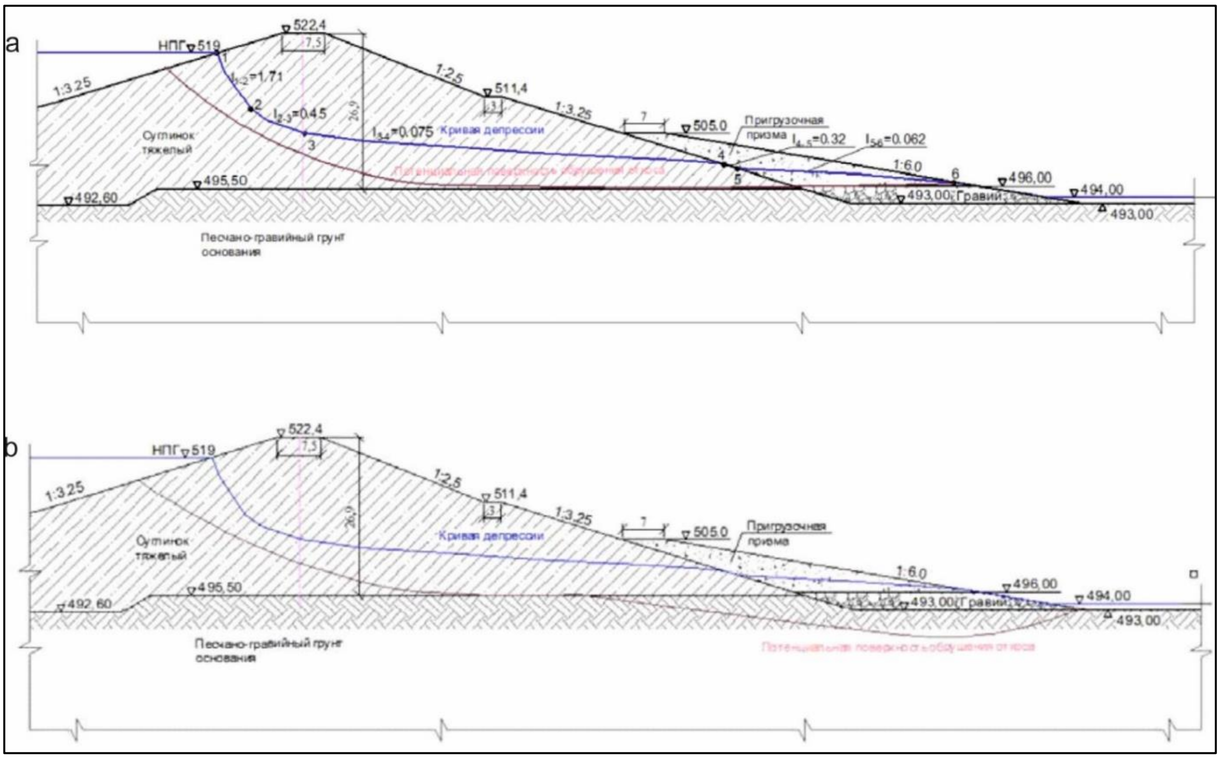

Figure 7 – Calculation Schemes:
a – PK 5+00, Load Case 1, Seismic Intensity – 7 points, Safety Factor (k) = 1.227;
b – PK 5+00, Load Case 2, Seismic Intensity – 8 points, Safety Factor (k) = 1.035

