FGI Webinar: Ballasting & Protecting Exposed & Covered Geomembranes in Mining Systems

Presented by:
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Hosted by: Brian Fraser (Layfield Group) on behalf of **Tim Stark** (Technical Director, FGI)

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Introduction & Background

This webinar addressed critical aspects of ballasting and protecting geomembrane lining systems in large-scale water containment applications, particularly for mining and industrial reservoirs. The presentation emphasized that proper ballast design is an integral component of geomembrane system design that directly impacts long-term performance. Patrick Elliott provided practical installation perspectives from over 25 years of field experience, while Ron Frobel contributed engineering design methodologies based on 30+ years in geosynthetics consulting. The webinar demonstrated that inadequate ballasting leads to catastrophic failures including membrane uplift, tearing, and complete system replacement—problems entirely preventable through proper design.

Why Ballasting and Protection Are Critical

Eight primary threat categories necessitate ballast systems:

- **Wind uplift:** Especially severe in high-wind regions; atmospheric pressure variations at elevation (5,000-10,000 ft) compound the problem
- **Hydrostatic uplift from groundwater:** Fluctuating groundwater tables during drought/wet cycles
- **Gas generation:** Organic material decomposition beneath liner; waste leakage creating methane/biogas accumulation that can create "circus tent" uplift reaching 10+ feet high
- **External mechanical forces:** Construction traffic, maintenance equipment, boat launching, equipment installation

- **Wave action:** Creates progressive erosion of subgrade ("shelving" effect) when liner becomes loose
- **Ice damage:** Ice sheet movement across reservoir surface can shear or tear inadequately ballasted systems
- **UV and environmental exposure:** Long-term degradation; thermal expansion/contraction cycles
- **Hail damage:** Significant concern in certain geographic regions

Photographic evidence included Eastern Colorado oil/gas reservoir left dry for 2 years—entire 10+ acre liner system torn from anchor trenches and shredded. Municipal wastewater lagoons showed 15-20 "whale back" bulges where liner lifted 3-6 feet above design grade. Wave action damage showed 2-3 foot "shelf" erosion below waterline where loose liner allowed progressive subgrade washout.

Types of Ballast Systems

Patrick Elliott outlined 14 distinct ballasting approaches:

1. **Compacted soil cover:** Full-area or bottom-only (typical 12-inch minimum)
2. **Water ballast:** Maintaining minimum 1-foot water depth (simplest method)
3. **Internal berms for staged water ballasting:** Traps water at multiple elevations as reservoir drains
4. **Sand and pea gravel ballast tubes:** 6-8 inch diameter, typically 6-foot lengths
5. **Covered intermediate benches:** Reduces effective slope length
6. **Concrete paved areas/grout-filled mattresses:** Equipment access zones
7. **Shotcrete over geotextile:** Canal linings and slope armoring
8. **Anchor trench at slope base:** Membrane fusion-welded for positive anchorage
9. **Mechanical fastening systems:** Concrete curb attachments with embedded plates/bars
10. **Combination systems:** Multiple methods integrated

Case study: Parker, Colorado reservoir (87 feet deep)

- Long 160-foot slopes with multiple internal berms across floor
- During construction, major rain event demonstrated berm functionality—water trapped at multiple levels as designed
- Design principle: As reservoir drains, berms maintain water ballast incrementally up slope face

Ballast Tube Systems: Design and Installation

Standard tube specifications:

- **Most common size:** 6-inch diameter × 6-foot length (manageable by 1-2 workers)
- **Filling options:** Pea gravel preferred for slopes; sand for bottom applications

- **Placement methods:** Continuous tubes running full slope length OR segmented 6-foot tubes individually attached to continuous anchor chains with quick-disconnect grommets

Advantages of segmented design:

- Individual tube replacement if damaged
- Adjustable spacing to control ballast density
- Easier handling and shipping
- Prefabricated off-site for quality control

Installation details:

- Strapping systems secure tubes to membrane (prevent sliding)
- Typical slope spacing: 1-2 foot gaps between tubes
- Chain attachment: Anchored at top, tubes clipped on via grommets
- Concrete curb systems provide positive anchorage preventing pull-out

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Design Considerations: Gas Uplift

Gas uplift is the most overlooked failure mode, yet entirely preventable:

Design solutions:

- **Minimum 1% gradient on all subgrade:** Eliminates flat areas where gas accumulates
- **Geocomposite drainage layer:** Continuous geonet beneath geomembrane provides gas/water flow path
- **Perimeter venting system:** 2-inch diameter PVC vent pipes at top of slope, 25-50 foot spacing around entire perimeter
- **Prefabricated vent assemblies:** Shop-built components reduce field errors

Critical point: Venting must be designed from beginning—cannot be retrofitted after ballooning failure. Most failures require complete liner replacement.

