EPS Geofoam Seismic Applications

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Topics

- Introduction to EPS Guidance Documents
- Seismic Evaluations of Free-standing EPS Embankment
- Protection of Buried Pipelines from Permanent Ground Displacement
- Reduction of Static and Seismic Earth Pressures Against Buried Structures and Facilities

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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

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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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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

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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 seismic loads to wall & 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

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Beginnings of Geofoam

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

Flom Bridge – 1972 - Norway

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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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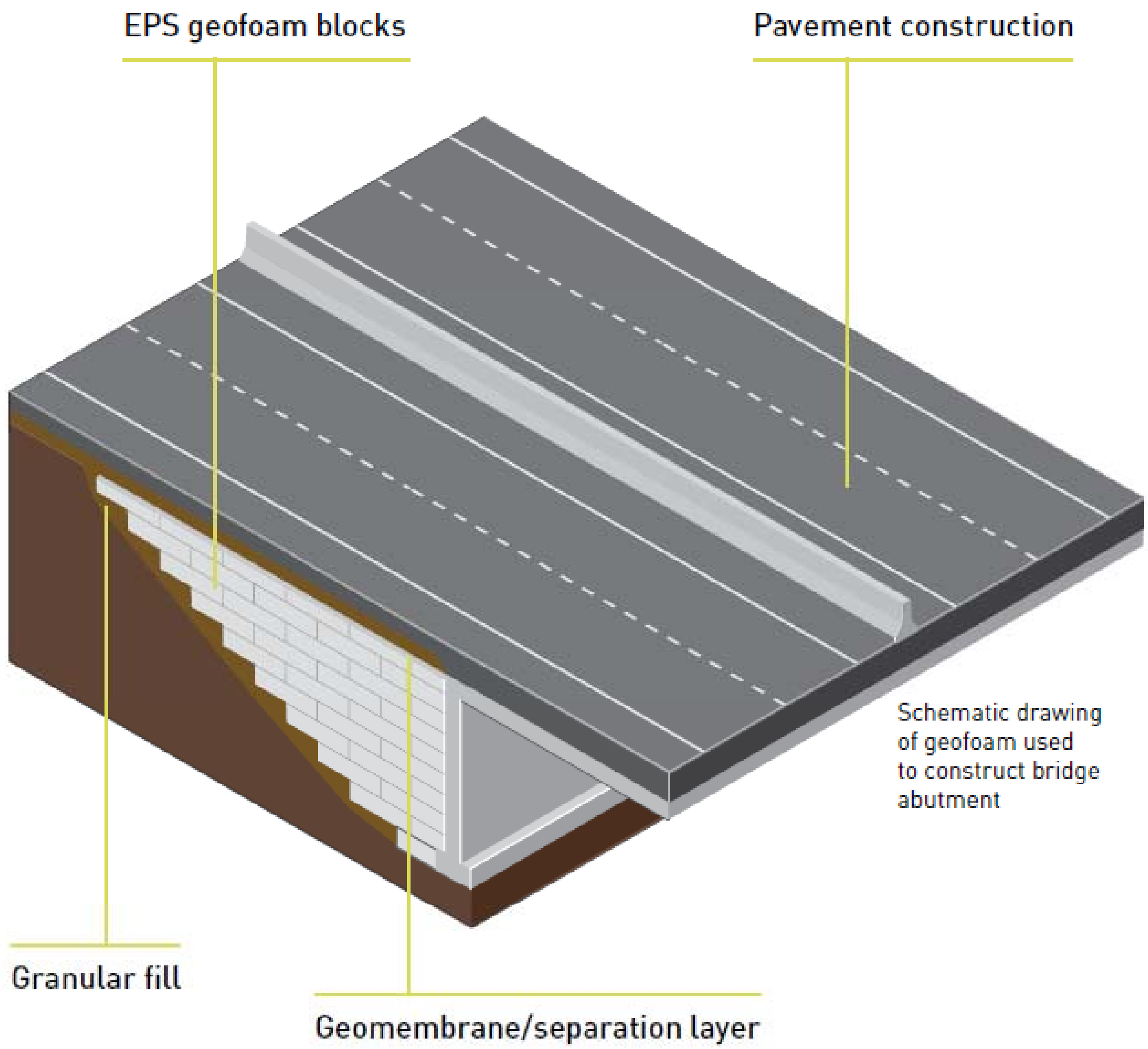
Bridge Abutment



Schematic drawing of geofoam used to construct bridge abutment

Geofoam Embankments

Freestanding Embankment

Sloped Embankment

UTA –Light Rail – Salt Lake City, Utah

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Typical Construction at Bridge Abutments

Details of Geofoam Construction at Bridge Abutments

Seismic Stability Considerations

- Primary Modes
  - Sliding
  - Rocking
  - Bearing Capacity?
  - Overturning?

- Analysis
  - Sliding
    - Interlayer sliding
    - Basal sliding
    - Sliding of the cap
  - Rocking and Sway
    - Compressional yielding at basal corner
    - Tensile failure with the geofoam mass

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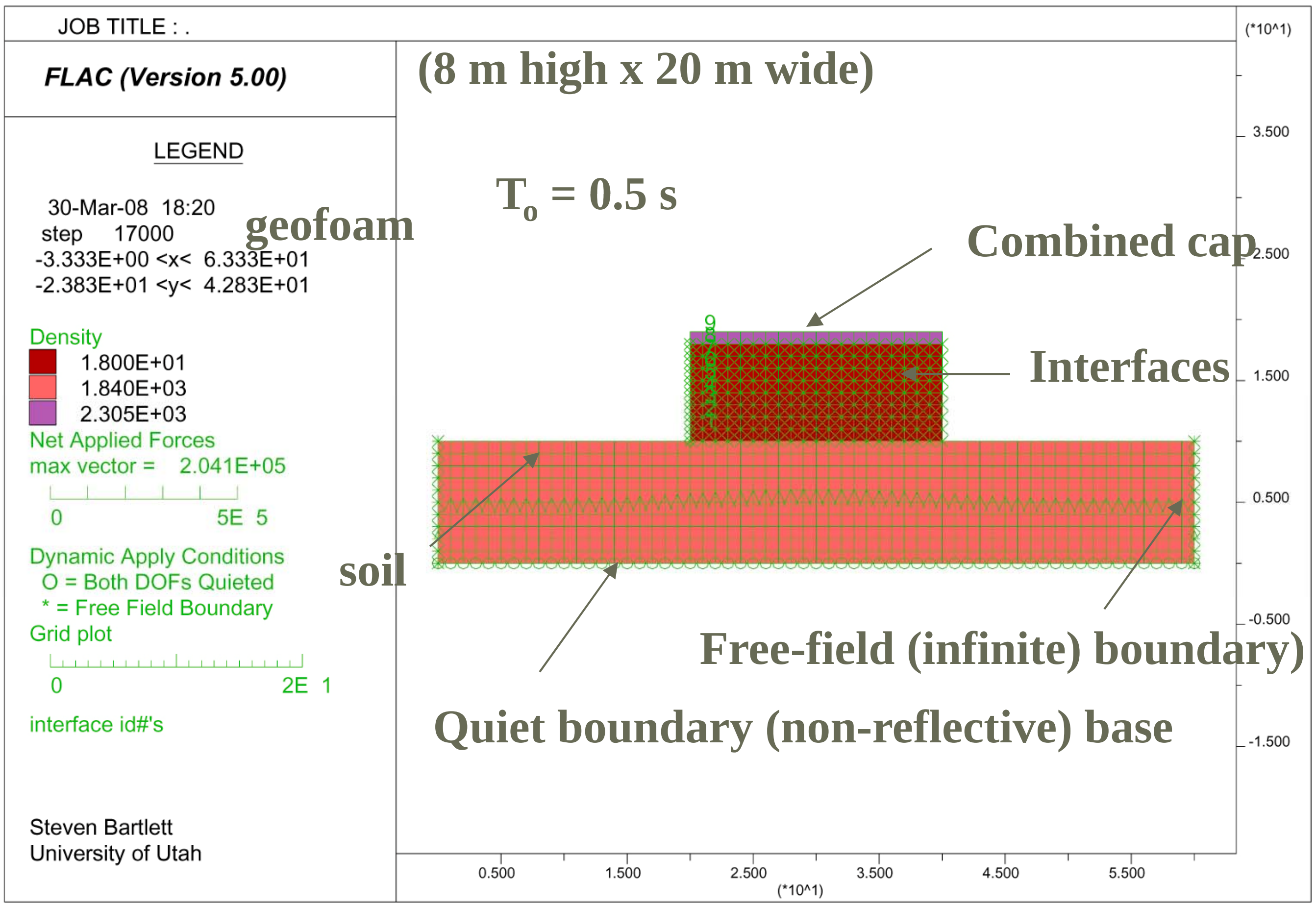
Numerical Modeling Approach

- FLAC (Fast Lagrangian Analysis of Continua)
  - 2D
  - Large Strain Mode
    - Friction contact between EPS layers
    - Sliding and Separation at Nodal Interfaces
  - Nonlinear Modeling capability
    - Elasto-Plastic Model w/ Mohr-Coulomb Failure Criteria and Plastic Post-Yield Behavior
    - Hysteretic damping for EPS in some models