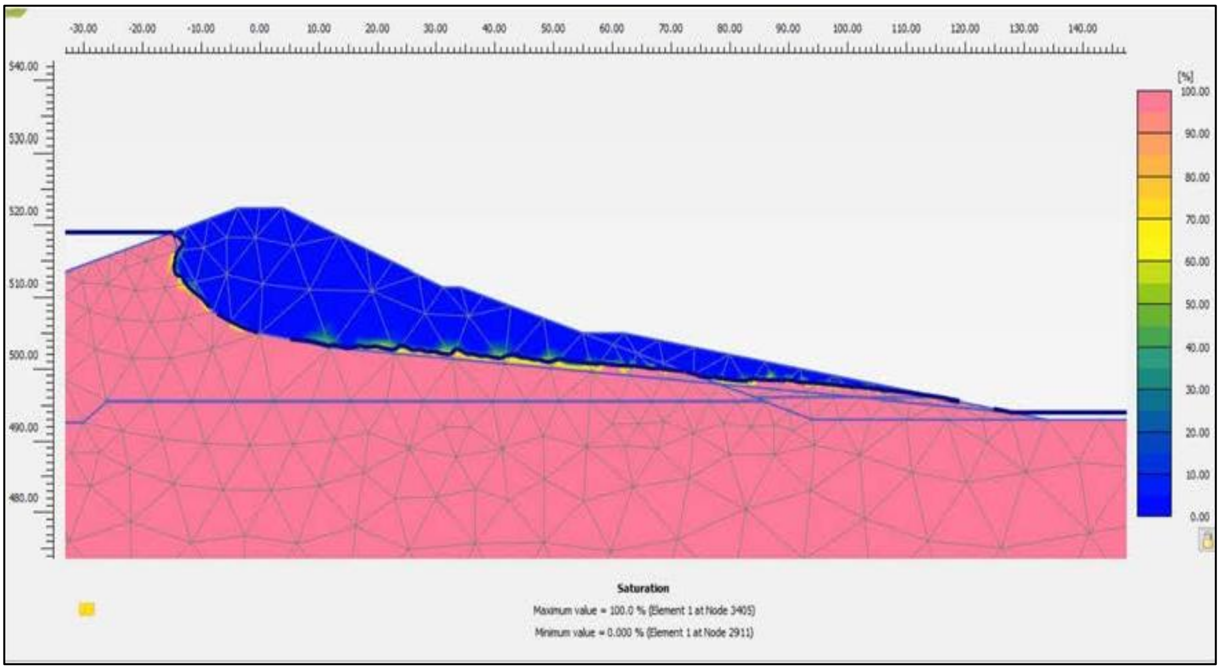

Figure 8 – Phreatic Surface at the Upstream Water Level of 519 m

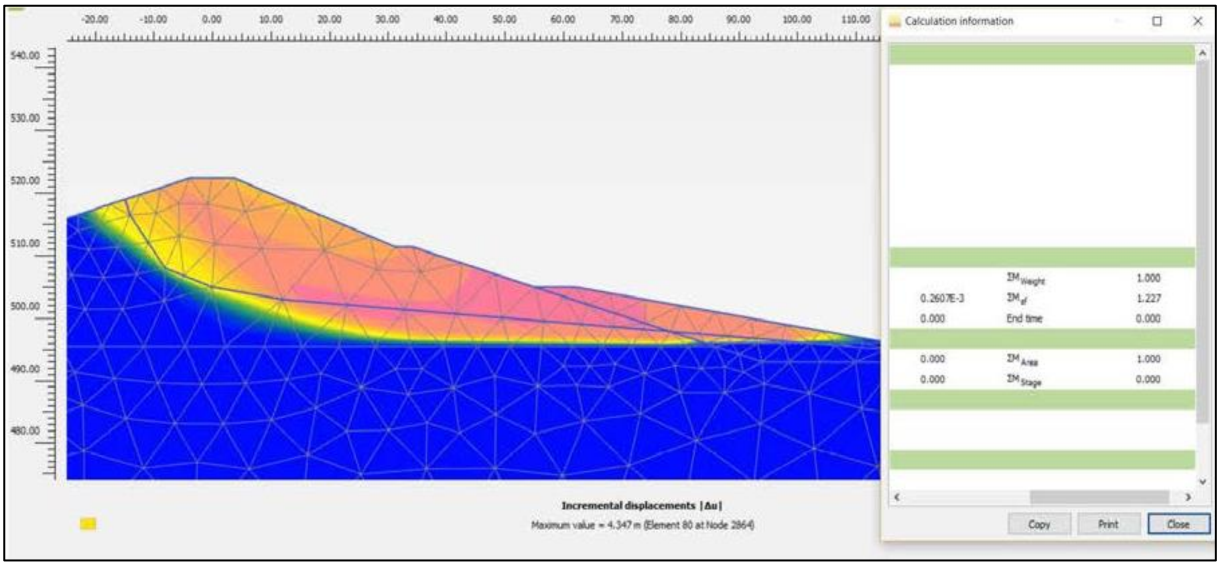

Figure 9 – Special Case 1: Potential Failure Surface of the Downstream Slope and Safety Factor

