Use of EPS Geofoam in Seismic and Slope Applications
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Topics

- Introduction to EPS
- Protection of Buried Pipelines from Permanent Ground Displacement
- Static and Seismic Earth Pressures Against Buried Structures and Facilities
- Slope and Embankment Applications

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

General Applications

2.1	Road construction over poor soils
2.2	Road widening
2.3	Bridge abutment
2.4	Bridge underfill
2.5	Culverts, pipelines & buried structures
2.6	Compensating foundation
2.7	Rail embankment
2.8	Landscaping & vegetative green roofs
2.9	Retaining and buried wall backfill
2.10	Slope stabilization
2.11	Stadium & theater seating
2.12	Levees
2.13	Airport runway/taxiway
2.14	Foundations for lightweight structures

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Geofoam Properties

ASTM D6817 Physical Property Requirements of EPS Geofoam

Type	EPS12	EPS15	EPS19	EPS22	EPS29	EPS39	EPS46
Density, min., kg/m^3(lb/ft^3)	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

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Geofoam Advantages

- Light weight material
  - Reduces static and seismic loads to walls, buried structures
  - Improves slope stability (static & dynamic)
  - Reduces consolidation settlement on soft ground
- Controlled Compression (Compression Inclusion)
  - Can undergo elastic and plastic deformation but maintains general shape
  - Reduces load to buried structures by compression and mobilization of surround soil strength

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Beginnings of Geofoam

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

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Flom Bridge – 1972 - Norway

Road Construction Over Poor Soils

LESSONS LEARNED

At the time of the first project we were particularly concerned about the following

- the constant vibrations of the traffic which possibly could cause horizontal movements of the fill structure
- leakage of petrol following a tanker accident which could cause the embankment to dissolve

In order to safeguard the repeated vibrations, the first EPS embankment was meant to be built up with a small slope towards the centre of the road. The contractor eventually ignored this, and such precautions were later never prescribed.

In order to protect against petrol leakage, the embankment was protected with a 10 cm polyurethane cover. Very soon it also became apparent that the risk for an overturning tanker on an EPS embankment was extremely low, and that the use of a 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.

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Typical Roadway Construction

Details of Geofoam Construction at Bridge Abutments

Geofoam Embankments

Freestanding Embankment

Sloped Embankment

UTA –Light Rail – Salt Lake City, Utah

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Sources of Permanent Ground Deformation

- Tectonic Faulting
- Subsidence and Settlement
- Landsliding and Other Types of Mass Movement
- Liquefaction and Lateral Spread
- Karst
- Collapsible Soils
- Expansive Soils

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Fault-Induced Pipeline Rupture

Pipelines (Protection for Normal and Reverse Faults)

Shallow Burial – Normal Faulting

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Pipelines (Protection for Strike Slip Faults)

Alaskan Pipeline – Strike Slip Fault

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Wasatch Fault at Little Cottonwood Canyon

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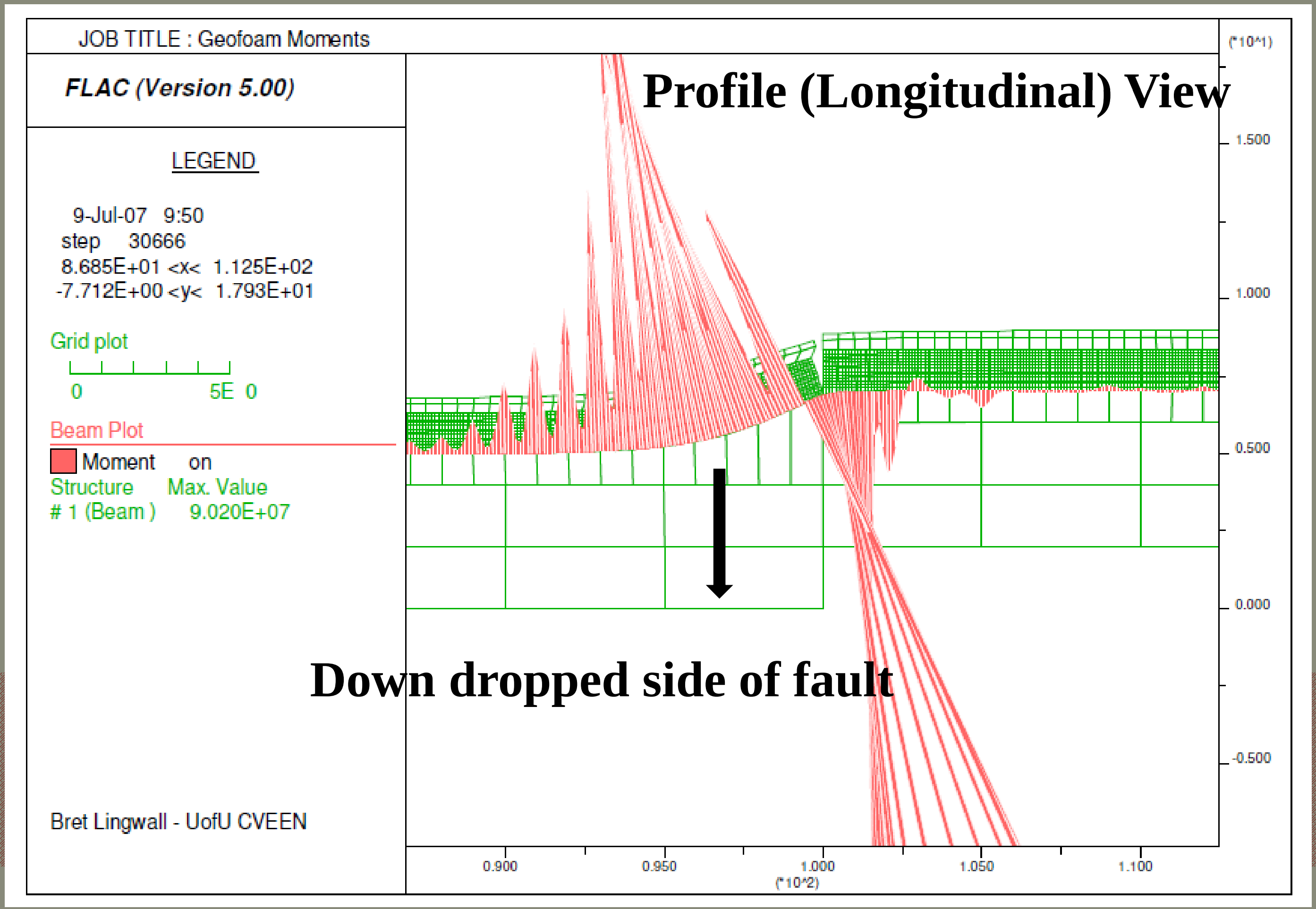
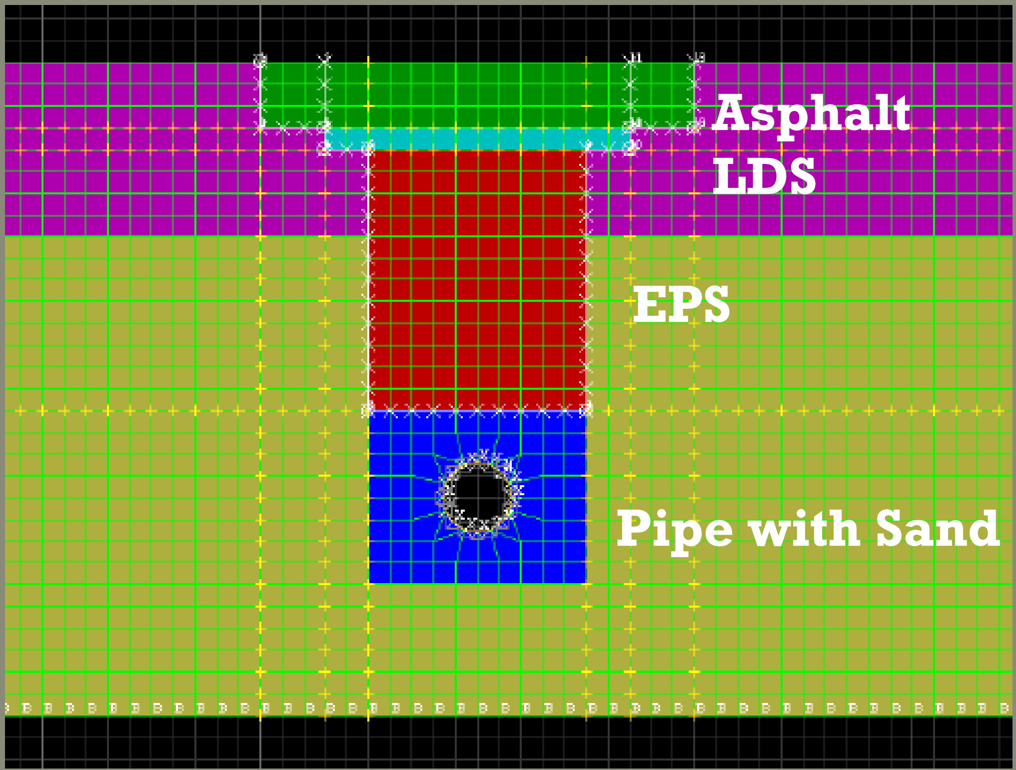
Pipelines (Light-weight Cover Over Normal Faults)



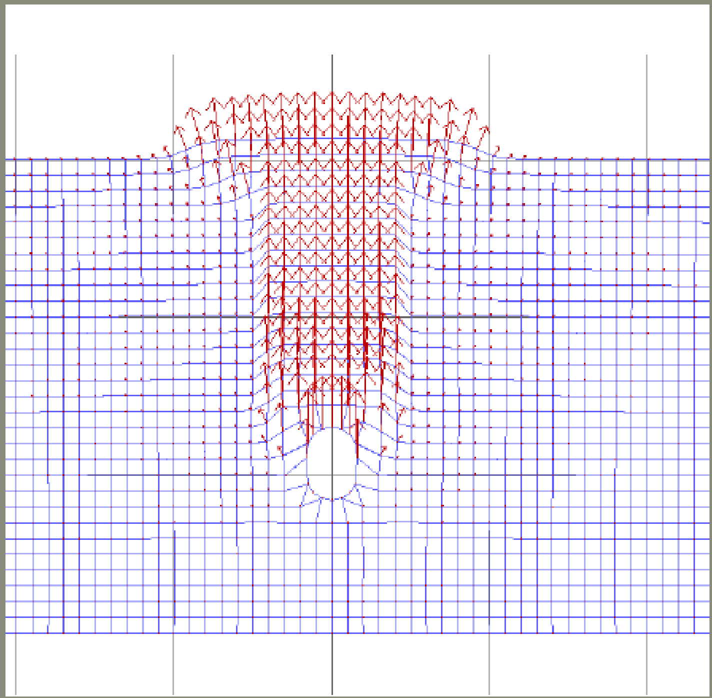
Bending Moments in Pipe from 2 m offset

Pipelines (Light-weight Cover Over Normal Faults)



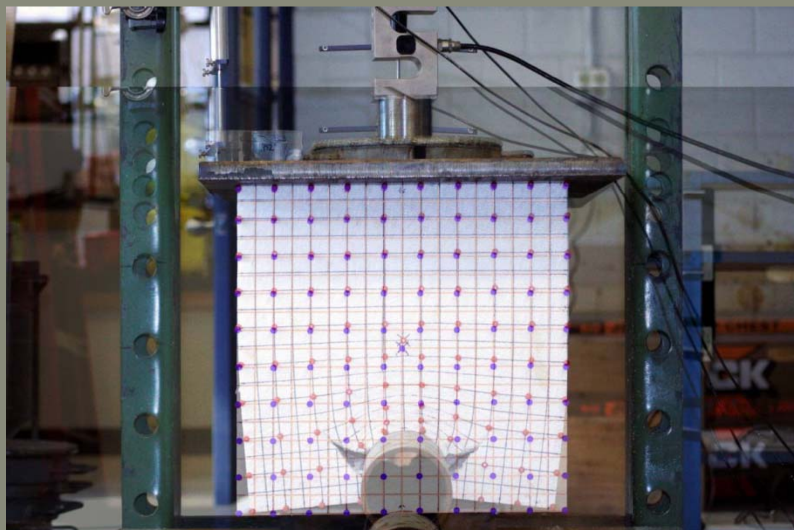
Lightweight-Cover System
(X-sectional View)

