I-15 Reconstruction Project: Innovative Foundation and Embankment Construction

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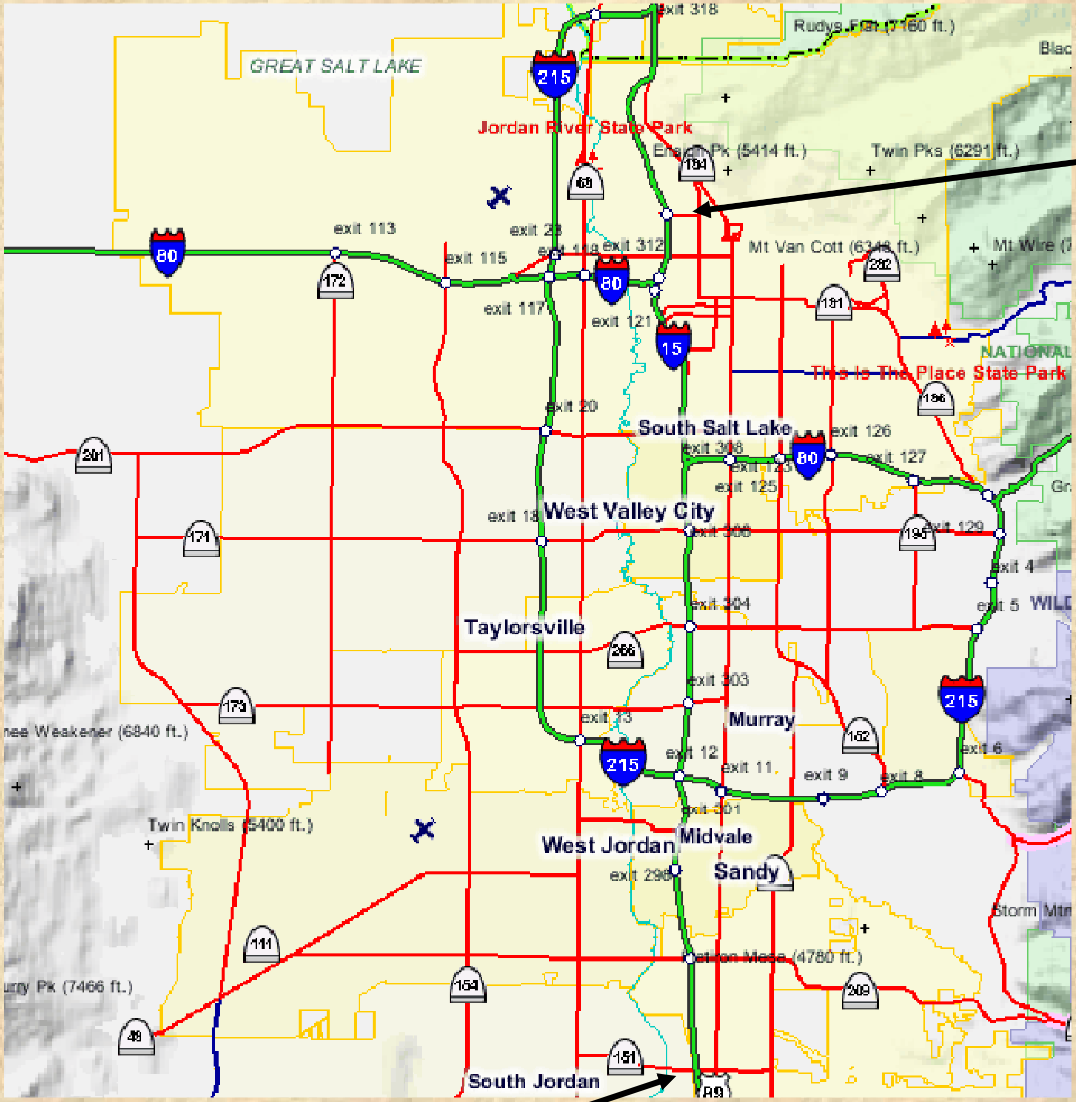
I-15 Reconstruction – Project Extents



End Project 600 N.

Beg. Project 10600 S.

I-15 Reconstruction - Quick Facts

- **Single Largest Design-Build Highway Contract in U.S.**
- **17 Miles of Urban Interstate**
- **$1.5 Billion (Project Cost)**
- **Wasatch Constructors (Prime Contractor)**
  - **Kiewit, Granite, Washington Construction**
- **4 Year Construction Duration (1997 - 2001)**
- **144 Bridges/Overpass Structures**
- **160 Retaining Walls (mostly MSE Walls)**
- **Approximate $6 M Research Program (4 years)**

Geotechnical Issues

- Large Primary Consolidation Settlement (1 to 1.5 m)
- Time Rate of Consolidation (2 years to end of primary)
- Creep Settlement (Bump at Bridge)
- Foundation Stability (Large Embankments on Soft Soils)
- Schedule Constraints (two 2-year projects)
- Maintenance of Traffic (Had to be maintained)
- New Technologies and Development of Specifications

Selected Topics

PV Drains

Surcharging

Geotextile Reinforced Slopes

Selected Topics (cont.)

2-Stage MSE Walls

Lime Cement Columns

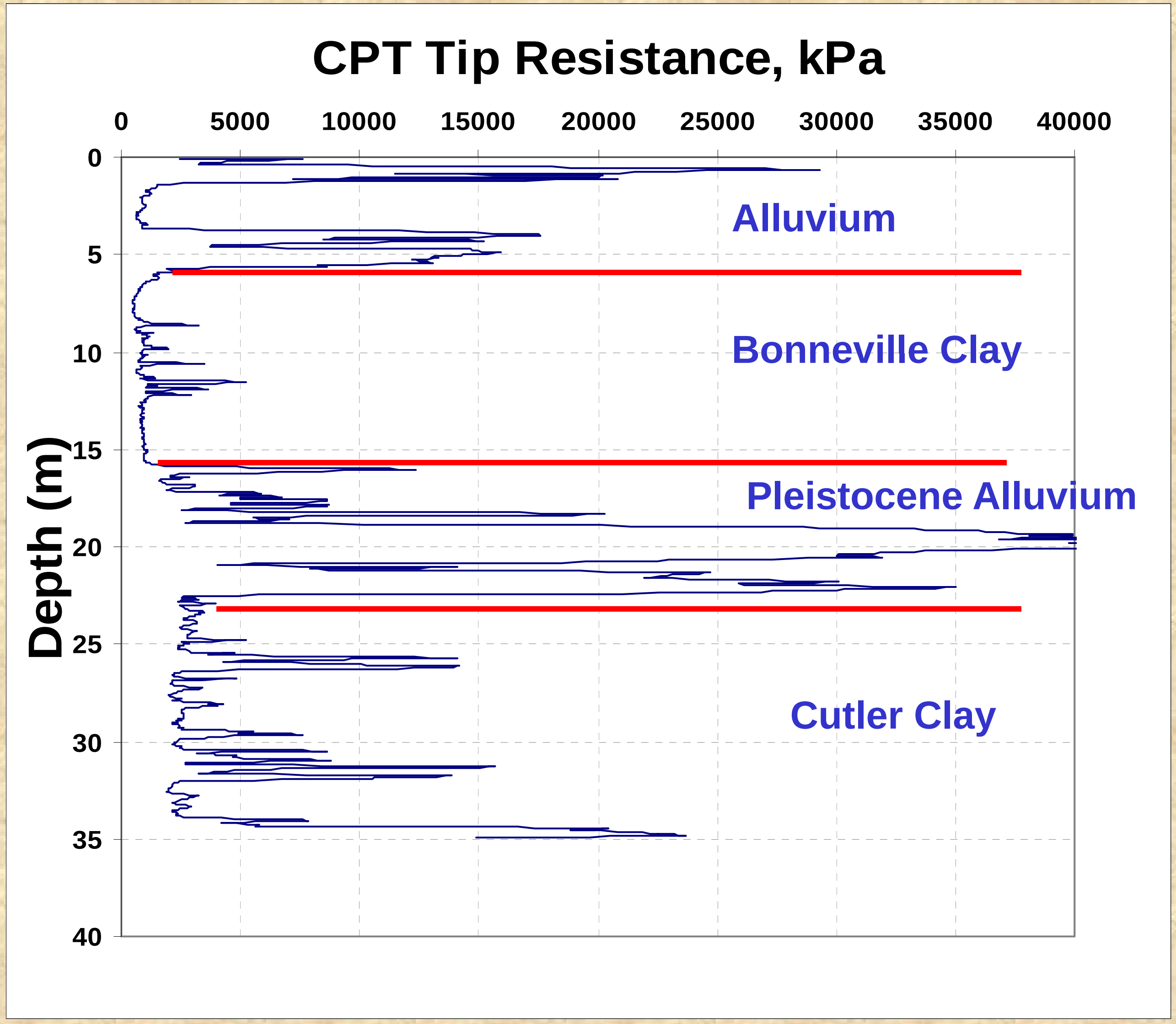
Geofoam – Light Weight Fill

Quantity and Cost Summary

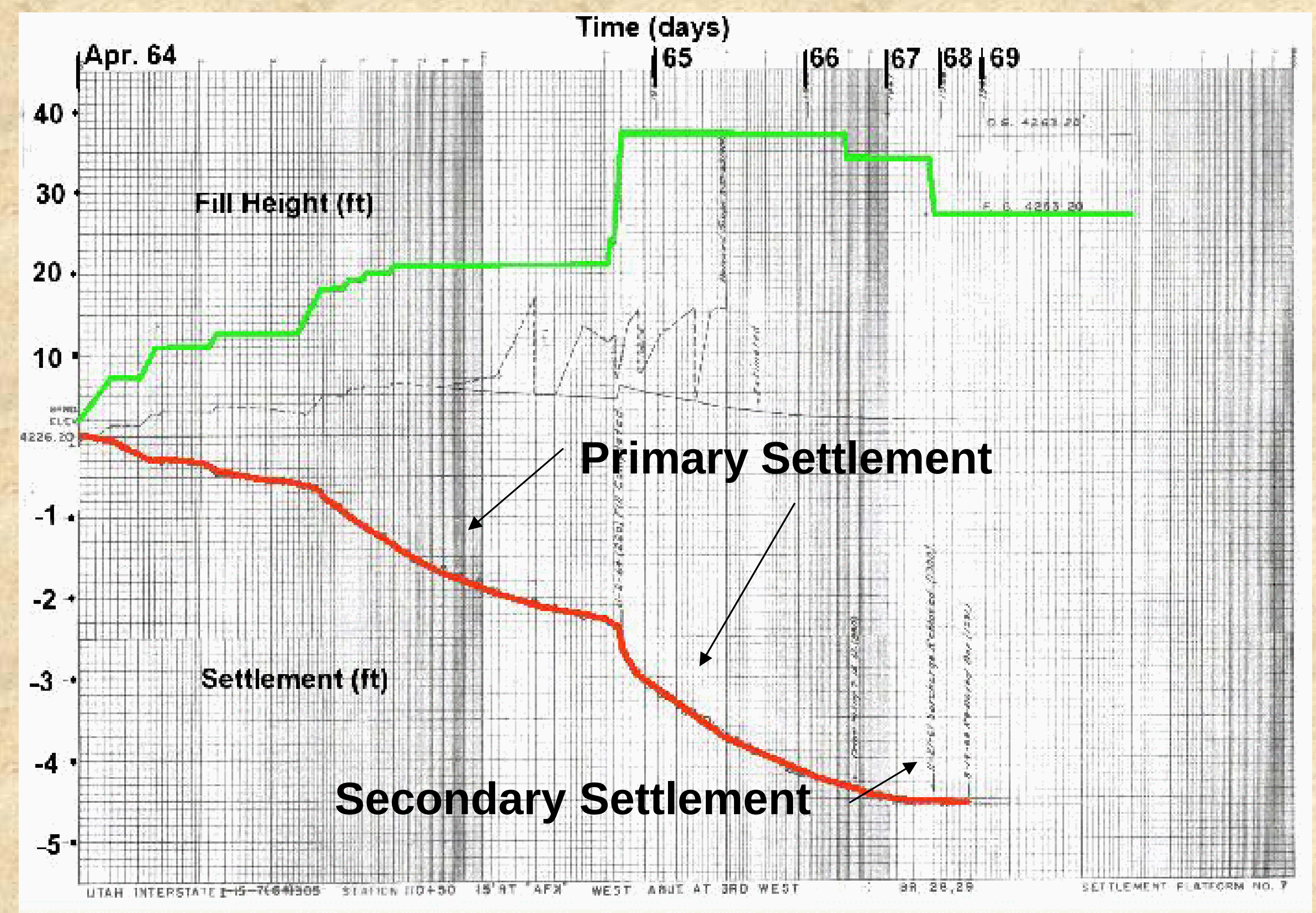
Embankment or Treatment Type	Approximate Quantity	Average In Place Unit Cost
Earthen Embankment	5,00,000 m^3	\$9 / m^3
Pre-fabricated Vertical Drains	7,400,000 m	\$1.50 / m (without pre-drilling) \$3.00 / m (with pre-drilling)
High Strength Geotextile	670,000 m^2	\$12 / m^2
Geofoam Embankment (Type VIII)	107,000 m^3	\$60 / m^3 (without wall) \$70 /m^3 (with wall)
Surcharge Fill Removal	500,000 m^3	\$6 / m^3
Slag Light Weight Aggregate	141,000 m^3	\$18 / m^3
Scoria Light Weight Aggregate	50,000 m^3	\$31 m^3
Lime Cement Column Treatment	68,000 m	\$16 / m (0.6 m diameter) \$18 / m (0.8 m diameter)
Mechanically Stabilized Earth (MSE) Walls	160 walls	\$200 / m^2 face of wall (one-stage) \$300 / m^2 face of wall (two-stage)

Table 1. Foundation treatments and embankment used on the I-15 Reconstruction Project with approximate quantities and unit costs (adapted from Saye et al., 2001).

Subsurface Profile in Salt Lake Valley

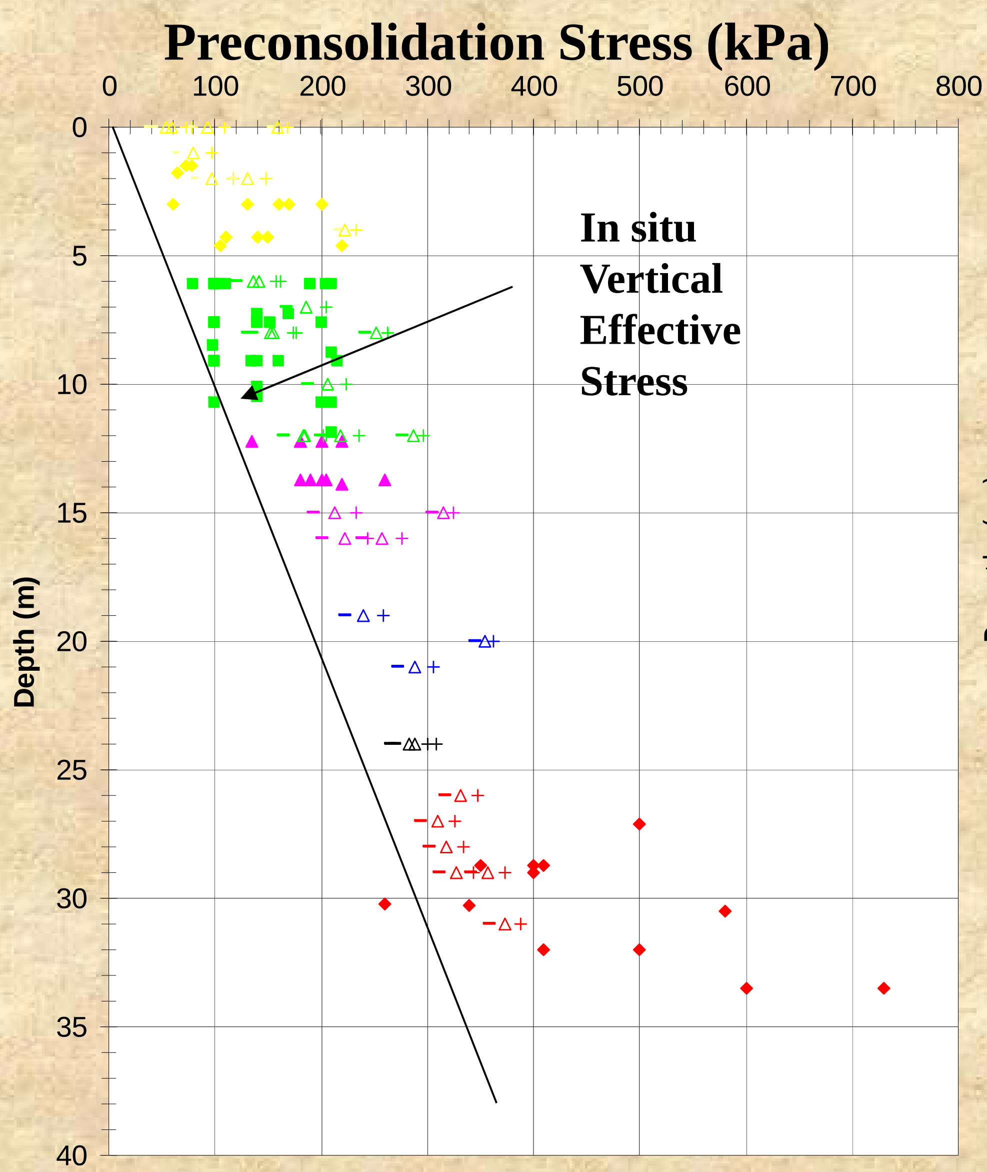


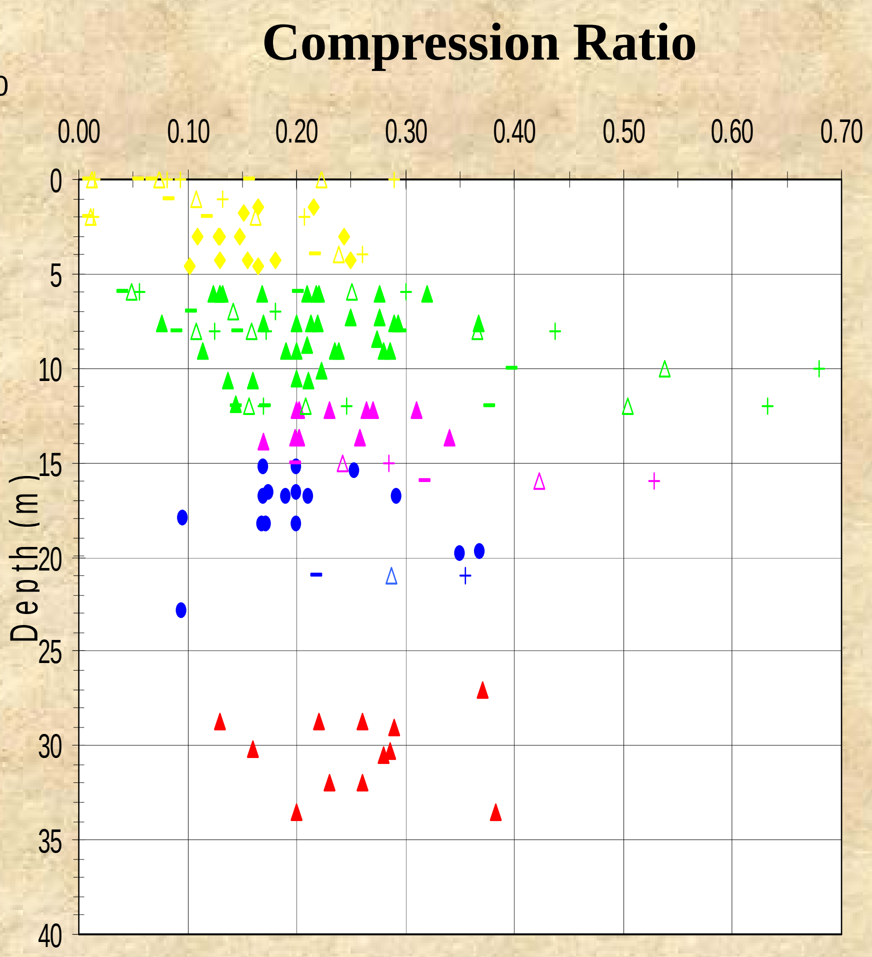
Settlement of Soft Clays in Salt Lake Valley



