Issues Associated with Design of Allowable Stress for Free-Standing EPS Embankments

S. Bartlett, Ph.D, P.E.

March 2013

THE UNIVERSITY OF UTAH

Topics

- Summary of Design Methods
    - Focus on Allowable Stress to Prevent Long-Term Creep
    - Compressive Resistance Used in Design
    - Load and Resistance Factors
    - Calculation of Stress in EPS
- Summary of Performance Data
- Conclusions

Summary of Design Methods

- European Draft Standard (1998)
- EDO (Japanese) Method (2000)
- NCHRP 529 (2004)
- European EPS White Book (2011)

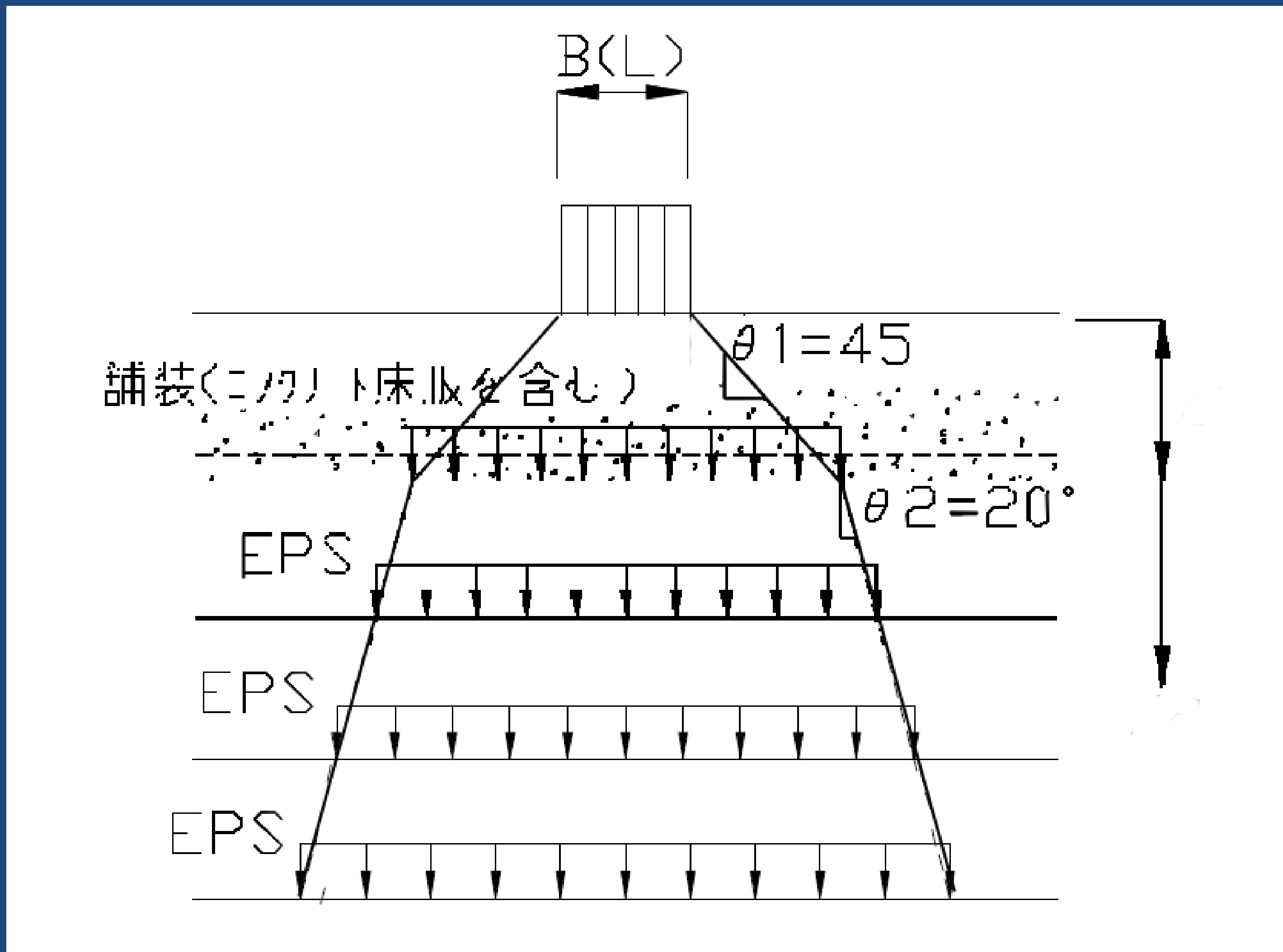
European Draft Standard (1998)

- Design values based on compressive resistance at 10% axial strain
- Resistance Factors
  - Total allowable compressive resistance = 40%
  - 30% compressive resistance allowed for dead loads
  - 10% compressive resistance allowed for live loads
- Load Factors
  - No load applied
  - No recommendations regarding vertical stress calculations
- I-15 reconstruction project was design consistent with this method

EDO (2000)

- Design values based on compressive resistance at 10% axial strain
- Resistance Factors
  - Total allowable compressive resistance = 50%
- Load Factors
  - No load applied
  - Simplified stress distribution (next slide)

EDO (2000)



Calculation of Vertical Stress Distribution

NCHRP 529 (2004)

- Design values based on compressive resistance at 1% axial strain
- Resistance Factors
    - No resistance factors applied
- Load Factors
    - 1.2 (DL + 1.3 LL)
    - Burmister (1943) recommended vertical stress for calculations
        - Does not account for effects of load distribution slab
- Many states are adopting this as the defacto "standard" without understanding this history of EPS design and lessons learned from performance monitoring

EPS White Book (2011)