Sliding Evaluations



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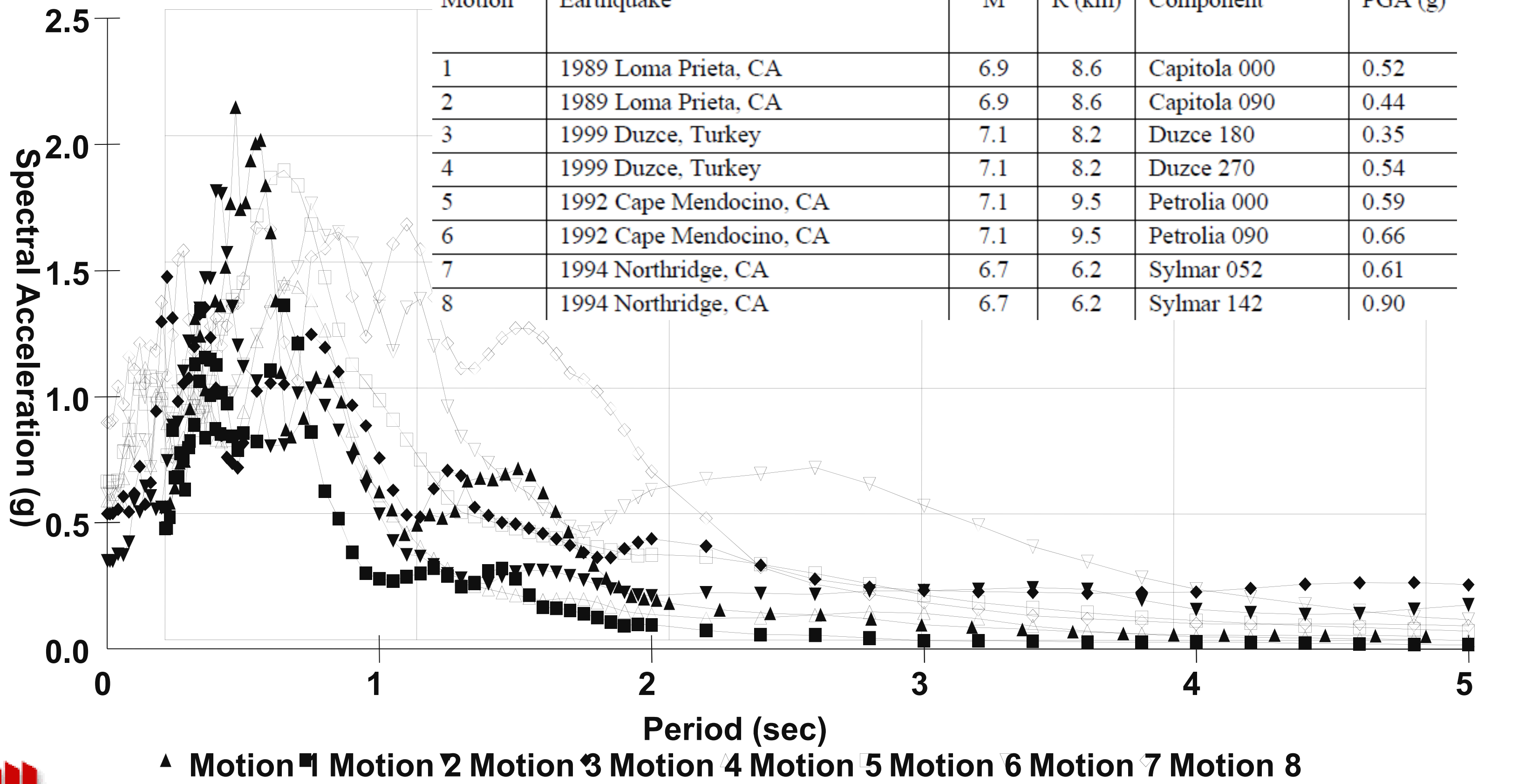
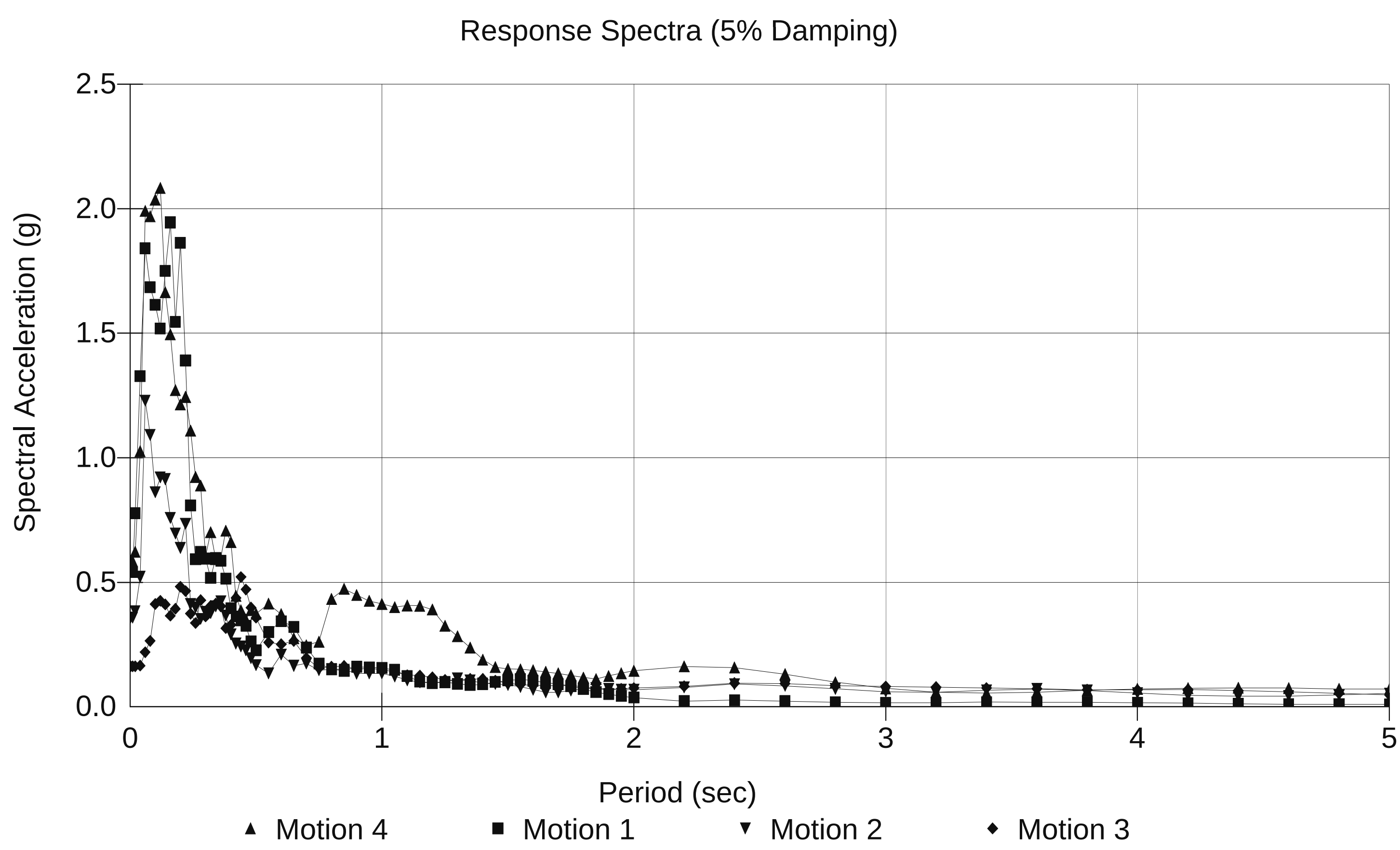
Horizontal Acceleration Response Spectra

Response Spectra (5% Damping)

