Seismic Restraint System for Expanded Polystyrene (EPS) Bridge Support Systems

Temporary Bridge Supported on EPS

Lokkeberg Bridge,
Norway

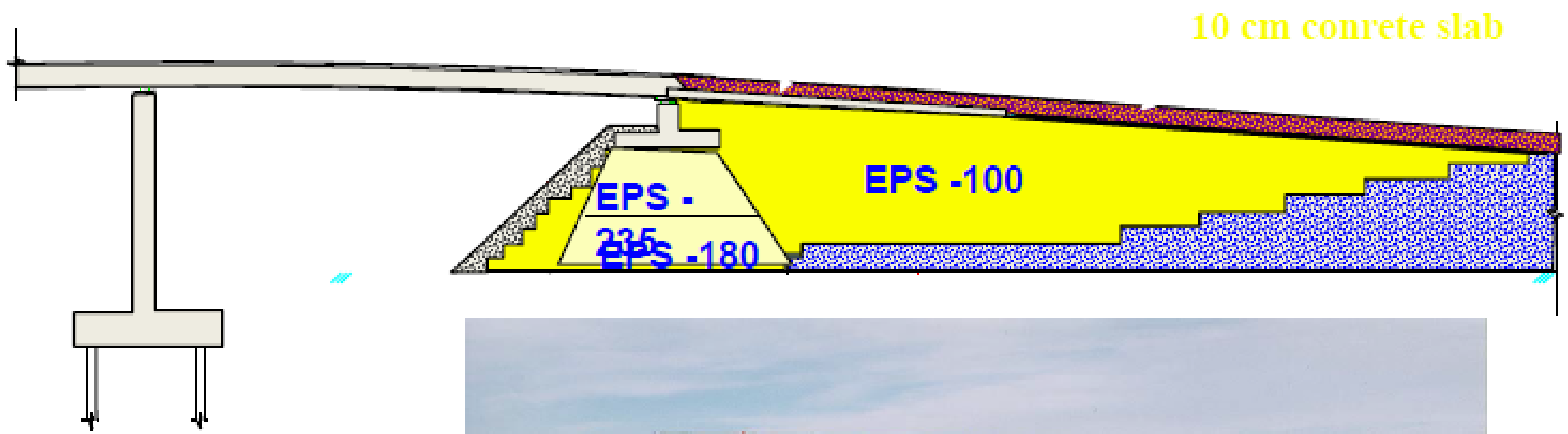
Statens vegvesen
Norwegian Public Roads Administration

Temporary Bridge Supported on EPS

Grimsoyveien
Norway

Statens vegvesen
Norwegian Public Roads Administration

Permanent Bridge Supported on EPS



Vegdirektoratet
Vegteknisk avd.

Hjelmungen bru, Norway

EPS block

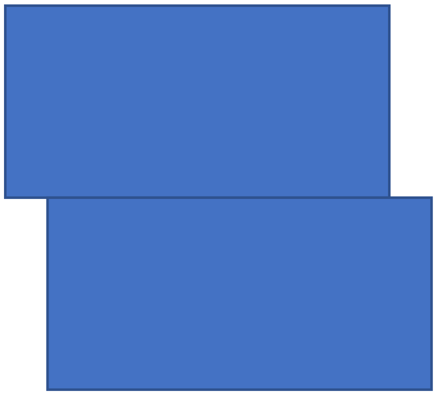
Statens vegvesen
Norwegian Public Roads Administration

Earthquake Hazard

Wasatch Fault at Little Cottonwood Canyon

Modes of Excitation / Failure

Internal Stability

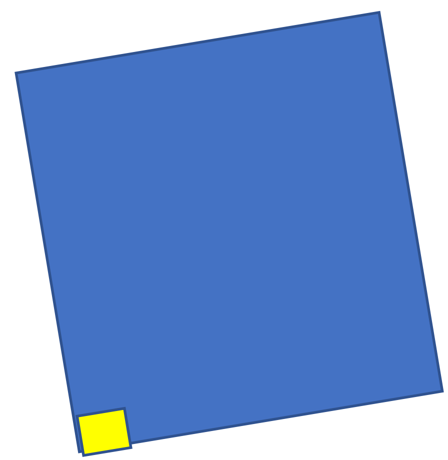


Interlayer Sliding

Horizontal Sway and Shear

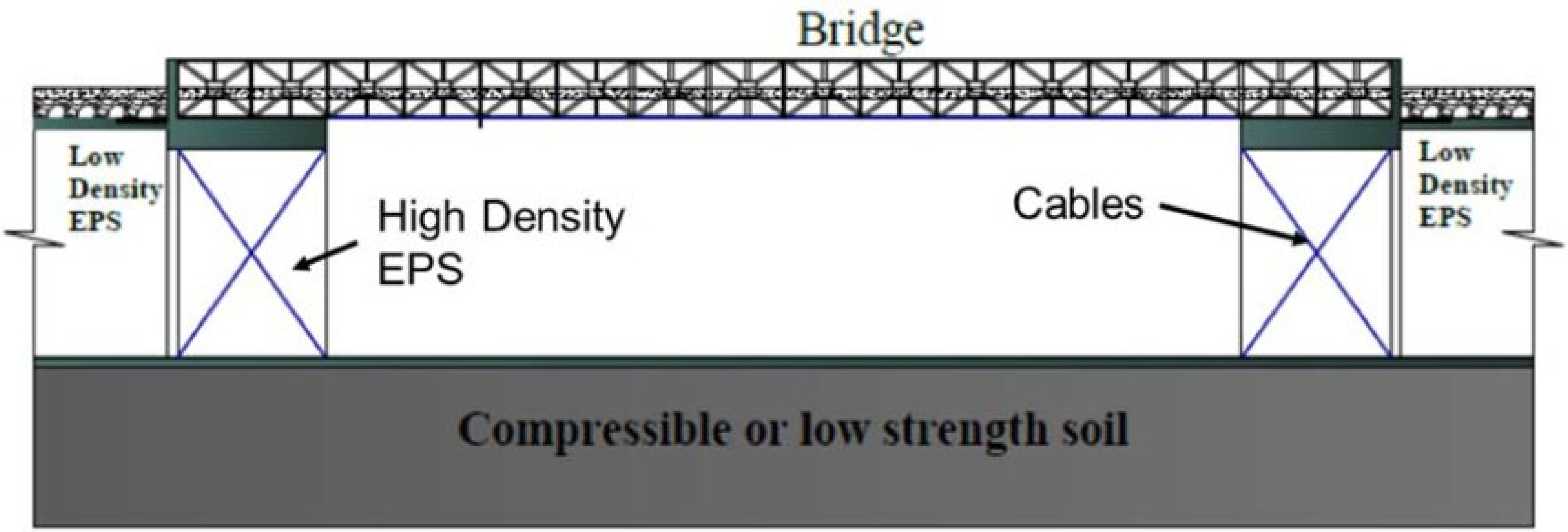
External Stability

Basal Sliding

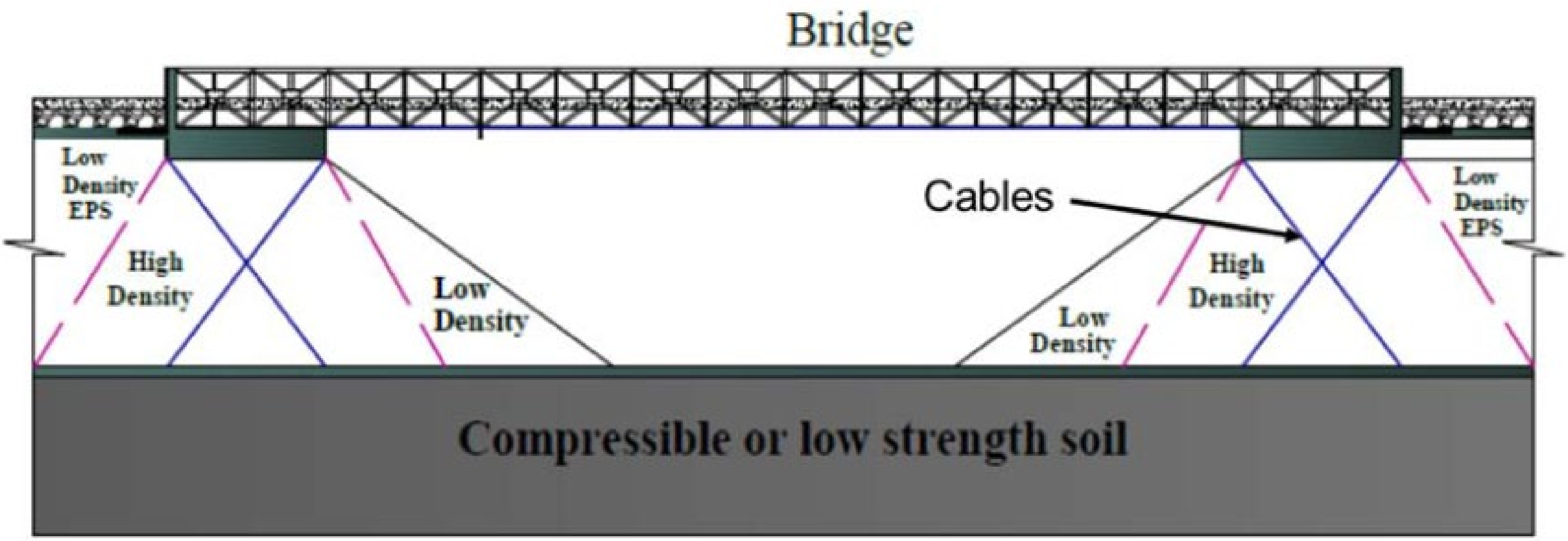


Rocking and Uplift

Conceptual Vertical Freestanding Support Embankment



Conceptual Sloped Trapezoidal Support Embankment



Sizing the Potential Span Lengths of the Bridge

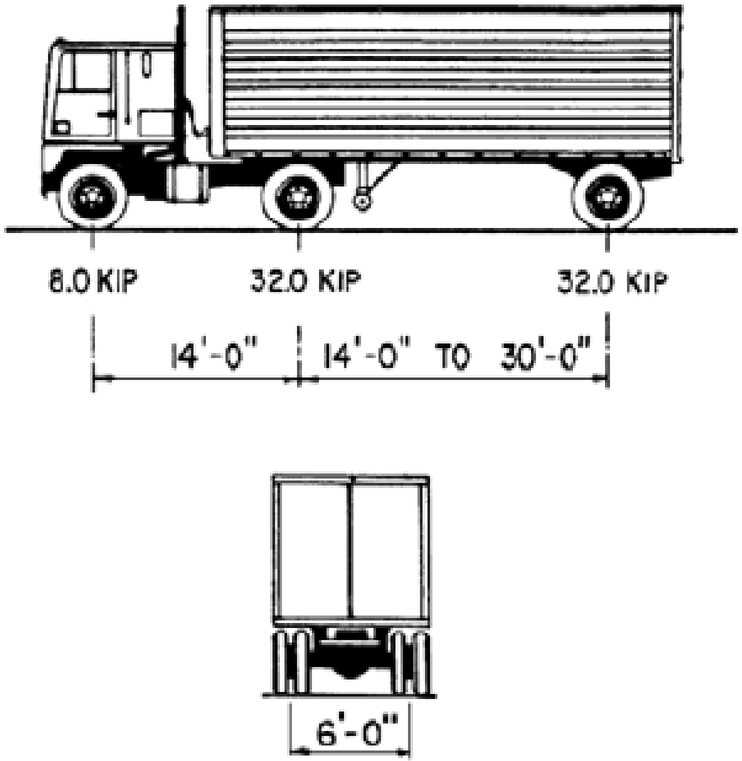


Figure 3-4 Characteristic of the HL-93 design truck (AASHTO, 2012)