- Design values based on compressive resistance at 10% axial strain
- 3 Design Cases (short-term, permanent, cyclic (i.e., traffic)
  - Short-term = 100 % design value
  - Permanent = 30% design value
  - Cyclic = 35% design value
- Resistance Factors
  - 1.25 (for all design cases)
- Load Factors
  - 1.35 permanent
  - 1.5 cyclic
  - No recommendations regarding vertical stress calculations; however numerical modeling has been employed by the developers of this standard

EPS Density

Property	ASTM Test C 578	Type XI	Type I	Type VIII*	Type II	Type IX
Nominal Density (kg/m^3)	C303 / D 1622	12	16	20	24	32
Minimum Density (kg/m^3)	C303 / D 1622	11	15	18	22	29

*** Type VIII was used for I-15 Reconstruction**

EPS Compressive Resistance

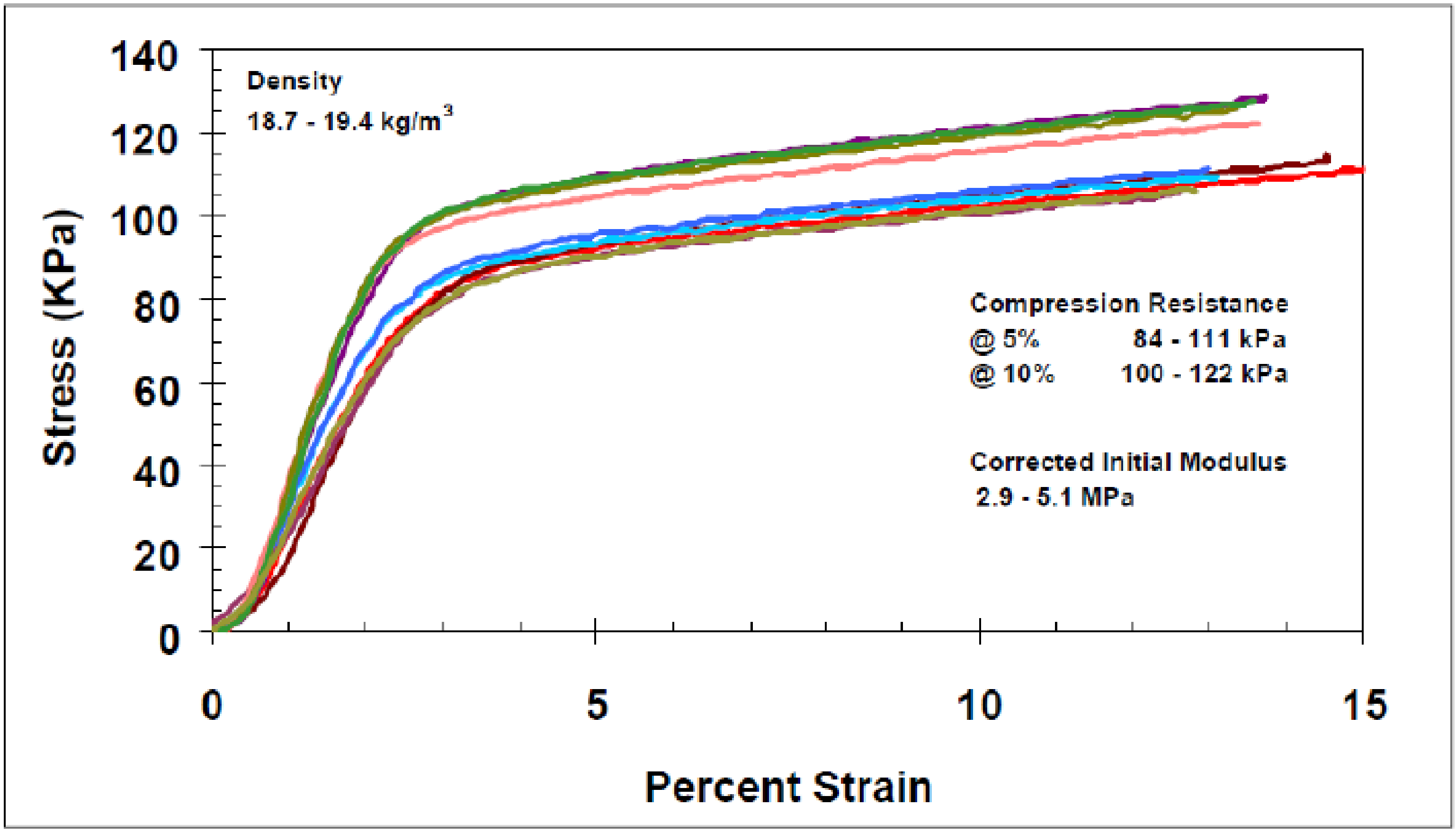


Figure 2-1 Compressive Resistance (Stress) Versus Strain for I-15 Type VIII Geofoam (from Bartlett et al., 2000).

Geofoam Properties (ASTM D6817)

Table 4-1 Physical Properties of Geofoam (from ASTM D6817).

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)
Flexural Strength, min., kPa (psi)	69 (10.0)	172 (25.0)	207 (30.0)	276 (40.0)	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

