

Assessment 02

Design for Industry 4.0 (ACPA7001)

**Reflective Essay on Quality Control for Hydroelectric Dam
Failures in Libya in Context of Industry 4.0**

Submitted to:

Dr. Fred Cooper

by:

Yasir Joya

05/10/2023

Contents

1. Abstract.....	3
2. Background and Introduction	3
3. Industry 4.0 Revolution and impact on dam's failure.....	5
3.1 Internet of Things and Early Detection System:.....	6
3.2 Predictive Analytics for Quality Control of Dam Structures:	6
3.3 Digital Twins:	7
3.4 Automation and Robotics:	7
3.5 Collaboration and Information Sharing:.....	7
4. Economic and Social Factors Impacting Quality Control	8
4.1. Economic Factors:.....	8
4.2. Social Factors:.....	9
4.3. Environmental Factors:	9
5. Conclusions:.....	10
6. References	10

Total Word Count: 2705

1. Abstract

Hydroelectric dams are one of the major renewable energy sources providing continuous supply of clean energy at lower cost for industrial and domestic needs. These tremendous structures demand large investment in time, costs and expertise to warrant unmatched quality, maintenance and regular monitoring for risk-free long-term operation. Any quality issues that arise over time, due to internal or external factors, and go unnoticed can lead to catastrophic failure and heavy loss of lives as witnessed in Libya when two dams could not sustain blow of flood water in Derna city in Libya leaving thousands of people dead and infrastructure destroyed. This essay reflects on the potential quality issues with dam structures and what designers could do to prevent such failures. The potential use of I4.0 technologies to limit the impact of quality failure are also discussed. Finally, the impact of quality control process on broader social or economic factors is highlighted.

2. Background and Introduction

A catastrophic flooding from storm Daniel severely hit Derna (Libya) leading to widespread destruction as the two dams collapsed inundating the port city by release of 30 million cubic metres of water. This resulted in loss of thousands of lives, cattle and the infrastructure was severely damaged (Motamedi, 2023). Although it's too early to know whether the extreme rainfall was simply too much for the dams to handle, or whether the condition of the structures also played a role (BBC, 2023), there is debate and questions being raised on the design and quality provisions of the dam to cope with the extreme environment. Figure 1 shows a satellite image of the city after dams were failed to sustain the enormous pressure of the flood water. It is crucial to understand the causes of the quality failure and what is required to be implemented to prevent such incidents in the future.



Figure 1. A satellite photo taken from the city of Derna after the catastrophic flooding, (c) 2023 Maxar Technologies (GettyImages, 2023)

So, why did the dams break, what quality control measures are required for safety and integrity of dam structures, this report will investigate the answers to these questions keeping in view the fourth industrial revolution that could help engineers to assess, design and build more safe and sound dam structures. There are several models and techniques, and each dam has its unique features that the designer suggests. Planning for extreme weather events is usually done at the design stage of the dam. The designer is meant to give a thorough report on the stability of the dam against various factors, including weather. Earth dams are the most common of all dams (ICOLD, 2020) and are responsible for one-third of dam failures worldwide (ICOLD, 1995). It is relevant to consider the modes of failure that are involved in typical dam installation. Earth dam failures can be grouped into three general categories: overtopping failures, seepage failures, and structural failures. Zhang et. al has accumulated several reasons why earth dams would fail as shown in Figure 2. In most cases, either overtopping or technical deficiencies are the cause of the damage accounting for over 80% of all failures.

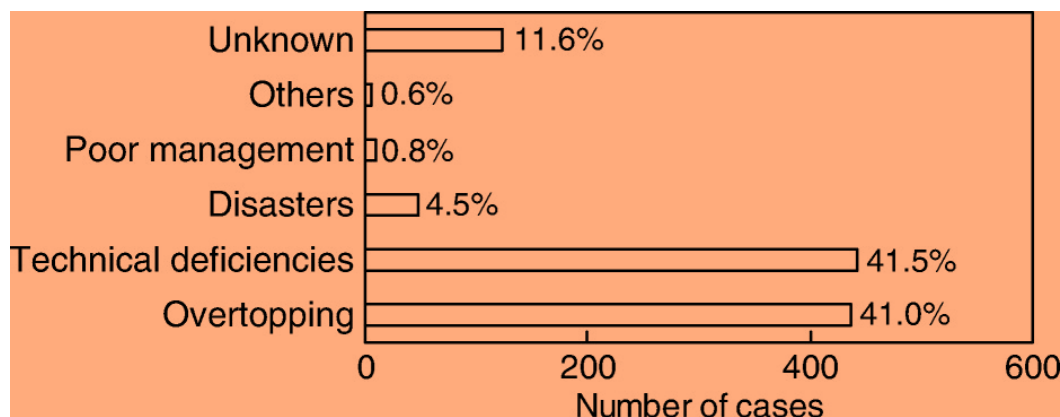


Figure 2. Percentages of technical deficiencies for earth dam failures (Zhang, et al., 2009)