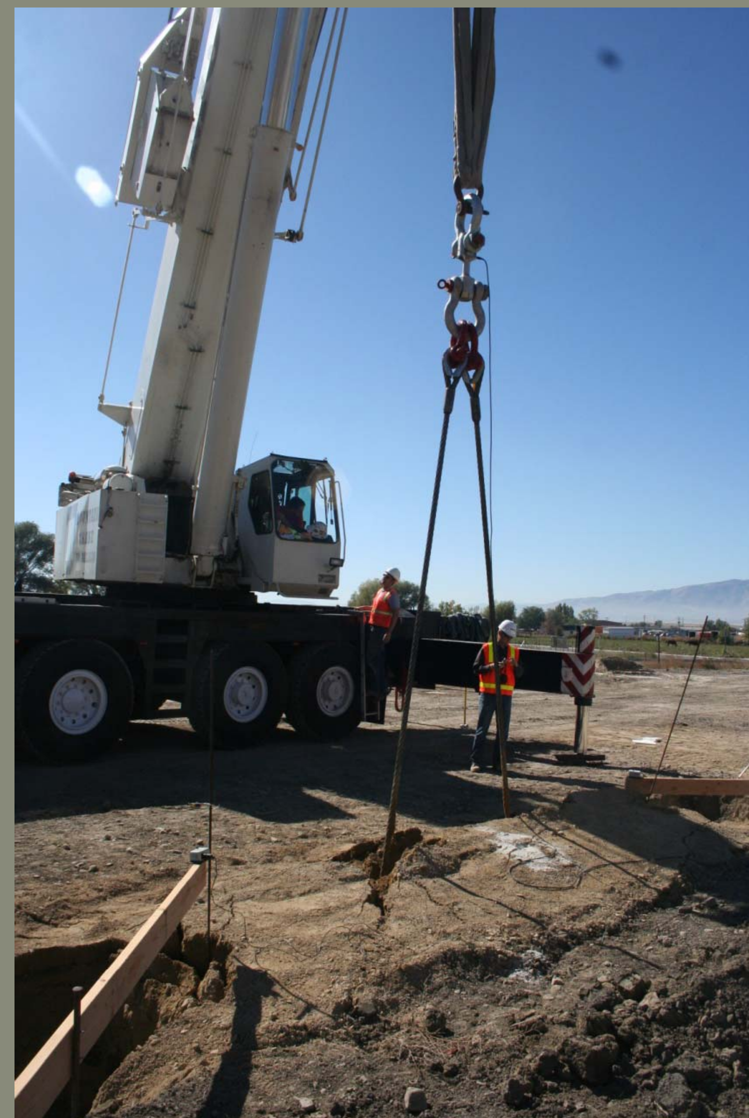
Video



Displacement Vectors During Failure

Vertical Uplift Tests





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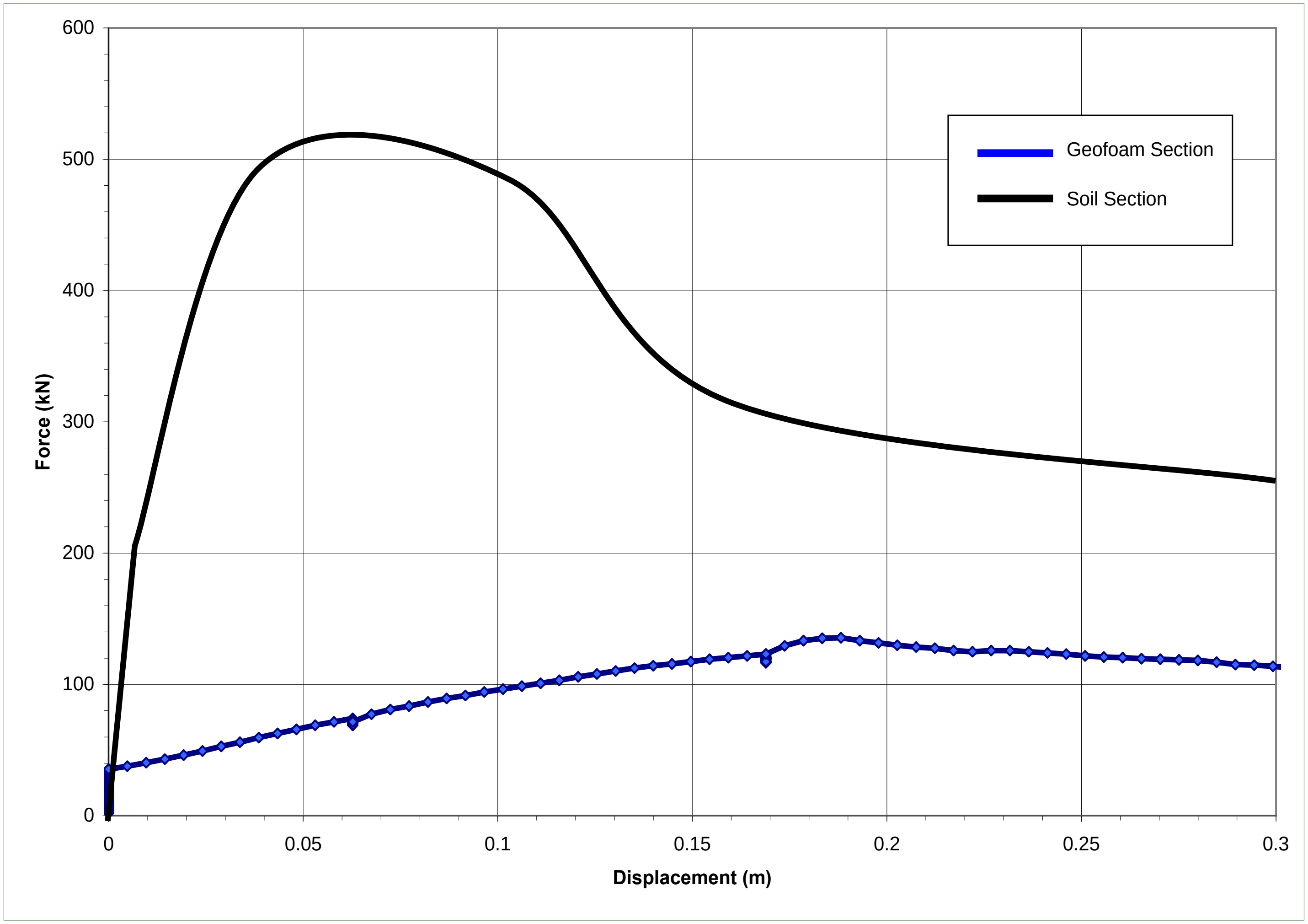
Force-Displacement Curves from Uplift Tests

Uplift Force (kN)



Vertical Displacement (m)

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Pipelines (Light-weight Cover Over Faults)

Questar Gas Line
3500 South Street
Salt Lake City, Ut

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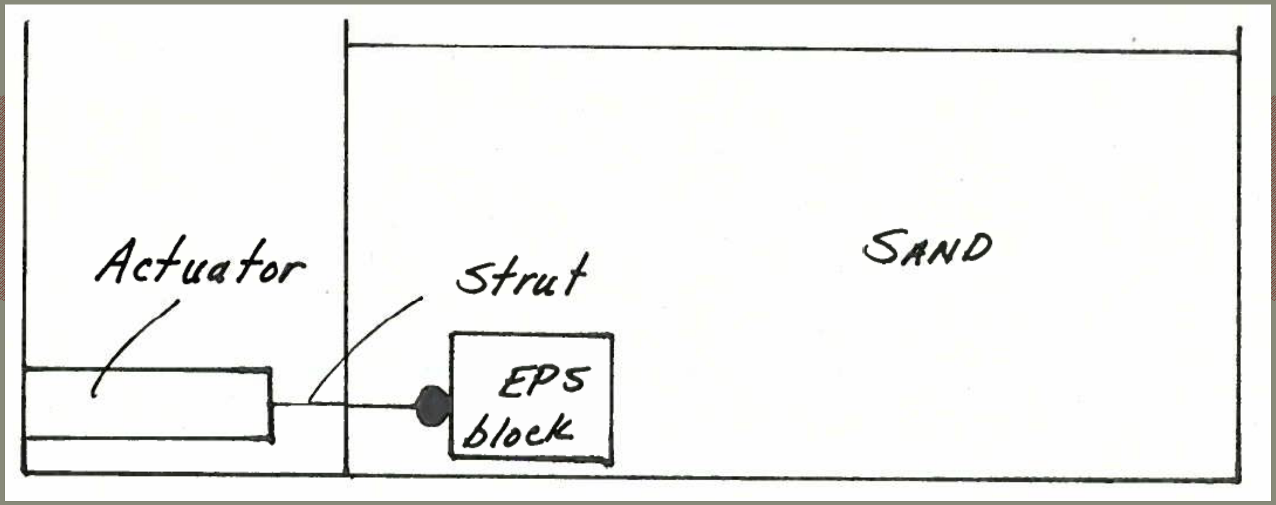
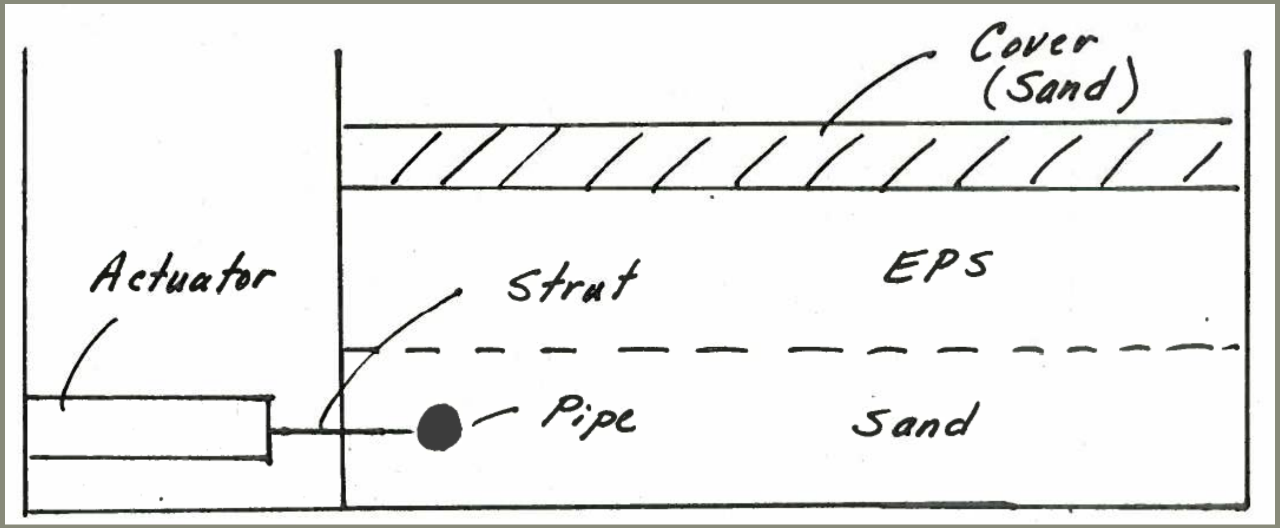
Horizontal Offset from Permanent Ground Displacement





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Horizontal Offset from Permanent Ground Displacement