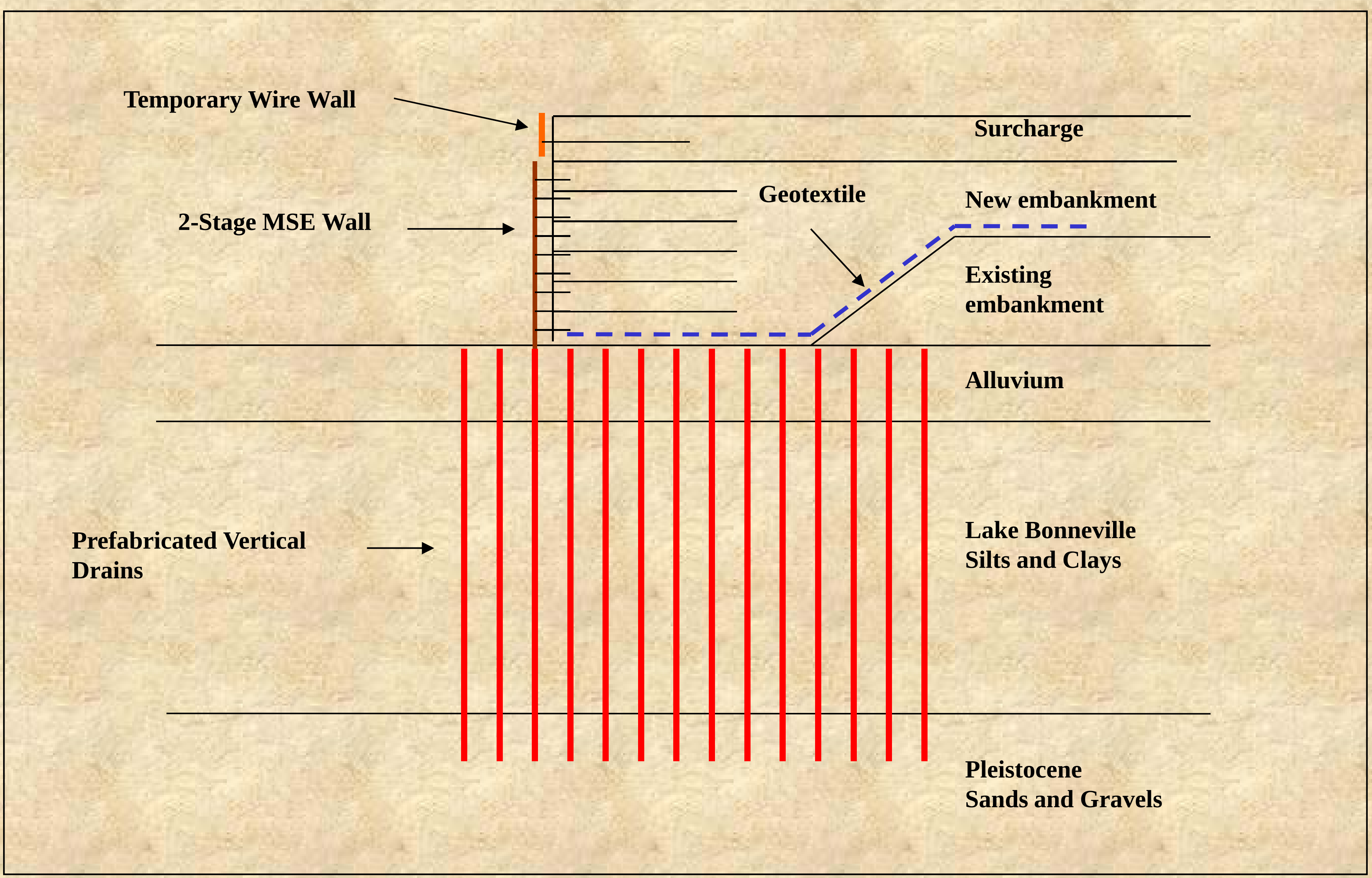
Approximate 2 years of primary settlement

Consolidation Properties

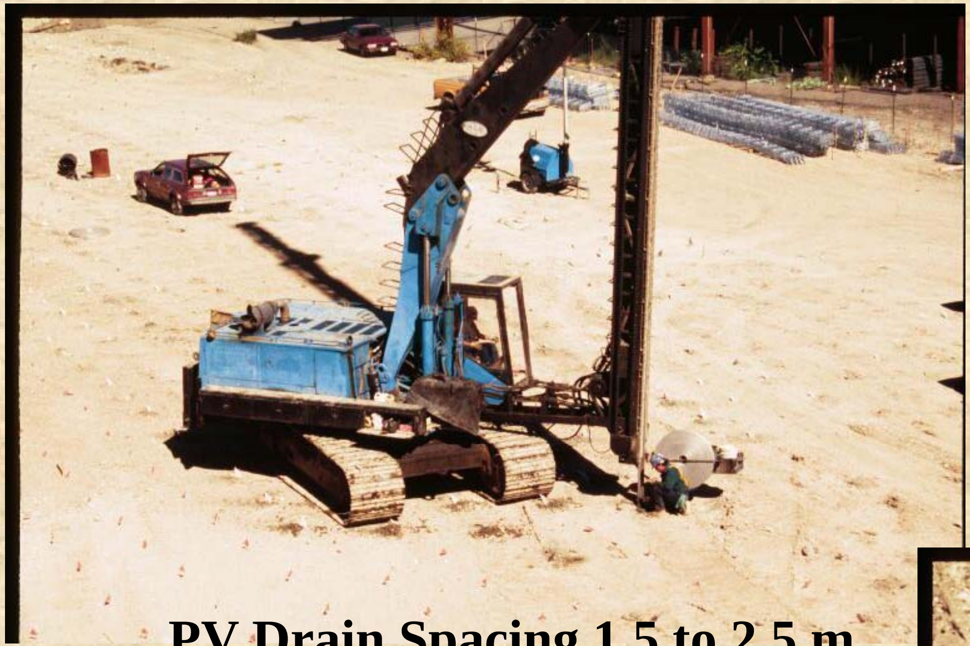




Typical I-15 Embankment Construction



Prefabricated Vertical Drains



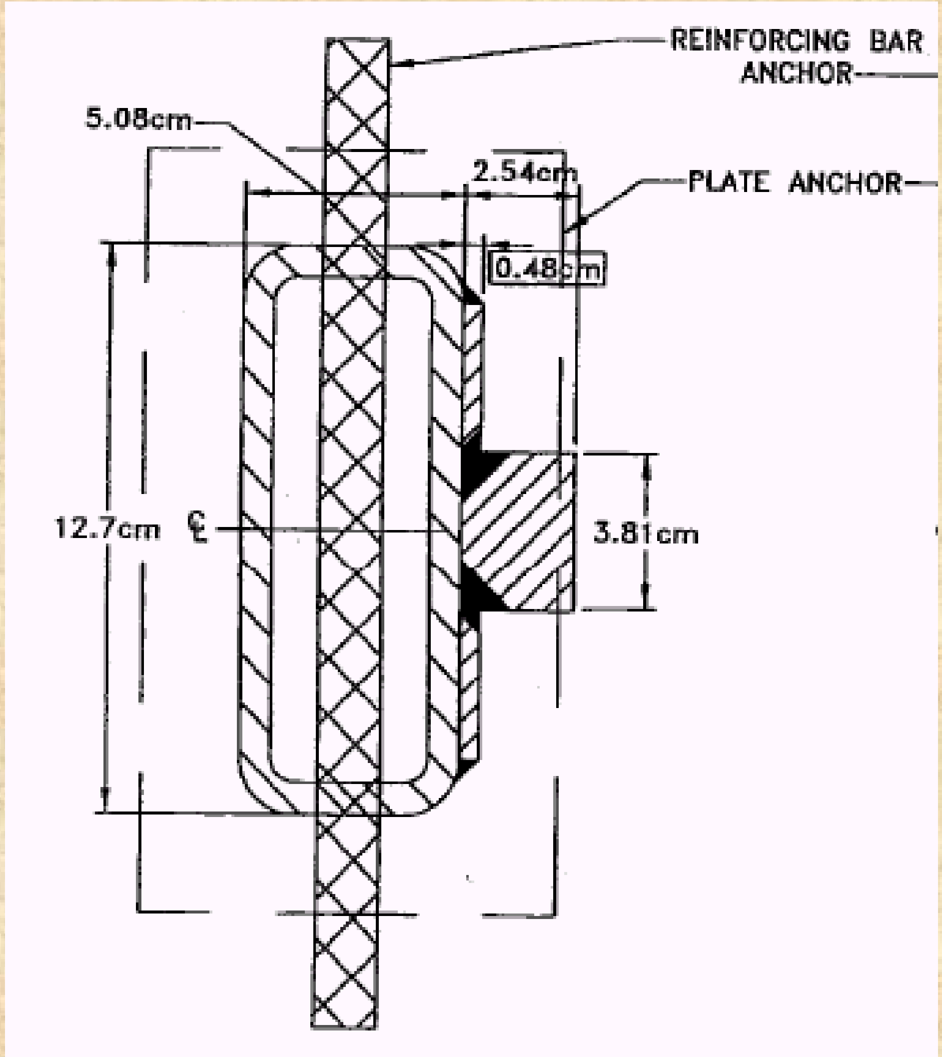
PV Drain Spacing 1.5 to 2.5 m
triangular spacing

Installed drain

Placement of anchor bar

PV drain pushed into ground

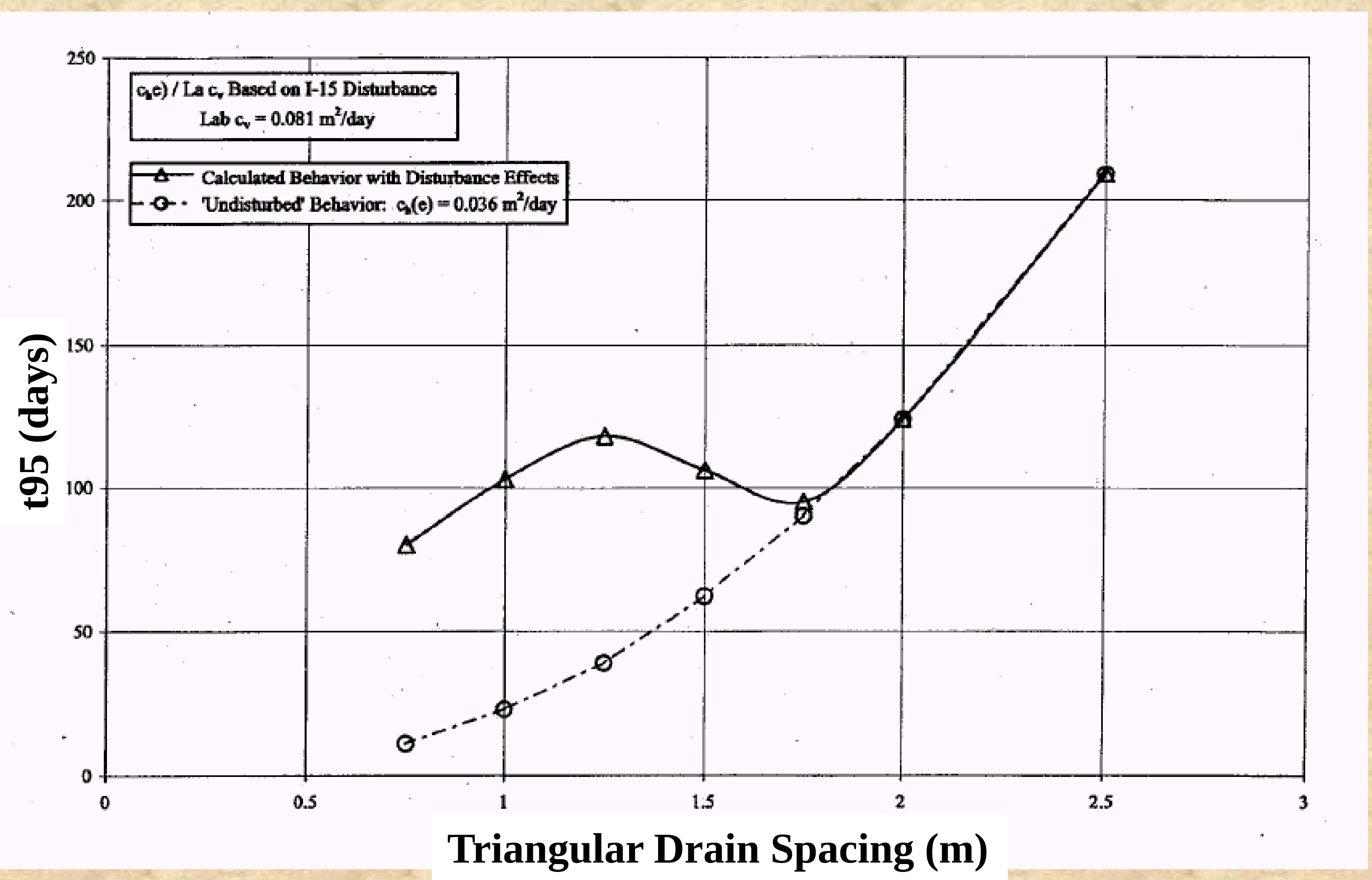
PVD Installation Issues



Mandrel used on the I-15 Project

1. **Consolidation times need to be reduced to 3 to 6 month to accommodate schedule**
2. **Large, atypical mandrels and anchor plates may cause excessive disturbance and reduce time rate of consolidation**
3. **PV drains spaced too closely together may cause disturbance and reduce time rate of consolidation**
4. **PV drain contractor may not be able to push drains through existing embankment**

Rate of Consolidation Vs. Drain Spacing



Pre-drilling of PV Drains Required through Existing Embankment

Cost:

$1.50/ m (without predrilling)

$3.00/m (with predrilling)

Approximate 3 drill rigs req'd for one PV drain rig

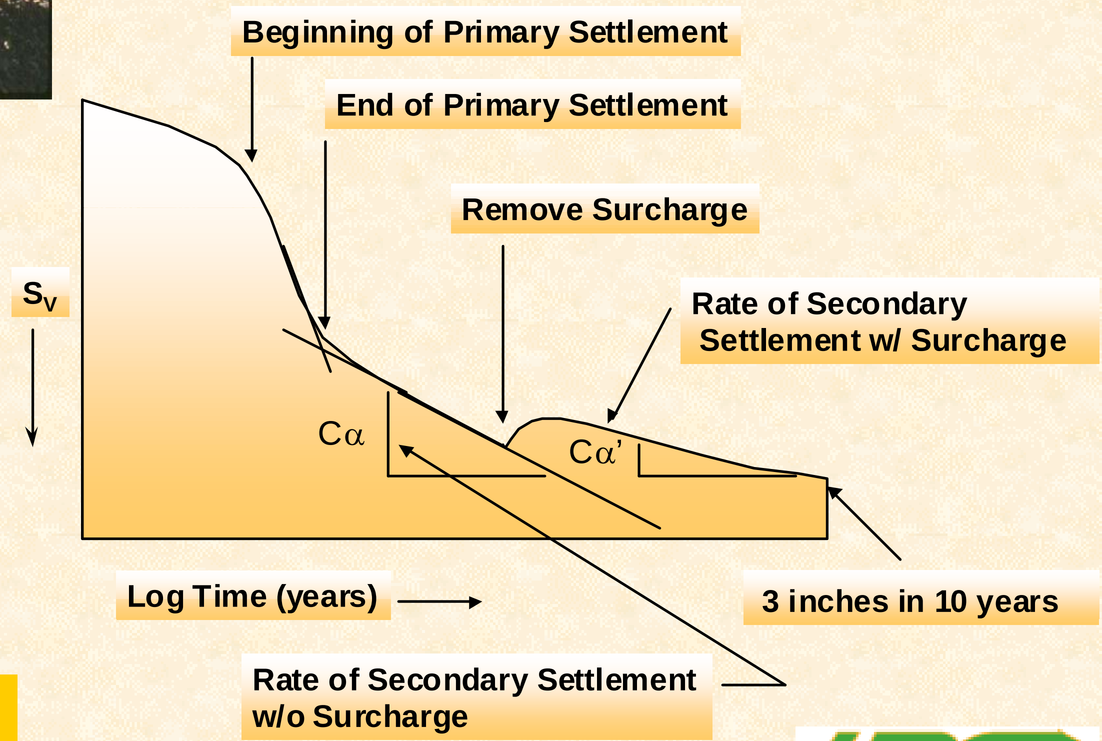
PV Drain Summary

1. **PVDs reduced settlement to 3 to 6 months and were the key component to I-15 success.**
2. **PVDs performed as expected.**
3. **Size and geometry of installation mandrel and anchor plate should be controlled by specification.**
4. **PVDs should not be spaced closer than 1.5 m triangular spacing for Lake Bonneville Deposits**
5. **Predrilling was required for installation through large (8 m high) preexisting embankments.**

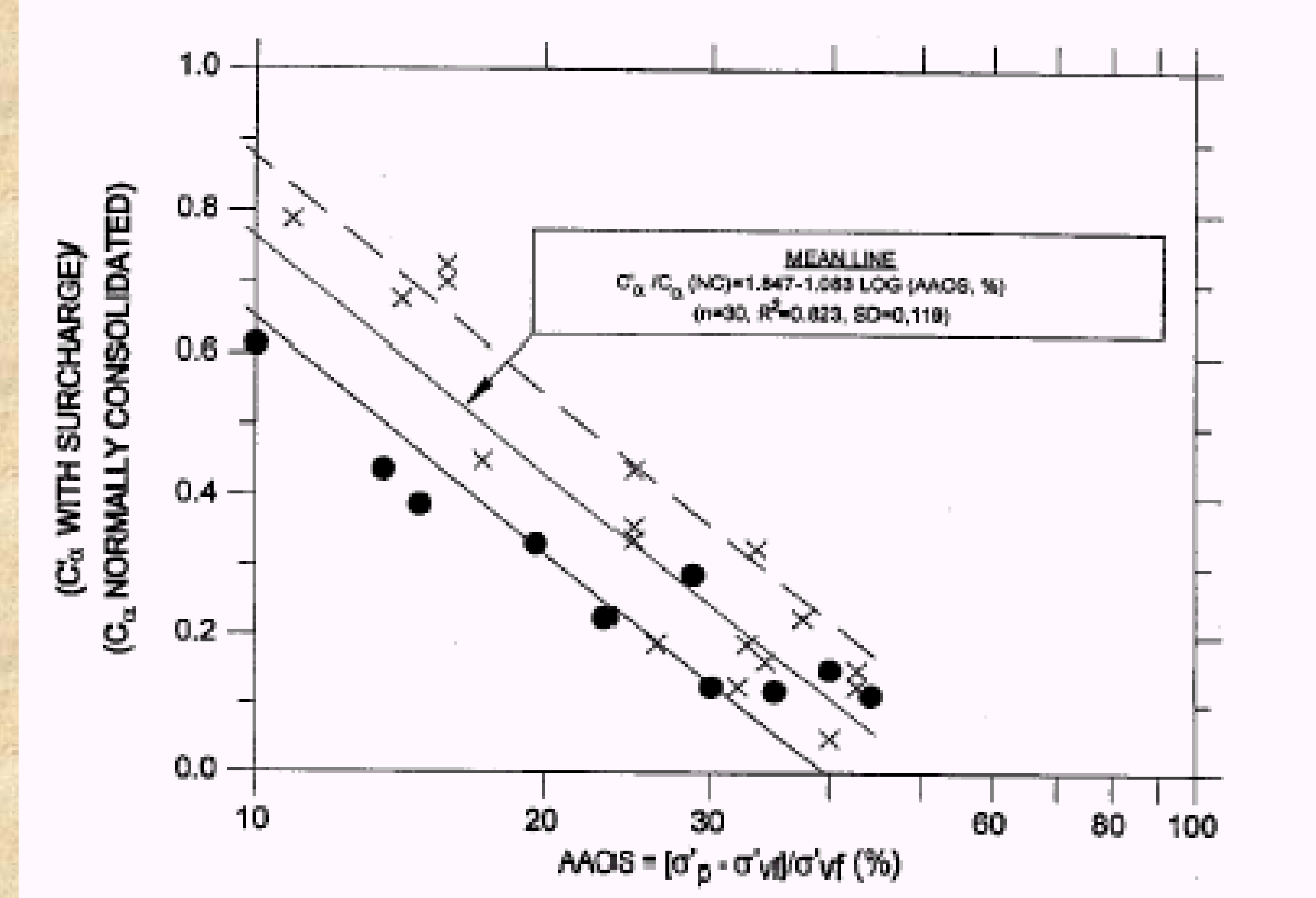
Surcharging to Reduce Settlement

5 million cubic meters of embankment placed on project

Model for Secondary Consolidation



Surcharging to Reduce Settlement

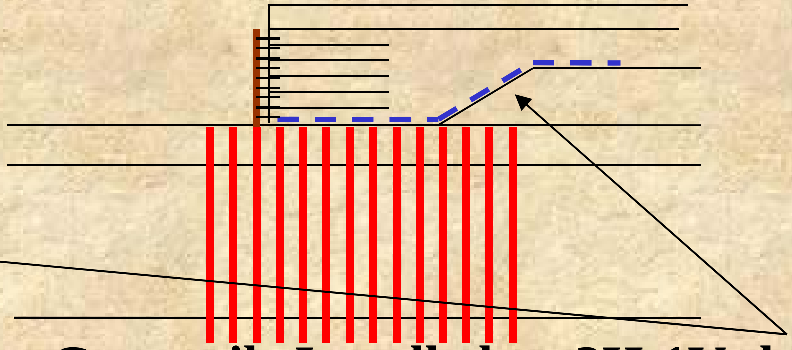


Amount of Surcharge

Surcharging Summary

1. **Design goal was to reduce secondary settlement to 3 inches or less in 10 years.**
2. **Post construction monitoring has shown that surcharging has been successful in achieving this goal.**
3. **Surcharges of 30 to 40 percent of the final embankment height were used.**
4. **Large surcharged fills introduced stability concerns in some locations.**
5. **Surcharge were to remain in place until 98 percent EOP consolidation was reached.**