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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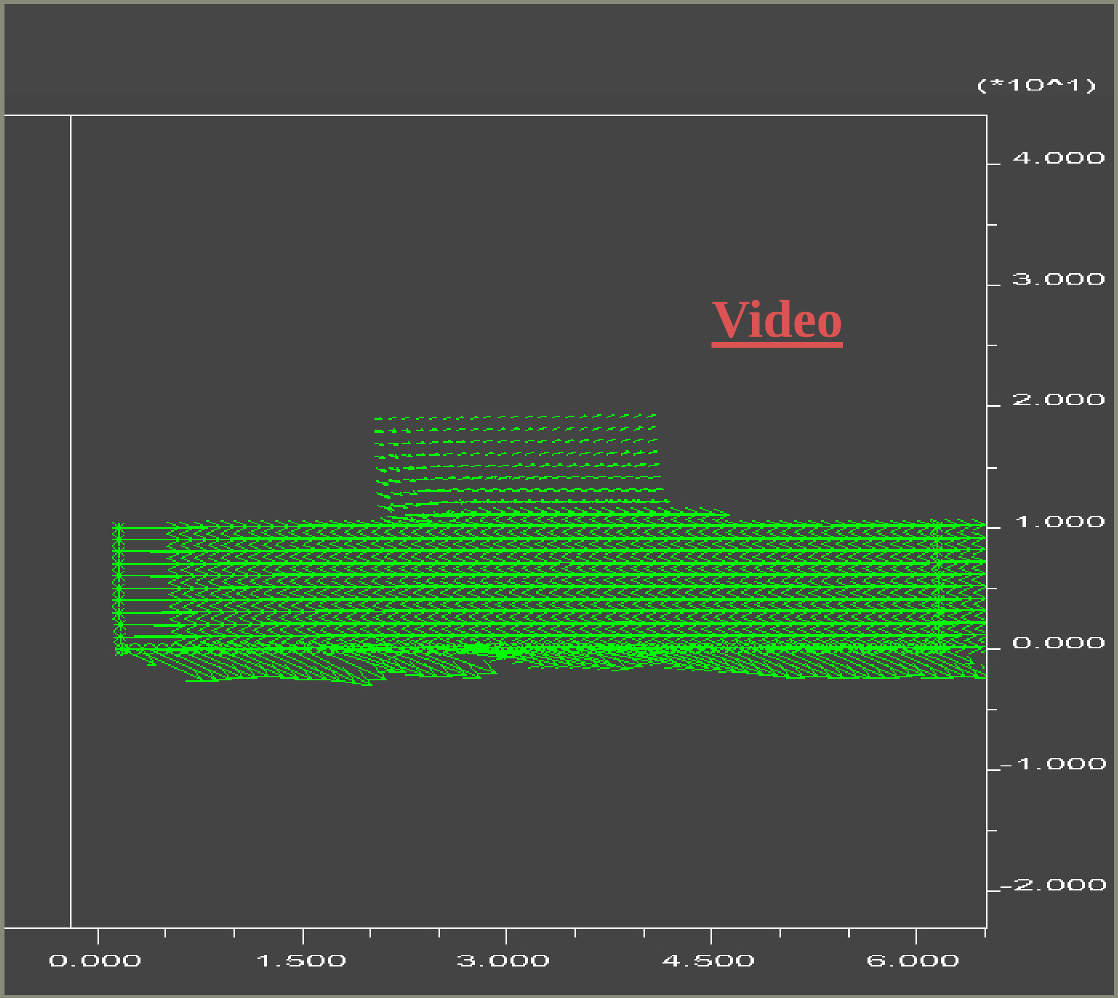
Interface Properties for Sliding Evaluations

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]

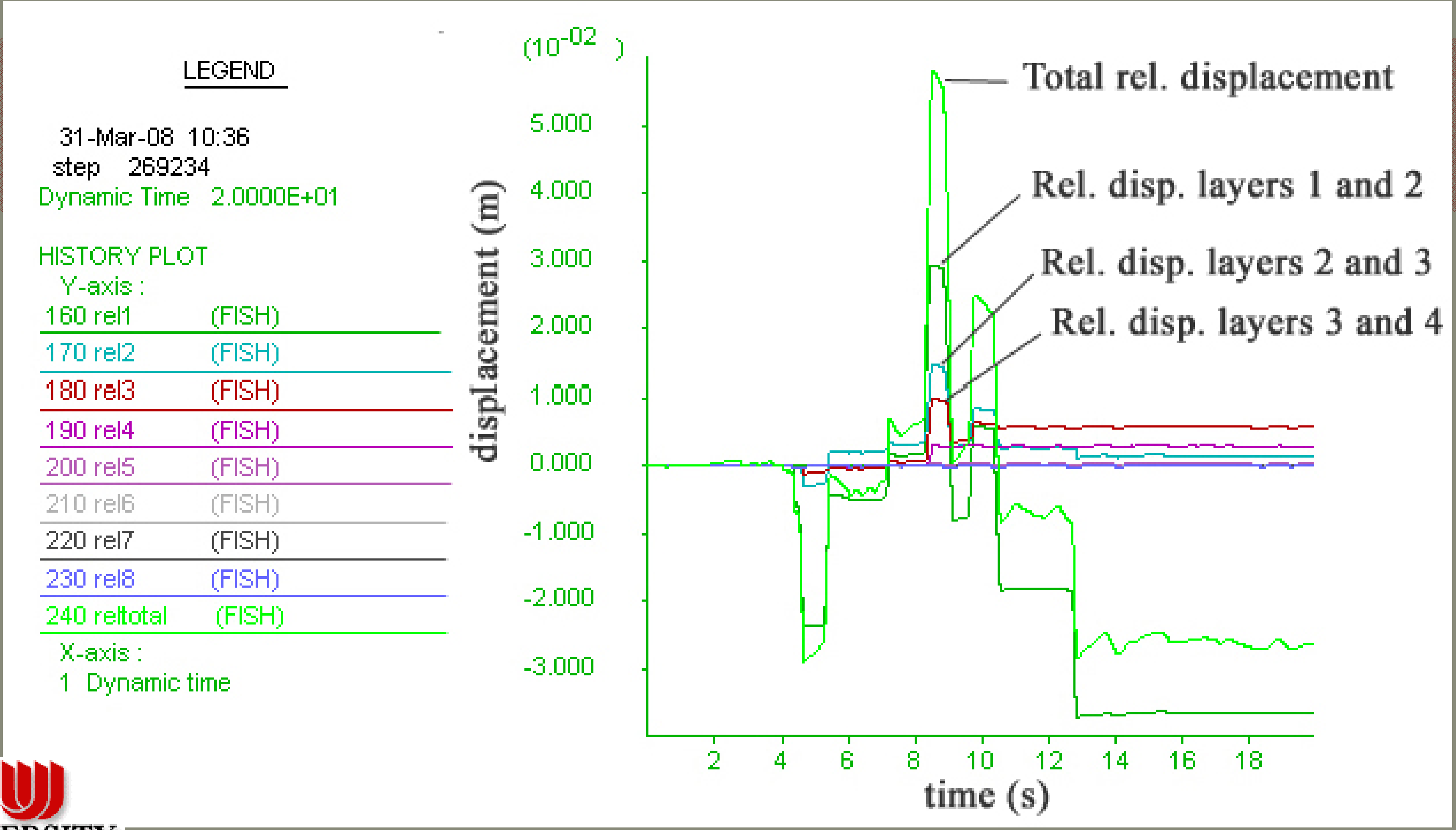
[1] A glued interface was used for interface 1 in FLAC because the geofoam is abutted against the panel wall footing and cannot slide. [2] Neglects any tensile or shear bonding that may develop between the top of geofoam and base of the load distribution slab.

Displacement Vectors from FLAC



Video

Relative and Total Sliding Displacement



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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

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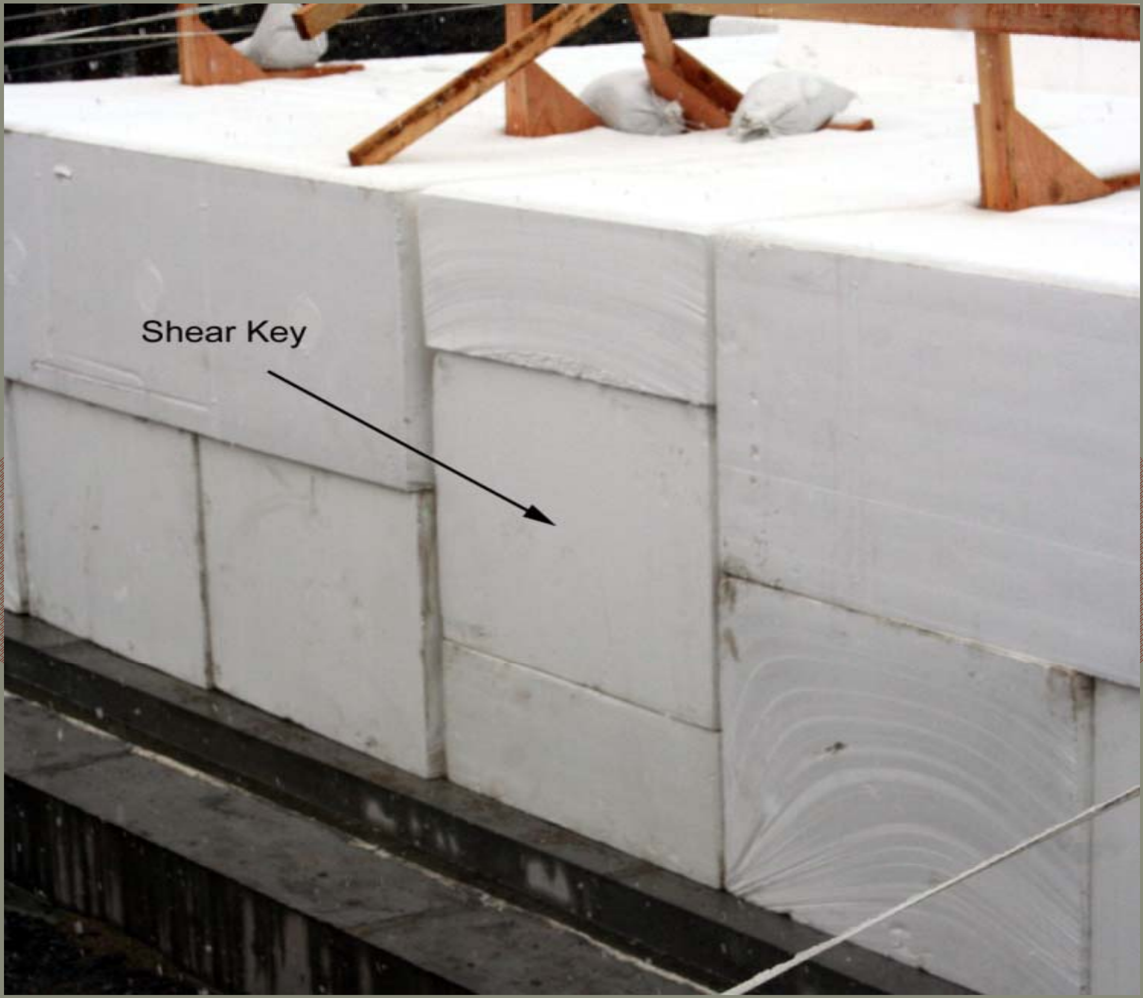
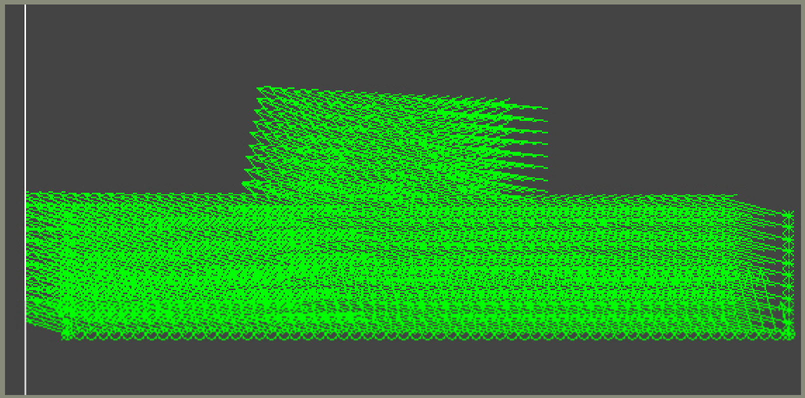
Shear Keys to Prevent Sliding



