Real Time Deformation Monitoring for Wall Construction

by

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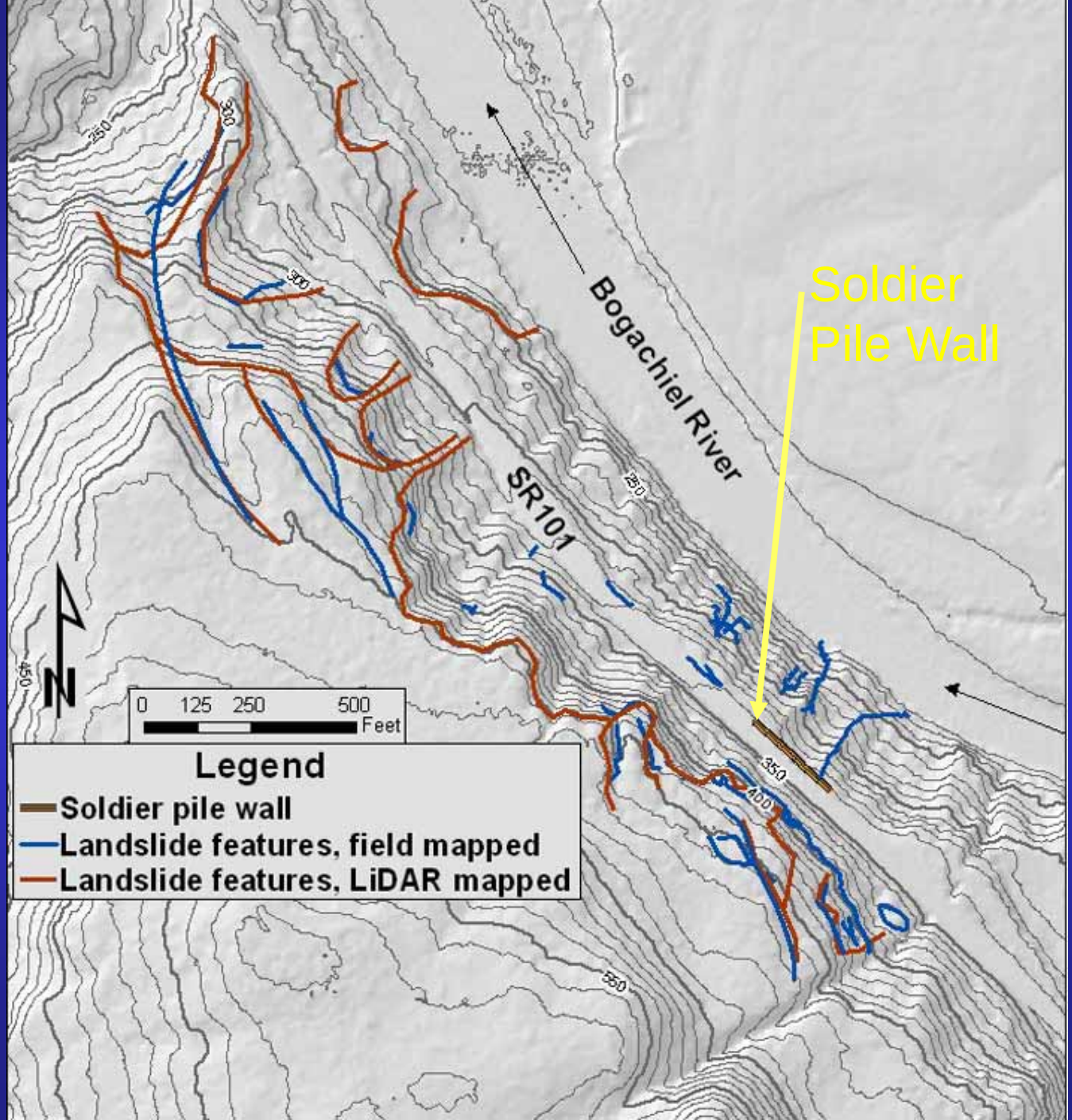
SR-101 Bogachiel Slide Repair