Geotextile Installation in Reinforced Slopes



Geotextile Installed on 3H:1V slope

Geotextile placement on sloped, pre-existing embankment

Geotextile lapped into MSE wall

Stability Criteria for Reinforced Slopes

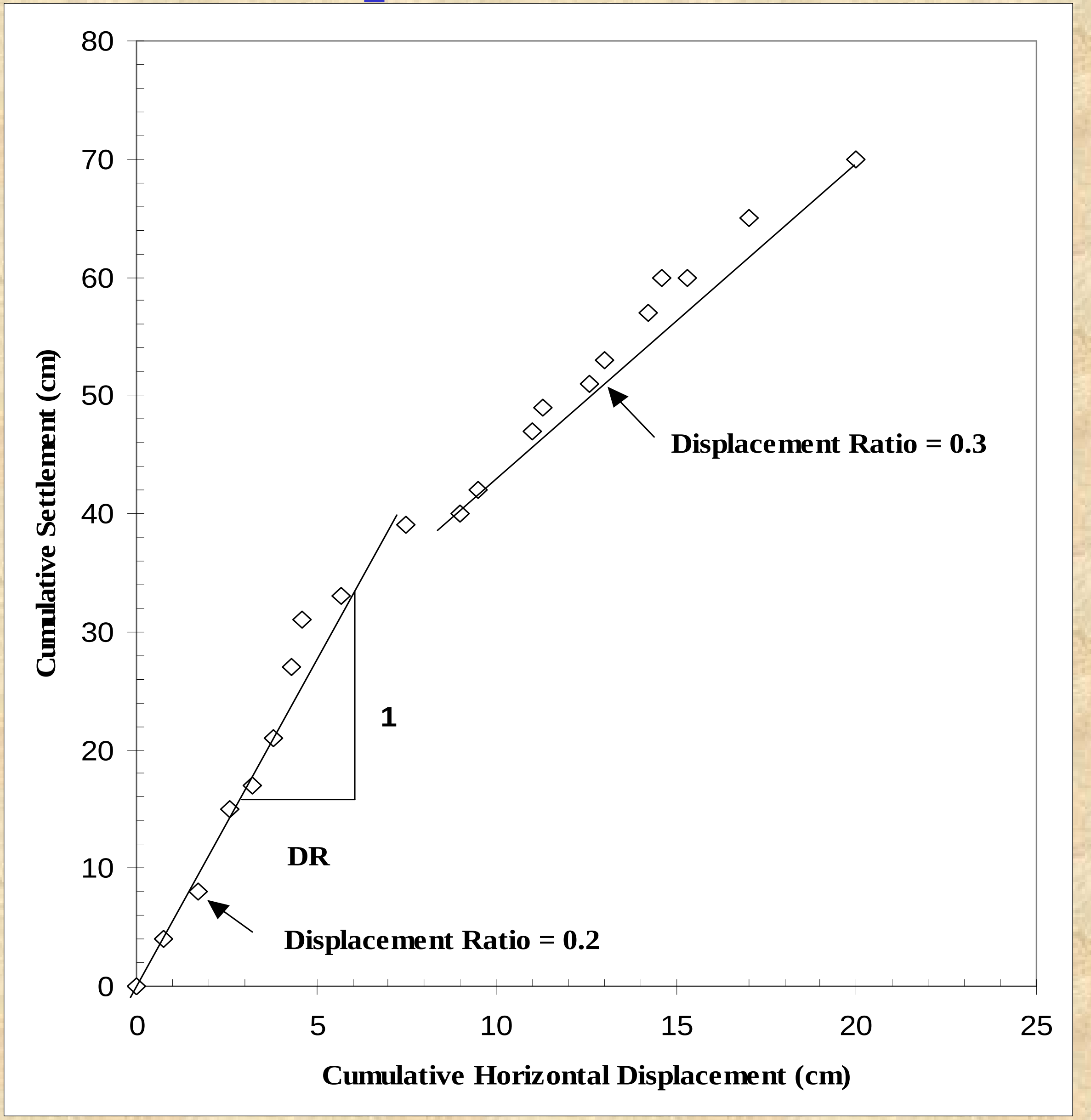
Stability Parameter	Threshold Level 1	Threshold Level 2	Threshold Level 3
Horizontal Displacement Rate (mm/day)	3.8 - 7.6	7.6 - 25.0	> 25.0
Displacement Ratio (DR)	0.2 - 0.3	0.3 – 0.4	> 0.4
Piezometric Head Increase	---------	> 200% of Load due to Fill Placement	same as threshold 2
Response Action	• Notify Field Construction Manager of threshold 1 • Increase Monitoring Frequency	• Stop Fill Placement • Prepare Specific Action Plan • Implement Plan if Conditions Worsen	• Buttress Slope and Remove Fill • Notify Senior Project Management • Notify UDOT

Stability Criteria -Displacement Ratio

DR = horz. Displacement / vert. settlement

Horz. displacement from Vertical inclinometers

Vert. Settlement from Settlement plates

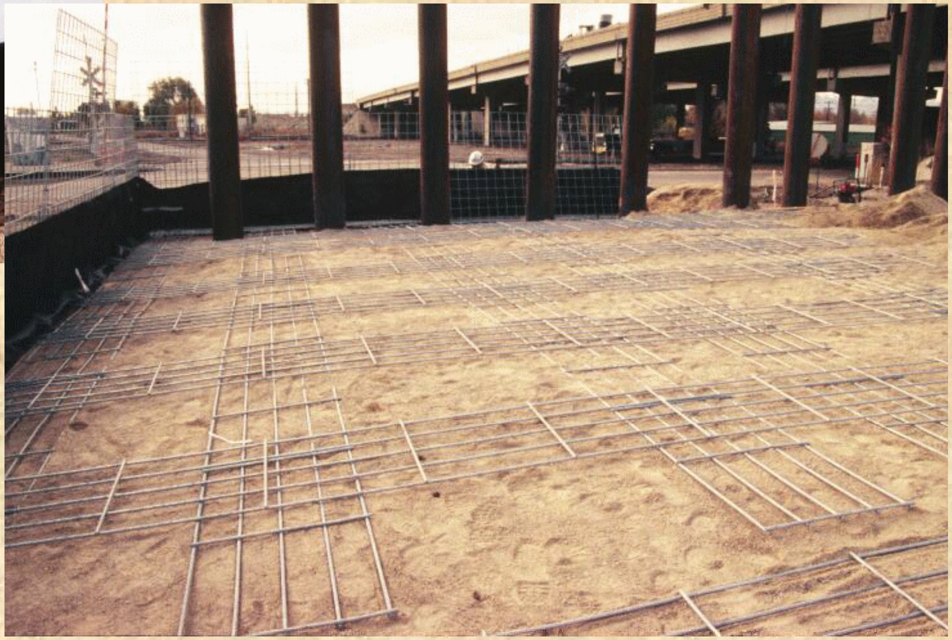


Stability Summary

1. Large embankments with surcharge introduced foundation stability issues at many bridge crossings.
2. No embankment failures occurred on the project.
3. High strength geotextile (max. 3 layers) was used to achieve global stability with a FS of 1.3.
4. Staged construction was used in many locales to reduce geotextile requirements.
5. Vertical inclinometers and settlement plates were used to monitor stability
6. Stability criteria based on the displacement ratio (DR) proved to be the most useful means of monitoring embankment stability.

2-Stage MSE Walls

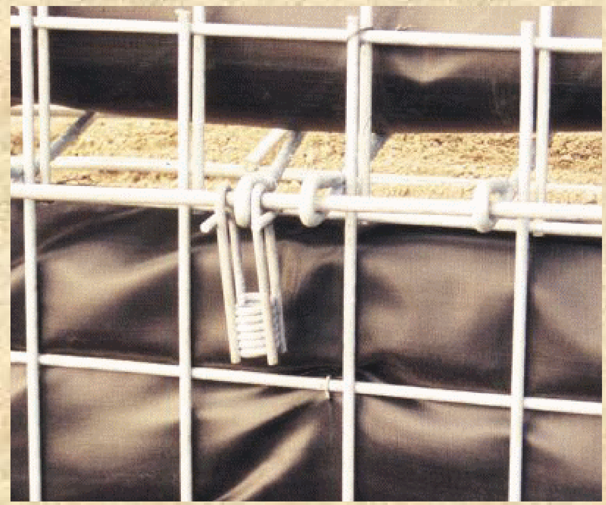
Right-of-way constraints required many slopes to be built vertically.



Beginning of 2-stage MSE Wall

2-Stage MSE Wall Connections

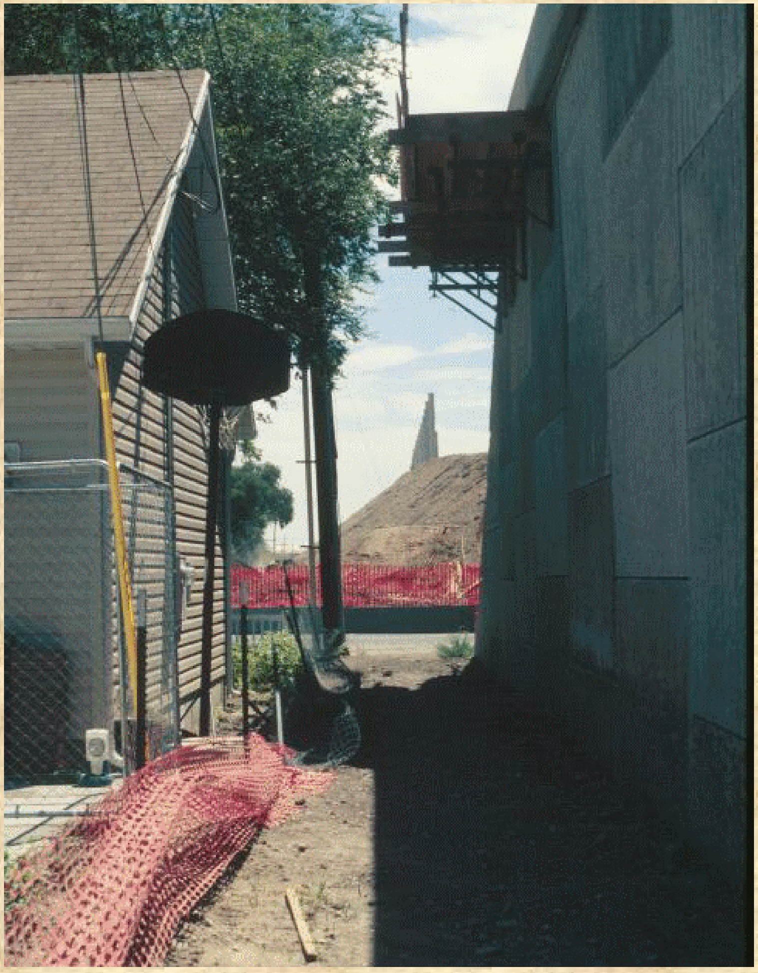
Attachment of Panels with threaded rod



Female threaded rod coupler

Concrete
Fascia Panel

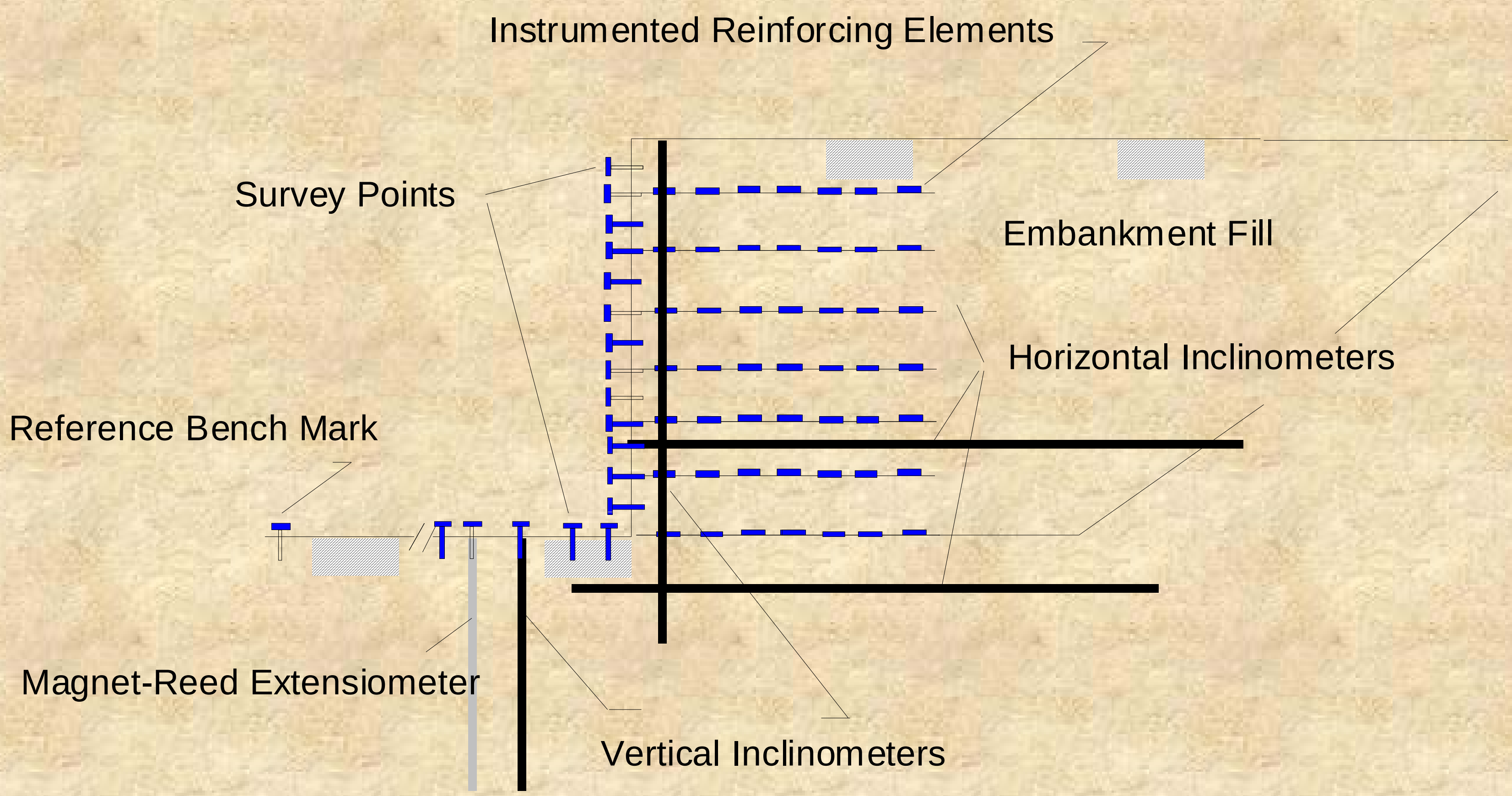
MSE Wall Settlement and Deformation Issues



Settlement Impacts to Adjacent Structures

Deformation of Welded Wire Face at Toe of Wall

3500 South MSE Wall Array



Objectives of MSE Wall Arrays

1. **Monitor Stress and Strains within Wall and Foundation**

2. **Determine Settlement Distribution Away from Wall**

3. **Monitor Transitions Zones**

4. **Deformation Modeling**

UTAH STATE AGGIES

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Strain Gauges on Welded-Wire Reinforcing

Horizontal reinforcing (bar mat) with strain gages.