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Sizing the Potential Span Lengths of the Bridge

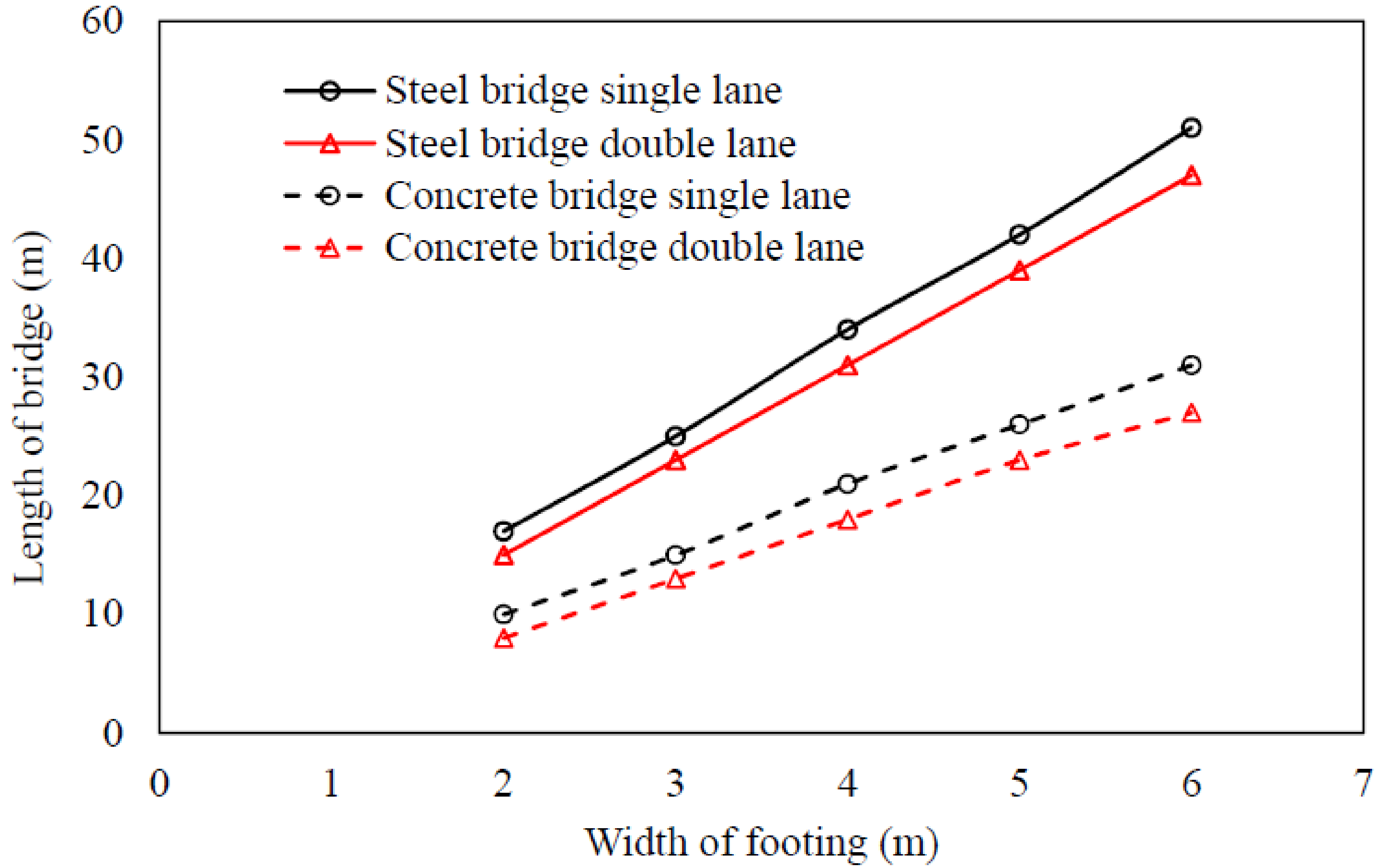
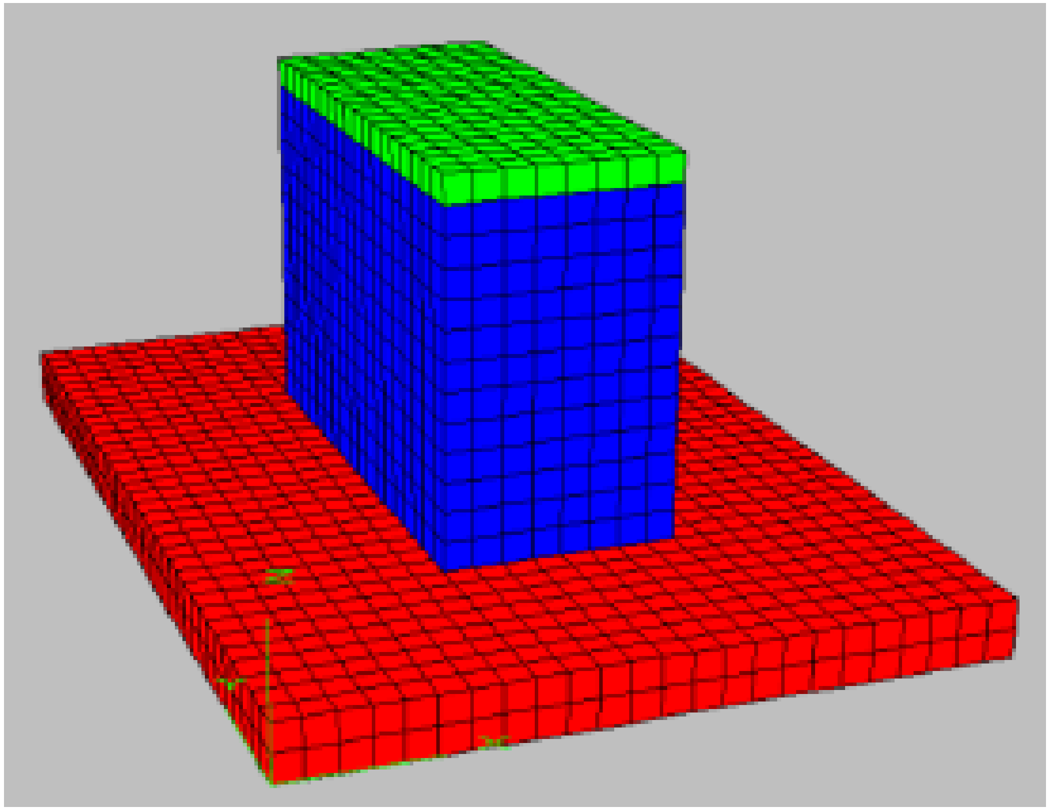


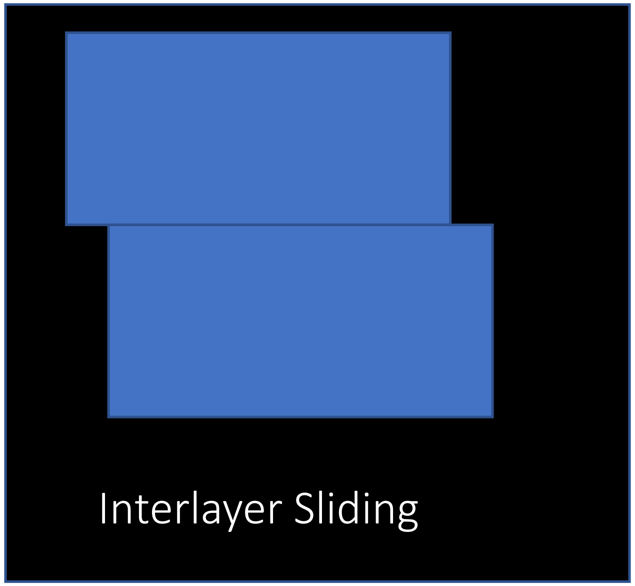
Figure 3-5 Relationship of length of bridge with length of footing for single and double-lane bridges supported on EPS 22 (red) and EPS 29 (black)

