Applications of EPS Geofoam in Civil Engineering

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Geofoam Research Consortium




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Statens vegvesen
Norwegian Public Roads Administration

Resources

Expanded Polystyrene (EPS)
Geofoam Applications
& Technical Data

The EPS Industry Alliance
1298 Cronson Boulevard
Suite 201
Crofton, MD 21114
800.607.3772
info@epscentral.org
www.epsmolders.org

Authors: Stark, Bartlett and Arellano, 2012

Available from: www.civil.utah.edu\~bartlett\geofoam

Primary Uses

- Road construction over poor soils
- Road widening
- Bridge abutments
- Bridge underfill
- Culverts, pipelines and buried structures
- Compensating foundations
- Rail embankment
- Landscaping and vegetative green roofs
- Retaining and buried wall backfill
- Slope stabilization
- Stadium and theater seating
- Leeves
- Airport runway and taxiways
- Foundation for lightweight structures

Design Guidance for Transportation Projects

- Current Design Methods / Guidance
  - Norwegian Public Roads Administration (1987)
  - Japanese Practice – EDO (1996, 2001)
  - Draft European Design Code (1998)
    - I-15 Reconstruction Project (1998-2001)
  - NCHRP 529 and Web Document 65 (2004)
  - European EPS White Book (2011)
  - NCHRP Project 24-11(02) Phase I Study (slopes) (20110
  - Various Research Reports
  - Technical Papers

Material, Design and Construction Considerations

- Material
  - EPS Density
  - Compressive Strength
  - Insect Control
  - Flame Resistance
  - Moisture Absorption
  - Chemical Resistance

- Design
  - Design Methodology
  - Allowable Stress
  - Concentrated Loads
  - Drainage / Buoyancy
  - Seismic Loadings
  - Stability of Adjacent Ground
  - Settlement
  - Bearing Capacity
  - Pavement Design

- Construction
  - Bedding Material
  - Compaction
  - Handling
  - Block Dimensions
  - Block Layout & Placement
  - Cover and UV protection

- Quality Assurance/Control
  - Specifications / Provisions
  - Testing and Sampling
  - Inspection
  - Corrective Action

Expanded-Polystyrene Block Geofoam

(Legacy Highway Project, Utah Dept. of Transportation)

- Typical Block dimensions
  - 0.6 x 1.2 x 2.4 m
  - 0.8 x 1.2 x 4.9 m
- Density/unit weight

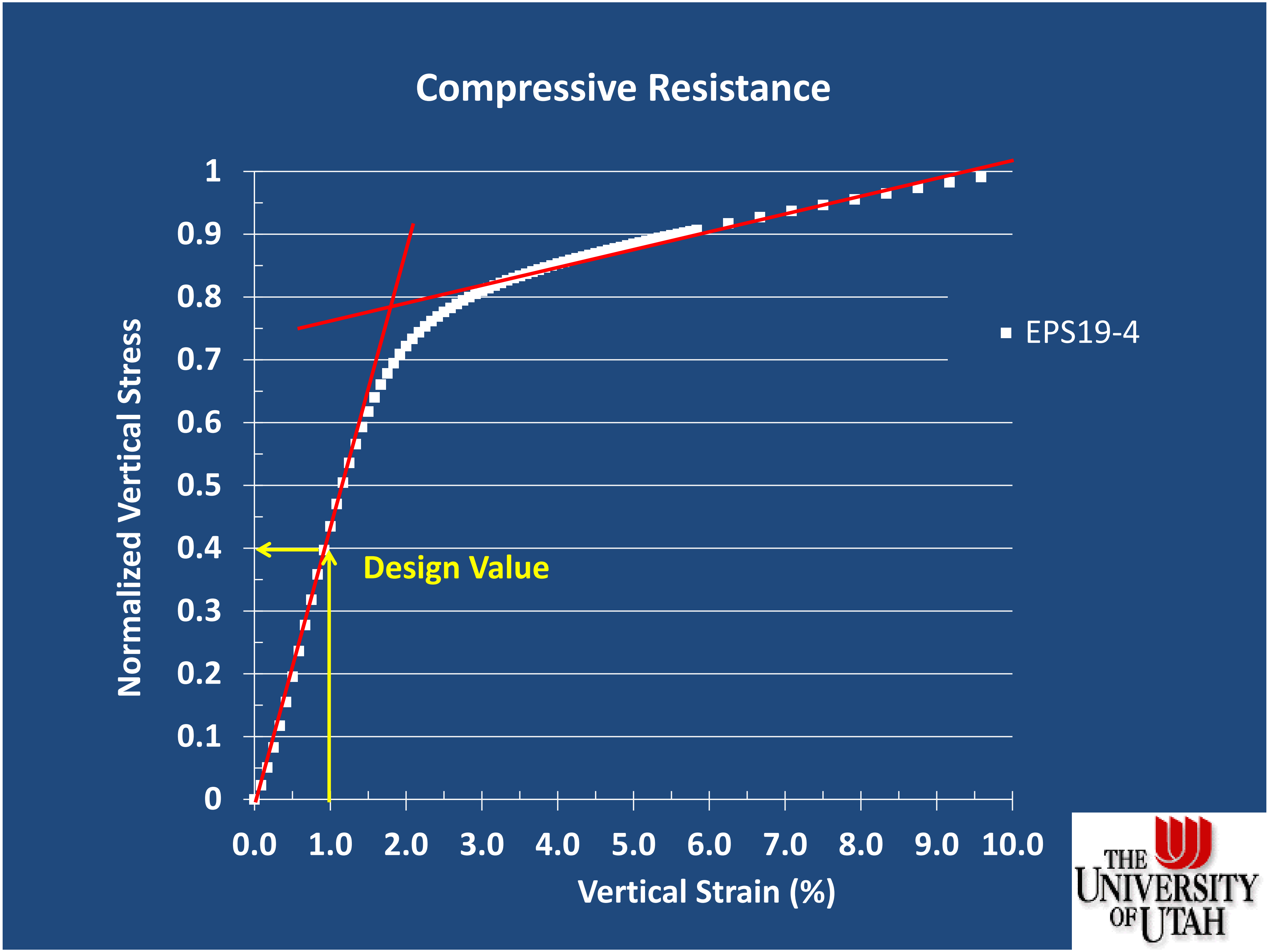
  16 to 45.7 kg/m^3

Geofoam Properties

ASTM D6817 Physical Property Requirements of EPS Geofoam

Type	EPS12	EPS15	EPS19	EPS22	EPS29	EPS39	EPS46
Density, min., kg/m³(lb/ft³)	11.2 (0.70)	14.4 (0.90)	18.4 (1.15)	21.6 (1.35)	28.8 (1.80)	38.4 (2.40)	45.7 (2.85)
Compressive Resistance, min., kPa (psi) at 1 %	15 (2.2)	25 (3.6)	40 (5.8)	50 (7.3)	75 (10.9)	103 (15.0)	128 (18.6)
Compressive Resistance, min., kPa (psi) at 5 %	35 (5.1)	55 (8.0)	90 (13.1)	115 (16.7)	170 (24.7)	241 (35.0)	300 (43.5)
Compressive Resistance, min., kPa (psi) at 10 % [A]	40 (5.8)	70 (10.2)	110 (16.0)	135 (19.6)	200 (29.0)	276 (40.0)	345 (50.0)
Flexural Strength, min., kPa (psi)	69 (10.0)	172 (25.0)	207 (30.0)	240 (35.0)	345 (50.0)	414 (60.0)	517 (75.0)
Oxygen index, min., volume %	24.0	24.0	24.0	24.0	24.0	24.0	24.0

(EPS19 is the most commonly used density for roadway construction)


Compressive Resistance
Normalized Vertical Stress
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Vertical Strain (%)
Design Value
EPS19-4
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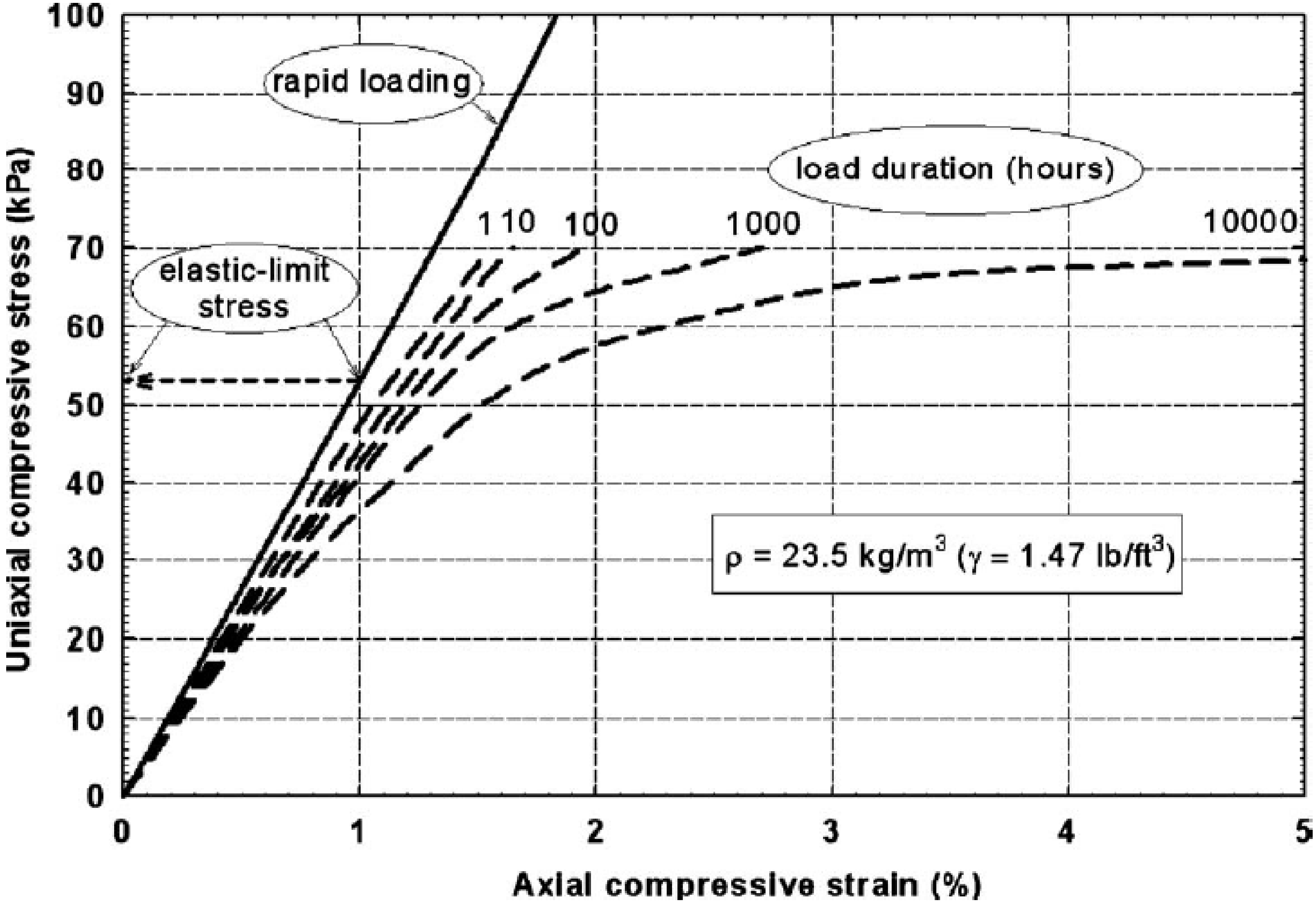
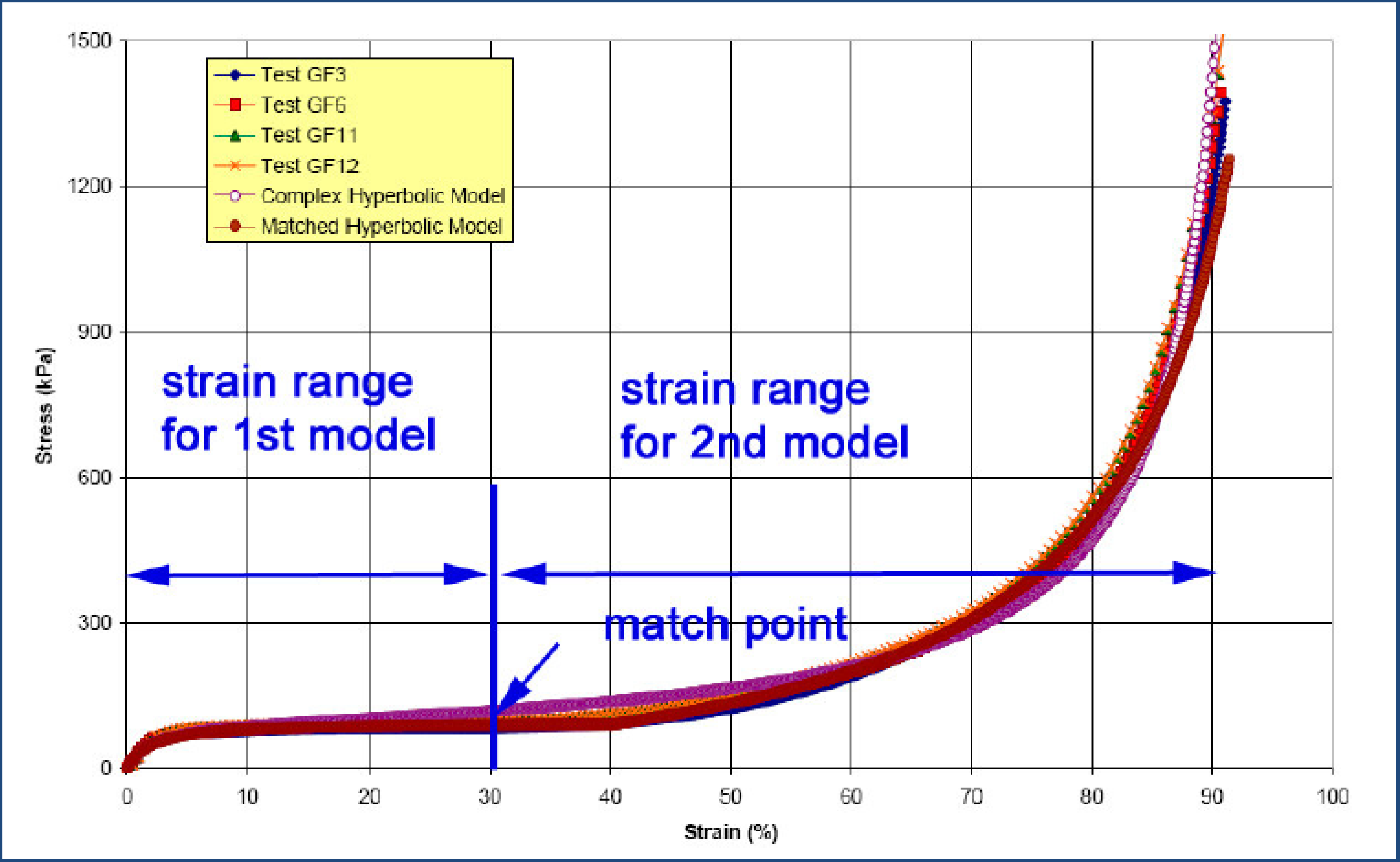
Geofoam Properties Under Monotonic Loading



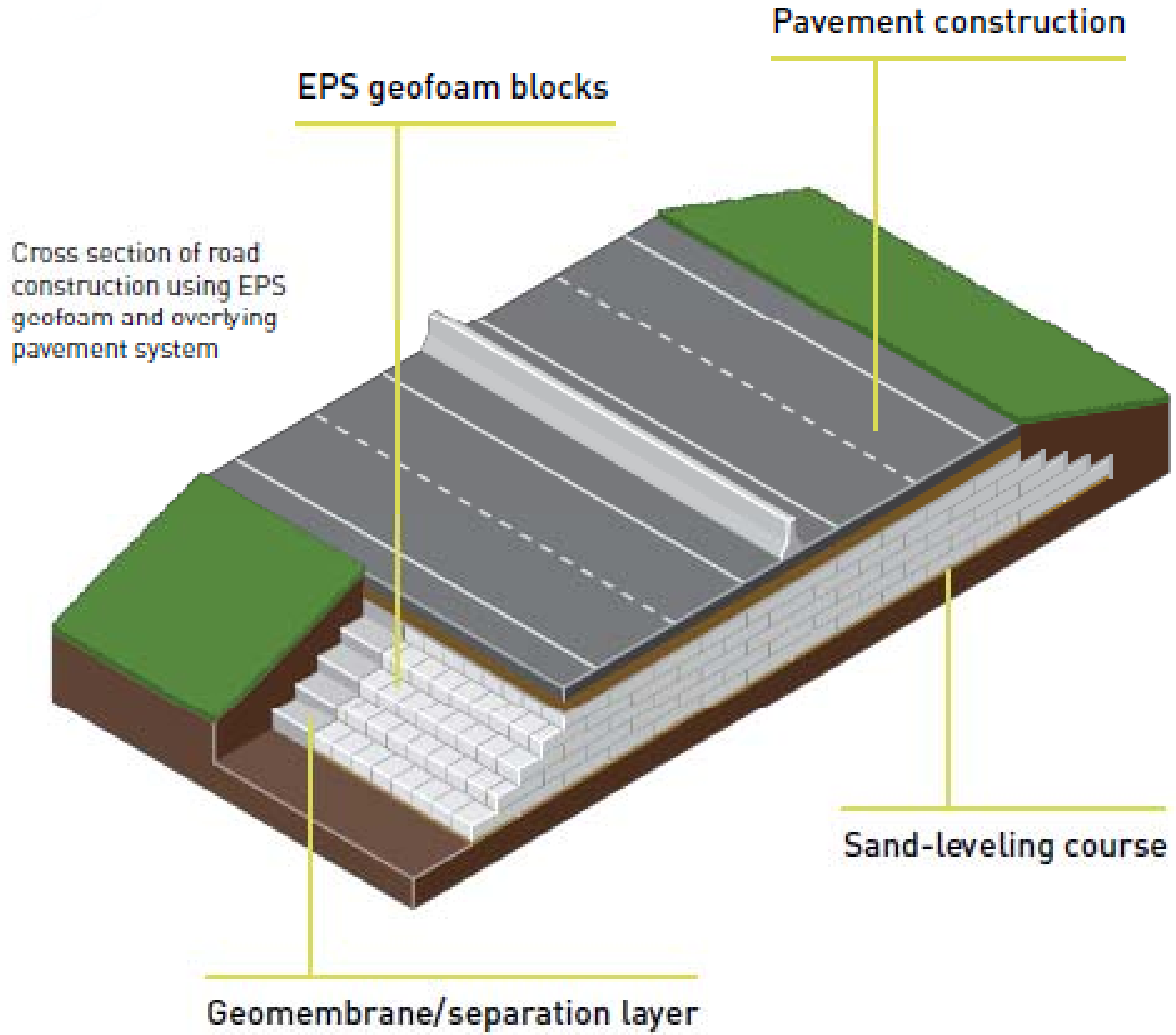
Rate of Loading and Load Duration Effects (Horvath, 2010)

Large Strain Geofoam Properties



Typical Stress – Strain Curve for EPS (Lingwall and Bartlett, 2010)

Road Construction Over Poor Soils



Road Construction Over Poor Soils

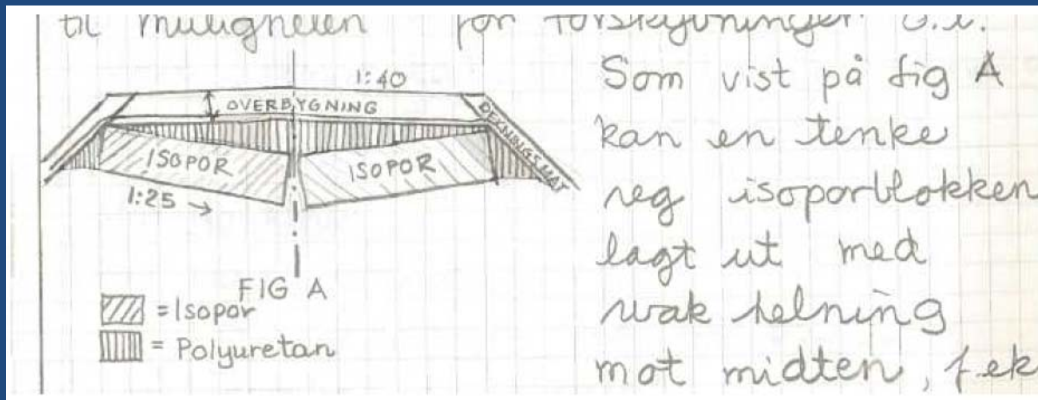


Figure 3. Excavation of the first EPS embankment at Flom bridge (EPS and polyurethane as protective layer).