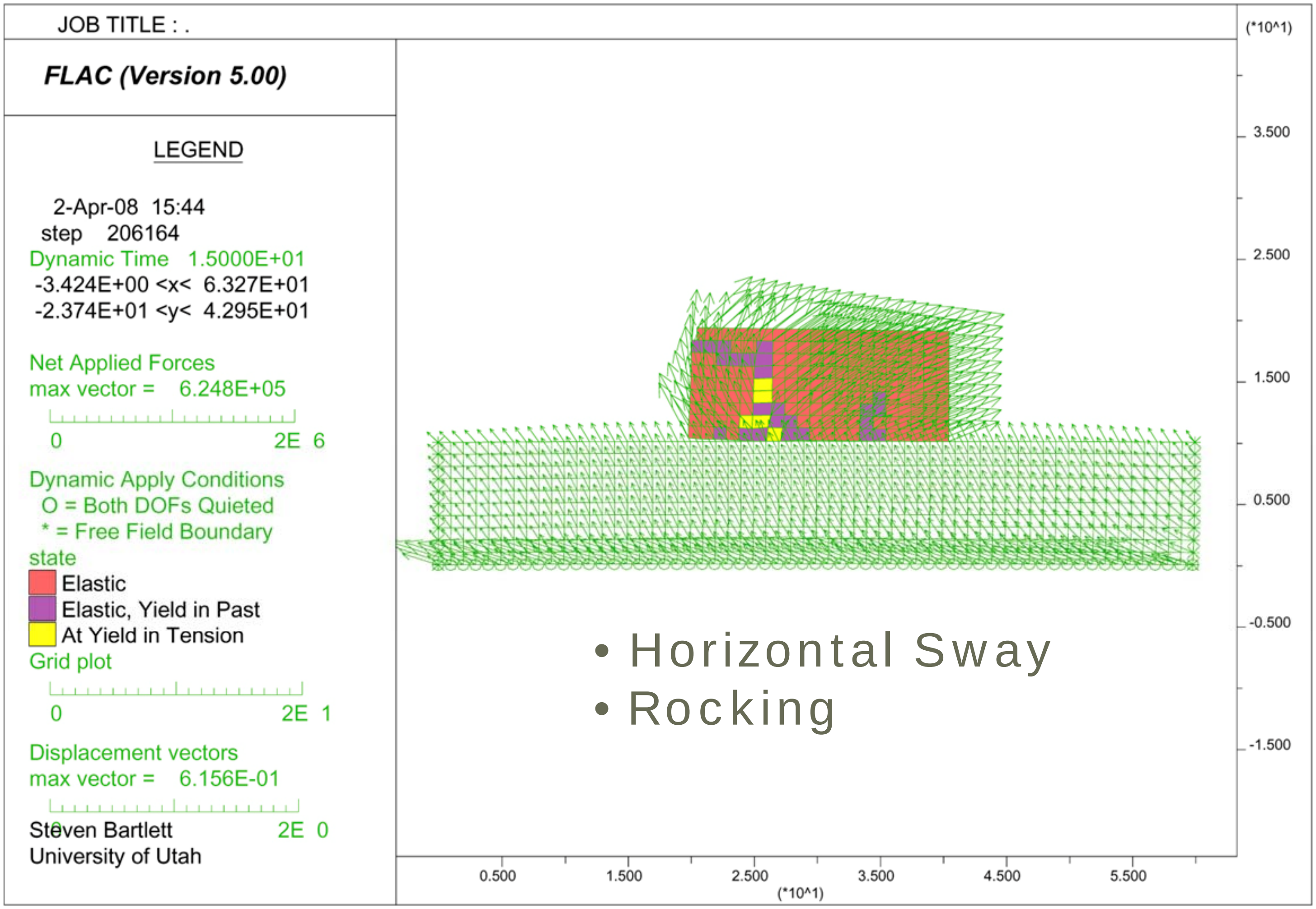
Rocking/Uplift and Sway Evaluations



Model Modifications

- **interface nodes removed (no sliding between layers)**
- **overlying concrete was “bonded” to geofoam**
- **basal sliding prohibited**
- **M-C model with hysteretic damping including tensile, compression and shear properties specified**
- **both vertical and horizontal component present**

Seismic Behavior Modes



- Horizontal Sway
- Rocking

Rocking and Uplift Results

Case	Max. uplift (left corner) (m)	Max. uplift (right corner) (m)
1b	0.06	0.05
2b	0.02	0.04
3b	0.2	0.2
4b	0.2	? rotation due to tensile yielding
5b	0.01	0.01
6b	0.03	0.03
7b	? rotation due to tensile yielding	0.2
8b	0.25	0.25

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Rocking and Horizontal Sway Results

Case	Local Yielding of Block	Bond broken between geofoam and LDS[1]
1b	No	No
2b	No	No
3b	Yes (some blocks in basal layer and 1 block under LDS)	Yes
4b	Yes (some blocks in basal layers; tensile yielding developing)	Yes
5b	No	No
6b	No	No
7b	Yes (some blocks in basal layers; tensile yielding developing)	Yes
8b	Yes (some blocks in basal layer)	No

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Fault-Induced Pipeline Rupture

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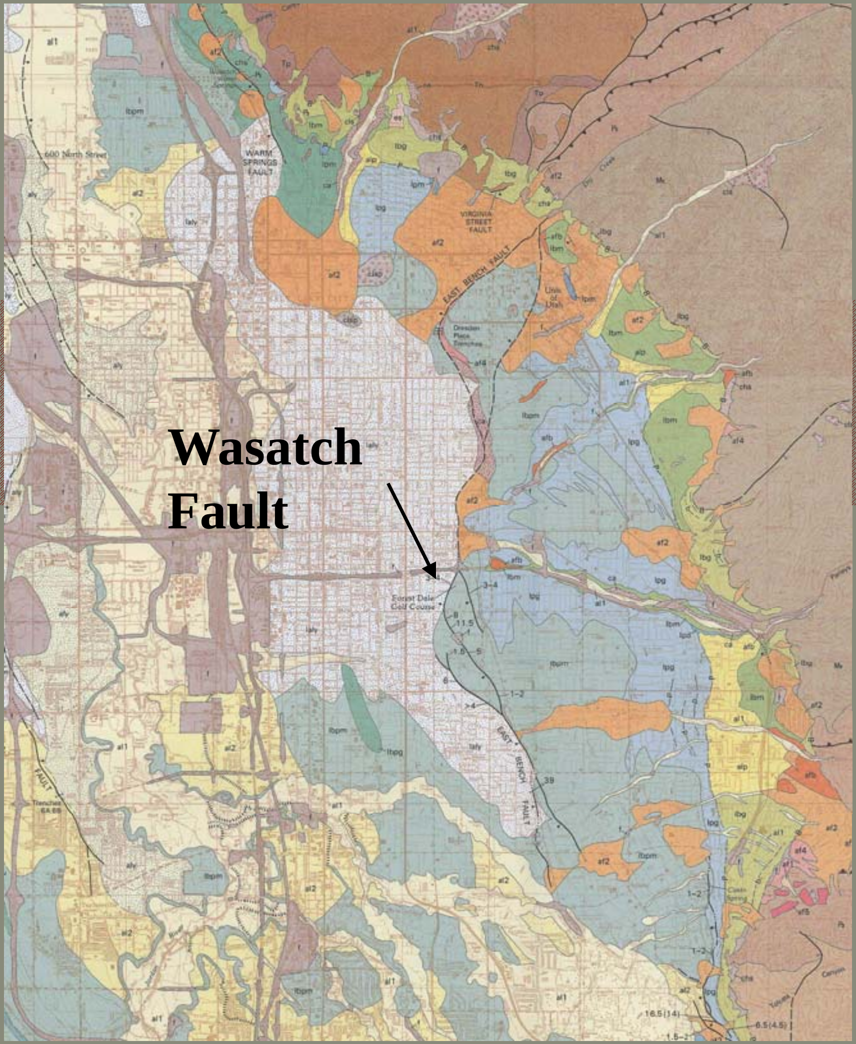
Wasatch Fault – Salt Lake Valley

