Emergency Stabilization of Fountain Slide
Lillooet, British Columbia

Rick Deschamps, PE, PhD
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Presentation Outline

• Background information
• Available geotechnical data.
• Design expectations
• Design considerations
• Contract negotiation
• Construction activities
• Construction monitoring
• Summary
Project Location

- Four hours north of Vancouver
- 2000 miles from Kansas City
Project Location
First Site Visit – Reality Sets In…
Scarp Above Tracks
Recent History

- Slide active since 1970's and detrimentally impacting BC 99.
- Began impacting BC Rail in 1990s.
- CN acquired BC Rail in 2004 and began remedial work.
  - Track realignment (many)
  - Soil nail wall (2005)
  - Soldier pile and lagging wall (2008)
  - Add row of anchors to wall as downslope keeps moving (2010).
- Slide retrogresses above tracks (2014).
- Slide moving between 4 and 10 mm/day.
- RFP for design-build repair January 2016.
- Construction completed in fall of 2016.
Figure 26: Surface to surface change detection between ALS data collected in June 2014 versus 2006
Figure 27: Surface to surface change detection between ALS data collected in July 2015 versus 2006
Active Slide Zone
Geotechnical Information

- Deep colluvial valley (60 to 80 feet)
- Fluvial glacial deposits over till (> 150 feet).
- Volcanic Bedrock.
General Geotechnical Conditions

- Landslide hodge-podge for 30 to 50 ft.
  - Heterogeneous fine grained material including CL and CH
  - Shear zone appeared to be CH, but areal extent?
- Coarse grained colluvium for 15 to 30 ft.
  - Silty sands, sands, rounded gravel.
- Coarse glacial fluvial for 15 to 30 ft
- Glacial till (clay) bedrock (deep).
- No water encountered.
Owner Design Expectations/Impacts

- Safety Factor between 1.2 and 1.5.
- Consider active block only (tension crack 200 ft above tracks).
- Avoid (minimize?) activities on First Nation land.
Nicholson/Agra Considerations/Concerns

- Active slide – 4 to 10 mm/day.
- Characterization of strength given active movement.
- Relic slide extends about a mile up slope.
- Limited access for materials and equipment.
- Limited work area (existing easement).
- Test anchors installed on site by competitor.
- "Brittleness" of solutions.
- Disruption in production due to rail activity/supply.
Strength along the Sliding Surface

- How to characterize strength?
- Safety factor is less than 1.0 because slide is moving.
- What happens when the displacement is fixed?
- Is a safety factor of 1.2 enough?
Estimate of Required Resisting Load

- From back-analysis and geotech interpretation need about 275 kips/ft to stabilize the slope (SF ~ 0.9).
- Length to be stabilized is approximately 300 feet.
- With this information, pros and cons of various approaches were considered.
Hollow Bar Anchors

Pros:
1. Competitive cost?

Cons:
1. Limited load per element.
2. Uncertain installation in boney ground.
3. Infringe in First Nations land.
Large Tendon Anchors

Pros:
1. Competitive cost.
2. Carry high loads

Cons:
1. Load transfer at surface.
2. Lock off load and slope movement.
3. Infringe on First Nations land.
Shear Walls (soil mix, C-B, Concrete)

Pros:
1. Carry large loads.
2. Possibly constructed within easement.

Cons:
1. Limited equipment and bench access.
2. Very boney ground.
3. Movement rate.
Drilled Shafts from Tracks

Pros:
1. Work within level "stable" area.
2. Carry large loads.
3. Constructed within easement.

Cons:
1. Close rail service
2. Potentially damage existing anchors
3. Rate of construction relative to movement.
4. Big equipment
Driven Piles as Shear Piles

Pros:
1. Cost effective.
2. Constructed within easement.

Cons:
1. Penetrating very boney ground.
2. Vibration on existing structure.
3. Large Equipment.
Micropiles as Shear Piles

Pros:
1. Reasonable cost
2. Constructed within easement
3. Can penetrate boney ground
4. A "ductile" solution.

Cons:
1. Need to create bench below wall.
Micropiles Preferred Approach

- High certainty of installation.
- High load per element (13 5/8" OD by 5/8" wall).
- Modest size equipment.
- Cost competitive.
- Relatively ductile load transfer.
- Budget submitted using L-Pile load transfer model.
- Four rows of vertical piles proposed about 4 ft c-c.
Nagging Concerns

- Mass to be stabilized – how well defined.
- What is the existing safety factor 0.9, 0.8?
- Low safety factor – how good is the L-Pile model for soil movement? Used in the past, but…
- Loehr and Brown (2008) interpret and recommend that substantial py reductions are needed.
- Decision – engage Itasca for FLAC3D analyses -- Augusto Lucarelli
FLAC3D Results

- Proposed solution as designed would not work.
- Piles had to be installed in an A-Frame arrangement to carry loads axially.
- Pile lengths would increase.
- External grout needed to optimize load transfer.
- Additional elements needed if external grout not achieved.
- $\text{py}$ reductions (0.2 to 0.25) suggested by Loehr and Brown compare favorably to FLAC3D.
- Add thirty 12 strand anchors (~ 500 kips each).
- Price increased.
- System less ductile.
Itasca's FLAC3D Results

FLAC3D 5.01
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Step 36716
4/7/2016 9:33:41 AM

Zone
Color by: Group
1
- Soil2
- TopSoil

SEL Geometry
Color by: ID
0
- 1
- 2
- 3
- 4
Node marker: cube
Scale: 0.2

Top view
3D Beam Elements
Site Grading Begins
Early win – able to negotiate road access with First Nations!
Displacement Monitoring - Soldata
Materials

Neat Portland Cement Grout

Strand Anchors

N80 Casing
13 5/8" OD by 5/8" wall
A Lot of Movement During Construction
Displacement Rates During Construction

Site: Lillooet Slide - Acquisition
Detailed values (after 5/15/2016 7:49 AM)

- < 1 mm/day
- 5 mm/day
- 20 mm/day
Modify Anchor to be Passive
Three Strands Carried to Wale

TYPICAL CONCRETE WALE SECTION @ EXISTING HP PILES
Anchor Installation
Final Completion – Concrete Wale in Place
CN's Optical Survey Data

No additional movement to date.
Summary/Epilogue

Challenging project for several reasons:

• Difficult heterogeneous geologic environment – limited info.
• Soil Parameter selection.
• When will the next retrogressive block slide?
• Moving mass – will solution be ductile enough?
• Will activities cause major movements and a safety concern?
• Low safety factor requested (what will it cover).
• Work within easement and all materials brought by rail.
• Limited budget.
Contract reflected perceived risks

Design Evolution

- L-Pile soil movement model used initially.
- *FLAC3D* used to investigate Loehr-Brown recommendations.
- Lack of slope response and blips caused some concern.
- Voids behind existing wall caused concern for load transfer.
- Changed anchor from 12 to 18 strand and active to passive.
- So far so good, but……
Is the shear stress now stable or still decreasing?

![Graph showing shear stress vs. displacement with a residual strength marker.](image-url)
BC 99 Remediation

- Additional anchors were added at toe to shift road.
- Highway remediation planned for this year (but??)