Flom Bridge – 1972 – Lillestrom, Norway

Road Construction Over Poor Soils

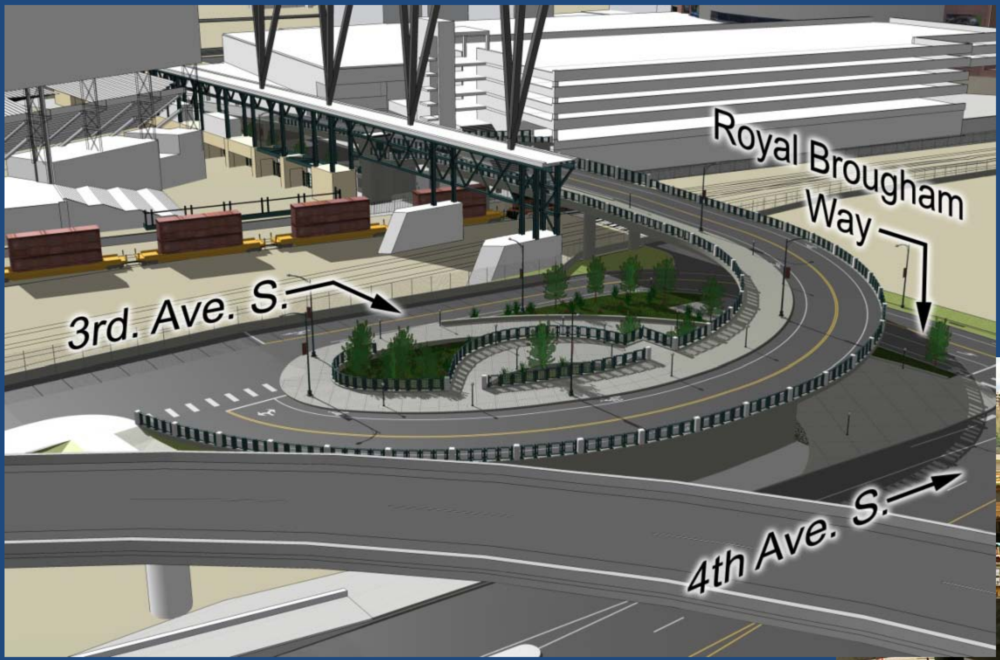
DESIGN ISSUES FROM FIRST FILL IN NORWAY

Initial concerns

- **vibrations of the traffic which possibly could cause horizontal movements of the fill structure**
- **petroleum spill and leakage**

- **Design countermeasures**
  - **slope block toward center of road (The contractor eventually ignored this and placed the block horizontal).**
  - **embankment was protected with a 10 cm polyurethane cover; however**
  - **became apparent that the risk for an overturning tanker on an EPS embankment was extremely low**
  - **concrete slab was a more practical way of combining the required protection of the underlying EPS blocks with the need for pavement strength and binding together the EPS structure.**

Road Construction Over Poor Soils



SR-519 Interchange
Seattle, Washington

Road Construction Over Poor Soils

St. Rosa Road

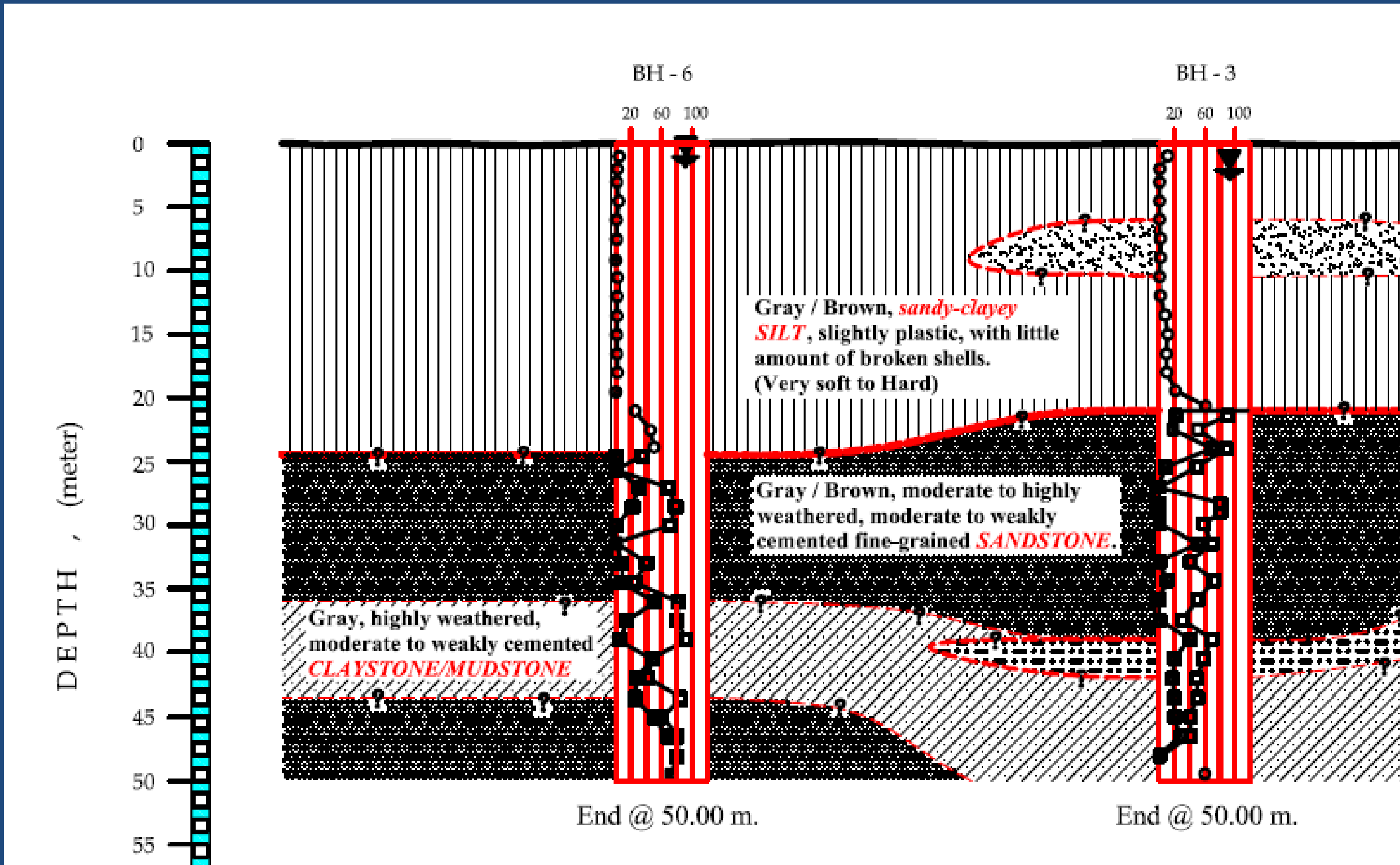
Private Road Constructed Over Rice Fields

St. Rosa, Philippines

Road Construction Over Poor Soils

Reclaimed Land – Casino Project – Manila Philippines

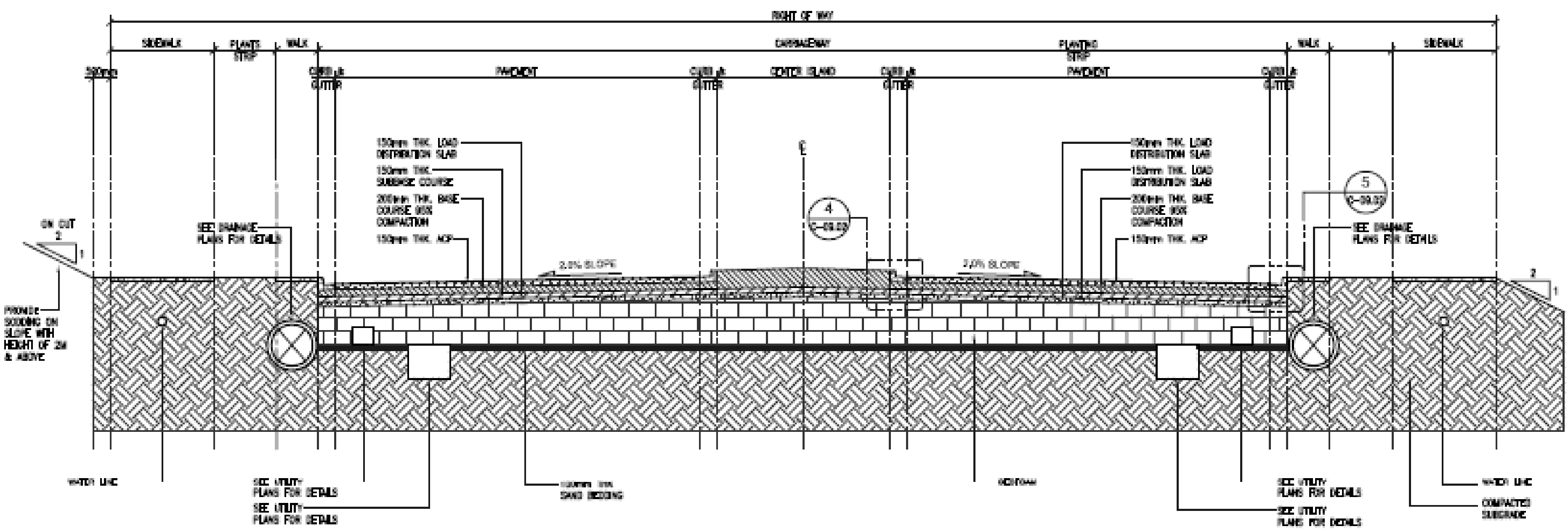
Road Construction Over Poor Soils



Reclaimed Land – Aruze Project – Manila Philippines

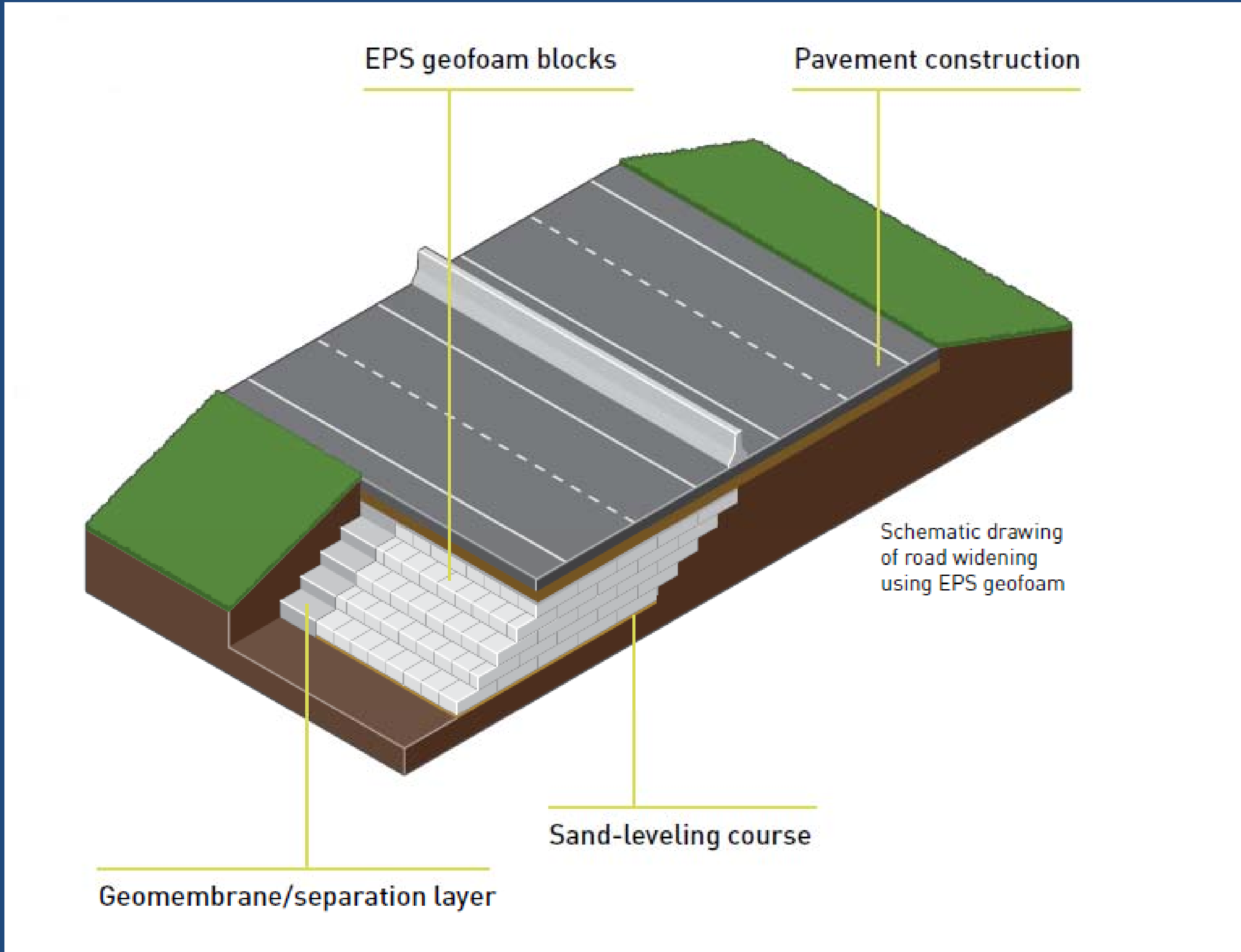
Road Construction Over Poor Soils

ROAD 3 & 4 PLAN



Reclaimed Land – Casino Project – Manila Philippines

Road Widening



Roadway Widening (I-15 Project)

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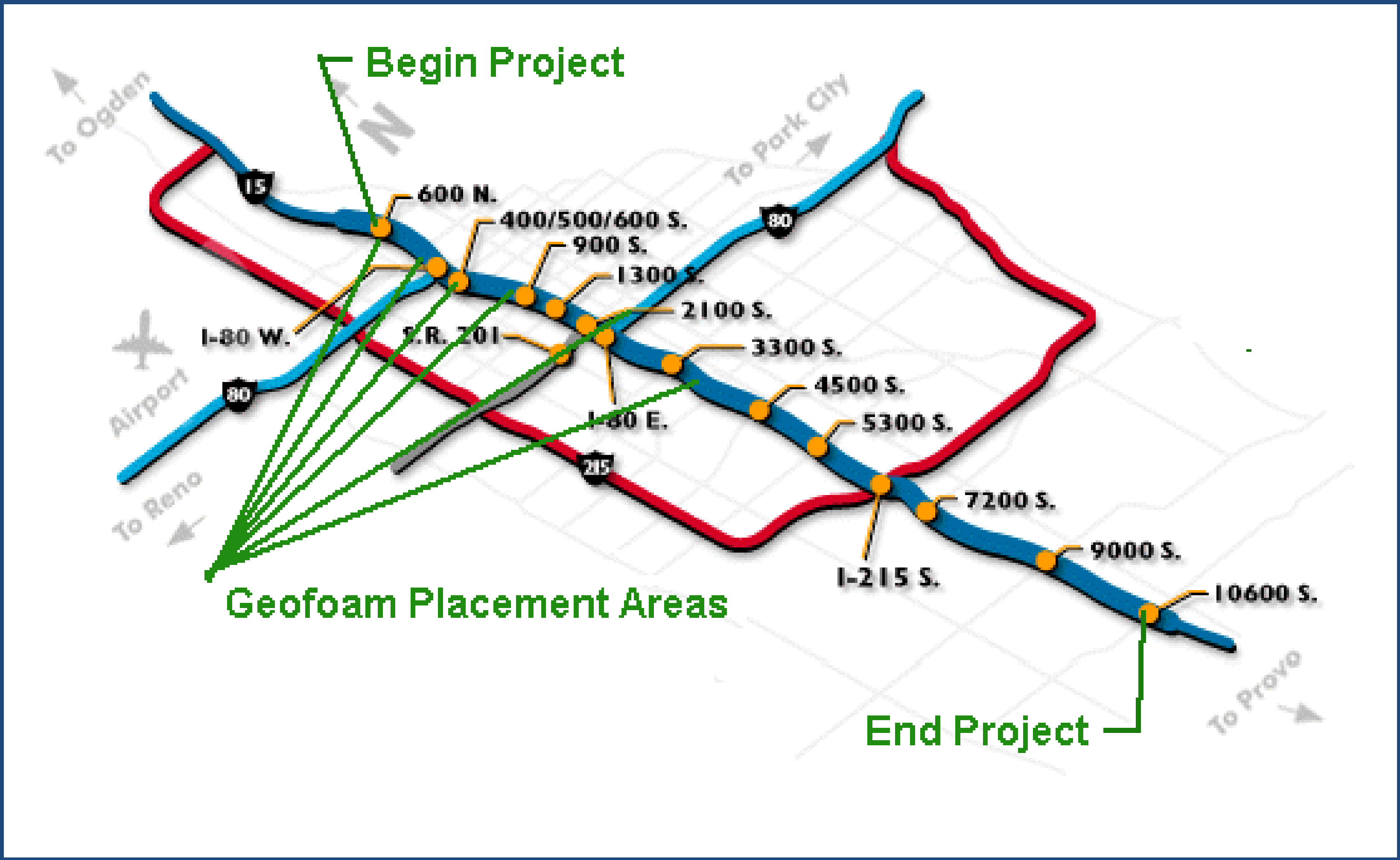
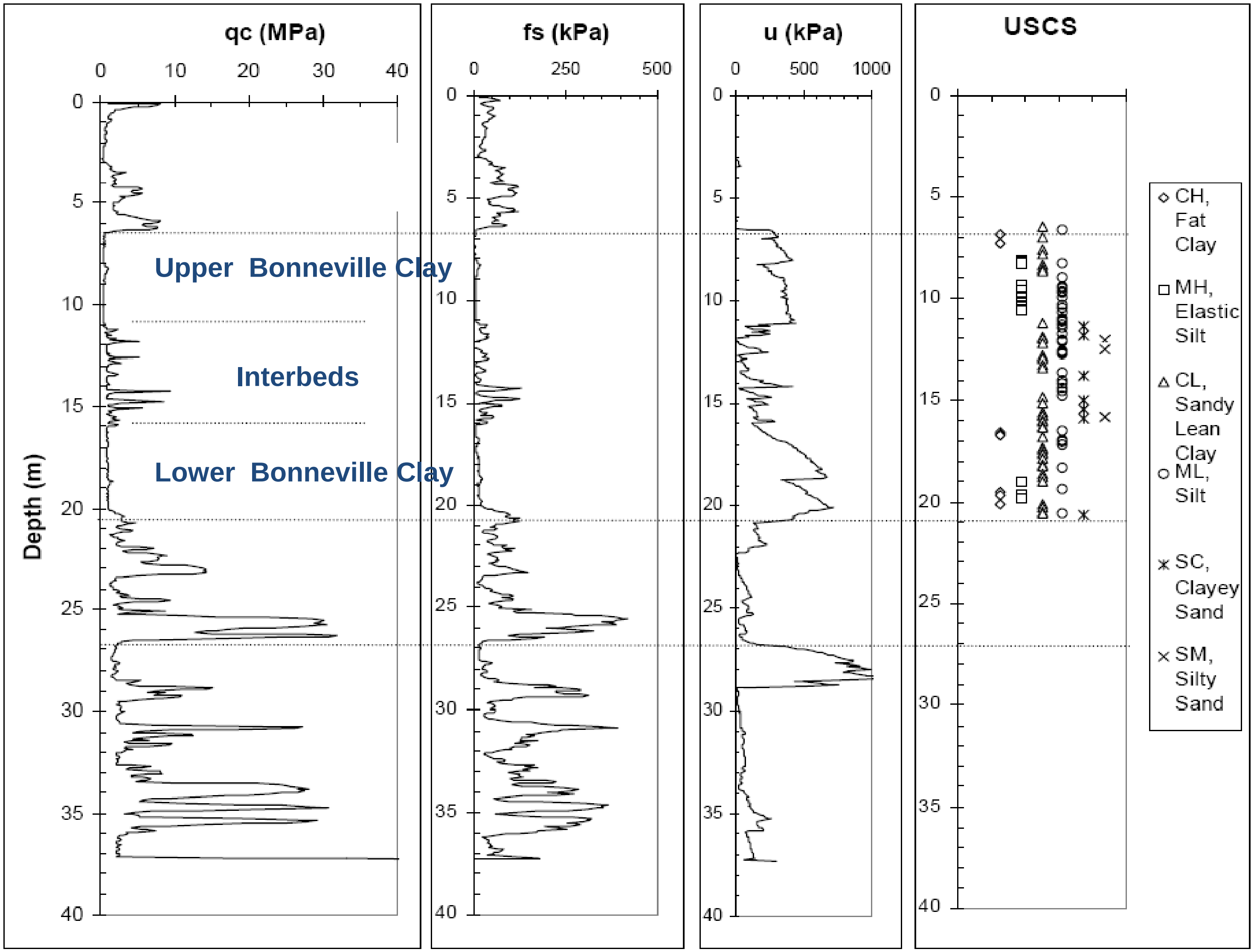
I-15 Project (Road Widening)