Sample Size Effects

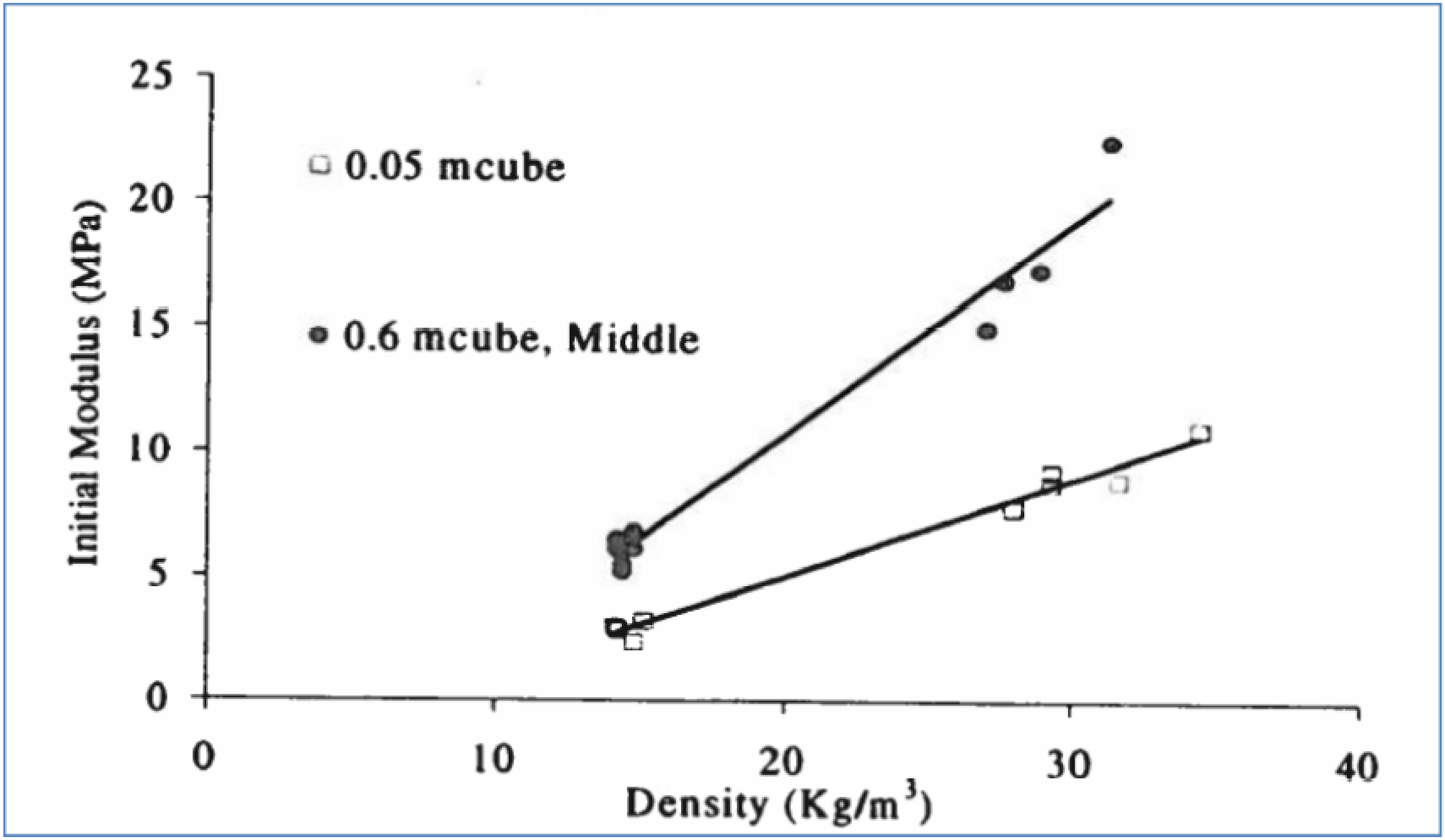