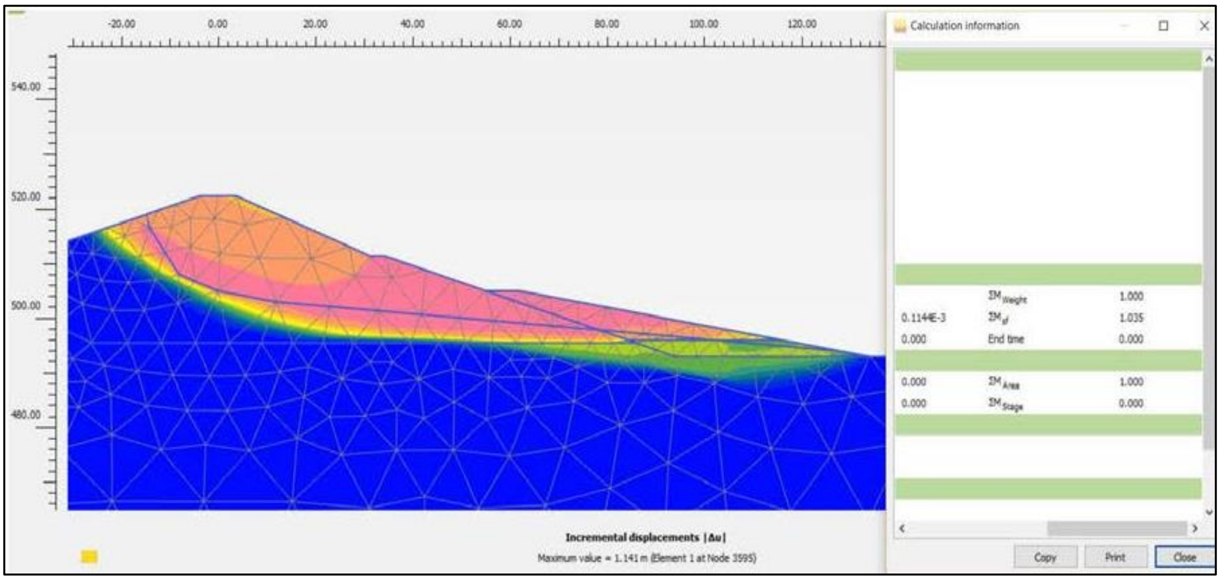

Figure 10 – Special Case 2: Potential Failure Surface of the Downstream Slope and Safety Factor

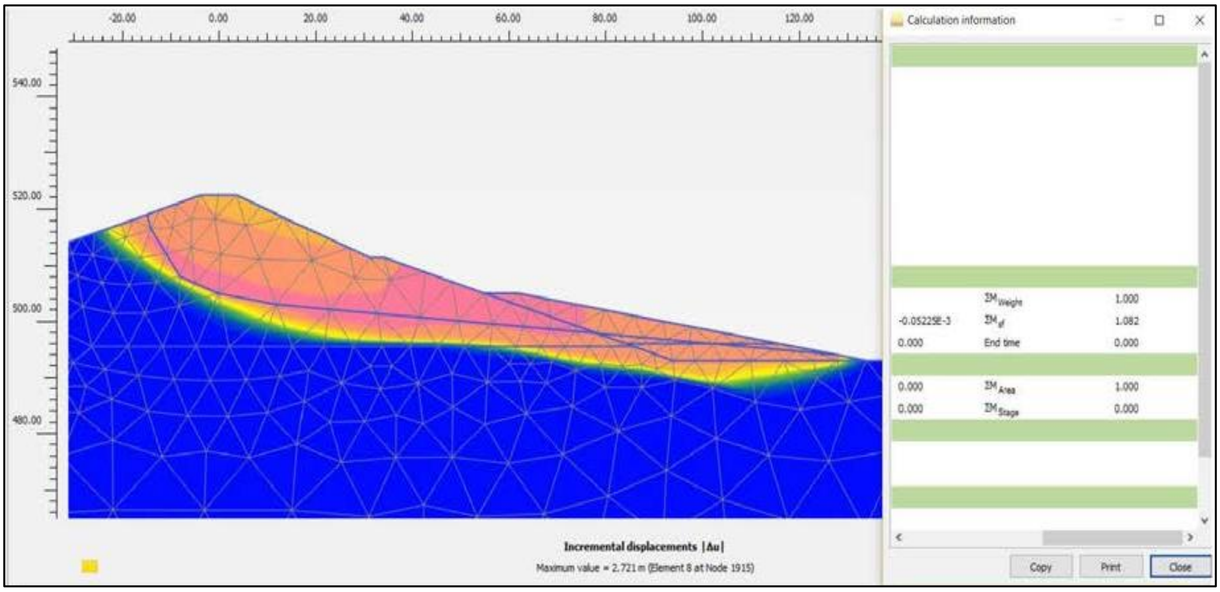

Figure 11 – Special Case 3: Potential Failure Surface of the Downstream Slope and Safety Factor