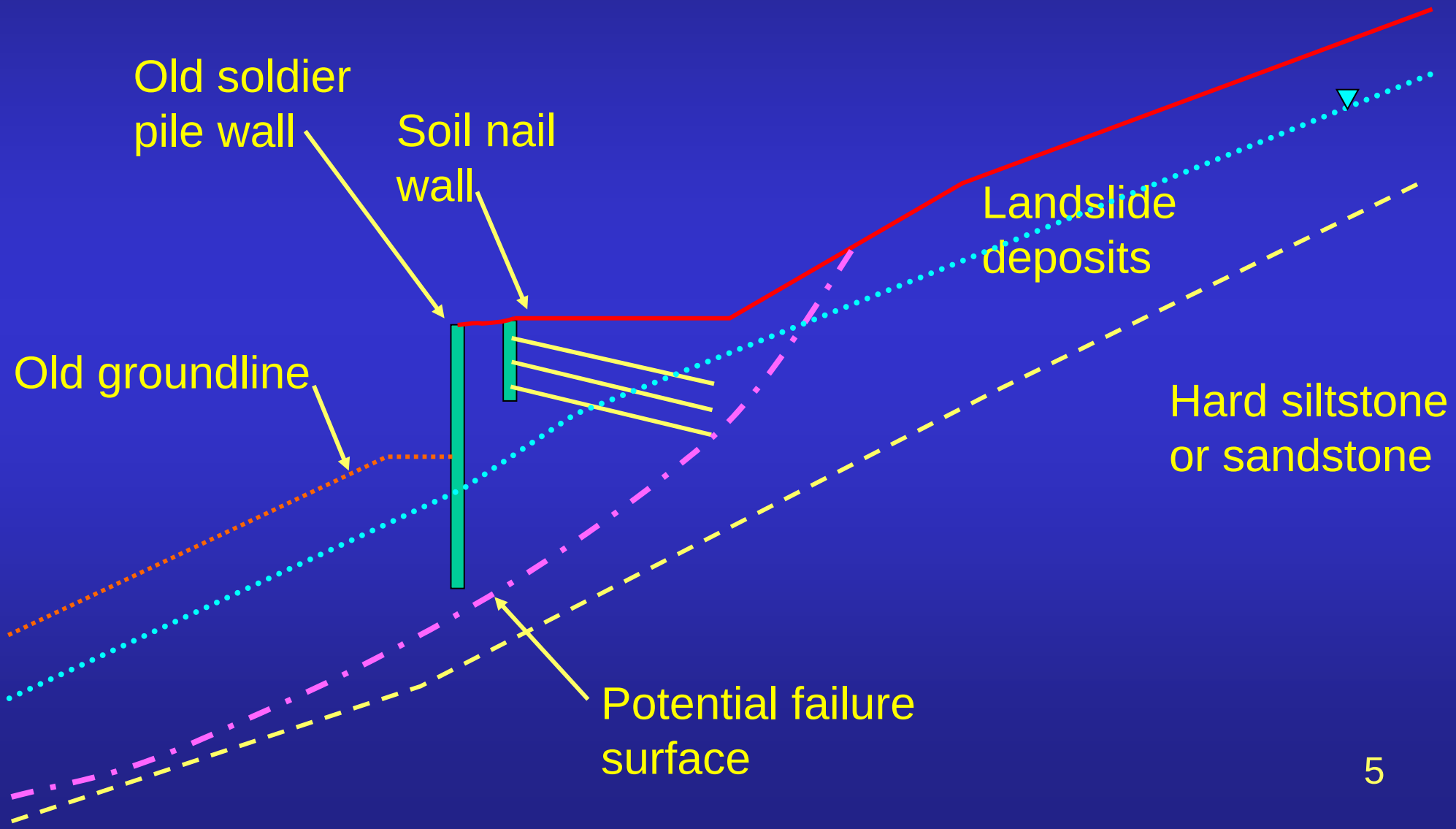


Overview of Slide Area

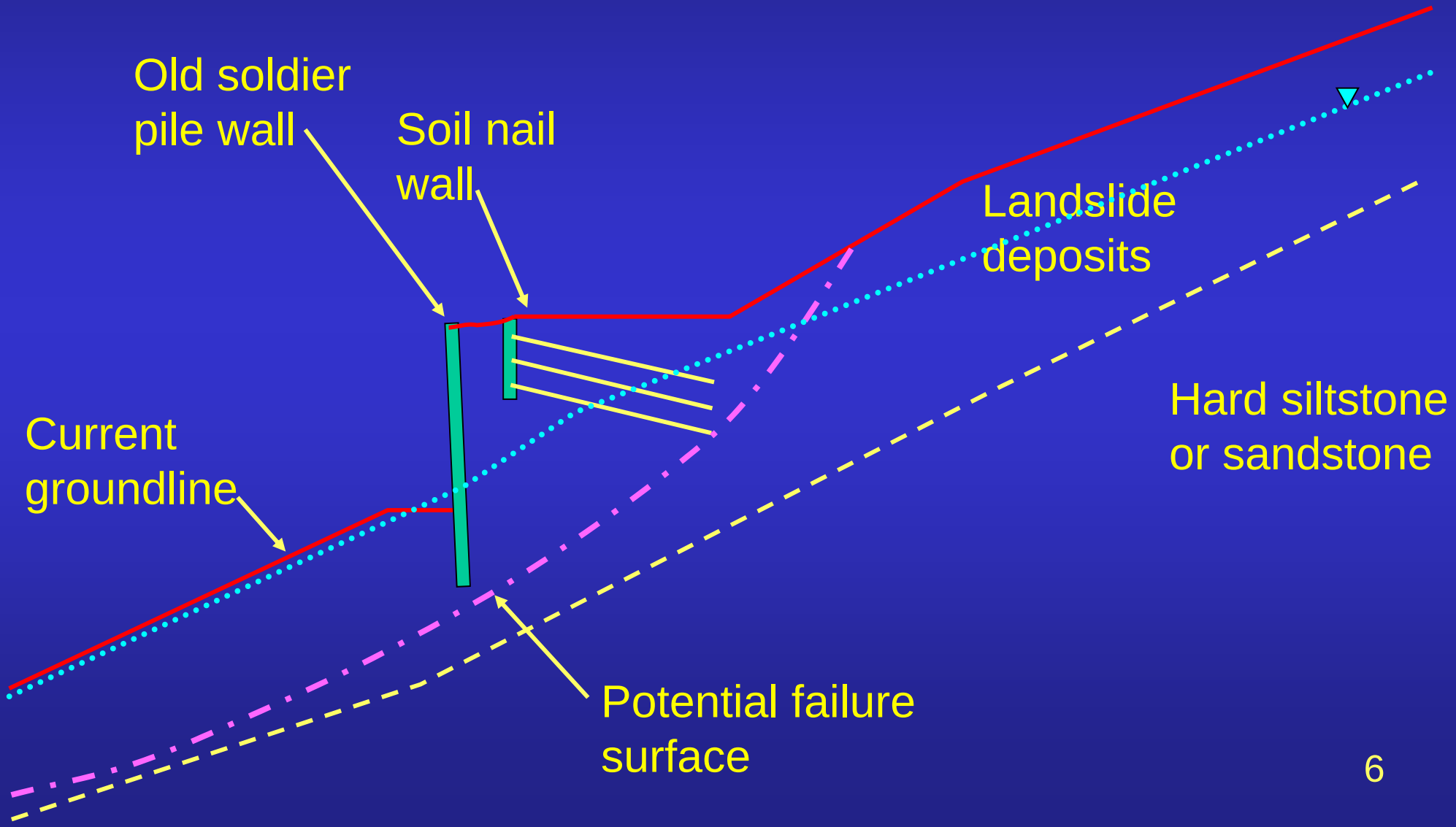
Bogachiel Slide History

- 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

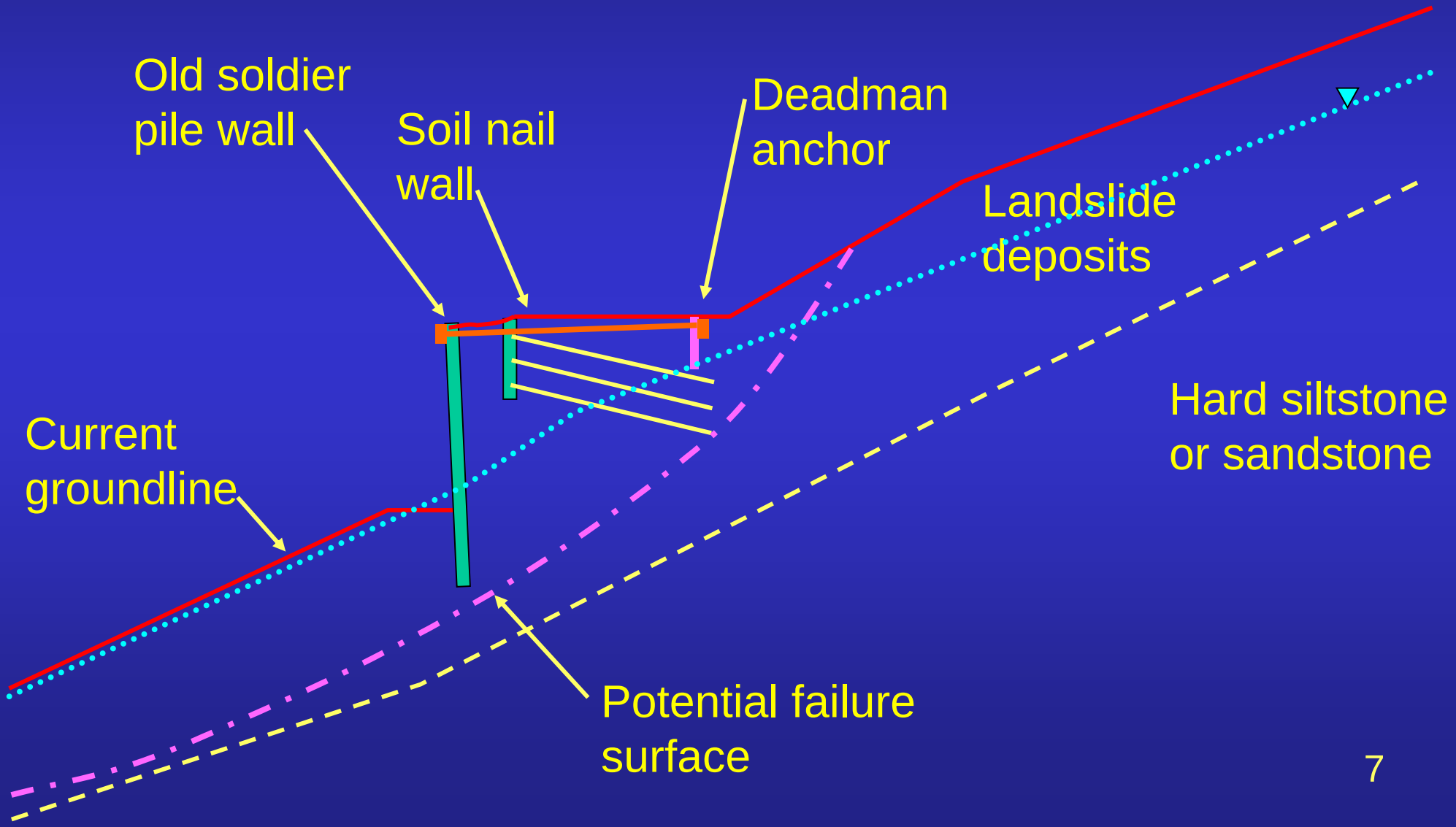
Cross-Section of Previous and New Slide Repairs – Original Condition (11/2004)



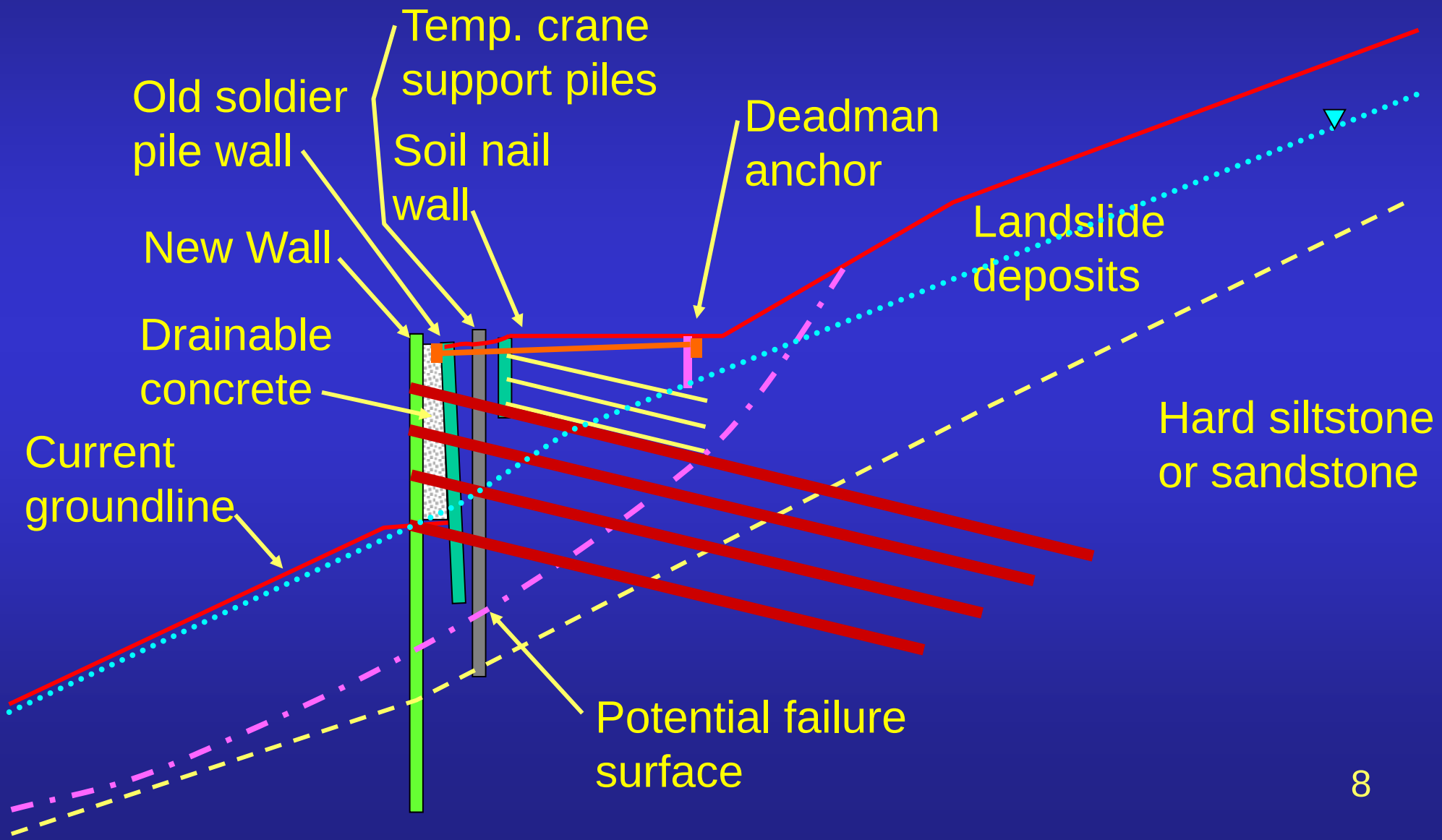
Cross-Section of Previous and New Slide Repairs – Sept. 2005



Cross-Section of Previous and New Slide Repairs



Cross-Section of Previous and New Slide Repairs



Slide Repair Overview

View Down to River from Wall Top

First Slide Repair Wall

Deformation in First Repair Wall

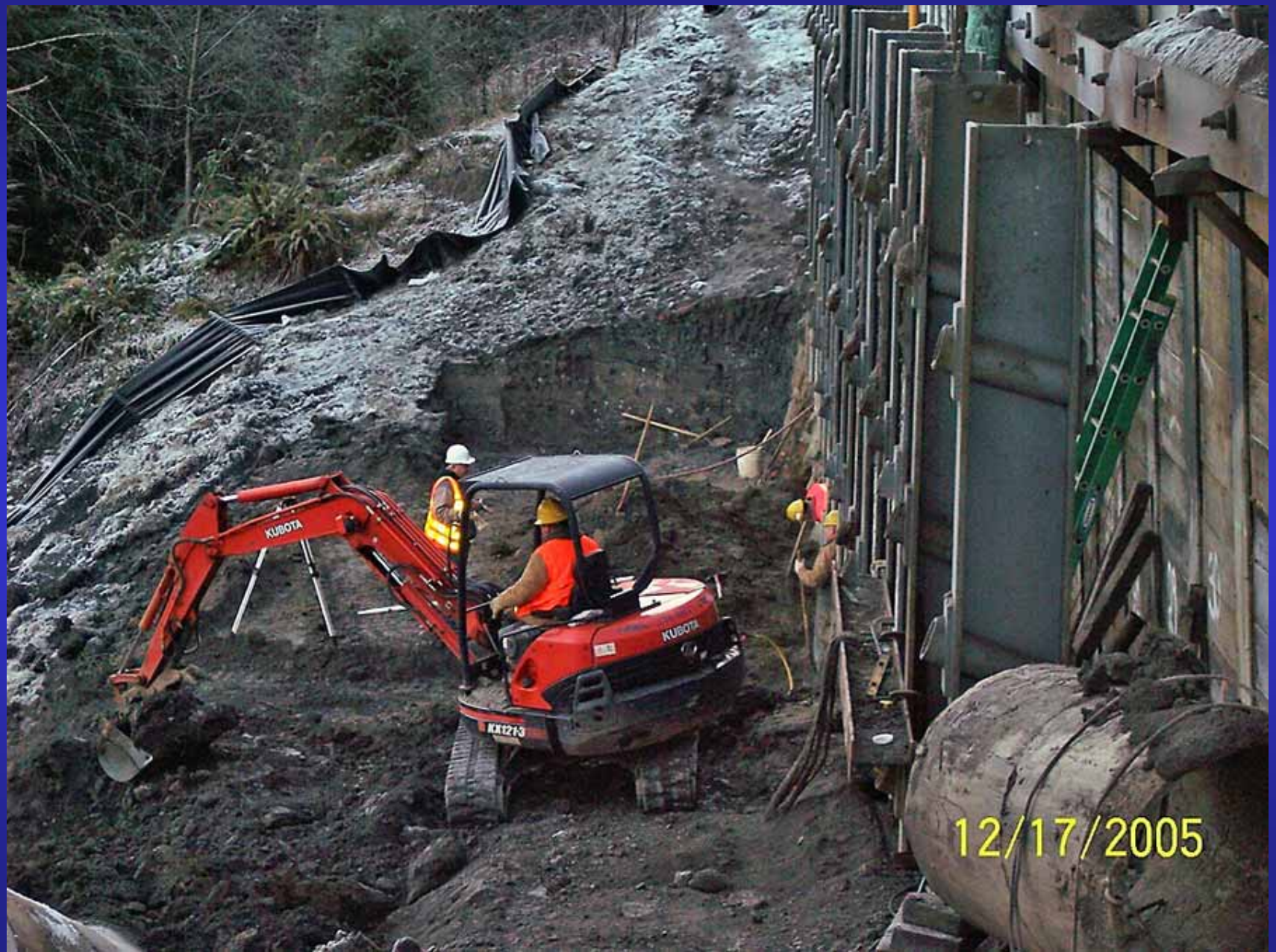
Deadman Installation – 2nd Repair Contract