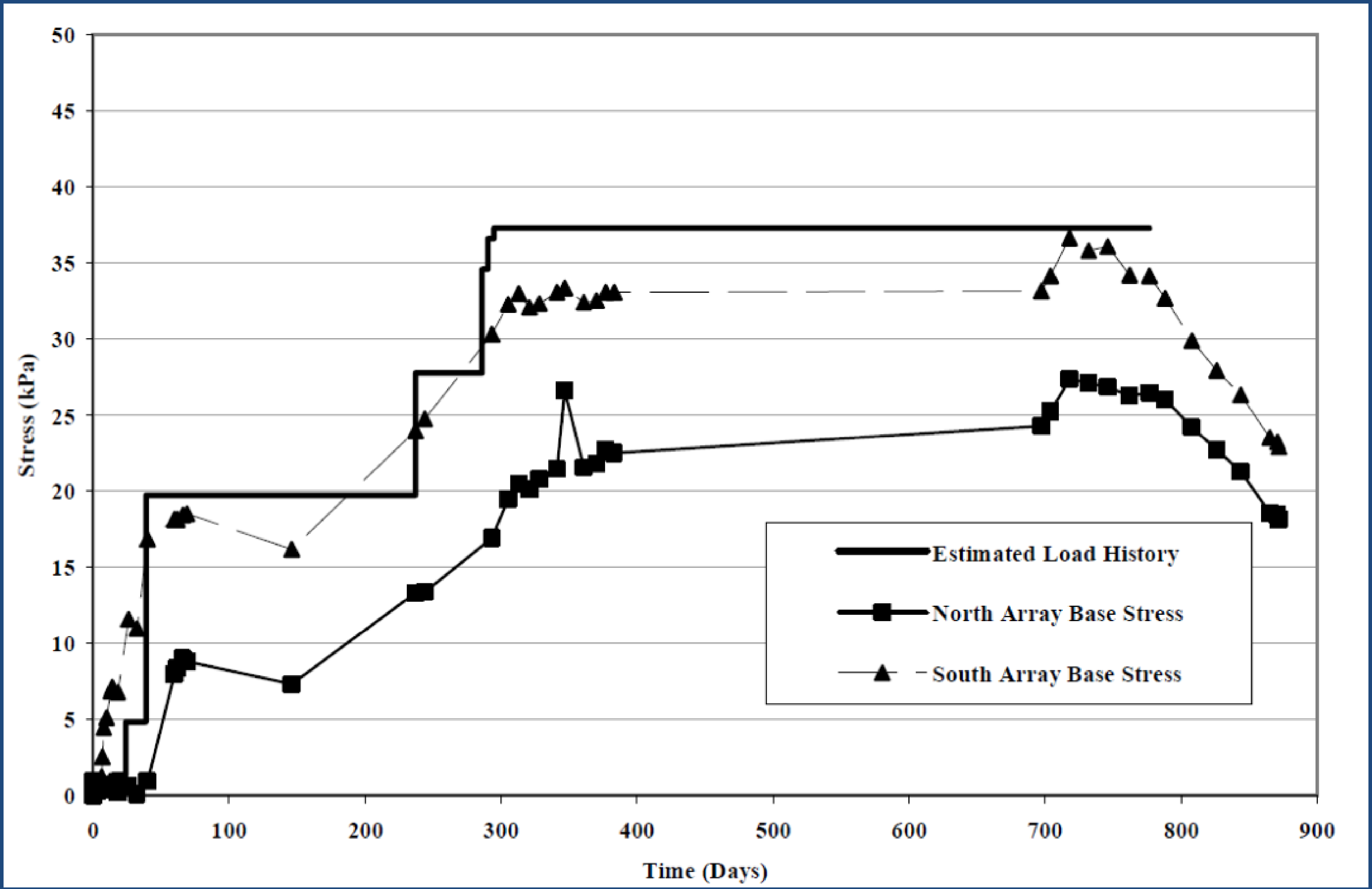
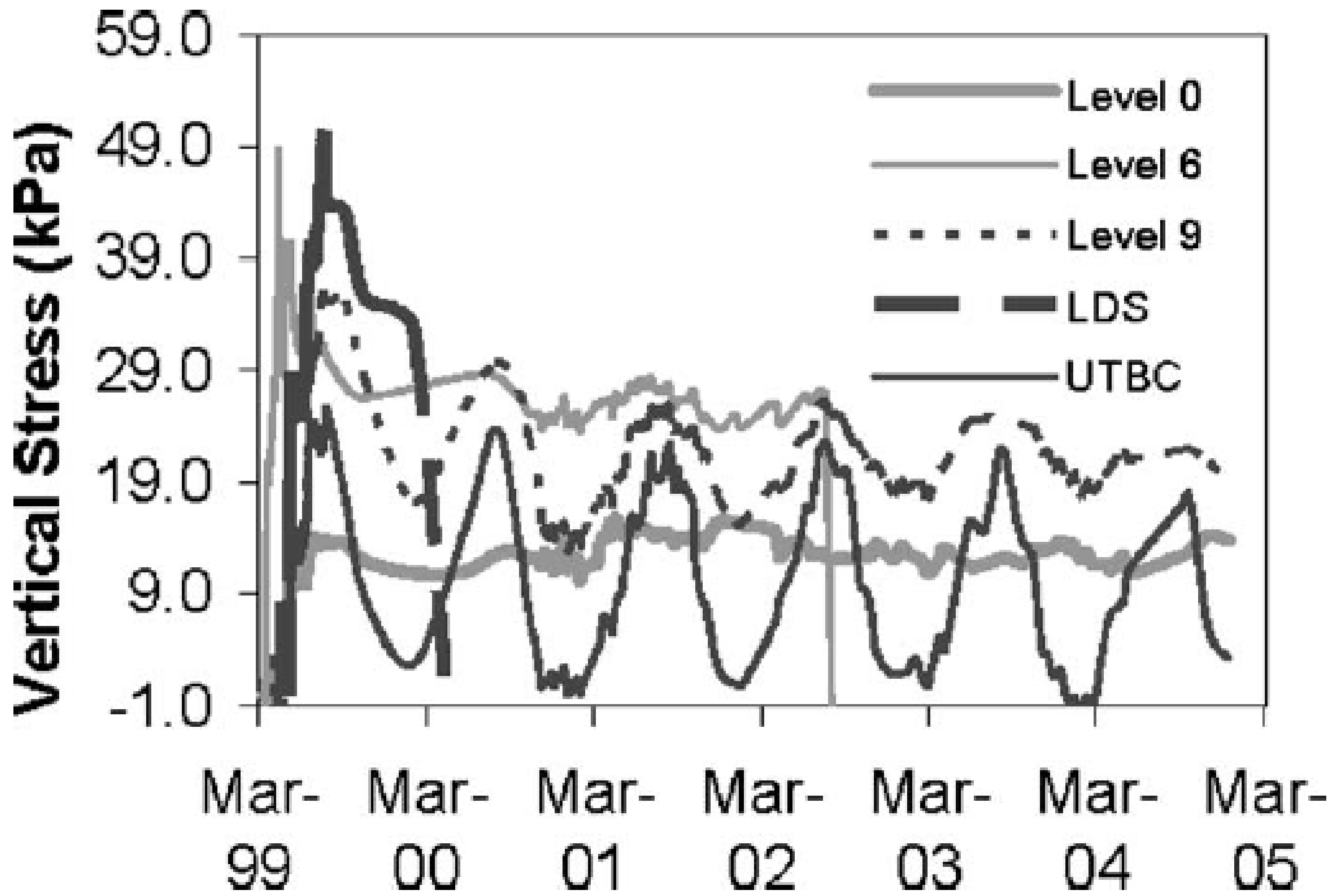


