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TRANSPORTATION RESEARCH BOARD

Evaluating the Performance of Retaining Walls and Embankments

September 15, 2021

@NASEMTRB
#TRBwebinar

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- 1.5 Professional Development Hour (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
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#TRBwebinar

Learning Objectives

1. Identify the economy and risk management provided by geotechnical instrumentation and monitoring
2. Identify new design methods and modeling from instrumentation and monitoring of column-supported embankments
3. Discuss the interaction between wall and wall foundations for load support improved by geotechnical instrumentation of full-scale construction

Evaluating the Performance of Retaining Walls and Embankments

Economy and Risk Control

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barryc325@aol.com

Retaining Walls

INTERNALLY BRACED EXCAVATIONS

EXTERNALLY BRACED EXCAVATIONS

MECHANICALLY STABILIZED EARTH WALLS

Geotechnical Questions. Methods of Measurement and Instrumentation?

Why monitor performance?
The real answer--

- **TO SAVE MONEY**
  - Save Lives
  - Minimize Damages
  - Reduce Delays
- **Instrumentation answers questions to remove uncertainties**

- **See "Why Monitor Geotechnical Performance" by Marr for simplified method to help quantify benefits of geotechnical instrumentation.**

Monitoring Schemes

- Confirm design stress levels
- Monitor safety during construction
- Allow modification of construction methods
- Control construction rates

Monitoring Schemes
(cont.)

- Provide base reference for future designs
  - Improve design
  - Improve economy
  - Confirm performance of materials
  - Allow use of new materials
- Establish maintenance requirements

Monitor when:

undesirable outcome $ x probability of occurrence > monitoring $

Instruments for monitoring Retaining Walls & Embankments

Golden Rules of Instrumentation

- Every instrument must have a purpose (every instrument should provide data to help answer a question)
- Instrumentation program must be planned and executed in a systematic way
- Watch the details

Principal Measurements

- Groundwater Level and Flow
- Lateral and Vertical Deformation
- Strain
- Load and Pressure
- Time and Temperature