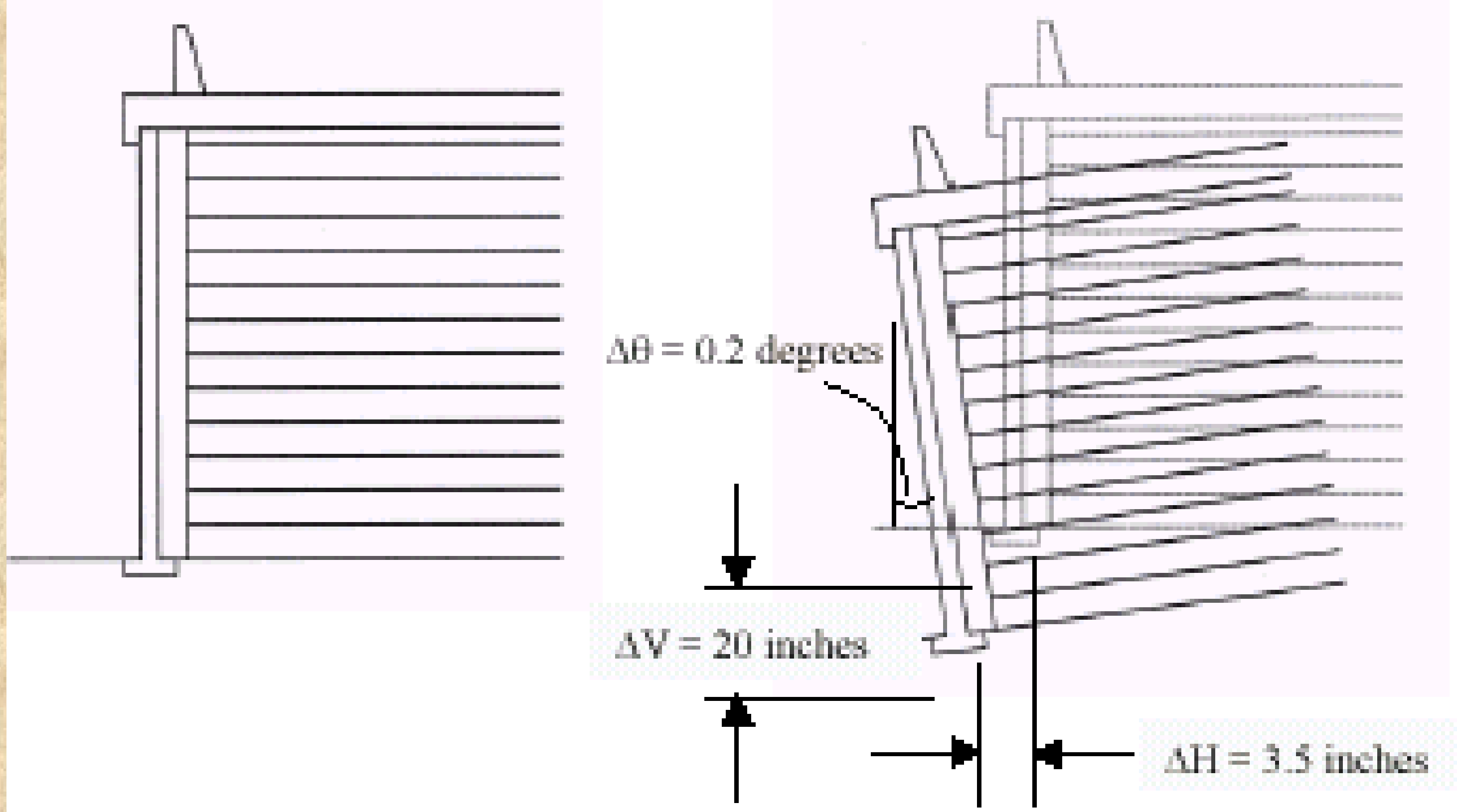
Strain gage wiring at face of MSE wall

3500 South MSE Wall Array

Inclinometer and Sondex Locations

Reading of Sondex Extensometer

3500 S. MSE Wall Deformations



a) Undeformed Wall   b) Exaggerated Deformed Wall

MSE Wall Summary

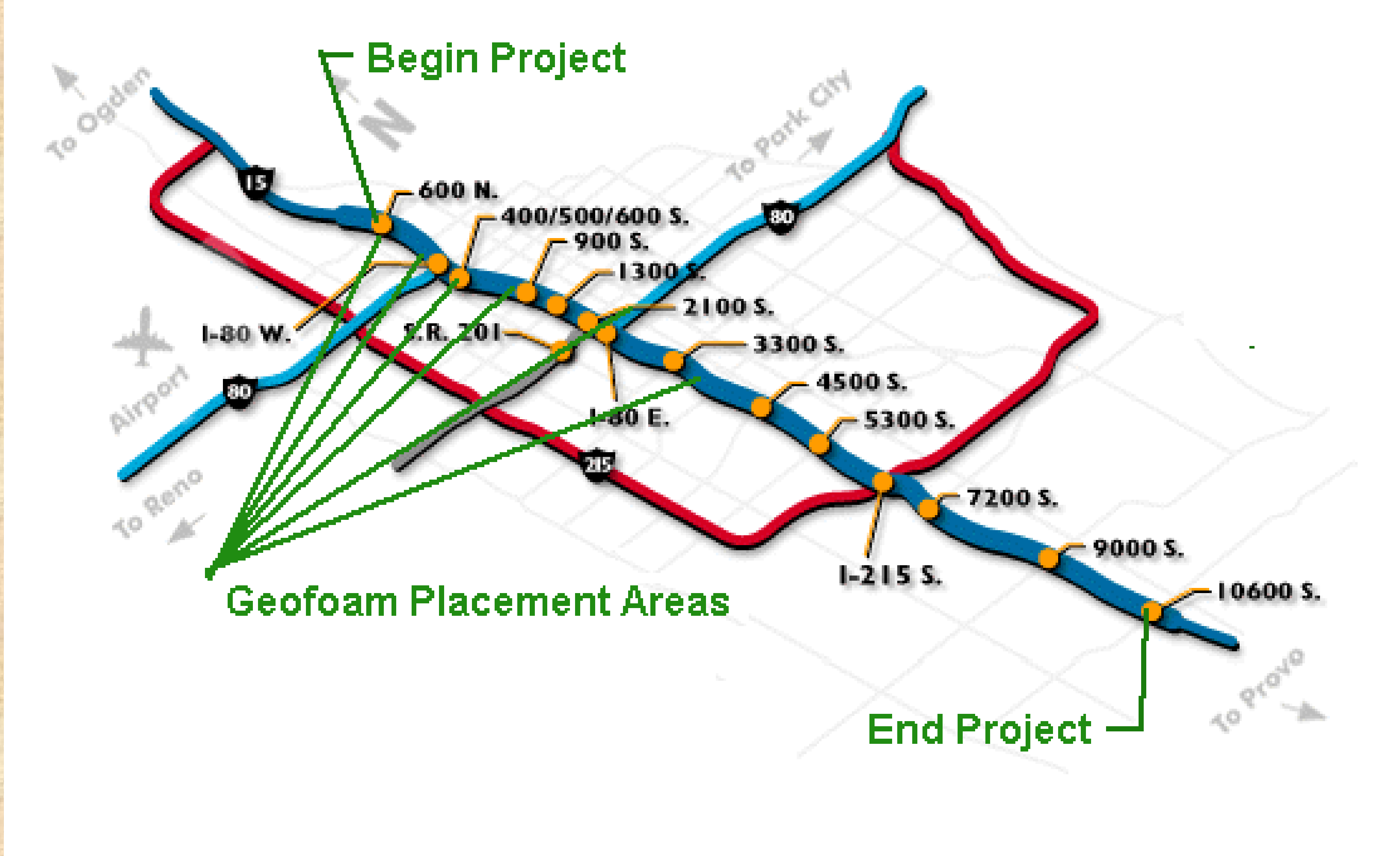
1. **Large primary consolidation settlement req'd use of two stage MSE wall with flexible wire face.**
2. **Flexible faces can deform during construction and post-construction.**
3. **Increasing the horizontal reinforcement in the bottom half of the wall can reduce the deformation, but not completely eliminate it (horzizontal buldge reduce by a factor of 2.)**
4. **Material type, compaction and construction procedures can also help in reducing face deformation.**
5. **Specifications should be written to control allowable face deformation.**
6. **Zone of settlement influence is 1.5 times wall height.**

Geofoam Embankment For Settlement Reduction

Buried Utilities

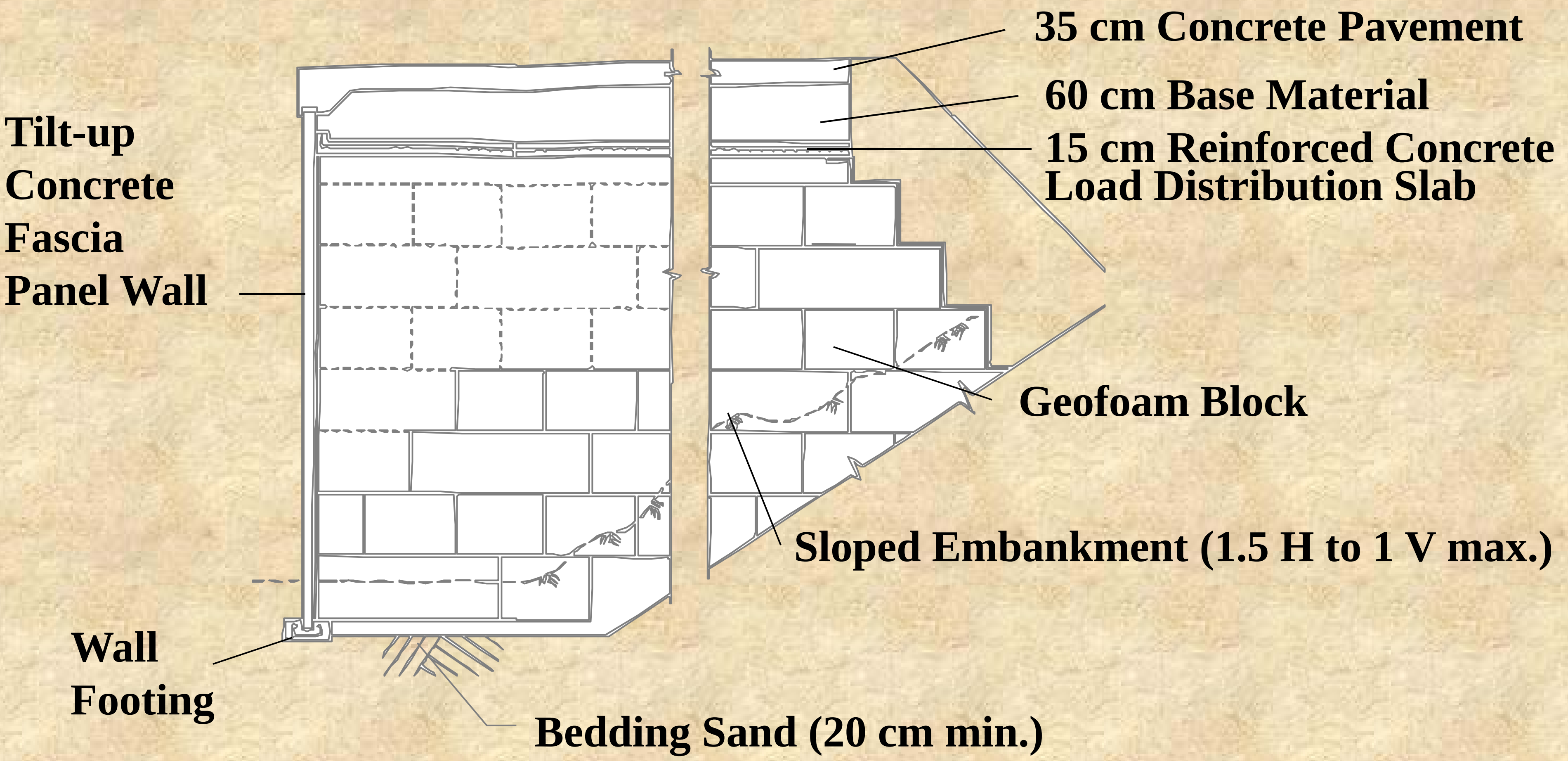
Geofoam Embankment from State St. to 200 W. Along Interstate I-80, Salt Lake City, Utah

Geofoam Placement Areas



100,000 cubic meters of Geofoam

Geofoam Cross Section (Typical)



Geofoam Properties

Physical Property	ASTM Test Procedure	Type VIII Accepted Value	Type II Accepted Value	Tolerances
Density	D1622	18 kg/m^3	22 kg/m^3	± 10 %
Compressive Resistance	D1621	90 kN/m^2	104 kN/m^2	minimum @ yield or 10 percent axial deformation
Flexural Strength	C203	208 kN/m^2	276 kN/m^2	Minimum
Water Absorption	C272	3	3	< % by volume

Table 2. Properties of Type VIII Geofoam Specified for the Reconstruction I-15 Project.

*** I-15 used 1.25 pcf density exclusively (i.e., type VIII geofoam)**

Geofoam Embankment

Construction of Geofoam Embankment and Footing for Tilt-up Panel Wall

Leveling Course of Sand for Geofoam Embankment

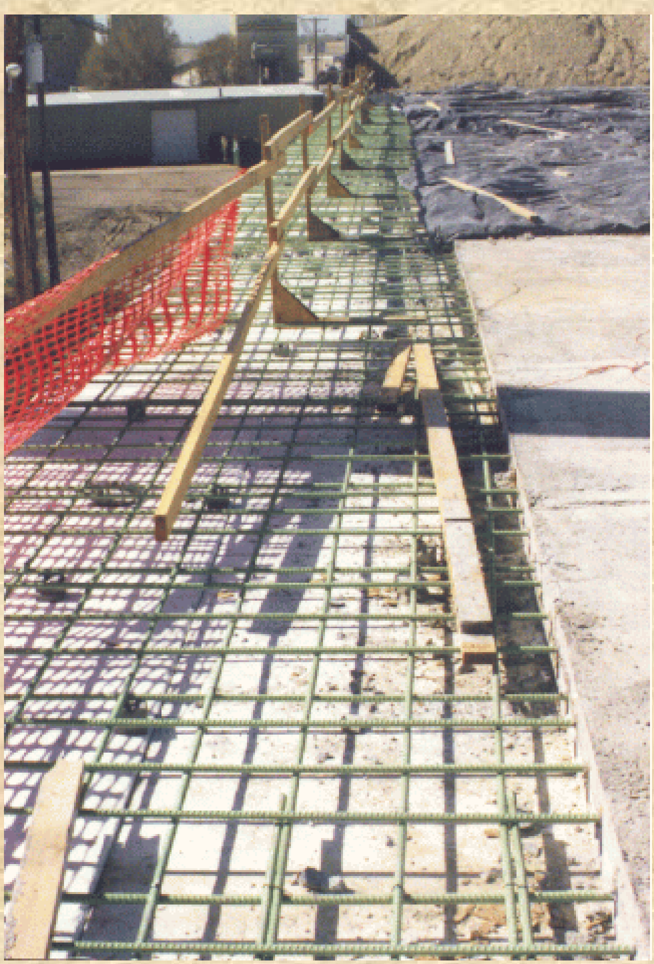
Geofoam Embankment

Nearly Completed Geofoam Embankment with Vertical Face

Geofoam cut and placed around piling at bridge abutment

Transition Zone with MSE Wall

Load Distribution Slab Atop Geofoam

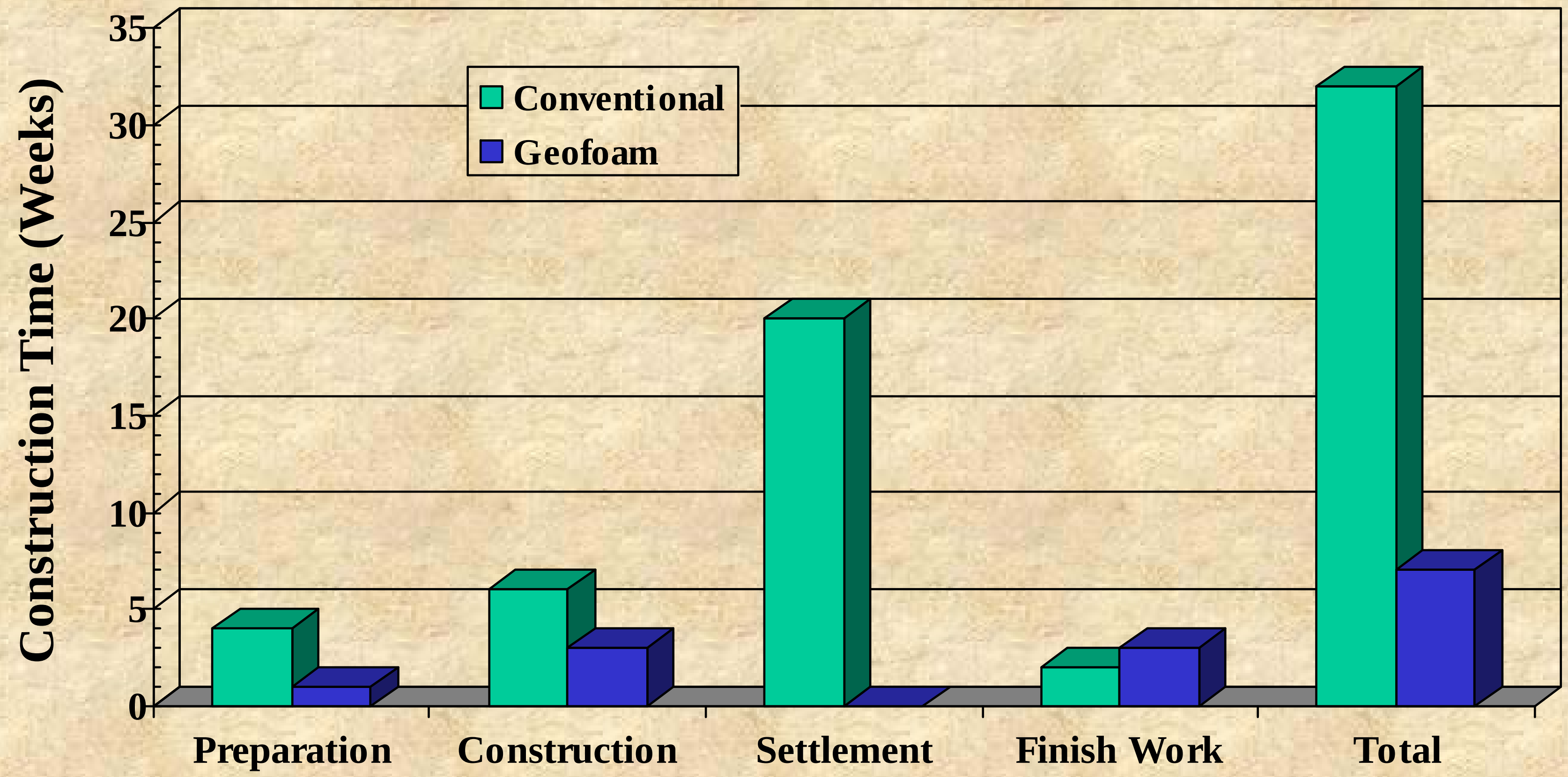


Reinforced Concrete Load Distribution Slab atop Geofoam

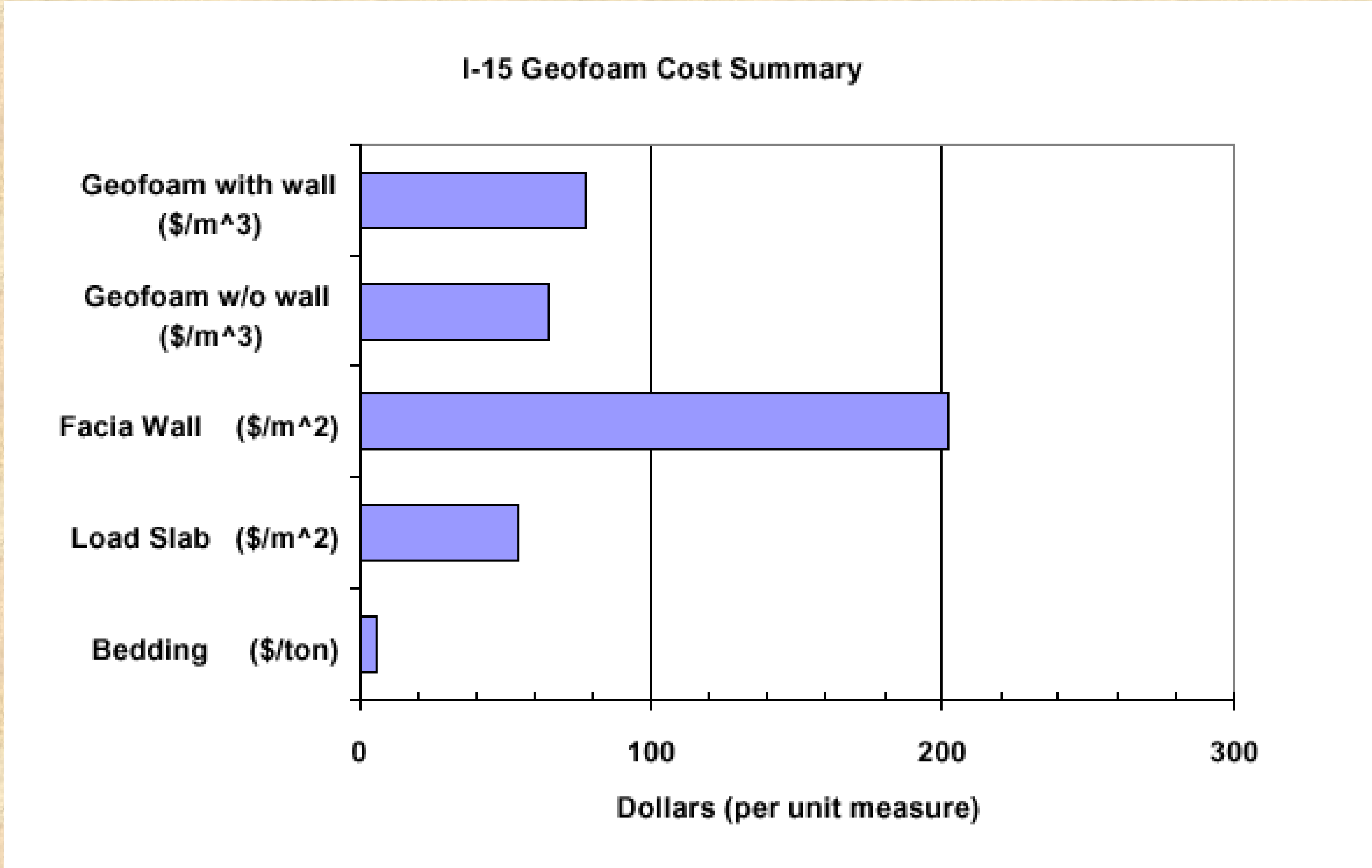
Completed Load Distribution Slab

Geofoam (Finished Cross Section)