Figure 2-4 Initial Young's Modulus Values for 5-cm and 60 cm Cube Samples as a Function of EPS Density and Sample Size (Elragi et al., 2000).

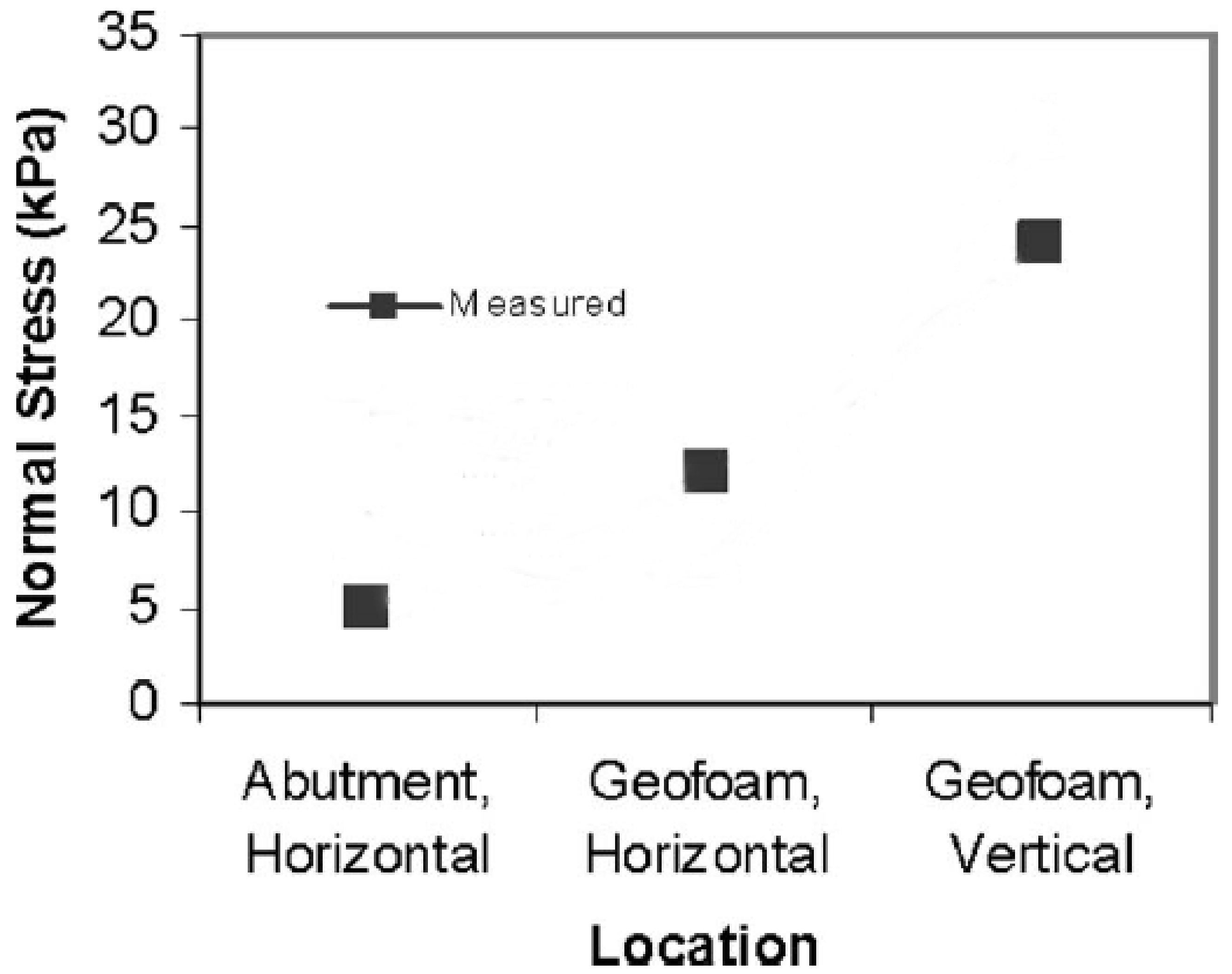
100 South Array
(Load and Pressure Cells)



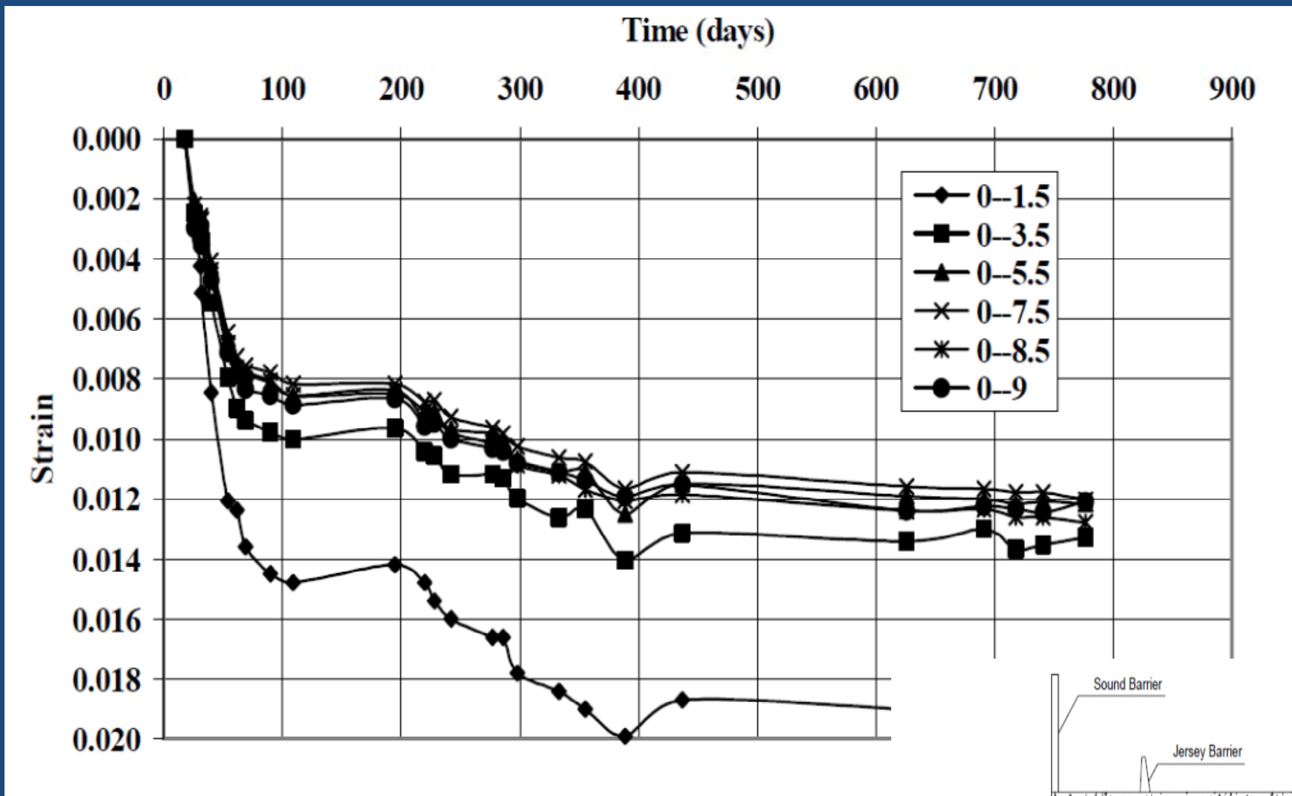
3300 South Array
(Load and Pressure Cells)

