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MYTHS AND REALITIES OF LINING SYSTEMS IN DAMS: A SUCCESS CASE FROM A PERUVIAN MINE

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ABSTRACT

The integrity and performance of tailings and water dams fundamentally depend on the appropriate selection and implementation of lining systems. These barriers are critical components to minimise seepage, protect downstream ecosystems, and ensure long-term structural and environmental safety. This article provides a technical review of dam lining systems, including synthetic geomembranes (HDPE, PVC), compacted natural materials (compacted clay liners, GCLs), and semi-rigid linings (shotcrete, RCC). Key design criteria are discussed, such as chemical compatibility, UV resistance, installation feasibility, and cost considerations. A comparative matrix between HDPE, PVC and compacted clay is presented, alongside an exploration of common myths and realities regarding lining systems in mining applications. A case study highlights the successful implementation of the Geomembrane Sealing System (GSS) in the tailings dam of Las Bambas mine, Peru, demonstrating a significant reduction in seepage and contributing to sustainability, cost-effectiveness, and operational safety under demanding conditions. This work contributes to a better understanding of current challenges and future opportunities in the design of effective and sustainable dam lining solutions, in accordance with frameworks such as GISTM and ICOLD.

RESUMO

A integridade e o desempenho de barragens de rejeitos e de água dependem fundamentalmente da seleção e implementação adequadas dos sistemas de revestimento. Essas barreiras são componentes críticos para minimizar infiltrações, proteger os ecossistemas a jusante e assegurar a segurança estrutural e ambiental a longo prazo. Este artigo apresenta uma revisão técnica dos sistemas de revestimento em barragens, incluindo geomembranas sintéticas (PEAD, PVC), materiais naturais compactados (revestimentos de argila compactada, GCLs) e revestimentos semirrígidos (shotcrete, CCR). São discutidos critérios chave de *projeto, como compatibilidade química, resistência aos raios UV, viabilidade de instalação e considerações de custo. É apresentada uma matriz comparativa entre PEAD, PVC e argila compactada, juntamente com a análise de mitos e realidades comuns sobre os sistemas de revestimento em aplicações na mineração. Um estudo de caso destaca a implementação bem-sucedida do Sistema de Vedação com Geomembrana (GSS) na barragem de rejeitos da mina Las Bambas, no Peru, demonstrando uma redução significativa nas infiltrações e contribuindo para a sustentabilidade, eficiência econômica e segurança operacional em condições desafiadoras. Este trabalho contribui para uma melhor compreensão dos desafios atuais e das oportunidades futuras no desenvolvimento de soluções de revestimento de barragens eficazes e sustentáveis, em conformidade com referenciais como o GISTM e o ICOLD.*

1. INTRODUCTION

The implementation of linings in tailings storage facilities (TSFs) and water dams has become standard practice under modern environmental and safety standards. These systems aim to limit contaminant migration, reduce water losses, and provide long-term resilience to dam structures. In high-risk mining contexts, the selection of an appropriate lining is essential to meet both geotechnical and hydro chemical demands. Lining systems in tailings dams are key measures to control seepage, protect structures, and prevent environmental impacts. With technological advancements, their relevance has increased in large-scale mining operations.

This article explores the taxonomy of lining systems, the engineering criteria guiding their design, and lessons learned from real-world applications, with a focus on common myths and realities.

2. TYPES OF DAM LININGS

Linings are employed to control infiltration, protect the dam structure, and mitigate environmental impacts. According to their nature and application, they are classified into three main categories:

2.1 Synthetic Geomembranes

These are impermeable sheets made of polymers, widely used in tailings and water dams.

- HDPE (High-Density Polyethylene): Offers high chemical and UV resistance. It is relatively low-cost, with a service life exceeding 20 years, and is commonly used in harsh environments.
- PVC (Polyvinyl Chloride): More flexible and easier to install, but sensitive to prolonged UV exposure and certain solvents.
- LLDPE / EPDM: Used in specific conditions requiring high adaptability and elongation. EPDM is noted for its excellent elasticity and durability, albeit at higher cost.

2.2. Natural or Compacted Linings

Use clay or bentonite-based materials to create low-permeability barriers.

- CCL (Compacted Clay Liners): Traditional low-permeability barriers, economical but prone to cracking if poorly installed. Typically, ≥ 0.6 m thick with permeability $\leq 10^{-7}$ cm/s.
- GCL (Geosynthetic Clay Liners): Prefabricated sheets containing bentonite clay between geotextiles, offering good impermeability and ease of installation.

2.3. Rigid or Semi-Rigid Linings

Cementitious materials that provide structural reinforcement and surface erosion resistance, often combined with flexible linings.

- Shotcrete: Sprayed application, suitable for slopes or difficult-to-access areas.
- RCC (Roller Compacted Concrete): Dry, compact concrete, ideal for dam crests and foundations.
- Mortars: Thin cementitious mixes used for repairs or secondary coatings.