Numerical Model for Freestanding Embankment – Seismic Excitation



Modes of Excitation / Failure

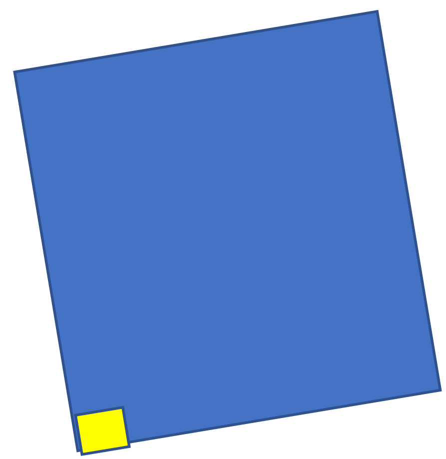
Internal Stability



Horizontal Sway and Shear

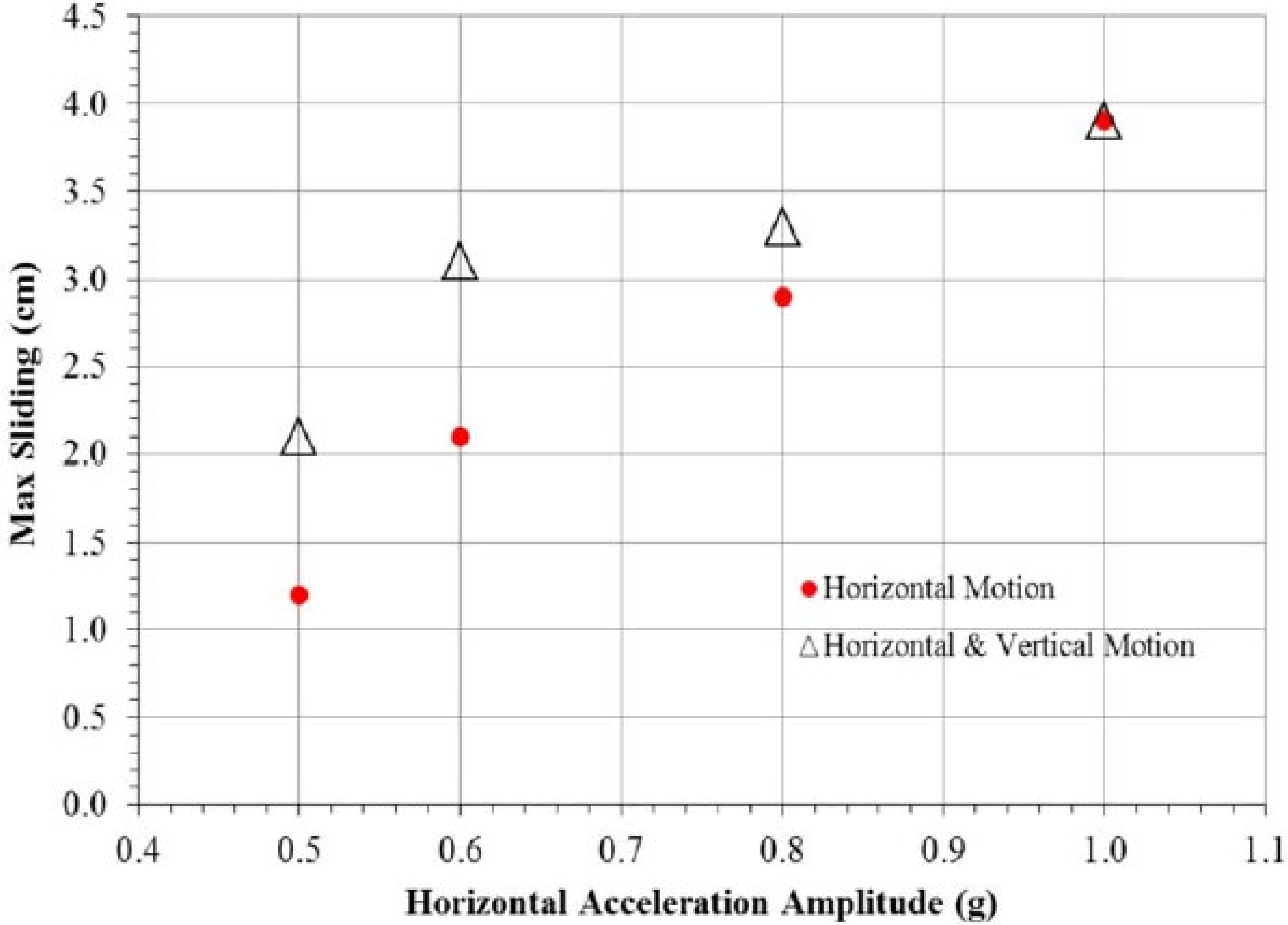
External Stability

Basal Sliding



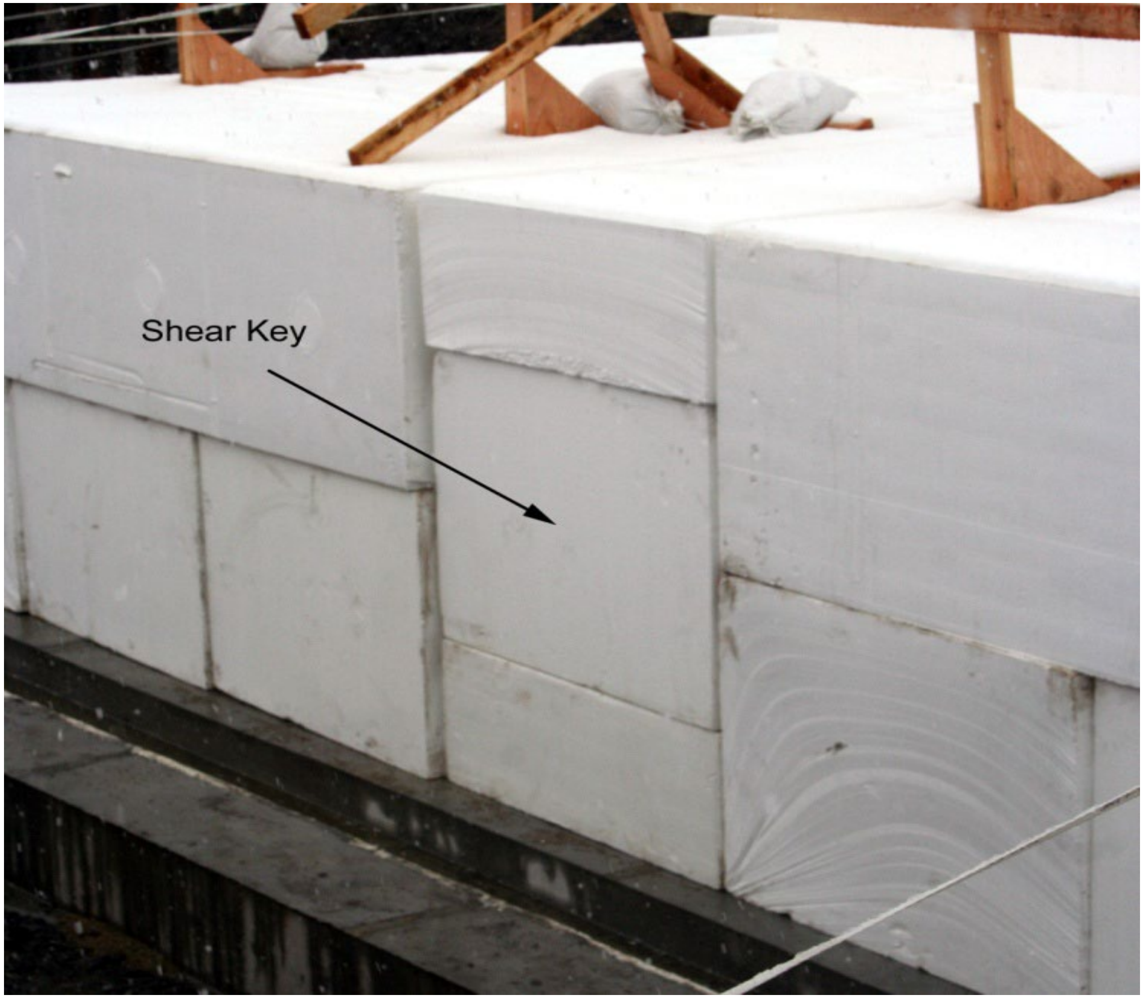
Rocking and Uplift

Interlayer Sliding Evaluations



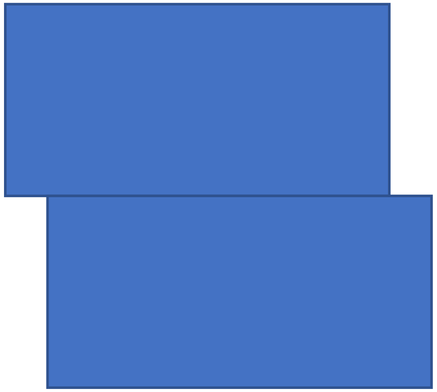
Shear Keys to Prevent Sliding

Sliding begins in the numerical model at about 0.5 g horizontal acceleration. Can be arrested up to 1.0 g with shear keys and cabling.



Modes of Excitation / Failure

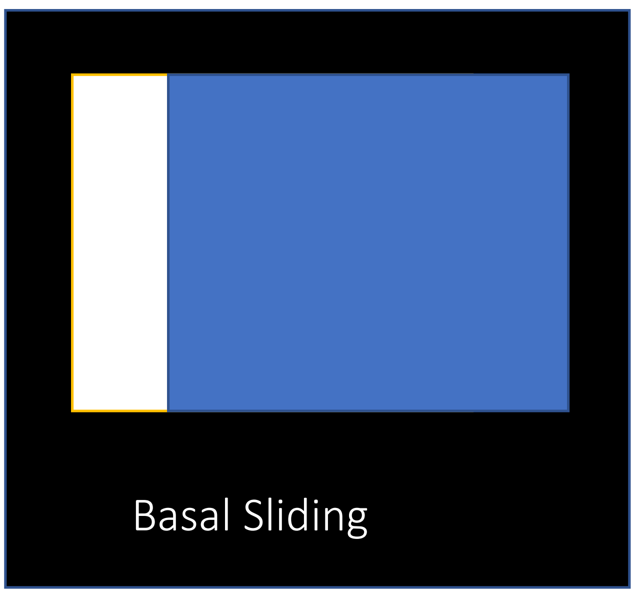
Internal Stability

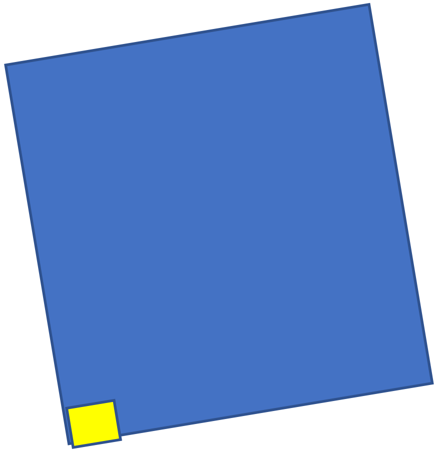


Interlayer Sliding

Horizontal Sway and Shear

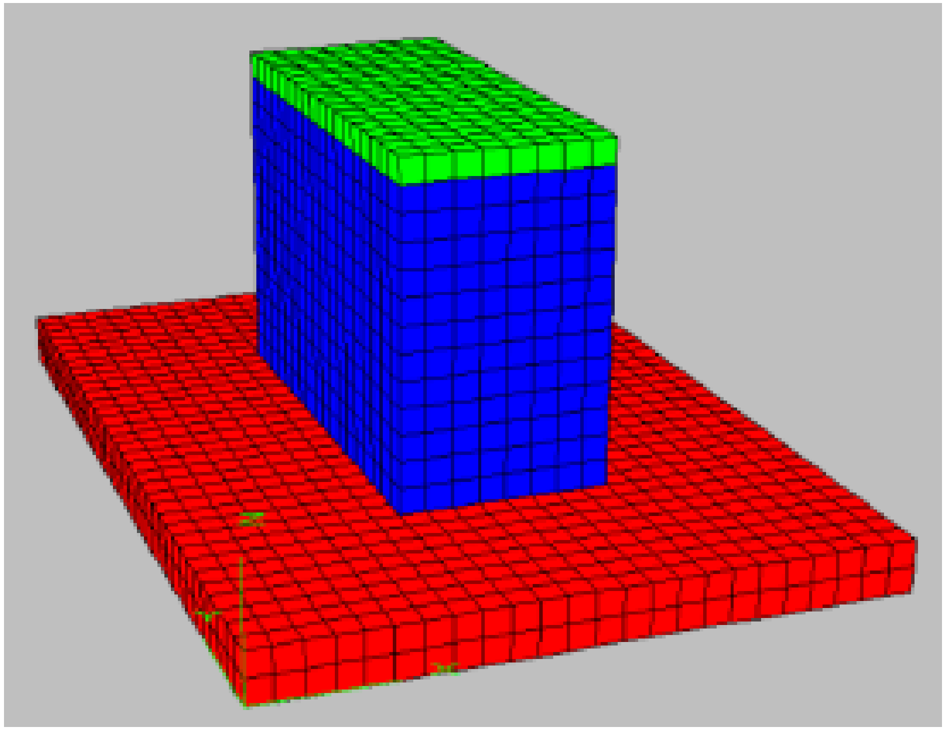
External Stability





Rocking and Uplift

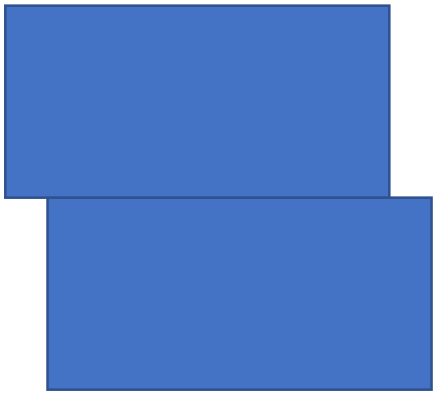
Basal Sliding



Without embedment of the EPS embankment, basal sliding began at about 0.6 g; however with about 1 to 1.4 m of embedment, basal sliding resistance can be increased to 1 g.