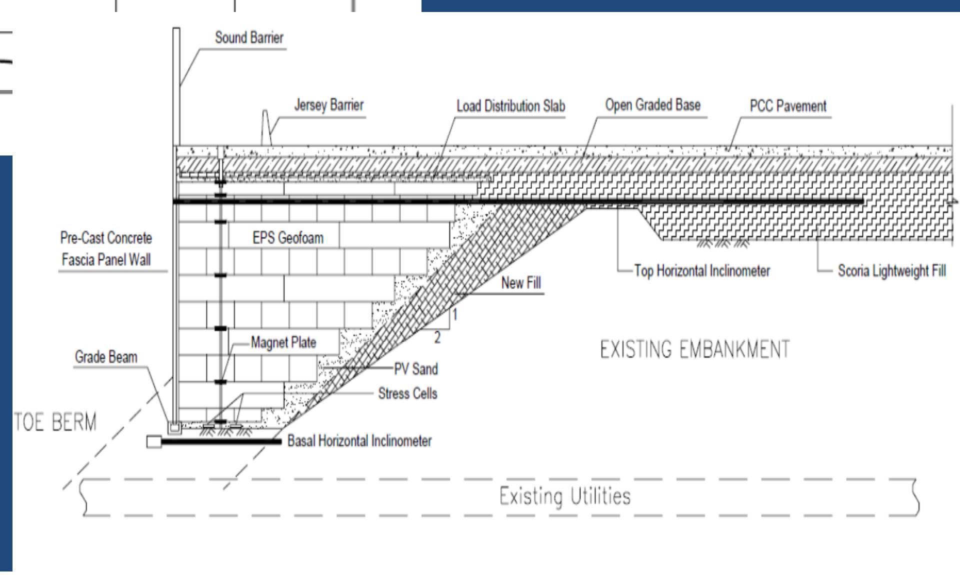


State Street Array
(Pressure Cells Measurements)