Geofoam for Rapid Construction
Comparison of Construction Times

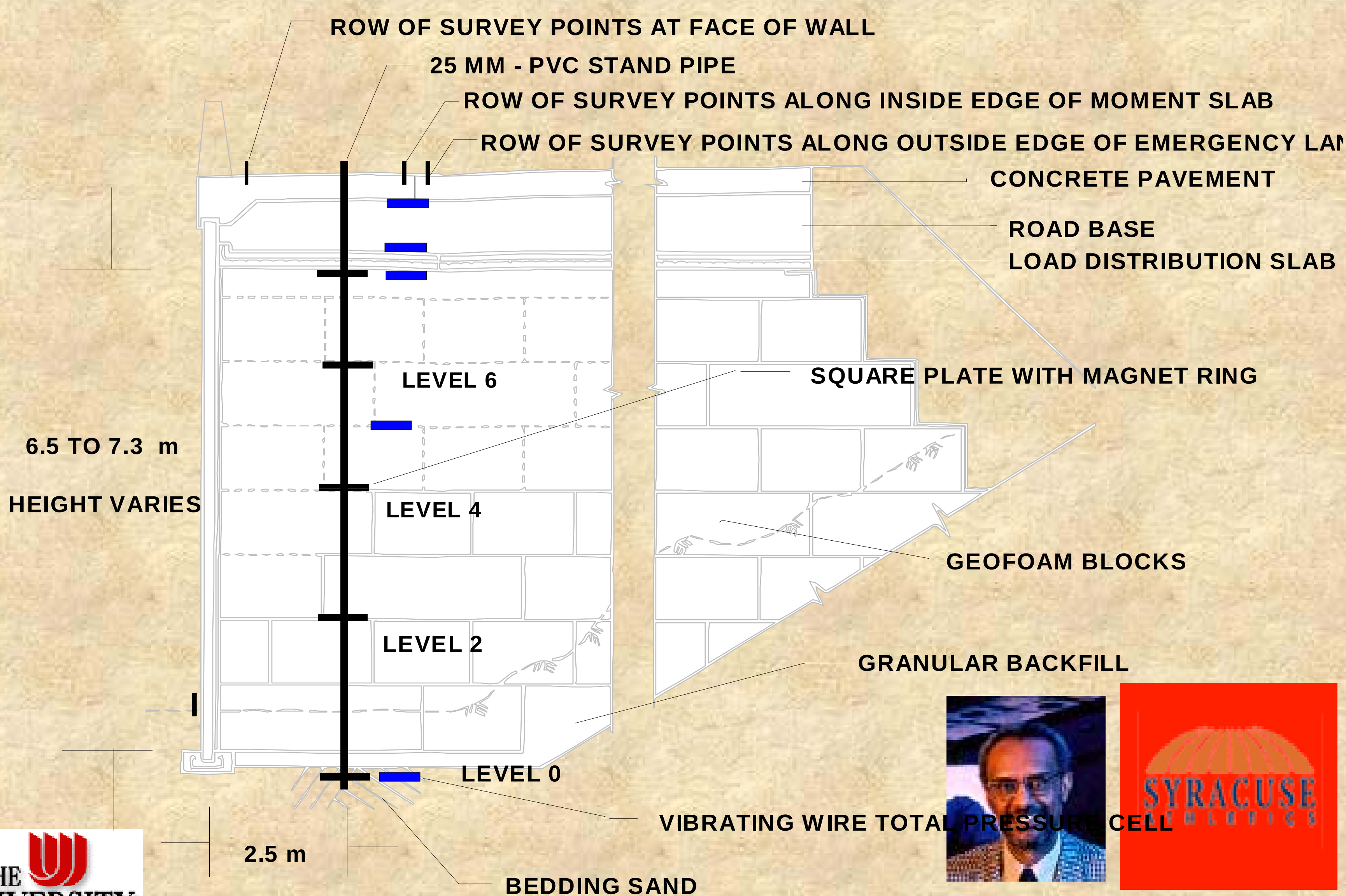


Geofoam Wall Costs



Geofoam wall system (total cost) is about 2 ¼ times more expensive than conventional 2-Stage MSE wall with PV drains

3300 South Geofoam Array



SYRACUSE ORANGEMEN

Objectives of Geofoam Arrays

- Measure Creep Settlement of Geofoam Mass (10 yr.)
- Measure the Pressure Distribution within Mass
- Measure Differential Settlement in Transition Zones
- Measure Lateral Earth Pressure at Abutments
- Monitor for Differential Icing at Geofoam / Embankment Transition Zones
- Model Stress / Strain Behavior

3300 South Geofoam Array Installation

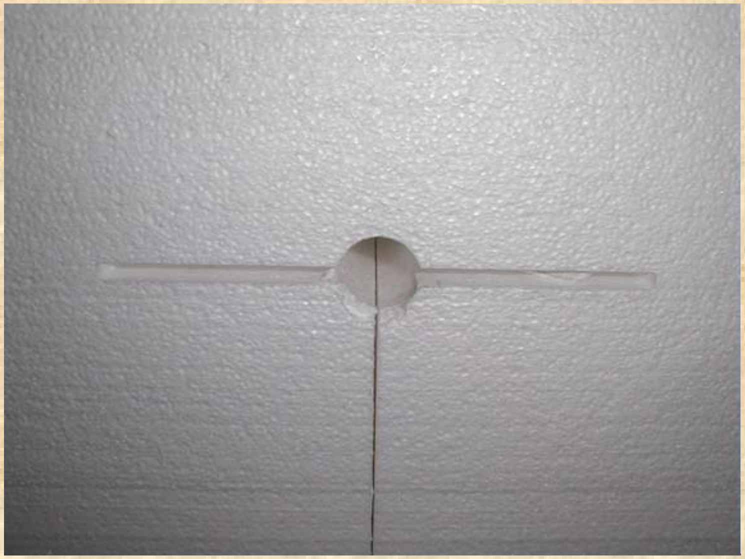
Magnet Extensometer and
Pressure Cell Installation

Pressure Cell in Base Sand

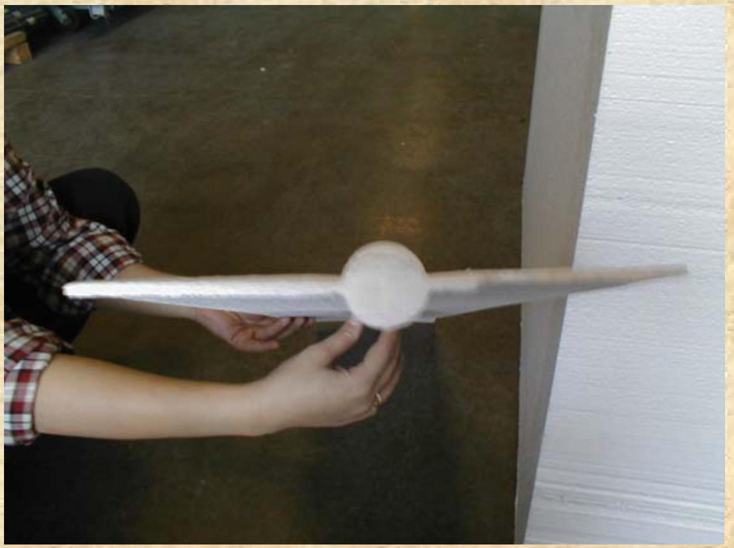
Pressure Cell Cast in Bridge Abutment

First Method of Placing Pressure Cell

Improved Method of Placing Pressure Cell

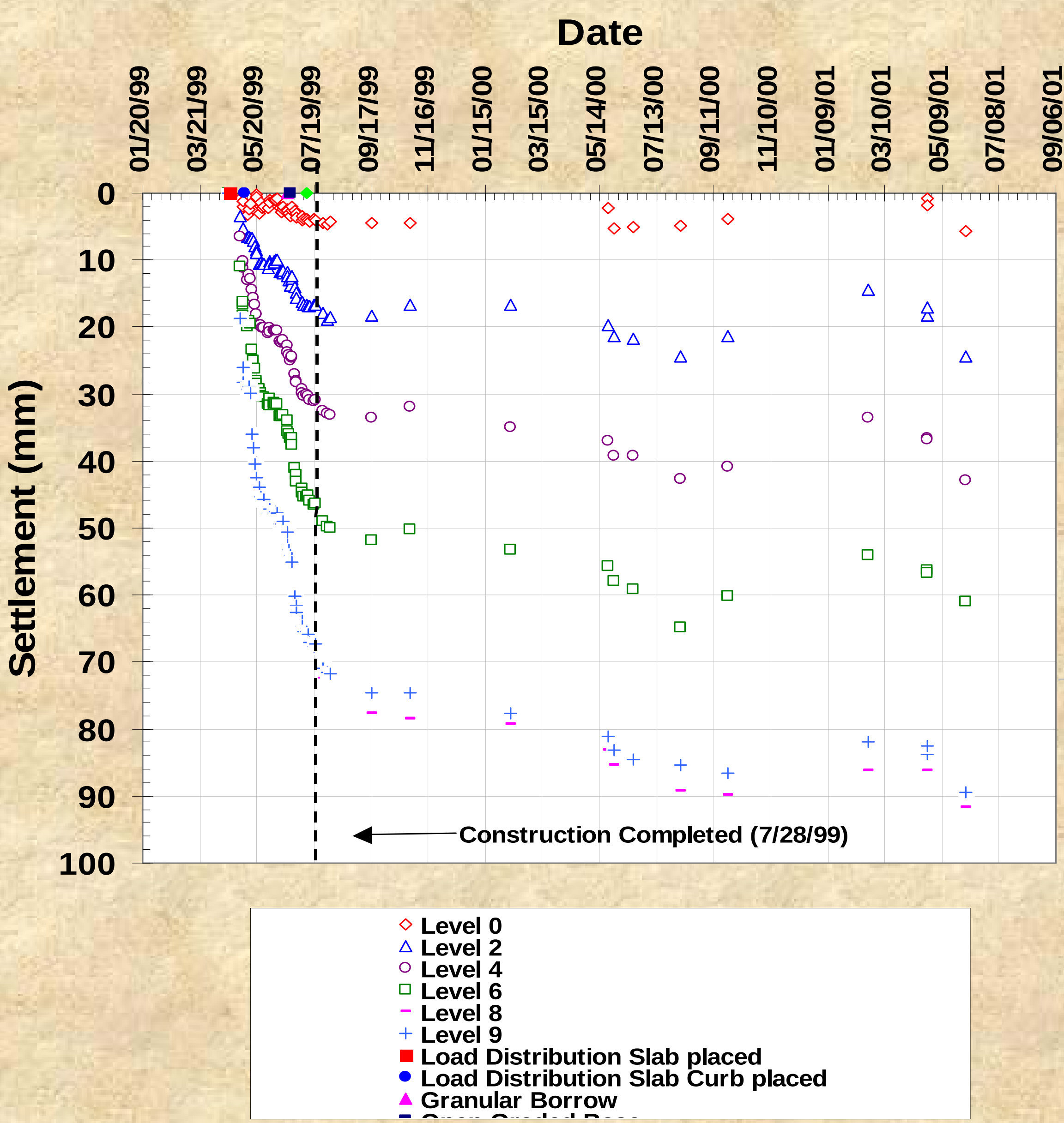


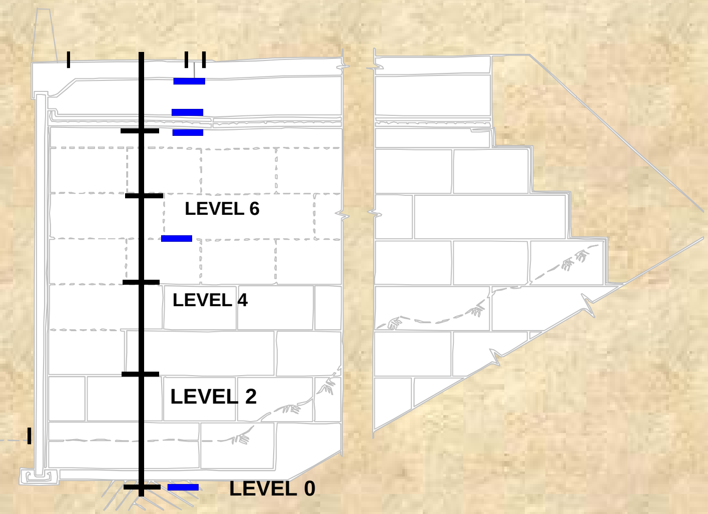
Hot Wire Cut



Pressure Cell Placed in Cut

3300 South Magnet Extensometer Data





1% Construction Strain

100 South Magnet Extensometer Data
Post-Construction Settlement

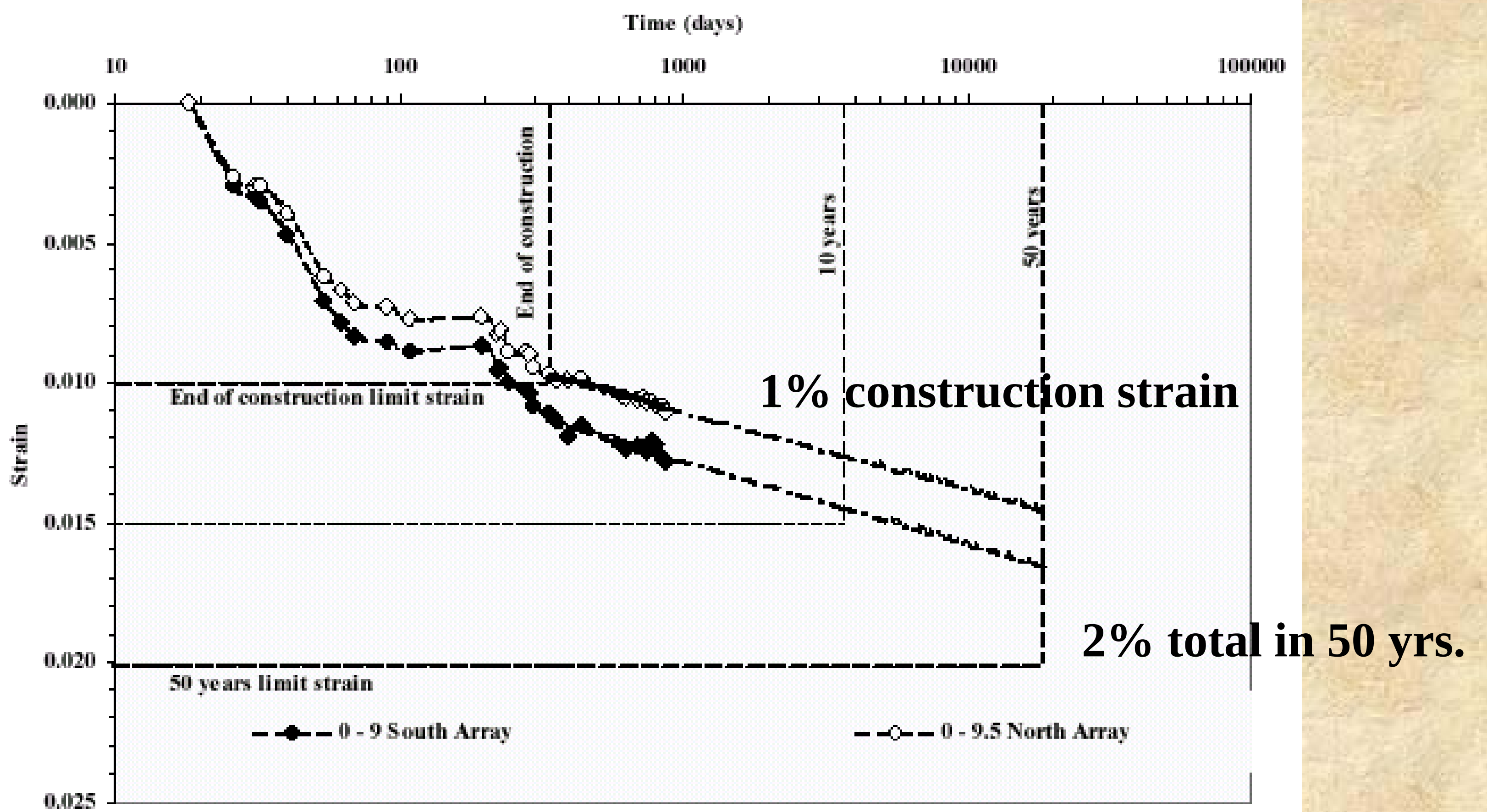
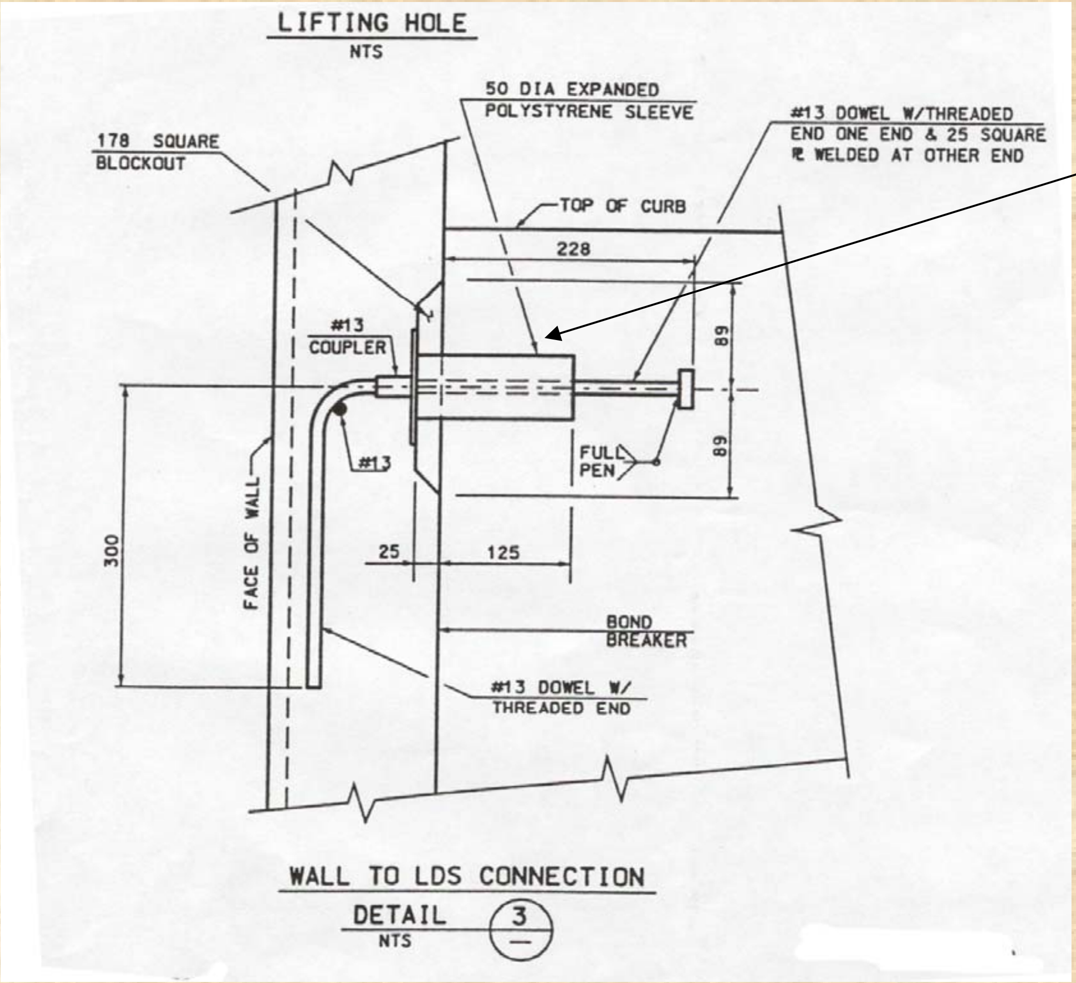


Figure 37 – Projected settlement trend for I-15 geofoam at 100 South.

