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AN INTEGRATED FRAMEWORK FOR TECHNICAL CONDITION ASSESSMENT AND OPERATIONAL SAFETY OF HYDRAULIC STRUCTURES: PROPOSED APPLICATION TO THE BESHARIQ HYDRAULIC COMPLEX

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Abstract. The reliable operation of hydraulic structures requires systematic assessment of their physical condition, hydraulic performance, and operational readiness. This article proposes an integrated assessment framework for potential application to the Beshariq Hydraulic Complex. The framework combines document review, visual inspection, targeted instrumental investigation, and potential failure mode analysis. Particular attention is given to concrete deterioration, seepage, structural movement, gate operation, and erosion. An assessment matrix is proposed to connect observable defects with verification methods and management responses. The framework distinguishes physical condition from failure consequences and explicitly records uncertainty where evidence is incomplete. Its practical output is a component-based inspection register and a prioritized action plan. Since site-specific inspection records and monitoring data were not available for this study, the article presents a methodological proposal rather than an empirical safety evaluation. Field application is necessary to establish the actual condition of the complex and validate the proposed assessment procedure.

Keywords: hydraulic structures; technical condition assessment; operational safety; hydraulic complex; structural monitoring; maintenance planning; Beshariq.

Introduction

Hydraulic infrastructure must retain its structural integrity while performing its intended water-control functions. Assessing its technical condition therefore requires consideration of both physical deterioration and operational performance. A structure may exhibit limited visible damage while containing defects that require further investigation. Conversely, visible surface deterioration does not necessarily indicate an immediate threat to overall stability.The Bureau of Reclamation provides guidance for identifying concrete maintenance problems and planning appropriate repairs. Its canal operation and maintenance resources offer a useful reference for developing systematic inspection procedures for water-conveyance infrastructure.Safety assessment also requires attention to the mechanisms through which a defect could develop into failure. The Federal Energy Regulatory Commission promotes performance monitoring linked to identified potential failure modes. This principle provides a methodological basis for connecting inspections with specific safety concerns.The objective of this article is to propose an integrated procedure for assessing

technical condition and supporting operational safety management, with the Beshariq Hydraulic Complex identified as the intended application site [1].

Research scope and evidence requirements

The proposed study begins with verification of the complex's asset inventory. Structural dimensions, foundation characteristics, construction materials, operating arrangements, and design conditions must be established from reliable records.

The required evidence includes:

- design drawings and available as-built documentation;
- operating instructions and maintenance records;
- previous inspection and repair reports;
- water-level and discharge records;
- available deformation, seepage, and groundwater observations;
- records of equipment malfunction or unusual operating events.

The presence of particular components, monitoring instruments, or deterioration mechanisms at Beshariq is not assumed. These must be confirmed during the initial investigation.

Document review and component identification

Each confirmed structural and mechanical component should receive a unique identification code to ensure that inspection findings, photographs, maintenance records, and monitoring results can be linked to the same element throughout subsequent assessments. Available records should be reviewed to establish its intended function, relevant loading conditions, previous repairs, and outstanding concerns. Particular attention should be given to alterations that may have changed the original structural configuration or operating conditions. The information obtained should be organized in a component register containing the location, function, available documentation, and inspection history of each element.Missing documentation should be recorded as an evidence gap. An absence of recorded defects should not automatically be interpreted as evidence of satisfactory condition. Where drawings, repair records, or previous inspection reports are incomplete, the assessment should identify which technical questions remain unresolved and whether additional measurements or investigations are required [2].

Visual inspection should document accessible surfaces and operating equipment using photographs, location references, and consistent descriptions. Where relevant, observations should include crack distribution, surface loss, exposed reinforcement, joint condition, leakage, corrosion, and erosion. Inspection records should distinguish directly observed defects from suspected causes, since similar surface symptoms may arise from different deterioration mechanisms. Water levels, weather conditions, and equipment operating status should also be recorded where they influence the observations. Each defect should be recorded with its location, extent, observation date, and supporting evidence. Photographs should include an overall view showing the position of the defect and a closer view with a suitable scale where practical. Repeated inspections should use comparable viewpoints and measurement locations to support identification of changes over time. Inaccessible areas and limitations affecting visibility should be clearly documented. The resulting

defect register should provide a consistent basis for selecting targeted investigations and planning subsequent monitoring and maintenance.

Targeted investigation

Instrumental investigation should address specific technical questions identified during the document review and visual inspection. The selection of investigation methods should be guided by the function of the component, the suspected deterioration mechanism, the accessibility of the affected area, and the potential consequences of malfunction. Rather than applying an identical testing programme to all components, the investigation should concentrate on obtaining the evidence needed to resolve significant uncertainties. For the proposed application at the Beshariq Hydraulic Complex, the scope of testing should be established after confirming the structural inventory and reviewing the available operational records.Crack investigation should document the location, orientation, length, and width of observed cracks, together with their relationship to joints, reinforcement, and changes in structural geometry. Where repeated measurements are necessary, monitoring points should be clearly identified to ensure consistency between inspections. Measurements should be accompanied by observations of temperature, water level, and operating conditions, where relevant. This information would help determine whether changes in crack width are associated with environmental variations, hydraulic loading, or progressive structural movement. The significance of a crack should be evaluated in relation to its likely cause and structural context rather than its width alone [3].

