Real Time Deformation Monitoring for Wall Construction

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SR-101 Bogachiel Slide Repair
Overview of Slide Area
Bogachiel Slide History

- Problems began in 1985 - resulted in loss of over 1,000 ft of SR-101
- SR-101 was rebuilt once the slide stopped moving
- Settlement and movement continues to occur at various points along this section of SR-101 due to slide
- The location of the soldier pile wall is one of the most active areas
- Landslide results from a combination of high groundwater charged up by rainfall, weak deeply weathered siltstone and claystone, shearing caused by tectonic activity, and erosion at the slide toe by the river
Cross-Section of Previous and New Slide Repairs – Original Condition (11/2004)

- Old soldier pile wall
- Soil nail wall
- Old groundline
- Potential failure surface
- Landslide deposits
- Hard siltstone or sandstone

Materials:
- Hard siltstone or sandstone

Notes:
- Cross-section diagram showing the original condition of the slide repairs.
Cross-Section of Previous and New Slide Repairs – Sept. 2005

- Old soldier pile wall
- Soil nail wall
- Current groundline
- Potential failure surface
- Landslide deposits
- Hard siltstone or sandstone

Hard siltstone or sandstone
Cross-Section of Previous and New Slide Repairs

- Old soldier pile wall
- Soil nail wall
- Deadman anchor
- Landslide deposits
- Hard siltstone or sandstone
- Current groundline
- Potential failure surface
Cross-Section of Previous and New Slide Repairs

- Old soldier pile wall
- New Wall
- Drainable concrete
- Current groundline
- Temp. crane support piles
- Soil nail wall
- Deadman anchor
- Landslide deposits
- Potential failure surface
- Hard siltstone or sandstone
Slide Repair Overview
View Down to River from Wall Top
First Slide Repair Wall
Deformation in First Repair Wall
Installation of Temp. Crane Support Piles
Installing Soldier Piles for New Wall
Preparing to Install Bottom Tieback Row
Tieback Installation
Existing and Permanent Anchored Walls
Inclinometer Location

- Old soldier pile wall
- Inclinometer
- Soil nail wall
- Old groundline
- Potential failure surface
SR-101 Bogachiel Slide Soldier Pile Wall Inclinometer Measurements

- Excavation in front of wall to install bottom tieback row
- SPW-2 at wall bottom
- 0.2 deg. = 0.8 inches
- SPW-2 at Wall Top
- 19.6 inches displ. at wall top
- Bottom 5 ft of concrete fill placed between old and new wall; some tieback anchors stressed
- Existing wall deadman anchors installed
- Temporary crane support trestle piles driven behind existing wall

Date:
- 17-Sep-05
- 22-Sep-05
- 28-Sep-05
- 03-Oct-05
- 08-Oct-05
- 13-Oct-05
- 18-Oct-05
- 24-Oct-05
- 29-Oct-05
- 03-Nov-05
- 08-Nov-05
- 13-Nov-05
- 19-Nov-05
- 24-Nov-05
- 30-Nov-05
- 06-Dec-05
- 11-Dec-05
- 16-Dec-05
- 21-Dec-05
- 26-Dec-05
- 01-Jan-06
- 06-Jan-06
- 11-Jan-06
- 16-Jan-06
SR-101 Bogachiel Slide Soldier Pile Wall Inclinometer Measurements Plus Rainfall

SPW-2 at wall bottom

SPW-2 at wall top

Daily rainfall

Date

5-Sep-05  15-Sep-05  25-Sep-05  5-Oct-05  15-Oct-05  25-Oct-05  4-Nov-05  14-Nov-05  24-Nov-05  4-Dec-05  14-Dec-05  24-Dec-05  3-Jan-06  13-Jan-06  23-Jan-06  2-Feb-06

Angle (degrees)

Daily Rainfall (in.)
Post-Construction Bogachiel Wall Monitoring

- Load cells on tiebacks to monitor long-term wall loads
- Continued conventional monitoring of inclinometers
SR-18 Geogrid Reinforced Block Faced Wall Monitoring
Cross-Section at Instrumented Section for Wall C (WB 1399+00)
Purpose of Instrumentation Program

- Verify wall performance, since a new, less conservative, design technique was used (i.e., the K-Stiffness Method)
- Provide real time, early warning of performance problems so that design adjustments could be made, if necessary
Wall C Reinforcement Design Summary

- **Compound stability controls**
  - $S_v = 2$ ft for all layers, except
    - 1.3 ft bottom 3 layers

- **Total** $T_{al} = 23,250$ lbs/ft
- **Total** $T_{al} = 35,780$ lbs/ft
Wall D Reinforcement Design Summary

- **UXK1100**
  - Depth Below Wall Top, Z (ft)
  - K-Stiffness Method
- **UXK1400**
- **UXK1500**
- **UXK1600**

