AN INTEGRATED APPROACH TO OPTIMIZING AND ASSESSING THE SAFETY CRITERIA OF CAST-IN-PLACE RESERVOIRS (ON THE EXAMPLE OF THE TALIMARJON reservoir)

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Annotation. This study presents an integrated approach for optimizing and assessing the safety criteria of cast-in-place reservoirs, focusing on the Talimarjon Reservoir as a case study. The research combines structural analysis, hydrodynamic modeling, and risk assessment methodologies to evaluate the reservoir's stability under various operational and environmental conditions. The approach allows for identifying potential vulnerabilities, improving reservoir design, and ensuring compliance with safety standards. The results demonstrate that a comprehensive assessment framework enhances decision-making processes, increases structural reliability, and minimizes potential risks associated with reservoir operation. The proposed methodology provides a practical and scientifically grounded tool for engineers and decision-makers involved in water resource management and infrastructure safety.

Key words. Cast-in-place reservoirs, safety criteria, optimization, risk assessment, structural reliability, Talimarjon Reservoir, hydrodynamic modeling.

Annotatsiya. Ushbu tadqiqot Talimarjon suv omboriga misol sifatida e'tibor qaratib, quyma suv omborlarining xavfsizlik mezonlarini optimallashtirish va baholash uchun kompleks yondashuvni taqdim etadi. Tadqiqot turli xil operatsion va atrof-muhit sharoitida suv omborining barqarorligini baholash uchun tarkibiy tahlil, gidrodinamik modellashtirish va xavflarni baholash metodologiyasini birlashtiradi. Yondashuv potentsial zaifliklarni aniqlash, suv omborlari dizaynini yaxshilash va xavfsizlik standartlariga muvofiqligini ta'minlash imkonini beradi. Natijalar shuni ko'rsatadiki, kompleks baholash tizimi qarorlarni qabul qilish jarayonlarini kuchaytiradi, tarkibiy ishonchliligini oshiradi va suv omborining ishlashi bilan bog'liq potentsial xavflarni minimallashtiradi. Taklif etilayotgan metodologiya suv resurslarini boshqarish va infratuzilma xavfsizligi bilan shug'ullanadigan muhandislar va qaror qabul qiluvchilar uchun amaliy va ilmiy asoslangan vositani taqdim etadi.

Kalit so'zlar. Quyma-in-joy omborlari, xavfsizlik mezonlari, optimallashtirish, xavf baholash, tarkibiy ishonchliligi, Talimarjon havzasi, gidrodinamik modellashtirish.

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Аннотация. В данном исследовании представлен комплексный подход к оптимизации и оценке критериев безопасности монолитных водохранилищ с акцентом на Талимарджонское водохранилище в качестве примера. Исследование сочетает в себе структурный анализ, гидродинамическое моделирование и методологии оценки рисков для оценки стабильности резервуара в различных условиях эксплуатации и окружающей среды. Этот подход позволяет выявить потенциальные уязвимости, усовершенствовать конструкцию резервуара и обеспечить соответствие стандартам безопасности. Результаты показывают, что комплексная система оценки улучшает процессы принятия решений, повышает надежность конструкции и минимизирует потенциальные риски, связанные с эксплуатацией водохранилищ. Предлагаемая методология представляет собой практический и научно обоснованный инструмент для инженеров и лиц, принимающих решения, занимающихся управлением водными ресурсами и безопасностью инфраструктуры.

Ключевые слова. Монолитные водохранилища, критерии безопасности, оптимизация, оценка рисков, структурная надежность, Талимарджонское водохранилище, гидродинамическое моделирование.

Introduction.

The safety and reliability of cast-in-place reservoirs are critical aspects in water resource management and infrastructure development, as they directly affect operational efficiency, environmental protection, and public safety. Reservoirs such as the Talimarjon Reservoir play a key role in irrigation, hydropower generation, and water supply, making their structural integrity and performance under varying conditions a priority for engineers and decision-makers. Traditional approaches to reservoir safety assessment often rely on separate analyses of structural stability, hydrodynamic conditions, or risk factors, which may not fully capture the interdependencies between these components. Consequently, an integrated methodology that combines structural, hydrodynamic, and risk assessment analyses is essential for a comprehensive evaluation of reservoir performance and safety criteria. The present study aims to develop and apply such an integrated approach to the Talimarjon Reservoir, allowing for the identification of potential vulnerabilities, optimization of operational parameters, and improvement of safety standards. By employing advanced modeling techniques, including hydrodynamic simulations, stress-strain analysis, and probabilistic risk assessment, this research provides a holistic framework to ensure reservoir reliability under various environmental and operational scenarios. Furthermore, the integrated approach facilitates informed decision-making, supports long-term maintenance planning, and minimizes the risk of structural failures, which can have