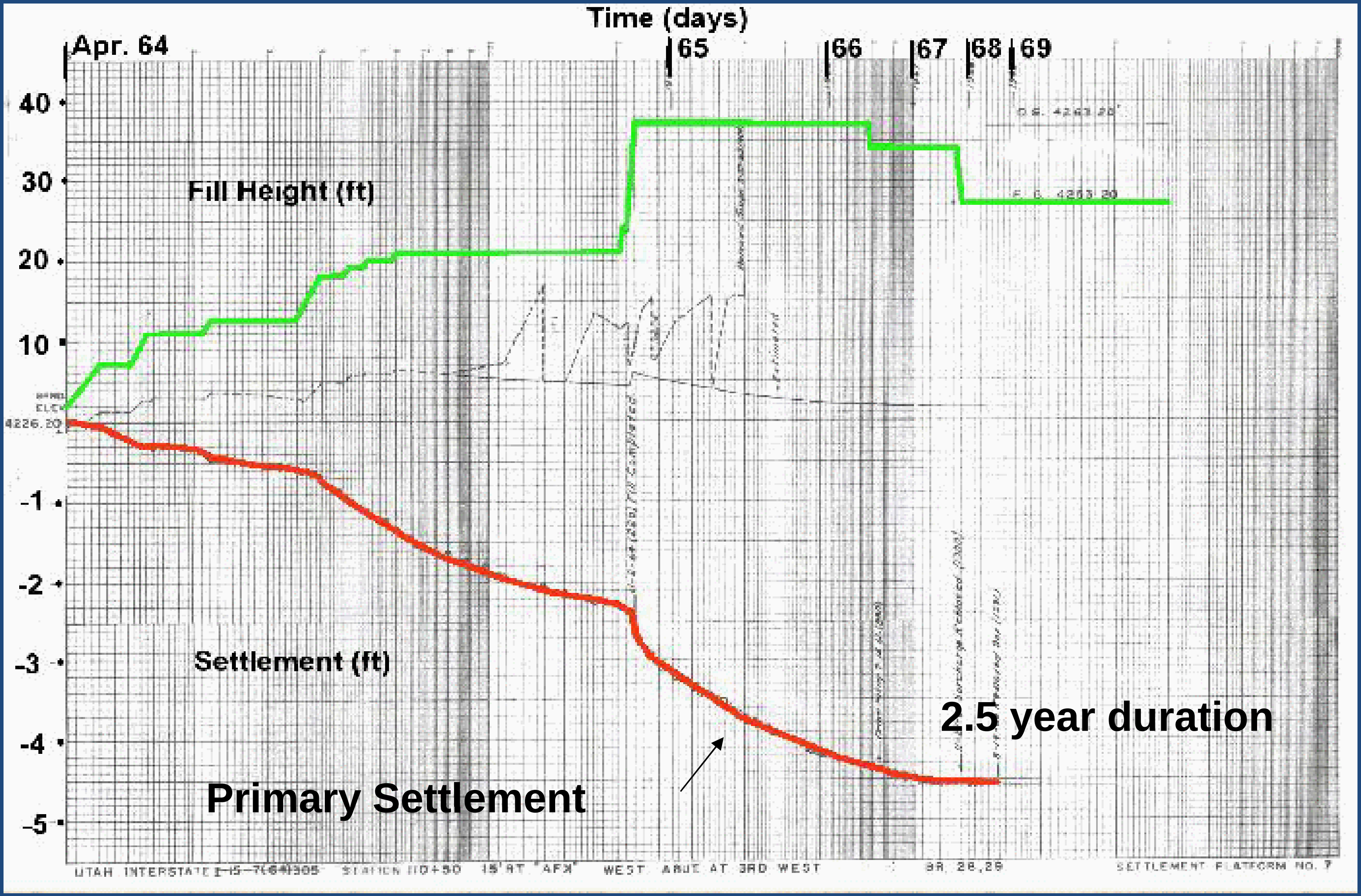
Approx. 100,000 cubic meters of geofoam was placed

Road Widening (I-15 Project)



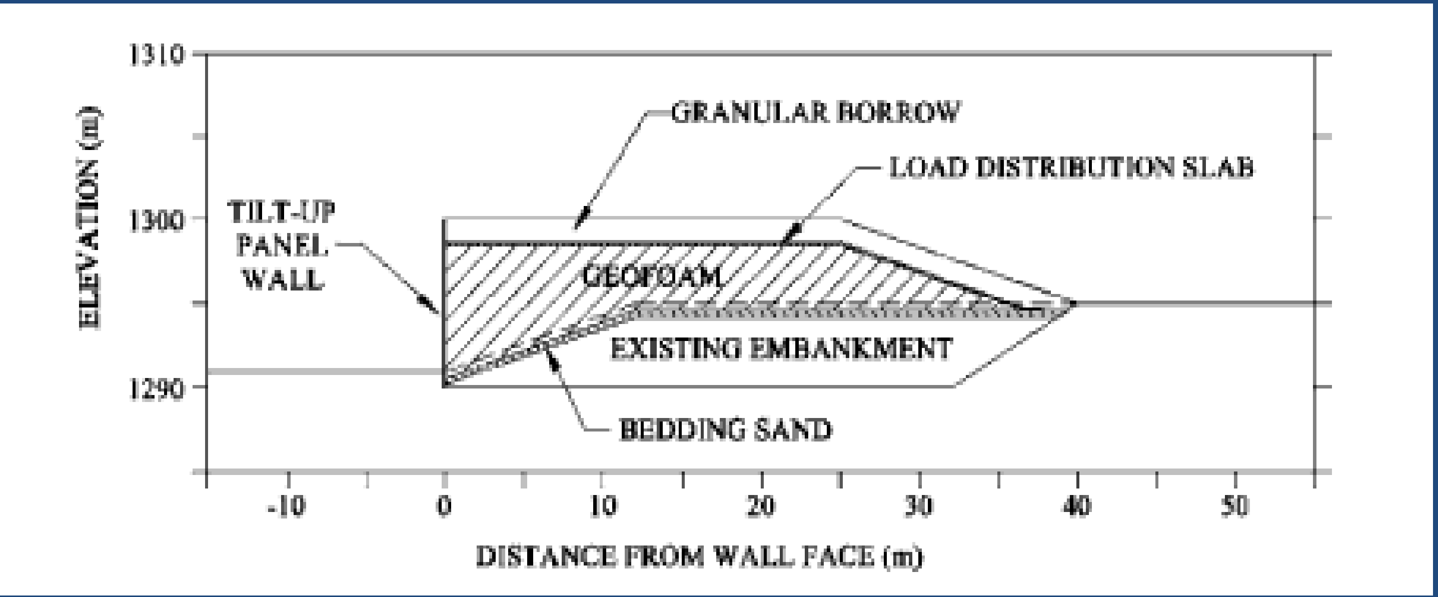
Subsurface Profile in Salt Lake Valley

Road Widening - I-15 Project - Settlement



Road Widening

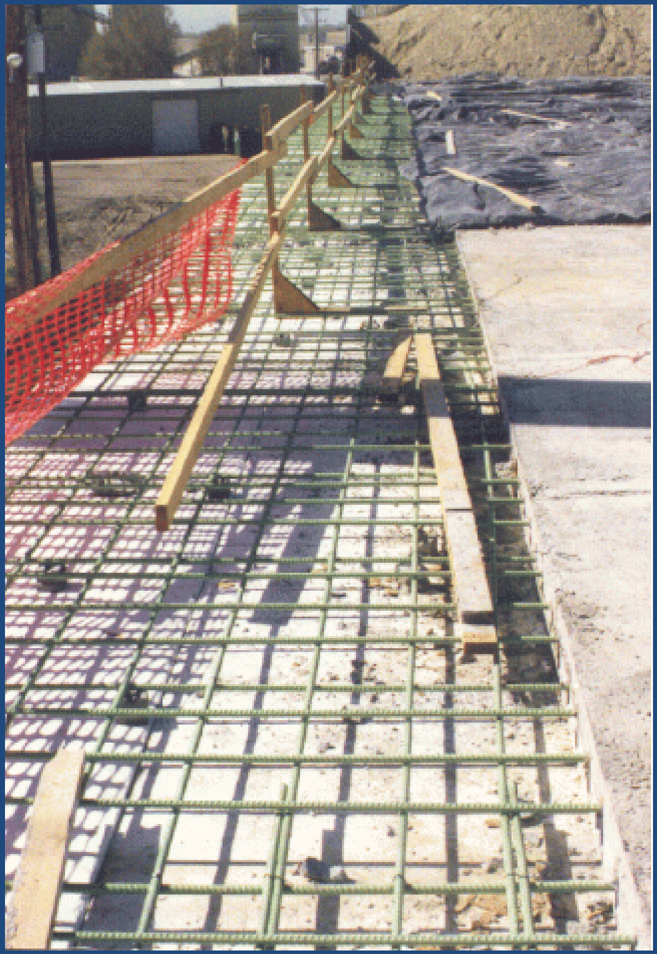
I-15 Reconstruction Project
Salt Lake City, Utah



Road Widening

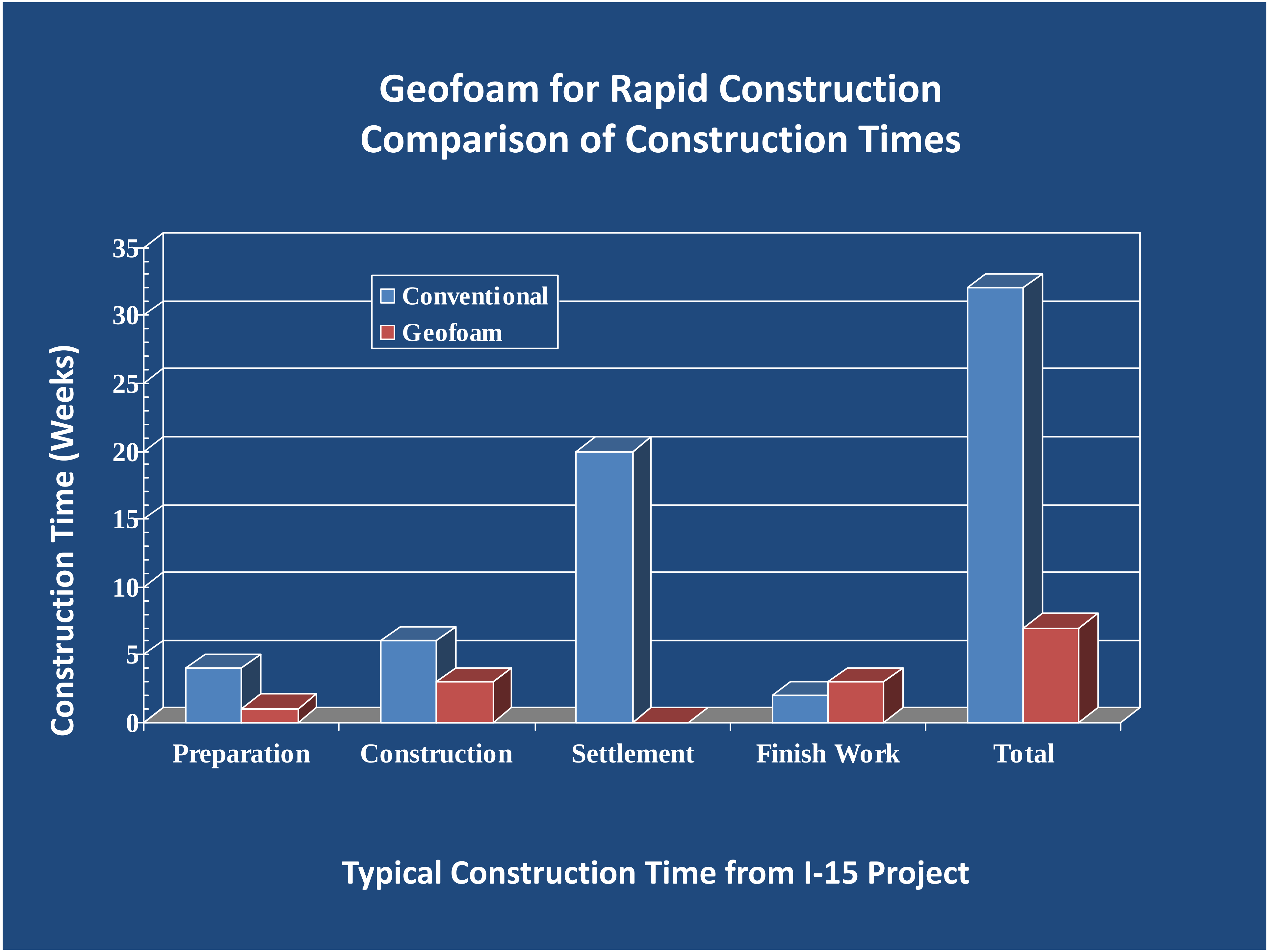
I-15 Reconstruction Project, Salt Lake City, Utah

Roadway Widening – I-15 Reconstruction



Reinforced Concrete
Load Distribution Slab

Completed Load Distribution Slab

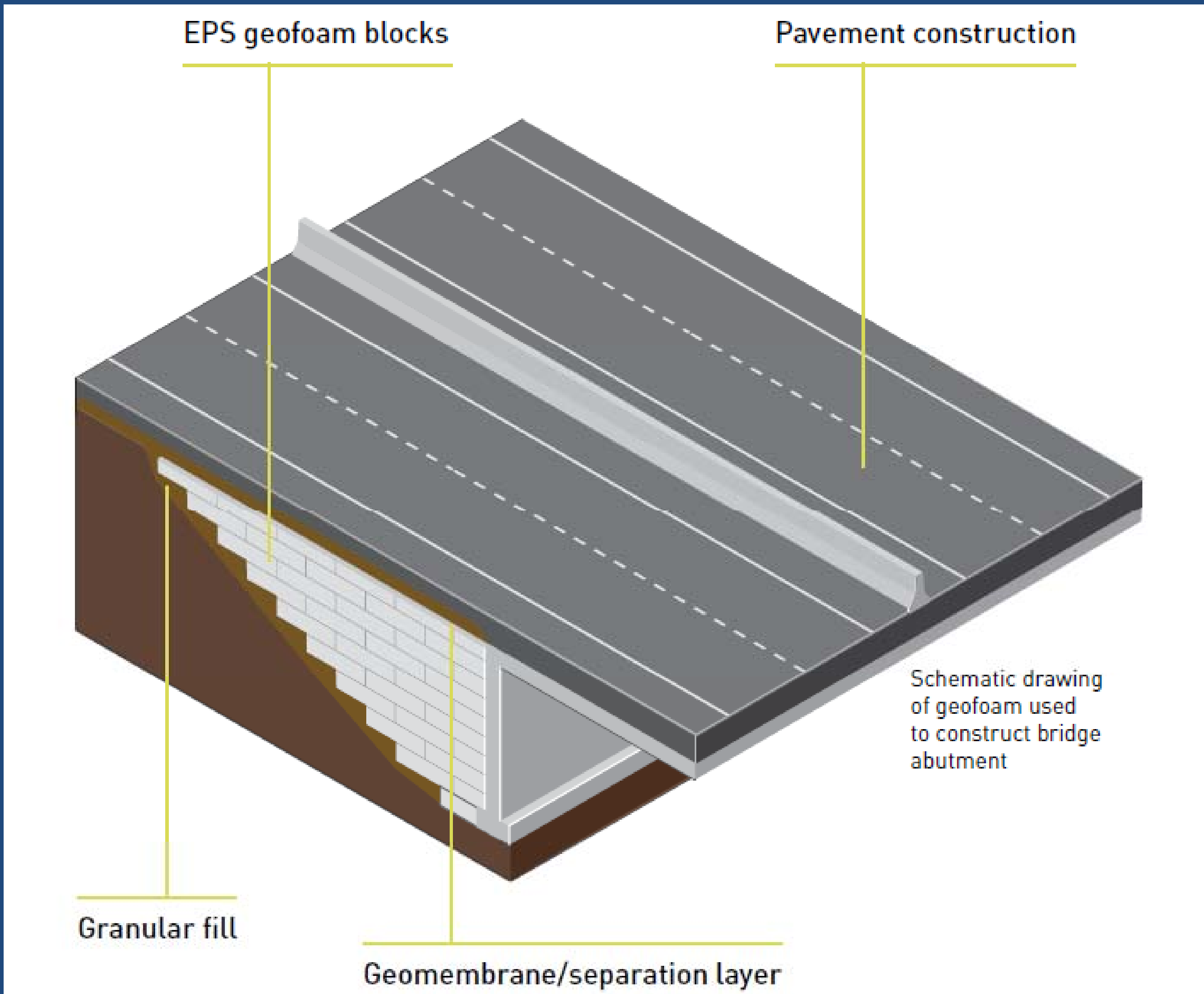

Geofoam for Rapid Construction
Comparison of Construction Times
Construction Time (Weeks)
35
30
25
20
15
10
5
0
Conventional
Geofoam
Preparation
Construction
Settlement
Finish Work
Total
Typical Construction Time from I-15 Project

Geofoam for Rapid Construction
Cost Comparison

Geotechnology	Various construction activities (*With typical unit cost*)	Associated costs (Year 2000)
Lime cement columns	Existing embankment removal ($6/m^3)	$9,500
	Lime cement column installation (0.8 m *column*—$17.5/m, 0.6 m *column*—$16/m)	$97,000
	One-stage MSE wall/embankment construction ($200/m^2 *wall face*)	$43,500
	One-stage embankment construction, surcharging, settlement, and removal (*placement*—$9/m^3, *removal* $6/m^3)	$10,000
	Total=	**$160,000**
Geofoam	Existing embankment removal ($6/m^3)	$1,500
	Bedding sand ($7/ton, *with 1 crew 1* week)	$5,500
	Geofoam embankment ($45/m^3)	$65,000
	Tilt-up panel wall ($200/m^2 *wall face*)	$20,000
	Load distribution slab ($60/m^2 *surface area*)	$23,000
	Embankment above geofoam ($9/m^3)	$5,000
	Total=	**$120,000**
Two-stage MSE wall	Existing embankment removal ($6/m^3)	$9,500
	Bedding sand ($7/ton, *1 crew* 2 days)	$2,500
	PV drain installation (1.5 m triangular spacing) ($1.5/m *without predrilling*, $3/m *with predrilling*)	$14,000
	Wall/embankment construction and settlement time ($300/m^2 *wall face*, $9/m^3 *embankment*)	$54,000
	Three-stage embankment construction, surcharging, settlement time, and removal (*placement*—$9/m^3, *removal* $6/m^3)	$20,000
	Total=	**$100,000**