Ground water

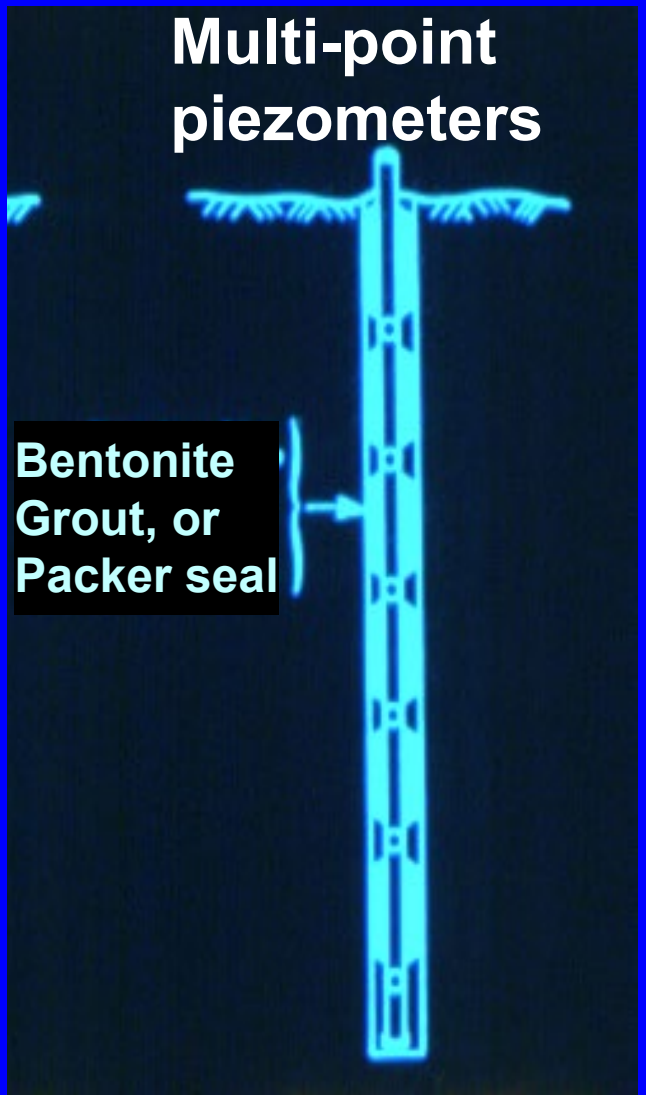
Piezometers

➢ Open standpipe

➢ Piezoresistive

➢ Vibrating Wire

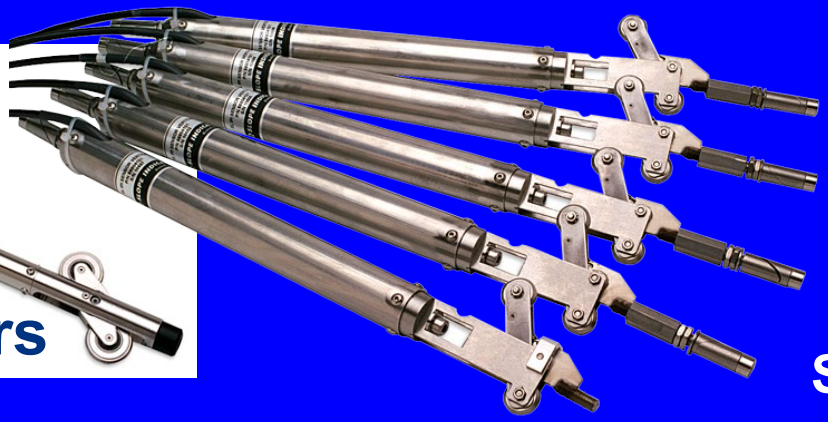
Moisture meters & Tensiometers

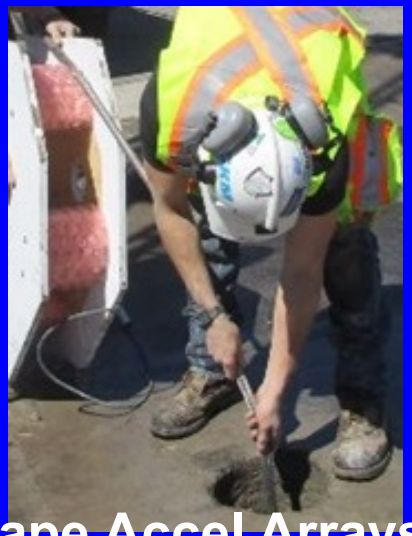


Deformation Measurements

- Crack gages

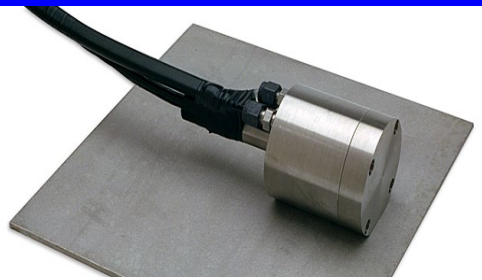
- Inclinometers





Shape Accel Arrays

Laser Extensometers ±1 mm in 100 m



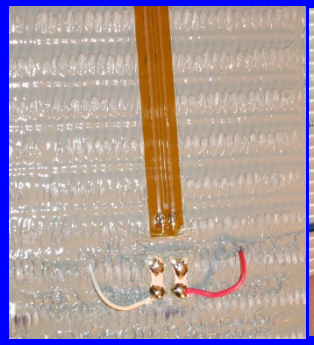
- Pore pressure transducer Profilers

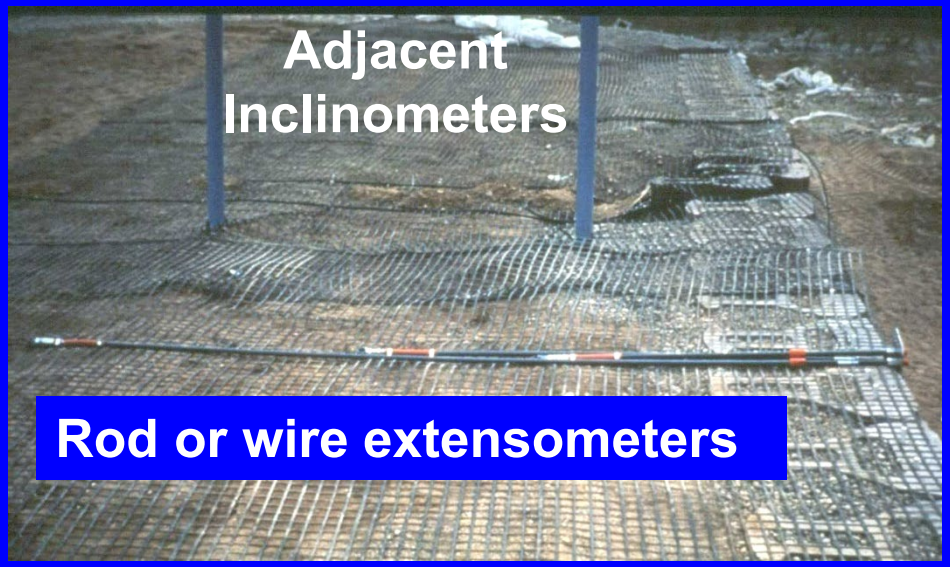
- Tilt meters

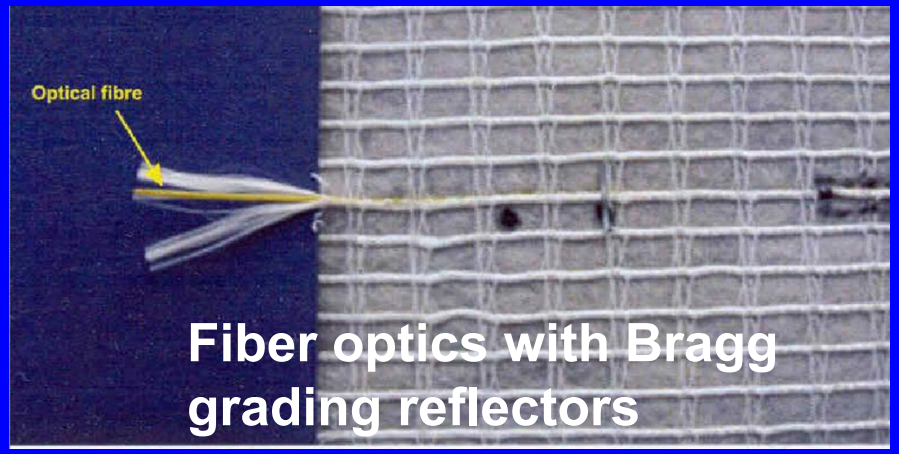
- Photogrammetry
- Automated Total Station

Strain Measurements
(Local and Average)

Bonded Resistance &
Vibrating wire
Strain gages

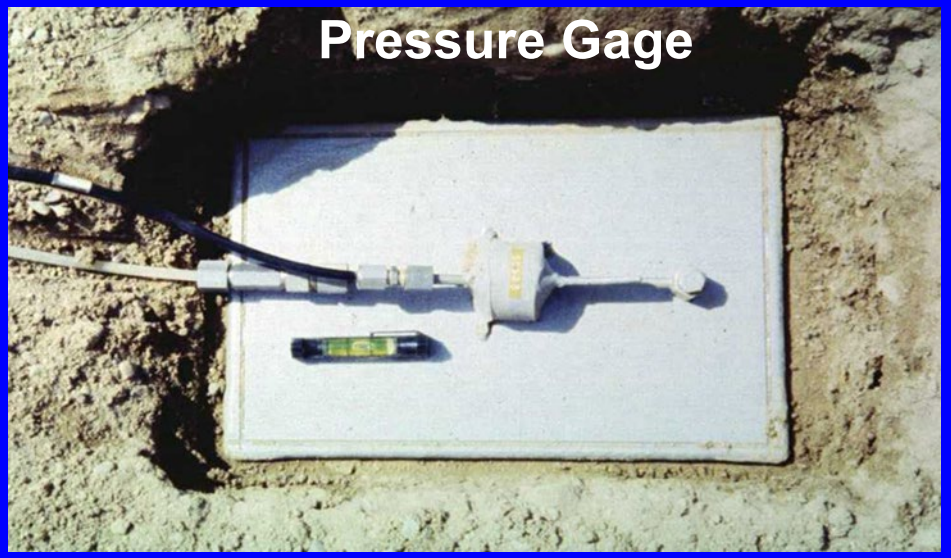


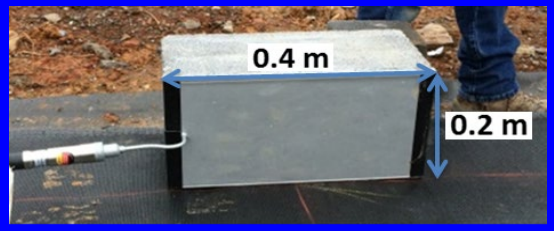


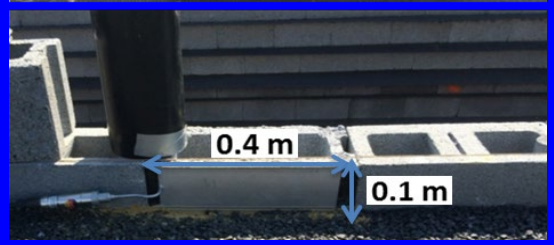


Load and Pressure Measurements

Embedment
Pressure Gage







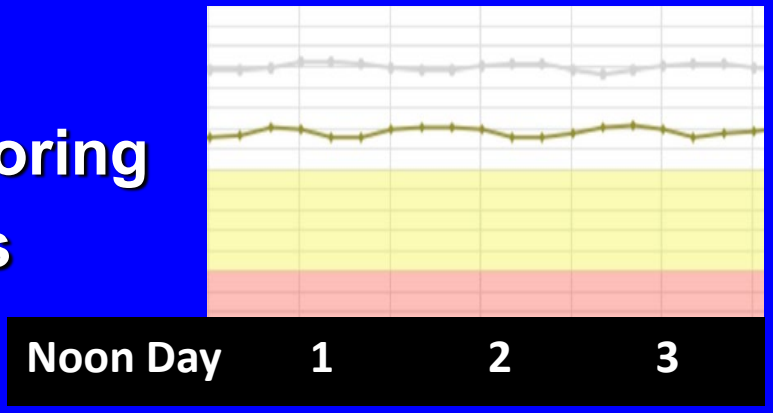
Time and Temperature

Temperature 🌡

- Thermocouples, thermistors, and weather station

Time

- Automated Continuous monitoring calibrates temperature effects



- Best Instrument
  - Your eyes👀
  - Cameras (especially during construction)

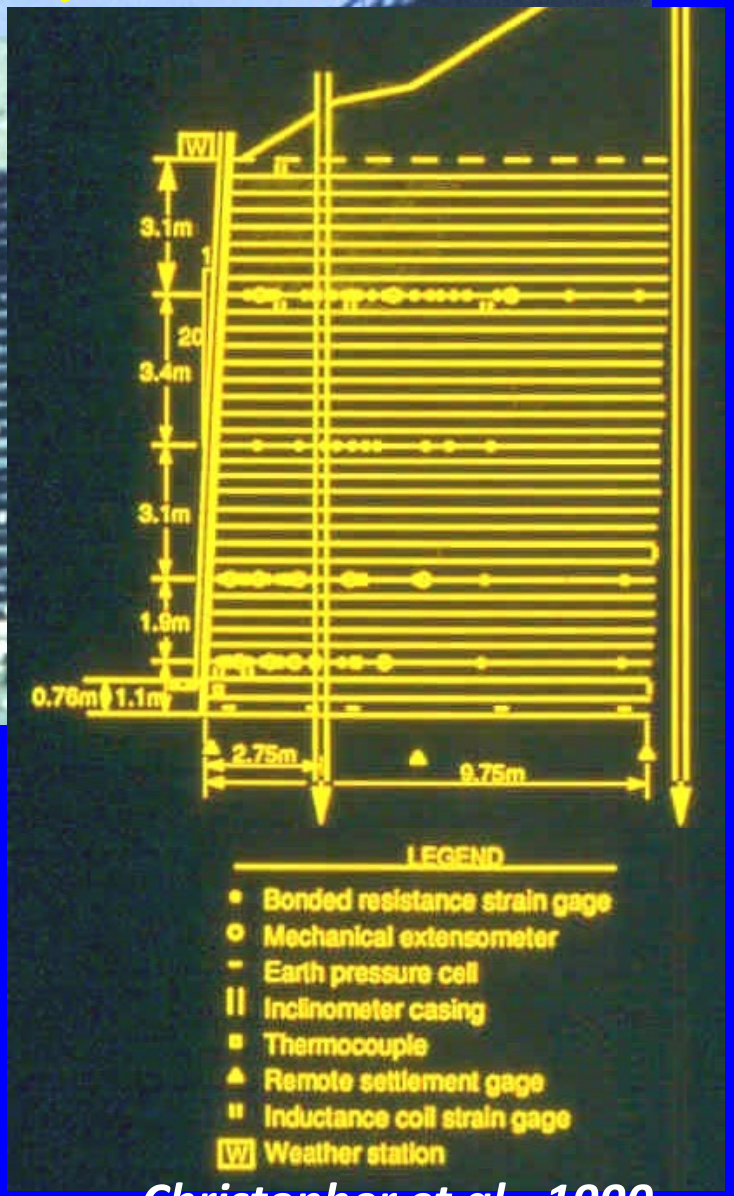
Retaining Walls
Two Types of Monitoring Programs

- Comprehensive Instrumentation Program
  - When justified by improved safety and reduced time, cost and/or delays.