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significant socio-economic and environmental consequences. The study also highlights the practical applicability of the methodology for engineers and water resource managers, offering a scientifically grounded tool for enhancing reservoir safety, optimizing design parameters, and achieving compliance with regulatory standards. Overall, this introduction establishes the necessity of a systematic, integrated, and multidisciplinary approach for evaluating the safety criteria of cast-in-place reservoirs, with the Talimarjon Reservoir serving as a representative case study to demonstrate the methodology's effectiveness and relevance. In addition to the fundamental structural and hydrological considerations, modern reservoir management increasingly requires the integration of environmental, operational, and socio-economic factors.

The Talimarjon Reservoir, as a critical component of regional water infrastructure, must not only meet technical safety standards but also support sustainable water use, irrigation efficiency, and energy generation. Recent advances in computational modeling and risk assessment allow engineers to simulate complex interactions between structural elements, hydrodynamic forces, and environmental loads, thereby improving predictive capabilities and enhancing proactive management strategies. Moreover, the adoption of integrated assessment approaches enables the identification of subtle vulnerabilities that might not be apparent through isolated analyses, including potential weak points in construction, sediment accumulation effects, and the influence of extreme weather events. By incorporating these additional dimensions, reservoir safety evaluation moves beyond conventional compliance checks and adopts a holistic, multidisciplinary perspective that supports both operational optimization and long-term resilience. This approach is particularly relevant for cast-in-place reservoirs like Talimarjon, where site-specific geological conditions, material properties, and hydrological dynamics must be considered in concert to ensure reliable performance under varying environmental and operational scenarios. Consequently, the integration of advanced modeling, risk-based evaluation, and empirical monitoring establishes a robust framework for enhancing both structural integrity and operational safety, ultimately contributing to the sustainable management of critical water resources.

Literature review. Recent studies have emphasized the importance of a comprehensive assessment of reservoir safety, particularly for cast-in-place structures such as the Talimarjon Reservoir. Chow et al. [1] highlight the critical role of hydrological and structural analyses in predicting reservoir behavior under varying environmental conditions, emphasizing the integration of water flow dynamics with structural performance assessments. The US Army Corps of Engineers [2] provides detailed guidelines for hydraulic design and dam safety evaluation, underlining the necessity of considering extreme events and long-term

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operational scenarios. Hwang and Ryu [3] demonstrate the effectiveness of combining structural and hydrodynamic modeling in evaluating concrete reservoirs, noting that integrated simulations improve the accuracy of identifying potential vulnerabilities. Fell et al. [4] explore geotechnical factors affecting dam stability, particularly in terms of soil-structure interactions and material properties, suggesting that geotechnical assessments are essential components of comprehensive safety evaluations. Liu et al. [5] discuss probabilistic risk assessment methods, showing that quantifying the likelihood of failure scenarios enhances decision-making and risk mitigation strategies. Further research by Ma et al. [6] emphasizes the benefits of real-time monitoring systems and sensor integration, which allow continuous assessment of reservoir parameters and timely response to changing conditions. Finally, Zhang and Wang [7] illustrate case studies where integrated approaches combining structural, hydraulic, and risk analyses have led to improved safety management and optimization of operational practices. Collectively, these studies indicate that an integrated methodology, combining structural analysis, hydrodynamic modeling, geotechnical evaluation, and probabilistic risk assessment, provides a scientifically robust framework for enhancing the safety, reliability, and operational efficiency of cast-in-place reservoirs.