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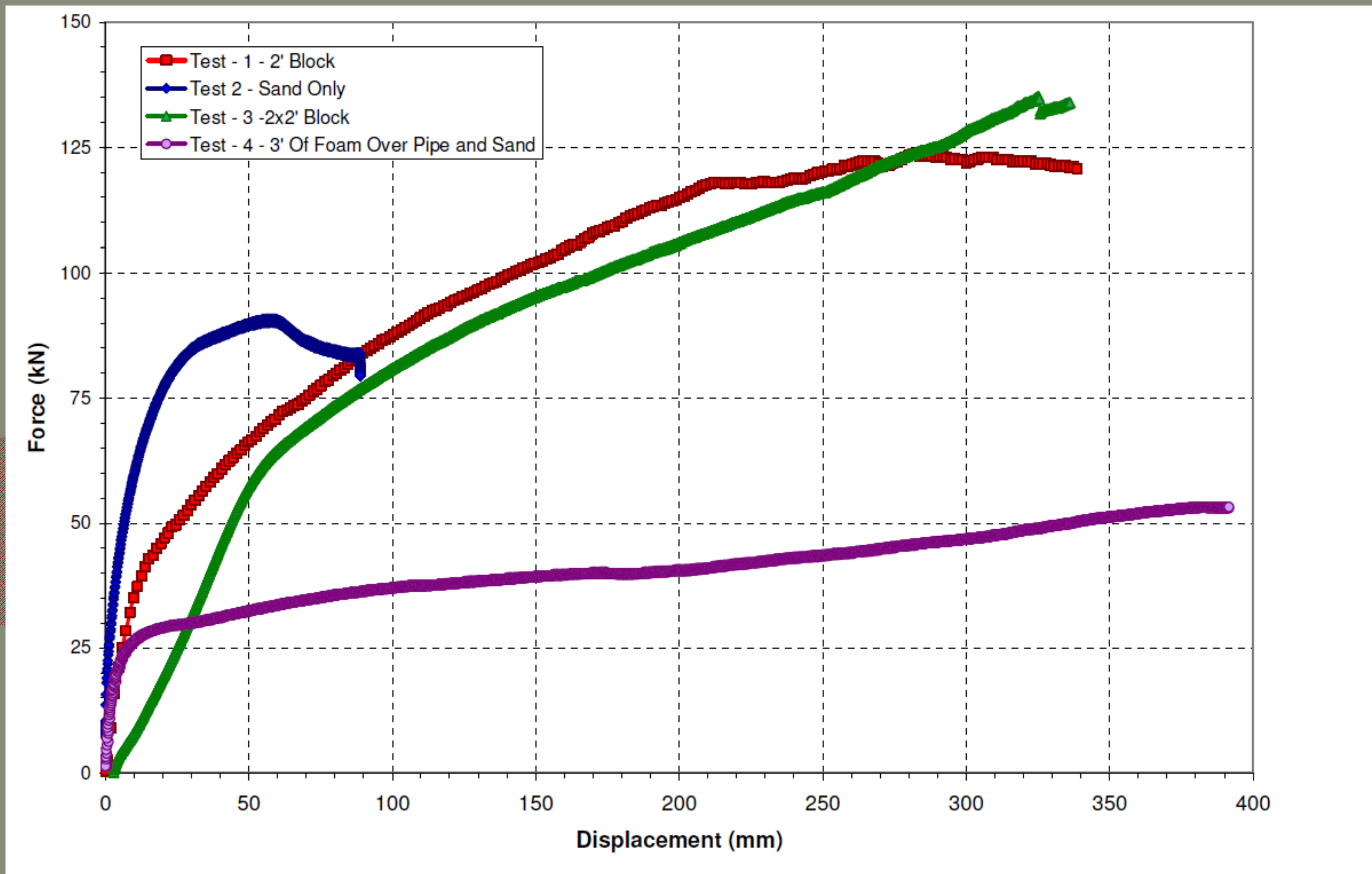
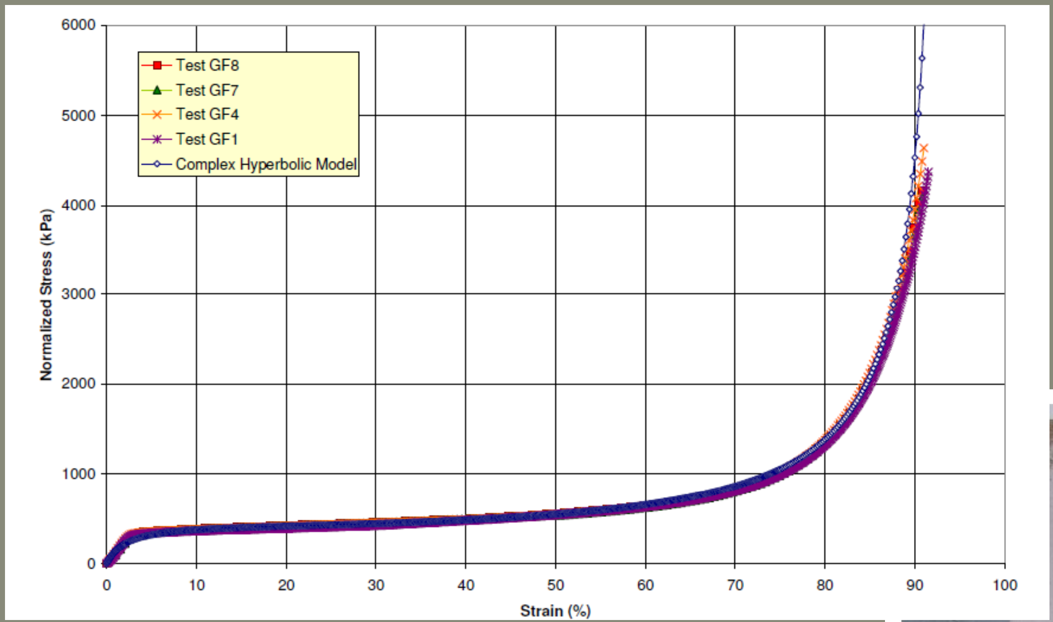
Horizontal Offset from Permanent Ground Displacement



Horizontal Offset from Permanent Ground Displacement



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Reduction of Settlement around Buried Structures

Federal Courthouse

IHC Hospital – Murray, Ut

Casino/Hotel – Reidoso, NM

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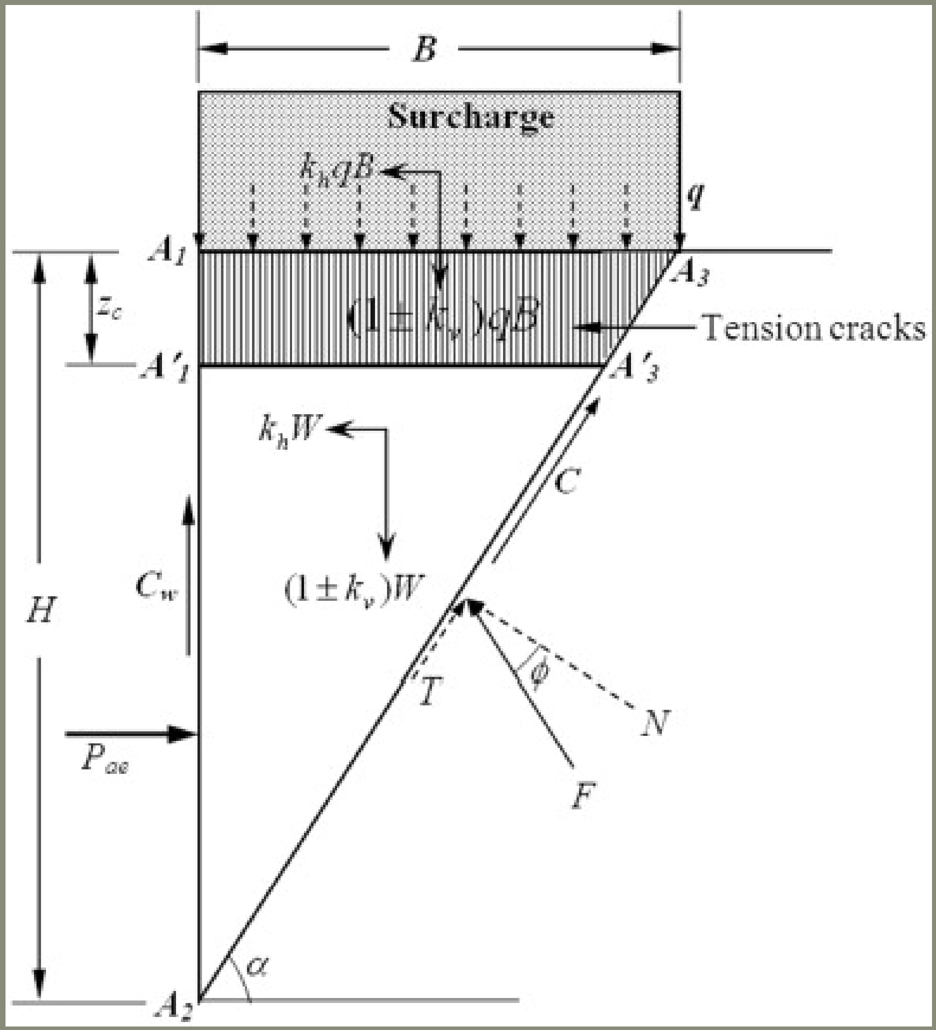
Earth Pressure Theory - Active Case



Buried Structures and Walls (Compressible Inclusion)

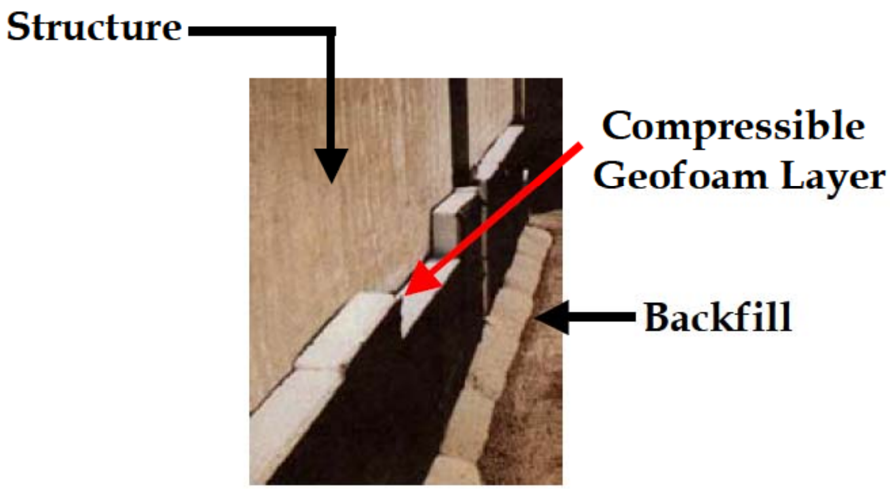
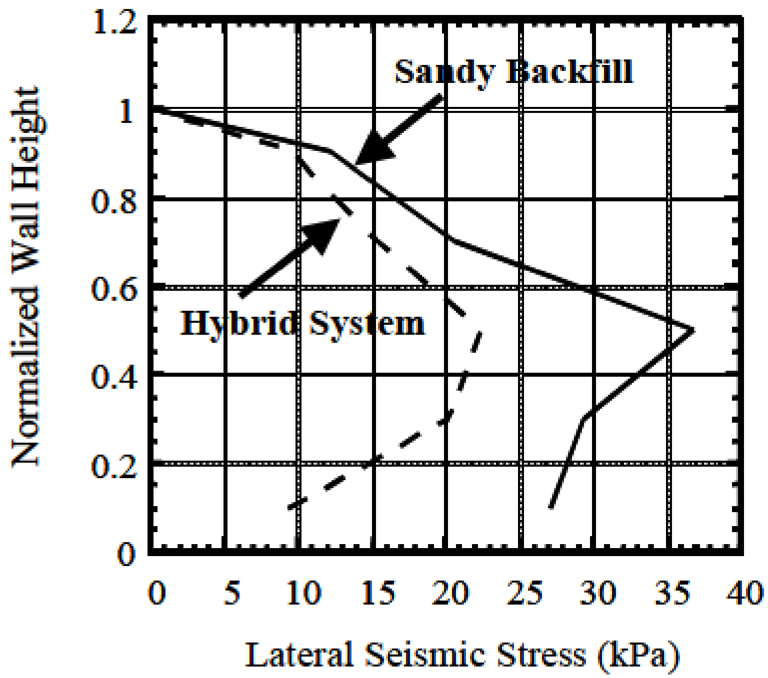