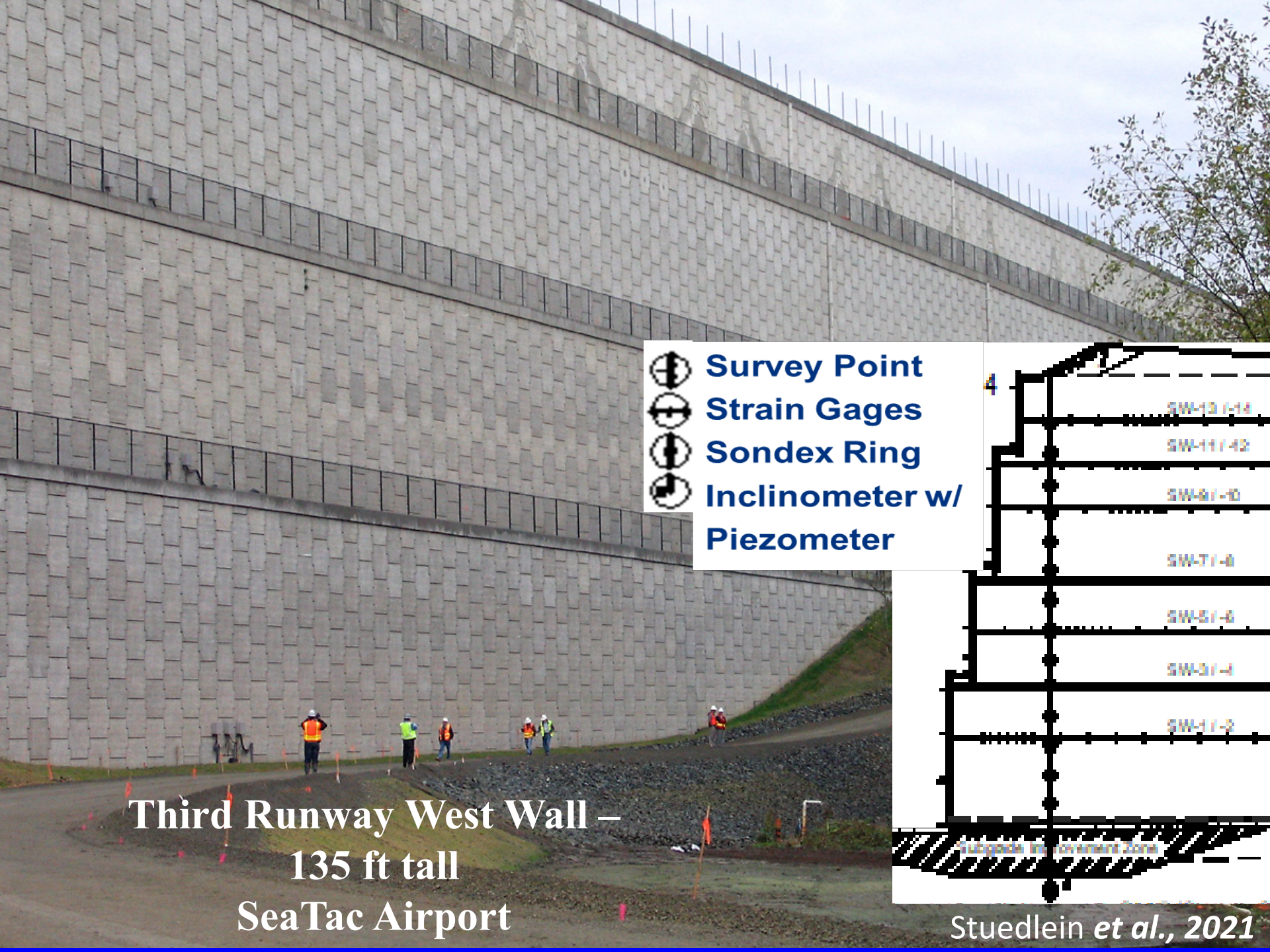
Limited (Minimum) Program

- Should always be considered

Comprehensive Program Example
(Reiner Ave. MSE wall)



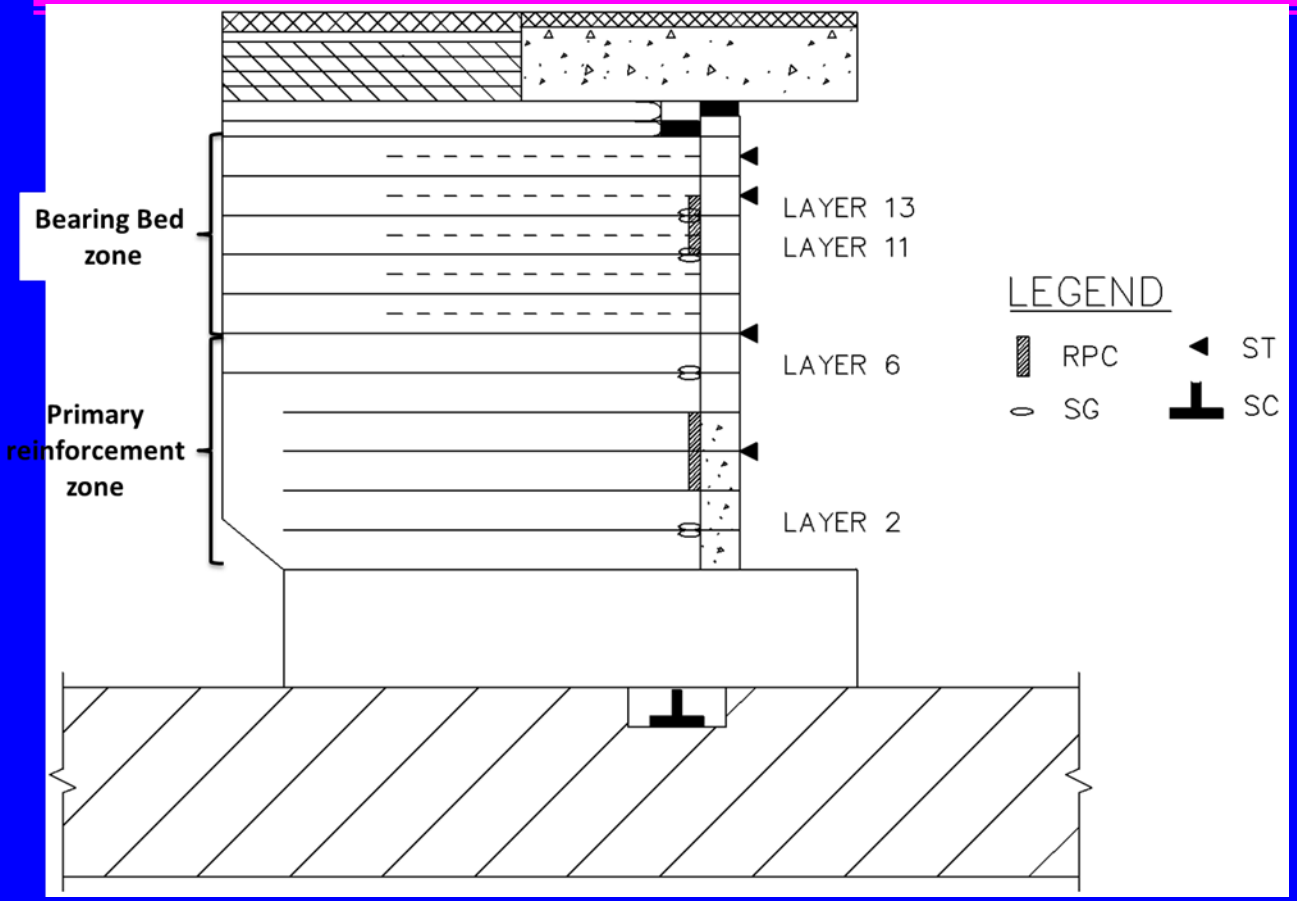
Christopher et al., 1990



Third Runway West Wall –
135 ft tall
SeaTac Airport

Stuedlein ***et al., 2021***

GRS-IBS Wall (VDOT)



Note:
RPC: Rectangular pressure cell,
SG: strain gage,
SC: settlement cell, &
ST: survey targets

Instrumentation used to verify design for cost effective and easier to construct retaining wall, with reduced maintenance (no bump)

Gebremariam et al., 2020


Comprehensive Monitoring Program
1 Single-Channel Dataloggers
2 Piezometers
3 In-Place Inclinometers
4 Load Cells
5 Strain Gages
6 Extensometers
7 Tiltmeters
8 Crackmeters
9 Multi-Channel Dataloggers
10 Portable Inclinometers
11 Jack-Out Pressure Cells
12 Sister Bars

Limited Monitoring Program

- Horizontal movement of face
- Vertical movement of surface
- Local movement / deterioration of face
- Performance of supported structures

Minimum – As built with Survey Points
Alternates - total station pts., laser extensometers

A Reason for Monitoring Performance

Any QUESTIONS?