Typical Construction Costs from I-15 Project for 100 m embankment

Bridge Abutments



Schematic drawing of geofoam used to construct bridge abutment

Bridge Abutment

Boston Artery Project, Boston, Massachusetts

Bridge Abutment

I-15 Reconstruction,
Salt Lake City, Utah

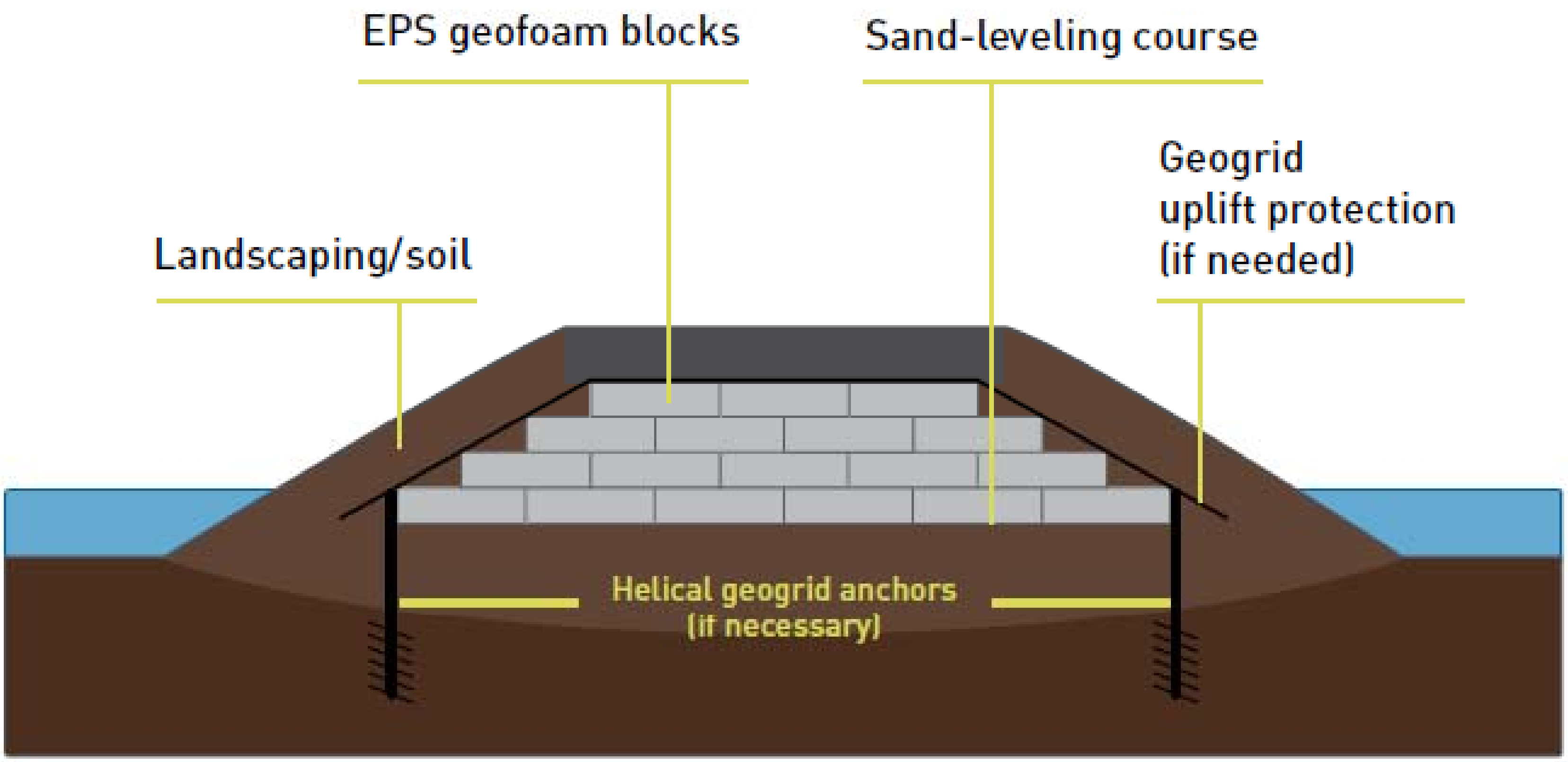
Overpass, 5300 S. over UTA TRAX
Salt Lake City, Utah

Bridge / Tunnel Underfill

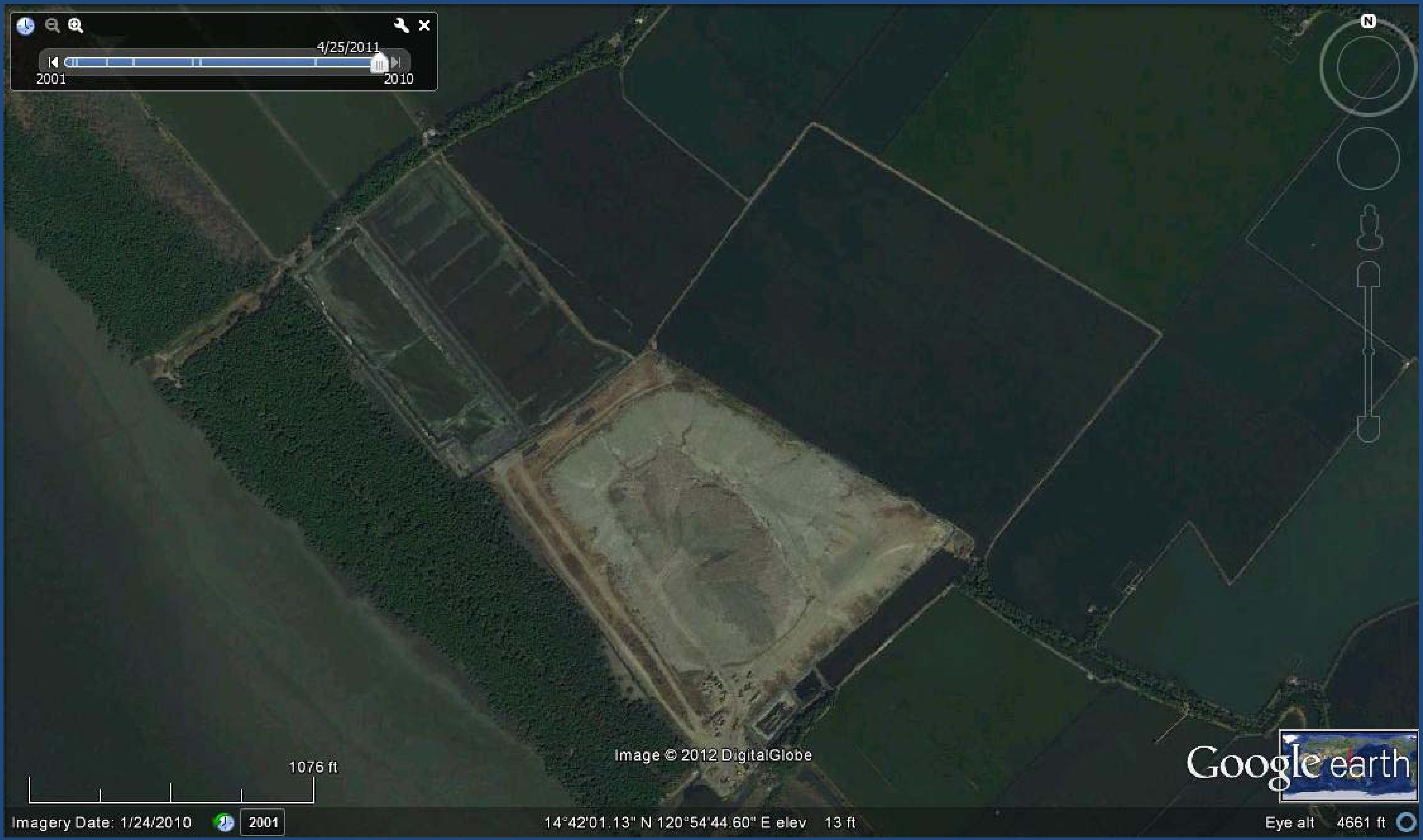
I-215 at 3300 South,
Salt Lake City, Utah

Tunnel Infill, Tucker Blvd.,
St. Louis, Missouri

Levees and Dikes



Levees and Dikes

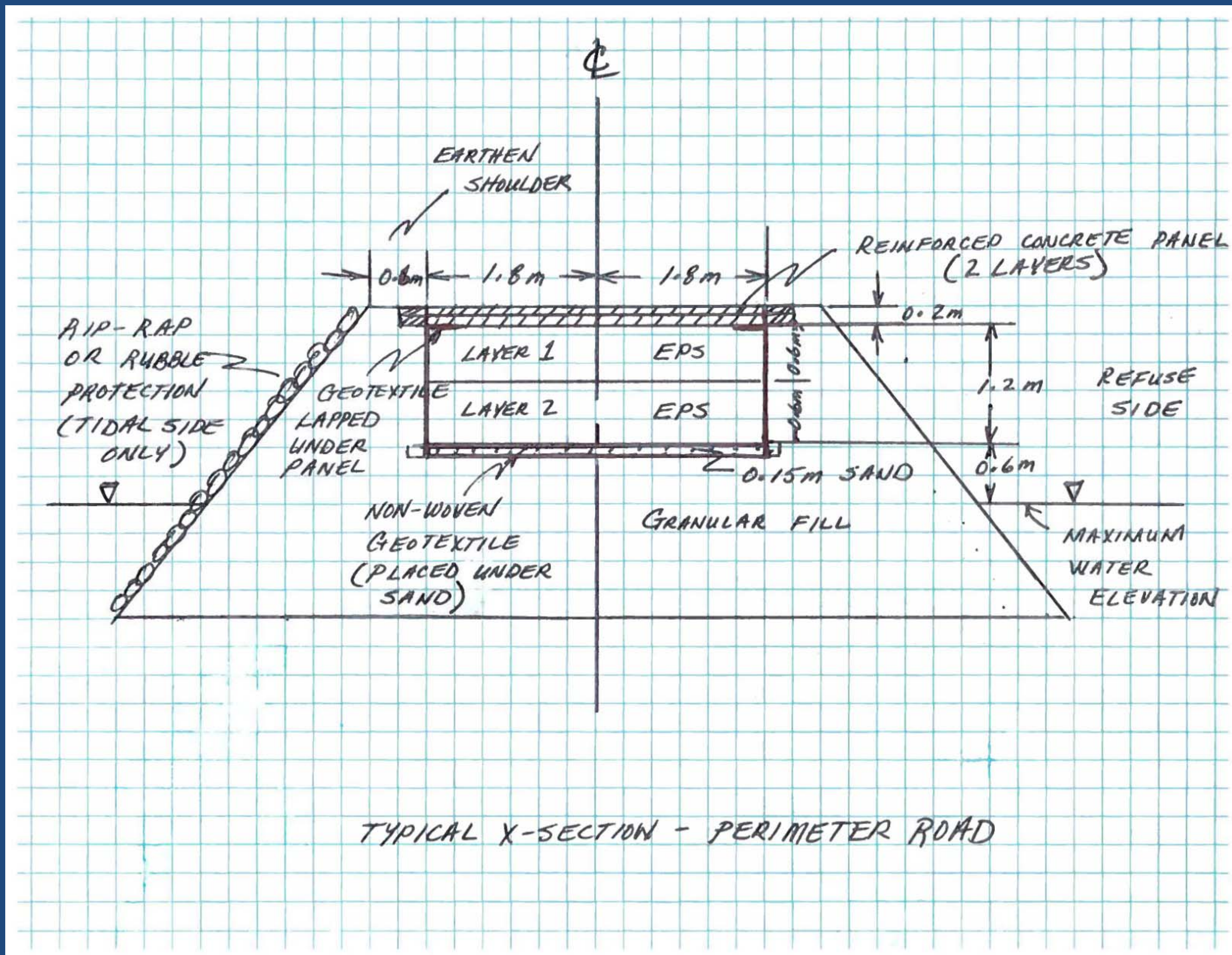


Landfill – Manila Bay - Philippines

Levees and Dikes

Landfill – Manila Bay - Philippines

Levees and Dikes

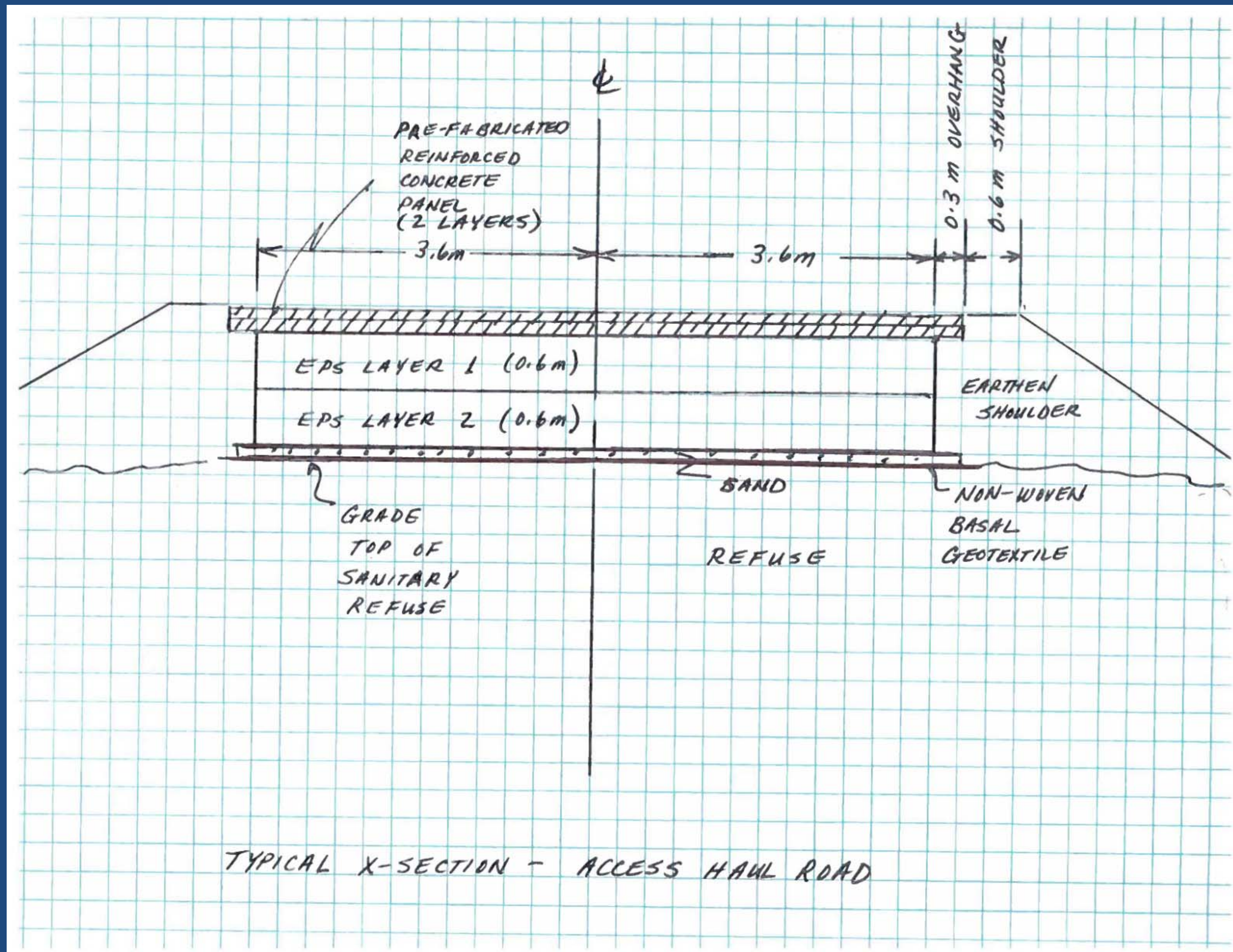


Landfill – Manila Bay - Philippines

Temporary Roads

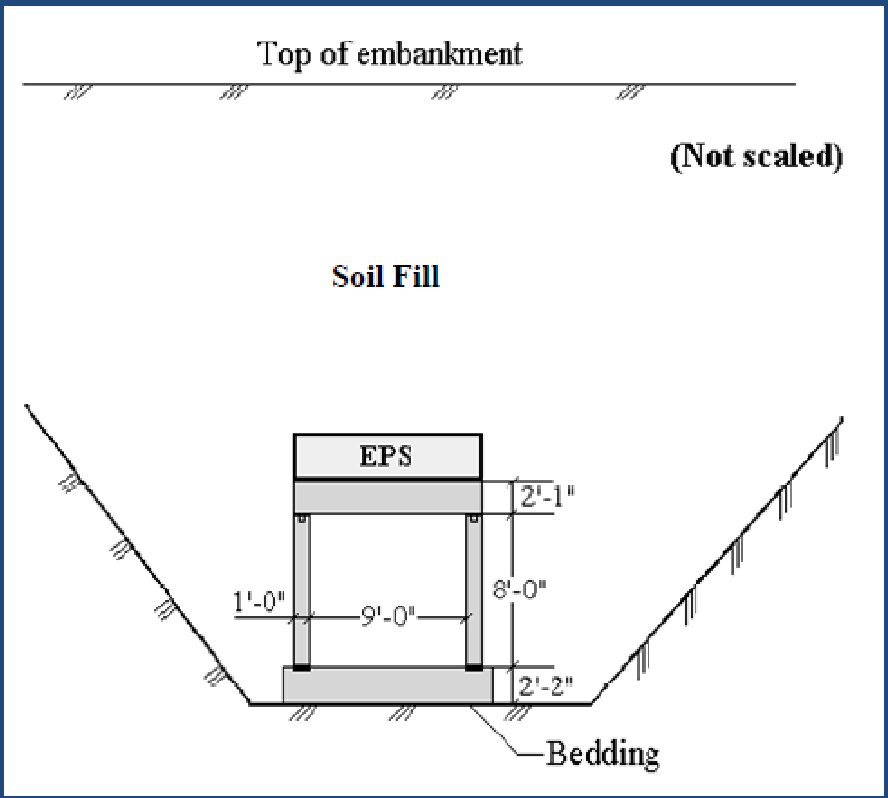
Landfill – Manila Bay - Philippines

Temporary Roads



Landfill – Manila Bay - Philippines

Culverts (Compressible Inclusion)