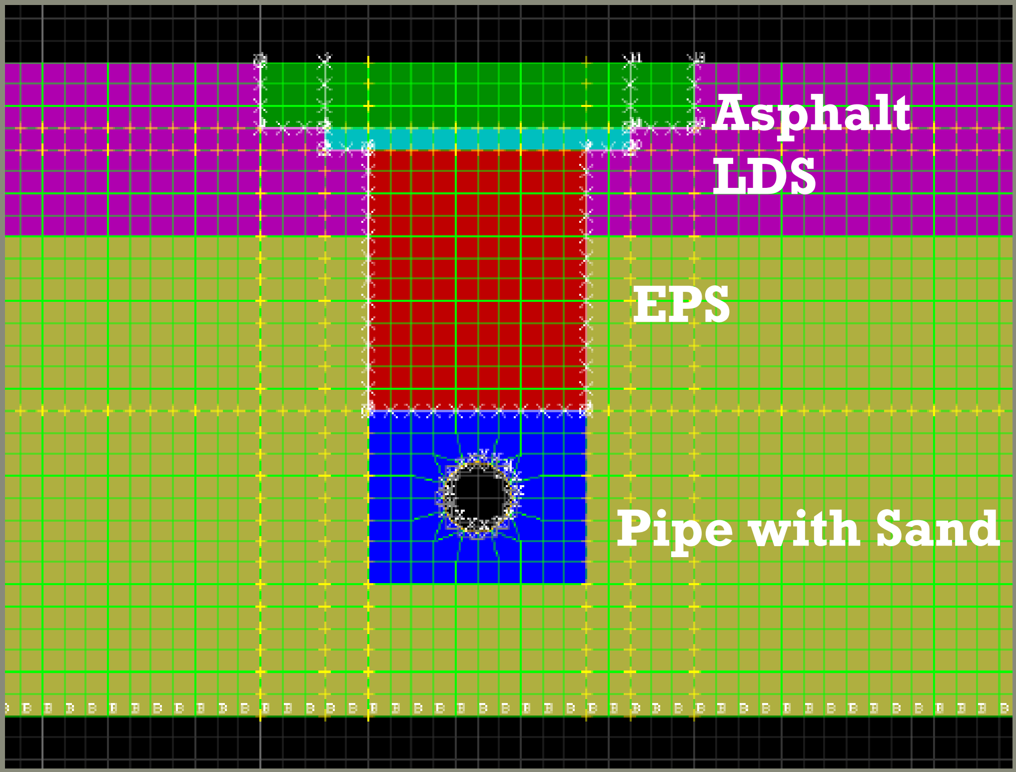


Wasatch Fault at Little Cottonwood Canyon

Pipelines (Light-weight Cover Over Faults)

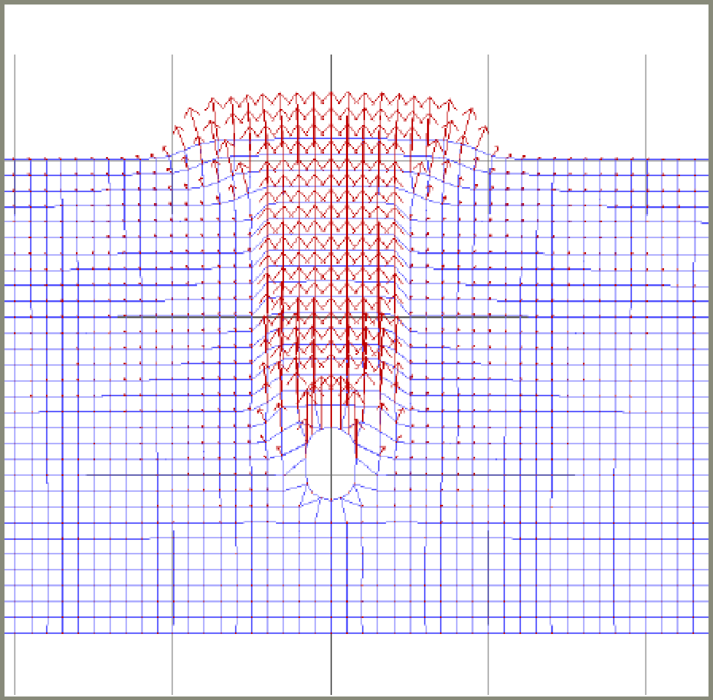
Shallow Burial – Normal Faulting

Pipelines (Light-weight Cover Over Faults)



Lightweight-Cover System

Video



Displacement Vectors During Failure

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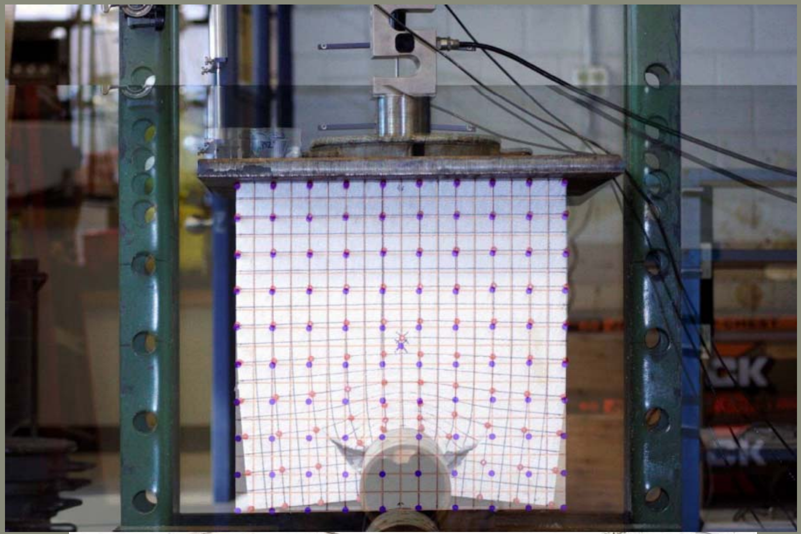
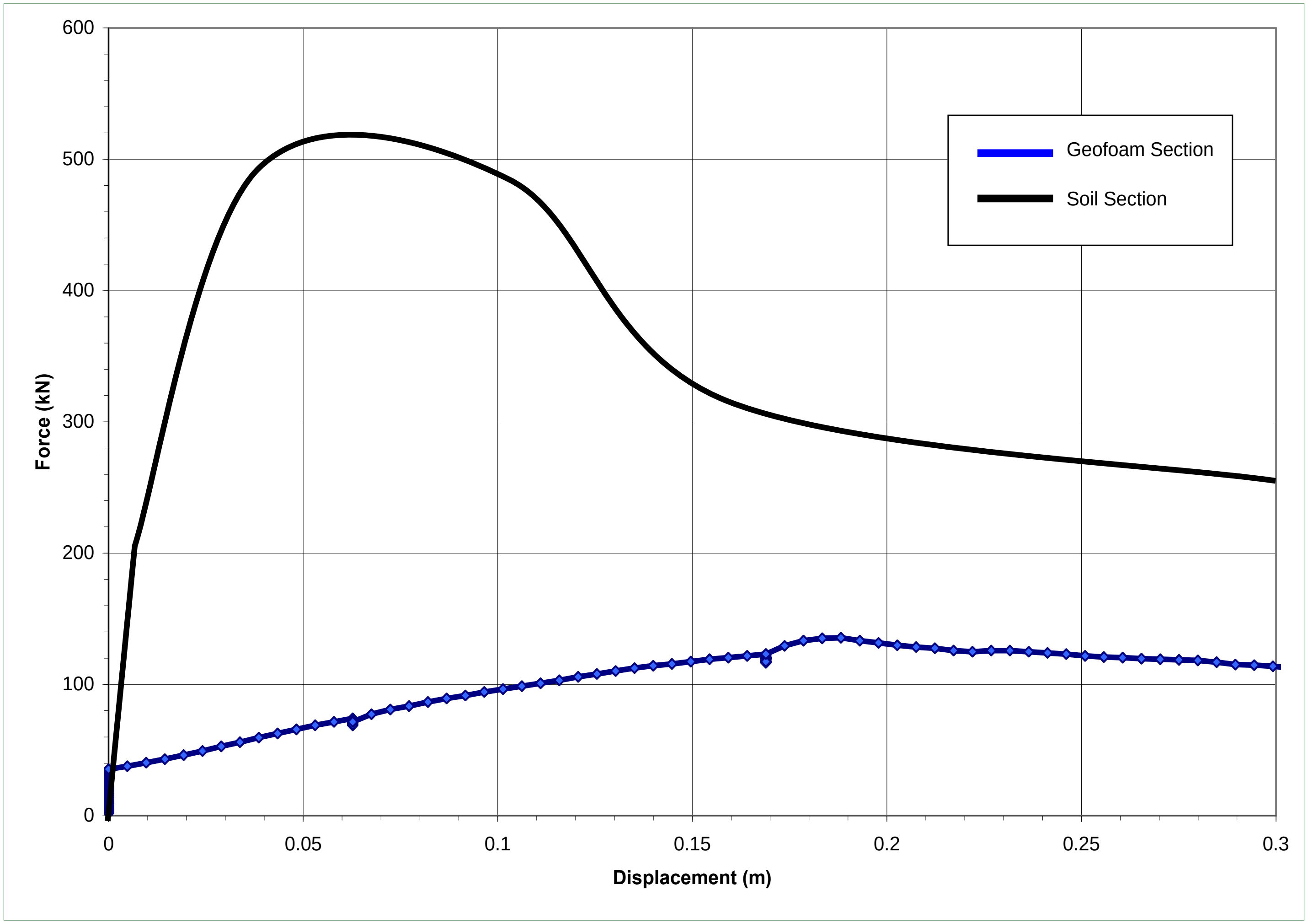
Uplift Tests