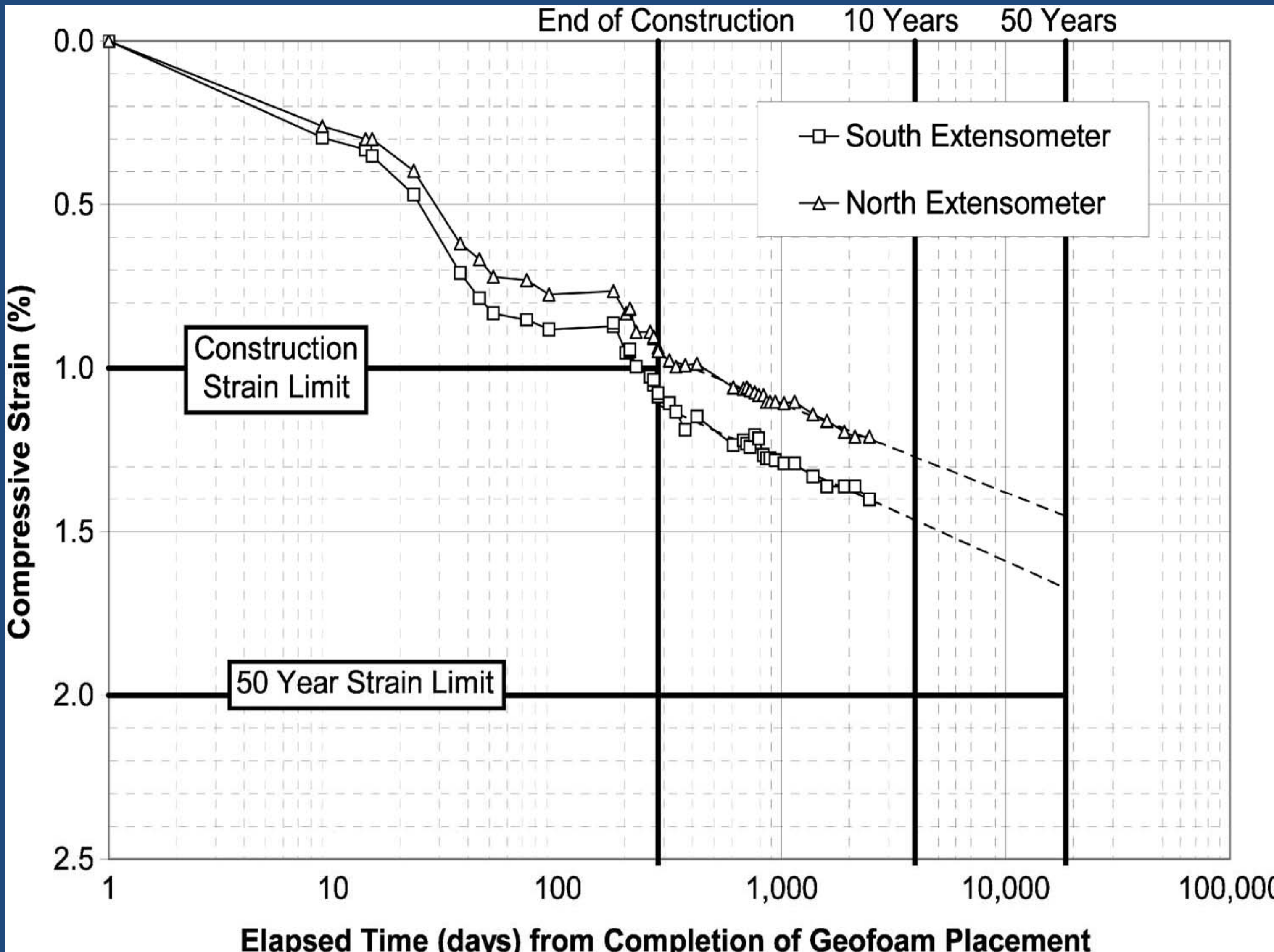


100 South Array (Vertical Strain)

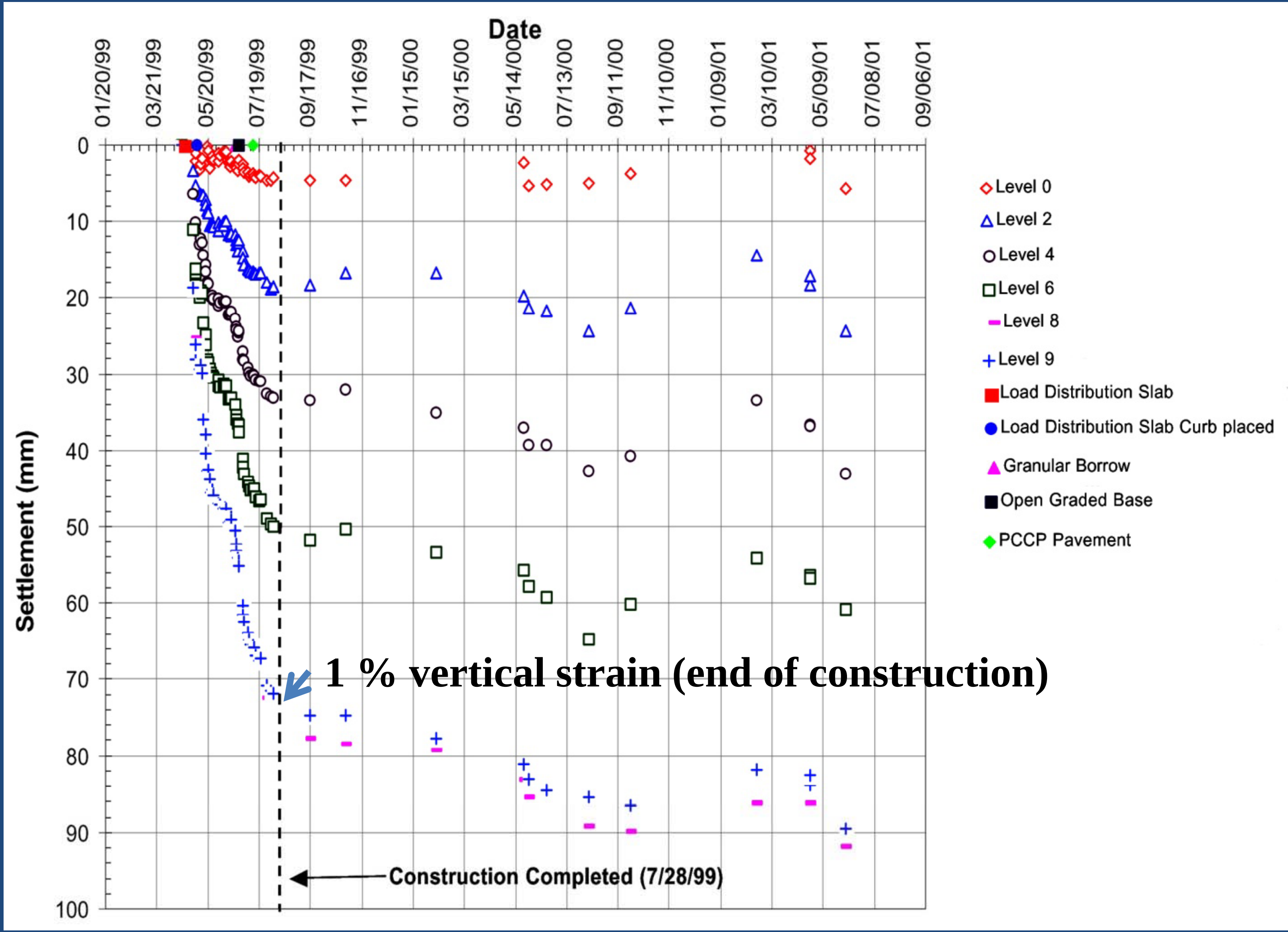




100 South Array
(Creep Settlment)



3300 South Array
(Vertical Settlement / Strain)