Geodetic surveying may be used to investigate settlement, horizontal displacement, differential movement, or rotation of structural elements. Reliable interpretation requires a stable reference system and a documented measurement procedure. Survey results should therefore include information on instrument accuracy, reference-point stability, and measurement uncertainty. Repeated observations should be compared under clearly recorded loading and operating conditions. Apparent displacement should not be interpreted as structural movement until possible measurement errors and instability of the reference network have been considered. Seepage investigation should examine both the quantity of water and the characteristics of the observed flow. Where leakage or drainage discharge can be measured, the results should be assessed alongside upstream and downstream water levels, recent precipitation, and changes in operation. New seepage locations, increasing discharge under comparable hydraulic conditions, or sediment-bearing flow should receive particular attention because they may require further investigation. However, seepage measurements alone cannot establish the condition of the foundation or confirm a specific internal deterioration mechanism. Interpretation should combine monitoring records with geological information, drainage arrangements, and other available evidence [4].

Proposed assessment matrix

The following matrix is a methodological proposal. It does not represent observed conditions at the Beshariq Hydraulic Complex.

Assessment area	Indicators to investigate	Verification approach	Proposed management

			response
Concrete condition	Cracking, spalling, surface loss, exposed reinforcement	Defect mapping and targeted material investigation	Establish cause and define appropriate repair
Seepage and drainage	New leakage, changing discharge, sediment-bearing flow	Repeated measurements and comparison with operating conditions	Investigate changes and assess their significance
Structural movement	Settlement, displacement, differential movement	Surveying and repeat measurements	Evaluate trends against expected structural behaviour
Gates and operating equipment	Corrosion, abnormal movement, incomplete closure	Documented functional checks under approved procedures	Restore reliable operation and verify corrective work
Hydraulic performance	Unexpected water levels, restricted flow, unusual flow patterns	Operating-record review and hydraulic evaluation	Identify causes and assess operational implications
Erosion and scour	Bed lowering, undermining, damaged protection	Surveying and underwater inspection where required	Assess foundation exposure and protection needs

Proposed Application and Discussion

Application at Beshariq should produce an evidence-based component register, a mapped defect inventory, and a prioritized list of investigations and maintenance actions. These are intended outputs, rather than results already obtained. Each identified concern should be linked to its location, supporting documentation, investigation requirements, and recommended follow-up. This arrangement would support continuity between inspections and allow subsequent assessments to examine whether previously identified defects have remained stable or progressed.Prioritization should consider the defect mechanism, observed progression, operational importance, and possible consequences. Uncertainty should influence the need for further investigation instead of being hidden within a numerical score. Components with insufficient information may require additional examination before a reliable maintenance decision can be made. Similarly, a localized defect with potentially serious consequences should receive specific attention even when the overall condition of the structure appears satisfactory.

Monitoring should also be linked to decisions. For each selected indicator, the assessment should specify who reviews the information, what constitutes an unusual change, and which response is required. Thresholds must be established from site-specific engineering analysis, expected performance, and relevant operating requirements. Where sufficient historical records exist, measurements should be compared under similar hydraulic and environmental conditions. This comparison would help distinguish expected variations from changes requiring further investigation.The proposed framework should also support maintenance planning by connecting recommended actions with responsible personnel, completion dates, and verification procedures.

Completed repairs should be documented and reviewed to determine whether they have addressed the identified cause of deterioration. In this way, inspection and maintenance would form a continuous assessment process rather than separate activities [5].

Limitations

No site-specific inspection dataset, verified structural inventory, or monitoring time series was available for this article. Consequently, the study cannot determine the present safety status, remaining service life, or rehabilitation needs of the Beshariq Hydraulic Complex. The assessment areas discussed represent proposed investigation categories and should not be interpreted as evidence that the corresponding defects exist at the site.The applicability of individual investigation methods will depend on accessibility, structural configuration, hydraulic conditions, and the availability of suitable equipment. Visual inspection alone cannot establish the condition of concealed reinforcement, submerged surfaces, or foundation materials. Furthermore, isolated measurements may provide insufficient evidence to distinguish temporary variations from progressive deterioration.The proposed framework requires field application and independent technical review. Future research should evaluate its consistency between inspectors and its usefulness for maintenance decisions. Validation should examine the completeness of defect records, the repeatability of observations, and the extent to which recommended investigations resolve identified uncertainties. Longer-term monitoring would also be needed to assess deterioration trends and evaluate the effectiveness of corrective actions [6].

Conclusion

An integrated assessment of hydraulic structures should connect physical observations, operational performance, and potential failure mechanisms. The proposed framework provides a structured basis for organizing these elements for future application at the Beshariq Hydraulic Complex. By combining document review, visual inspection, targeted investigation, and monitoring, it offers a consistent procedure for identifying concerns and determining the evidence required for further evaluation.Its main contribution is a transparent process that links identified concerns with verification methods and management actions while retaining uncertainty explicitly. Separate consideration of physical condition, evidence quality, and potential consequences would help prevent critical defects from being obscured by an overall condition rating. Clearly assigned responsibilities and documented follow-up procedures would also support continuity between assessment, maintenance, and subsequent inspections. Establishing the complex's actual technical condition will require verified documentation, site inspections, targeted measurements, and engineering analysis. The framework should therefore be regarded as a methodological foundation rather than confirmation of the structure's safety. Future field application should evaluate its practical usefulness, refine the assessment criteria, and establish monitoring procedures suited to the complex's verified characteristics and operating requirements.

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