Force-Displacement Curves from Uplift Tests

Uplift Force (kN)



Vertical Displacement (m)

Pipelines (Light-weight Cover Over Faults)

Questar Gas Line
3500 South Street
Salt Lake City, Ut

Pipelines (Light-weight Cover Over Faults)

Alaskan Pipeline – Strike Slip Fault

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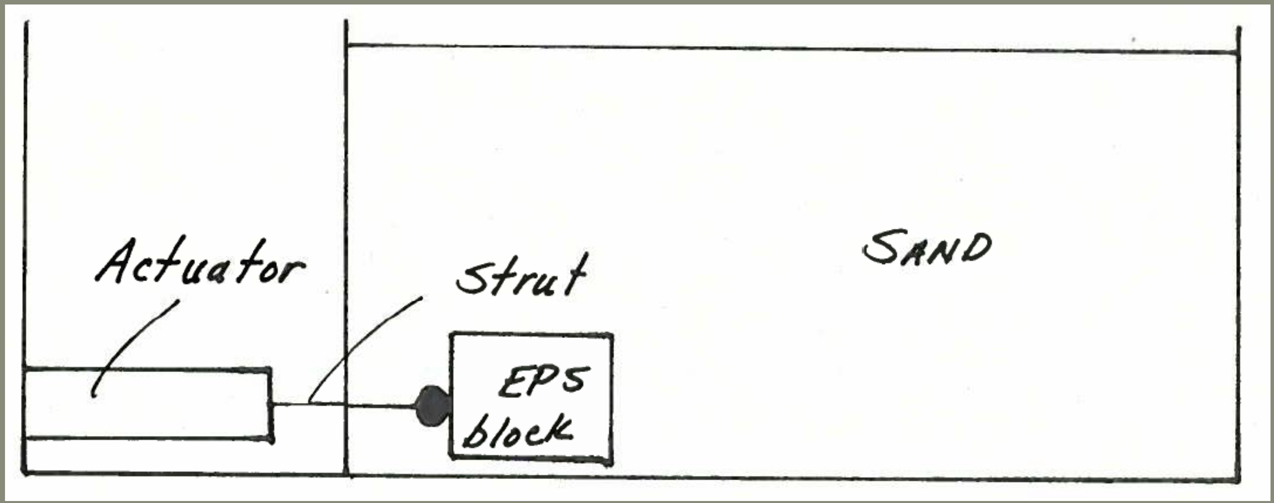
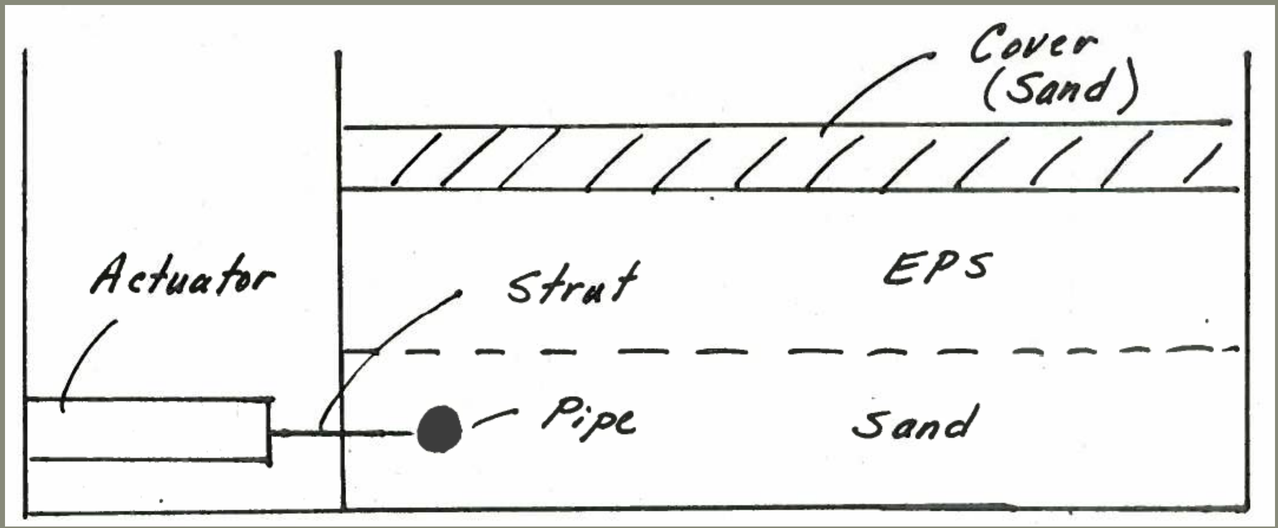
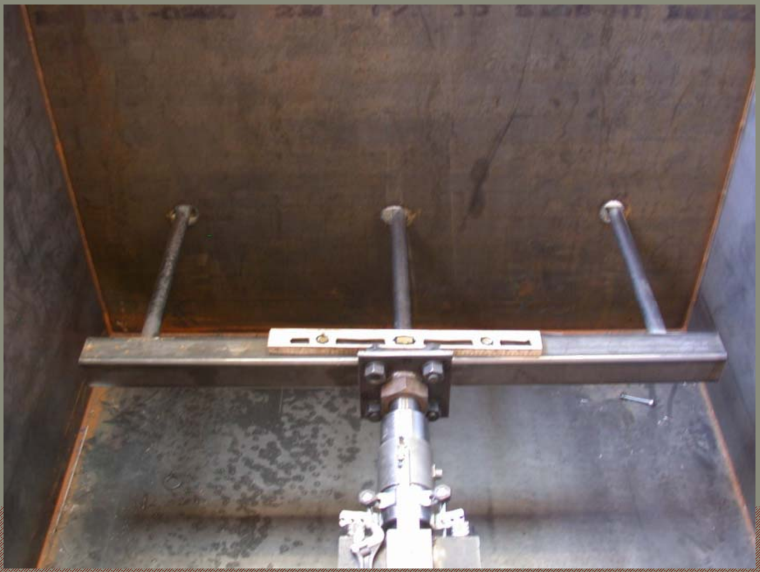
Horizontal Offset from Permanent Ground Displacement