**Compound stability controls**

- **Total $T_{al} = 5,765$ lbs/ft**
- **Total $T_{al} = 16,735$ lbs/ft**

- $S_v = 2$ ft for all layers

**K-Stiffness Method**

**AASHTO Simplified Method**

**Reinforcement Long-Term $T_{al}$ Required (lbs/ft)**
Installation of First Geogrid Layer and Facing Connection – Wall C
Close-Up of facing Connection with Geogrid
Wall Face Connection Problems

- HDPE Connector
- Fiberglass alignment pin
Wall C Strain Gauge installation, 1st Instrumented Layer (6/29/04)

Note: Wood slats removed prior to final layer installation.
Wall C 2nd Instrumented Layer (7/12/04)

Strain gauges covered with sand
Automated Data Acquisition Cabinet at Wall C

Campbell CR-10X datalogger

AM416 Multiplexer (16 channel, 4 wire input)
Wall C as Completed – Instrumented Section

Survey target

Instrumentation cable conduits

Data acquisition system
Wall C at effective EOC, but with facing stiffness reduced (w = 8 in., effective column height = 2 ft) - K-Stiffness Class C Prediction

Note: Previous load factor of 1.5 used

Using as measured parameters:
\[ \phi_{ps} = 54^\circ \]
\[ \gamma = 140 \text{ pcf} \]
Wall C at effective EOC, but with facing stiffness reduced (w = 8 in., effective column height = 2 ft) - Class C Prediction of Maximum Facing Deflection as a Function of Total Wall Height

Using as measured parameters:
\( \phi_{ps} = 54^\circ \)
\( \gamma = 140 \) pcf
Small Excavator Used to Place Facing Blocks
Facing Batter Adjustment Technique Using Small Excavator
Facing Batter Adjustment Technique Using Small Excavator
Result of Facing Batter Adjustment Technique

- Poor facing alignment
- Damage to extensometers
- Excessive geogrid strain at connection with facing (observed only at Instrumentation layer 3)
Jump here from 0.12 to 0.35% strain is likely due to forced wall face alignment shift by contractor.
Wall C Profile at Instrumented Section

Note: Yellow line is visual aid to assist in seeing face batter variances.
SR-18 Walls C and D Summary

• The K-Stiffness method primarily reduces the amount of reinforcement needed in the lower half of the wall in taller walls, but significantly reduces reinforcement needs at all levels in walls less than 20 to 25 ft in height.

• For Walls C and D, the amount of reinforcement was reduced by 30 and 50%, respectively, relative to AASHTO requirements (materials cost savings of 20 and 40%, respectively, resulting in an estimated savings of $62,000).
SR-18 Walls C and D Summary, Cont.

- Contractor wall face/connection installation technique can have a significant effect on reinforcement stresses and strains
  - Poor geosynthetic tensioning can result in slack at connection, lowering stresses, but increasing deformation and likelihood of face batter problems
  - Poor compaction at face can increase downdrag loads and connection stresses
  - Forced facing batter adjustments can increase loads by 20 to 30%

- Therefore, it may very important to vigorously inspect the facing/reinforcement connection construction activities
Lessons Learned Regarding the Benefits of Real Time Monitoring of Deformation, Load, or other parameters

• Deformation measurements combined with a written and/or digital photographic record of construction can be used by Geotech Division staff to:
  – Accurately assess what is really happening as construction takes place through data that could not be obtained through visual observations (i.e., as a construction inspection tool)
  – Maximize the effective use of staff time and minimize travel time
  – Tie structure performance problems to construction activities and weather conditions
  – Adjust the design, if necessary, should performance problems occur, before it is too late

• Real time monitoring can be especially useful when stabilizing unstable areas (i.e., the FS is low, and construction technique and adverse weather can have a significant influence on performance)
Lessons Learned Regarding the Benefits of Real Time Monitoring of Deformation, Load, or Other Parameters

• Real time monitoring can also be useful to monitor landslide and rockfall movements to provide a warning to the public regarding an emergent safety concern – if a threshold is exceeded, measurements can automatically be tied to variable message sign or beacon to warn public – data can also be transmitted remotely using modem, modem/radio or satellite link

• Disadvantages of real time monitoring:
  – The contractor must learn to work around instrumentation and associated cables to prevent damage to the instrumentation
  – Long-term installations can be subject to vandalism or equipment can simply wear out
  – Instrumentation programs can be costly – this type of approach is not for every project – benefit should be assessed on project specific basis
Other Potential Real Time Monitoring Uses

• To monitor vertical movements of a critical facility (e.g., I-5 in downtown Seattle) caused by tunneling activities (e.g., Sound Transit work)

• To provide warning of debris flow or rockfall using geophones and other data if source zone is adequately above highway and there is adequate time before impact to make warning useful

• Monitor crack growth and/or water levels in rock masses using extensometers and piezometers, respectively to warn of impending failure (feasibility depends on site specific conditions)

• Rainfall and groundwater measurements can be tied to landslide movement to aid in landslide analysis (e.g., SR-101 along Hood Canal, and Bogachiel slide)