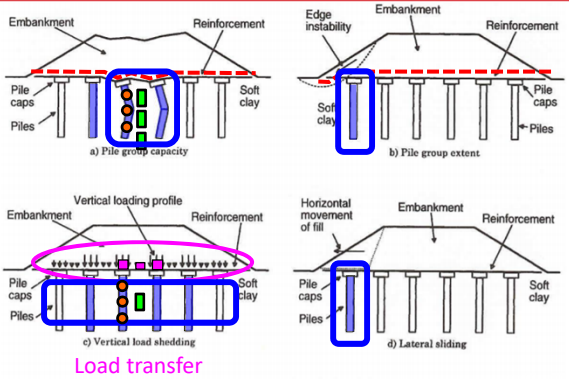
References

- FHWA/NHI 13241 - Geotechnical Instrumentation
- Marr, W.A., "Why Monitor Geotechnical Performance" Seventh International Symposium on Field Measurements in Geomechanics, 2007. https://doi.org/10.1061/40940(307)4
- Christopher, B.R., Holtz, R.D. and Allen, T.M., "Instrumentation for a 12.6 m High Geotextile-Reinforced Wall", Proceedings of the International Reinforced Soil Conference, British Geotechnical Society, Glasgow, Scotland, Sep 1990, pp 73-78.
- Stuedlein, A.W., Allen, M.S., Holtz, R.D., and Christopher, B.R., "Assessment of Reinforcement Strains in Very Tall Mechanically Stabilized Earth Walls." Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 2012, pp. 345-356.
- Gebremariam, F., Tanyu, B.F., Christopher, B.R., Leshchinsky, D., Han, J., and Zornberg, J.G., Evaluation of Vertical Stress Distribution in Field Monitored GRS-IBS Structure," Geosynthetics International, 2020.

Load transfer and differential movement in column-supported embankments

Liang Chern Chow, PE
American Engineering Testing, Inc.
September 15, 2021

Modes of Failure



These columns are the foundations of the embankment.

BS Code, FHWA (2017)

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Case Study #1: I-35E Cayuga Interchange

- $115 million dollar project (1 mile)
- 10 bridges, new alignment, poor soils, big fills, RR

MnDOT 3

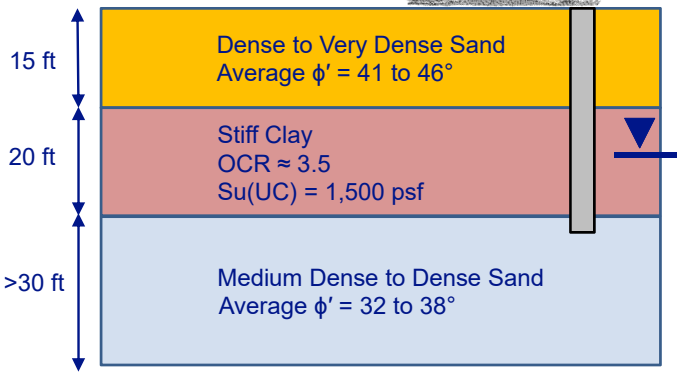
Value engineering proposal

- Value engineering proposal
  - Redesign of column-supported embankments
  - Menard became Geotech Engineer of Record

	Base Design	V.E. Proposal
Diameter	16 inch	15.5 inch
Quantity	1,481	1,597
* Depth	40-62 ft.	20-60 ft.
Improved Area	63,700 sq. ft.	77,100 sq. ft.
* LTP / Reinforcement	3 ft. thick with 3 layers biaxial	2 ft. thick – no reinforcement
Column Reinforcement – perimeter columns	Single bars and full depth cages	Single bars
Design Methodology	Beam Method - FHWA guidance manual	Plaxis Software
Instrumentation		More gages

MnDOT 4

CSE Mainline North



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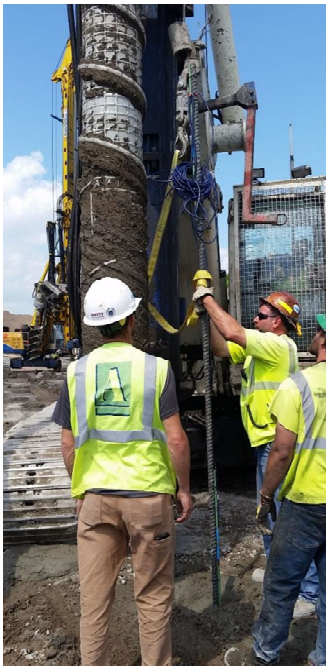
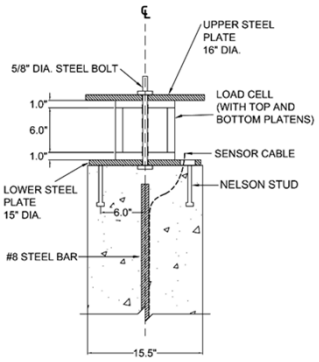
Strain gage/rebar strainmeter

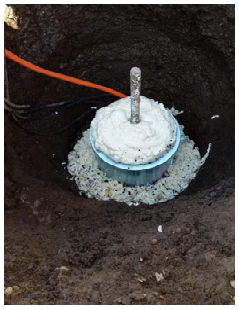
6



7

Load cell*


UPPER STEEL PLATE 16" DIA.
5/8" DIA. STEEL BOLT
LOAD CELL (WITH TOP AND BOTTOM PLATENS)
1.0"
6.0"
1.0"
SENSOR CABLE
NELSON STUD
LOWER STEEL PLATE 15" DIA.
6.0"
#8 STEEL BAR
15.5"



8

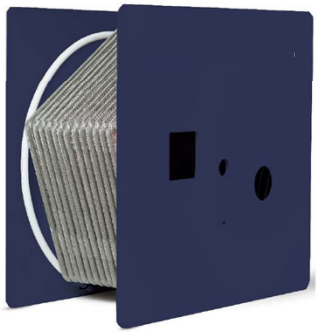
Earth pressure cell**

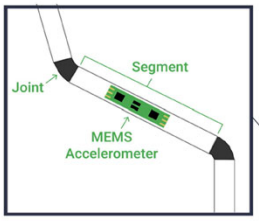


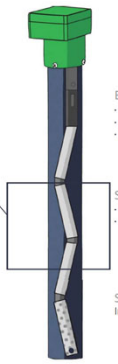
9

10

Shape Accel Arrays







EXTENSION TUBE
- Spring box
- Installed in field
- Cut to required length

SENSORIZED SEGMENTS
- Manufactured to required length
- 250 or 500 mm segments

SILENT SEGMENTS
Installed in field or in factory to order

Accuracy: 1.5 mm for every 32 metres

VERTICAL INSTALL

Patented cyclical installation to measure lateral deformation

Can be installed in 27, 47-100 mm ID conduit

HORIZONTAL INSTALL

To measure settlement deformation

ARC INSTALL

To measure convergence

Pros	Cons
High precision	Can be $$
Large movement	Need fixed ref end
Automated	Difficult to repair
Low maintenance	

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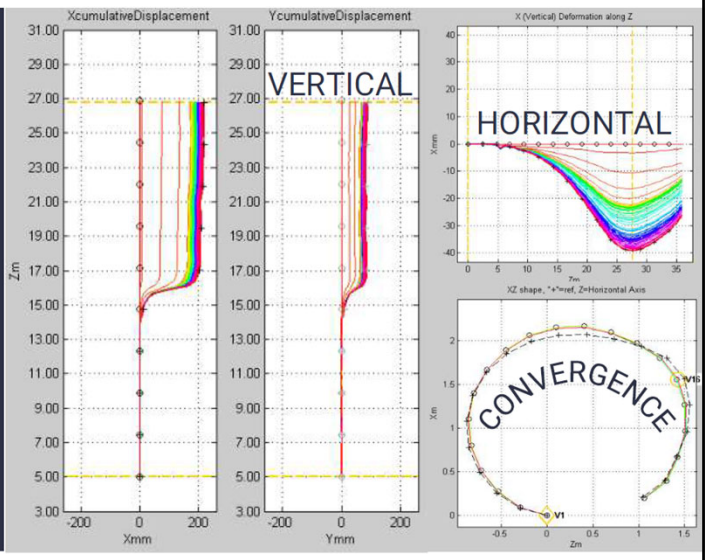
SAA data plots are presented with X and Y, calculating the Z value