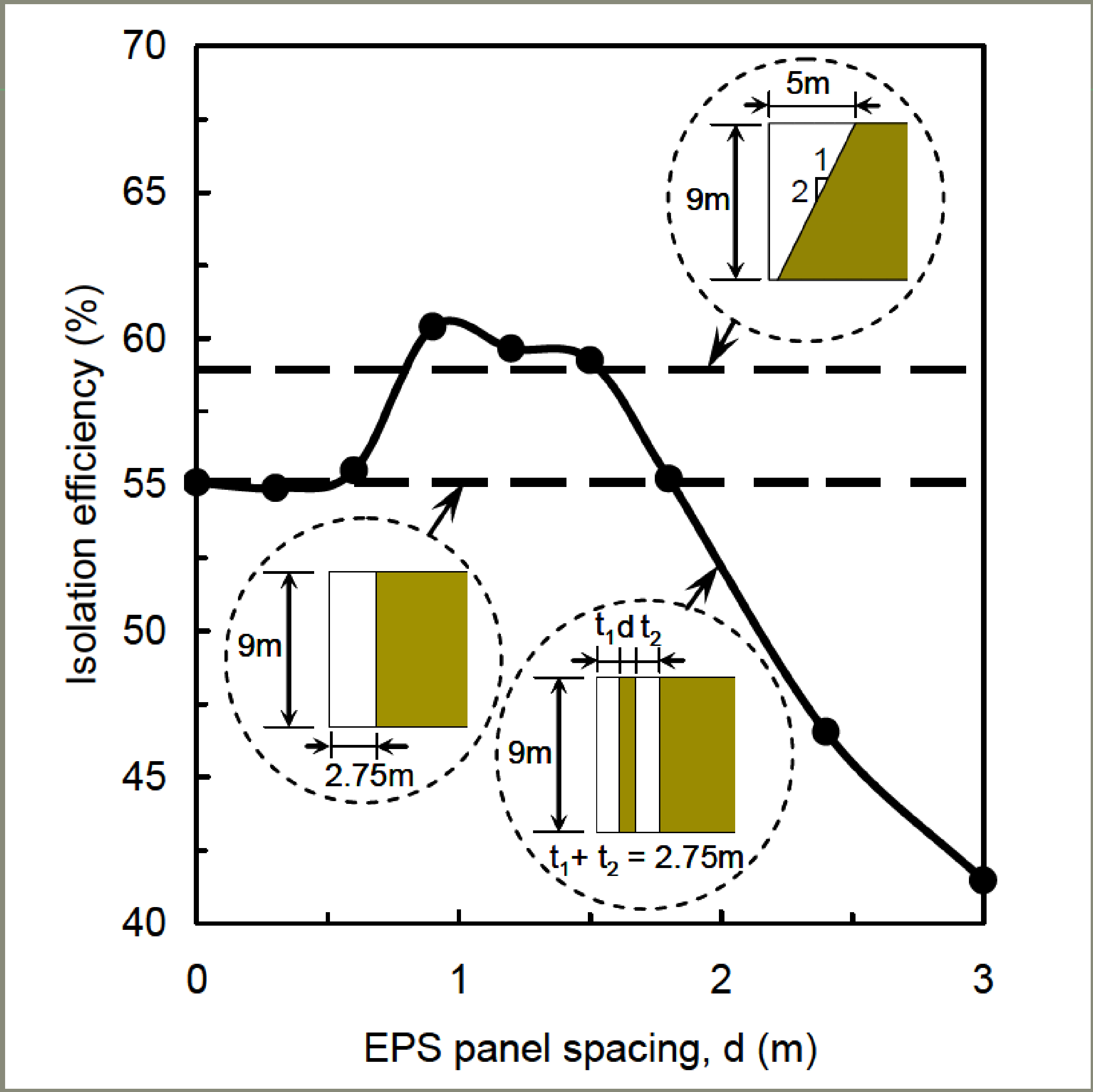
Fig. 1. Use of geofoam as compressible buffer



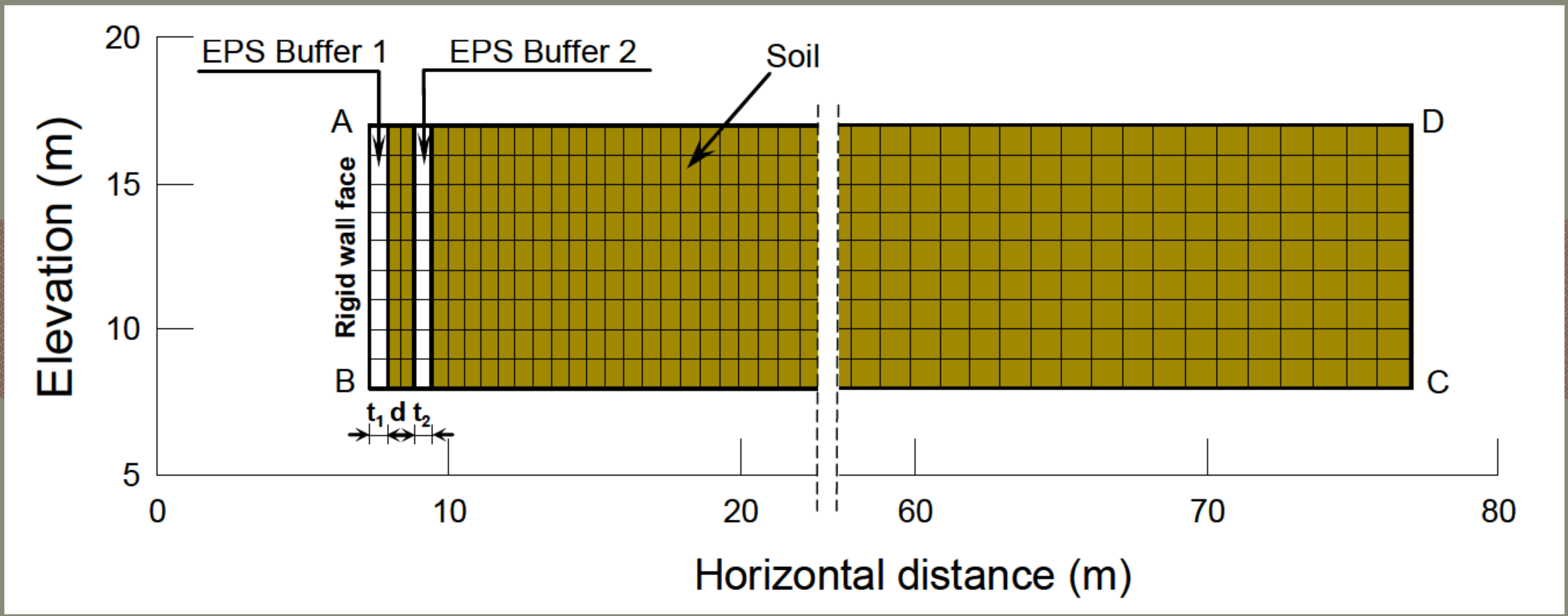
Reduction of Seismic Earth Pressure

(Hazarika, 2002)

Reduction of Peak Seismic Thrust



Reduction of Peak Seismic Thrust



Reduction of Peak Seismic Thrust

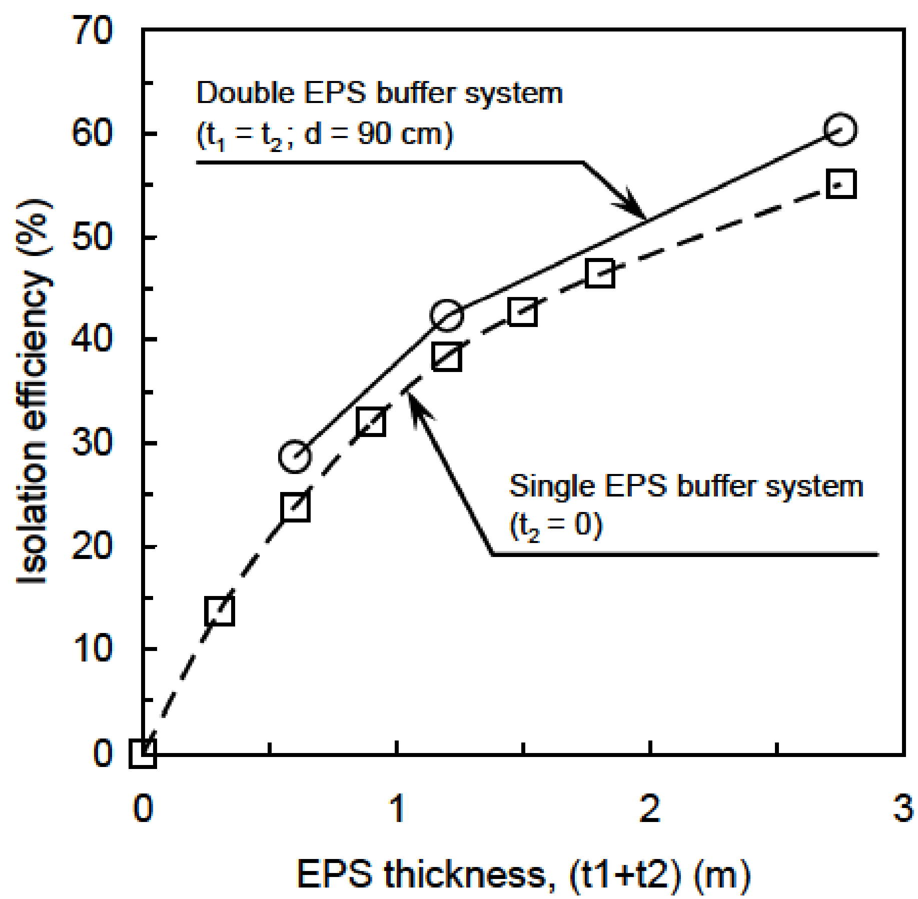


Fig. 8. Seismic isolation efficiency in relation to the total EPS thickness for single rectangular and double EPS buffer systems.

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Seismic Stability Considerations

- Primary Modes of Potential Failure
  - Global Stability of slope/embankment with strong motion
  - Sliding (Basal, Interlayer and Cap)
  - Rocking and Sway (Internal yielding and damage to corners)
  - Overturning (for slender aspect ratios)
  - Bearing Capacity?