Modes of Excitation / Failure

Internal Stability

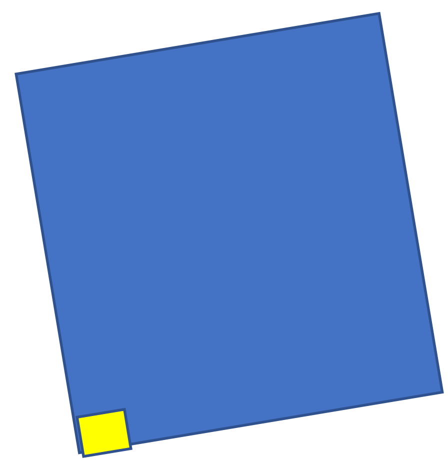


Interlayer Sliding

Horizontal Sway and Shear

External Stability

Basal Sliding



Rocking and Uplift

Determining Allowable Stress in EPS for Internal Seismic Stability Evaluations – Current Guidelines

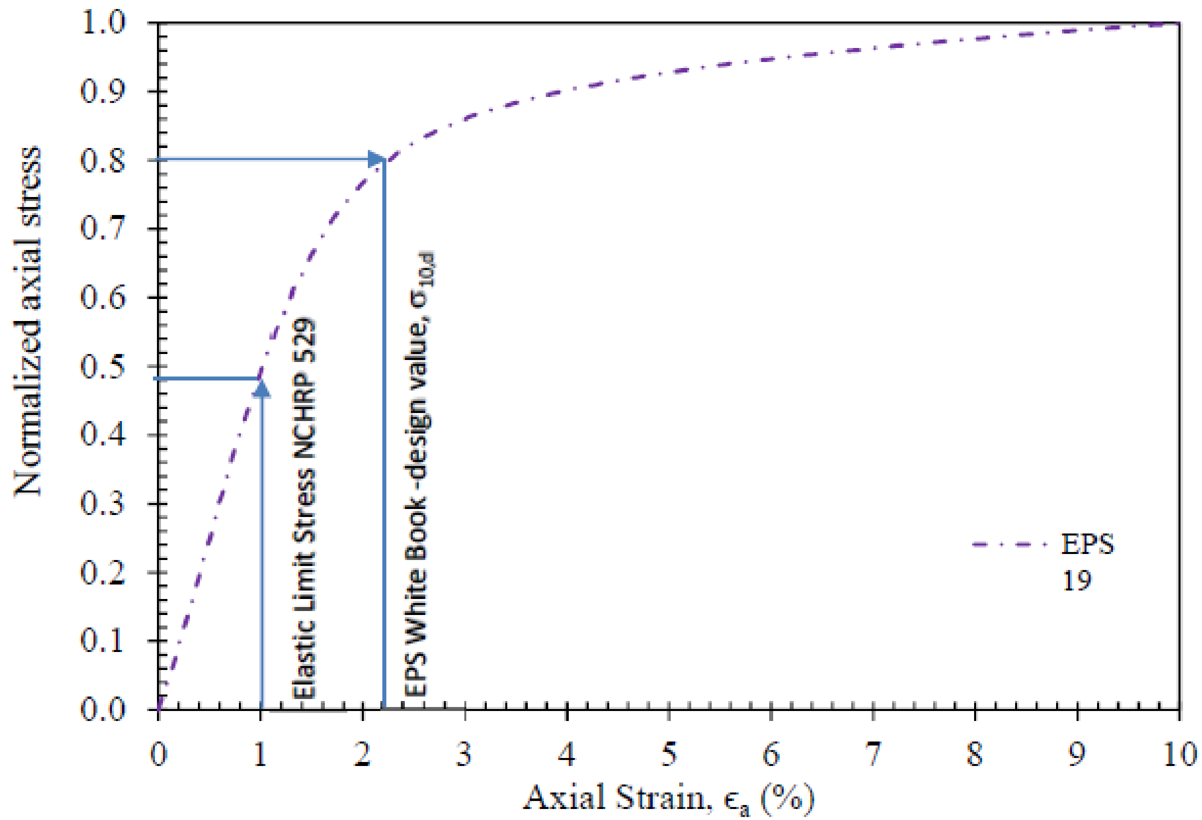


Figure 1-4. Typical axial stress versus axial strain curve for EPS 19 (i.e., density = 19 kg/m^3) normalized to compressive resistance at 10 percent strain.

Cyclic Triaxial Testing and Post-Cyclic Creep

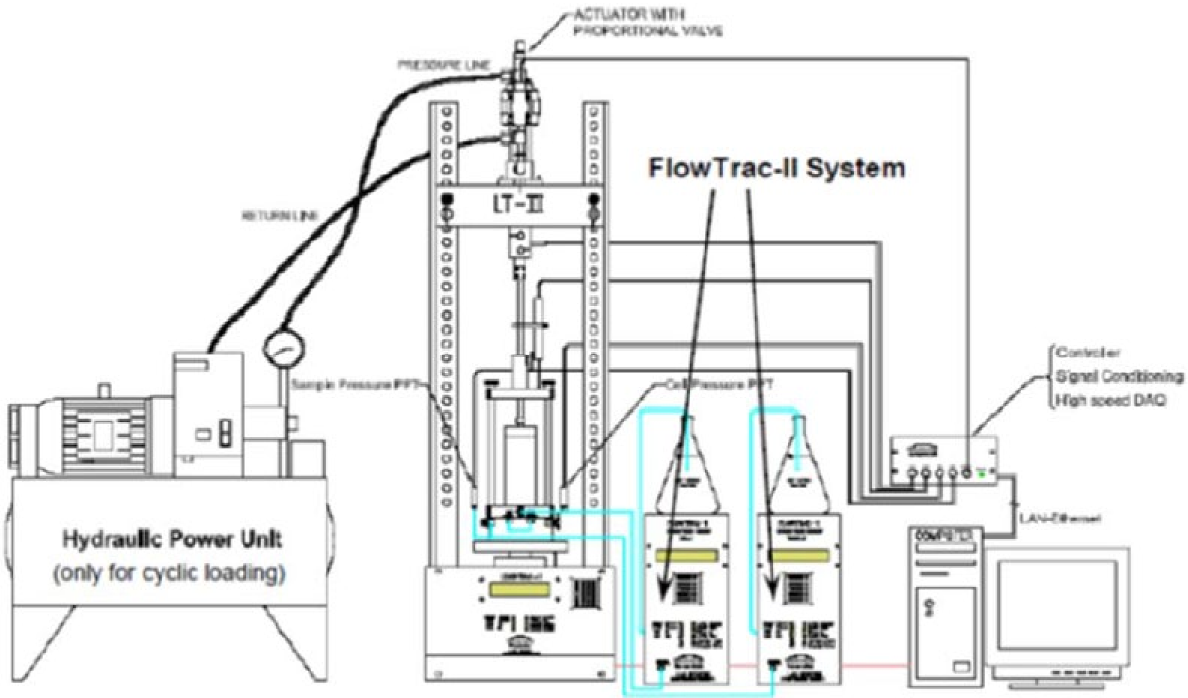
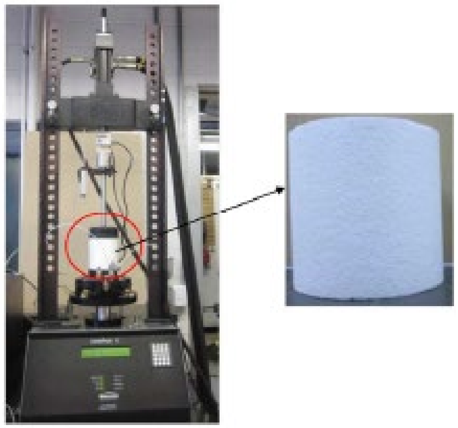


Figure 2-1. Cyclic triaxial equipment at the University of Utah , after Geocomp (2006)



Test Protocol

1. Apply vertical stress associated with 1 percent vertical strain and measure pre-cyclic creep strain (represents allowable dead load for design).
2. Allow creep to occur under dead load (pre-cyclic creep strain).
3. Cycle specimen to additional stress to higher strain levels (at least 1 percent additional axial strain.
4. Measure cyclic strains
5. Re-apply dead load stress (1 percent strain value)
6. Measure post-cyclic creep strain