Deadman Installation – 2nd Repair Contract

Installation of Temp. Crane Support Piles

Installing Soldier Piles for New Wall

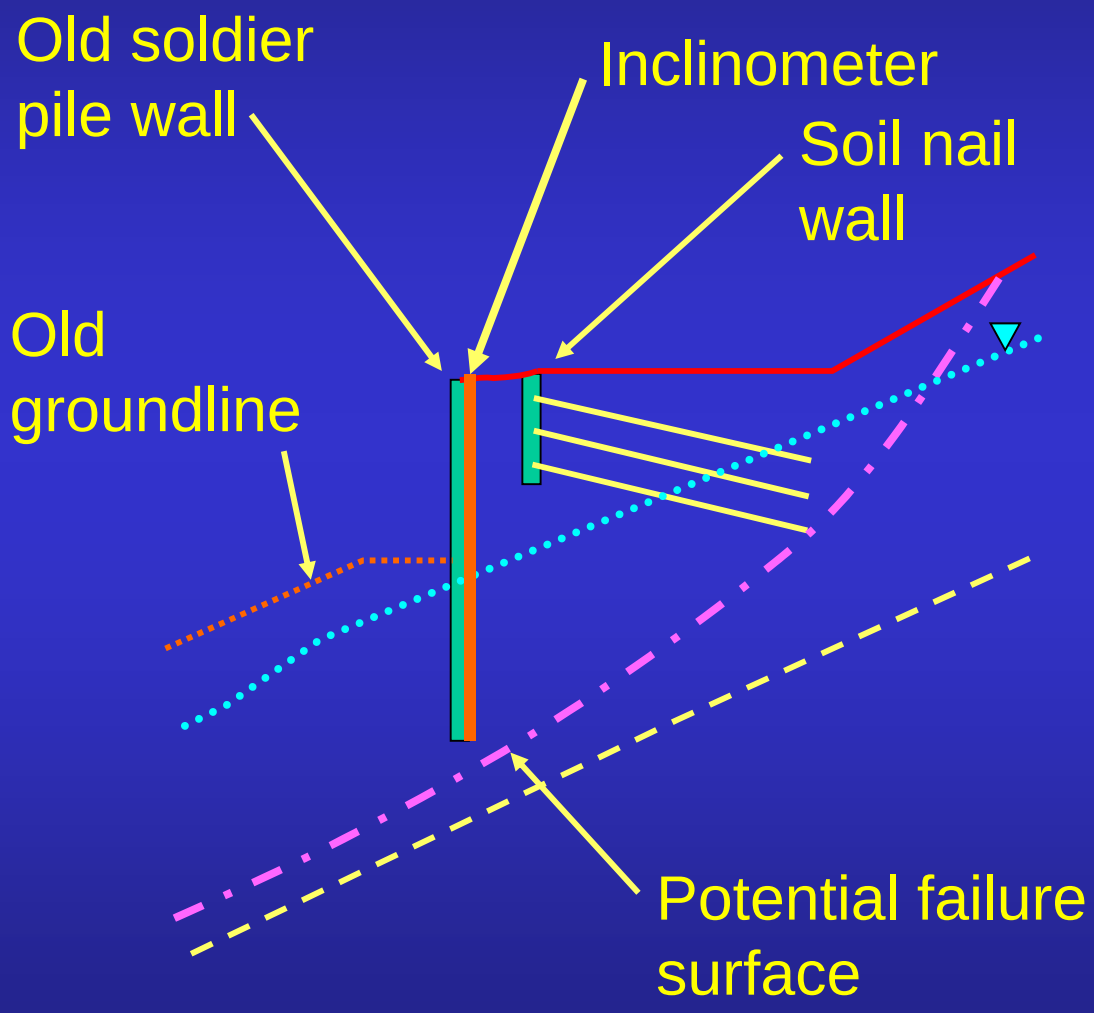
Preparing to Install Bottom Tieback Row

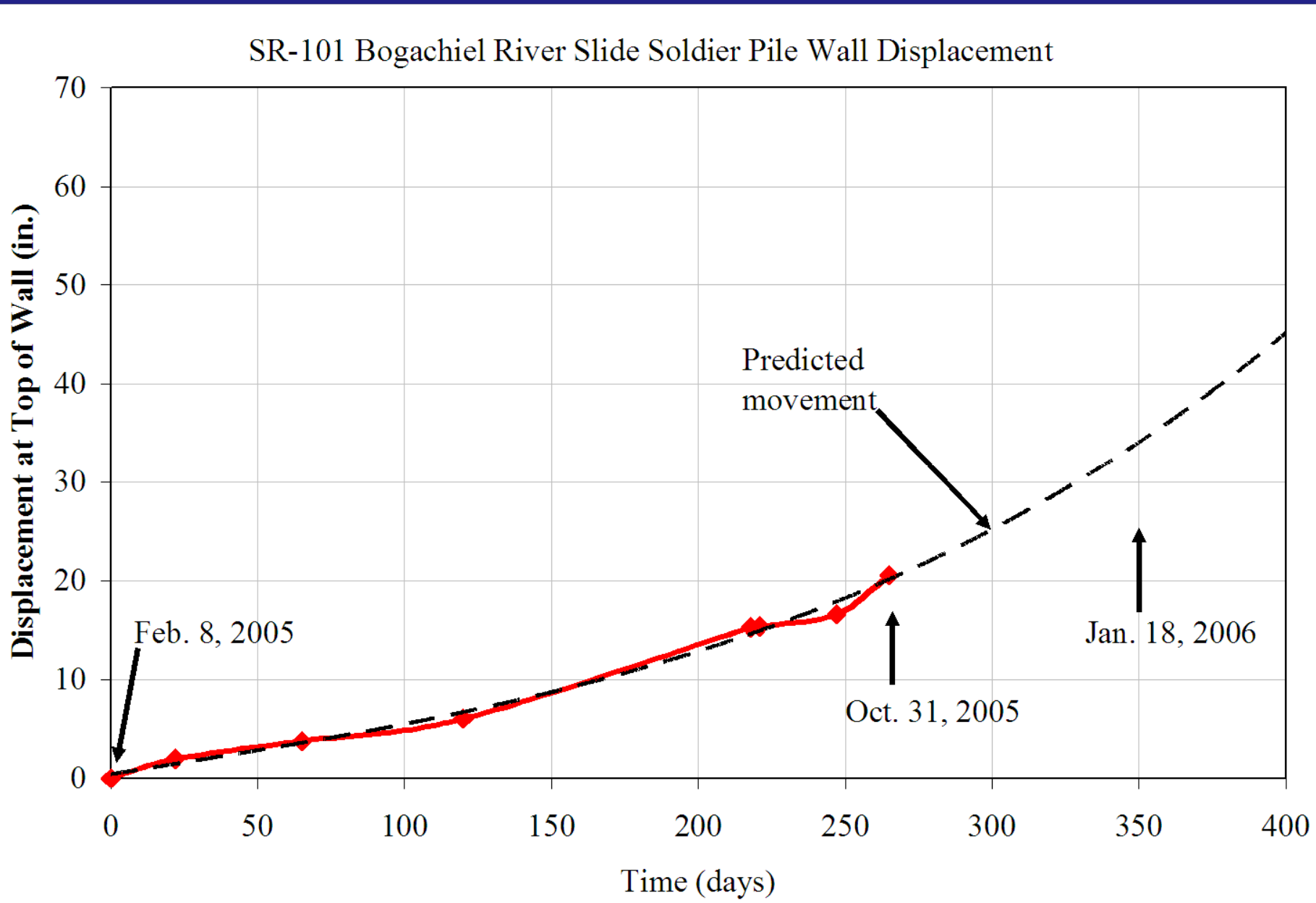


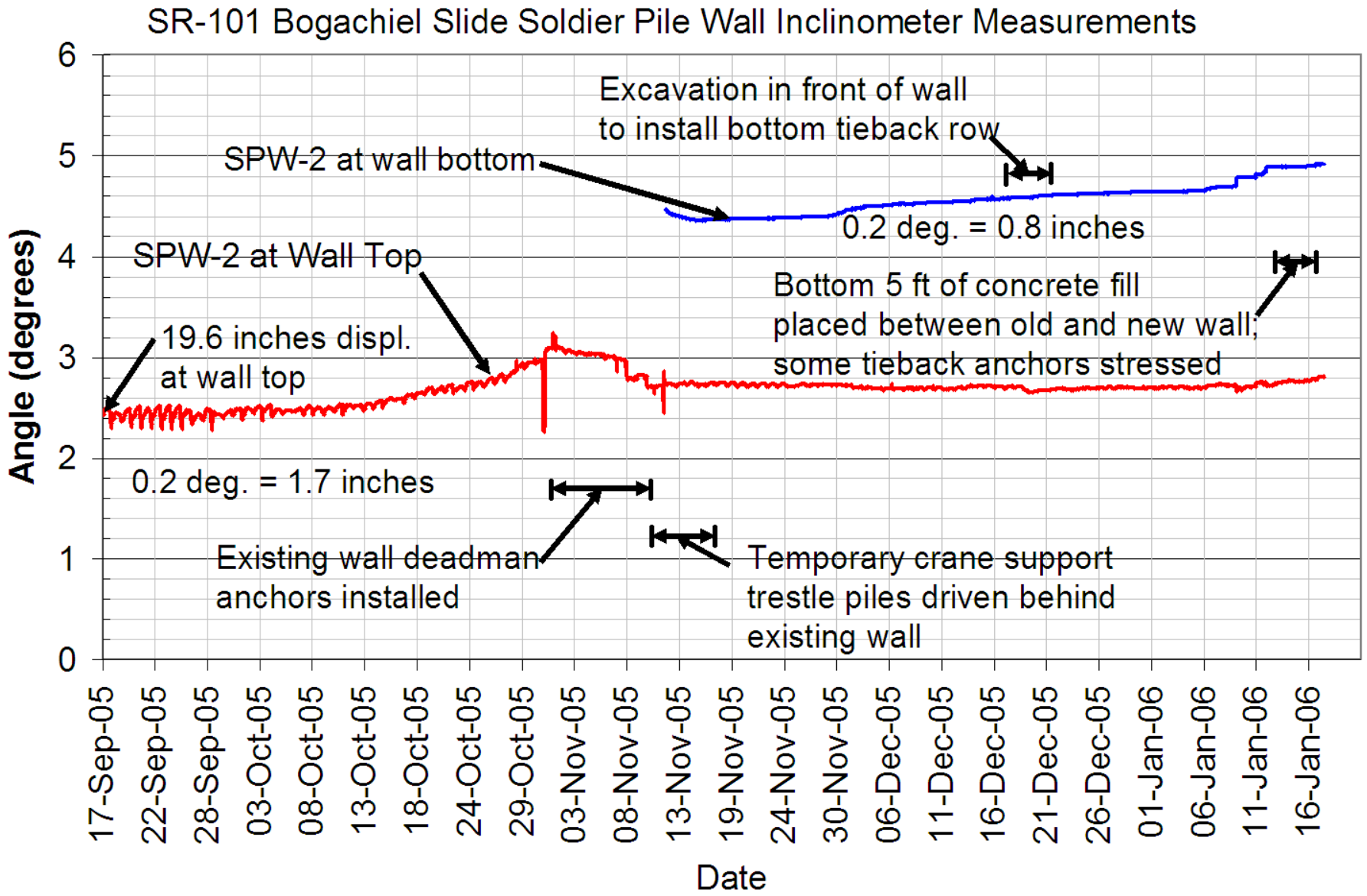
Tieback Installation

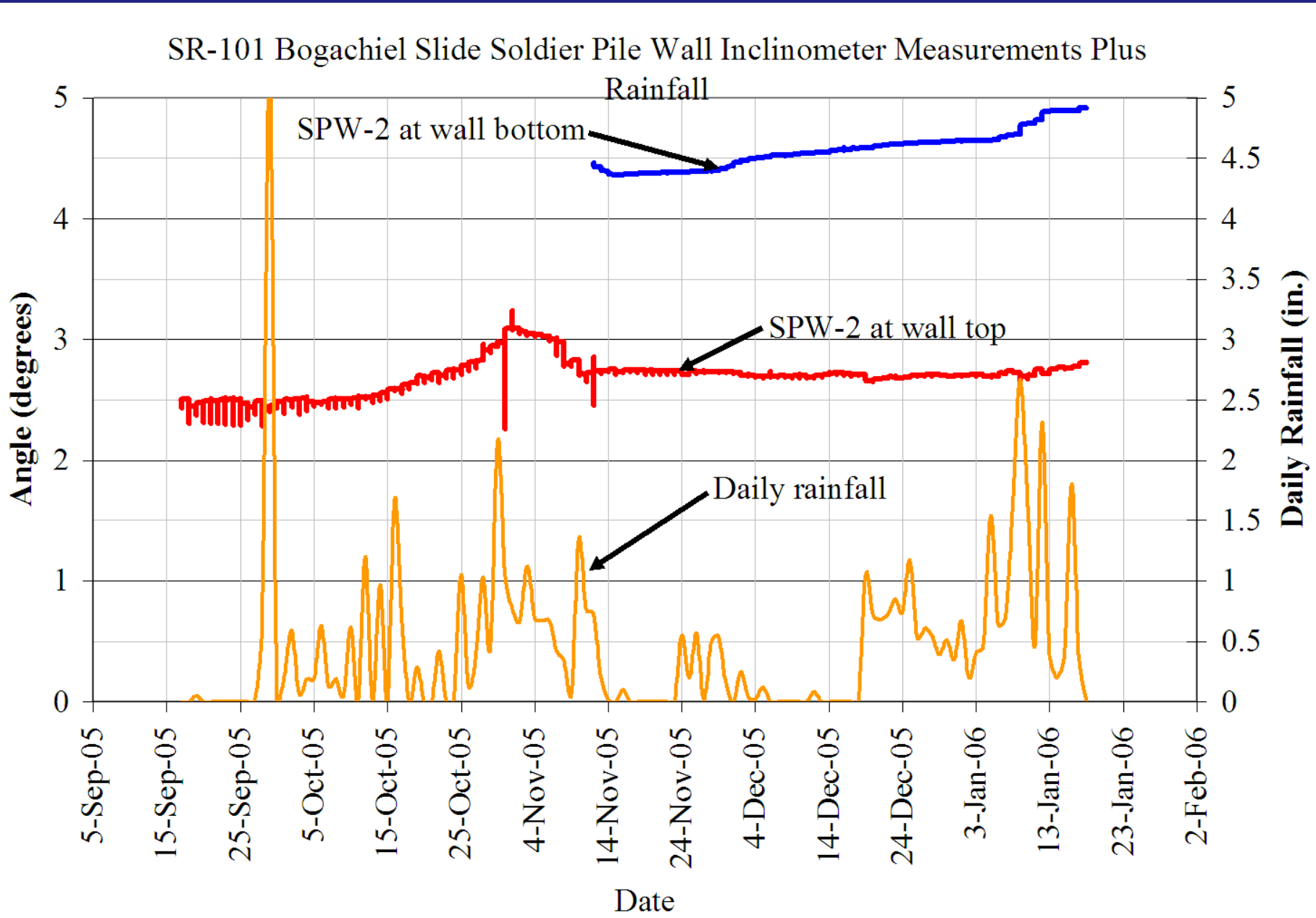
Existing and Permanent Anchored Walls

Inclinometer Location




SR-101 Bogachiel River Slide Soldier Pile Wall Displacement
Displacement at Top of Wall (in.)
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
Time (days)
Predicted movement
Feb. 8, 2005
Oct. 31, 2005
Jan. 18, 2006


SR-101 Bogachiel Slide Soldier Pile Wall Inclinometer Measurements