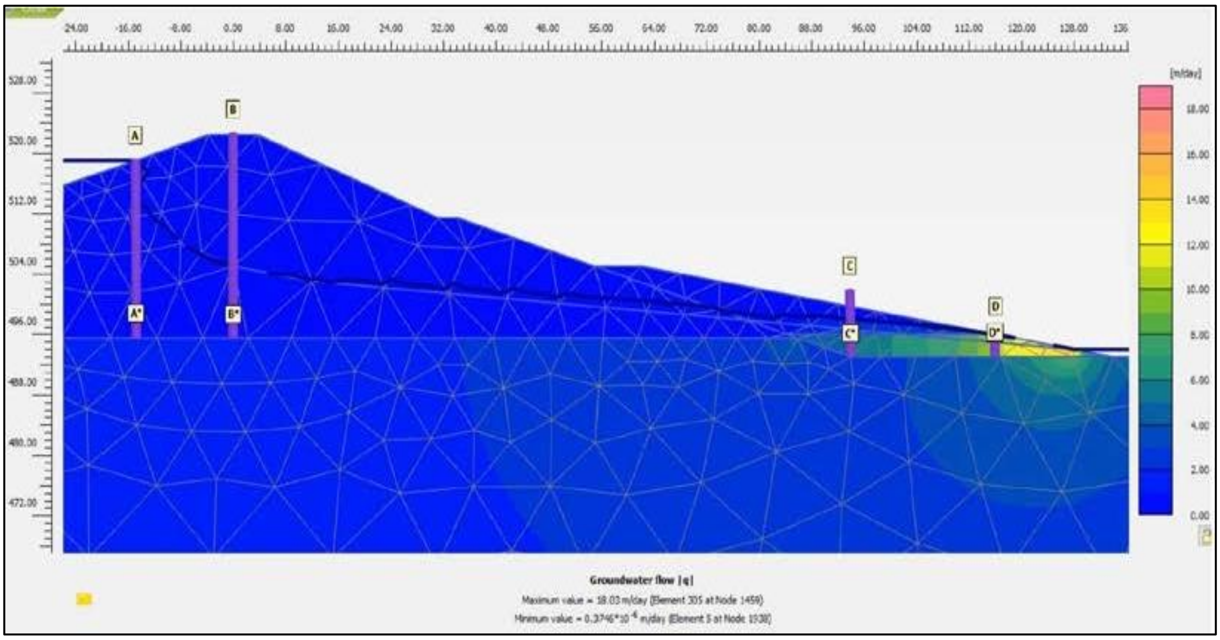

Figure 12 – Water Flow within the Dam Body at PK 05+00

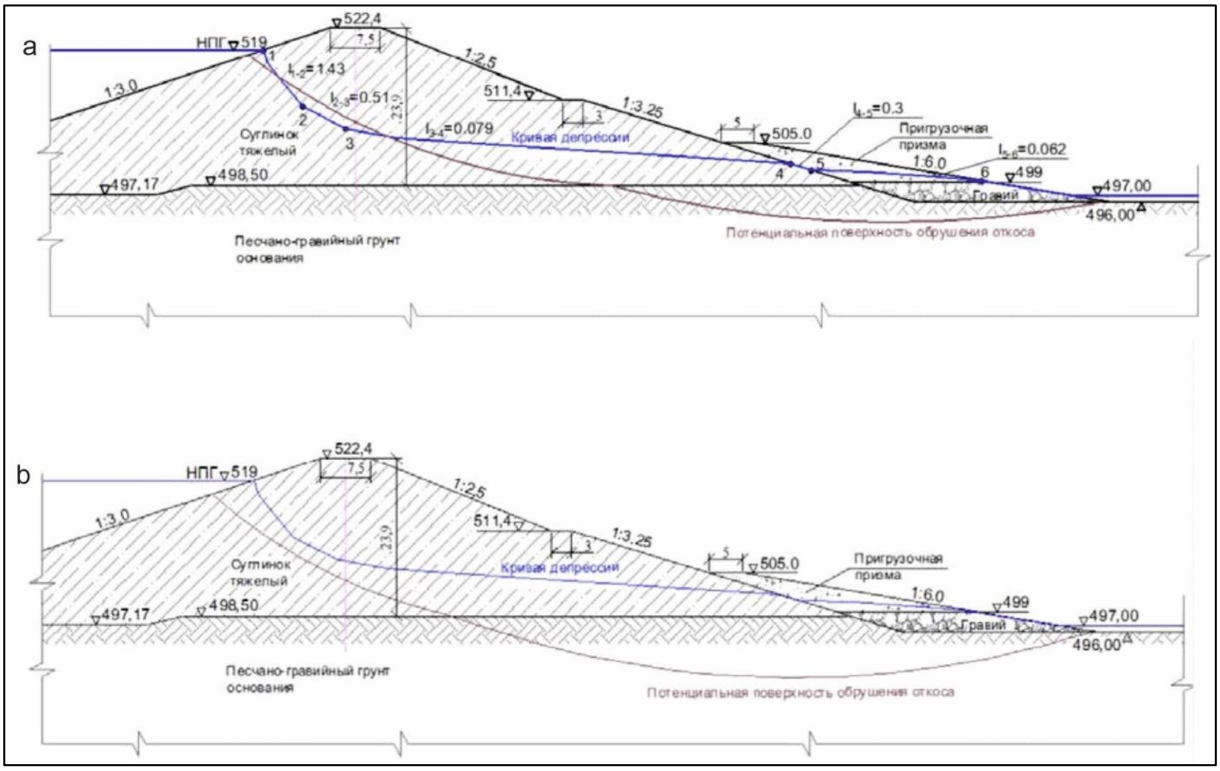

Figure 13 – Calculation Schemes:
a – PK 12+00, Load Case 1, Seismic Intensity – 7 points, Safety Factor (k) = 1.209;
b – PK 5+00, Load Case 2, Seismic Intensity – 8 points, Safety Factor (k) = 1.028