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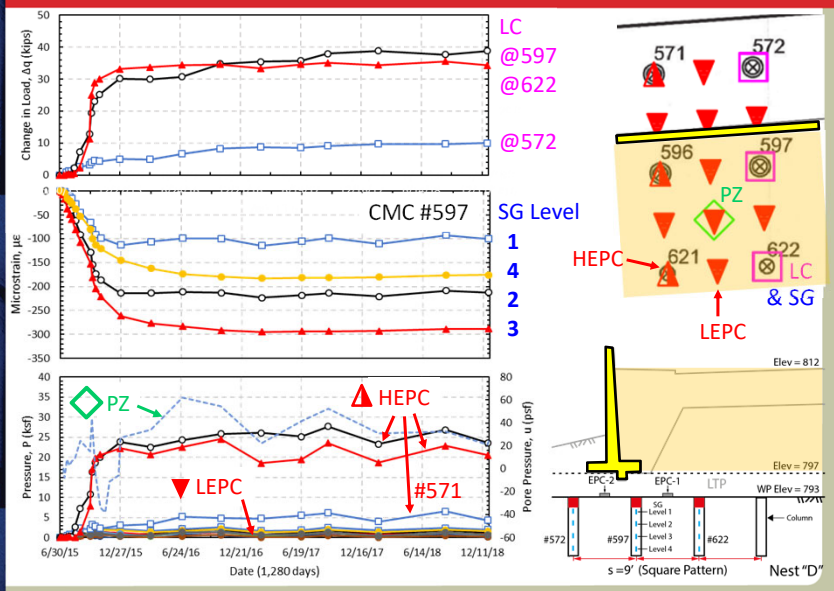
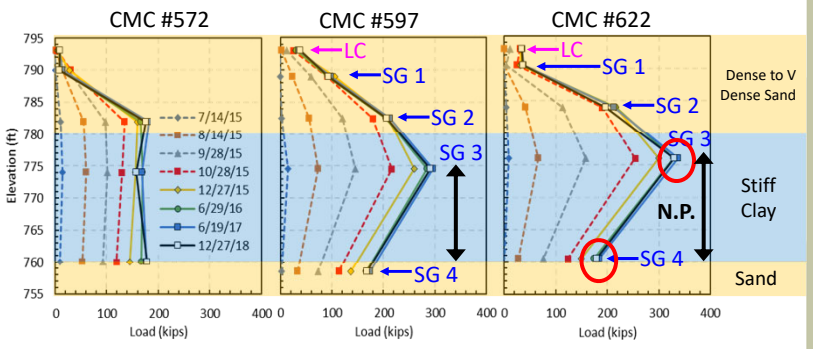
3.5 years of monitoring results



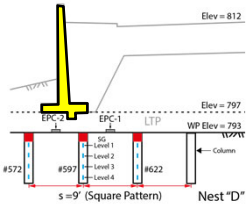
Chow, Han & Reuter (2020) 13

Load Distribution



#622
Max load = 320 kips
Stress = 1,650 psi < 3,440 psi (break)
End Bearing = 190 kips

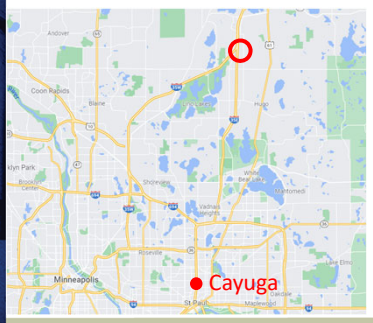
How about in soft clay?

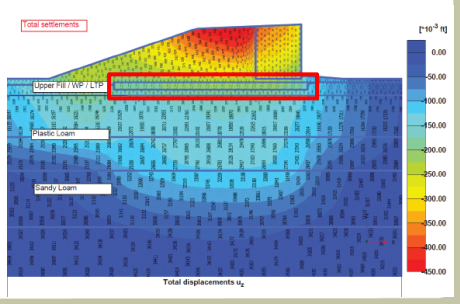


Chow, Han & Reuter (2020) 14

Case study #2: I-35 Flyover Bridge, MN

- I-35 Forest Lake UBOL and Bridges (Letting in 2017).
- Predicted approx. 3 inch max settlement at the top of the LTP. Less than 0.5 inch predicted after 6 to 9 months waiting period.

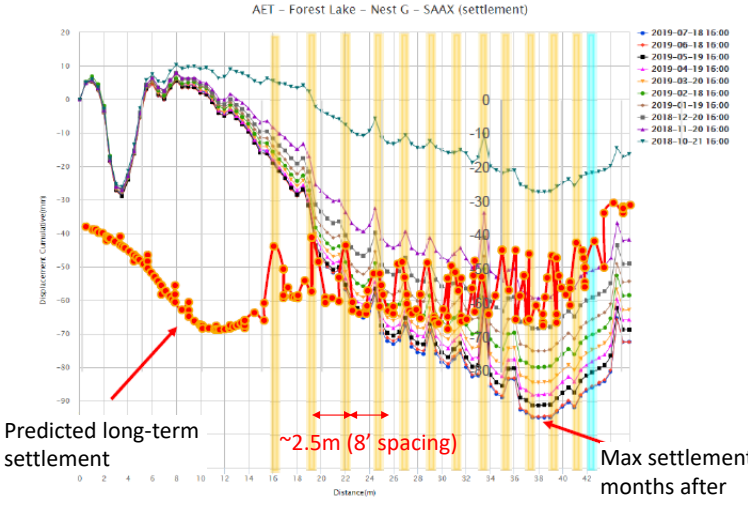




Menard DFI S3 (2019) 15

Settlement

- Horizontal SAA placed 6 inch above top of columns



Predicted long-term settlement

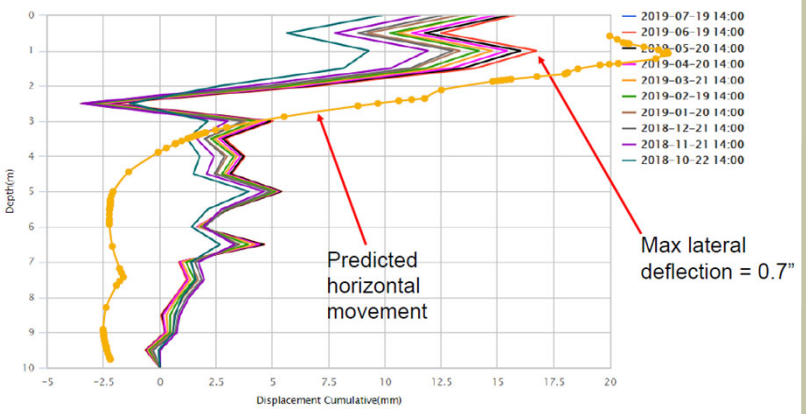
~2.5m (8' spacing)

Max settlement ~9 months after construction = 3.7"

Menard DFI S3 (2019) 16

Lateral displacements

- Vertical SAA placed in front of MSE wall



Menard DFI S3 (2019) 17

Damages & Risks

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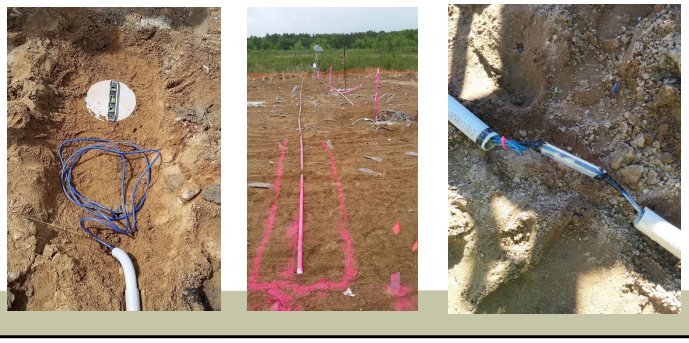
Protect your investments

- Provide cable protection and cable slacks:
  - Conduit type and size, e.g. electrical vs. plumbing conduits
  - Minimum buried depth, e.g. 6 inches
  - Visible markings, GPS coordinates
- Extra sensors for redundancy, e.g. piezometer saturation
- Good planning and communications with contractor, subcontractors, and owner/client.