Angle (degrees)
Date
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
0.2 deg. = 1.7 inches
Existing wall deadman
anchors installed
Temporary crane support
trestle piles driven behind
existing wall
0
1
2
3
4
5
6
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

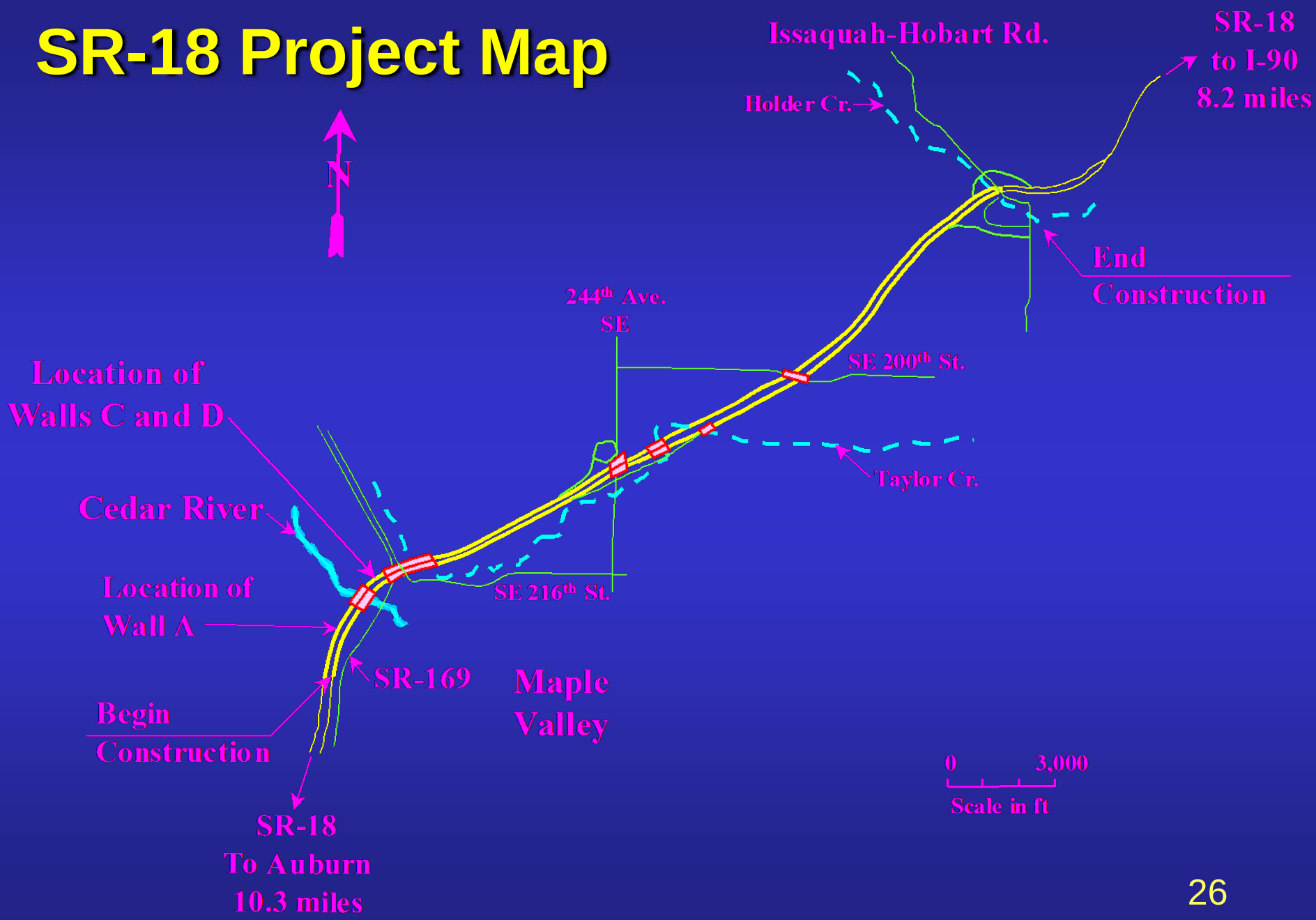

SR-101 Bogachiel Slide Soldier Pile Wall Inclinometer Measurements Plus Rainfall
SPW-2 at wall bottom
SPW-2 at wall top
Daily rainfall
Angle (degrees)
Daily Rainfall (in.)
Date
0
1
2
3
4
5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5-Sep-05
15-Sep-05
25-Sep-05
5-Oct-05
15-Oct-05
25-Oct-05
4-Nov-05
14-Nov-05
24-Nov-05
4-Dec-05
14-Dec-05
24-Dec-05
3-Jan-06
13-Jan-06
23-Jan-06
2-Feb-06