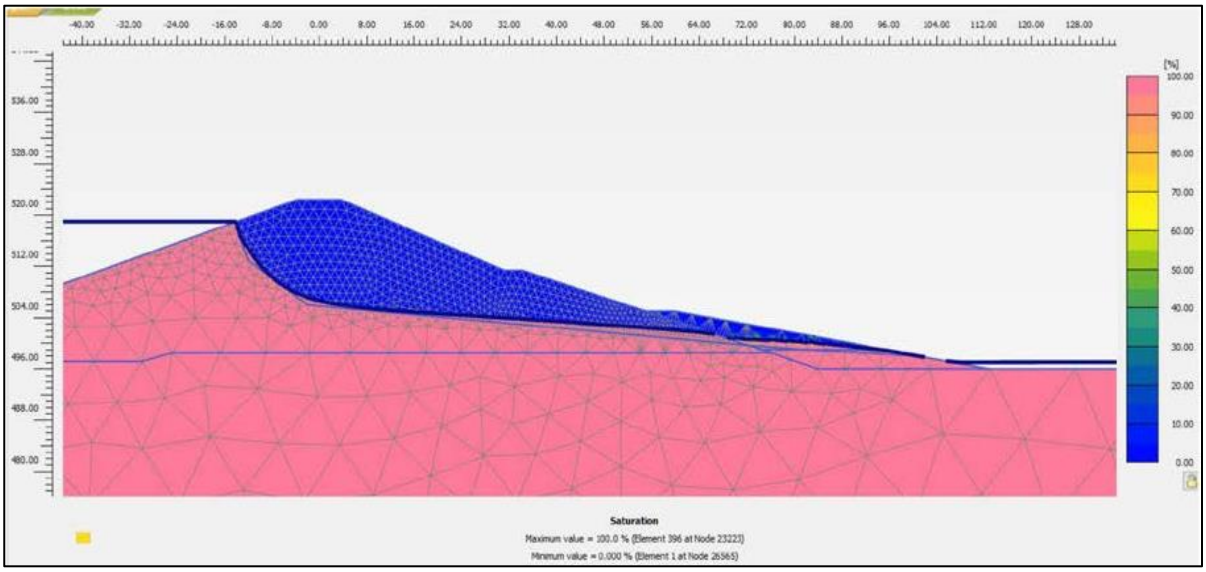

Figure 14 – Phreatic Surface at the Upstream Water Level of 519 m

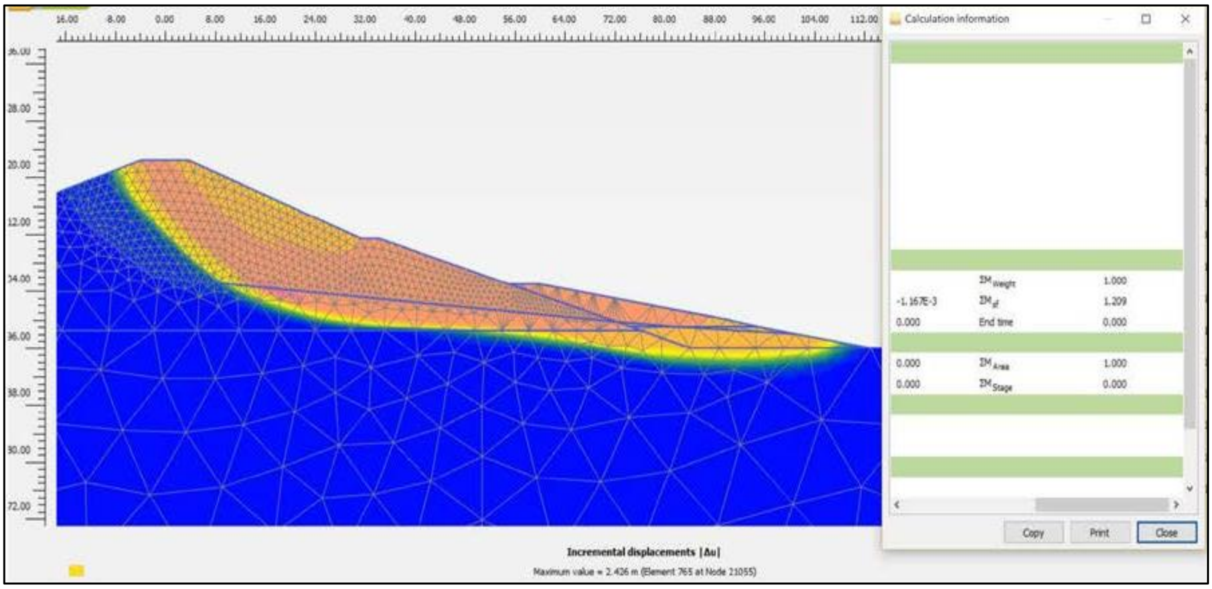

Figure 15 – Special Case 1: Potential Failure Surface of the Downstream Slope and Safety Factor