Horizontal Offset from Permanent Ground Displacement



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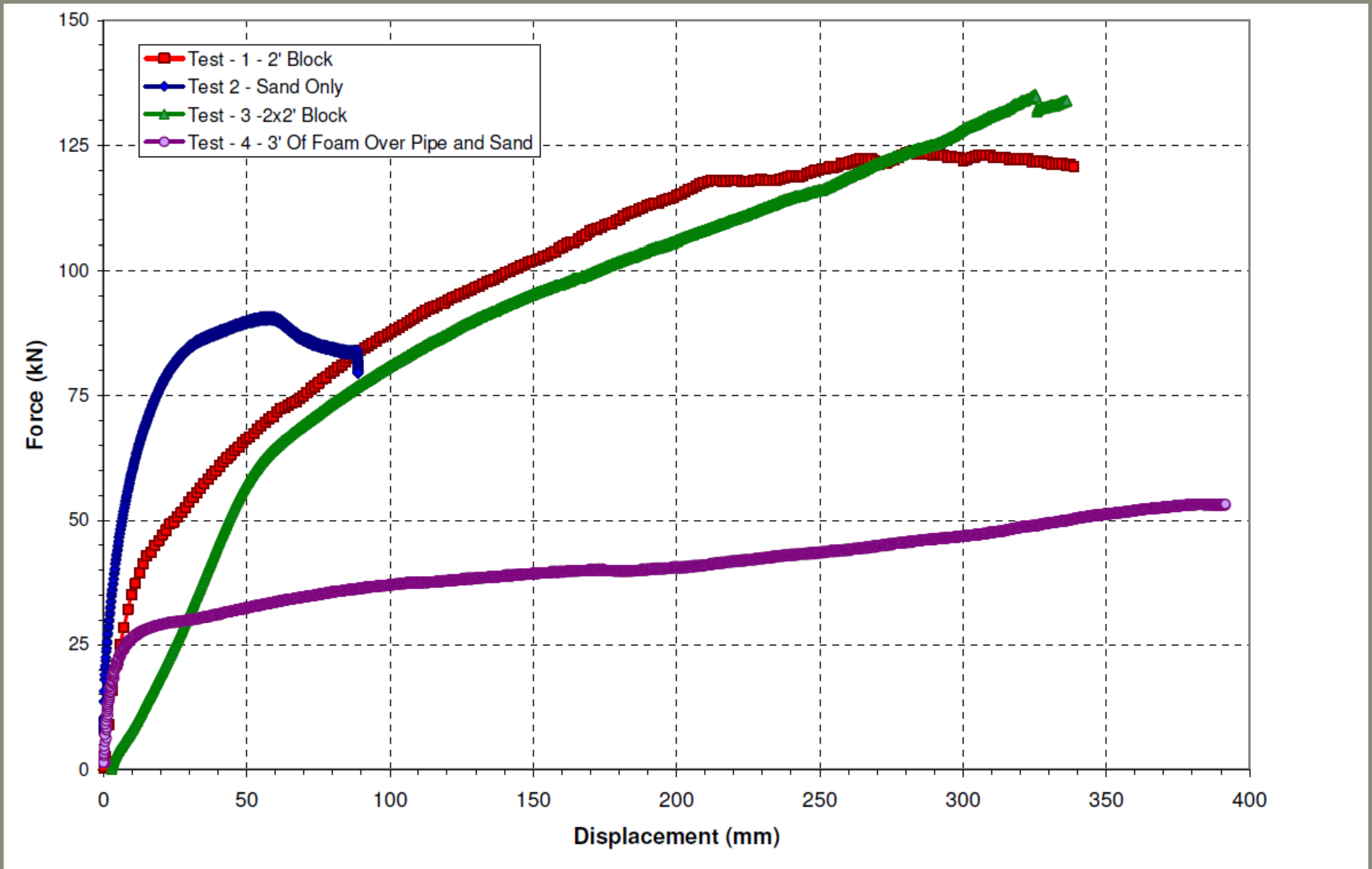
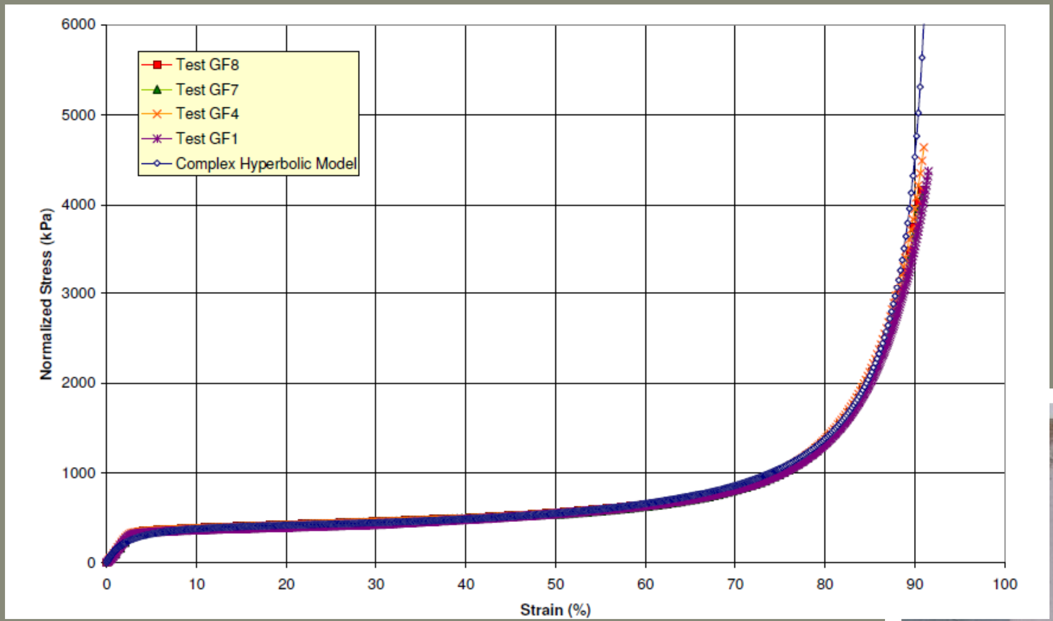
Horizontal Offset from Permanent Ground Displacement



Horizontal Offset from Permanent Ground Displacement



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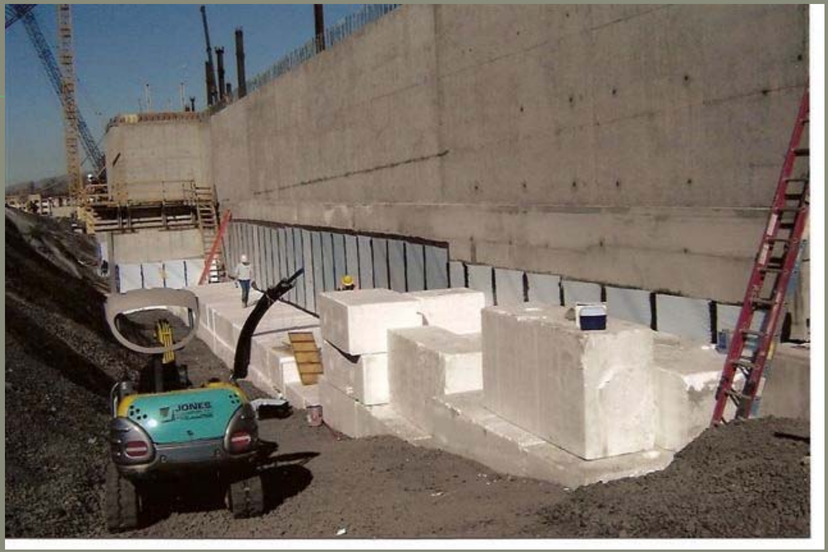
Buried Structures and Walls (Light-Weight Backfill)

Federal Courthouse



IHC Hospital – Murray, Ut

Casino/Hotel – Reidoso, NM

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Buried Structures and Walls (Compressible Inclusion)

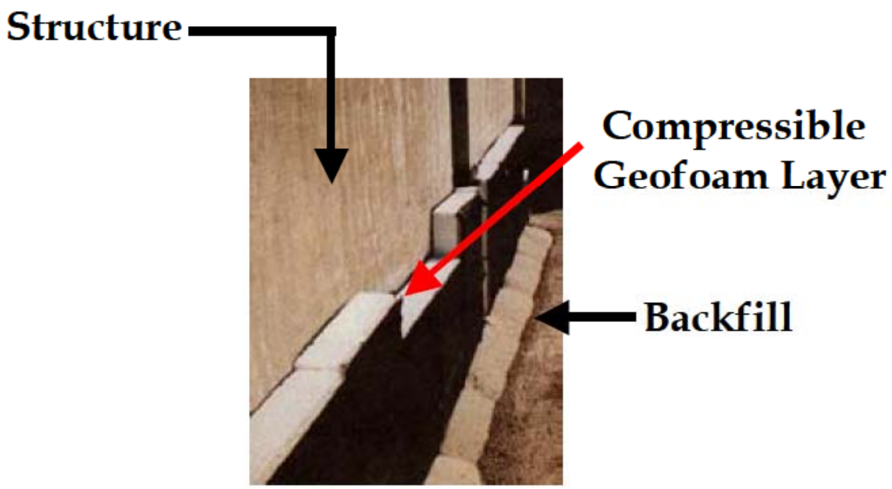
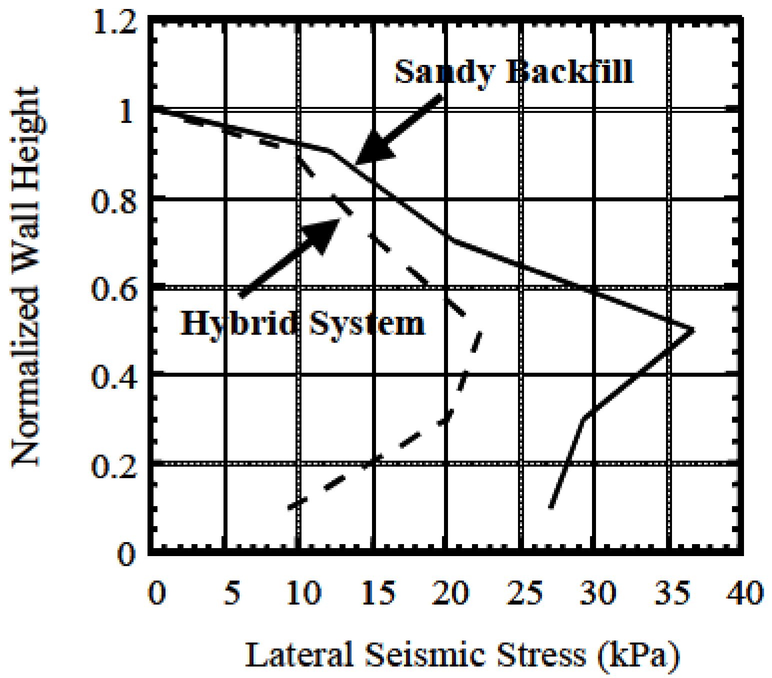
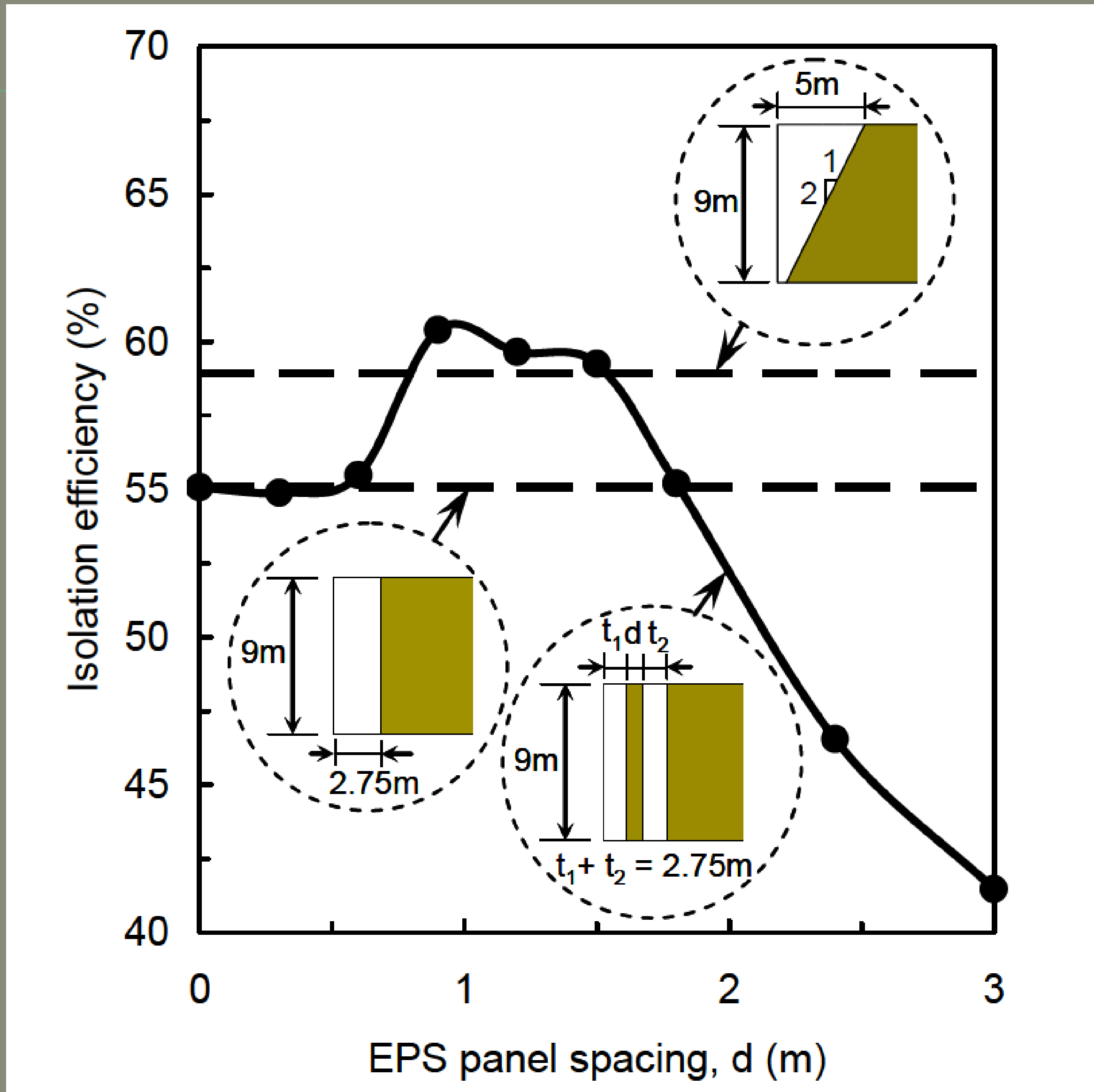