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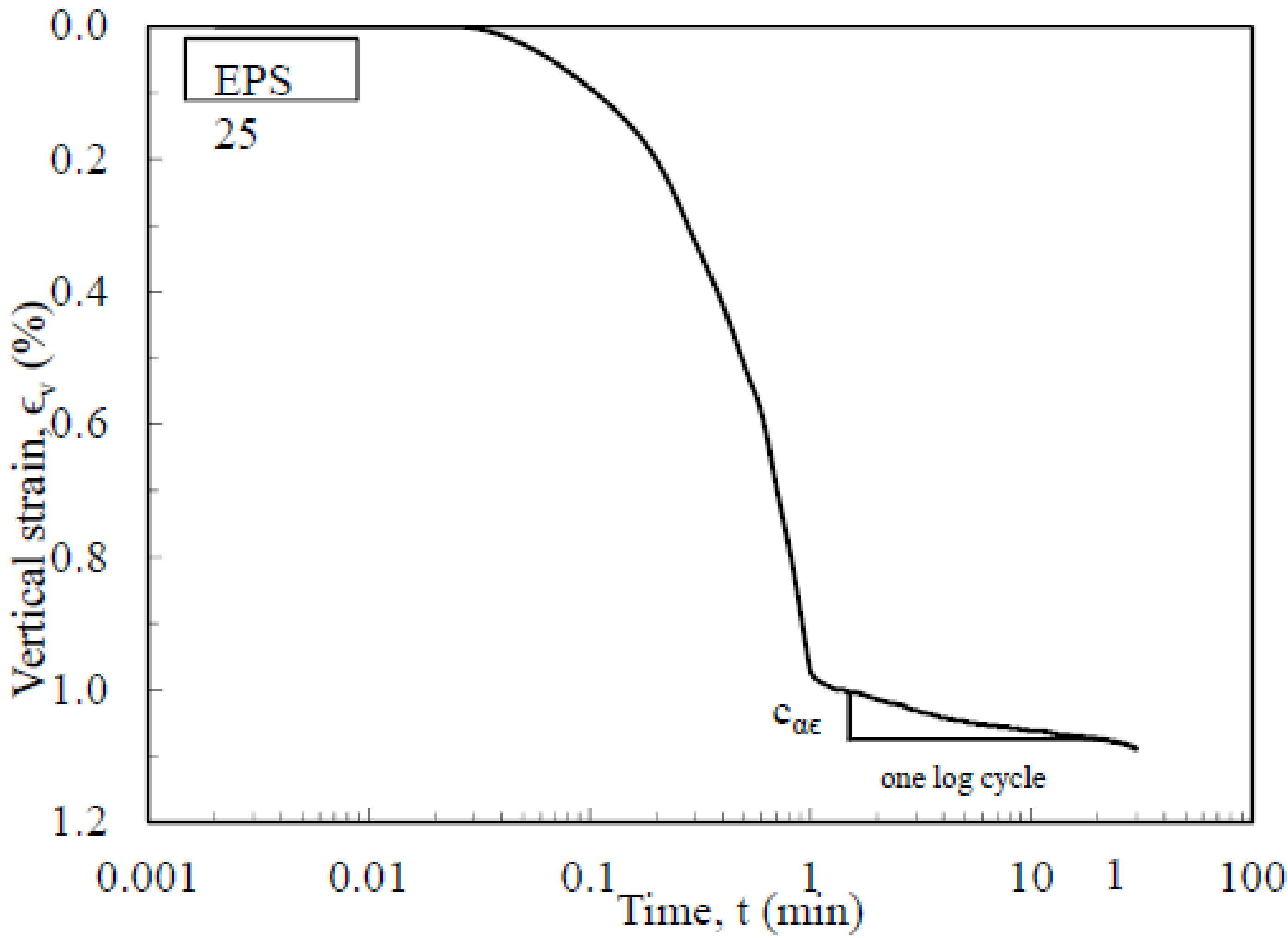
Pre-Cyclic Creep Strain



Pre-Cyclic Creep Strain

Table 2.2. Summary of pre-cyclic creep tests

EPS type	Density	Monotonic Axial strain	Static deviator stress	Pre-cyclic creep strain in 50 years
	(kg/m³)	*(%)*	*(kPa)*	*(%)*
EPS 25	25.0	1	72	0.311
	25.4	1	72	0.356
	25.5	1	72	0.351
	24.7	1	72	0.226
	25.6	1	72	0.267
	24.6	1	72	0.372
	24.9	1	72	0.389
	24.5	1	72	0.393
	25.8	1	72	0.250
	26.3	1	72	0.364
	24.5	1	72	0.436
	24.6	1	72	0.267
	24.8	1	72	0.286
EPS 29	33.8	1	108	0.441
	34.0	1	108	0.541
	33.2	1	108	0.352
	34.2	1	108	0.205
EPS 39	40.0	1	138	0.697
	41.1	1	138	0.243
	39.8	1	138	0.391

Example Test Results - Cycling

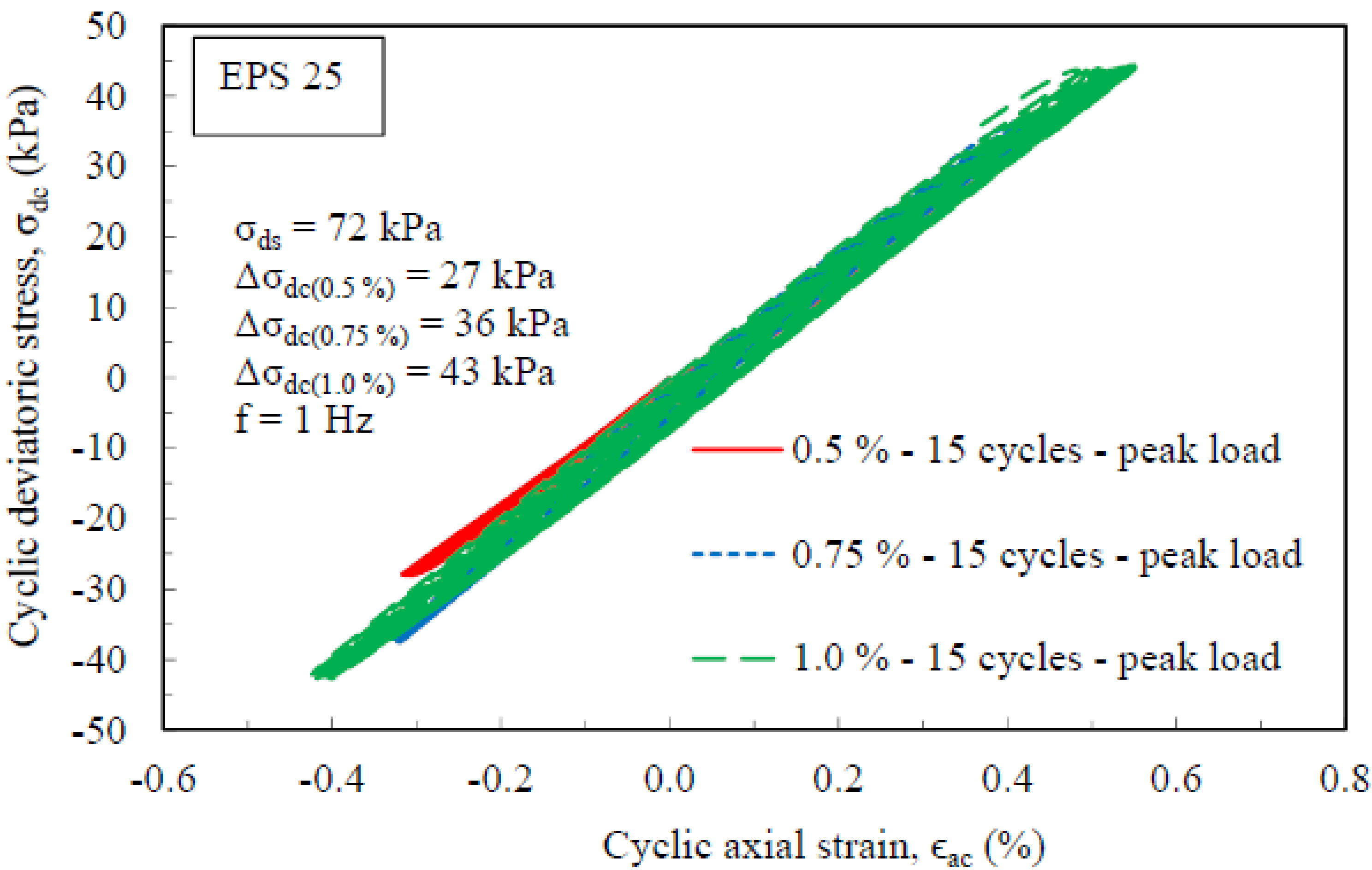
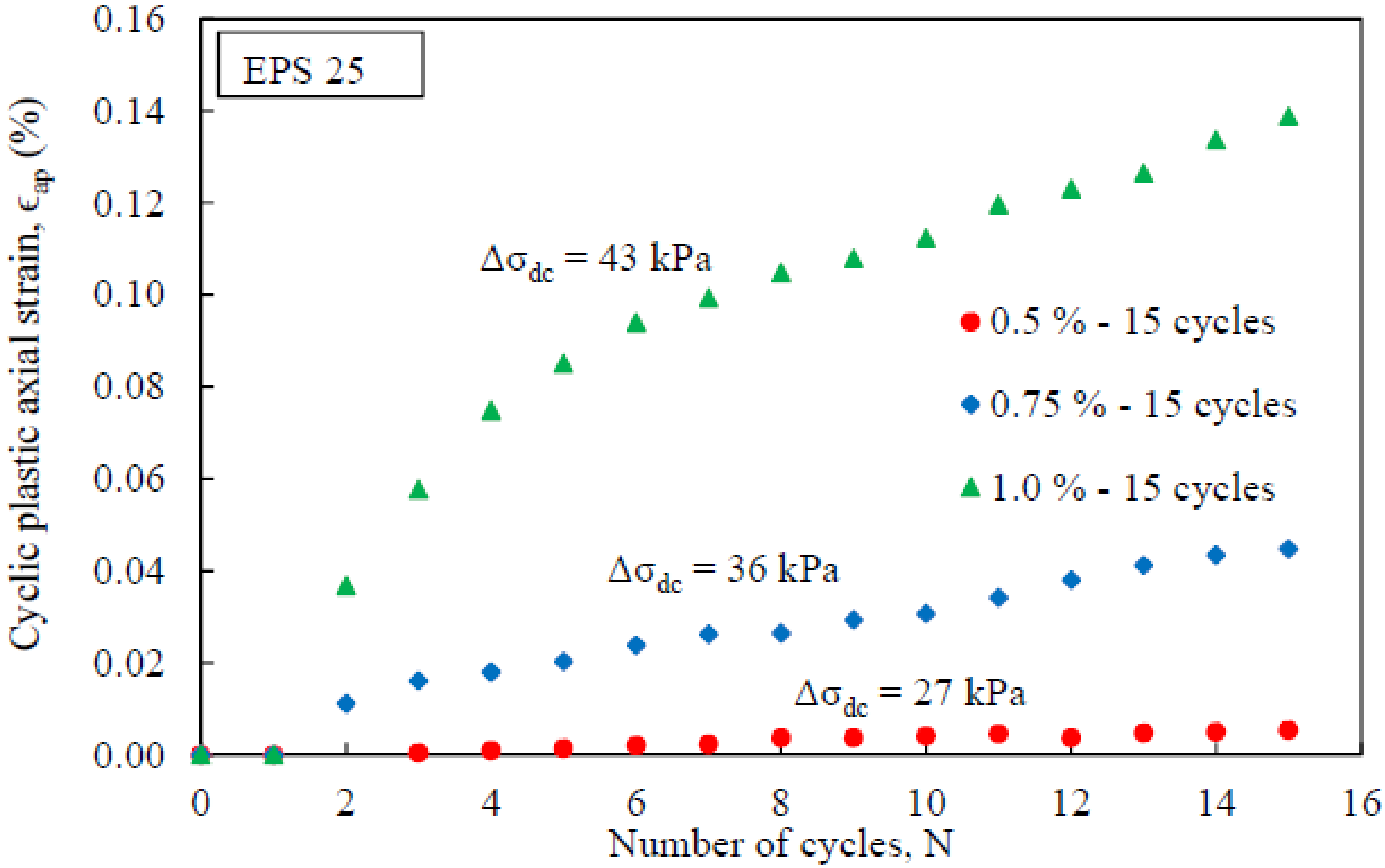