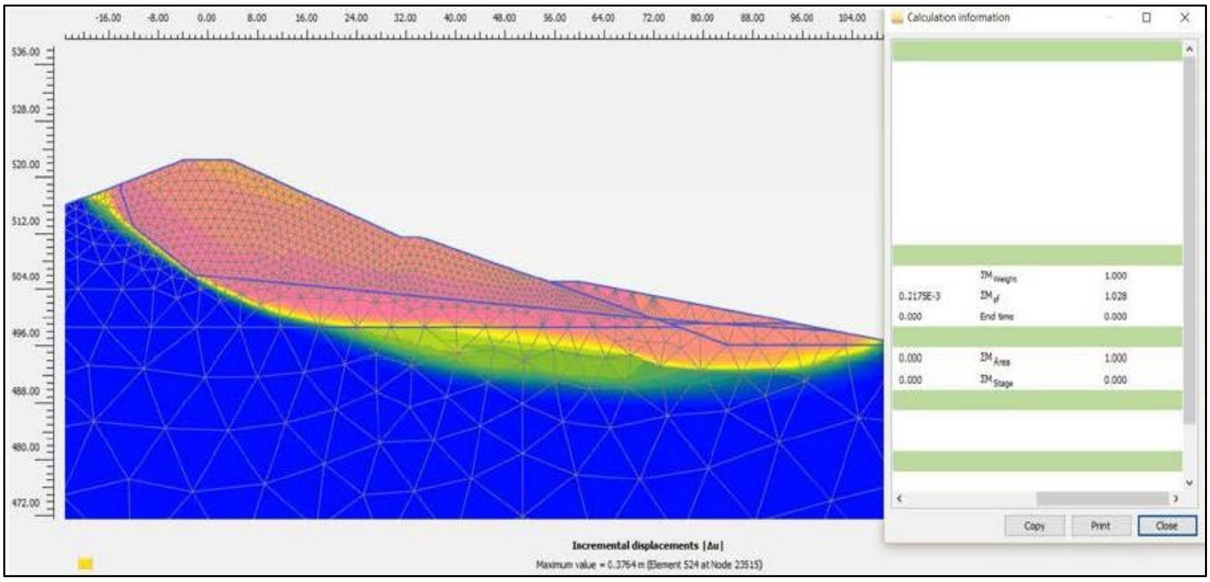

Figure 16 – Special Case 2: Potential Failure Surface of the Downstream Slope and Safety Factor

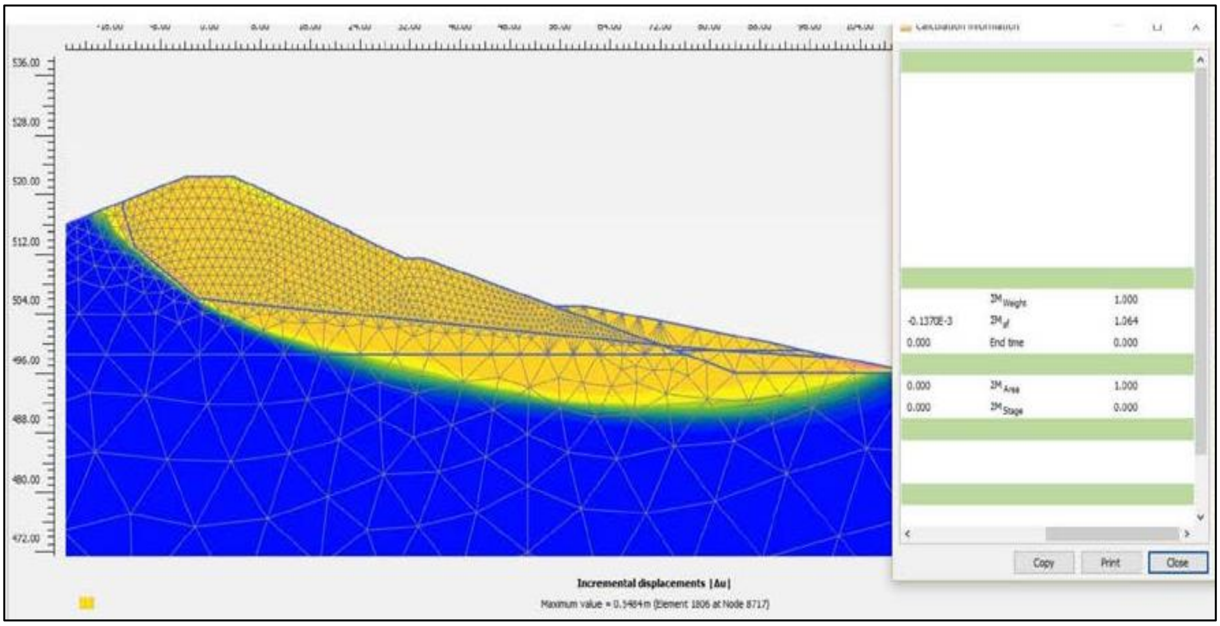

Figure 17 – Special Case 3: Potential Failure Surface of the Downstream Slope and Safety Factor

