Proceedings of the *1st Annual International Geotechnical Innovation Conference (IGIC 2024),* Jeddah Hilton, Kingdom of Saudi Arabia, May 06–07, 2024. Published and Indexed by Gulf Scholar.

Case studies of dams on problematic ground conditions in the Sultanate of Oman

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ARTICLE INFO

Published on 23rd of October 2024
Doi:10.54878/hb3znk53

KEYWORDS:

Dam Design, Geotechnical Challenges, Site Investigation, Modelling, Risk Mitigation

HOW TO CITE:

Case studies of dams on problematic ground conditions in the Sultanate of Oman. (2024). *1st International Geotechnical Innovation Conference*, *1*(1).

ABSTRACT

Designing dams in regions with complex geological and geotechnical conditions demands a meticulous approach to ensure safety and stability. This paper presents case studies from the Sultanate of Oman, highlighting the diverse challenges encountered and the strategies employed to address them. Through comprehensive site investigations, advanced modeling techniques, stakeholder engagement, and adherence to international standards, the paper underscores the importance of proactive measures in mitigating risks and enhancing the resilience of dam structures.

1. INTRODUCTION:

The Sultanate of Oman faces significant geographical and climatic challenges, including aridity, droughts, and periodic devasting floods. To address these issues and ensure sustainable water management, the country has invested in constructing dams for groundwater recharge and flood protection. However, the diverse geological makeup of Oman presents unique engineering hurdles that necessitate careful planning and execution in dam design and construction.

Historical dam failures underscore the paramount importance of dam safety throughout the project lifecycle. Therefore, this paper aims to elucidate the geotechnical complexities encountered in dam construction through case studies, shedding light on the strategies employed to ensure the safety and stability of these vital infrastructure projects.

Some of the geotechnical challenges encountered in the design of dams are listed below:

- Gypsum and Soluble Rocks: Certain regions in Oman are characterized by the presence of gypsum and other soluble rocks, which can lead to foundation instability and seepage issues if not properly managed during dam construction. Understanding the distribution and properties of these formations is crucial for effective dam design and construction.
- Expansive Soils: Swelling and expansive soils can lead to differential settlement and structural damage. Proper soil characterization and engineering solutions are necessary to mitigate these risks.
- Extremely soft conditions: Sabkha
- Karstic Features: Karst terrain, characterized by limestone dissolution and sinkholes, presents challenges for dam foundation stability. Specialized investigation techniques, such as borehole logging and geophysical surveys, are required to identify and mitigate karst-related hazards.
- Faults and Highly Fractured Rocks, open joint: Faults and fractures can compromise dam stability and integrity. Detailed geological mapping and analysis are essential for identifying fault zones and implementing appropriate mitigation measures.
- Deleterious Materials: Presence of hazardous materials such as asbestos requires special handling and disposal procedures to protect workers and the environment.

Understanding and mitigating these challenges are critical for ensuring the safety and long-term stability of dam structures

2. CASE STUDY 1: JURF DAM

Jurf Dam, located in Duqm, Oman, forms an integral part of the city's flood protection scheme. Completed in 2018, this zoned Earthfill dam with a clay core and plastic concrete core cut-off spans approximately 1.5 kilometres in length and reaches a height of 20 meters.

The dam's design and construction encountered several geotechnical challenges, including:

- **Foundation Variability:**
  The axis crosses a wide time scale stretching from the Permian basement of the Khafaji formation to the Um er Radhuma formation of the Paleogene. The complex geological formations, including limestone of different geological era, sandstone, and shale. Extensive geological, geophysical, and geotechnical surveys were conducted during the feasibility study to assess the stability of the foundation and identify potential weaknesses. Occurrence of Extremely weak and weathered Shale formation along part of the dam axis, soil like formation
- **Karstic Features + High Lugeon Values + Faults in foundations**
  The dam axis traverses several faults and runs parallel to an additional discontinuity. Weathering and fractures along the fault planes and extensive fracturing in the foundation rocks. The right abutment of the dam is located over calcarenitic limestone containing gypsum and erosion features requiring an extensive grout curtain to limit flow through the foundation (Umm er Radhuma formation). The borehole in this material showed extensive fracturing and or karst in depth.
- Presence of Soluble salts (Halite and Gypsum)
- Artesian Water
- The presence of gas (H2S) at the left abutment presents a health hazard during construction.

To address these challenges, mitigation measures such as pre-loading of weak rock masses, grout curtain design, and consolidation grouting were implemented. Additionally, provisions for dewatering during construction and mitigation of artesian water and gas emissions were incorporated into the project plan.