The design and construction of hydroelectric dams involve several critical considerations. The dam must be structurally sound, capable of withstanding the weight of water and potential seismic activity. Designers employ sophisticated modelling and analysis techniques to evaluate the dam's stability under various loading scenarios. Construction methodologies vary depending on the dam type, such as gravity dams, arch dams, or embankment dams, and must adhere to stringent engineering standards to ensure durability and structural integrity. The failures often result due to poor design, material quality and lack of monitoring tools to optimize the structure and take early steps in case of signs of deterioration are significant (Yaseen, et al., 2020).

To avoid quality failures during dam construction, strict quality assurance procedures must be followed. High-quality building materials, adherence to engineering standards, and extensive inspections over the course of a dam's existence are all part of its quality control process. Quality assurance has always relied mainly on labor-intensive, manual inspections and paperwork that can be time-consuming containing human errors. However, adopting I4.0 technologies such as the Internet of Things (IoT), drone surveillance, and the artificial intelligence (AI) can considerably improve quality assurance. A well-implemented quality

control process ensures that dams meet and exceed safety standards, reducing the likelihood of catastrophic failures and safeguarding communities and ecosystems downstream.

Due consideration of climate change projections and best practices in the construction and design of critical infrastructure is essential. Climate resilience must be pollicised into the planning stage to ensure that dam structures can withstand extreme weather, climate conditions such as strong winds, snow, volcanic activity, earthquakes, landslides, tsunamis, and wildfires. Zhang (Zhang, et al., 2009) identified the main failure modes as being overtopping, piping leakage, sliding; poor management, disasters such as earthquakes and spillway blockage. However, some of them should be classified as causes rather than modes. To evaluate mechanisms that might harm or breakdown dam structures, engineers typically use FMEA, a simple procedure that is self-documented and easy to integrate at the design phase of the earth dam (Ribas, et al., 2021). They help to capture and predict potential failure modes, and help to monitor them improving the life, safety and reliability of the vulnerable structures under extreme conditions. Figure 3 shows the FMEA process as proposed by (Ribas, et al., 2021) that can be integrated within the dam structure.

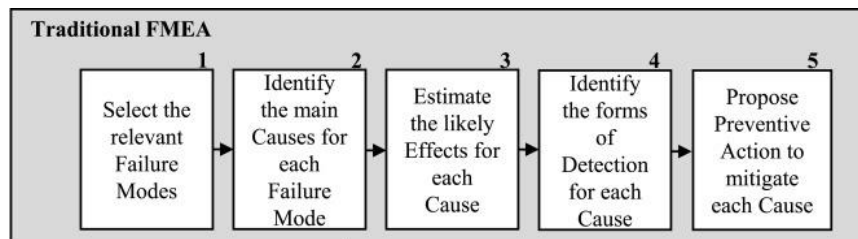


Figure 3. Typical FMEA assessment process adapted from (Ribas, et al., 2021)

3. Industry 4.0 Revolution and impact on dam's failure

Cutting edge advanced technologies such as Internet of Things (IoT), robotics and automation, big data analytics, artificial intelligence (AI) etc. are fore-front the advanced I4.0. The design engineers can make use of I4.0 tools in addition to the conventional tools, such as physical models, surveys, and calculations done by hand, to evaluate the quality control of strategic structures and assets, such as hydropower dams, and to prevent or mitigate the effects in the event that such structures begin to fail. Let's review how the I4.0 revolution relates to quality control in dams and how it affects their durability and long-term operation. Figure 4 depicts the I4.0 technologies that underpin the concepts of automation, machine and sensor network connectivity, and cloud computing to support the handling and storage of large amounts of data.



Figure 4. The fourth industrial revolution and industry 4.0 key technologies (HSRC, 2019)

3.1 Internet of Things and Early Detection System:

The modern technologies such as IoT has changed how hydropower dams are monitored and maintained. The IoT works on machines, tools which are linked together through a network of sensors and devices in cyberspace. The IoT sensors are mounted into dam structures enabling real-time data acquisition, processing, and decision-making capabilities, which dramatically improves their overall performance and lowers the likelihood of a quality failure. These are electronic or electromechanical sensors carefully installed to continuously monitor process variables i.e. temperature, pressure, vibration, water level, and structural deformations. This helps engineers to identify emerging problems quickly through data stores to a central control system, helps predict the future events preventing catastrophic failures and assuring smoother operation. IoT sensors usage for hydroelectric dam monitoring is proof that I4.0 principles have been successfully incorporated, allowing for intelligent, data-driven operations that improve the dam's resilience and long-term performance (Jaupi, 2017)