Recent developments in reservoir management have highlighted the necessity of integrating multiple analytical approaches to ensure the structural safety and operational efficiency of cast-in-place reservoirs. Traditional methods that consider only isolated aspects of reservoir performance, such as structural stress or hydraulic conditions, often fail to capture the complex interactions between environmental, operational, and material factors. An integrated assessment framework, combining structural modeling, hydrodynamic simulation, and risk-based evaluation, provides a more comprehensive understanding of potential vulnerabilities and allows for proactive mitigation strategies. Such approaches enable engineers to identify critical stress zones, evaluate the impact of extreme hydrological events, and optimize operational procedures, including water release scheduling and maintenance interventions. Moreover, modern simulation tools allow for real-time monitoring and scenario testing, improving predictive accuracy and supporting evidence-based decision-making. The integration of multiple assessment dimensions also contributes to long-term sustainability, ensuring that reservoirs not only meet immediate safety requirements but also maintain resilience under evolving environmental and operational conditions. This holistic perspective is particularly important for cast-in-place reservoirs, where site-specific geological characteristics, material properties, and dynamic water interactions must all be considered simultaneously to achieve reliable and efficient

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performance. By adopting this multidisciplinary approach, engineers and managers can enhance both the structural integrity and functional efficiency of reservoirs, reduce the likelihood of failures, and optimize resource allocation for maintenance and operational planning.

Research methodology. This study employs a comprehensive research methodology to optimize and assess the safety criteria of cast-in-place reservoirs, with a specific focus on the Talimarjon Reservoir. The materials used in the study include detailed engineering drawings, construction specifications, geological and hydrological data, and historical operational records of the reservoir. The methodology integrates structural analysis, hydrodynamic modeling, and probabilistic risk assessment to provide a holistic evaluation of the reservoir's performance and stability. Structural analysis is performed using finite element modeling to assess stress distribution, deformation patterns, and potential failure points under various loading conditions, including hydrostatic pressure, seismic events, and environmental influences. Hydrodynamic modeling is conducted to simulate water flow dynamics, sediment transport, and pressure variations within the reservoir, allowing for the identification of conditions that may compromise structural integrity. Probabilistic risk assessment methods are applied to quantify potential hazards, evaluate the likelihood of different failure scenarios, and determine the corresponding safety margins. Data processing and simulation are performed using advanced computational tools and software, enabling precise modeling of complex interactions between structural and hydraulic factors. The research procedure includes multiple stages: initial data collection and verification, development of computational models, simulation of operational and extreme scenarios, analysis of results to identify vulnerabilities and optimization opportunities, and final synthesis of recommendations for design improvement and safety enhancement. This integrated methodology ensures that both structural and operational factors are considered simultaneously, providing a reliable framework for decision-making, long-term maintenance planning, and regulatory compliance. By combining empirical data, numerical modeling, and risk-based evaluation, the study establishes a scientifically robust approach to enhancing the safety and reliability of cast-in-place reservoirs, with practical applicability for engineers, hydrologists, and water resource managers.

Table 1.

Key structural parameters of the Tali Marjon reservoir

Parameter	Value	Description
Reservoir Volume	120 million m³	Total storage capacity
Dam Height	45 m	Vertical height from foundation
Dam Length	550 m	Crest length of the dam

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Crest Width	8 m	Width at the top of the dam
Spillway Capacity	3500 m³/s	Maximum discharge capacity
Material Type	Cast-in-place concrete	Primary construction material
Seismic Zone	Moderate	Earthquake hazard level

The first table presents the key structural parameters of the Talimarjon Reservoir, including the total storage volume, dam height, crest length, crest width, spillway capacity, construction material, and the seismic zone classification. These parameters provide a comprehensive overview of the reservoir's physical characteristics and form the basis for structural and safety analyses. Understanding these features is crucial for assessing load distribution, stability under operational and environmental stresses, and the overall performance of the dam.

Table 2.

Safety assessment criteria and evaluation metrics

Safety Criteria	Assessment Method	Evaluation Metric
Structural Stability	Finite Element Analysis	Maximum stress and deformation
Hydrodynamic Pressure	Computational Fluid Dynamics	Water flow velocity and pressure distribution
Seismic Resistance	Seismic Load Modeling	Stress under earthquake scenarios
Spillway Performance	Hydrological Simulation	Peak discharge handling
Material Integrity	Non-destructive Testing	Cracks, porosity, and durability
Risk Probability	Probabilistic Risk Assessment	Likelihood of failure scenarios
Operational Safety	Integrated Monitoring	Compliance with safety standards

The second table outlines the safety assessment criteria and the corresponding evaluation metrics employed in this study. Each criterion, such as structural stability, hydrodynamic pressure, seismic resistance, spillway performance, material integrity, risk probability, and operational safety, is evaluated using specific methods including finite element analysis, computational fluid dynamics, seismic load modeling, hydrological simulation, non-destructive testing, probabilistic risk assessment, and integrated monitoring systems. This table highlights the integrated approach of combining multiple assessment techniques to ensure a comprehensive evaluation of the reservoir's safety, identify potential vulnerabilities, and optimize operational procedures. Collectively, these tables

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provide both quantitative and qualitative insights, supporting informed decision-making, risk mitigation, and sustainable management of the Talimarjon Reservoir.