Post-Construction Bogachiel Wall Monitoring

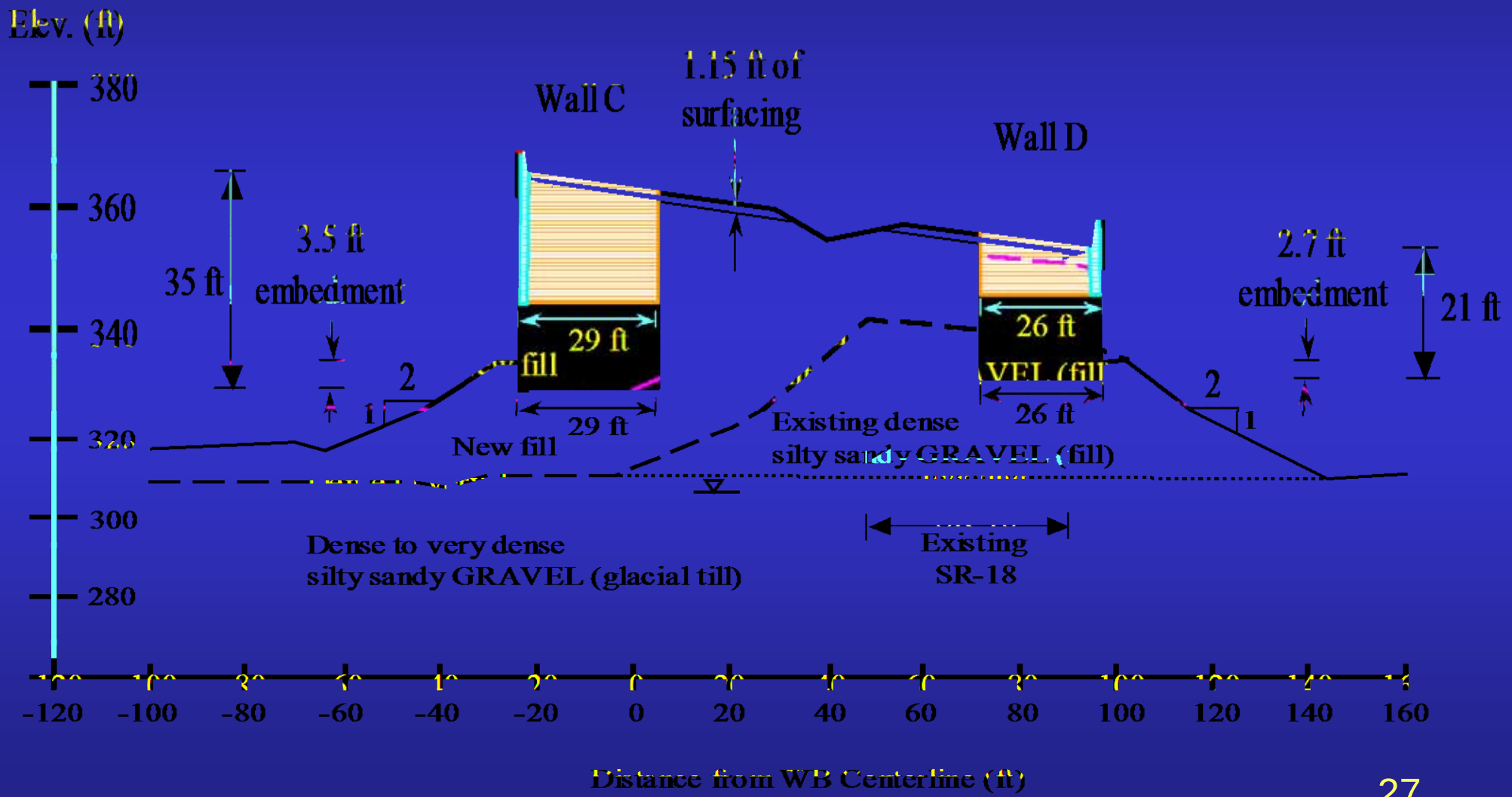
- Load cells on tiebacks to monitor long-term wall loads
- Continued conventional monitoring of inclinometers

SR-18 Geogrid Reinforced Block Faced Wall Monitoring

SR-18 Project Map



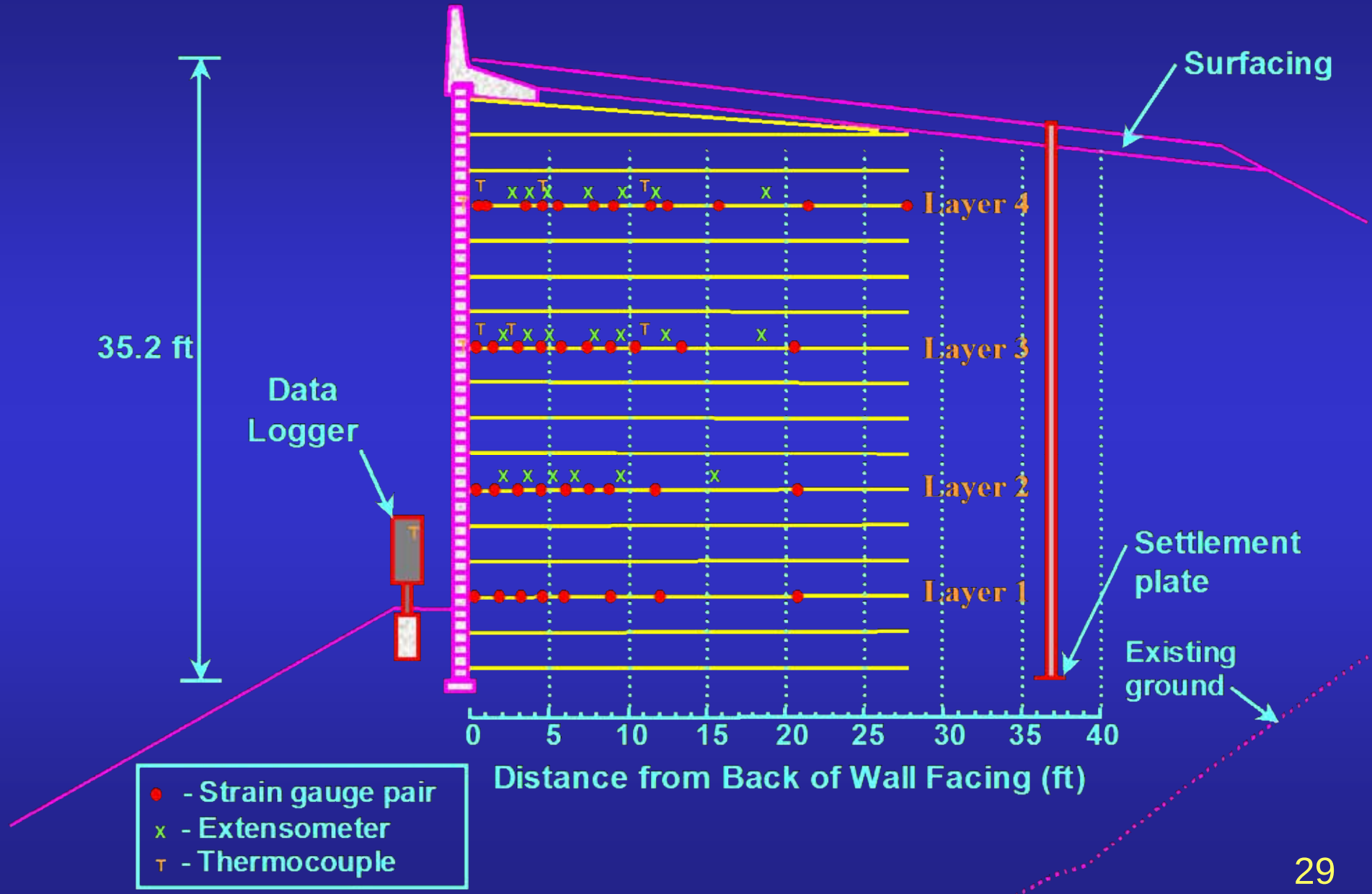
Cross-Section at Instrumented Section for Wall C (WB 1399+00)