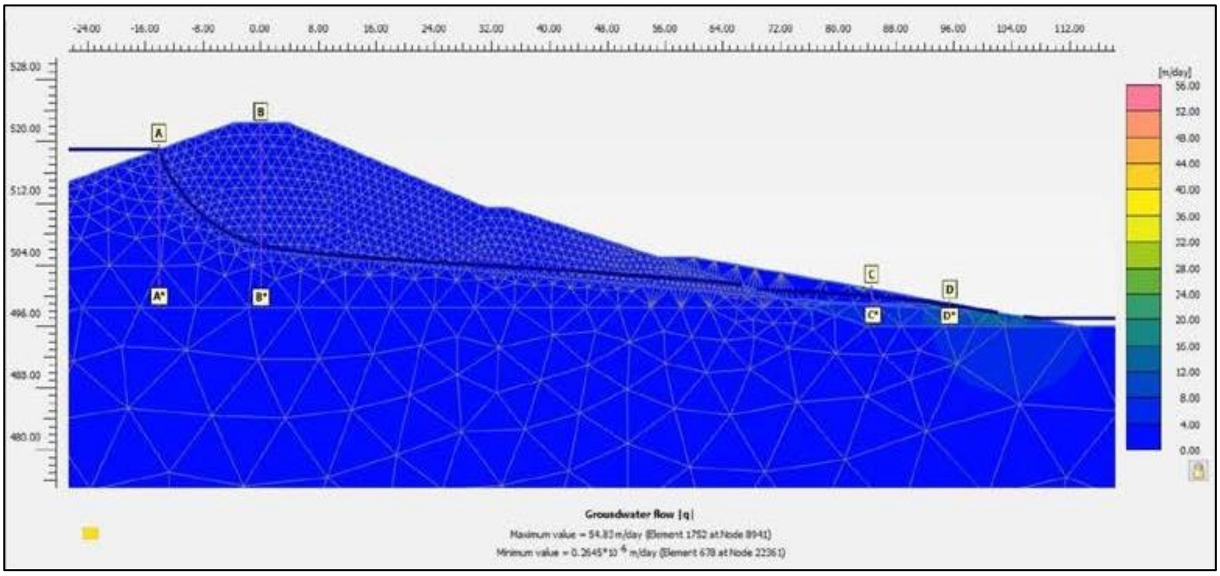

Figure 18 – Water Flow within the Dam Body at PK 12+00

The presented calculation results represent the initial iteration of numerical modeling. At this stage, preliminary data from engineering and geological investigations and field inspection parameters were used.

Further modeling and analysis will be refined and expanded based on the results of laboratory experimental studies, including tests for strength, permeability, and the deformation characteristics of soils and concrete. This will enhance the accuracy of computational models, enable calibration of input parameters, and provide a more reliable assessment of dam stability under various operational and seismic conditions.

The data obtained in subsequent stages will also serve as a basis for developing recommendations for seismic strengthening, monitoring, and planning of reconstruction measures.

5 CONCLUSIONS

1. A comprehensive multifactor assessment of the Tasotkel Dam, located in a seismically active zone of southern Kazakhstan, was conducted using modern methods for evaluating the technical condition of hydraulic structures. The assessment included visual inspection, instrumental and geodetic measurements, non-destructive testing, analysis of the physical and mechanical properties of soils, and inspection of reinforced concrete structures.
2. The inspection results revealed several defects and deviations from the design parameters, including localized damage to the upstream slope facing, signs of erosion, turf layer displacement, and discrepancies in the phreatic surface levels. Piezometric measurements confirmed the high drainage capacity of the foundation soils but also indicated the need for detailed monitoring of filtration processes.
3. Geodetic and instrumental observations did not identify critical deformations, though the analysis of archival data from 2010 to 2023 showed accumulated changes that require engineering intervention. The mechanical properties of soils mostly met regulatory standards, but certain zones with reduced strength were identified and required reinforcement.
4. Numerical modeling performed using the Plaxis 2D software allowed for an evaluation of slope stability under both static and seismic loading conditions (intensity of 7 and 8 on the MSK-64 scale). The calculations demonstrate satisfactory stability of the slopes after the proposed reconstruction measures. Visualization of filtration flows and potential failure surfaces identified critical zones and informed recommendations for their strengthening.
5. The study emphasizes the need to revise existing regulatory documents and standards governing the inspection of hydraulic structures. The analysis of previously conducted inspections revealed that they were largely superficial and fragmented, failing to meet modern safety and seismic resilience requirements.
6. The presented results represent an initial modeling iteration. Further laboratory testing is planned to refine input parameters and calibrate the models. This will improve the reliability of predictive assessments and support the development of reconstruction and seismic strengthening measures, as well as long-term monitoring programs.
7. The findings of this study confirm the importance of adopting a multifactorial approach to the diagnostics of hydraulic structures in seismically active regions. The methodology developed here can serve as a foundation for updating engineering safety guidelines and advancing national standards in the field of hydraulic infrastructure assessment.

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