In many cases, these linings are used in combination, depending on the hydraulic, geotechnical, and operational design of the project (e.g., HDPE geomembrane over GCL with a protective sand or concrete layer).

3. DESIGN CRITERIA AND KEY PARAMETERS

The selection of a lining system is governed by several key factors:

- Site Climatic and Geological Conditions: Including topography, dam geometry, slope, temperature, and UV radiation.
- Chemical Compatibility: Resistance to leachates (in tailings) or aggressive waters.
- Mechanical Performance: Resistance to tensile and puncture loads.
- Installation Feasibility and QA/QC Requirements: Weldability and ease of installation are crucial.
- Expected Service Life and Maintenance Needs: These influence the total cost of the solution.
- Economic Factors: Consideration of both CAPEX and OPEX.
- Regulatory Compliance: Adherence to standards such as GISTM, ICOLD, ANCOLD, and local regulations.

4. DESIGN CRITERIA AND KEY PARAMETERS

The table 1 shows the key parameters for defining the design criteria for a liner for a tailings and water dam for seepage control.

Table 1 - Comparison of parameters of main types of dam linings.

Parameter	**HDPE**	**PVC**	**CCL (Compacted Clay)**
Permeability	Very low	Low	Moderate (10^{-7}–10^{-9} m/s)
Flexibility	Low	High	Medium
Installation	Thermal welding	Chemical bonding	Mechanical compaction
Chemical/UV Resistance	Excellent	Moderate	Limited
Cost	Medium	High	Low
Maintenance Needs	Low	High	High (cracking risk)

5. MYTHS AND REALITIES OF LINING SYSTEMS

A proper understanding of the capabilities and limitations of lining systems is crucial to their successful application. Some common myths include:

Table 2 - Myths and realities of lining systems.

Myth	**Reality**
“HDPE is indestructible”	Puncture or installation flaws can compromise integrity.
“Clay alone is enough”	Requires precise compaction and moisture control.
“PVC and HDPE are interchangeable”	Different chemical and mechanical behaviors.
“Liners eliminate all seepage”	Residual leakage exists—design must include monitoring.
“Only the liner matters”	Requires proper subgrade, drainage, and anchorage systems.

6. CASE STUDY: LAS BAMBAS MINE, PERU

The Las Bambas mining operation in Peru has successfully implemented the GSS (Geomembrane Sealing System) in its tailings dam, demonstrating the effectiveness of lining technologies under demanding conditions.

6.1. GSS System and Technological Basis

A thermo-bonded plasticised PVC geocomposite with geotextile was used. The system features a flexible perimeter anchor designed to adapt to differential settlements, seismic events, and internal pressures. Its key technical attributes include:

- Ultra-low permeability: Coefficient of 6.25×10^{-14} cm/s and UV resistance exceeding 100 years.
- Mechanical tensile strength: Accommodates dam embankment deformations.
- Efficient installation: Lightweight equipment and simple site logistics reduce CAPEX and OPEX through rapid installation and low maintenance.

6.2. Monitoring and Results

A flow measurement weir downstream of the dam allows seasonal monitoring. A recorded flow of 50 l/s in a 4 km-long, 173 m-high dam confirms the GSS system’s success, indicating significantly reduced seepage.

6.3. Advantages and Contribution to Sustainability

The GSS system, implemented since 2014 and expected to cover 1,200,000 m² by 2028, offers multiple benefits:

- Structural Integrity: Ensures stability under extreme conditions such as UV radiation, high pressures, and earthquakes.
- Water Sustainability: Reduces water losses and contaminant migration, supporting environmental protection.
- Operational Safety: Enhances safety and protects nearby communities from potential dam failures.

This case highlights how proper selection and application of linings like PVC GSS can deliver significant benefits in terms of efficiency, safety, and environmental responsibility in tailings storage facility management.

The figures 1 and 2 show the results of monitoring water seepage and flow at the flow measurement spillway, located at the foot of the dam, and the flow measurements compared to recorded rainfall.