3. CASE STUDY 2: SAAY DAM

Saay Dam, also located in Duqm, serves as another critical component of the city's flood protection scheme. Completed in 2018, this zoned Earthfill dam with a clay core, upstream blanket, and plastic concrete core cut-off spans approximately 3.4 kilometers in length and reaches a height of 17 meters. The construction of the Saay Dam faced several geotechnical challenges, including:

- Foundation Variability: the presence of swelling rock/soil, Attapulgites (100<LL<140 and 38<PI<74), in contact with nodular limestone with karstic features required a flexible embankment design. Extensive site investigations and geotechnical assessments were conducted to optimize the dam's design and

ensure long-term stability.

- Swelling and Slaking Materials: Swelling soils, such as attapulgite, and slaking materials posed challenges for dam stability and required special attention to minimize moisture content changes.
- Karstic Features and Faults: these features required extensive grouting works.
- Presence of Gypsum and Soluble Solids

To mitigate these challenges, the dam was designed with a flexible embankment and an open bottom outlet to minimize moisture content changes in the foundation. Seepage and stability analyses were conducted to optimize the design, and innovative materials such as impervious core mixtures were utilized to enhance dam performance. The Impervious Core was realized by mixing sands and swelling soils.

4. CASE STUDY 3: JUFAINAH B6 DAM

Jufainah B6 Dam, located in Muscat Governorate, aims to provide flood protection to the capital area of Muscat. Substantially completed in 2023, this zoned Earthfill/schist rockfill dam with a plastic concrete core spans over 2 kilometers in length and reaches a height of 34 meters above excavation profile. During its construction, unexpected geotechnical conditions were encountered, including widened extremely weak/soil like fault zones, and non-uniform foundation conditions.

To address these challenges, extensive geotechnical investigations were conducted, including geological surveys, water pressure tests, and geophysical investigations. The non-uniform foundation conditions necessitated advanced modelling techniques. A 3D Finite Element Model was developed to assess the stress-strain condition of the Plastic Concrete Core, enabling engineers to optimize the design and ensure structural integrity.

5. FINDINGS:

These case studies underscore the necessity of comprehensive site investigations, advanced geotechnical analyses, and stakeholder engagement in managing dam construction on challenging ground conditions. By adopting a multidisciplinary approach and utilizing advanced modeling techniques, the safety and stability of dam structures can be ensured, mitigating risks, and optimizing construction outcomes. Establishing unified standards for geotechnical investigations and modeling approaches is essential for ensuring compliance with international safety standards and optimizing construction outcomes.

REFERENCE:

1. CIRIA R181 “Piled Foundation in Weak Rock”
2. Department of the Army U.S. Army Corps of Engineers Manual No 1110-2-1908, 2020 “Instrumentation of Embankment Dams and Levees”
3. Department of the Army U.S. Army Corps of Engineers Manual No 1110-2-1902, 2003 “Slope Stability”
4. Department of Civil and Architectural Engineering. “Sand–Attapulgite Clay Mixtures as a Landfill Liner”
5. Fell, MacGregor, Stapledon, Bell, Foster (2015). "Geotechnical Engineering of Dams" 2nd Edition.
6. Lee, His, 2015. “Simulation of Radial Consolidation Using Prefabricated Vertical Drains”
7. ICOLD Bulletin 164, 2018. “Internal Erosion of Existing Dam”
8. ICOLD Bulletin 129, 2005. “Dam Foundations”
9. Obrzud, Truty, 2018. “The Hardening Soil Model. A Practical guidebook”, Revised 21.10.2018.
10. Townsend, Anderson, Rahelison, 2001. “Evaluation of FEM Engineering Parameters from in situ Test”
11. U.S. Department of Interior Bureau of Reclamation, 2014. Design Standards No. 13 “Embankment Dam”, Chapter 15: Foundation Grouting
12. U.S. Department of Interior Bureau of Reclamation, 2012. Design Standards No. 13 “Embankment Dam”, Chapter 12: Foundation and Earth Materials Investigation
13. U.S. Department of Interior Bureau of Reclamation, 2012. Design Standards No. 13 “Embankment Dam”, Chapter 12: Foundation and Earth Materials Investigation
14. U.S. Department of Interior Bureau of Reclamation, 1987. “Design of Small Dams”
15. Van der Merwe, D M 1964. “The prediction of heave from the Plasticity Index and percentage clay fraction of soils”