3.2 Predictive Analytics for Quality Control of Dam Structures:

Predictive analytics are an important computational solution to monitor the quality and structural integrity of dams. By harnessing the power of advanced analytics techniques and machine learning algorithms, engineers analyse vast data streams collected from sensors, historical records, and other relevant sources to predict potential quality failures. Predictive analytic models can detect patterns, identify anomalies, and provide actionable insights to proactively address issues before they escalate to extremes. This allows for the implementation of preventive maintenance strategies, timely repairs, and necessary interventions, ultimately reducing the impact of quality failures on dam structures. Early

warning systems and emergency response protocols can be implemented and regularly tested. These systems play a crucial role in evacuating at-risk communities, mitigating loss of life, and assisting rescue and relief efforts during crises.

3.3 Digital Twins:

In the I4.0 revolution, digital twins are becoming more widely used for quality assurance of hydropower dam structures. Digital twins are representations of physical dams that incorporate simulations and real-time data to mimic their performance. Monitoring systems and historical records are continuously collected and analyzed by digital twins to provide a comprehensive picture of a dam's condition and performance. Engineers can use this to identify problems with structural integrity, spot early indicators of deterioration, and foresee potential failures. Engineers can test different scenarios, evaluate the effects of dynamic loads, stress, temperature, deformation, and vibration, and optimise maintenance plans using simulation and visualisation tools. This facilitates fast risk assessment, proactive decision-making, timely interventions, and maintenance, reducing the likelihood of premature failures and ensuring their long-term safety, efficiency, and reliability.

3.4 Automation and Robotics:

The robotics and process automation play a pivotal role in enhancing quality and reducing failure risks in the hydro power sector. By utilizing autonomous robots or radio-controlled drones equipped with advanced sensors and cameras, dams can be regularly inspected in hard-to-access or hazardous areas, identifying cracks, corrosion, deformation, and other defects promptly. By using these machines, engineers can evaluate the dam's structural integrity without risking the lives of human inspectors through surveillance imaging and data collection. Automated systems can also be used to precisely control gates and manage water flow, decreasing the chance of human error. Operators and designers can use automation and robotics to proactively identify and address problems at the source to improve the quality and safety of hydroelectric dams.

3.5 Collaboration and Information Sharing:

Facilitate collaboration and information sharing among different stakeholders, including designers, operators, and regulatory authorities, using digital platforms and communication tools. Collaboration of international community, support of UNO programs and developed nations are critical in emergency disaster management, and immediate response to save lives at risk especially poor and vulnerable. The global community should extend assistance to countries facing infrastructure challenges, such as Libya, to enhance their ability to cope with future disasters and improve overall resilience. The governments and management authorities must prioritize the regular inspection and maintenance of critical structures, ensuring that they remain resilient in the face of evolving climatic conditions and natural

disasters. This necessitates adequate investment and ongoing monitoring to identify vulnerabilities and address them promptly.

4. Economic and Social Factors Impacting Quality Control

The I4.0 revolution introduces significant technological advancements that can influence the quality control processes for materials or services, such as for preventing hydro power dam structures failure. The adoption and integration of I4.0 technologies can be influenced by both social and economic factors in the quality control process for those strategic assets. The interplay between these factors can drive a commitment to enhanced safety, reduced failure risks, and more sustainable dam operations, benefitting both communities and the broader economy. However, broader social and economic factors can influence the implementation and effectiveness of these technologies. They are described in the following sections,

4.1. Economic Factors:

Budget Constraints: The deployment of I4.0 technologies, such as IoT sensors, AI, and robotics, can be costly. Economic constraints may limit the extent to which dam operators and designers can invest in these advanced systems, potentially affecting the quality management. The supply chains and SMEs may find it even more difficult to adopt these technologies which are still in infancy and will develop more with time.

Cost-Benefit Analysis: Economic considerations can influence the decision-making process regarding the adoption of I4.0 technologies. Stakeholders may weigh the upfront costs against the potential long-term benefits, including the prevention of dam failures and associated economic losses. The costs associated with implementing advanced technologies such as IoT sensors, predictive maintenance systems, and remote monitoring can be significant. However, these investments often yield substantial benefits. Enhanced quality control not only reduces the risk of catastrophic dam failures, which can have devastating human and environmental consequences, but also leads to extended dam lifespans, optimized maintenance expenditures, and increased energy generation efficiency. Long-term cost savings are also achieved by avoiding environmental and legal liabilities. An analysis of the cost-benefits of hydropower dam quality control reveals that the initial financial expenditures outweigh the long-term economic, social, and environmental benefits of ensuring these critical infrastructure assets' safety and reliability.