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Closing notes

- Modes of failure is a good place to start for instrumentation planning.
- Presented two case studies and monitoring results:
  - Max. compressive stress in columns (Strain gage)
  - Validate model and design parameters

    model to understand the behavior
- Discussed potential damages and good practices

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Acknowledgement

Thank you

lchow@amengtest.com

rst INSTRUMENTS MEASURAND menard DEPARTMENT OF TRANSPORTATION

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Instrumentation to Evaluate Interaction between Wall and Foundation

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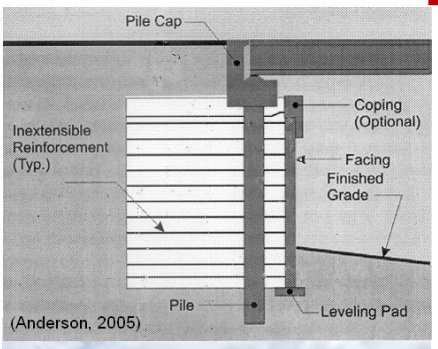
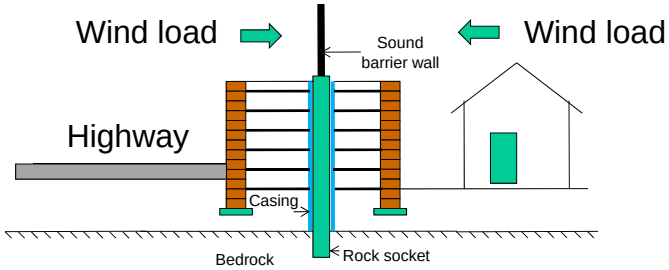
Outline of Presentation

- **Project Background**
- **Instrumentation**
- **Data Analysis**
- **Long-term Monitoring**
- **Concluding Remarks**

Background

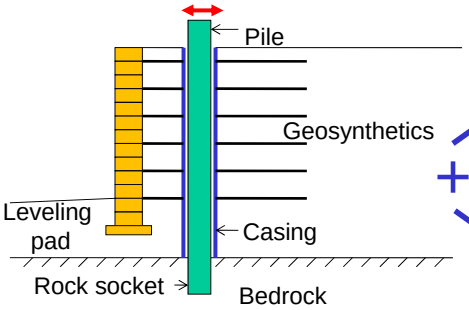


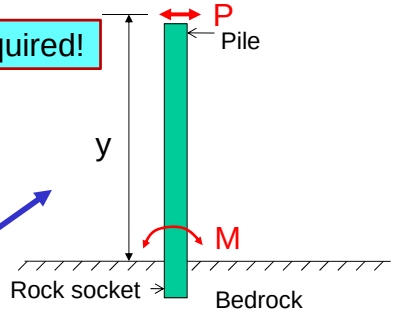


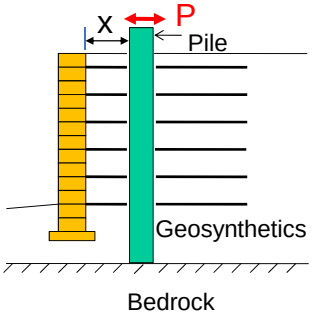
Current Practice and Issues

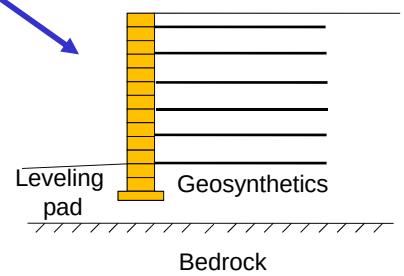
Proposed

Field test with instrumentation required!







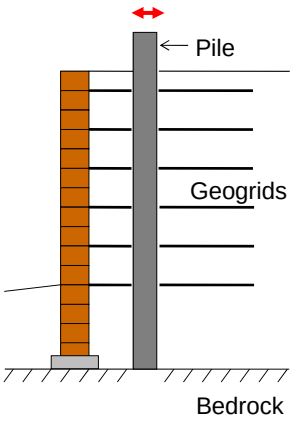


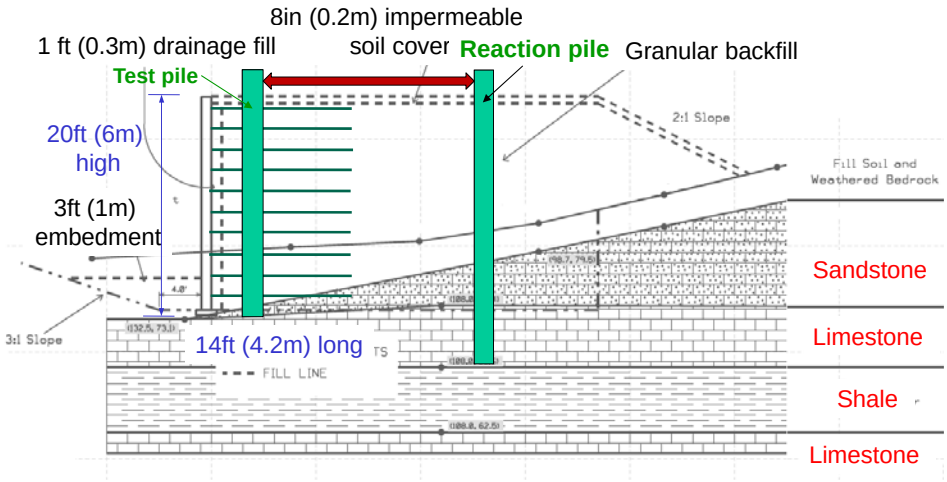
Long, large diameter piles socked into rock/firm soil, i.e., very costly

Issues:

- No design method available
- Pile capacity vs. offset
- Pile group effect

Test Section



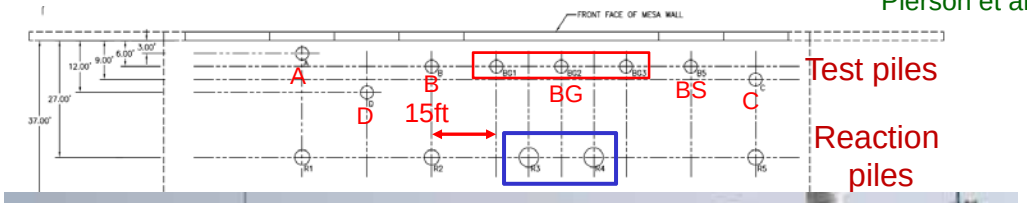


Maintained displacement method for loading tests

- 5 -

Test Wall and Test Piles

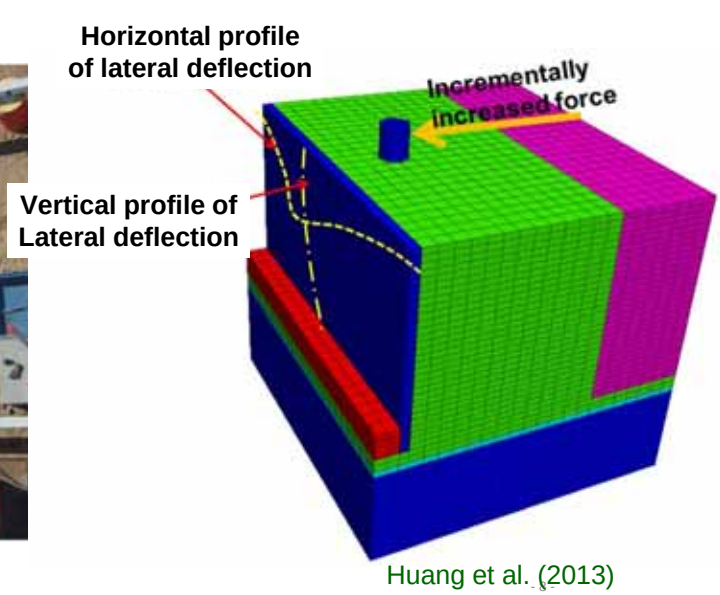
Pierson et al. (2011)