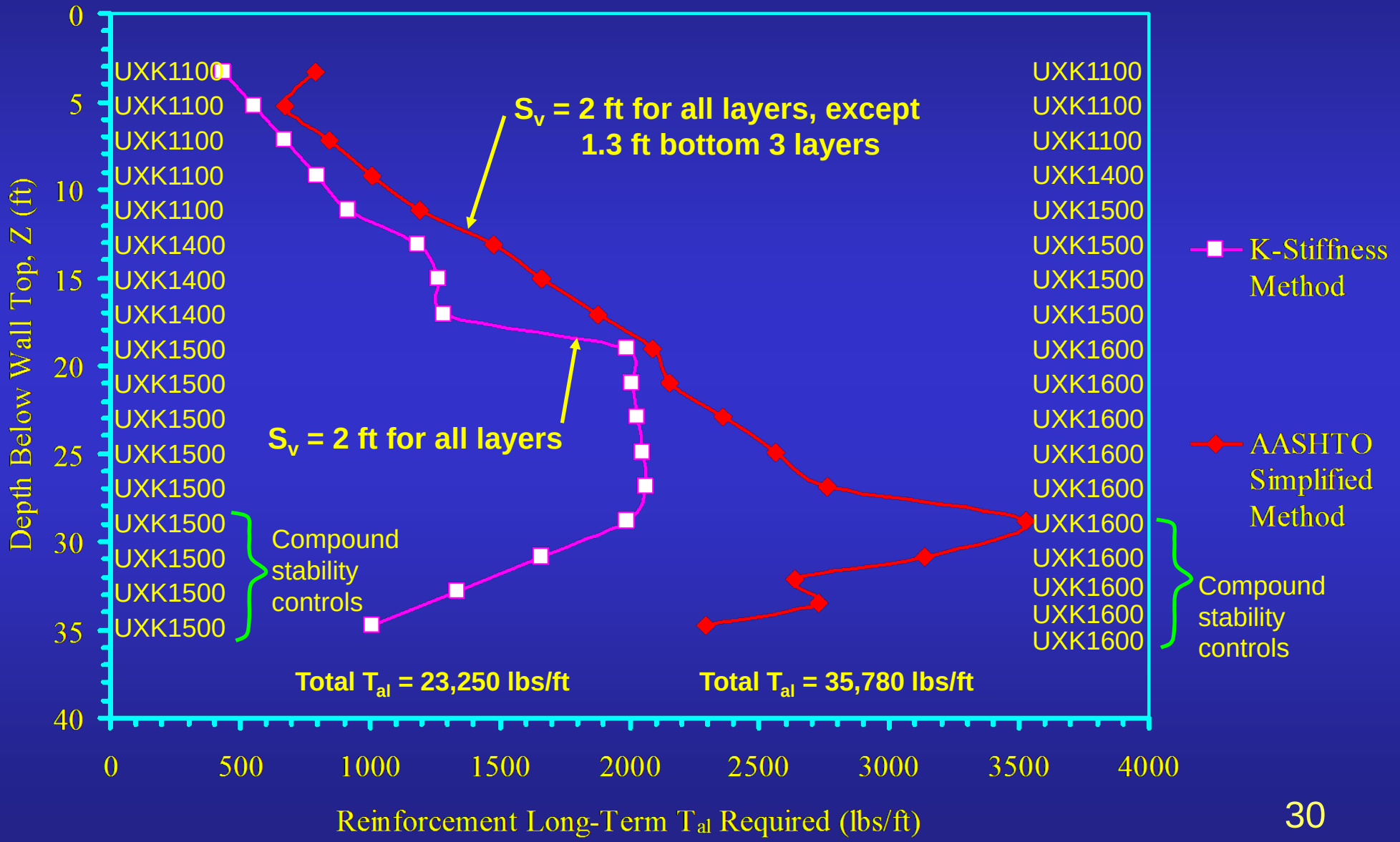
Purpose of Instrumentation Program

- 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

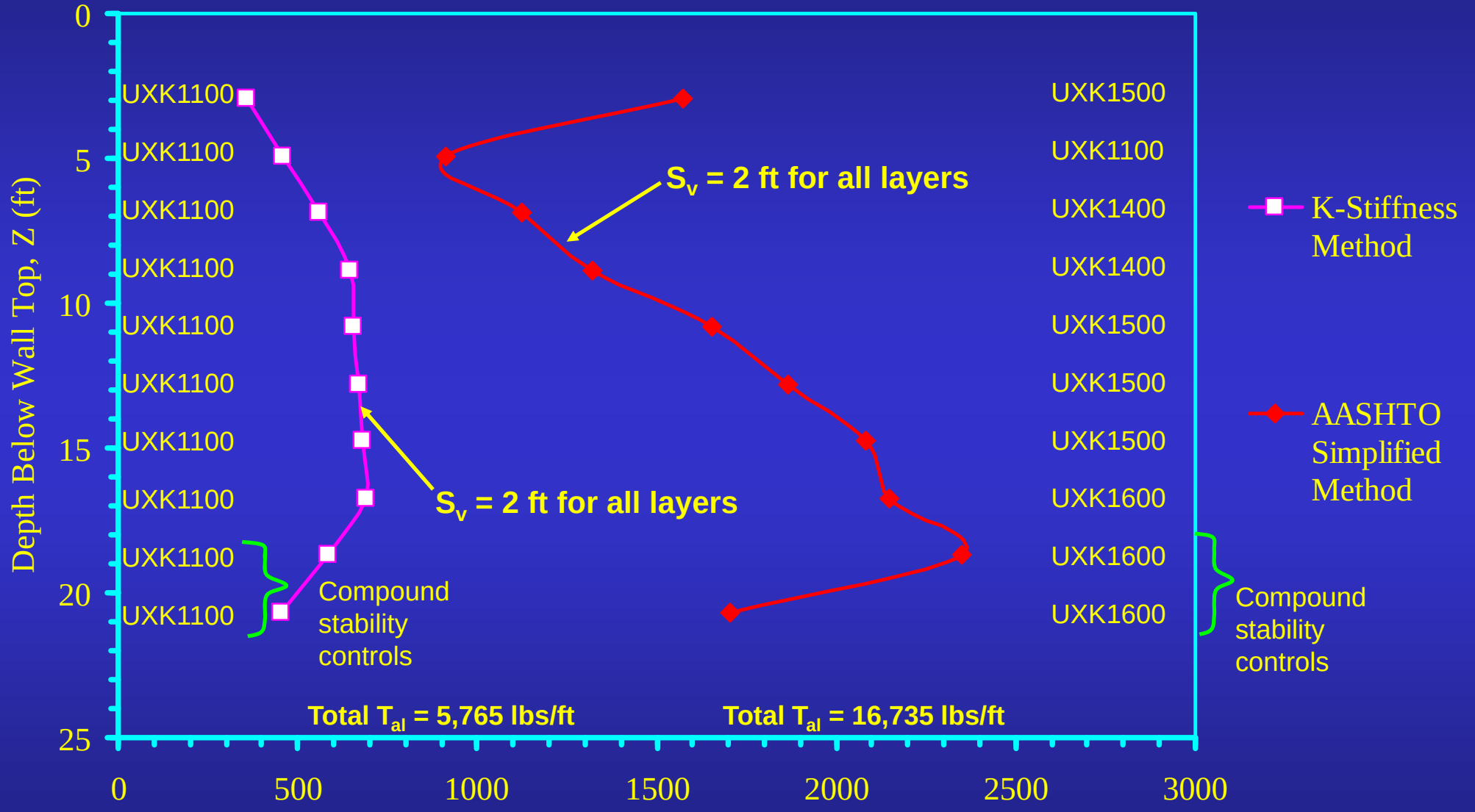
Wall C Instrumentation Cross-Section



Wall C Reinforcement Design Summary



Wall D Reinforcement Design Summary

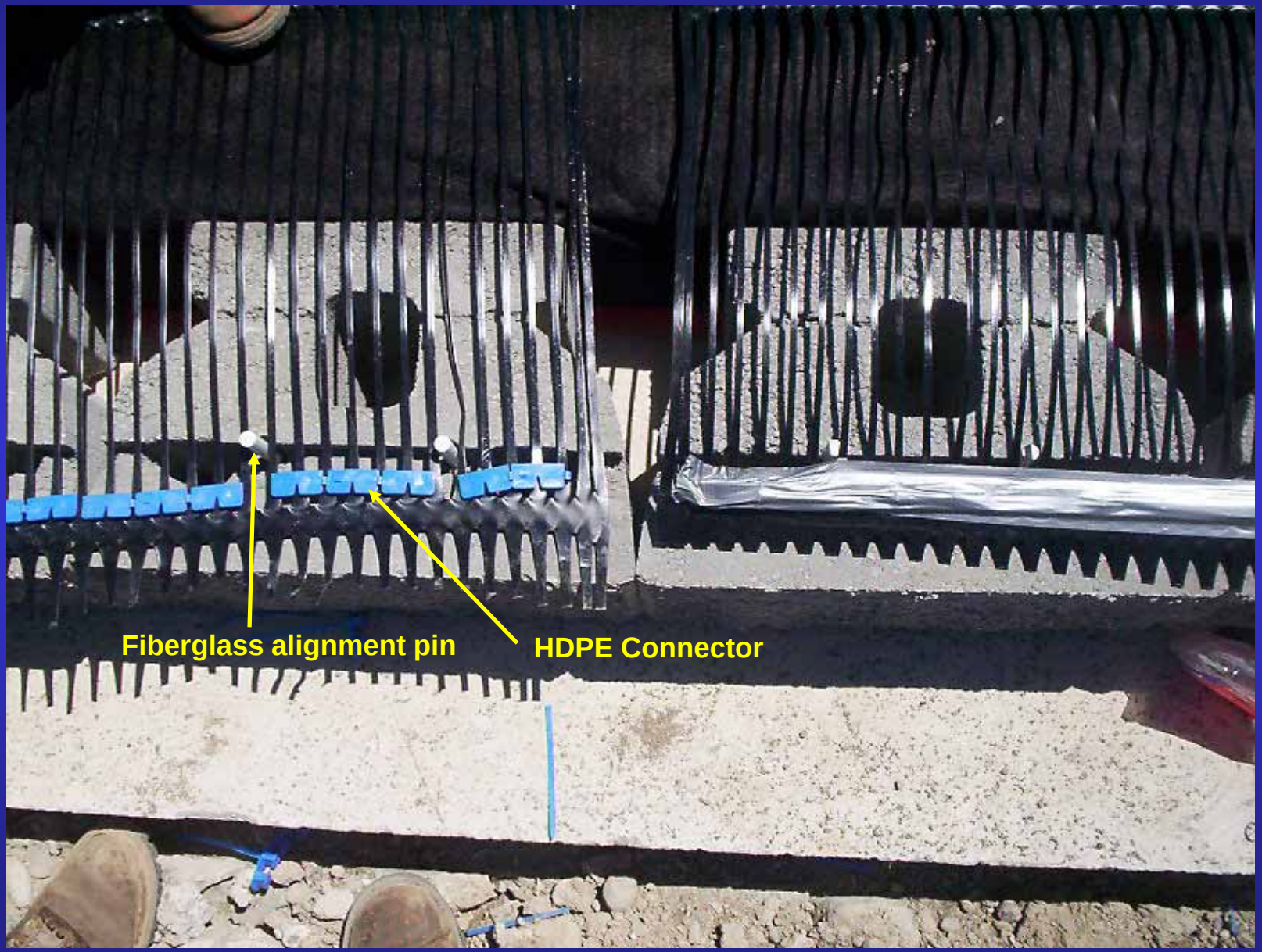


Overview of Wall C during 1st Instrumented Layer Install (6/29/04)

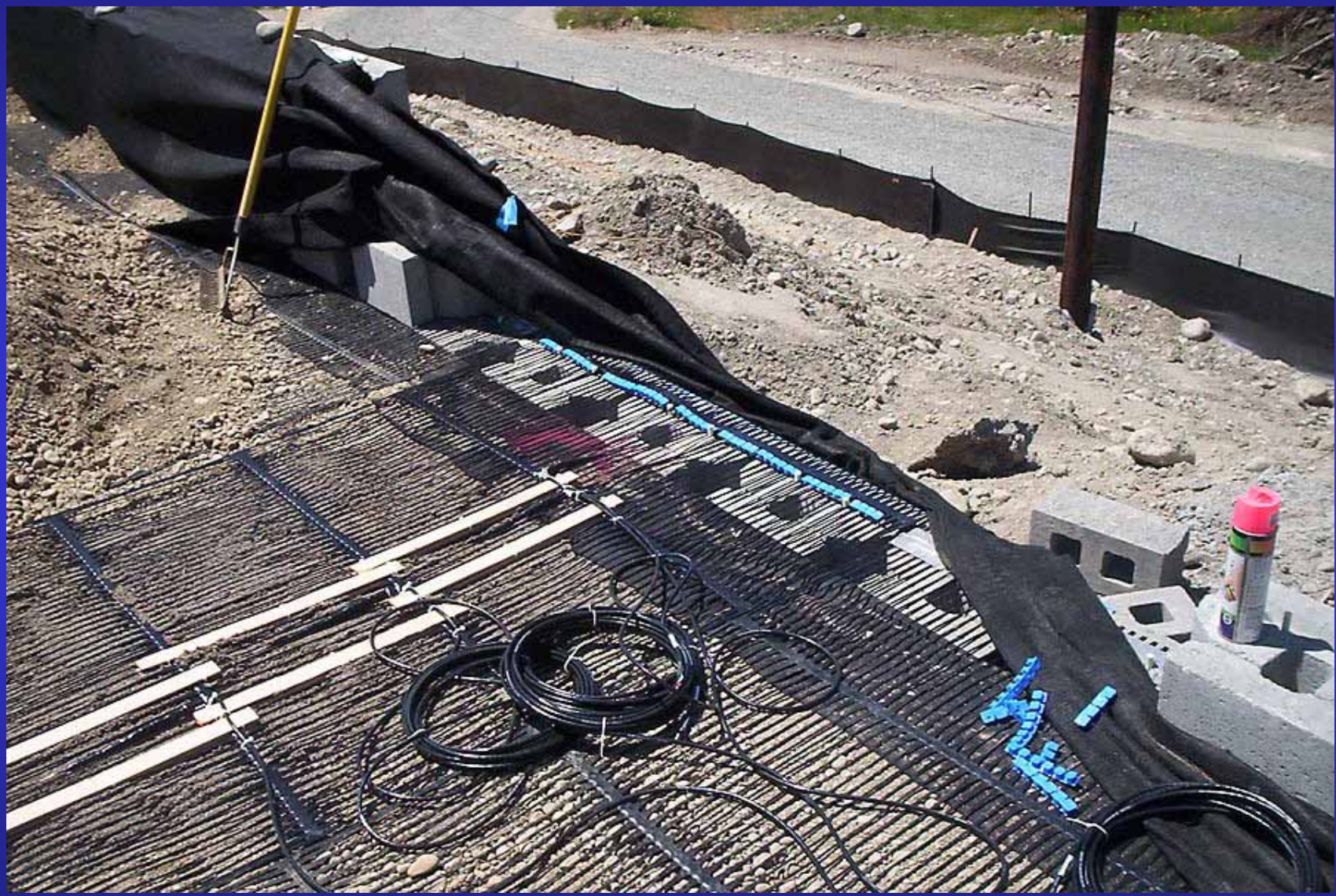
Installation of First Geogrid Layer and Facing Connection – Wall C