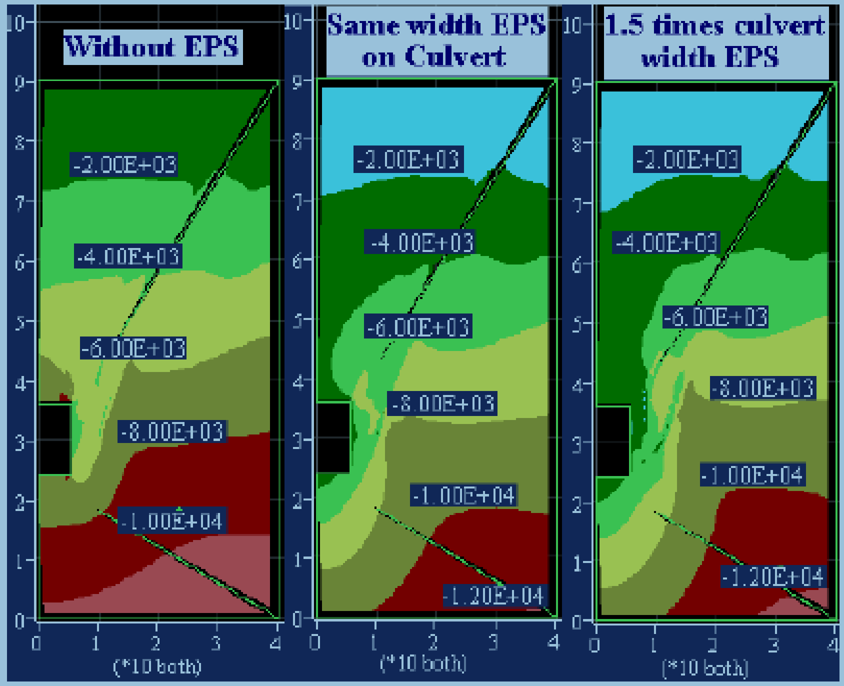
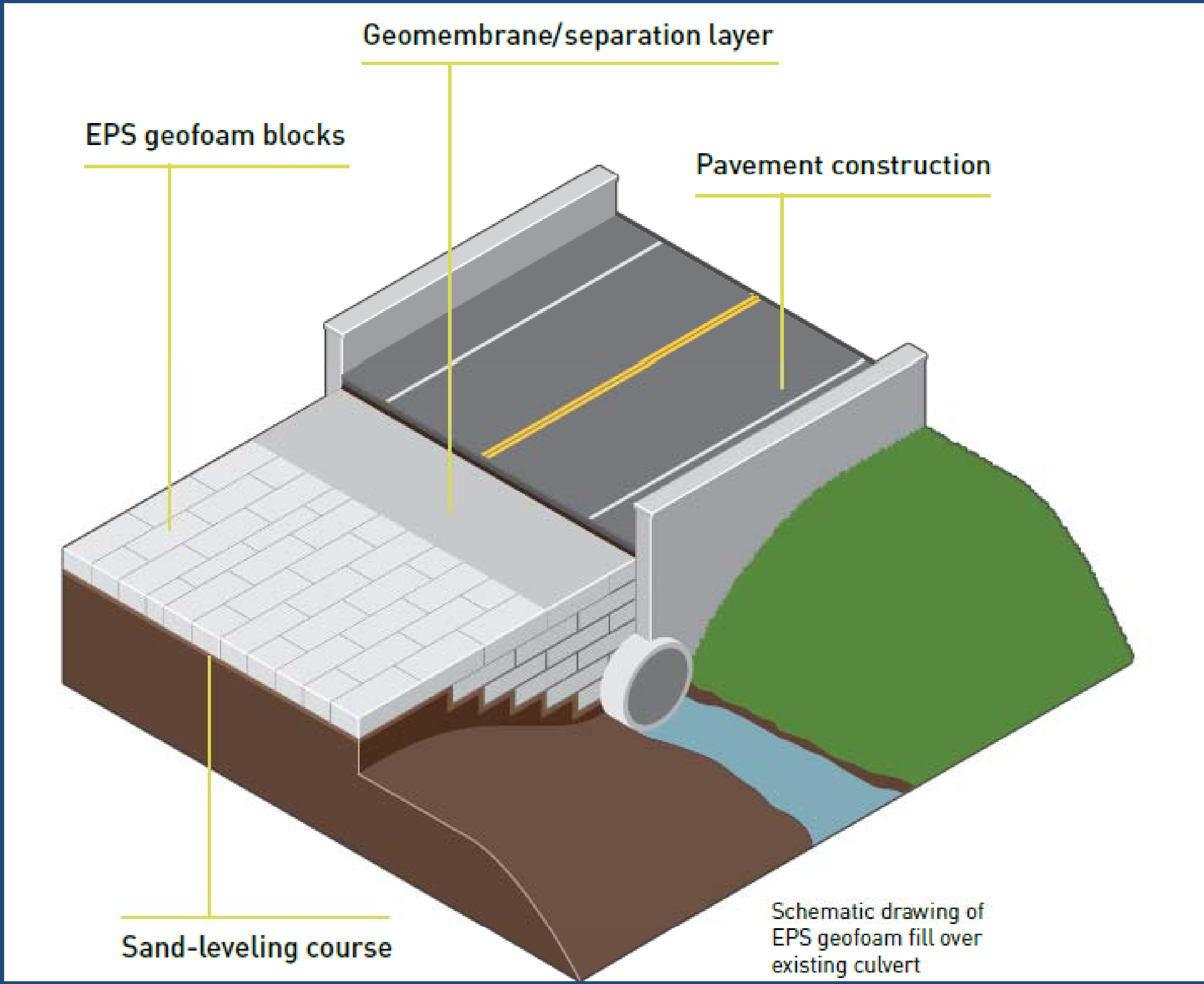


FIGURE 10. Contours of maximum principal stress with and without EPS on the top of culvert (psf)

Source: Kentucky Transportation Ctr.

Culverts (Light-Weight Fill)



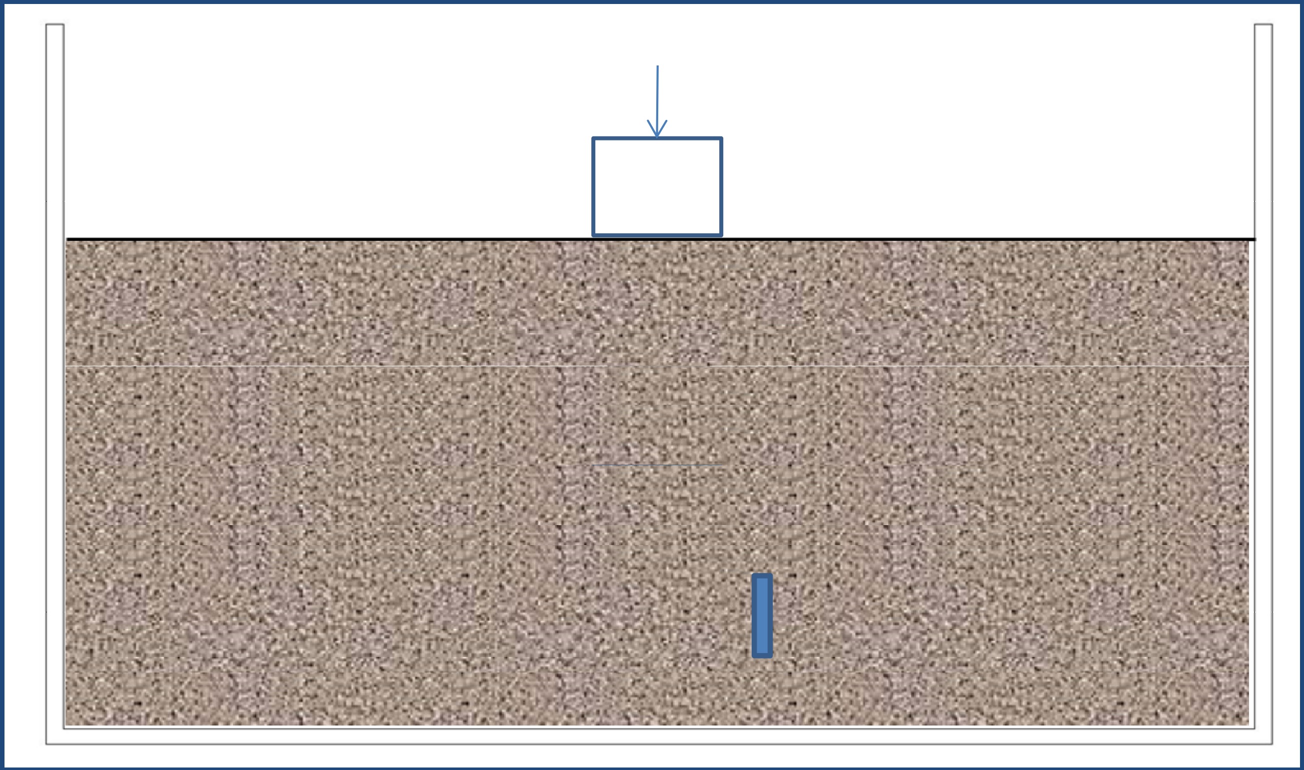
Schematic drawing of
EPS geofoam fill over
existing culvert

Culverts (Light-Weight Fill)

UTA Commuter Rail Widening Over Existing Culvert, Corner Canyon, Draper, Utah

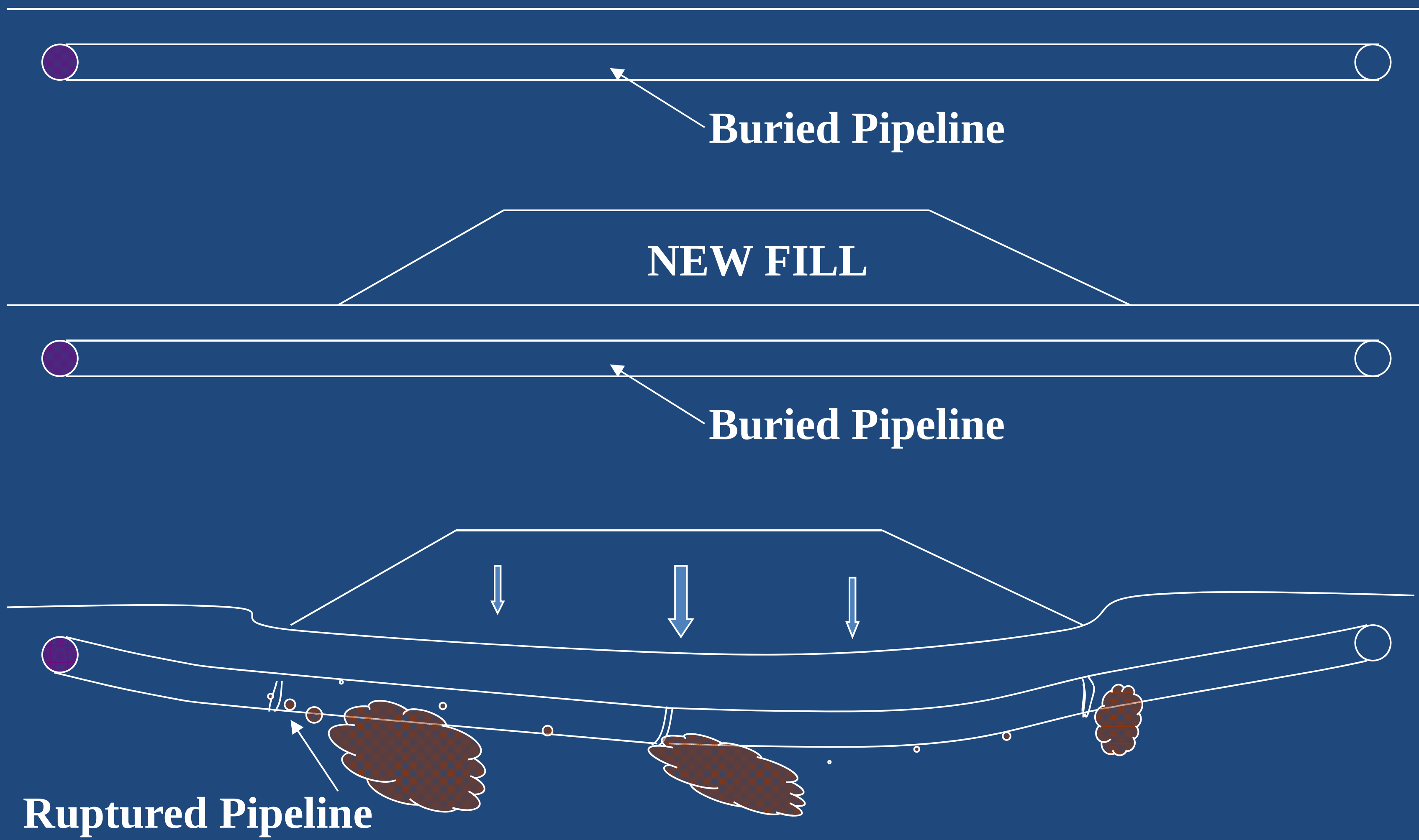
Unknown location

Pipeline (Compressible Inclusion)

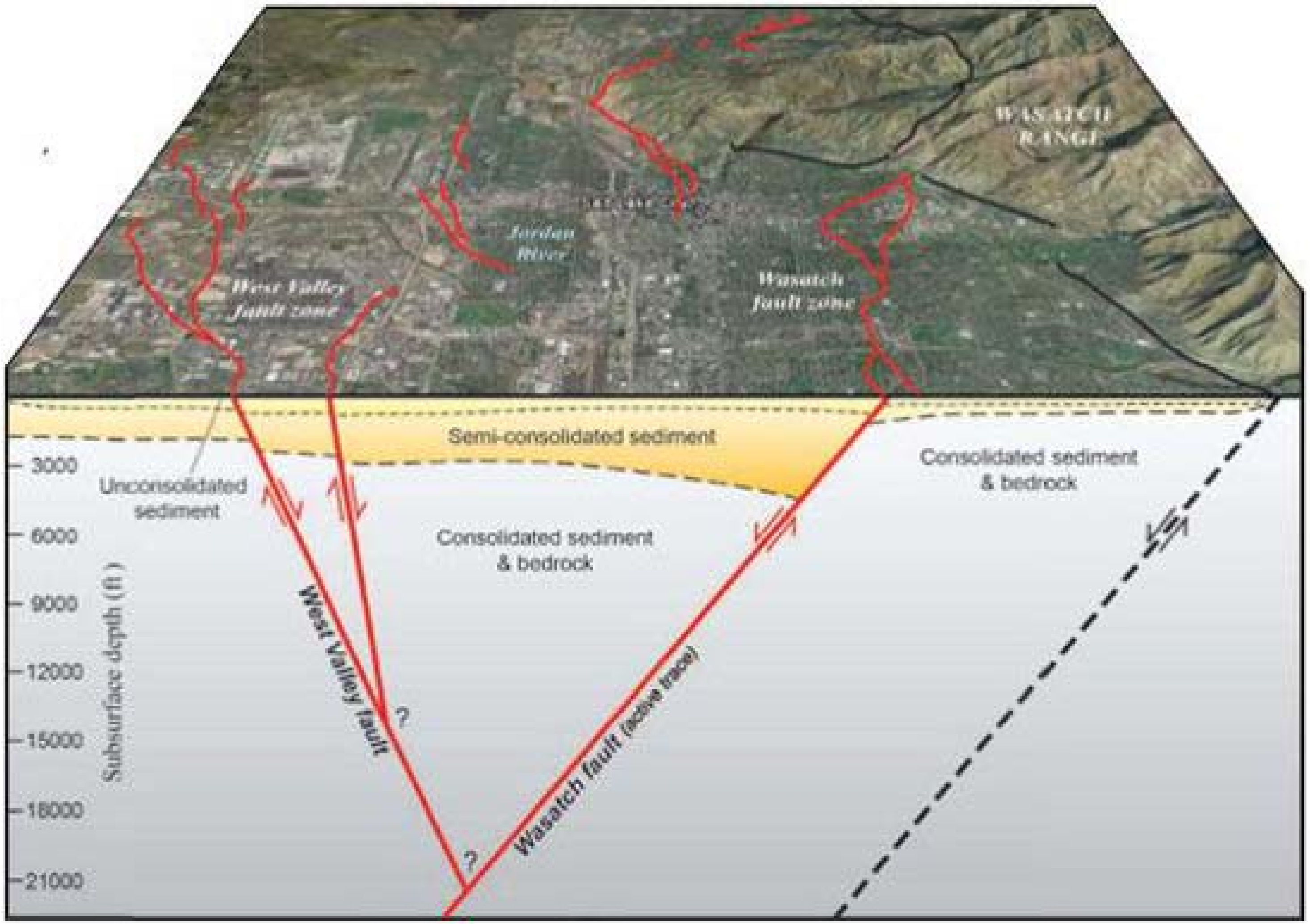


Induced Trench Testing

Pipelines (Light-Weight Fill)



Pipeline Protection



Wasatch Fault – Salt Lake City Segment

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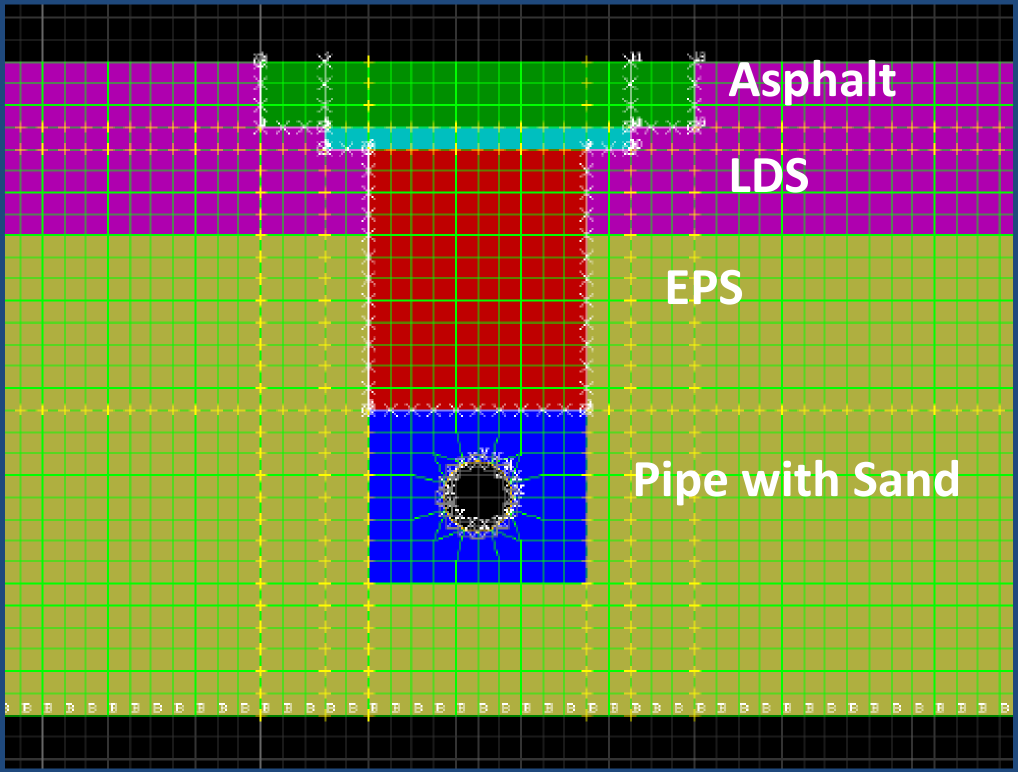
Pipelines (Light-weight Cover Over Faults)

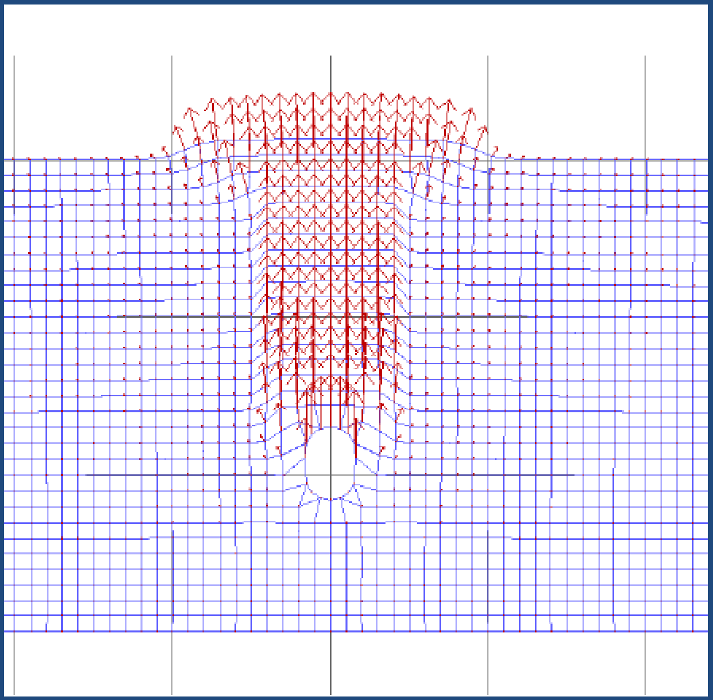
Alaskan Pipeline – Strike Slip Fault

Alaskan Pipeline – Normal Fault

Pipelines (Light-weight Cover Over Faults)