Fig. 1. Use of geofoam as compressible buffer

Reduction of Seismic Earth Pressure
(Hazarika, 2002)



Reduction of Peak Seismic Thrust



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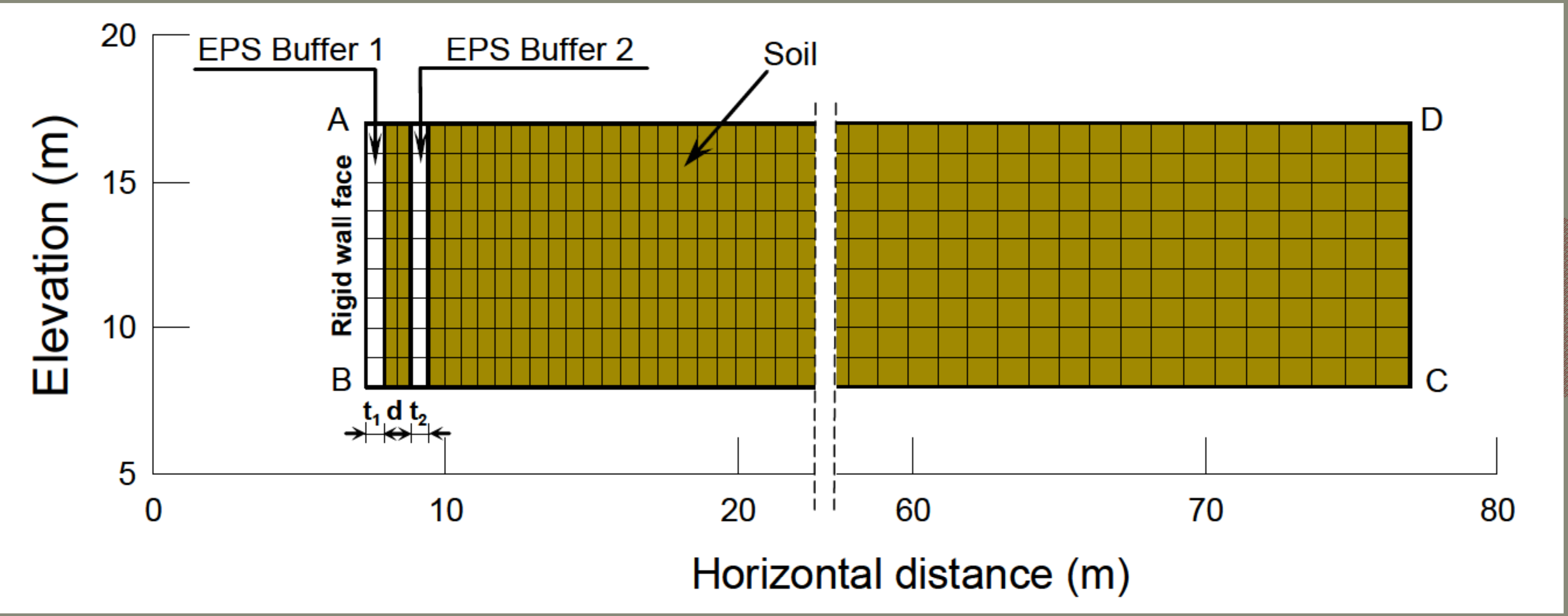
Reduction of Peak Seismic Thrust



Reduction of Peak Seismic Thrust

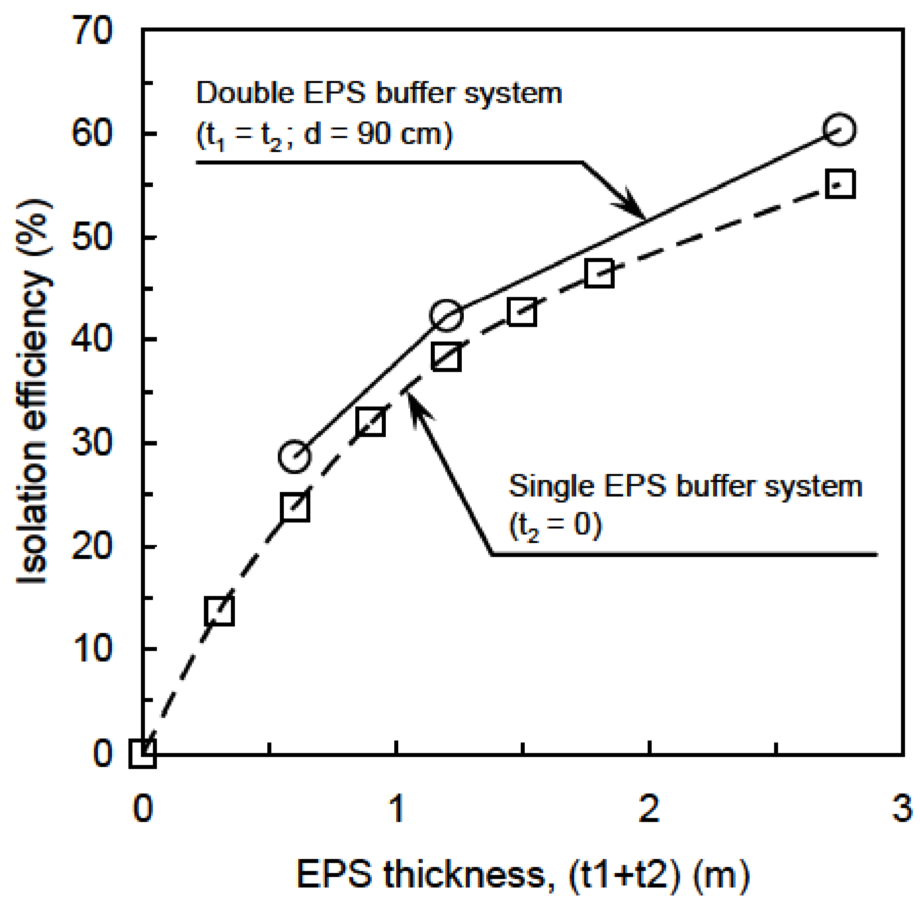


Fig. 8. Seismic isolation efficiency in relation to the total EPS thickness for single rectangular and double EPS buffer systems.

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Conclusions

- Numerical modeling can offer insight into the dynamic behavior of EPS embankments subjected to large, nearby earthquake.
  - Potential sliding can be inhibited by shear keys, adhesives, or other structural/mechanics restraints
- 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 seismic earth pressures can be reduced significantly using EPS placed against buried structures

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Questions ?