Close-Up of facing Connection with Geogrid

Wall Face Connection Problems



Wall C Strain Gauge installation, 1st Instrumented Layer (6/29/04)

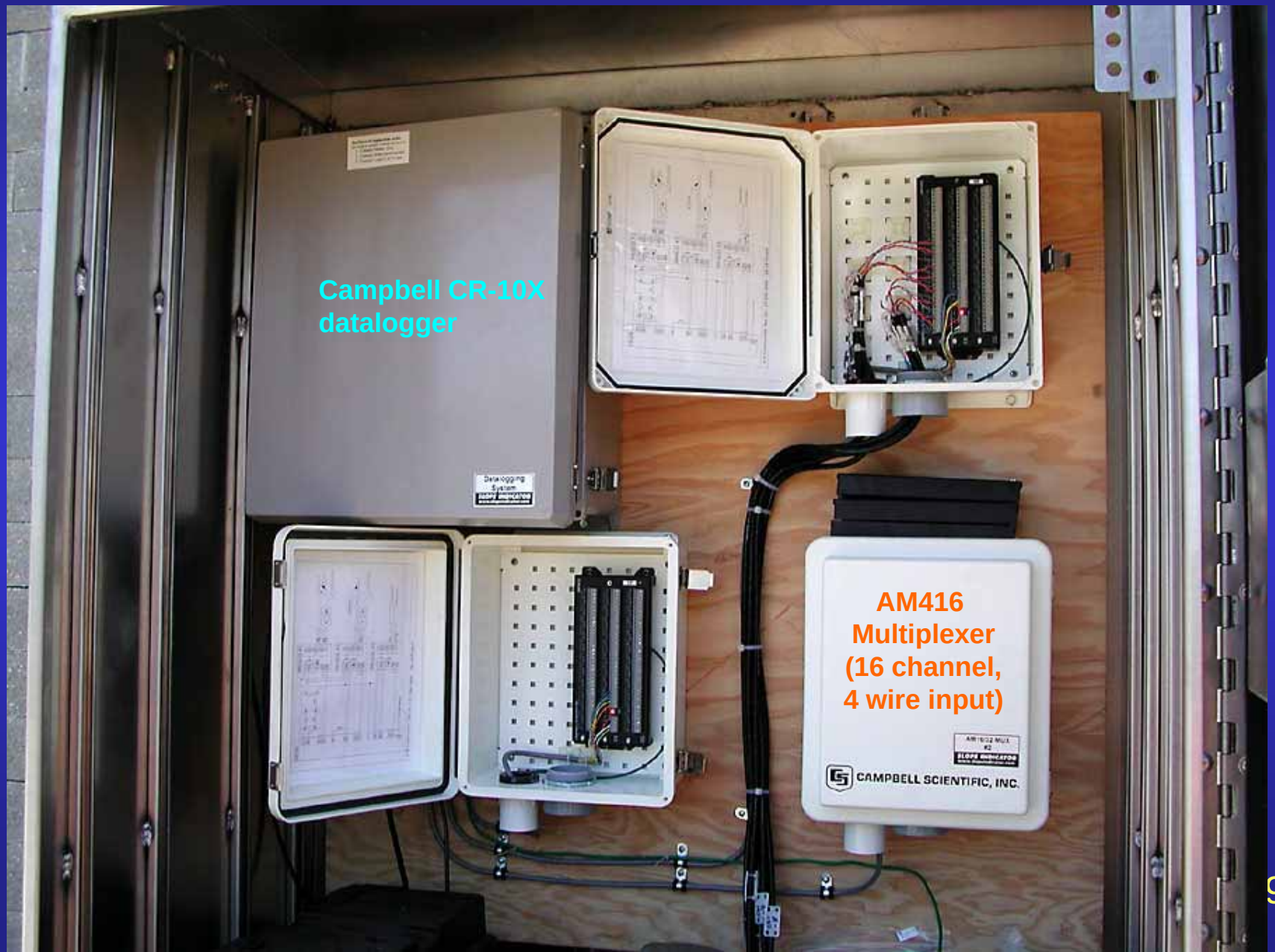


Note: Wood slats removed prior to final layer installation.

Installation of Extensometers in Wall C, 2nd Instrumented layer (7/12/04)

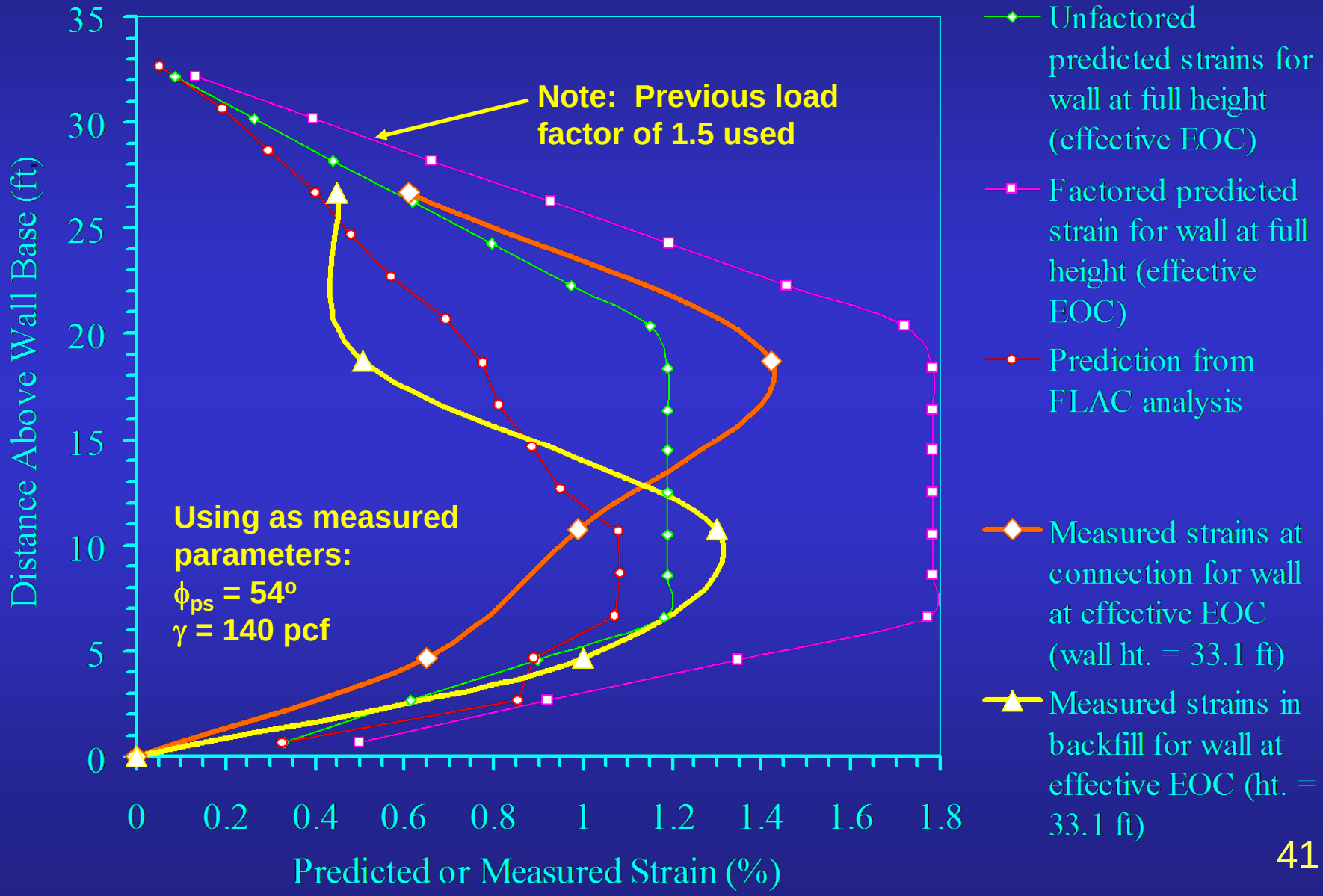
Wall C 2nd Instrumented Layer (7/12/04)