3300 South Geofoam Array

Damage to Connections During Construction Loading

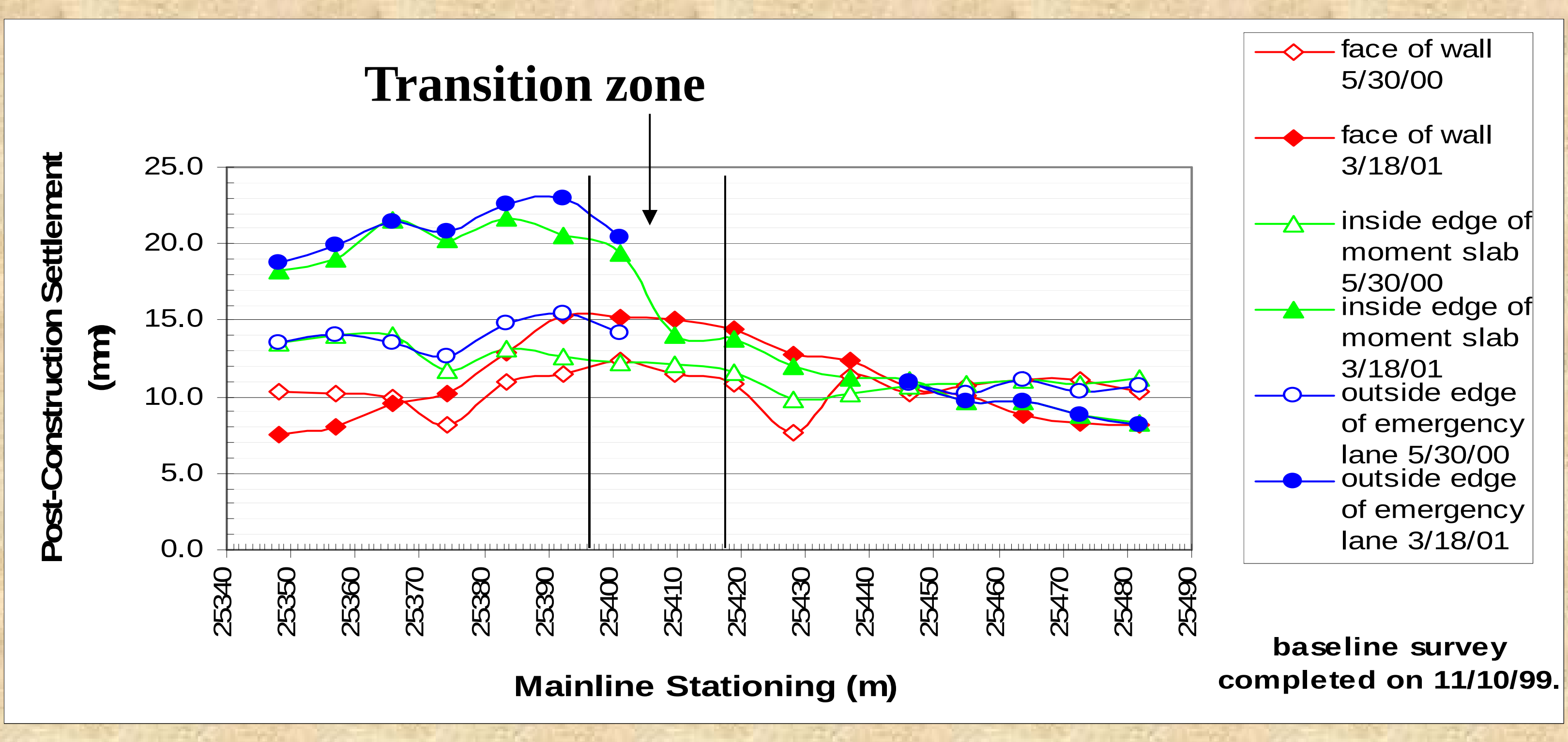


Damaged Connection

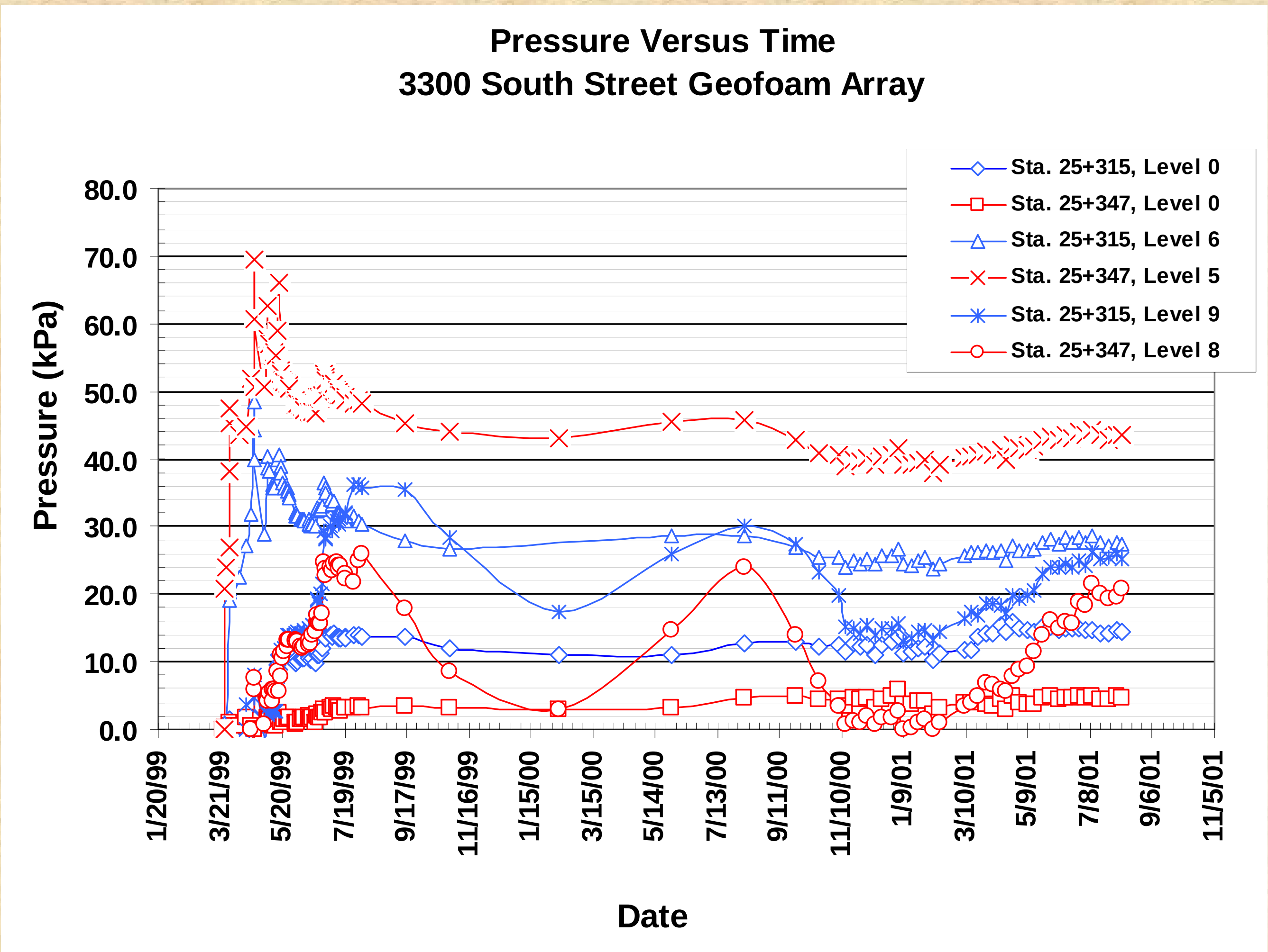
- **Approximately 1% loading strain can be expected.**
- **Strain due to seating of untrimmed block and elastic compression.**
- **Damaged connection was later repaired by dowels.**
- **Rigid connect should be avoided.**

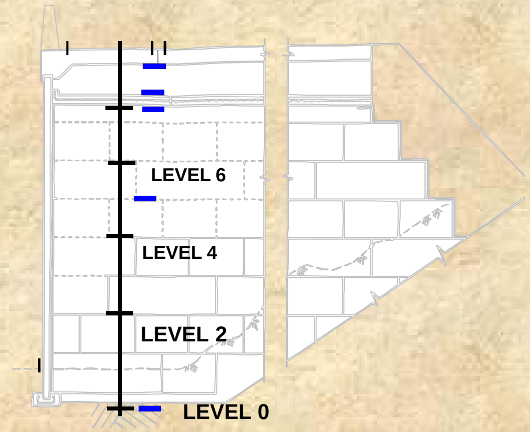
Geofoam Transition Zones
Post-Construction Settlement

Transition slope
3.5 H : 1 V



Geofoam Pressure Cell Measurements





Geofoam Conclusions

1. **Geofoam fills are performing as expected with no major issues.**
2. **Approximately 1 percent vertical strain occurred during construction.**
   a. **Strain due to seating and compression of geofoam.**
   b. **This strain can damage rigid connections.**
3. **Approximately 0.2 percent creep strain (15 mm) has occurred in a 2-year post construction period.**
4. **The vertical stress distribution that develops in a geofoam wedge fill is complex, but generally diminishes with depth.**
5. **Pressure cell measurements suggest that approximately 45 kPa of vertical stress has developed in the center of the geofoam mass. This is approximately 50 percent of the compressive strength of the geofoam.**

Geofoam Conclusions (cont.)

6. **Creep strain will be relatively small for dead loads that are less than 50 percent of the compressive strength.**
7. **Creep strain in a 10 year post-construction period is expected to be 0.25 to 0.3 percent (18 to 21 mm).**
8. **Transition zones with the MSE wall need to be designed carefully to minimize differential settlement in the transition zone**