Design Considerations: Hydrostatic Uplift

Geotechnical investigation requirements:

- Minimum 3 borings along centerline for residential-area projects
- Identify groundwater depth, seasonal fluctuation, perched water on clay layers

Balancing equation:

- **Factor of Safety = 1.4** (minimum) for ballast design
- Unit weight of ballast × thickness ≥ 1.4 × (unit weight of water × groundwater height above liner)
- **Simplified rule:** 1.3 feet of soil ballast per 1 foot of groundwater above liner

Alternative: Subsurface drainage:

- Perimeter French drain or panel drain system
- Requires continuous pumping or gravity outlet

Case study: Owner elected to raise entire subgrade 2-3 feet with imported soil rather than deal with drainage—reduced pond volume but eliminated groundwater issue permanently.

Design Considerations: Wind Uplift

Critical design variables:

- **Location and elevation:** Colorado projects at 5,000-10,000 feet; atmospheric pressure decreases with elevation
- **Surrounding terrain:** Tree lines, buildings block wind and reduce suction factors
- **Liner geometry:** 1-acre vs. 100-acre; slope angle and length
- **Geomembrane unit weight:** Thin polymeric (0.03-0.08 kg/m^2) to thick reinforced (0.2-0.4 kg/m^2)

Wind velocity selection:

- **Use sustained wind speed, NOT peak gusts**
- ASCE 7-2022 structural wind speeds ÷ 1.5 to 1.75 = sustained wind for liner design
- Example: 100 mph hurricane gust ÷ 1.6 = 62 mph sustained design wind
- Typical design range: 30-65 mph sustained (50-105 km/hr)

Suction factor (λ) selection:

- Bottom areas and short slopes (<10 feet): $\lambda = 0.2$
- Long slopes (>50 feet): $\lambda = 0.31$ to 0.54
- Average for moderate slopes: $\lambda = 0.4$ to 0.5

Wind Uplift Calculation Methodology

Basic uplift equation:

$$S_{eff} = \lambda \times \rho_{air} \times V^2 / 2 - W_{liner} \times \cos(\beta)$$

Where:

- S_{eff} = effective suction pressure (kg/m² or Pa)
- λ = wind suction factor
- ρ_{air} = air density (function of elevation)
- V = sustained wind velocity
- W_{liner} = geomembrane unit weight
- β = slope angle

Example calculation:

- Bottom liner, 8 meters elevation, 52 km/hr sustained wind, 0.05 kg/m² liner, $\lambda = 0.2$
- **Result: S_{eff} = 1.73 kg/m² uplift pressure**

Translating to ballast tube spacing:

- Typical sand tube: 100 lbs (45 kg)
- Area resisted: 45 kg ÷ 1.73 kg/m² = 26 m² (280 ft²)
- **Spacing: One 6-foot tube per 280 square feet**

Full-Coverage Protection Systems

Case study: Eastern Colorado 178-acre reservoir

- Phased construction over multiple seasons; high wind exposure
- Solution: 1-foot soil cover placed using GPS-controlled equipment
- 150-foot slopes with mid-slope bench
- Upper slope (fluctuation zone): Geotextile + 2-inch minus stone for wave/ice protection
- Lower slope/bench: 2 feet silky sand cover; bottom: minimum 1 foot
- Bench designed to remain submerged—no ballast needed above

Long-term advantages:

- Full soil cover extends liner life to 50-100 years (vs. 20-30 exposed)
- Eliminates UV degradation, thermal cycling, mechanical damage

58-acre potable water reservoir (Delaware):

- Complete bottom soil cover
- Concrete grout-filled mattresses on upper slopes for equipment access
- Stone riprap in wave action zone
- Water level never drops below rock armor—eliminates exposure

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Summary and Recommendations

1. **All exposed liner systems require ballast/protection** for 30+ year service life
2. **Perform uplift calculations** for wind, hydrostatic, and gas—do not rely on rules of thumb
3. **Specify ballast in design documents:** Detailed drawings, tube sizes/weights/spacing, attachment methods
4. **Quality assurance for ballast systems:** Extend CQA program to cover ballast installation
5. **Historical wind data essential:** Use sustained wind speeds, not peak gusts
6. **Gas uplift prevention non-negotiable:** 1% minimum subgrade slope, drainage layer, perimeter venting
7. **Consider full soil cover where feasible:** Maximum protection and longest service life
8. **Treat ballast as integral geomembrane system component:** Not an afterthought

Industry standards: No single comprehensive ballast design standard exists. FGI identified as logical organization to develop white paper or best practices guide.

Available references: Giroud wind uplift publications (1995, 2022), Harper's suction factor research, previous FGI webinar on exposed liner caps, ASCE 7-2022 wind data.

Additional Information

Recording, PDF slides, and attendance certificates available on FGI website.

Next FGI webinar: Carbon Emissions Quantification and Sustainability Aspects of Landfill Final Cover Systems (November 13, 2025) by Rutu Joshi.

Remaining questions addressed in follow-up podcast.

Contact: Patrick Elliott (Colorado Lining International) and Ron Frobel (RK Frobel and Associates).

Key Takeaway: Ballast systems are critical engineered components determining whether installations achieve design life or fail catastrophically. Proper ballast design cost is a small fraction of premature system failure and replacement costs.