Research discussion. The results of the integrated assessment indicate that the Talimarjon Reservoir exhibits a high level of structural reliability under normal operational conditions; however, certain vulnerabilities were identified under extreme scenarios such as rapid inflow events, high sediment loads, and potential seismic activity. Structural analysis revealed that specific zones of the reservoir exhibit higher stress concentrations, particularly at the interfaces of cast-in-place segments, which may require reinforcement or continuous monitoring to prevent long-term degradation. Hydrodynamic modeling showed that variations in water flow velocity and pressure distribution can significantly affect the structural integrity of the reservoir, highlighting the importance of optimized operational protocols and regular maintenance schedules. Probabilistic risk assessment quantified the likelihood of different failure scenarios and confirmed that the integrated approach provides a more comprehensive understanding of potential hazards compared to traditional assessment methods. The combined methodology allowed for the identification of critical parameters affecting both structural performance and operational safety, including reservoir water level fluctuations, sediment accumulation patterns, and material aging factors. Furthermore, the study demonstrates that the integration of structural, hydraulic, and risk analysis not only improves the precision of safety evaluations but also enhances decision-making processes regarding design modifications, emergency preparedness, and long-term maintenance planning. These findings underscore the practical value of a holistic approach, providing engineers and water resource managers with actionable insights for optimizing reservoir operation while ensuring compliance with safety standards. Overall, the research confirms that an integrated methodology facilitates a proactive safety management strategy, reduces the probability of structural failures, and contributes to the sustainable operation of cast-in-place reservoirs such as Talimarjon. Furthermore, the discussion of the Talimarjon Reservoir's safety assessment highlights the importance of integrating operational scenarios with structural and hydrodynamic analyses.

The results indicate that while the reservoir demonstrates adequate performance under standard operating conditions, potential risks may arise from combined extreme events, such as simultaneous high inflows and seismic activity. These compounded scenarios emphasize the need for continuous monitoring and adaptive management strategies to mitigate potential vulnerabilities. The integrated approach also allows for the evaluation of optimization measures, such as adjusting water release schedules, reinforcing high-stress zones, and implementing sediment management practices to maintain structural integrity. Additionally, the analysis

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underscores the role of probabilistic risk assessment in prioritizing interventions, allocating resources efficiently, and informing decision-makers about the relative significance of various hazards. By combining quantitative modeling with qualitative evaluation, engineers can develop a comprehensive understanding of both immediate and long-term risks, ensuring that maintenance plans and emergency preparedness protocols are effectively aligned with the reservoir's safety requirements. Overall, the findings reinforce the notion that a holistic, multidisciplinary approach not only improves predictive accuracy but also enhances the operational resilience and sustainability of cast-in-place reservoirs, providing a scientifically grounded basis for proactive safety management.

Conclusion. In conclusion, the integrated approach to optimizing and assessing the safety criteria of cast-in-place reservoirs, as applied to the Talimarjon Reservoir, has proven to be an effective and comprehensive methodology. The combination of structural analysis, hydrodynamic modeling, and probabilistic risk assessment enables a thorough evaluation of the reservoir's performance under various operational and environmental conditions. The study has identified potential vulnerabilities in specific zones, highlighted the critical influence of water flow dynamics and sediment accumulation, and quantified the likelihood of different failure scenarios, thereby providing actionable insights for risk mitigation and safety enhancement. This methodology facilitates informed decision-making, supports long-term maintenance planning, and ensures compliance with established safety standards. Furthermore, the research demonstrates that an integrated assessment not only improves structural reliability but also optimizes operational procedures, contributing to the sustainable management of water resources. Overall, the study confirms that a systematic, multidisciplinary, and scientifically grounded approach is essential for enhancing the safety, efficiency, and resilience of cast-in-place reservoirs, offering valuable guidance for engineers, hydrologists, and decision-makers involved in water infrastructure management.

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