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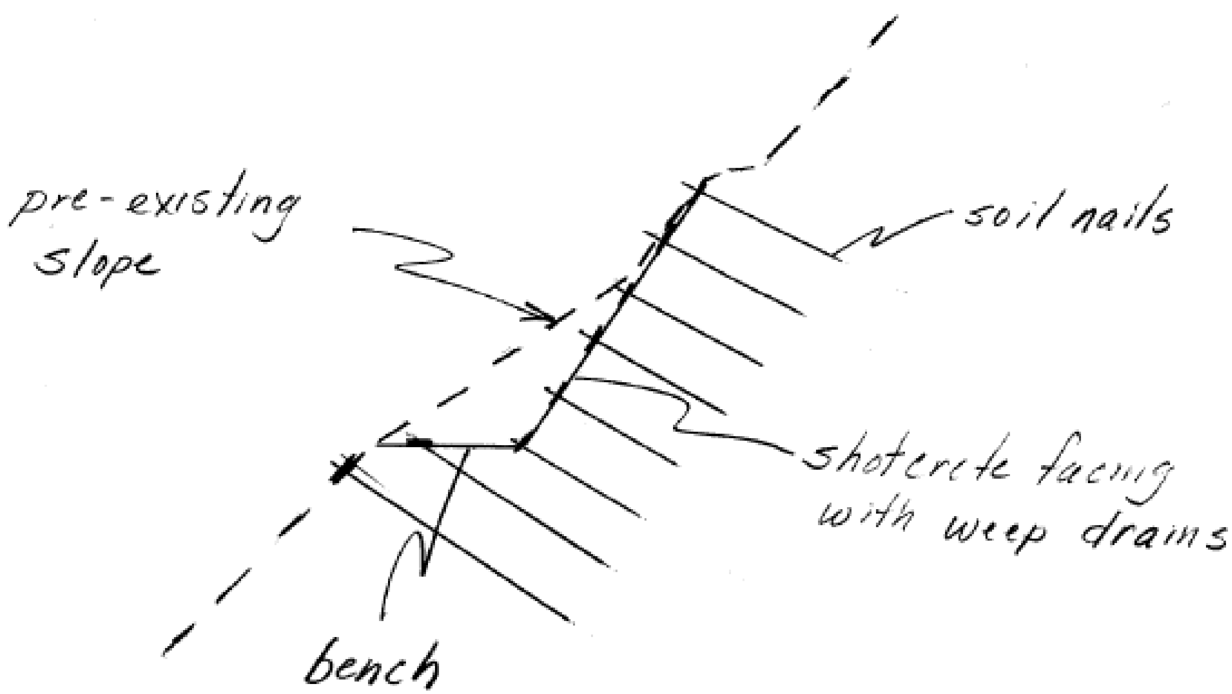
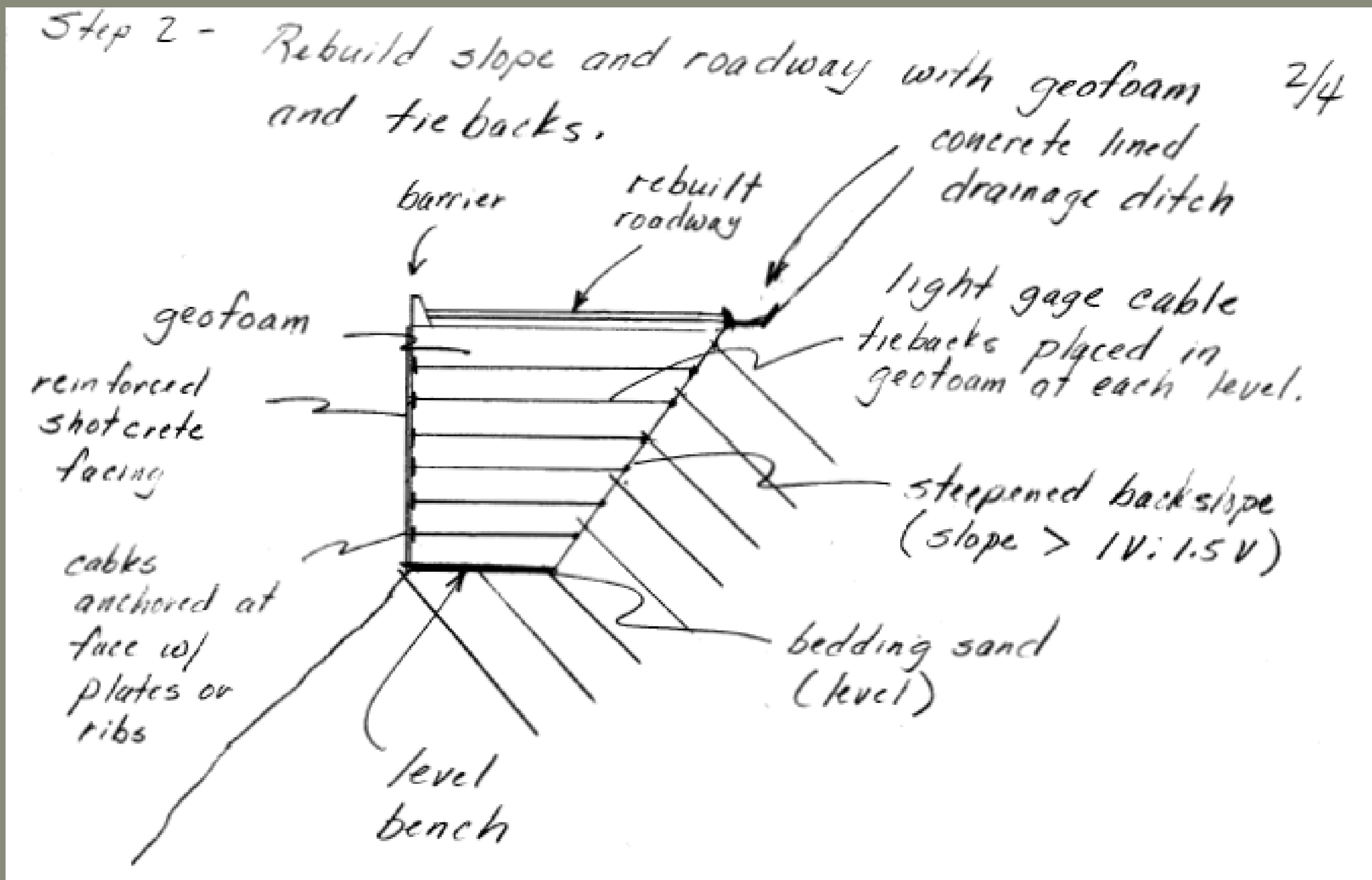
Conceptual Reconstruction of Failed Slope with EPS

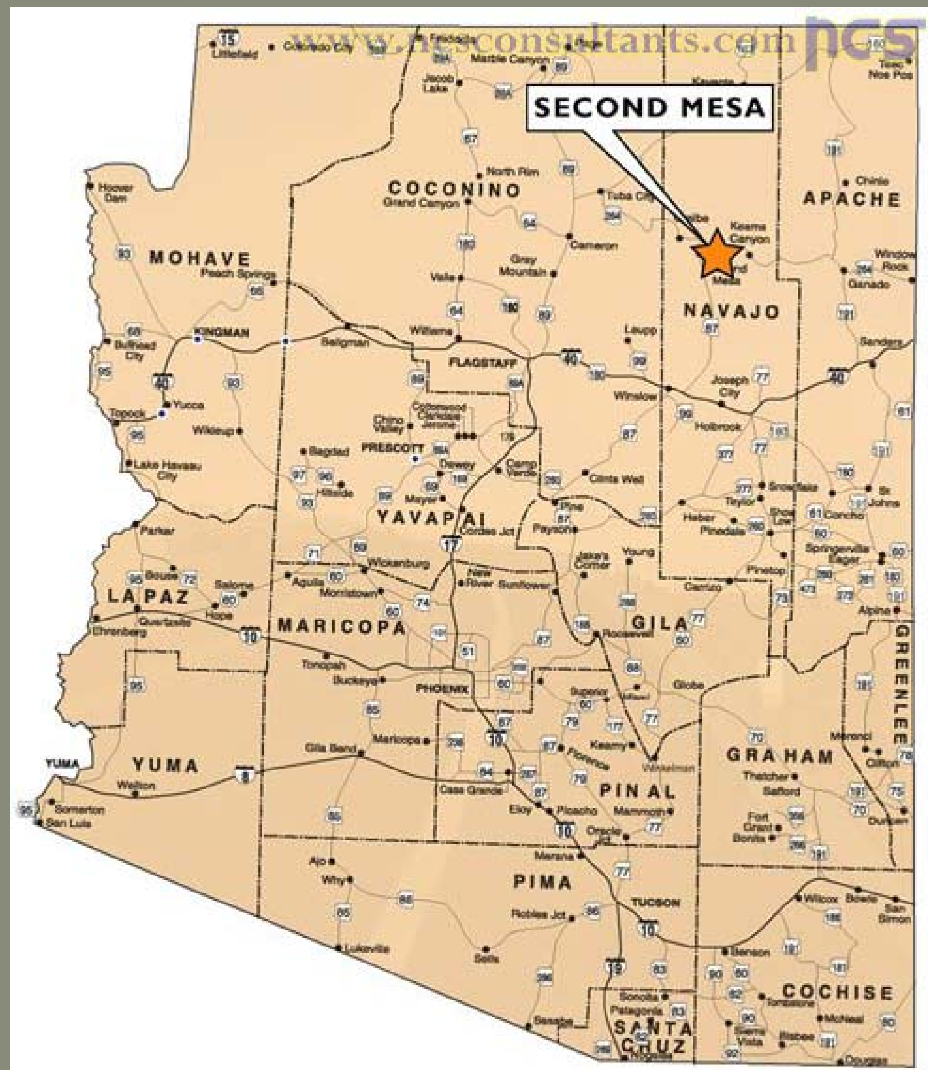
Step 1 - Soil nailing and shotcreting of existing slope and create bench for geofoam placement.



Conceptual Reconstruction of Failed Slope with EPS



Slope Remediation and Roadway Widening – 2nd Mesa Arizona



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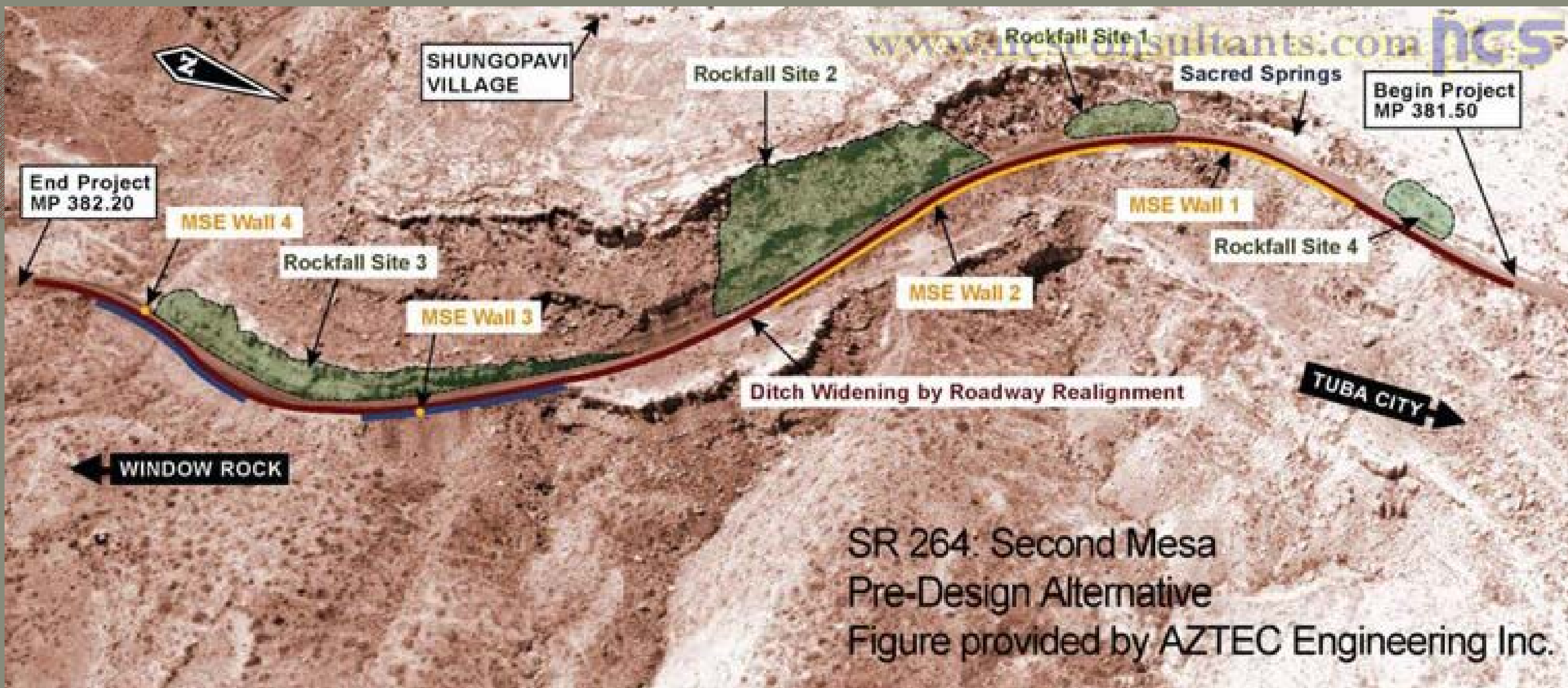
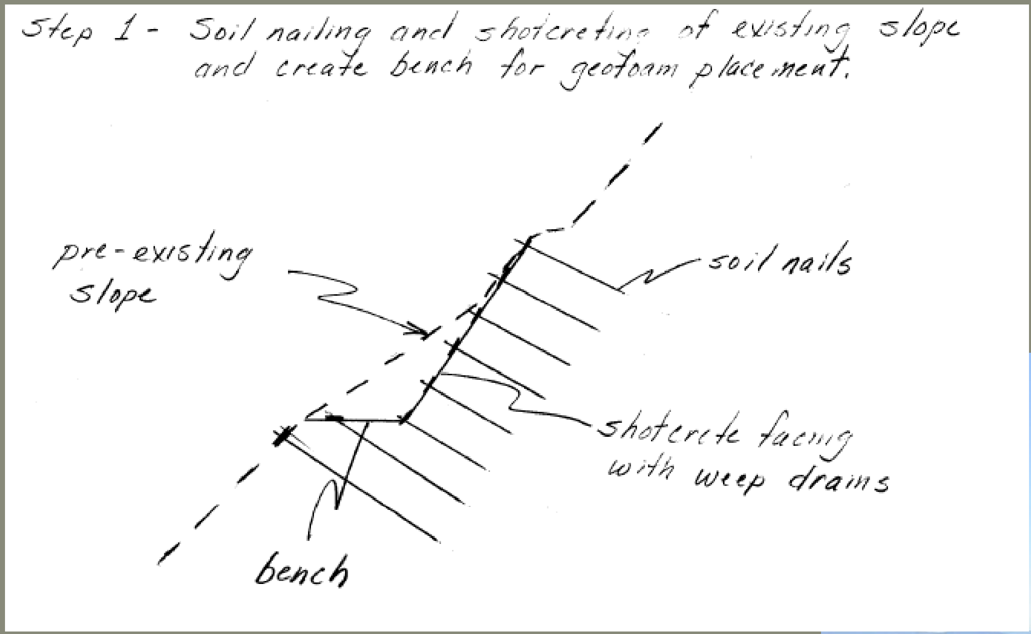
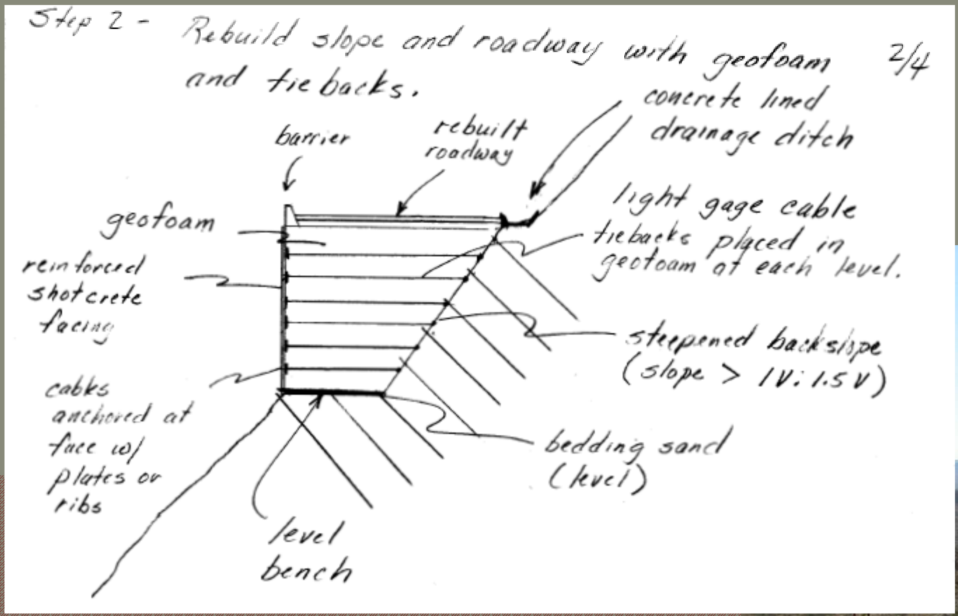
Slope Remediation and Roadway Widening – 2nd Mesa Arizona