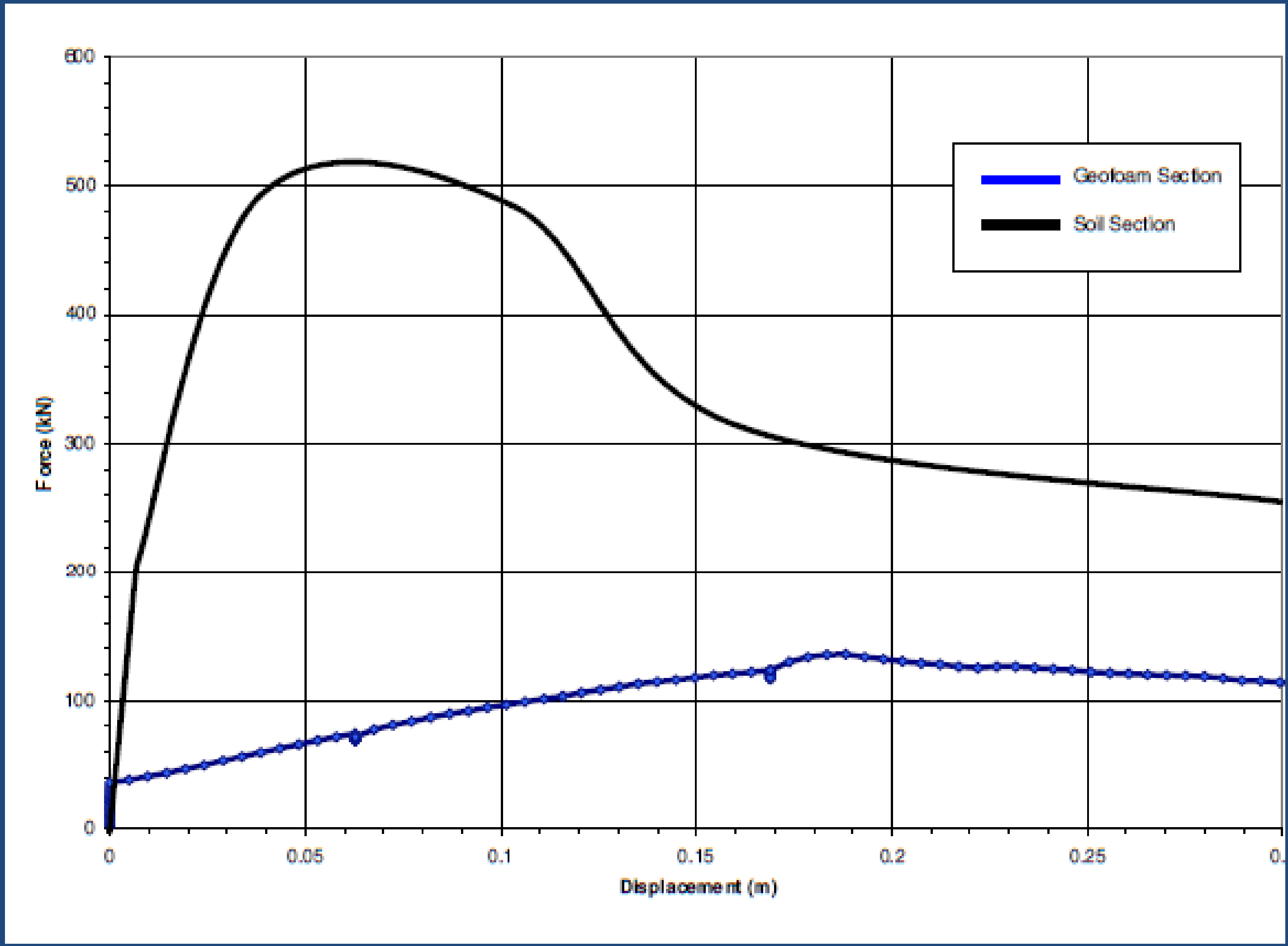


Lightweight-Cover System



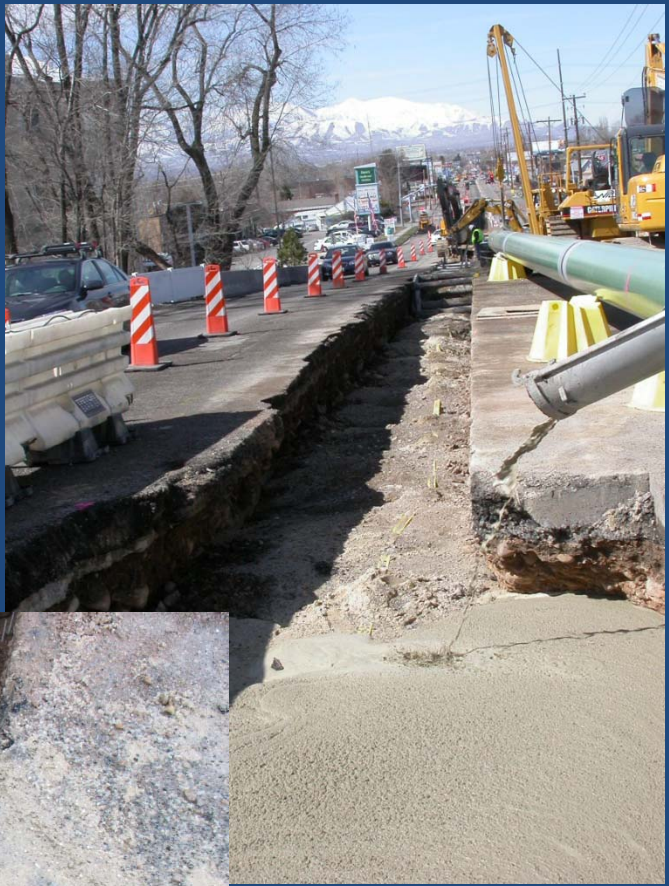
Displacement Vectors During Failure

Pipelines (Light-weight Cover Over Faults)



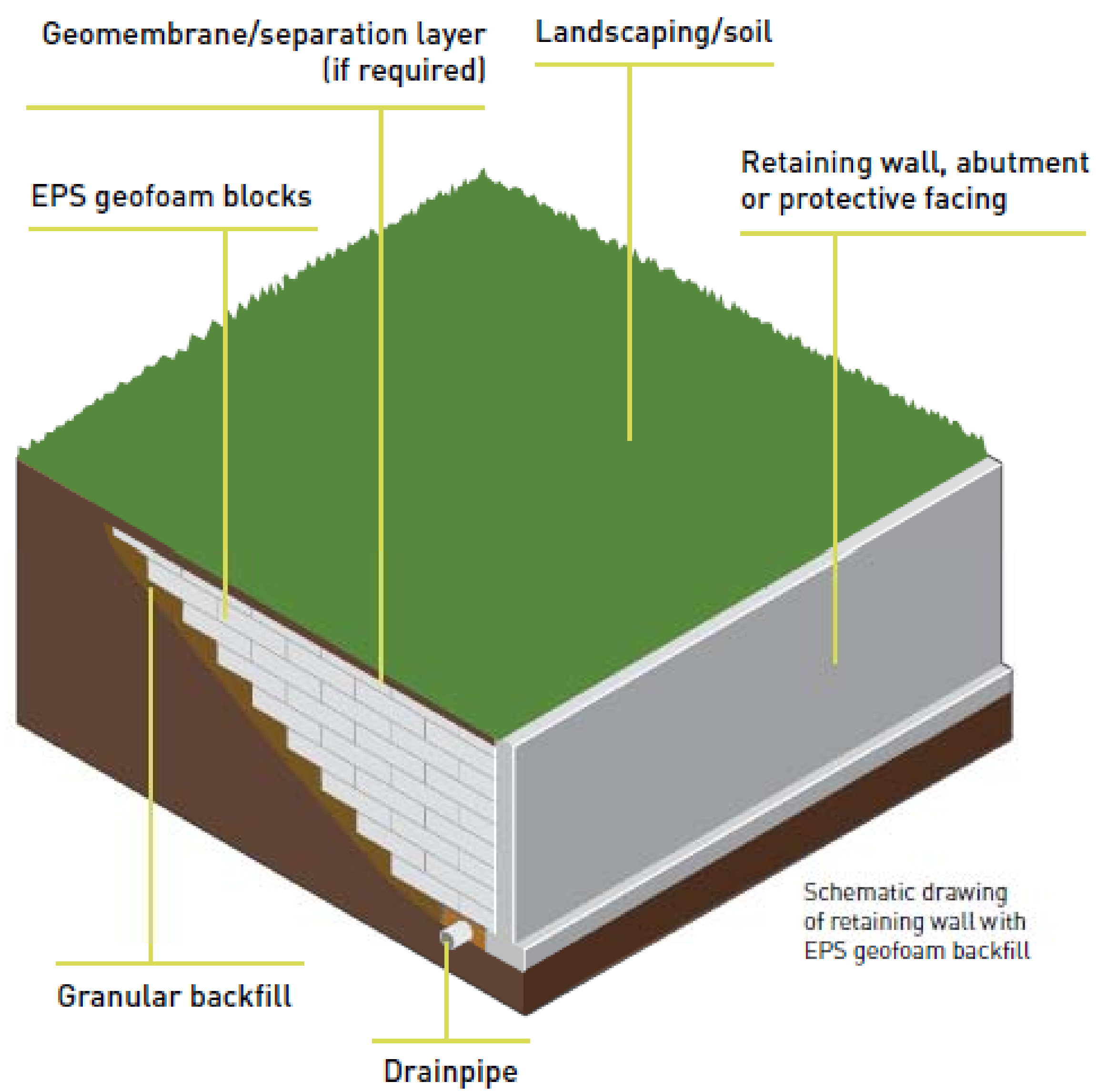
Force – Displacement Relation

Pipelines (Light-weight Cover Over Faults)



Questar Gas Line
3500 South Street
Salt Lake City, Ut

Buried Structures and Walls (Light-Weight Backfill)



Schematic drawing of retaining wall with EPS geofoam backfill

Buried Structures and Walls (Light-Weight Backfill)

Federal Courthouse – Salt Lake City

IHC Hospital – Murray, Ut

Casino/Hotel – Reidoso, NM

Buried Structures and Walls (Compressible Inclusion)

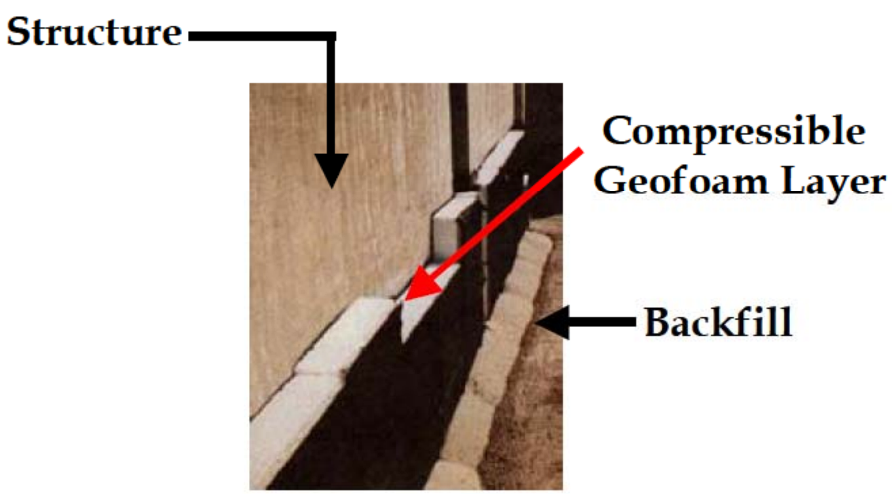
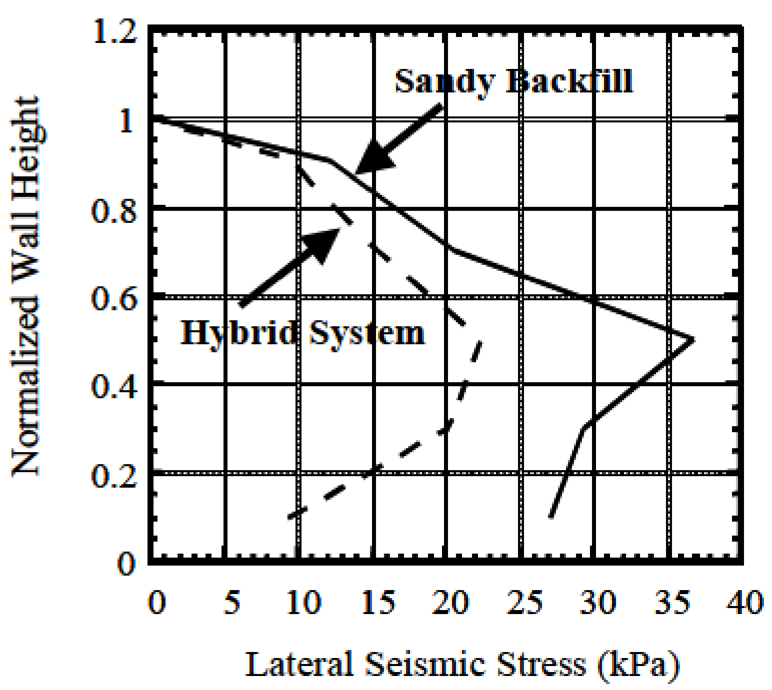
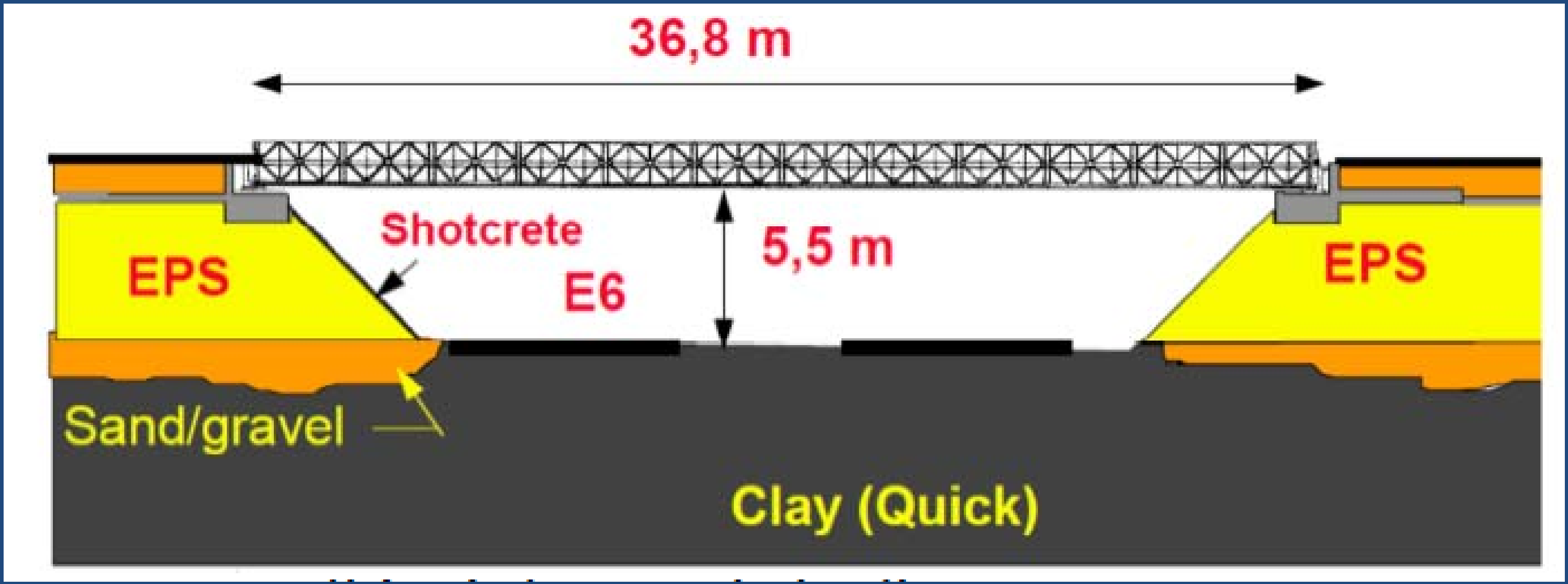


Fig. 1. Use of geofoam as compressible buffer

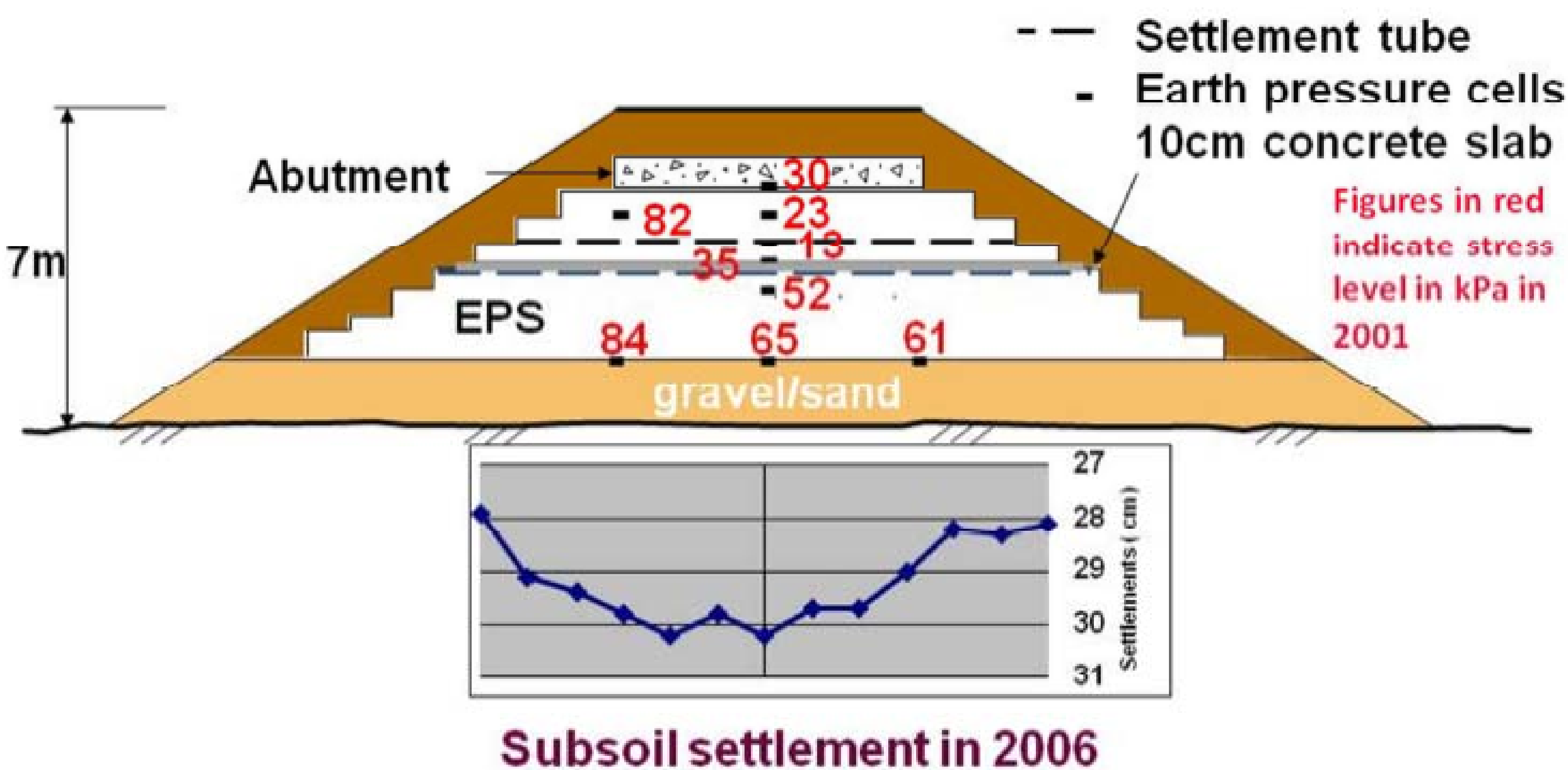


Compensating Foundations



Lokkeberg Bridge, Norway

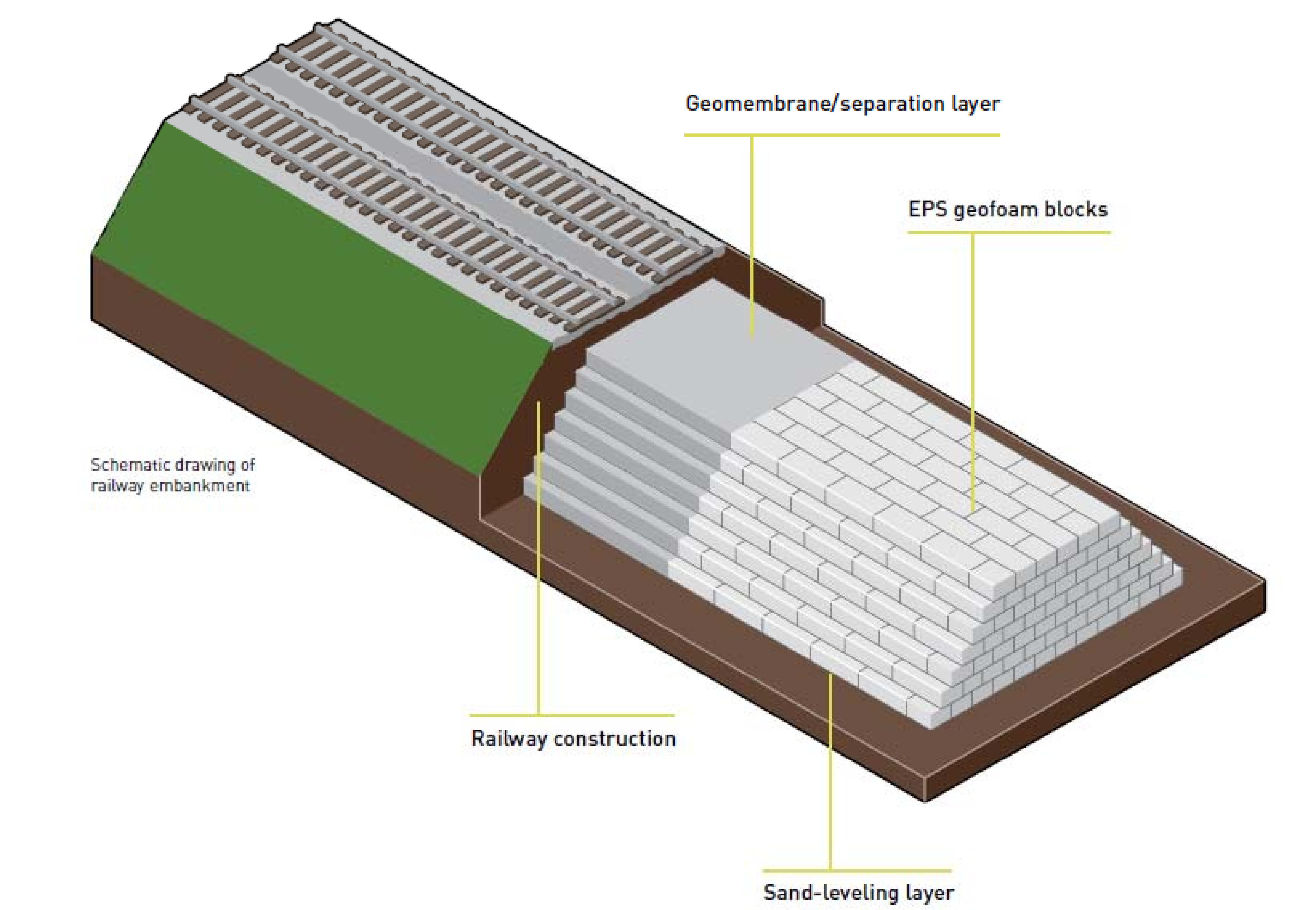
Compensating Foundations



Lokkeberg Bridge, Norway

Foundations for Light-weight Structures

Rail Embankments



Light Rail Embankments

UTA –Light Rail – Salt Lake City, Utah

Light Rail Embankments

UTA –Light Rail – Salt Lake City, Utah

Light Rail Embankments

UTA –Light Rail – Salt Lake City, Utah

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Geofoam for Rapid Construction

	Conceptual Cost (Based on 15,000 cy)	Settlement Amount	Construction Duration	Settlement Duration	Pro/Con – Issues and Risk	Risk and Issue Mitigations	Comments
Regular Fill Only Surcharge – 20'; multistage fill Liquefaction may need mitigation	Unit Cost – $95/cy Assumes difficult island fill and fill access Total Cost - $1,425,000	5' fill / 4" 41' fill / 34"	Longest settlement Add 3-6 month rest between stages (15' fill - 1st stage; 10' subsequent stages)	41 months	• Settlement time • Known performance • Cost • Surcharge removal • Differential settlement/utilities • Adjacent structure loadings	Liquefaction settlement up to 3". May not be acceptable. Mitigate possibly with 20' deep soil mixing	Settlement duration not feasible. Access drives up unit cost. Telebelt material into fill; Crane equipment onto fill and off fill; Removing burrito wrap/temp wall all drive up cost.