Lime Cement Stabilized Soil

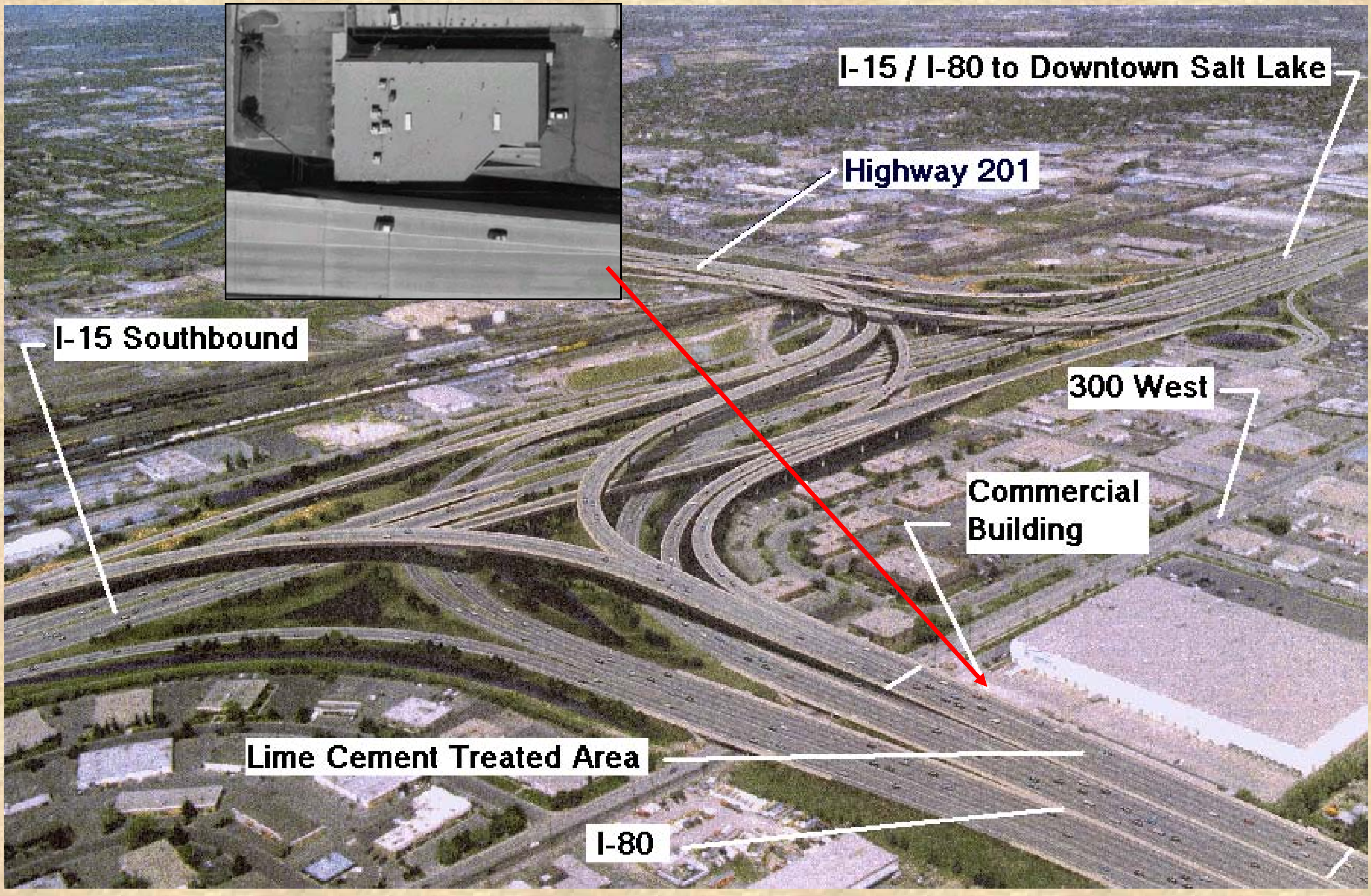
Lime Cement Column Rig

Auger / Mixer for Lime and Cement

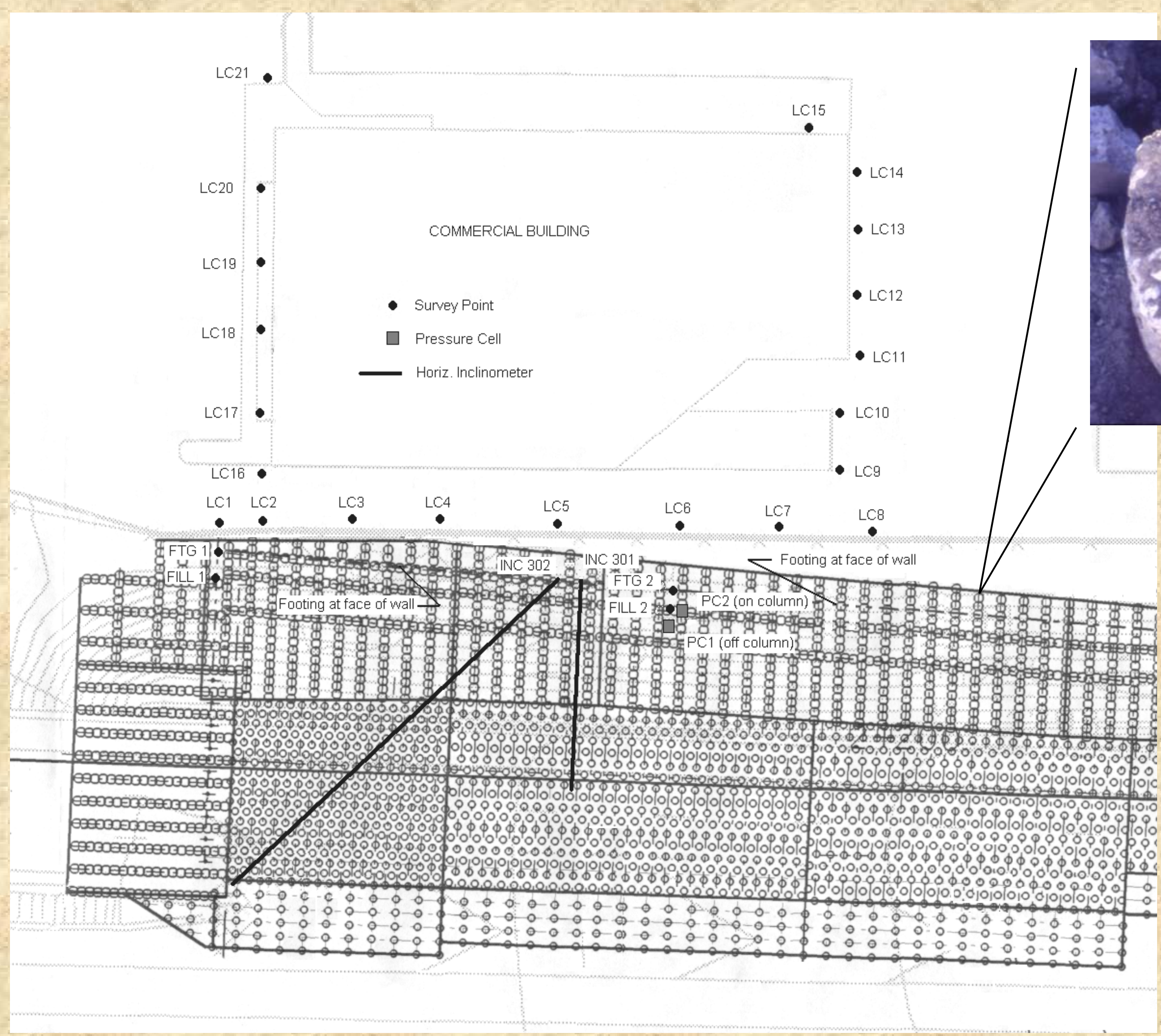
125 kg/m^3 15% lime 85% cement

M = 30 Mpa (design); Su 300 to 400 kPa

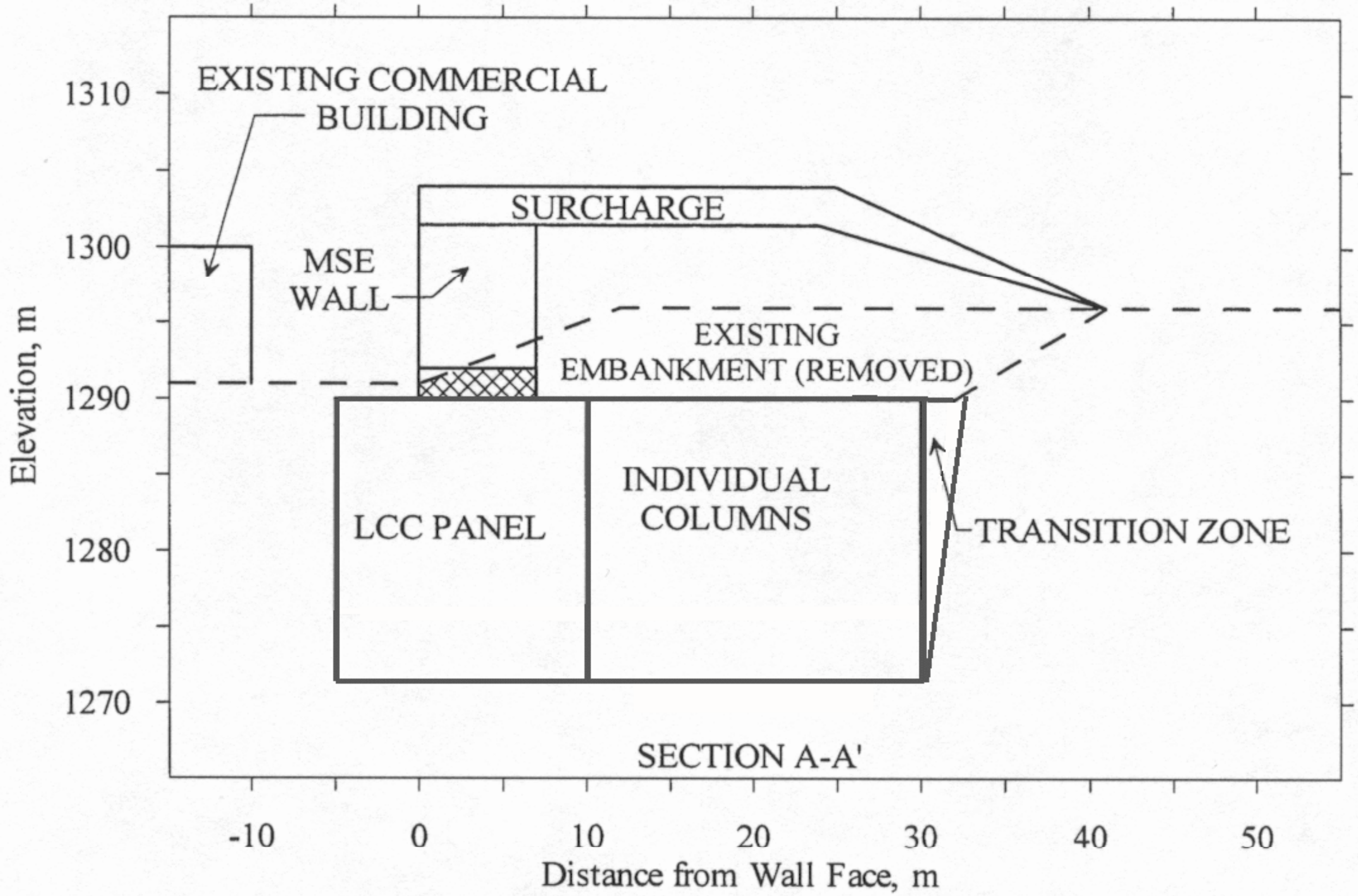
Lime Cement Treatment Area



Lime Cement Column Installation Pattern



Lime Cement Column Installation X-Section

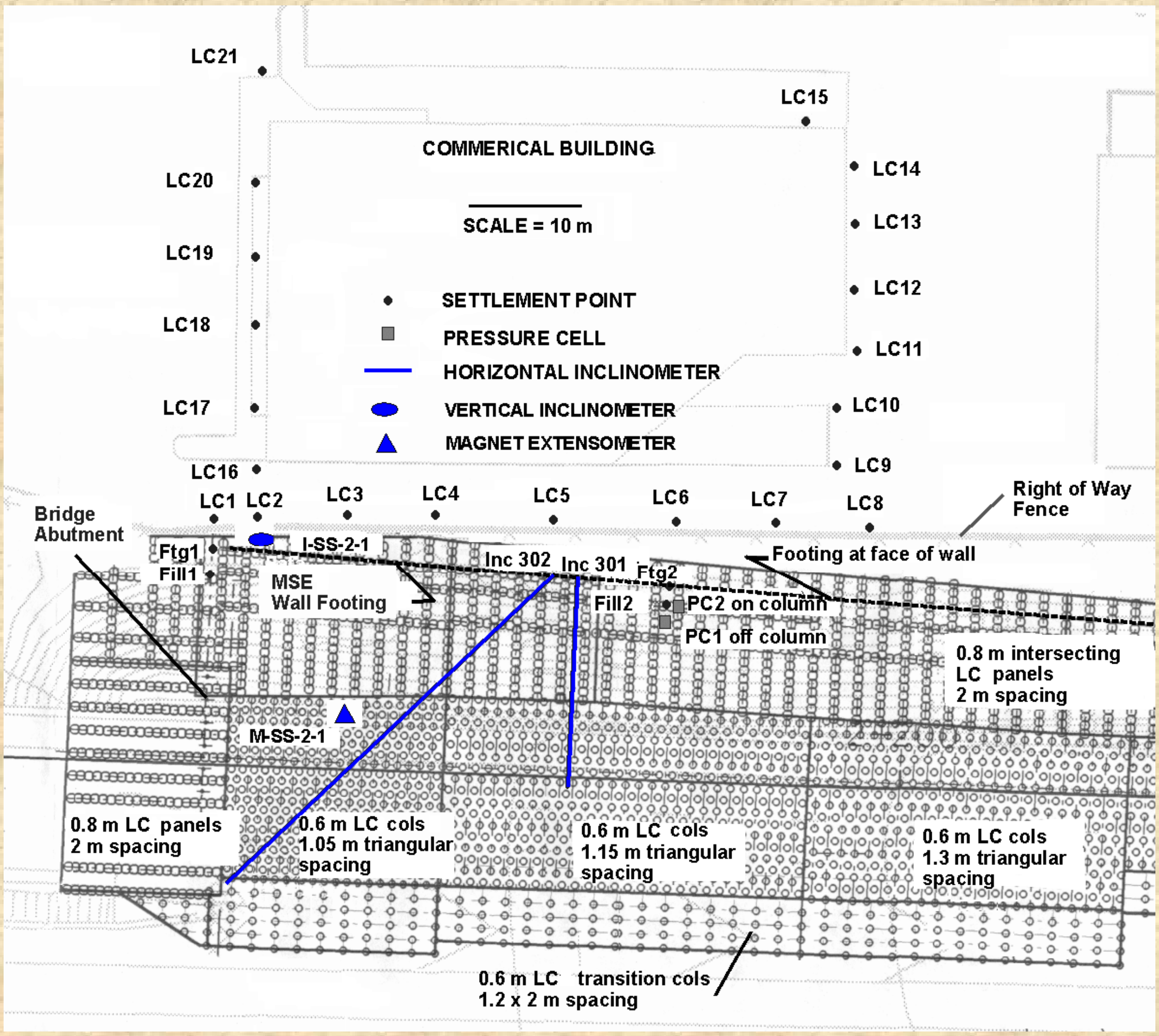


1-Stage MSE Wall Construction

1-stage MSE placed over columns

Finished MSE wall

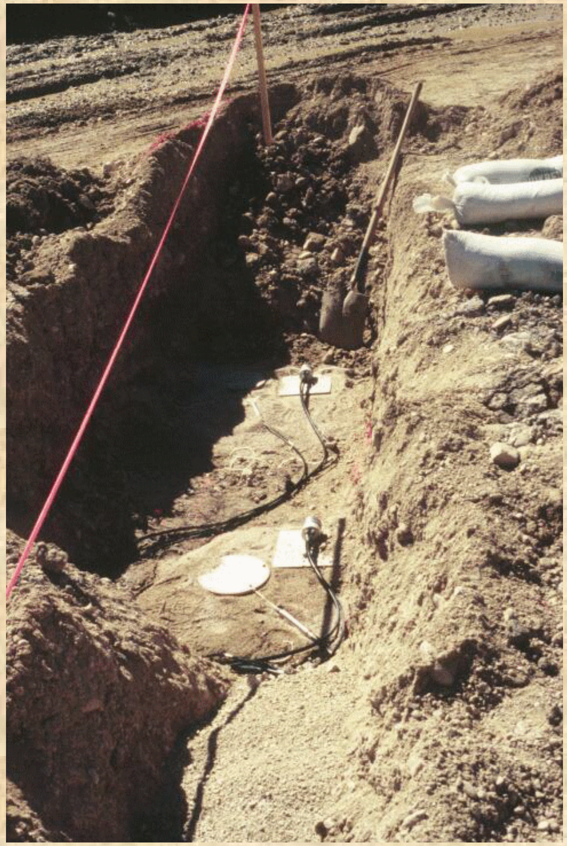
Lime Cement Column Array



Objectives of Lime Cement Column Array

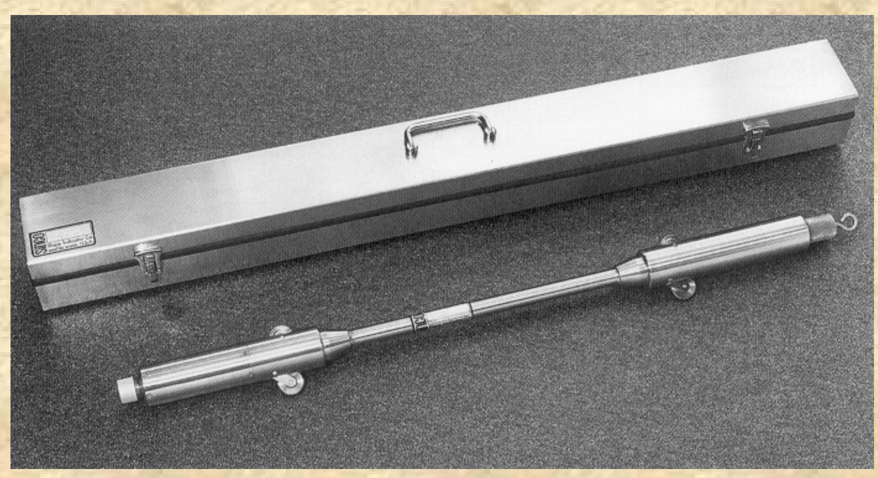
1. Determine the Primary Consolidation
2. Measure the Primary Settlement in the Treated Area and at adjacent structure
3. Measure the Secondary Settlement over 10 yr. Period
4. Determine the Modulus of Treated Area versus Untreated Ground
5. Measure the Shear Strength of the Treated Ground
6. Model the Construction and Long-Term Deformation Behavior

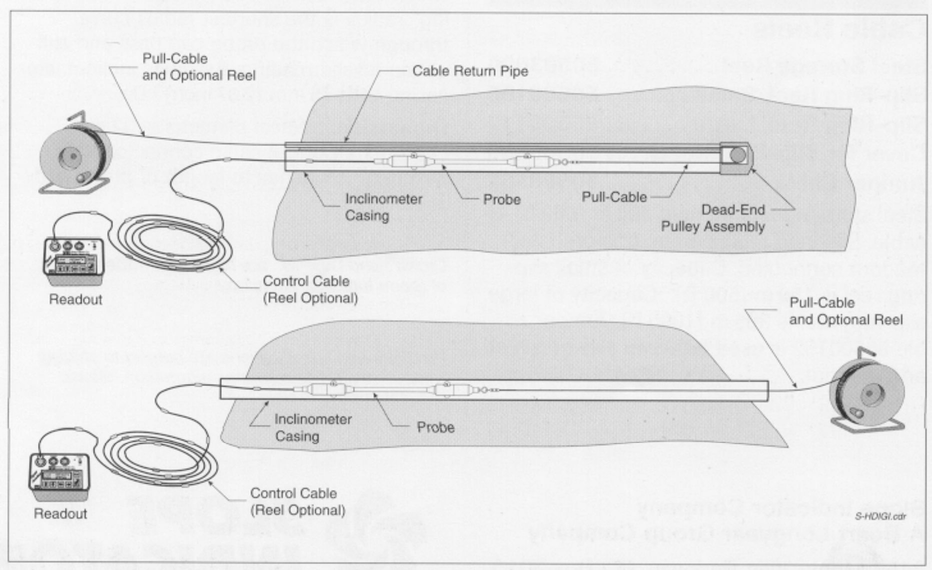
Pressure and Settlement Cells at Lime Cement Column Array