Soil Nail Stabilization of Slope



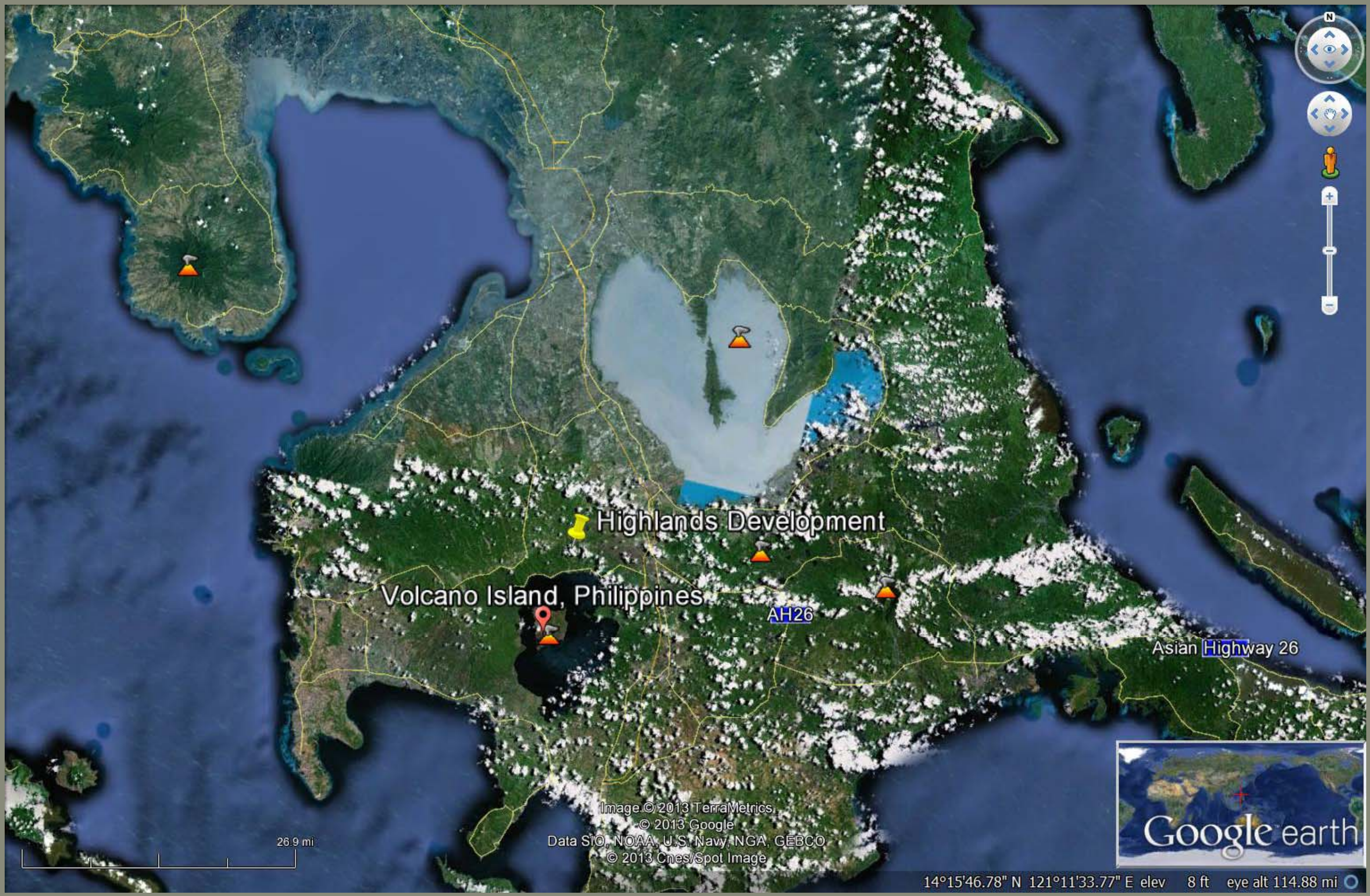
Placement of EPS



Construction of Load Distribution Slab

Finished Roadway

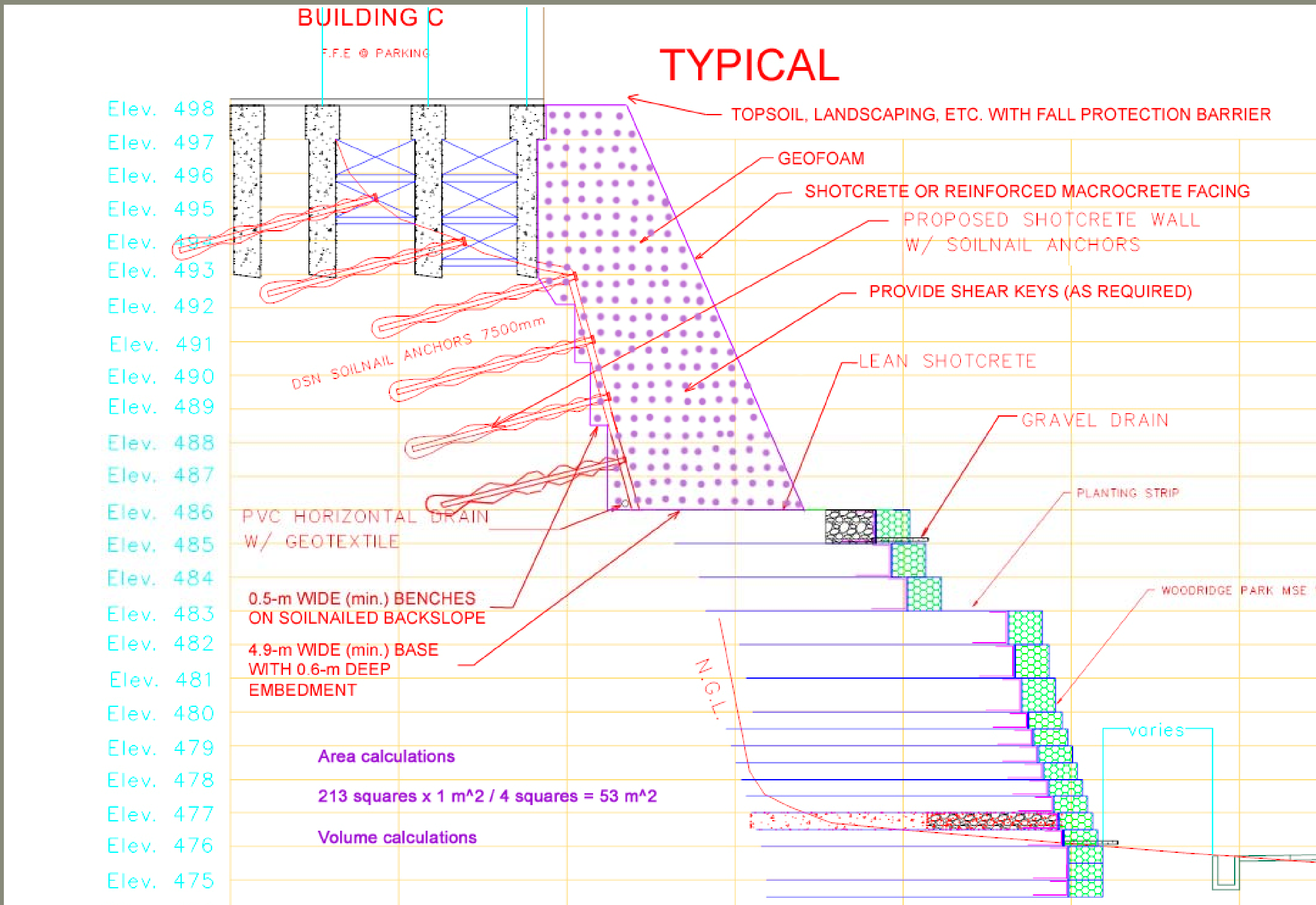
Global Stability Failure of Retaining Wall (Philippines)



Global Stability Failure (Philippines)