Figure 2-18 Results of cyclic uniaxial tests on three samples at three different level of cyclic deviatoric stresses under peak load with 15 number of cycles on EPS 25

Cyclic Strains



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Post-Cyclic Creep Strain

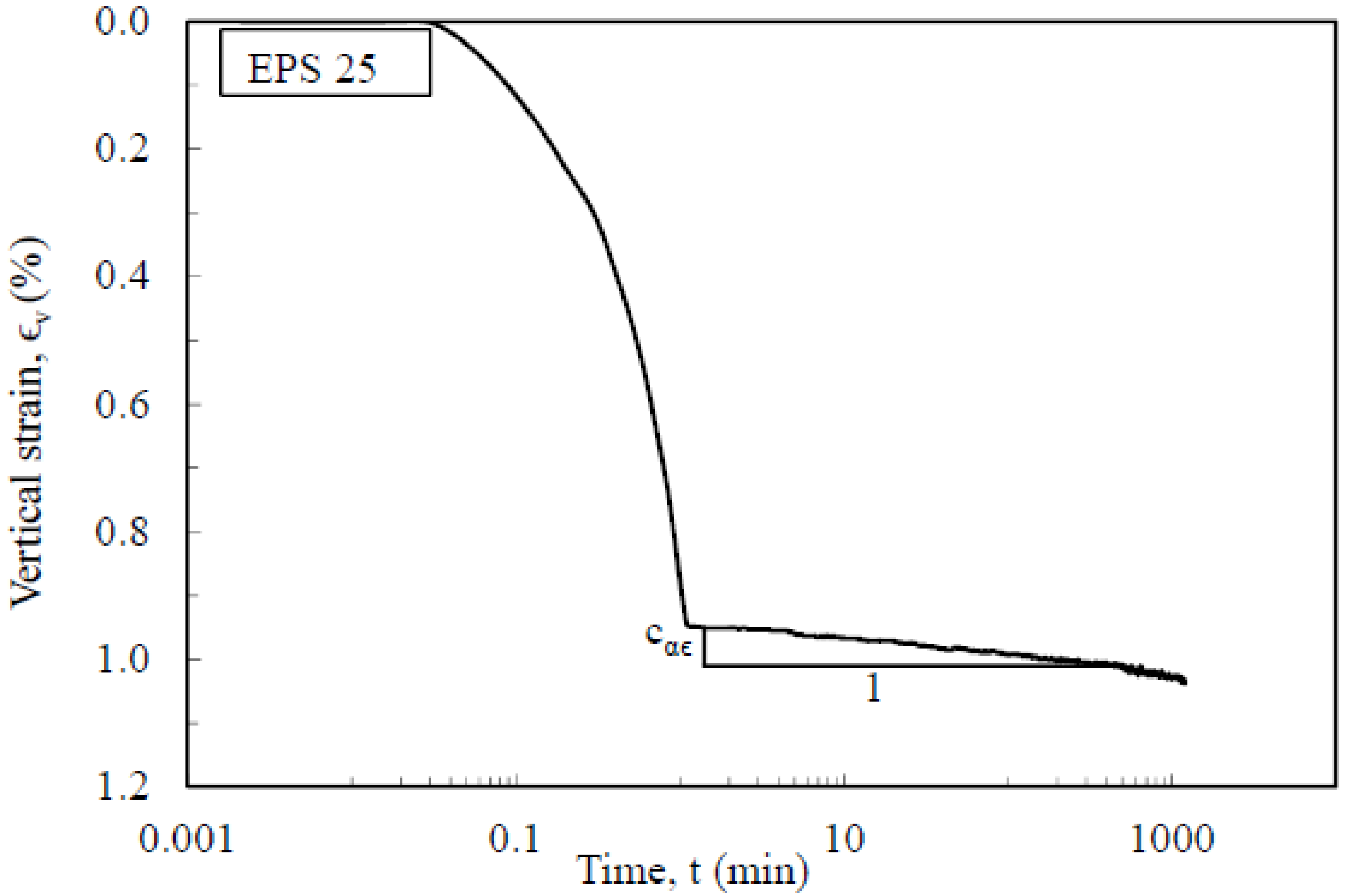

Figure 2-8 Vertical strain versus logarithm of time for post-cyclic test

Post-Cyclic Creep Strain Results

Table 2.5. Summary of pre and post-cyclic creep and estimated total strain permanent strain for 50-year design period

EPS nominal type	Density	Pre-cyclic Static deviatoric stress	Cyclic deviatoric stress	Total deviatoric stress	Axial strain from monotonic test	Number of cycles	Cyclic plastic axial strain	Estimated pre-cyclic creep strain in 50 years	Estimated post-cyclic creep strain in 50 years	Estimated permanent strain in 50 years
---------	*(kg/m3)*	(kPa)	(kPa)	(kPa)	*(%)*	*(N)*	*(%)*	*(%)*	*(%)*	*(%)*
EPS 25	25.0	72	27	99	1.5	5	0.008	0.311	0.298	0.319
	25.4	72	27	99	1.5	15	0.014	0.356	0.252	0.370
	25.5	72	27	99	1.5	30	0.028	0.351	0.283	0.379
	24.7	72	36	108	1.75	5	0.03	0.226	0.207	0.256
	25.6	72	36	108	1.75	15	0.045	0.267	0.262	0.312
	24.6	72	36	108	1.75	30	0.065	0.372	0.33	0.437
	24.9	72	43	115	2	5	0.048	0.389	0.286	0.437
	24.5	72	43	115	2	15	0.139	0.393	0.333	0.532
	25.8	72	43	115	2	30	0.14	0.25	0.351	0.491

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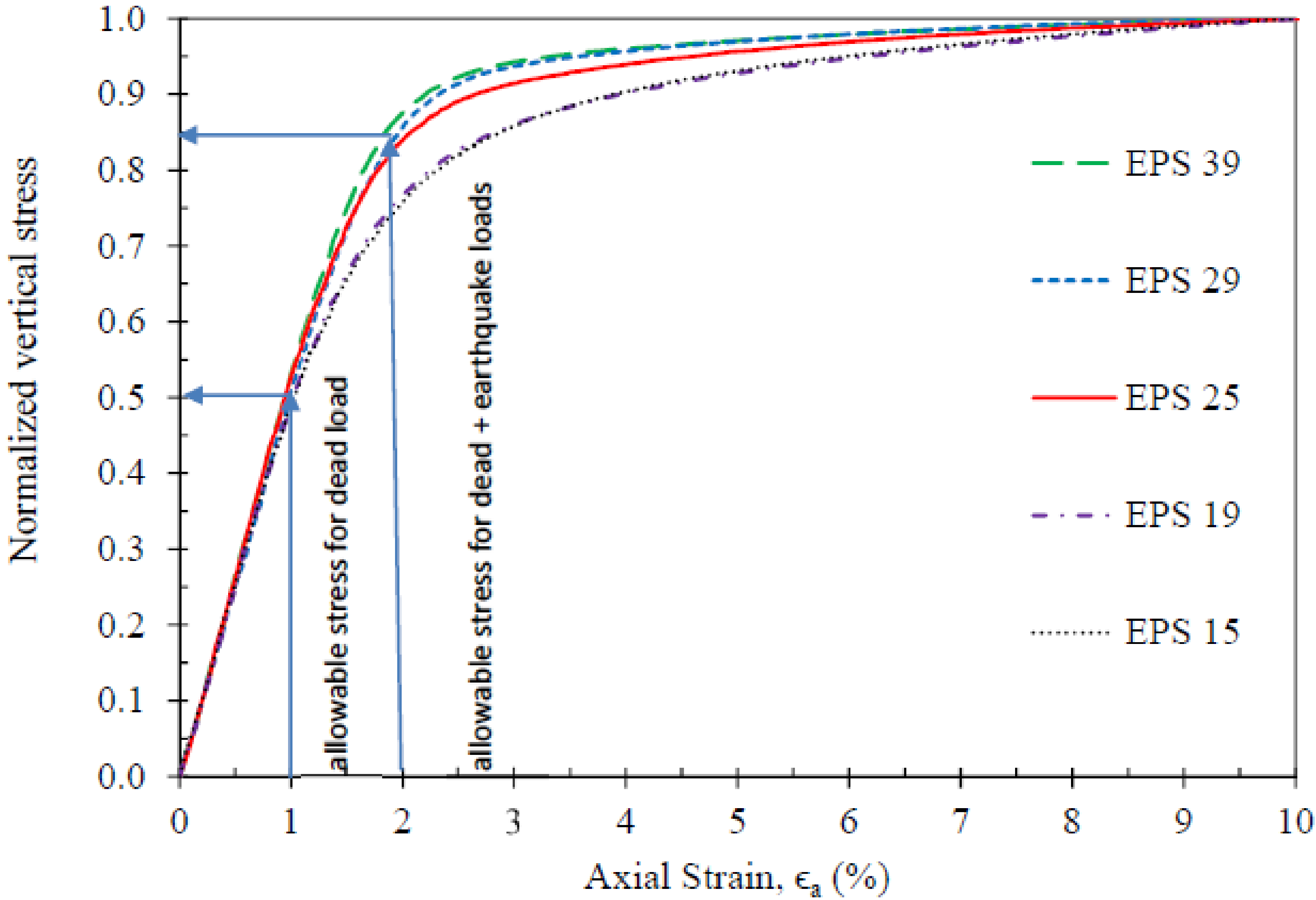
Recommended Allowable Stress Levels