Cost and Schedule Information – UTA Trax Project
Salt Lake City, Ut

Geofoam for Rapid Construction

	Conceptual Cost (Based on 15,000 cy)	Settlement Amount	Construction Duration	Settlement Duration	Pro/Con – Issues and Risk	Risk and Issue Mitigations	Comments
Geofoam Liquefaction may need mitigation	Unit Cost – $110/cy Total Cost – $1,650,000 % Increase over Reg. Fill – 27%	Negligible with Net Zero Loading	Shortest construction No settlement period Material lead time	Negligible with Net Zero Loading	• Decreased construction time • No settlement • 100-yr flood plain concern • Cat pole foundations	Liquefaction settlement up to 3". May not be acceptable. Mitigate possibly with 20' deep soil mixing	Preferred option.
Wick Drain / Surcharge Surcharge – 20'+; multistage fill Liquefaction may need mitigation 4' wick drain grid	Unit Cost – $103/cy Total Cost – $1,545,000 % Increase over Reg. Fill – 12%	5' fill / 4" 41' fill / 34"	Decreased settlement period Add 2-3 week rest between stages (15' fill - 1st stage; 10' subsequent stages) Wick drain install ~ 3 weeks	3-6 months	• Reduced settlement time over reg. fill • Overhead Restrictions • No guaranteed time reduction • Haz-Mat plumes • Still settlement period • Constructability issue (access) • Adjacent structure loadings	Liquefaction settlement up to 3". May not be acceptable. Mitigate with possibly 20' deep soil mixing	Settlement issue on utilities unresolved. Ditto UPRR. Settlement duration most likely exceeds schedule float. Access drives up unit cost. Telebelt material into fill; Crane equipment onto fill and off fill; Removing burrito wrap/temp wall all drive up cost.

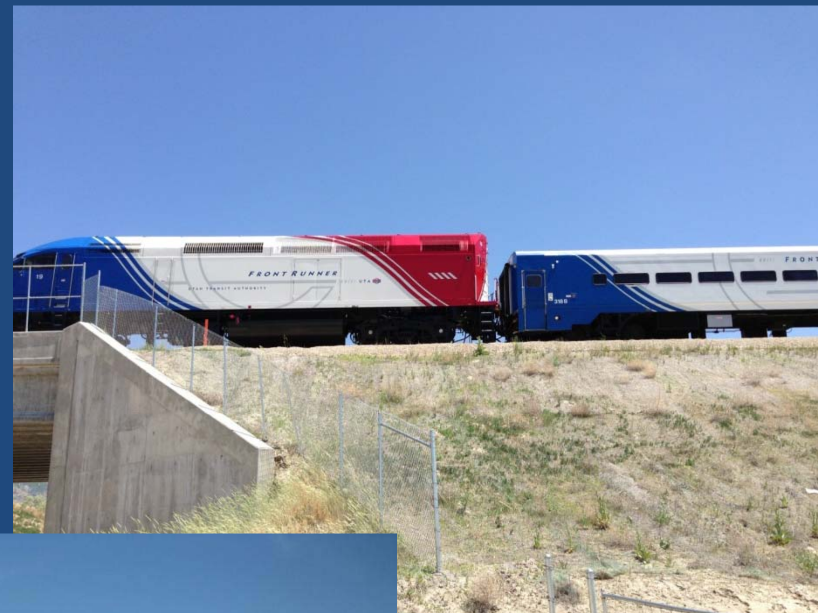
Cost and Schedule Information – UTA Trax Project
Salt Lake City, Ut

Geofoam for Rapid Construction

	Conceptual Cost (Based on 15,000 cy)	Settlement Amount	Construction Duration	Settlement Duration	Pro/Con – Issues and Risk	Risk and Issue Mitigations	Comments
Soil Mixing 40% coverage – jet grout/drill 80' deep	Unit Cost – $390/cy Total Cost – $5,850,000 % Increase over Reg. Fill – 480%	Negligible	Long construction effort – 6 months No settlement period	Negligible	• Cures liquefaction concerns • No settlement • Excessive cost • Messy/clean-up disposal • Time for construction effort		Best for Soft Cohesive Soils – Better solutions for other soil types (HB)
Stone Columns 40% coverage – drilled mms 80' deep	Unit Cost – $400/cy Total Cost – $6,000,000 % Increase over Reg. Fill – 495%	Negligible	Long construction effort – 6 months No settlement period	Negligible	• Cures liquefaction concerns • No settlement • Excessive cost • Time for construction effort		

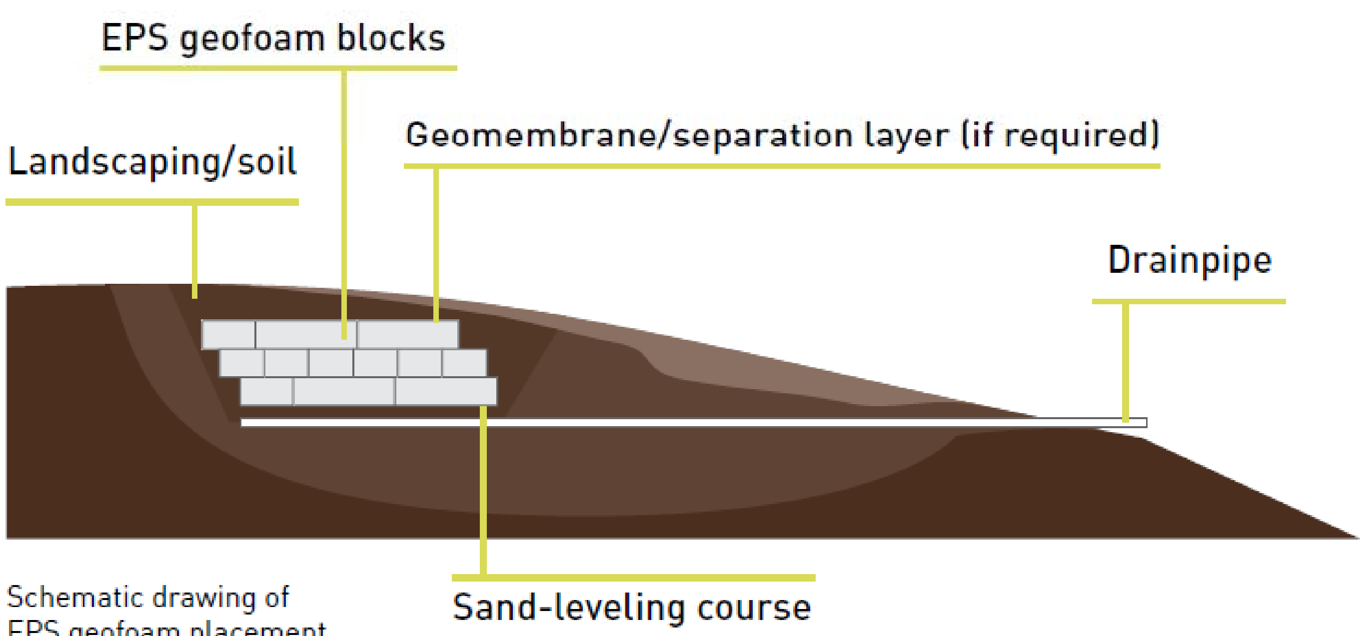
Cost and Schedule Information – UTA Trax Project
Salt Lake City, Ut

Heavy Rail Embankments

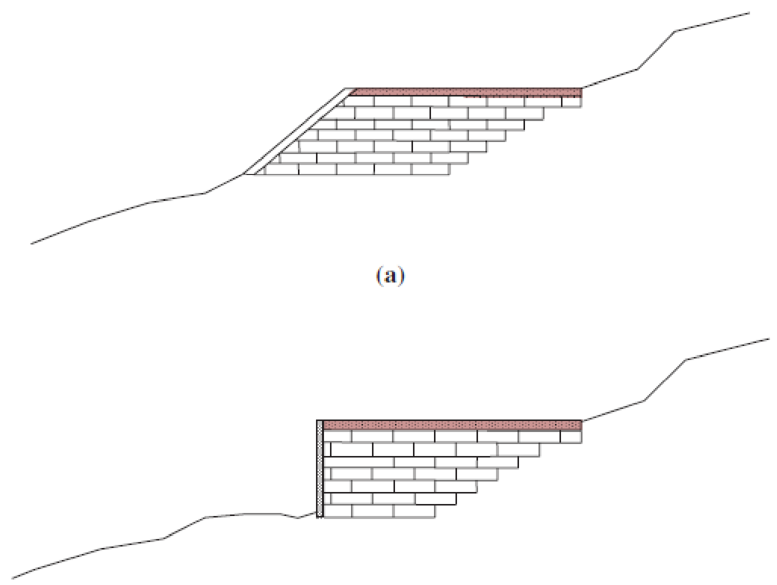


Front Runner – UTA – Corner Canyon – Draper Utah

Slope Stabilization



Schematic drawing of EPS geofoam placement in a slide area



Slope Stabilization

Pavement Cracking

Scarp

Alabama DOT

Slope Stabilization

Overview of EPS Block Placement Configuration

Alabama DOT

Slope Stabilization

Backfill Placement Behind EPS

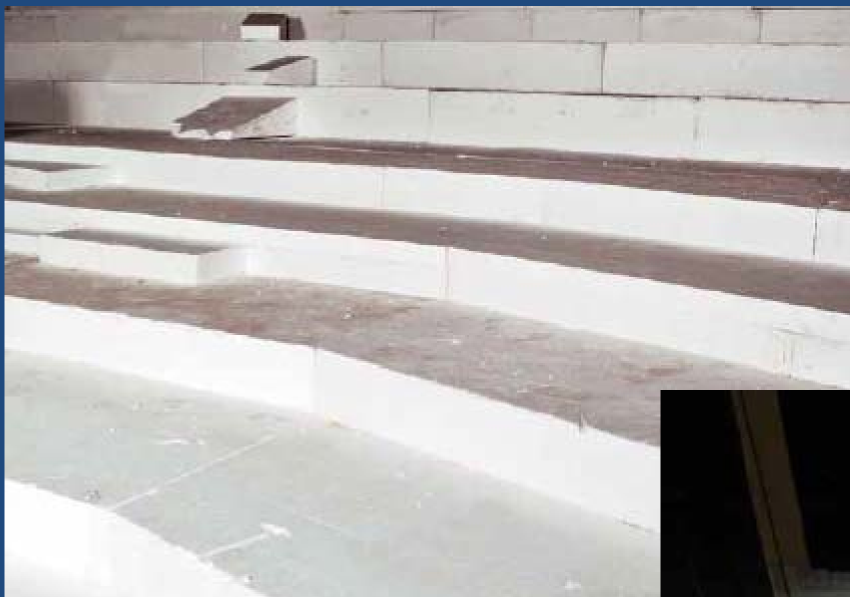
Completed Road

Alabama DOT

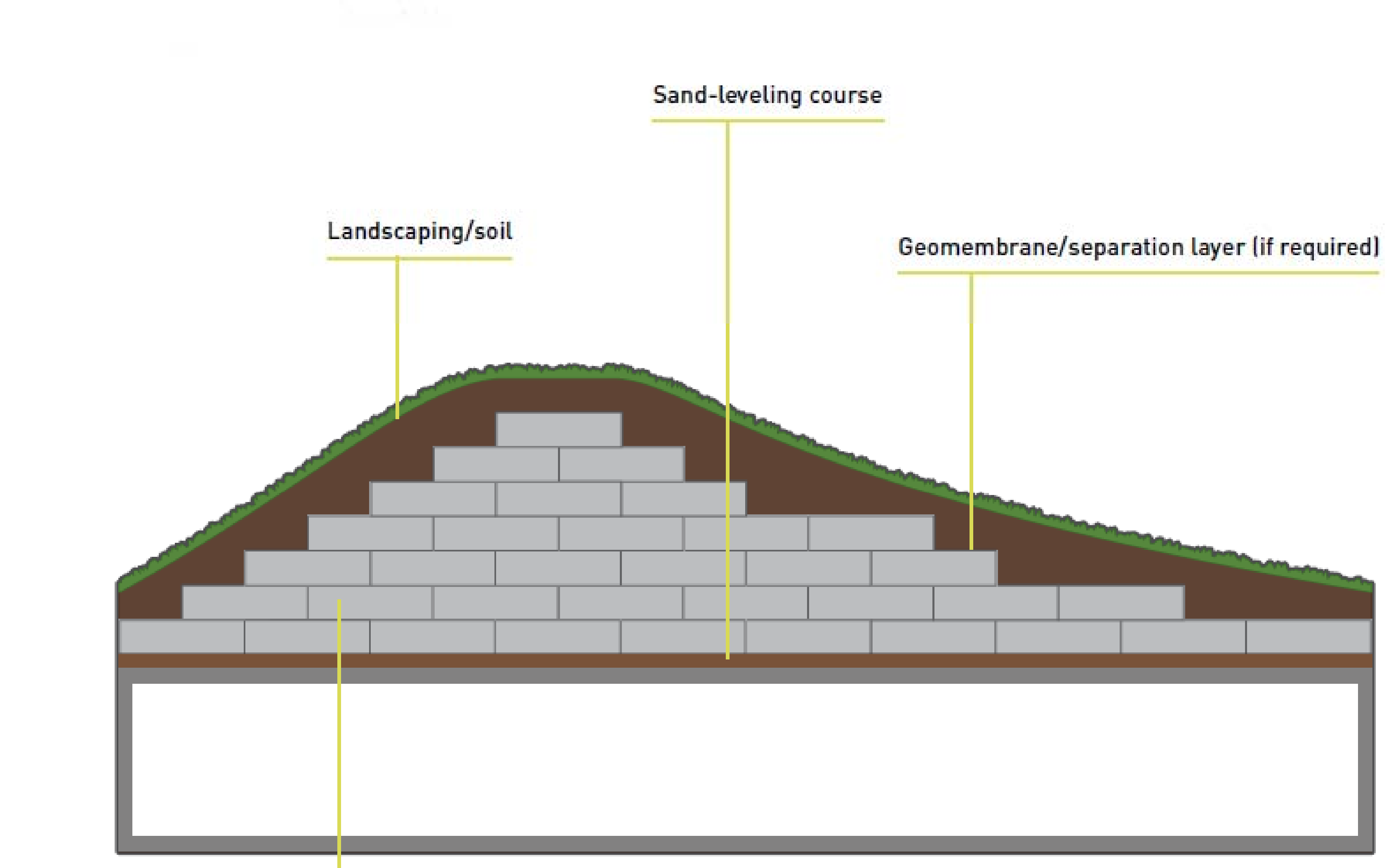
Slope Stabilization

SR264 at 2nd Mesa, Arizona

Stadium and Theater Seating



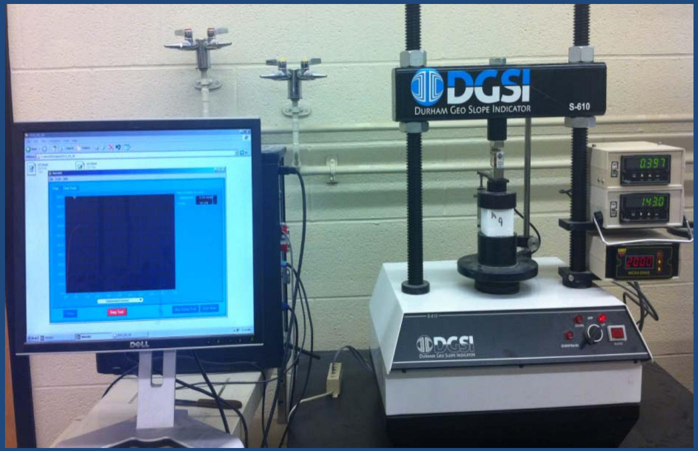
Landscaping and Green Roofs



Landscaping and Green Roofs

Conference Center, Salt Lake City, Utah

Sustainability and Recycling
Recycled-Content Geofoam



Compression

Flexure

Creep

Project: Evaluate stress-strain and stress-strain-time behavior of recycled-content EPS.