Global Stability Failure

Slope Remediation Design



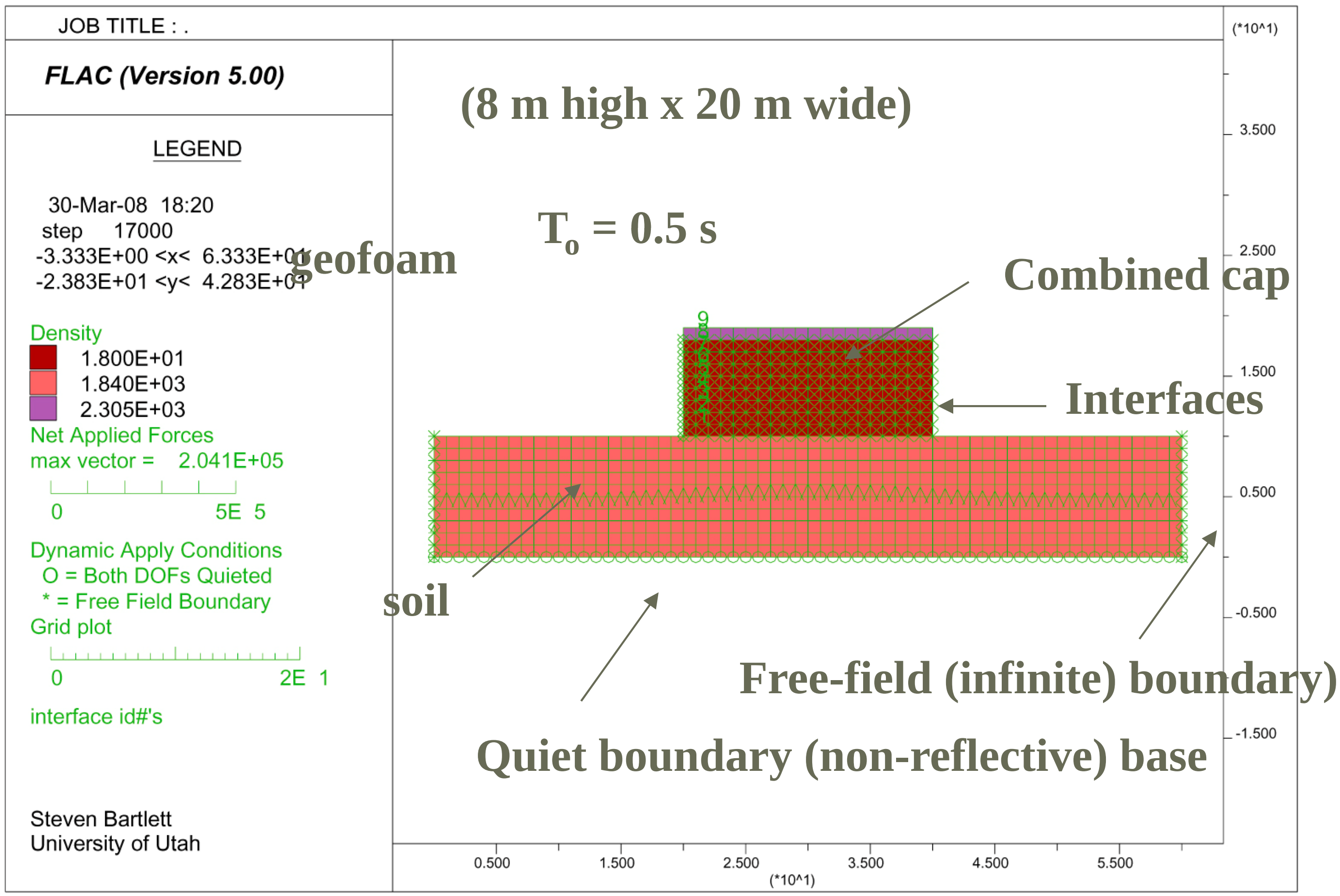
Final Slope Configuration

Seismic Evaluation of Free-Standing Embankments

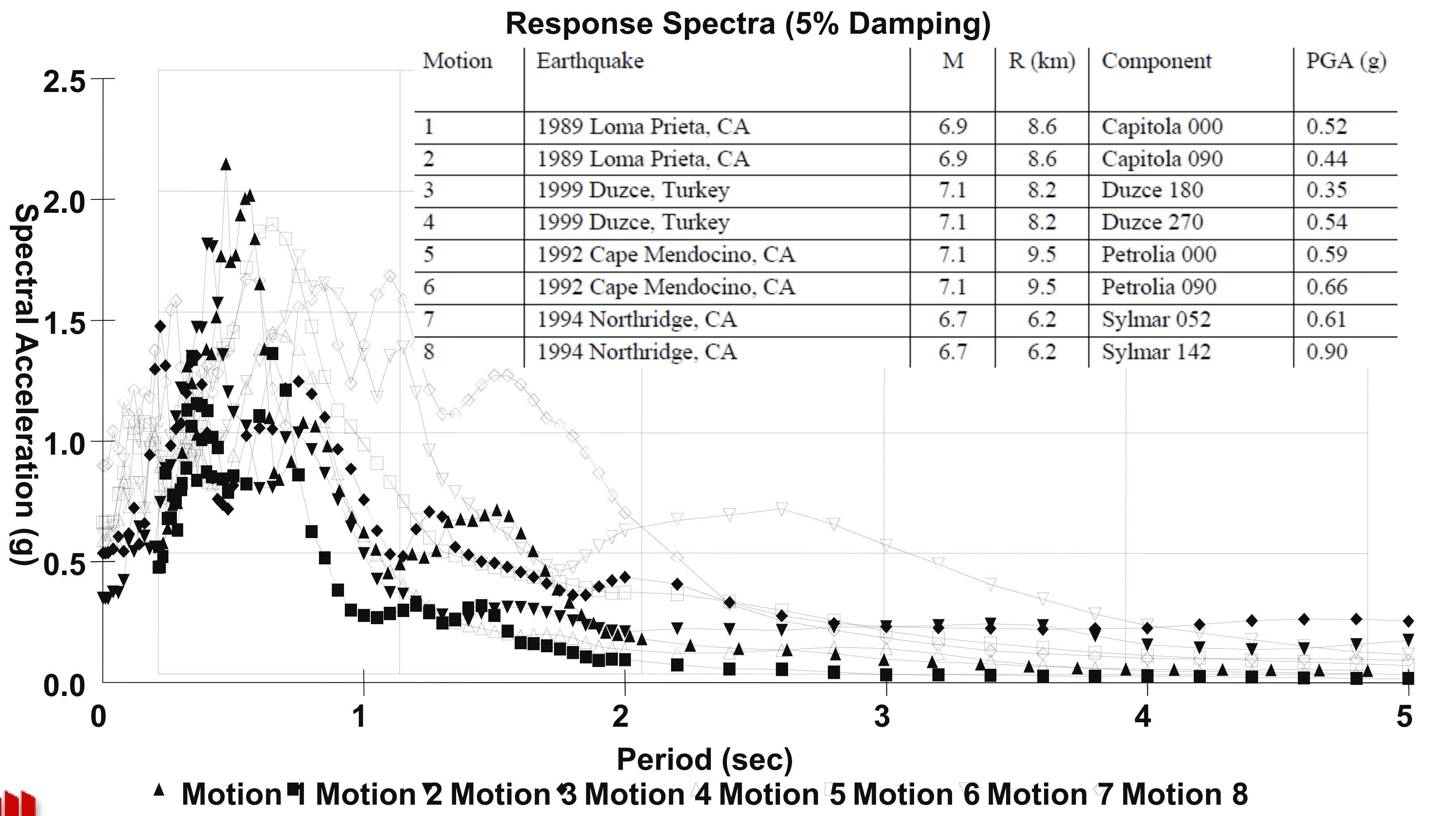
Freestanding Embankment

UTA –Light Rail – Salt Lake City, Utah

Sliding Evaluations

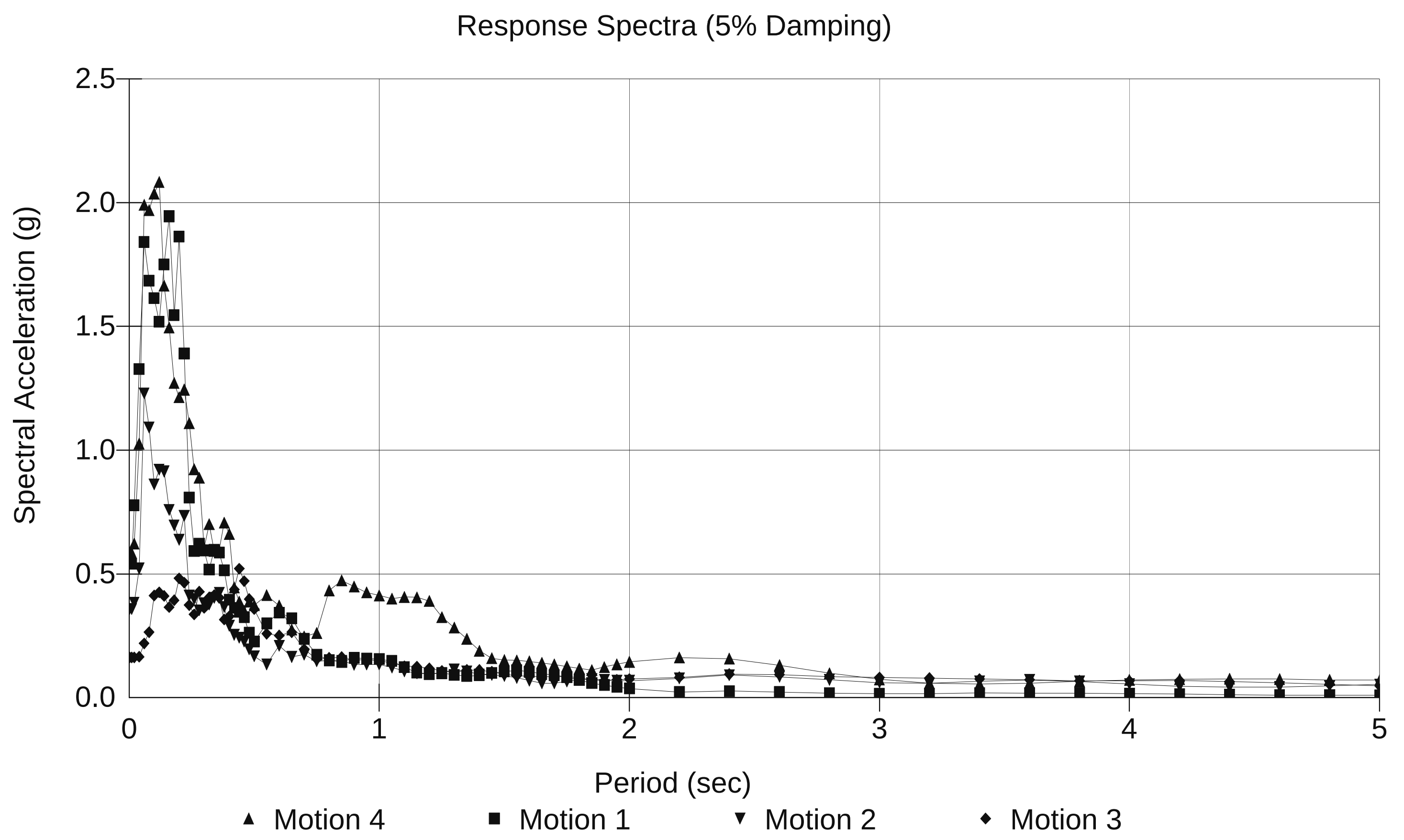


Horizontal Acceleration Response Spectra



Motion	Earthquake	M	R (km)	Component	PGA (g)
1	1989 Loma Prieta, CA	6.9	8.6	Capitola 000	0.52
2	1989 Loma Prieta, CA	6.9	8.6	Capitola 090	0.44
3	1999 Duzce, Turkey	7.1	8.2	Duzce 180	0.35
4	1999 Duzce, Turkey	7.1	8.2	Duzce 270	0.54
5	1992 Cape Mendocino, CA	7.1	9.5	Petrolia 000	0.59
6	1992 Cape Mendocino, CA	7.1	9.5	Petrolia 090	0.66
7	1994 Northridge, CA	6.7	6.2	Sylmar 052	0.61
8	1994 Northridge, CA	6.7	6.2	Sylmar 142	0.90

Vertical Acceleration Response Spectra



Elastic Properties for Sliding Evaluations

Material Type	Layer No.	ρ (kg/m³)[4]	E (MPa)[5]	ν[6]	K (MPa)[7]	G (MPa)[8]
Foundation Soil	1-10	1840	174	0.4	290.0	62.1
Geofoam	11-18	18	10	0.103	4.2	4.5
UTBC[1]	19	2241	570	0.35	633	211
LDS[2] & PCCP[3]	19	2401	30000	0.18	15625	12712

[1] Untreated base course, [2] Load distribution slab, [3] Portland concrete cement pavement, [4] Mass density, [5] Initial Young's modulus, [6] Poisson's ratio, [7] Bulk modulus, [8] Shear modulus

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Interface Properties for Sliding Evaluations

Contact Surface	Interface number (bottom to top)	Normal and Shear Stiffness ($k_n = k_s$) (MPa)	Friction angle (degrees)
Geofoam-soil	1	102	31[1]
Geofoam-Geofoam	2-8	102	38
Geofoam-Lump Mass	9	102	38[2]

[1] A glued interface was used for interface 1 in FLAC because the geofoam is abutted against the panel wall footing and cannot slide. [2] Neglects any tensile or shear bonding that may develop between the top of geofoam and base of the load distribution slab.