Types of Instrumentation

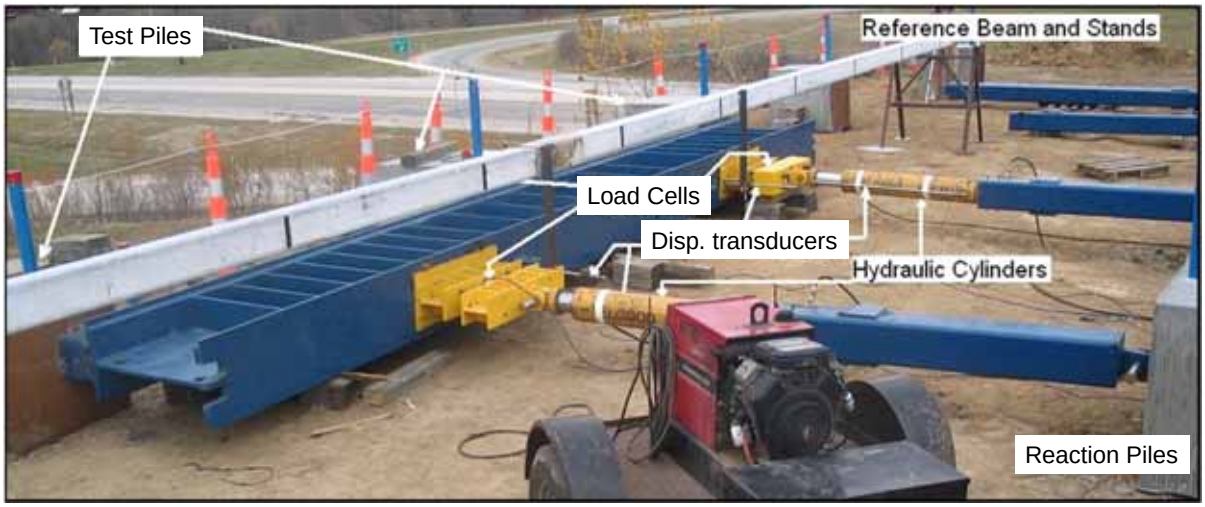
- Load Cells
- Displacement Transducers
- Earth Pressure Cells
- Strain Gauges on Geogrid
- Inclinometer and Casing
- Photo Targets Attached to Facing
- Tell-tales
- Data Acquisition

Lateral Loading Test of Single Pile



Huang et al. (2013)

Lateral Loading Test of Group Piles



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Earth Pressure Cell and Strain Gauges

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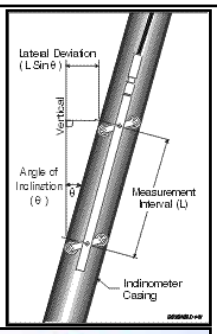
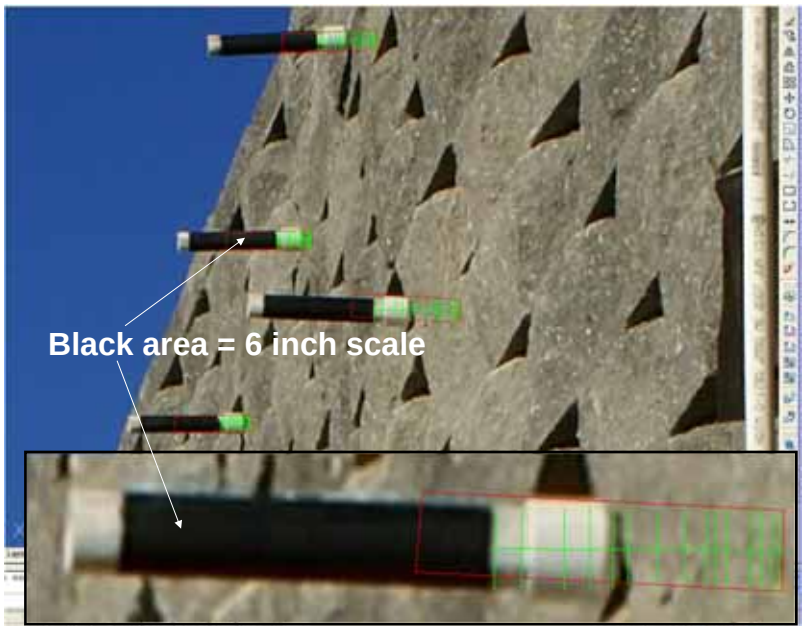
Inclinometer and Casing



Photogrammetry

Photogrammetry

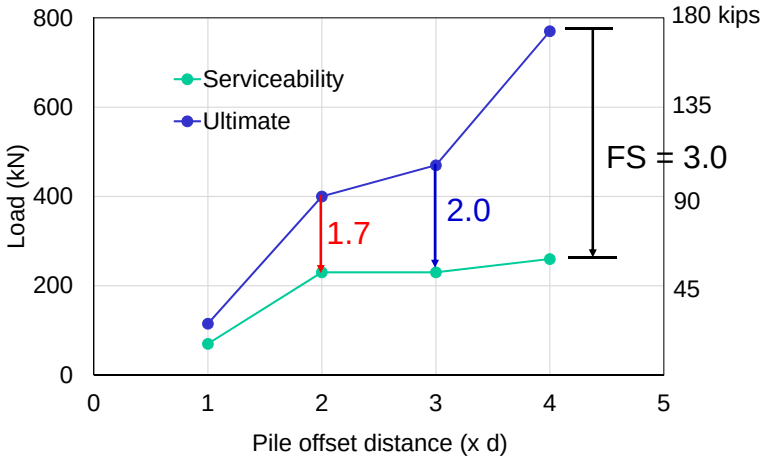


Tell-Tales

Similar to settlement plate

Data Acquisition

Serviceability and Ultimate Capacity



Serviceability = 25 mm (1 in.), Ultimate displacement = 20%d

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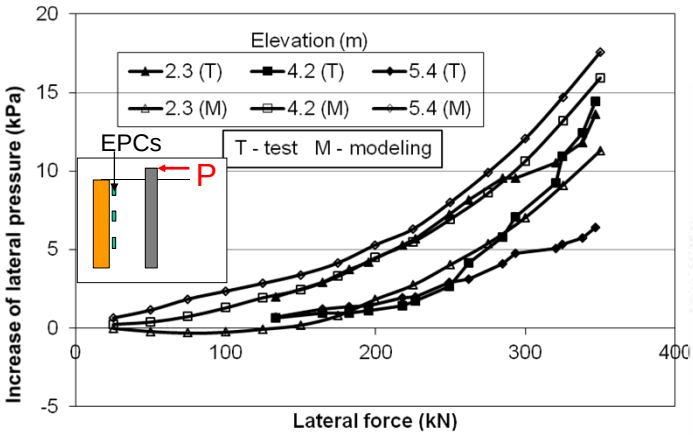
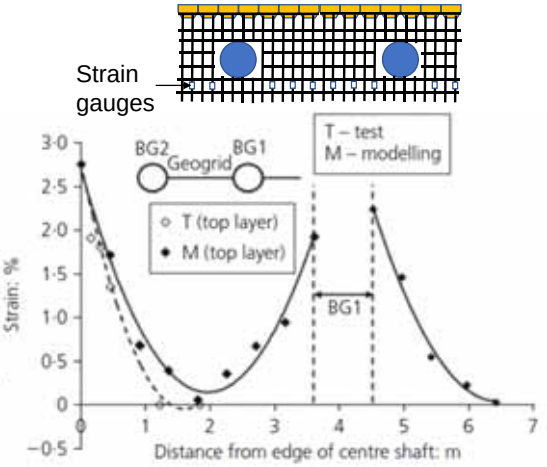
Earth Pressures and Geogrid Strains Induced by Laterally Loaded Piles



Sing Pile B

Huang et al. (2013)

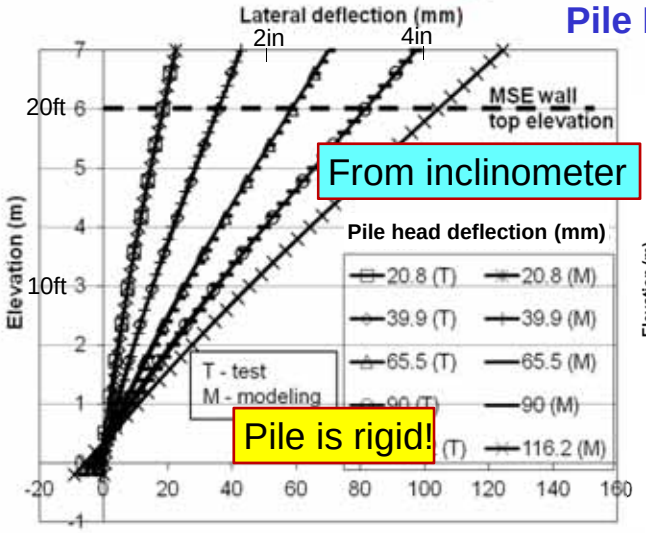


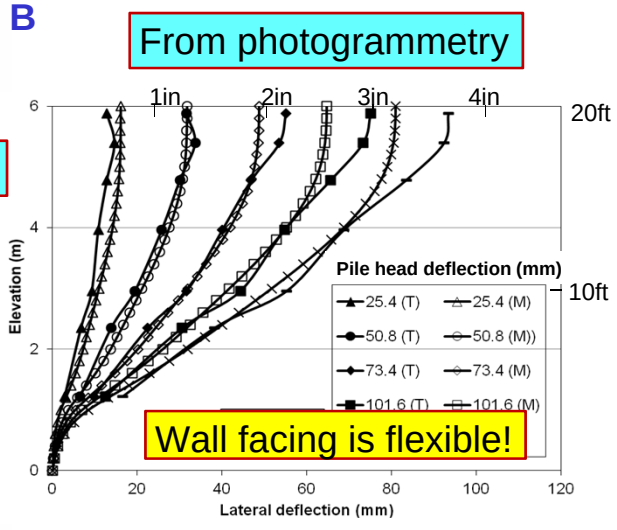
Group Pile B

Huang et al. (2014)