Geofoam Testing Capabilities

GeoComp^{TM} Cyclic Triaxial Device

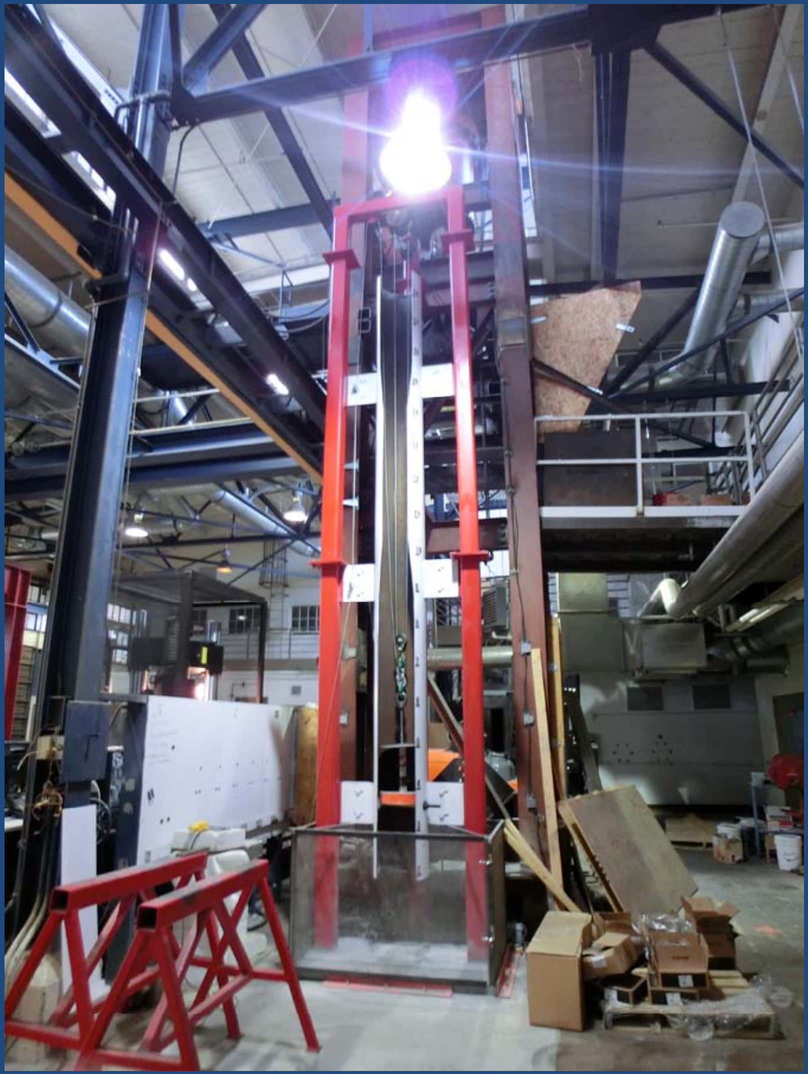
Geofoam Testing Capabilities

MTS™ Cyclic Triaxial Device

Geofoam Testing Capabilities

Large Diameter 1D Compression Chamber

Geofoam Testing Capabilities

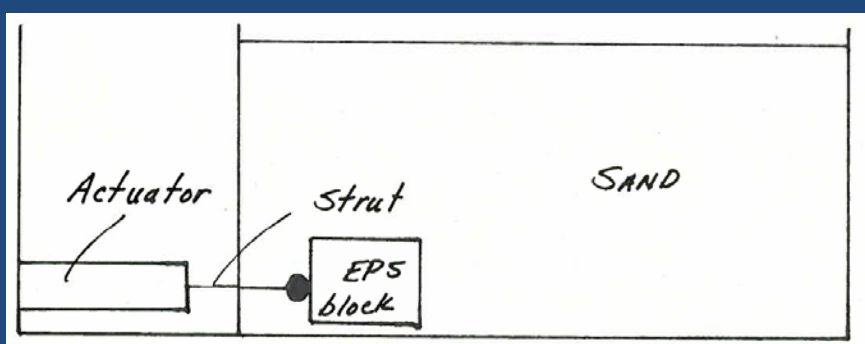


Impact Hammer and Test Frame

Geofoam Testing Capabilities

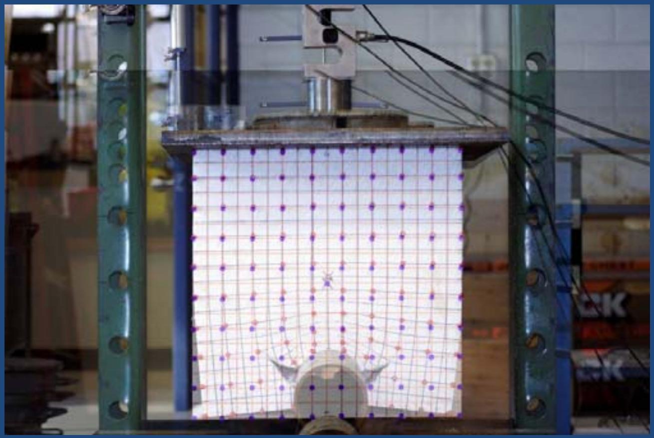
Large-Scale Test Frame

Geofoam Testing Capabilities



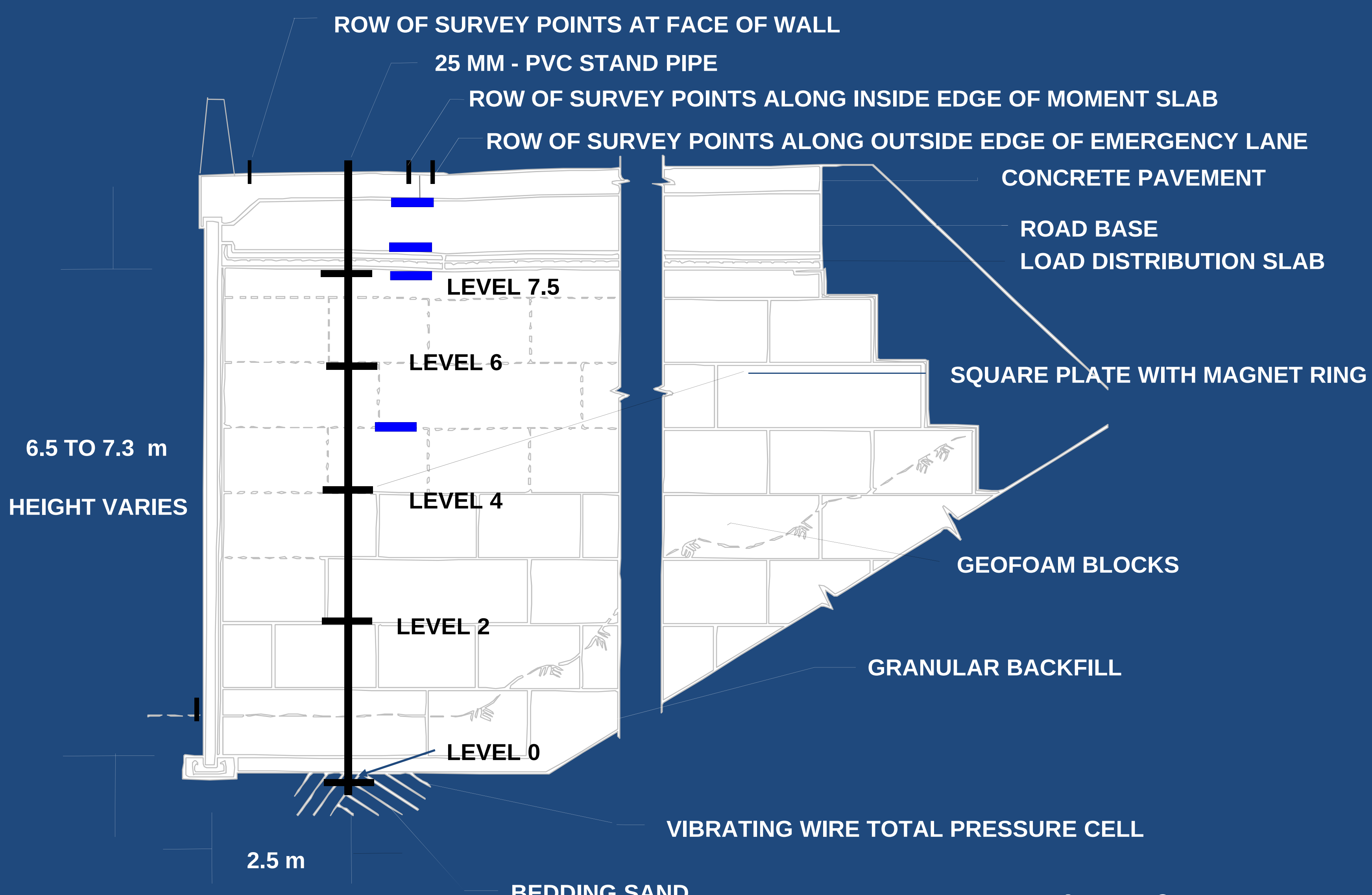
Trench Box Test Facility

Field Testing and Monitoring



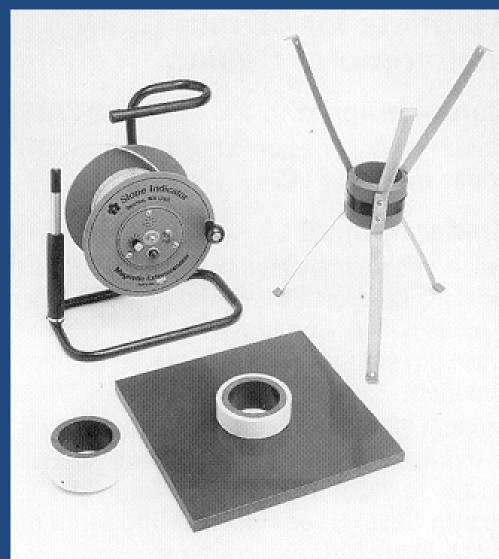
Pipe Interaction and Uplift Test

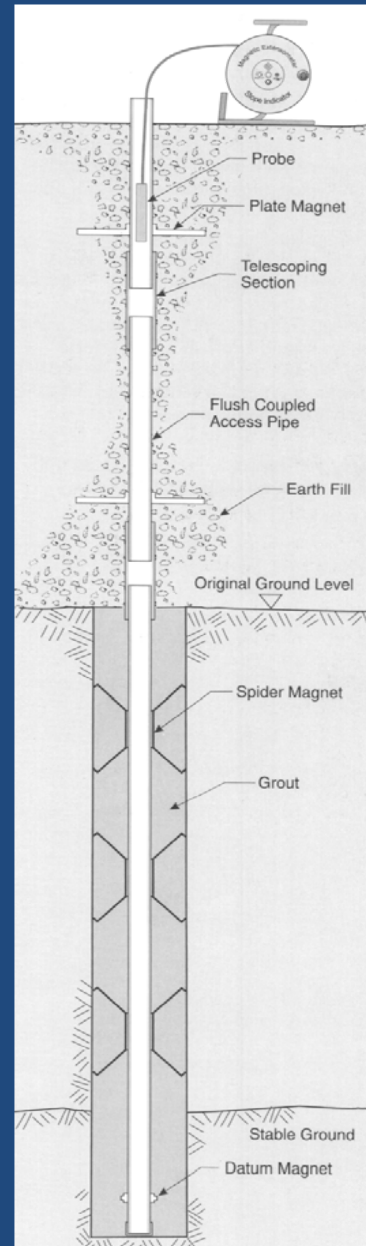
Field Testing and Monitoring



Typical Geofoam Array

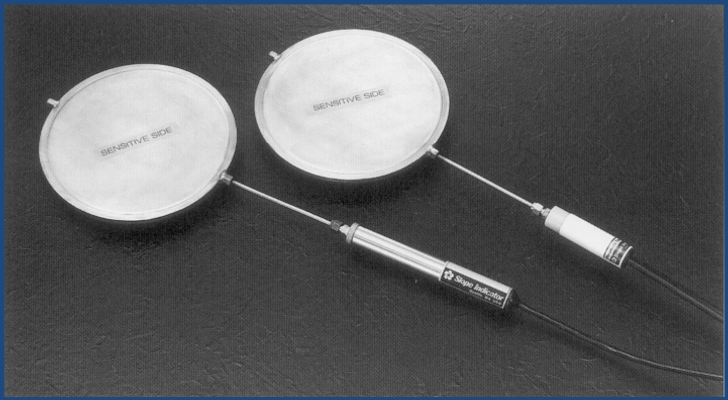
Field Testing and Monitoring





Magnet Extensometer Installation

Field Testing and Monitoring



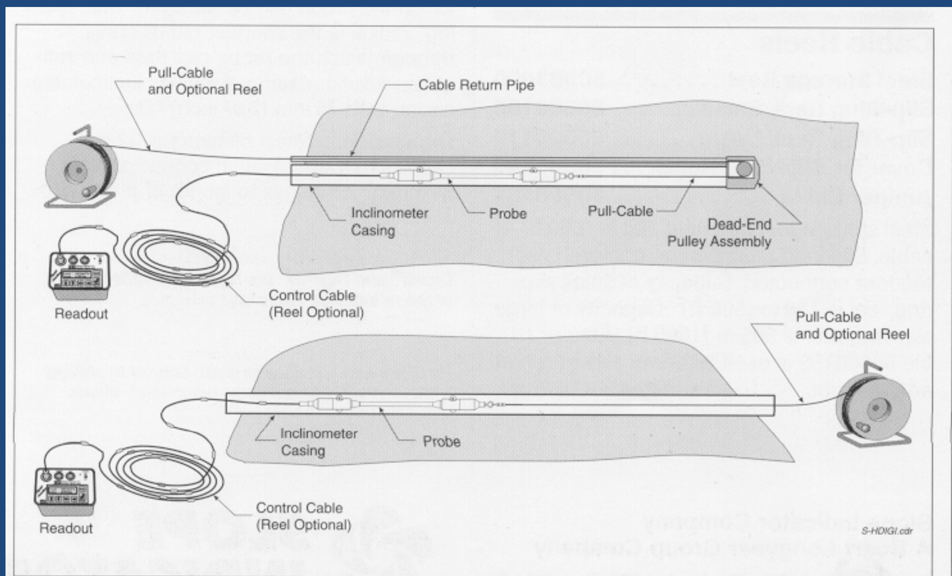
Vibrating Wire Total Pressure Cells

Hotwire Cut Slot for Pressure Cell

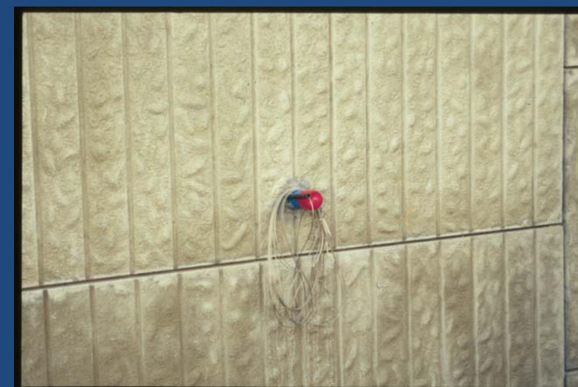
Pressure Cell Cast in Bridge Abutment

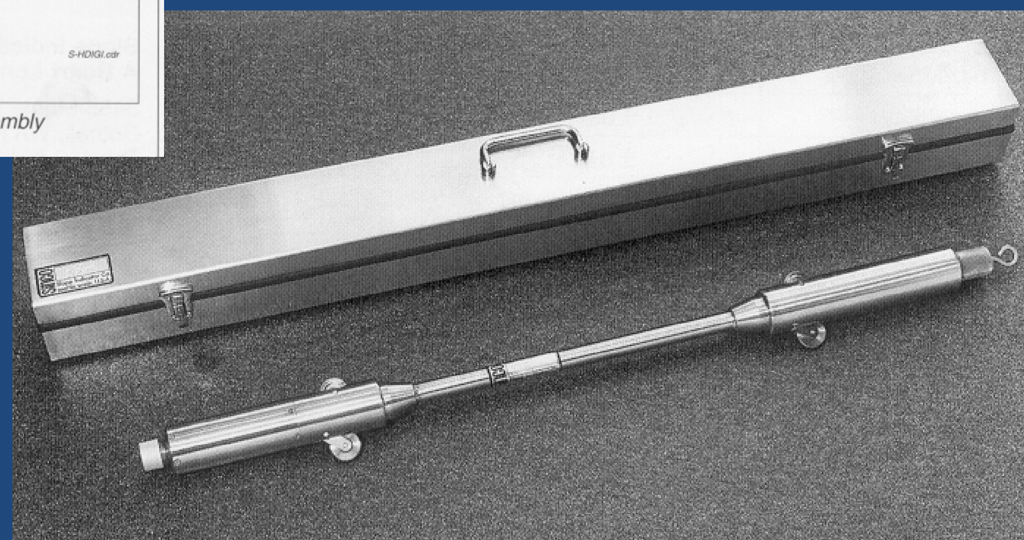
Pressure Cell in Base Sand

Field Testing and Monitoring



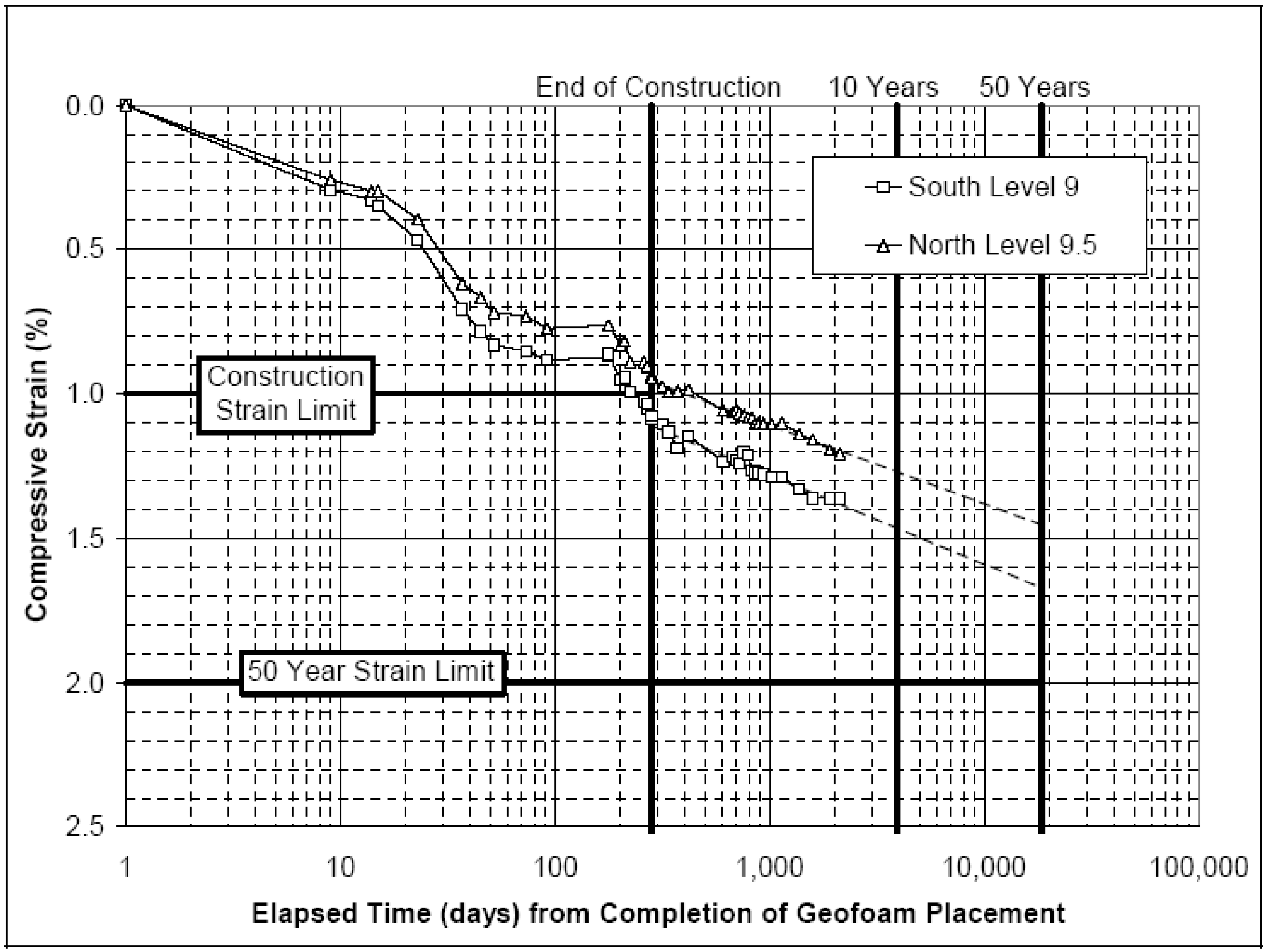
Horizontal Inclinometer Systems, with and without dead-end pulley assembly





Horizontal Inclinometer

Field Testing and Monitoring



1% construction strain **projected 0.5 % additional 50 yrs.**

Field Testing and Monitoring

Vibration Monitoring for Rail Systems

Rail line

The CR3000 Micrologger®.

Accelerometers

Future Growth and Development

- Geofoam Embankments
- Light-weight Fill Against Structures and Buried Walls
- Light Rail and Heavy Rail and High Speed Rail
  - Deflections
  - Vibrations
- Bridges Supported on EPS without Deep Foundations (e.g., piles)
  - Research with Norwegian Public Roads Administration
- Slope Stabilization
- Reclaimed Land
- Temporary Roads
- Pipelines
- Other
  - Sustainability (Reuse and Recycle)
  - New Facing Systems (Less Expensive Systems that Concrete Walls)
  - Education (Short Course)

Questions