Automated Data Acquisition Cabinet at Wall C

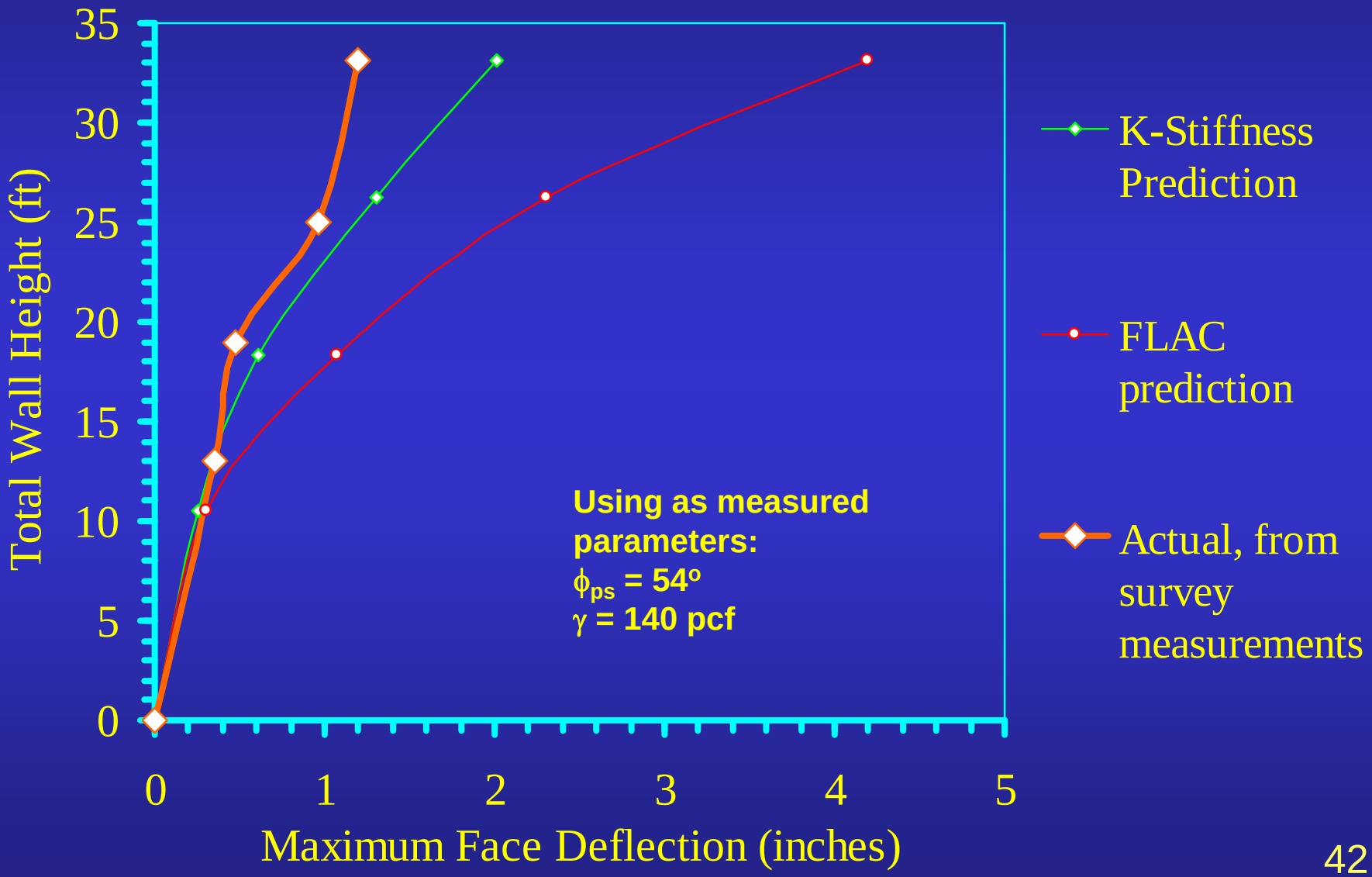


Wall C as Completed – Instrumented Section

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

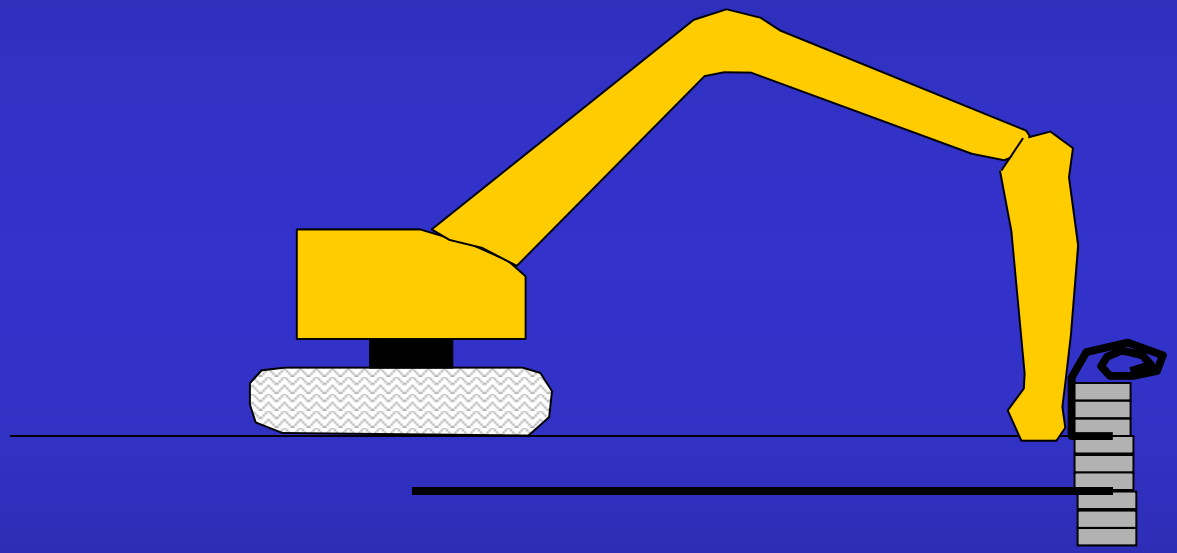


Wall C at effective EOC, but with facing stiffness reduced (w = 8 in., effective column height = 2 ft) - Class C Prediction of Maximum Facing Deflection as a Function of Total Wall Height

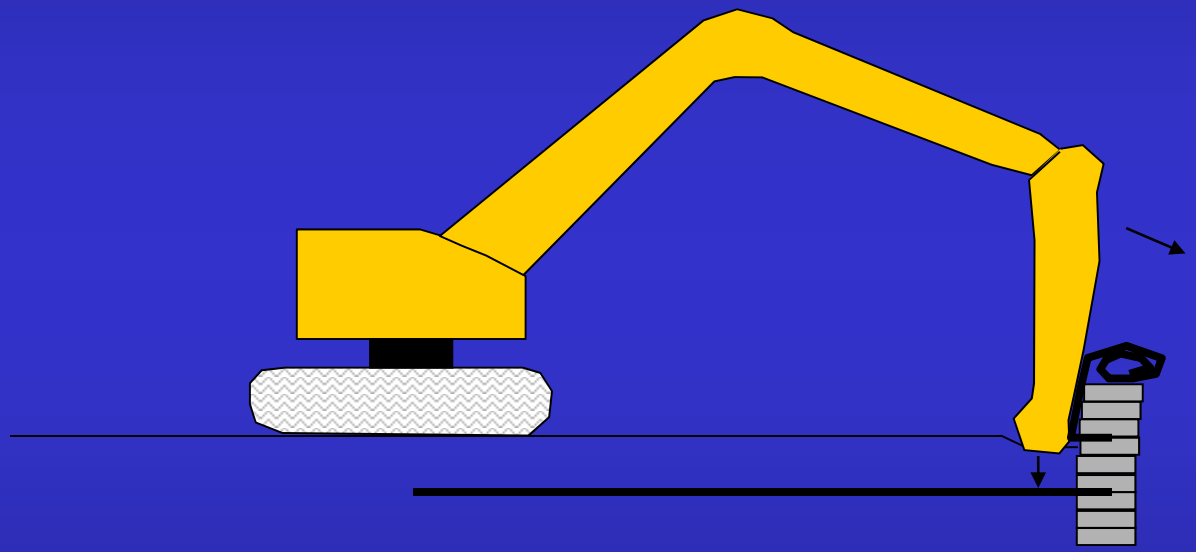


Small Excavator Used to Place Facing Blocks

Facing Batter Adjustment Technique Using Small Excavator

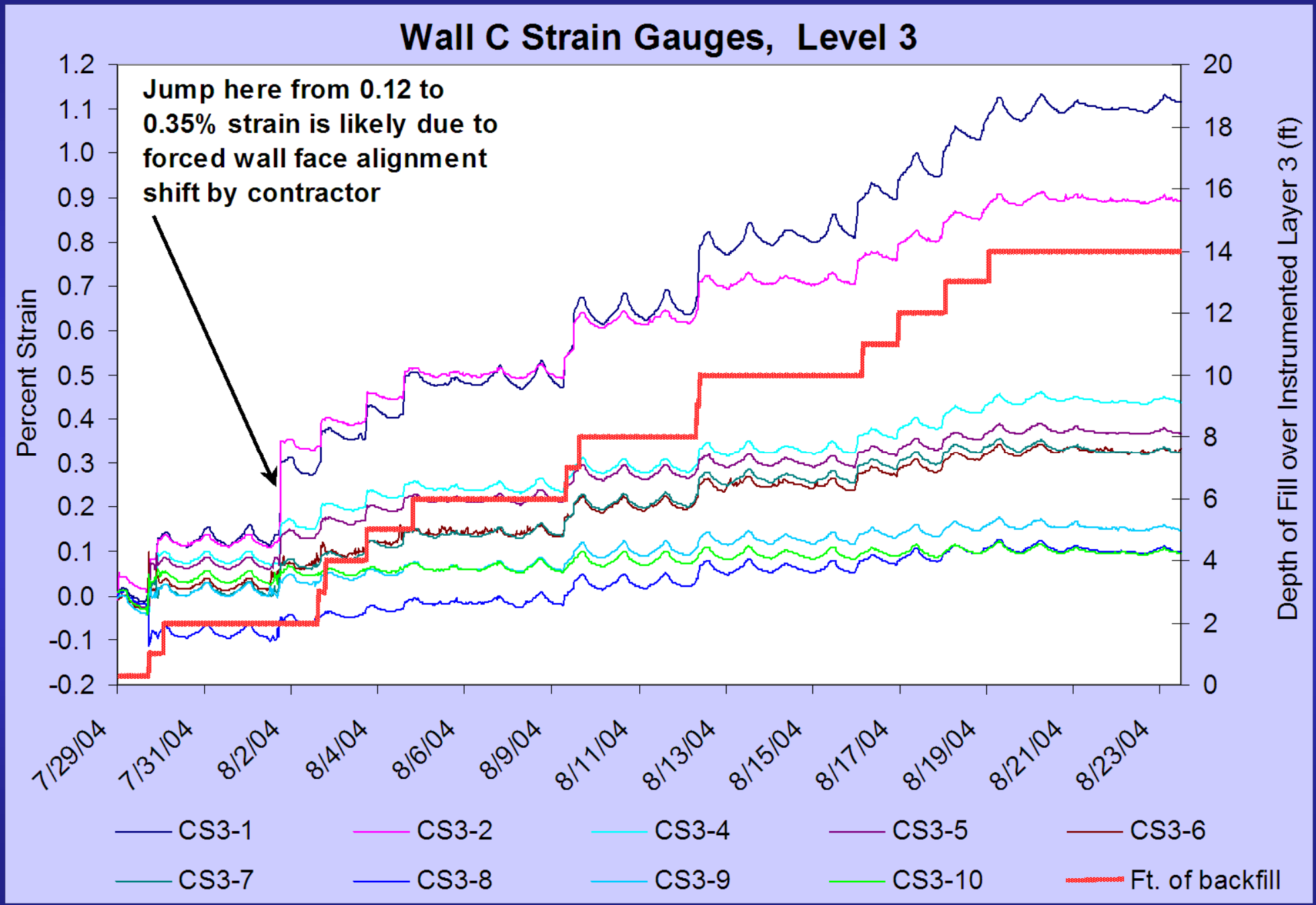


Facing Batter Adjustment Technique Using Small Excavator



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)


Wall C Strain Gauges, Level 3
Jump here from 0.12 to 0.35% strain is likely due to forced wall face alignment shift by contractor
Percent Strain
Depth of Fill over Instrumented Layer 3 (ft)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
20
18
16
14
12
10
8
6
4
2
0
7/29/04
7/31/04
8/2/04
8/4/04
8/6/04
8/9/04
8/11/04
8/13/04
8/15/04
8/17/04
8/19/04
8/21/04
8/23/04
CS3-1
CS3-2
CS3-4
CS3-5
CS3-6
CS3-7
CS3-8
CS3-9
CS3-10
Ft. of backfill

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)