Figure 5. Flow diagram of CBA adopted from (Thomson, et al., 2019)

Funding and Financing: Access to funding and financing for dam projects can impact the incorporation of I4.0 technologies. Government policies, private sector investments, and international financial institutions can play a role in facilitating or hindering the adoption of advanced quality control measures. On the other hand, the potential to attract financing may be contingent on demonstrating the economic and social benefits of quality control measures, reinforcing the need for a robust financial framework to support dam safety in the I4.0 era.

4.2. Social Factors:

Willingness and ability of regulatory authorities to enforce safety standards and require the use of I4.0 technologies can significantly influence quality control of hydropower dam structure. Strong regulatory frameworks can incentivize the adoption of advanced monitoring and maintenance practices. Public awareness of dam safety issues and advocacy for improved quality control can pressure stakeholders to invest in I4.0 solutions. Concerns about the social and environmental impact of dam failures may drive demand for enhanced safety measures. The availability of a skilled workforce trained in I4.0 technologies is essential. A lack of skilled personnel to operate and maintain these systems can hinder their effective implementation. Trained workforce skilled in I4.0 technologies for monitoring and maintenance of dam infrastructure can contribute to local job creation and economic development.

4.3. Environmental Factors:

Changes in climate patterns can affect dam safety. Increased rainfall, flooding, or droughts may necessitate adjustments in dam design, monitoring, and maintenance practices, potentially requiring the integration of I4.0 solutions. Social and environmental concerns may lead to stricter regulations and standards for dam construction and operation. The 4th

Industrial revolution and I4.0 technologies can help meet these requirements by ensuring the structural integrity and environmental impact of dams.

5. Conclusions:

While I4.0 technologies offer significant potential to reduce the hydropower dams failure and enhance quality, the broader social and economic factors mentioned above can shape the extent to which these technologies are implemented and their overall effectiveness in preventing dam failure. It is essential for stakeholders to consider these factors in the context of each dam project to ensure both safety and sustainability. Although adoption of the I4.0 technologies may be costly and cumbersome, it is low cost compared to the rebuilding process after failure which is time consuming and more costly, requiring significant financial resources and international assistance.

6. References

- Al-Ansari, N., 2023. *Libya dam collapse: engineering expert raises questions about management*. [Online]
Available at: <https://theconversation.com/libya-dam-collapse-engineering-expert-raises-questions-about-management-213546>
- BBC, 2023. *Libya floods: Why damage to Derna was so catastrophic*. [Online]
Available at: <https://www.bbc.co.uk/news/world-africa-66799518>
- GettyImages, 2023. *Satellite image (c) 2023 Maxar Technologies*. [Online]
Available at: <https://www.gettyimages.co.uk/detail/news-photo/02b-maxar-satellite-imagery-after-the-catastrophic-flooding-news-photo/1663381074?adppopup=true>
- HSRC, 2019. *Blog Industry 4.0 Technologies*. [Online]
Available at: https://industry40marketresearch.com/blog/industry_4-0_technologies/
- ICOLD, J., 1995. *Bulletin 99: Dam Failures–Statistical Analysis, International Committee of Large Dams, Paris*. [Online].
- ICOLD, J., 2020. *Technology of Dams, International Commission on Large Dams, Paris*. [Online]
Available at: https://www.icold-cigb.org/GB/dams/technology_of_dams.asp
- Jaupi, O., 2017. *Computer science: Application of technology/IoT in hydropower dams*. Albania, UBT International Conference 86.
- Motamedi, M., 2023. *Why did Derna's dams break when Storm Daniel hit Libya?*. [Online]
Available at: <https://www.aljazeera.com/news/2023/9/13/why-did-dernas-dams-break-when-storm-daniel-hit-libya>
- Ribas, J. R., Severo, J. C. R., Guimarães, L. F. & Perpetuo, K. P. C., 2021. A fuzzy FMEA assessment of hydroelectric earth dam failure modes: A case study in Central Brazil. *Energy Reports*, Volume 7, pp. 4412-4424.

Thomson, C., Franklin, R. & Groth, D. T., 2019. *District heating: guidance on project level socio-economic assessment*, s.l.: Energy & Climate Change Directorate.

Yaseen, Z. et al., 2020. State-of-the Art-Powerhouse, Dam Structure, and Turbine Operation and Vibrations. *Sustainability*, 12(4), p. 1676.

Zhang, L., Xu, Y. & Jia, J., 2009. Analysis of earth dam failures: A database approach. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, 3(3), pp. 184-189.