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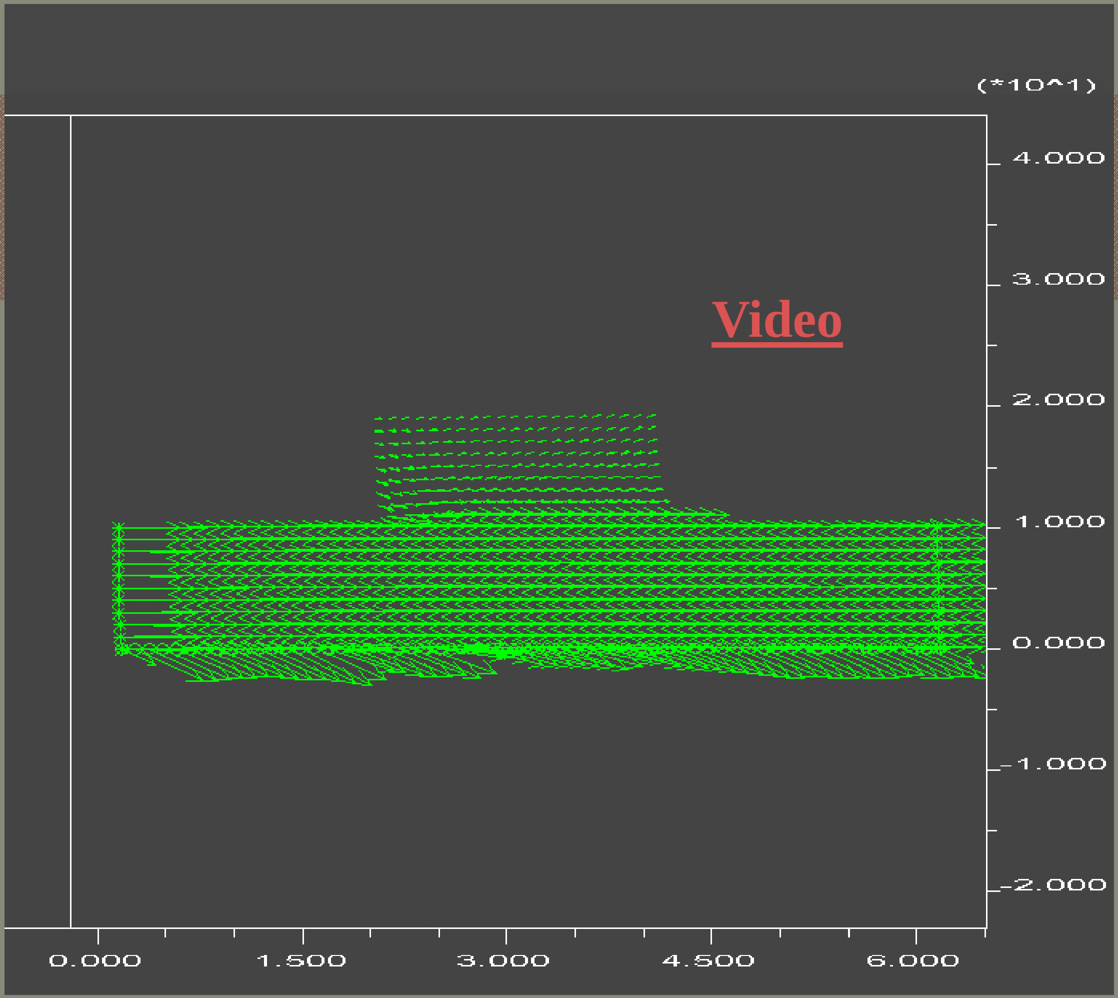
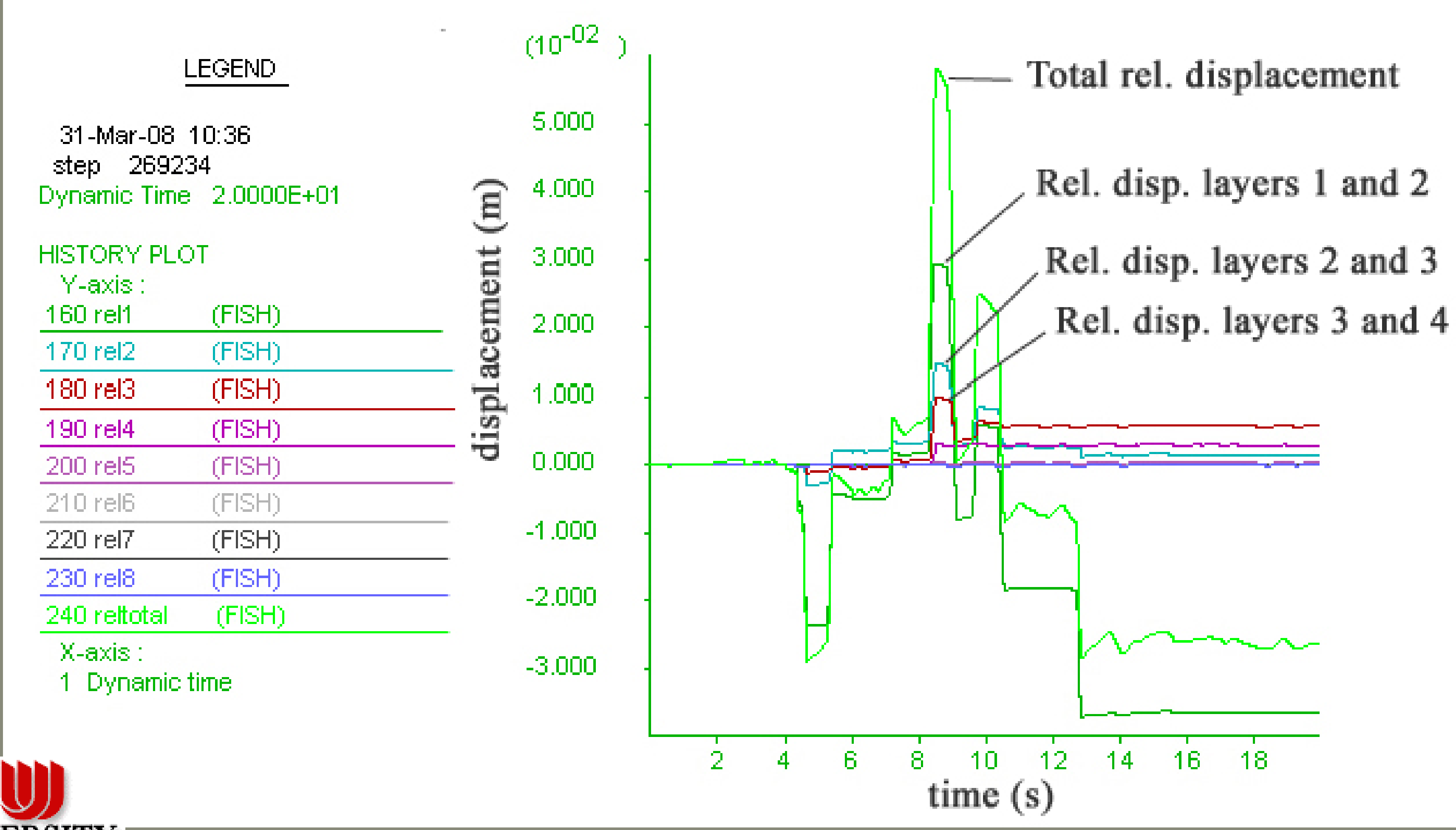
Displacement Vectors from FLAC



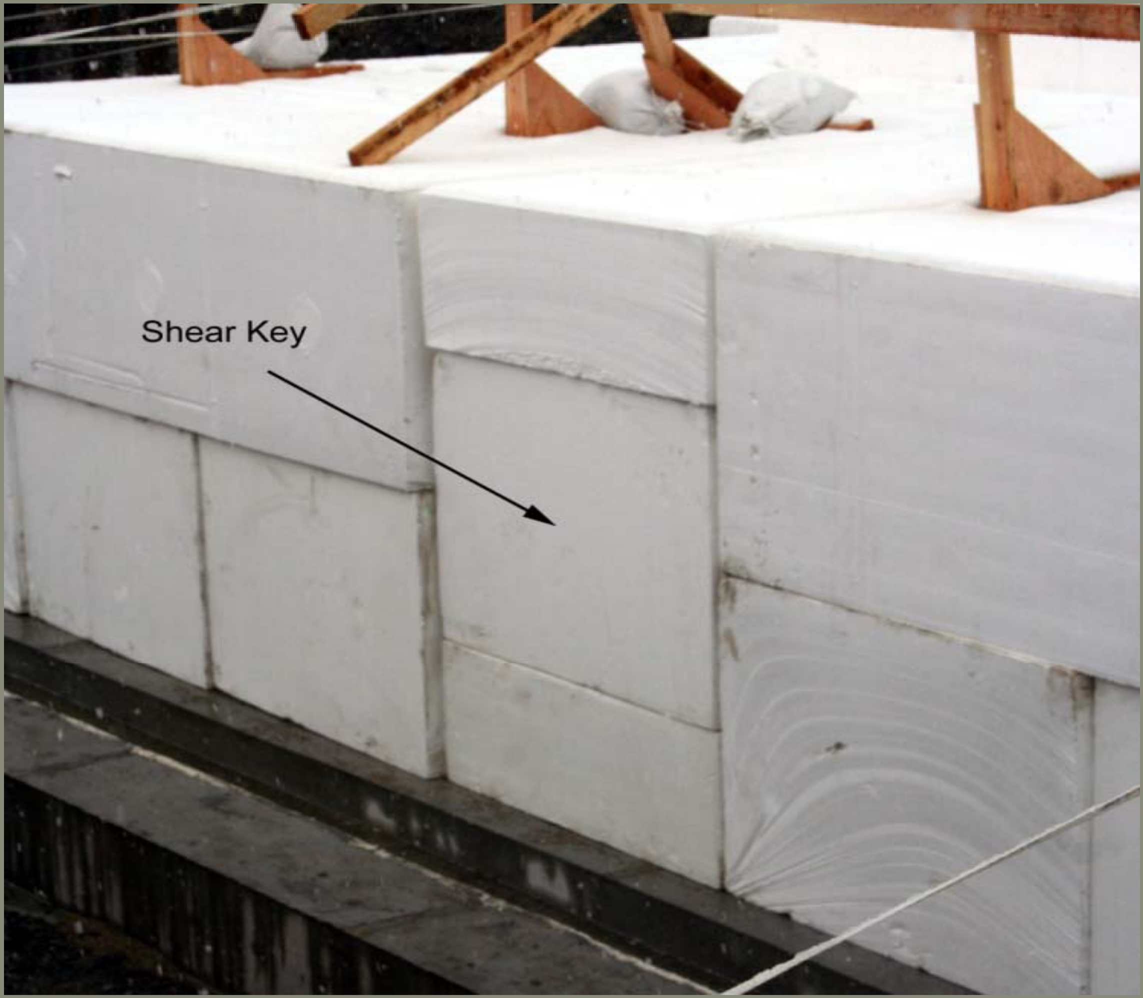
Relative and Total Sliding Displacement



Sliding Displacement Summary

Case	Horizontal Motion	Vertical Motion	Displacement (m)
1a	1	Not applied	0.06
1b	1	1	0.06
2a	2	Not applied	0.01
2b	2	1	0.05
3a	3	Not applied	0.06
3b	3	2	0.06
4a	4	Not applied	1.3
4b	4	2	1.3
5a	5	Not applied	0.005
5b	5	3	0.01
6a	6	Not applied	0.05
6b	6	3	0.06
7a	7	Not applied	0.5
7b	7	4	0.6
8a	8	Not applied	0.6
8b	8	4	0.5

Shear Keys to Prevent Sliding



Conclusions

- Light weight EPS cover systems can be effective in preventing rupture of steel-pipelines undergoing vertical offset from permanent ground displacement.
- Preliminary modeling results suggest that static and seismic earth pressures can be reduced significantly using EPS placed against buried structures.
- Because of its light-weight nature, EPS geofoam offers significant benefits in slope reconstruction .
- Large, free-standing EPS embankments are generally stable for earthquakes, but overall stability can be improved by including shear keys, adhesives or other mechanical or structure countermeasures.

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Questions ?