Vertical Profile of Lateral Deflections of Single Pile and Wall

Pile B



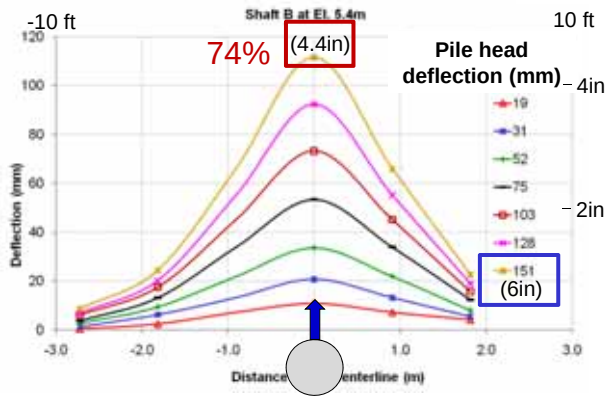


Huang et al. (2013)

Horizontal Profile of Lateral Deflections of Wall under Single and Group Pile Loading

Pile B at

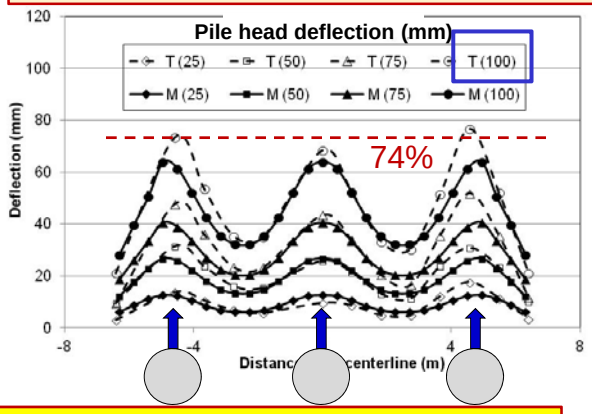
Instrumented data indicate group effect.



10 ft

4in

2in



All the wall facing deflection data were obtained by the photogrammetry method.

Huang et al. (20

How about long-term monitoring?

uang et al. (2014)

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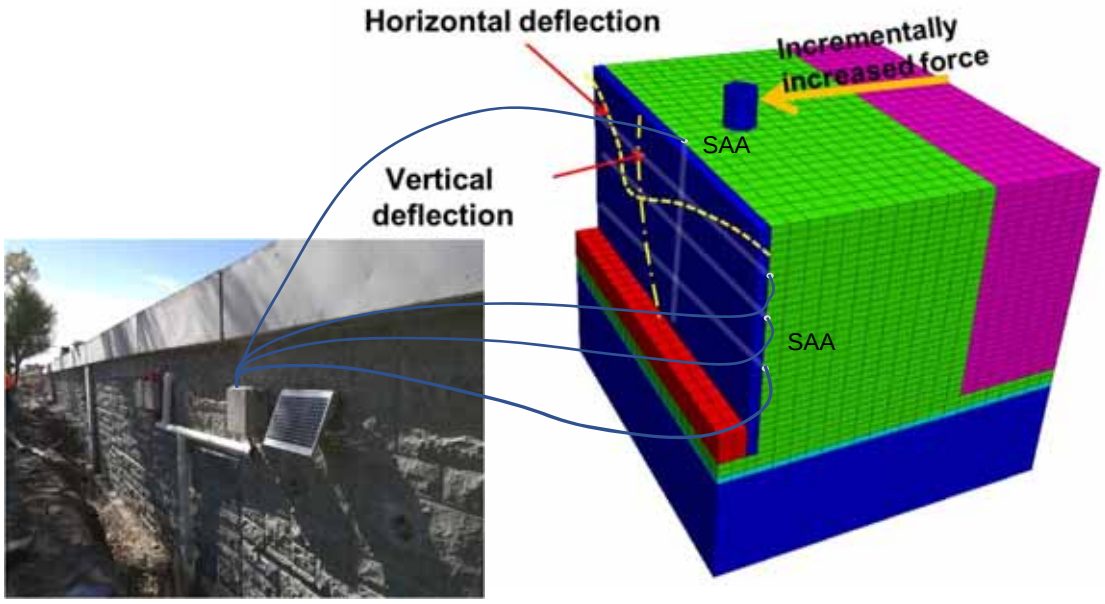
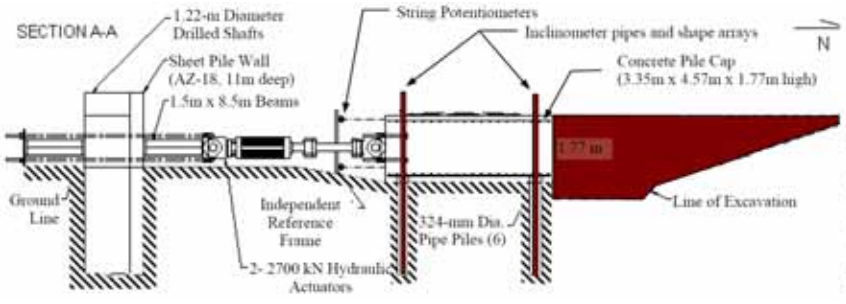
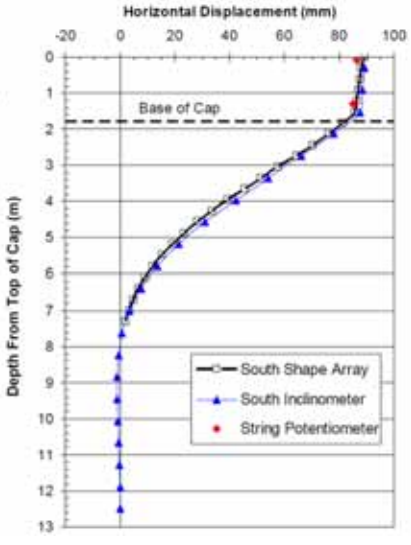
Shape Accelerometer Array for Long-term Monitoring

Monitoring with Shape Accelerometer Array



Lateral Pile Loading Test with Instrumentation





Rollins et al. (2009).

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Concluding Remarks

- Pile(s) in MSE wall subjected to lateral loading is a complicated interaction problem. Instrumentation helped verify a cost-effective design option and determine design parameters.
- Instrumentation including load cells, displacement transducers, earth pressure cells, strain gauges, inclinometer and casing, photogrammetry, tell-tales, and data acquisition system gathered useful data for this evaluation.
- The findings from the instrumentation and evaluation provide guidance for future design and applications.
- Recent technology - Shape Accelerometer Array (SAA) enables long-term automatic monitoring of earth structure performance.

Acknowledgements

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Research Investigators: Drs. R.L. Parsons, J. Han, M. Pierson, and J. Huang, the University of Kansas

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Thanks! Questions?

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Today's Panelists

Moderator:
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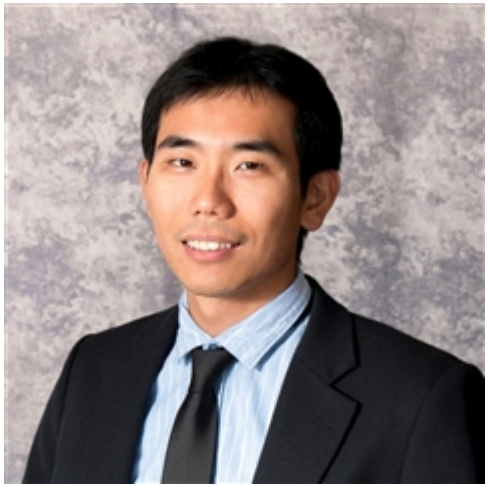

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