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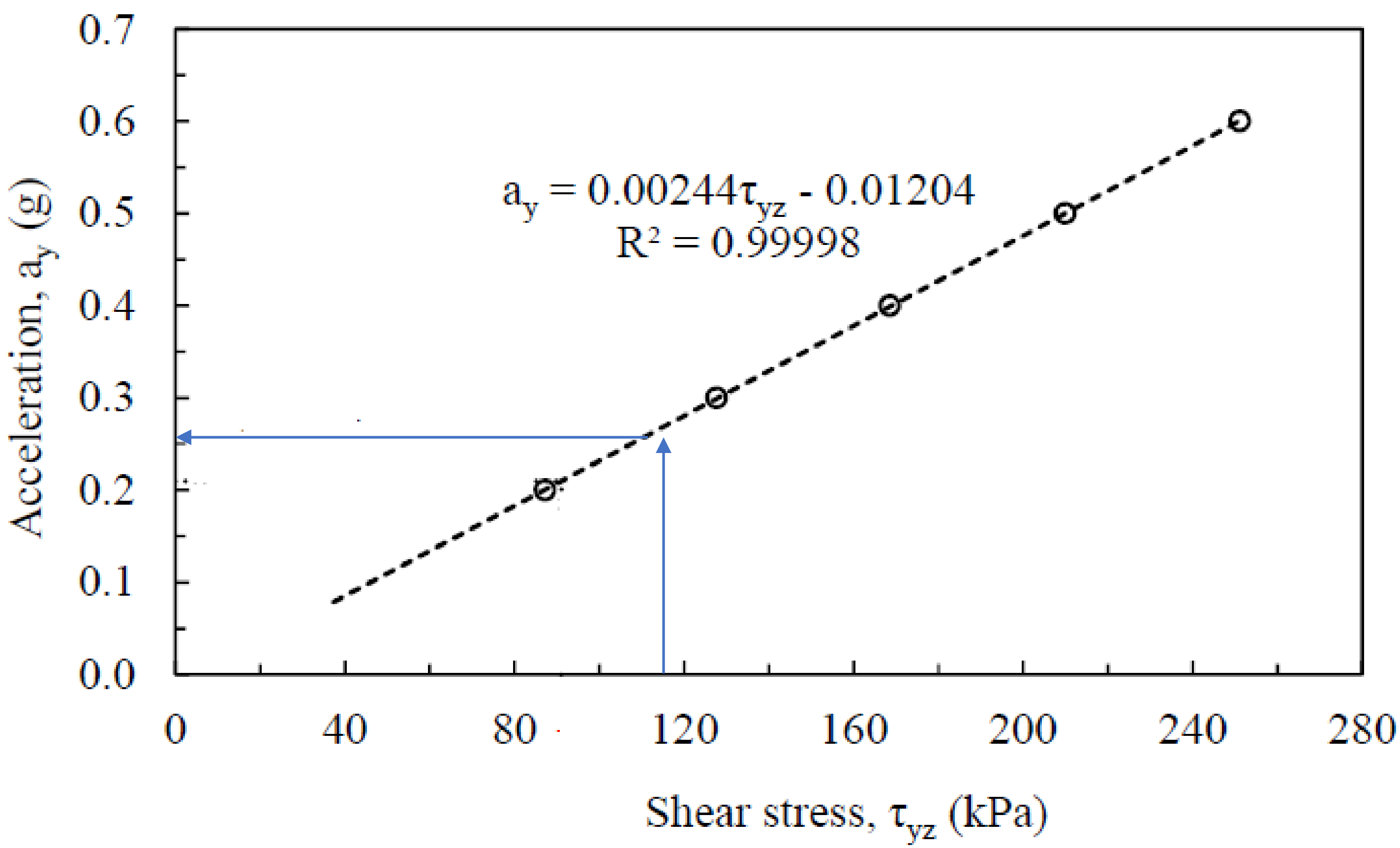
Acceleration Versus Peak Shear Stress Resulting from Horizontal Sway



$$\tau = \frac{1}{2}\sigma$$

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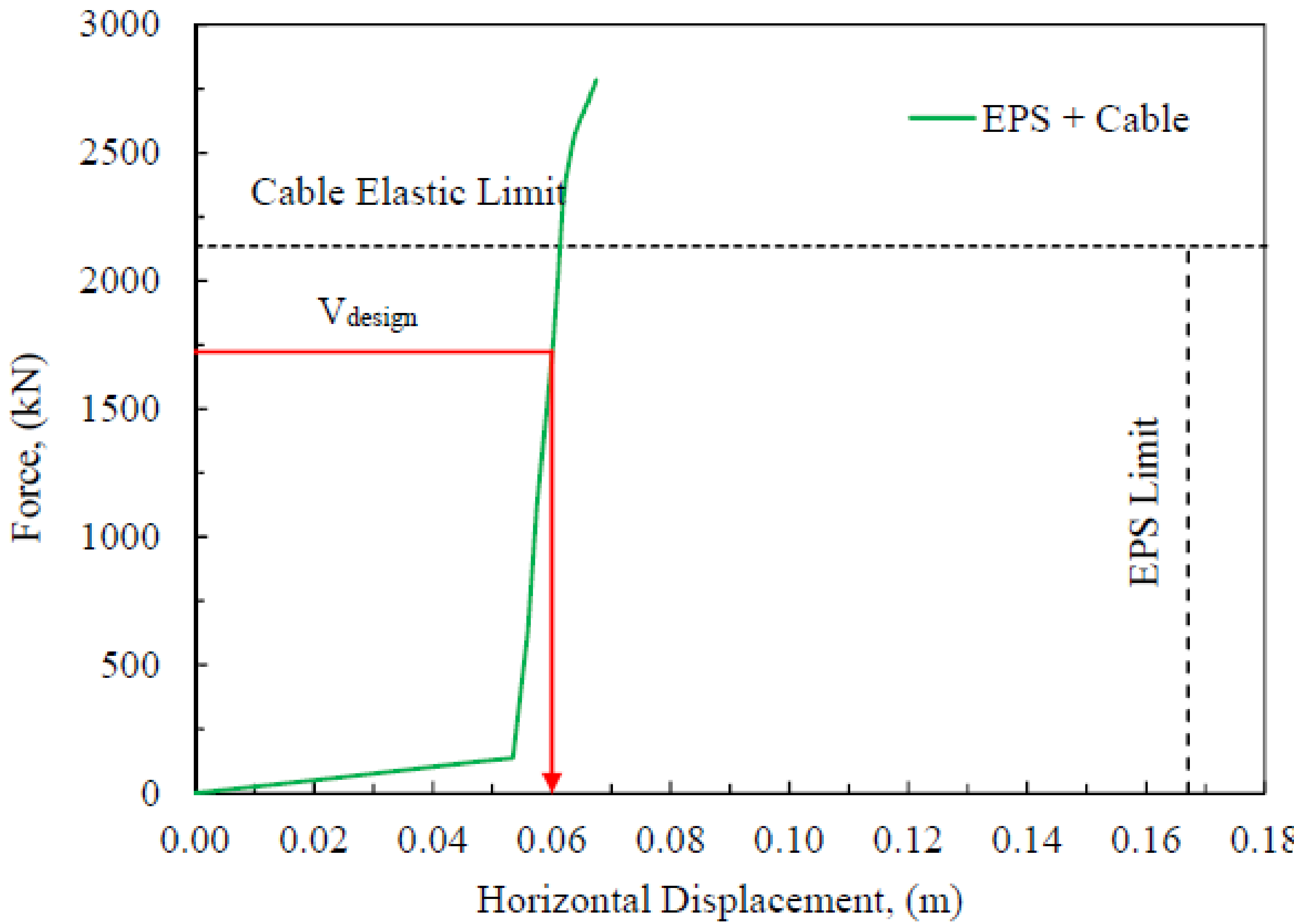
Compressive Resistance Versus Axial Strain

Table 2.5. Summary of pre and post-cyclic creep and estimated total strain permanent strain for 50-year design period

EPS nominal type	Density	Pre-cyclic Static deviatoric stress	Cyclic deviatoric stress	Total deviatoric stress	Axial strain from monotonic test	Number of cycles	Cyclic plastic axial strain	Estimated pre-cyclic creep strain in 50 years	Estimated post-cyclic creep strain in 50 years	Estimated permanent strain in 50 years
EPS 29	33.8	108	74	182	2	5	0.07	0.411	0.353	0.481
	34.0	108	74	182	2	15	0.147	0.541	0.381	0.688
	33.2	108	74	182	2	30	0.179	0.352	0.43	0.609
	34.2	108	98	206	5	15	0.288	0.205	0.419	0.707
EPS 39	40.0	138	90	228	2	5	0.032	0.697	0.393	0.729
	41.1	138	90	228	2	15	0.06	0.243	0.425	0.485
	39.8	138	90	228	2	30	0.11	0.391	0.397	0.507

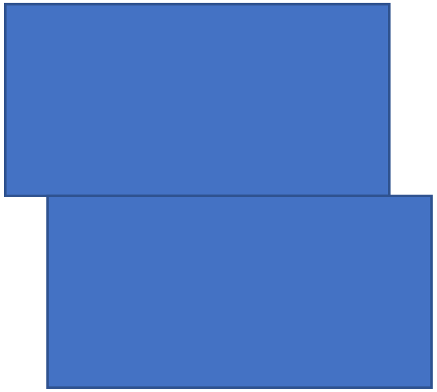
Shear resistance can be increased by using high density EPS and by cabling system to restrict sway mode.