Pressure and Settlement Cells Atop Column

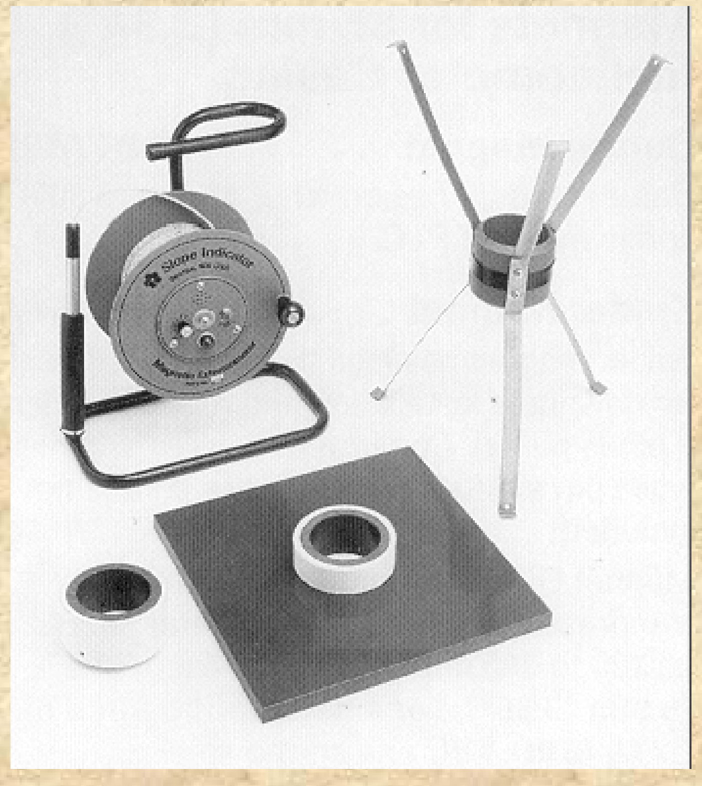
Horizontal Inclinometers

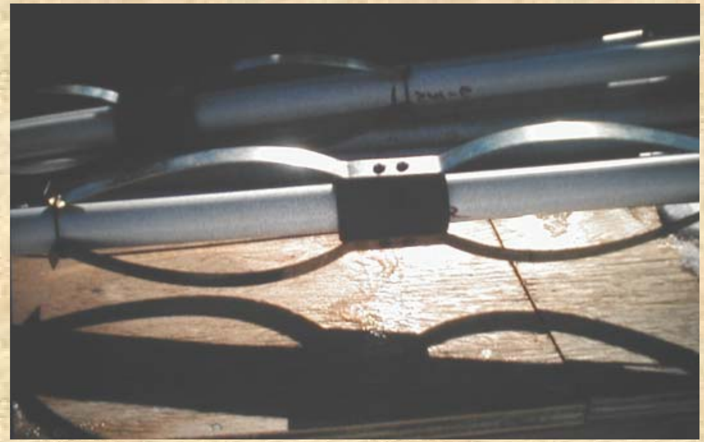


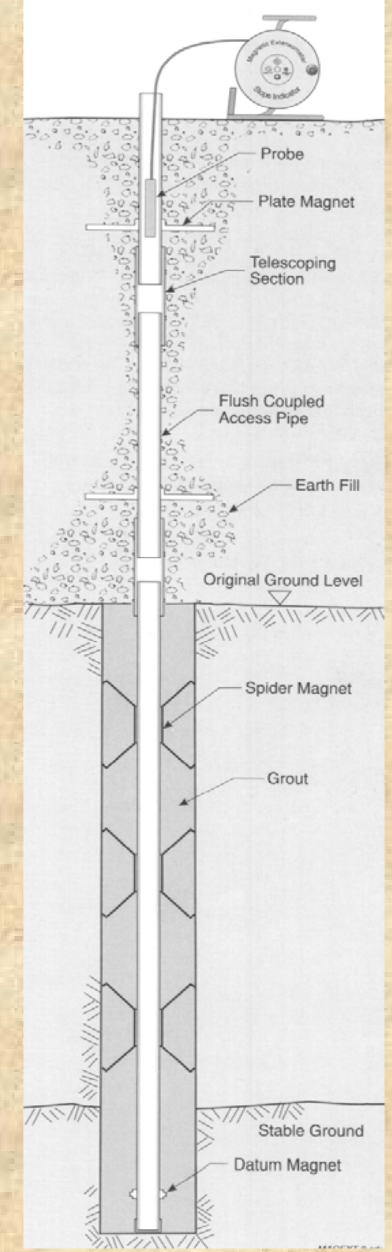


Horizontal Inclinometer Systems, with and without dead-end pulley assembly

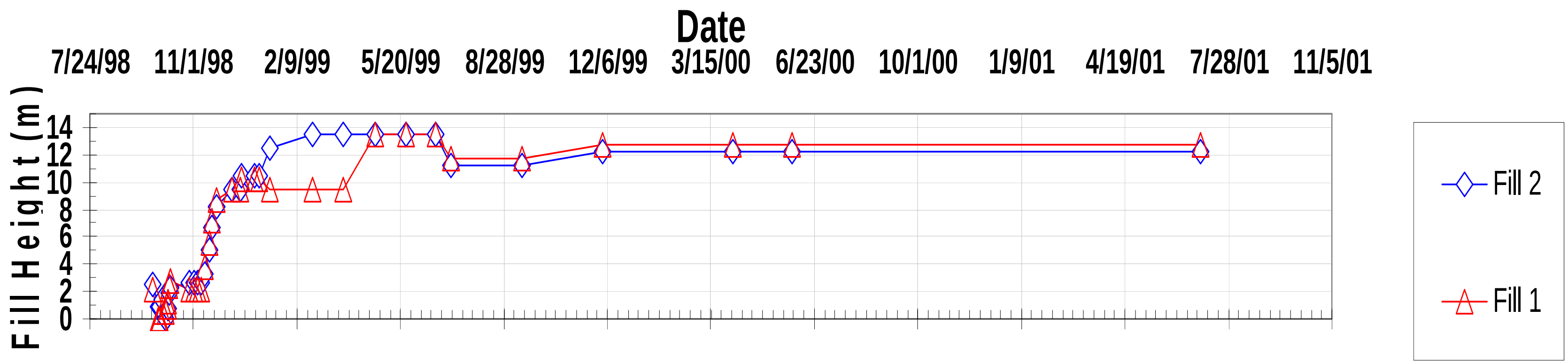
Borehole Magnetic Extensometer





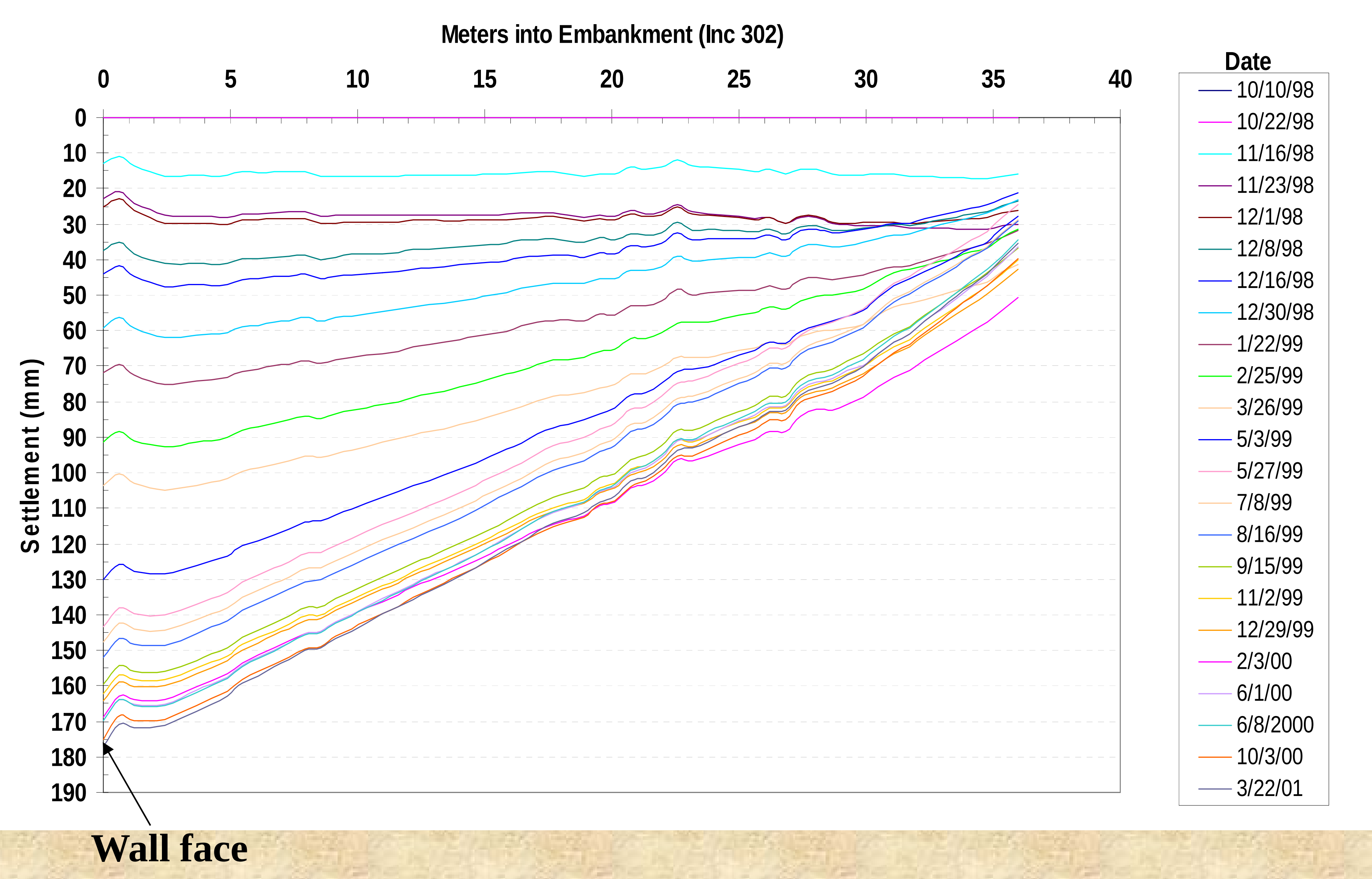


Fill Height vs. Load on Lime Cement Columns



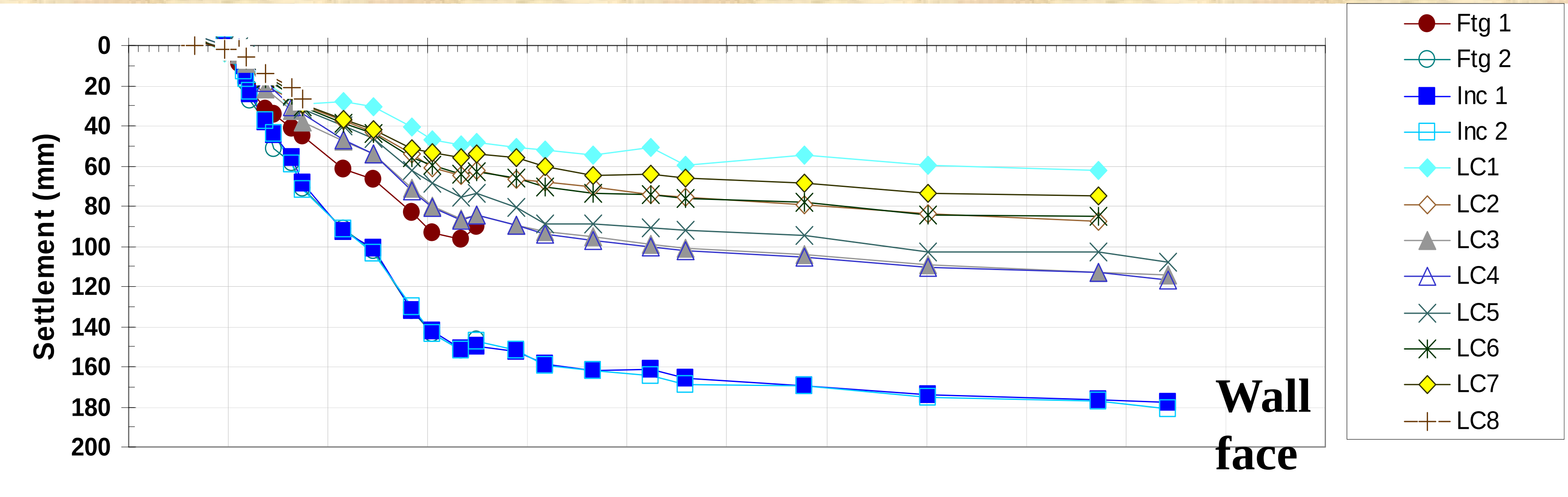
Stress ratio = 10:1

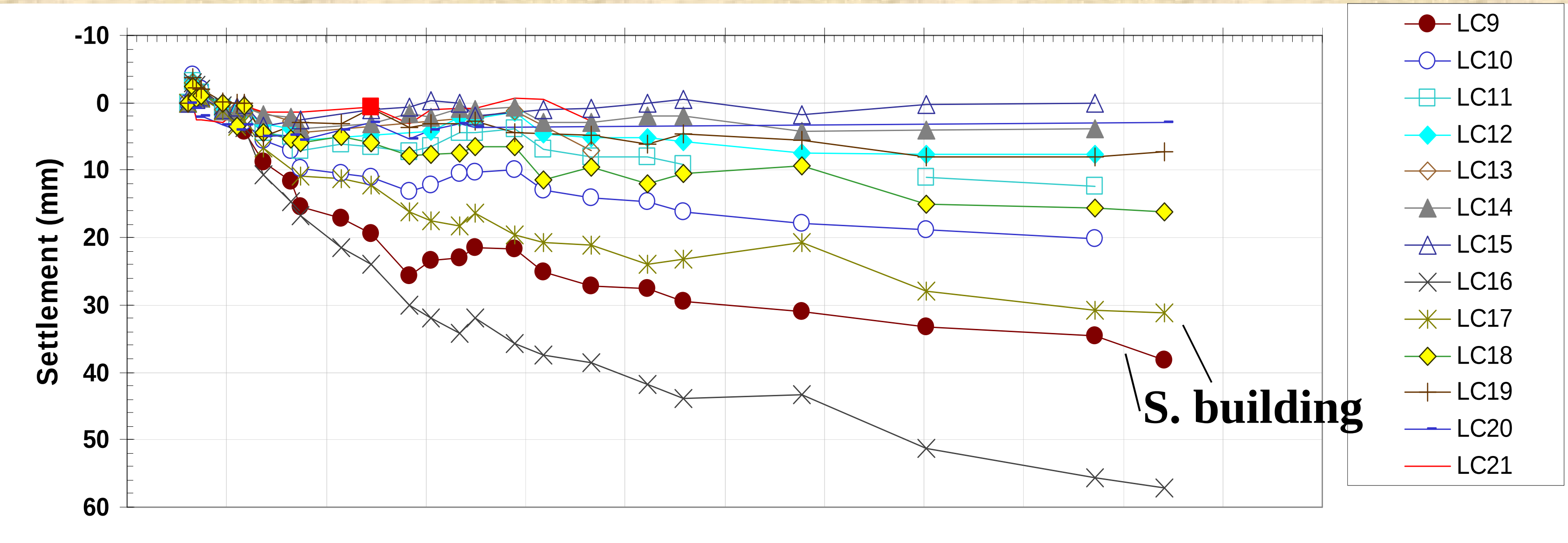
Inclinometer Measurements at LCC Array



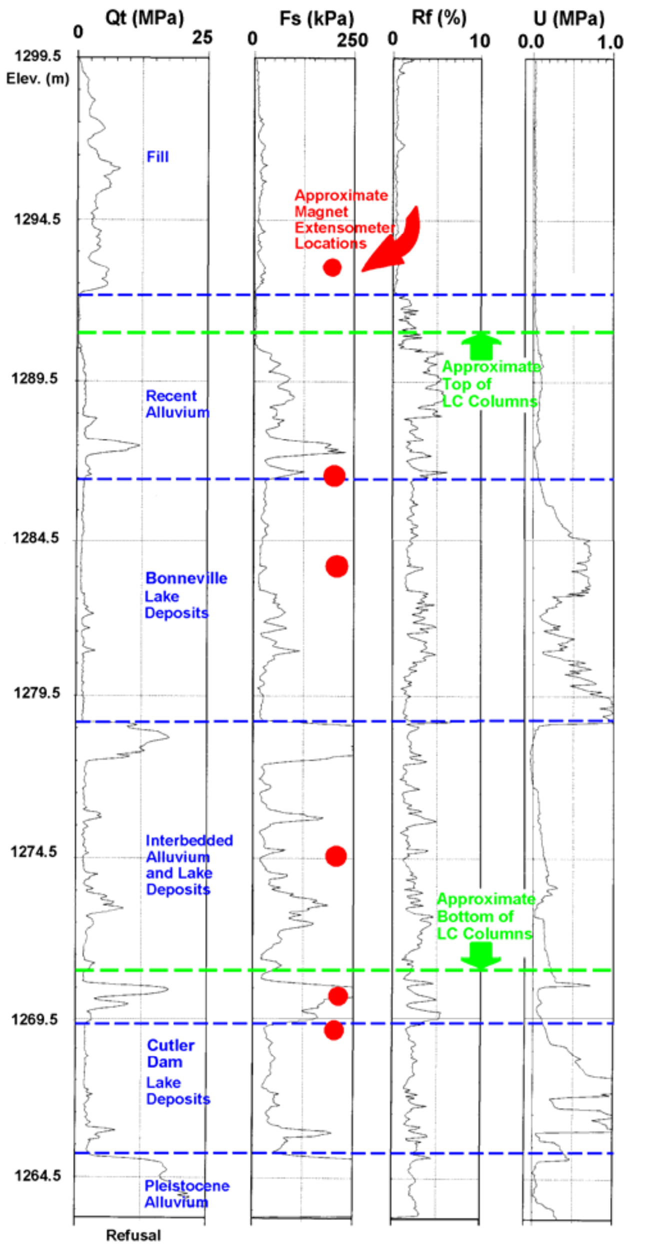
Ground Settlements at LCC Array

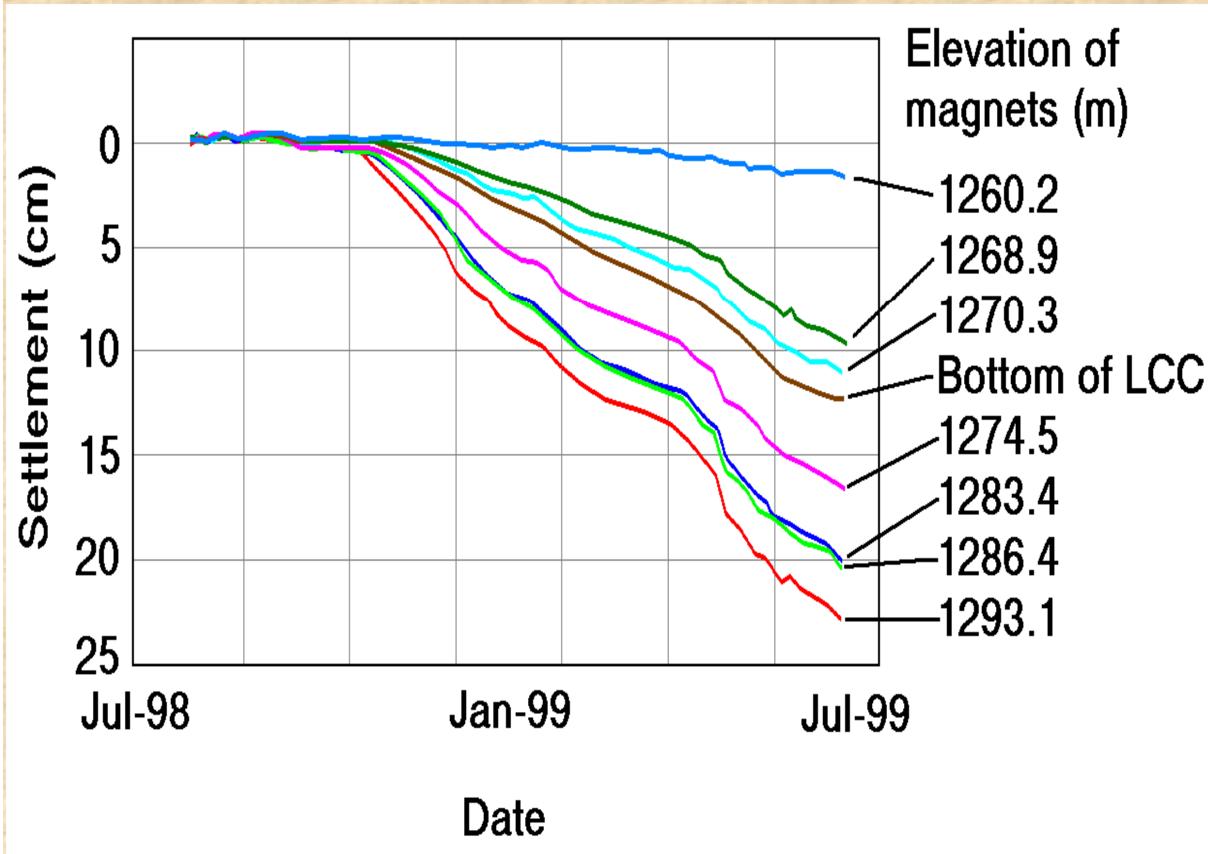
(July 98 to November 01)





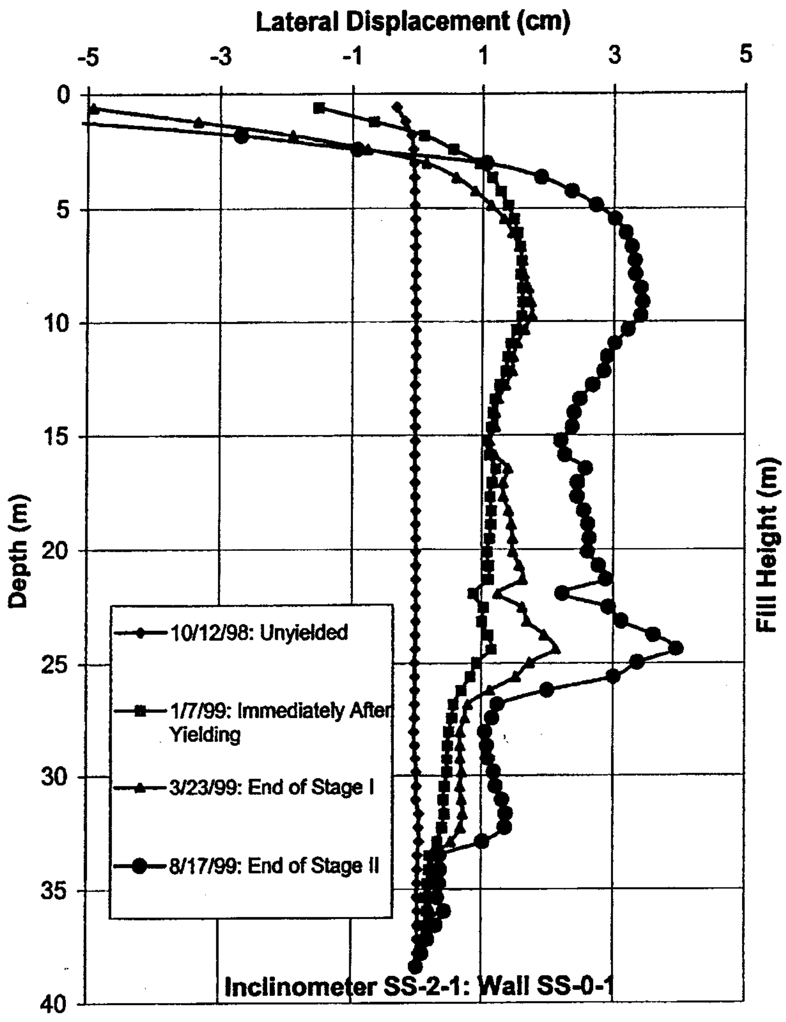
Magnetic Extensometer Measurement

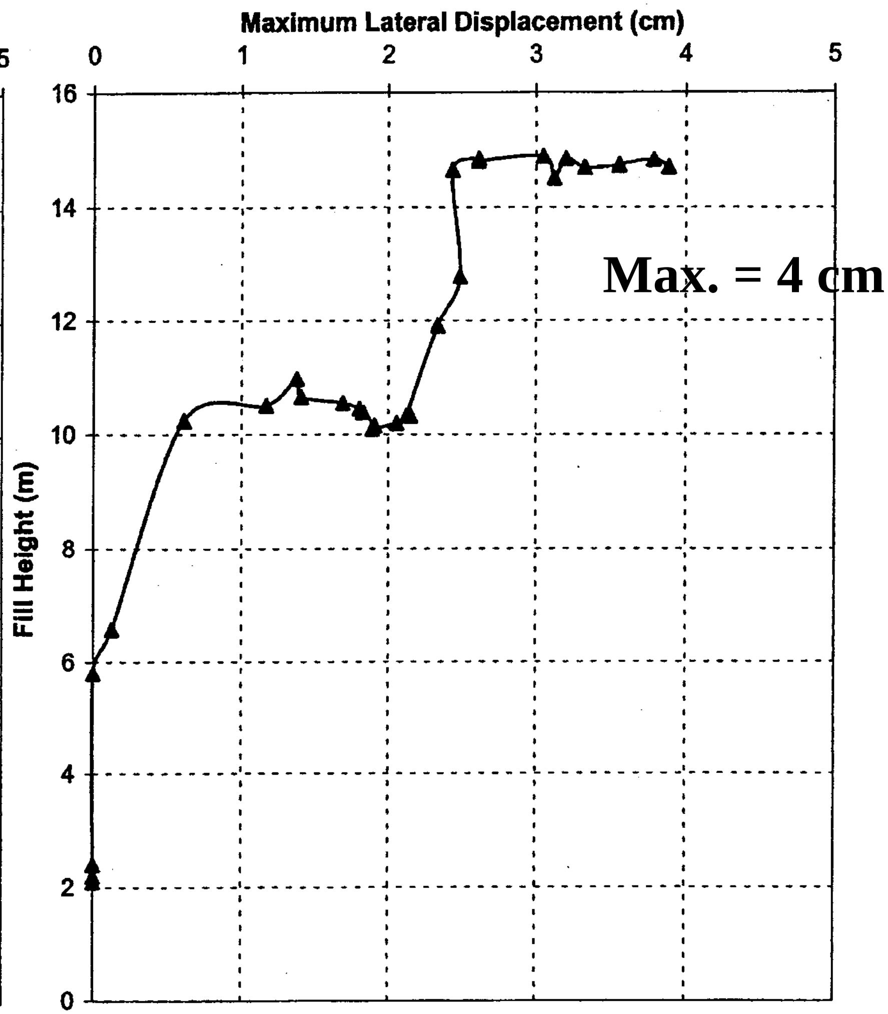




23 cm of settlement at magnet extensometer location w/ 12 cm of settlement below column installation depth

Horizontal Displacements from Vertical Inclinometer





LCC Construction Performance

1. Primary Consolidation Settlement was reduced from about 1.0m to 0.2 m at LCC array.
2. Construction Settlement of about 18 cm occurred at MSE wall face.
3. Construction Settlement of about 3 to 4 cm occurred at nearby bldg.
4. Lateral Displacement of about 4 cm occurred at wall face.
5. Column is carrying about 10 times the stress as the adjacent untreated ground.
6. Installation rates and cost became an issue with Wasatch Constructors and this technology was only used at one location.

INTERSTATE 15 RECONSTRUCTION

UDOT GOING THE EXTRA MILE

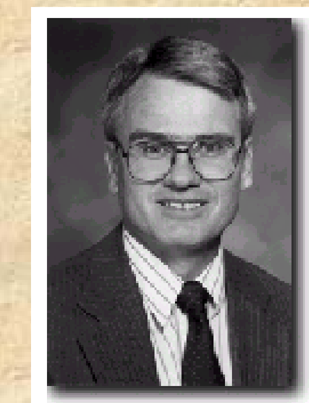
Long-Term Array Locations

Location	Type
I-80 @ 300 W.	MSE Wall on Lime Cement Columns
I-15 @ 3300 S.	Geofoam Wall (Creep & Load)
I-15 @ 3500 S.	MSE Wall (Deformation & Settlement)
I-15 @ 200 S.	MSE Wall (Settlement)
I-15 @ S. Univ.	Embankment (Settlement)
I-80 @ W. Temple	MSE Wall (Lt. Weight Backfill)
I-15 @ 800 S.	Geofoam (Lateral Earth Pressure)
I-15 @ 100 S.	Geofoam (Differential Icing)
I-15 @ 2100 S.	Embankment (Settlement)
I-15 @ 400 S.	Embankment (Settlement)

Questions

UTAH STATE AGGIES

UTAH UTES



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