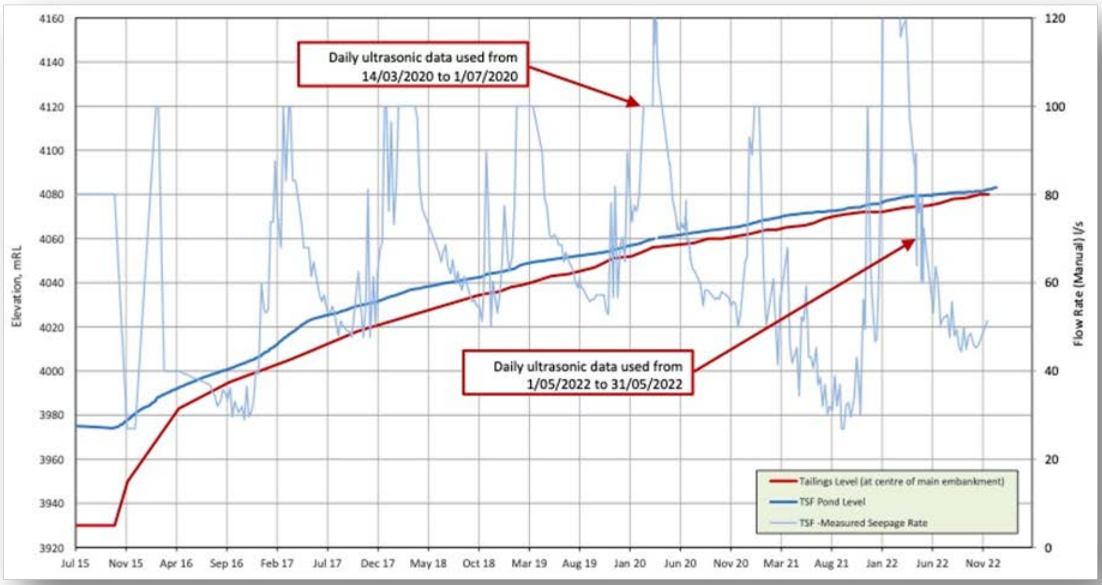

Figure 1 - Flow measurement weir, located at the foot downstream of the dam.

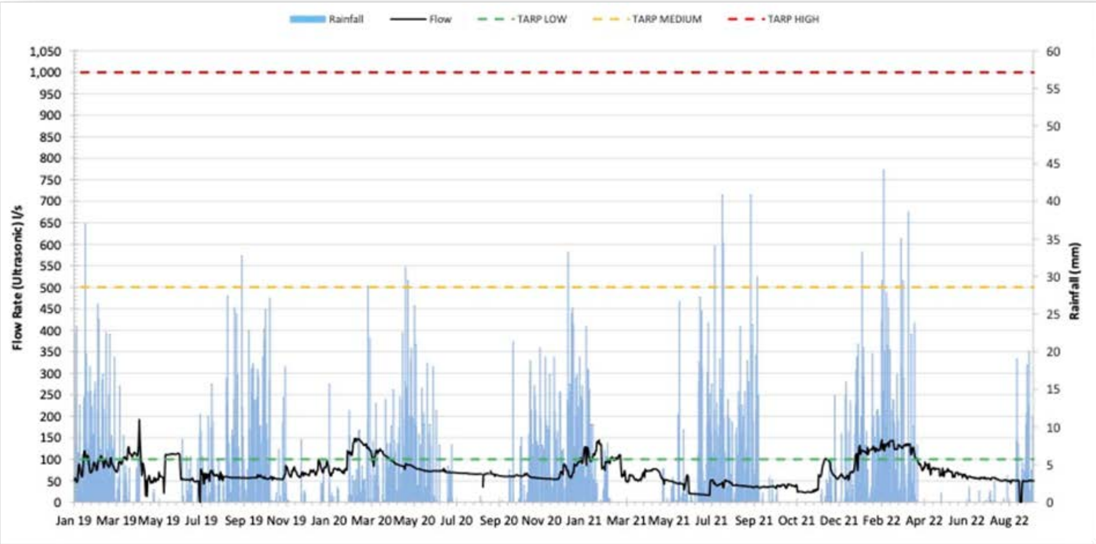

Figure 2 - Streamflow measurements versus precipitation.

7. CASE STUDY: LAS BAMBAS MINE, PERU

Selecting an appropriate lining system for tailings and water dams must follow a comprehensive approach balancing technical, environmental, and economic criteria.

- HDPE geomembranes are highly effective in chemically aggressive mining environments but demand strict installation and quality control. Natural linings, such as clay, can be economical but require precise engineering and moisture control to avoid cracking.
- Combining multiple lining types (e.g., geomembranes with protection layers or GCLs) often yields more robust and redundant systems.
- Continuous monitoring and maintenance programmes must be integrated throughout the liner's life cycle to ensure long-term performance and identify residual seepage risks.
- Investing in quality and design prevents operational and environmental failures, safeguarding both infrastructure and surrounding ecosystems and communities.

8. CONCLUSIONS

- PVC geocomposite geomembrane technology has been successfully implemented since 2014 at the Las Bambas Dam, with an expansion underway that will reach 1,200,000 m² by 2028.
- The system responds to the fundamental principles of design, construction, and operation of large-scale hydraulic infrastructure.
- The solution minimizes the ecological impact, reduces the carbon footprint, and protects communities and local biodiversity from potential leaks.
- It allows for reduced investment (CAPEX) and operating (OPEX) costs thanks to its rapid installation, low maintenance, and high durability.

- The geomembrane maintains its integrity in the face of earthquakes, high pressures, thermal changes, and UV exposure.
- It contributes to efficient management of water resources, preventing leaks and ensuring the stability of the dam.

9. KEYWORDS

- Geomembranes, Seepage, Tailings Dams, GSS (Geomembrane Sealing System) and Sustainability.

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