Cabling and Restriction of Sway



Modes of Excitation / Failure

Internal Stability

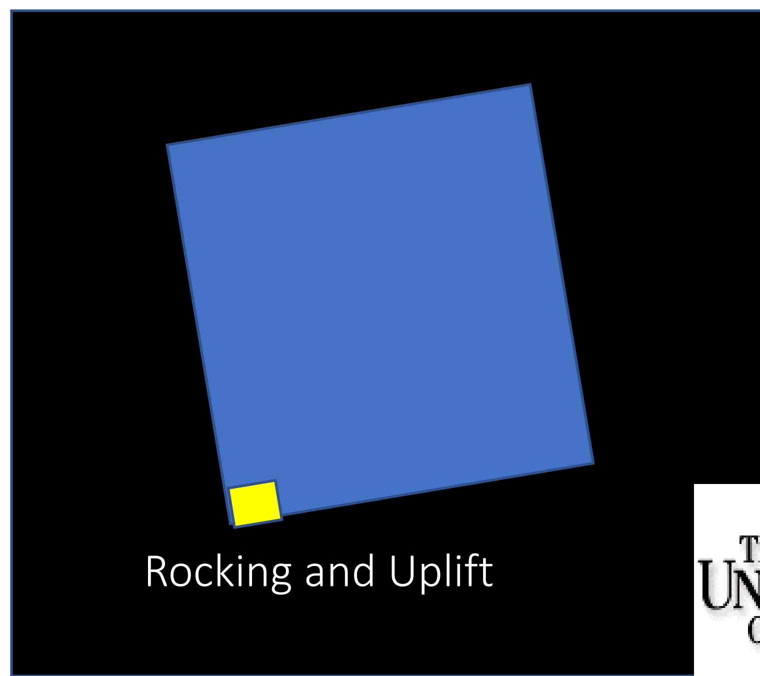


Interlayer Sliding

Horizontal Sway and Shear

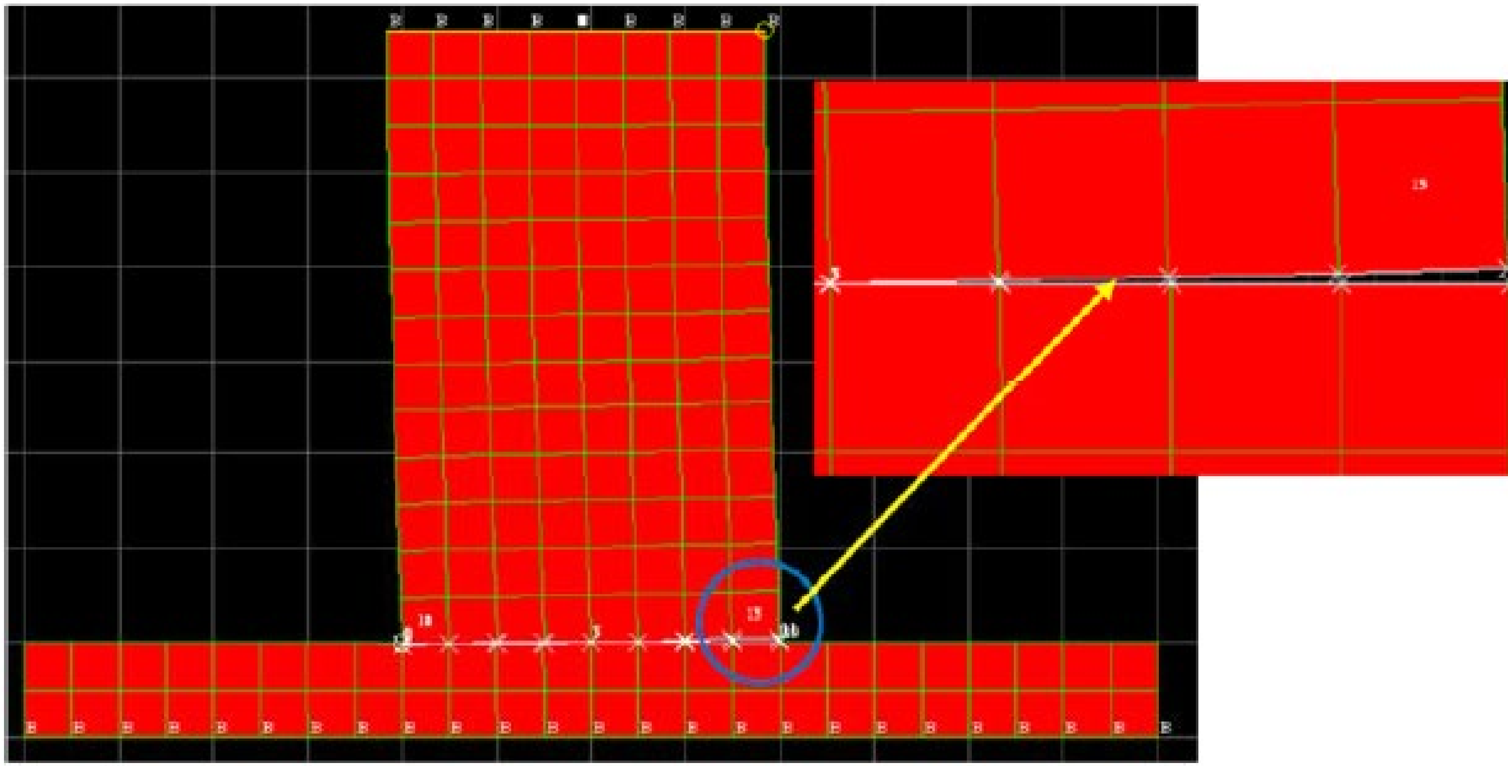
External Stability

Basal Sliding



Rocking and Uplift

Uplift Evaluations



Uplift Evaluations

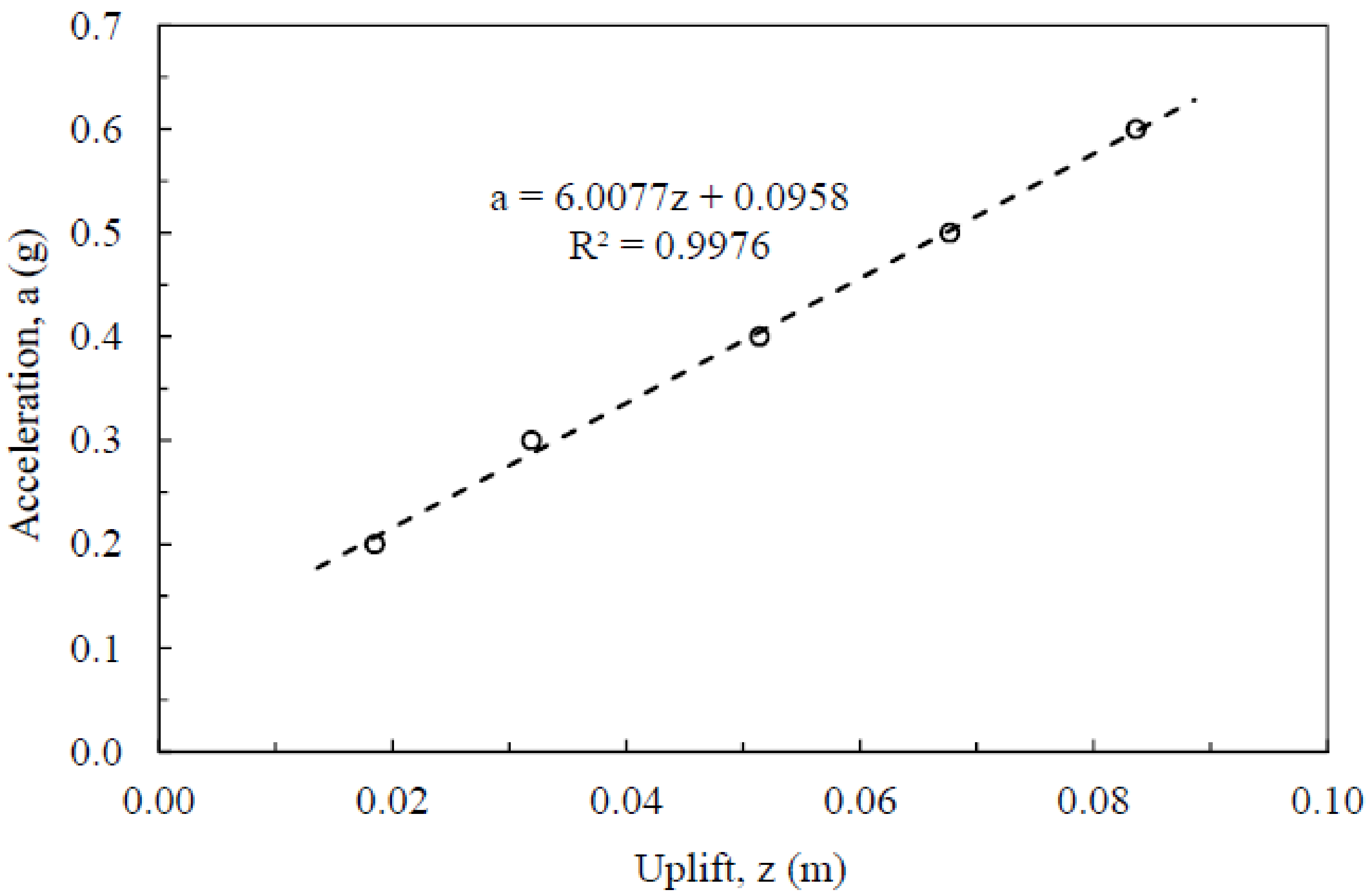


Figure 3-56. Relationship of acceleration and uplift for the excitation in the longitudinal, transverse and vertical directions

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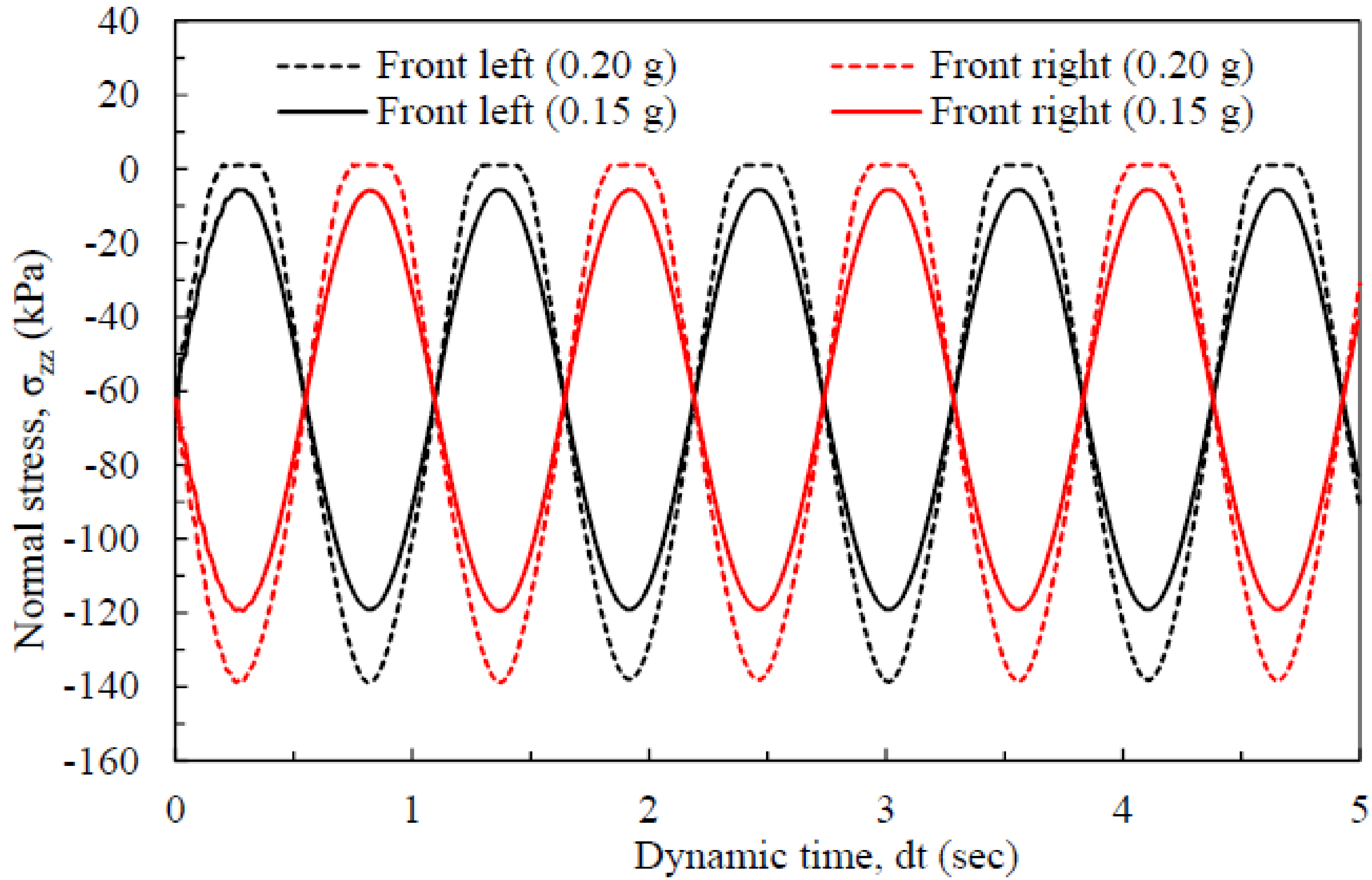
Uplift Evaluations – Peak Stress at Corner



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Title

Questions