Design Traffic Loading

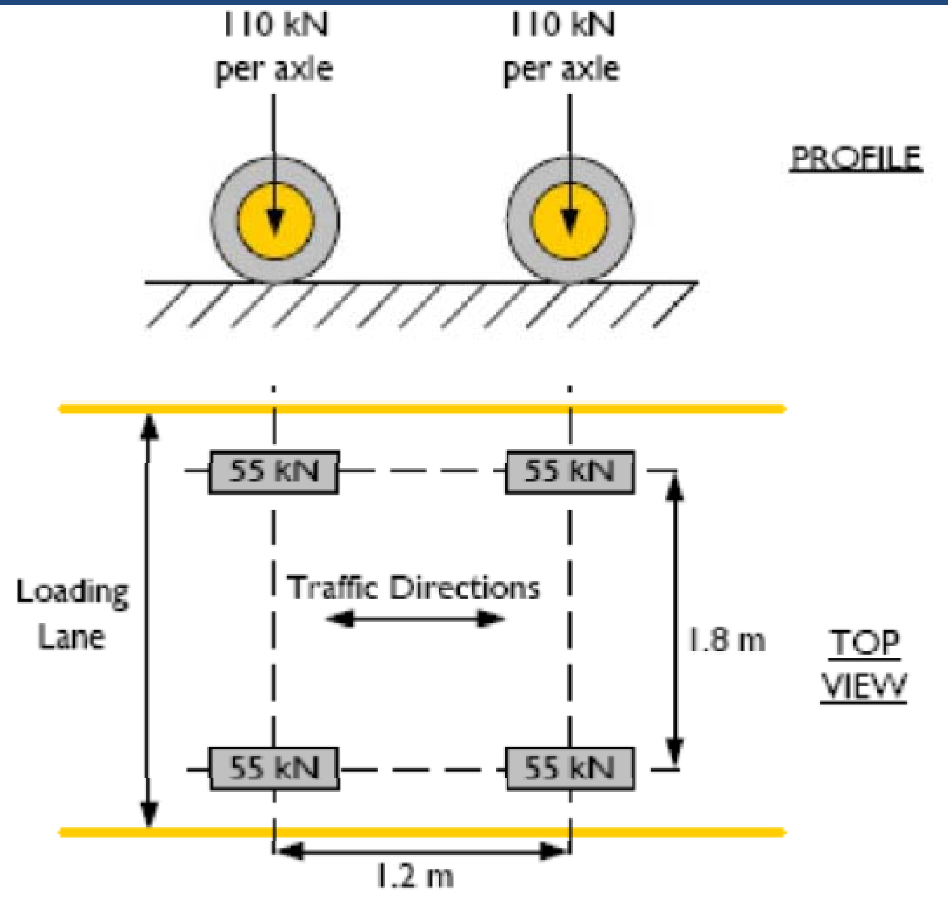


Figure 3-3 25-kip (110 kN) Dual Tire Load

X-Section View of Vertical Stress

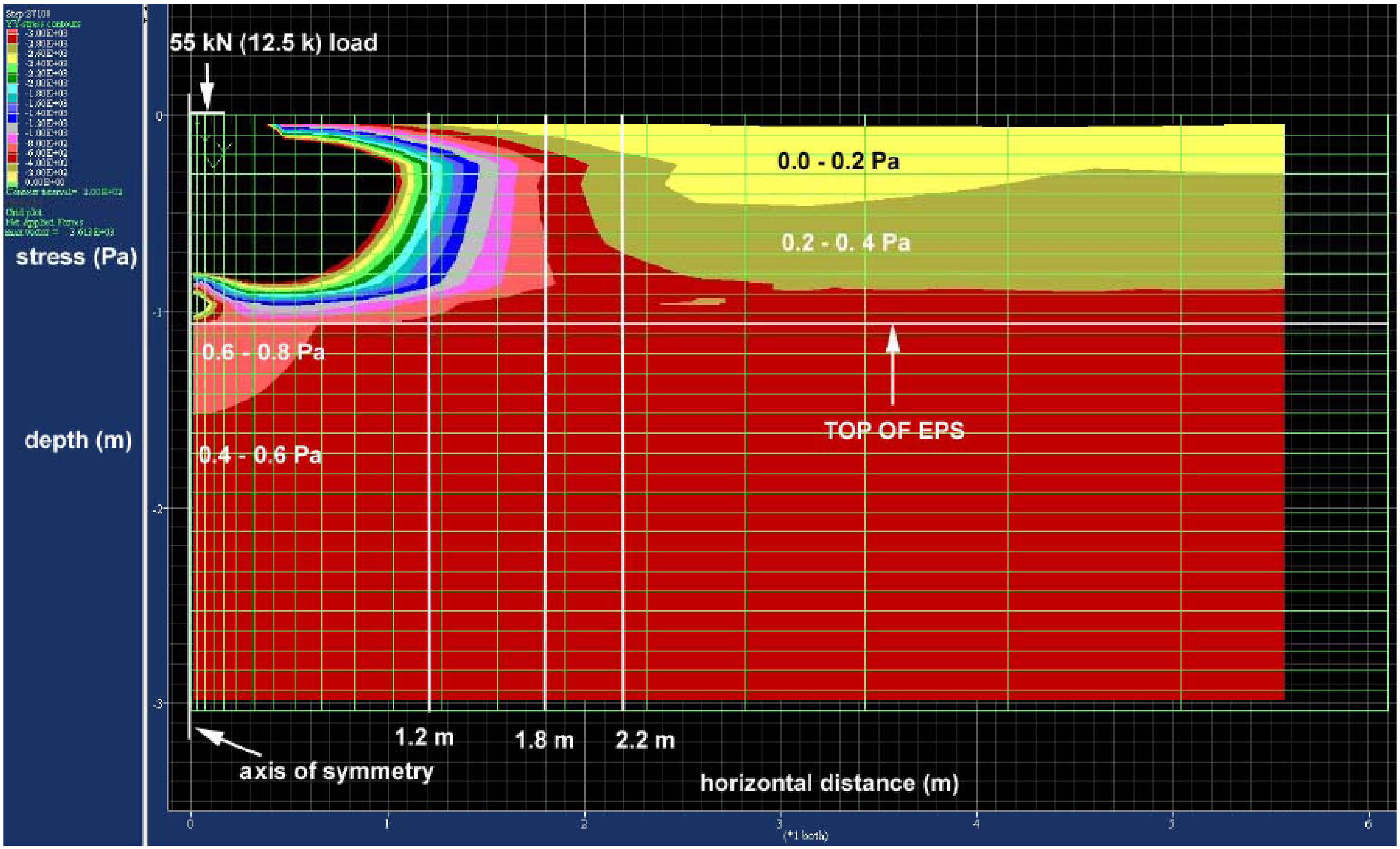
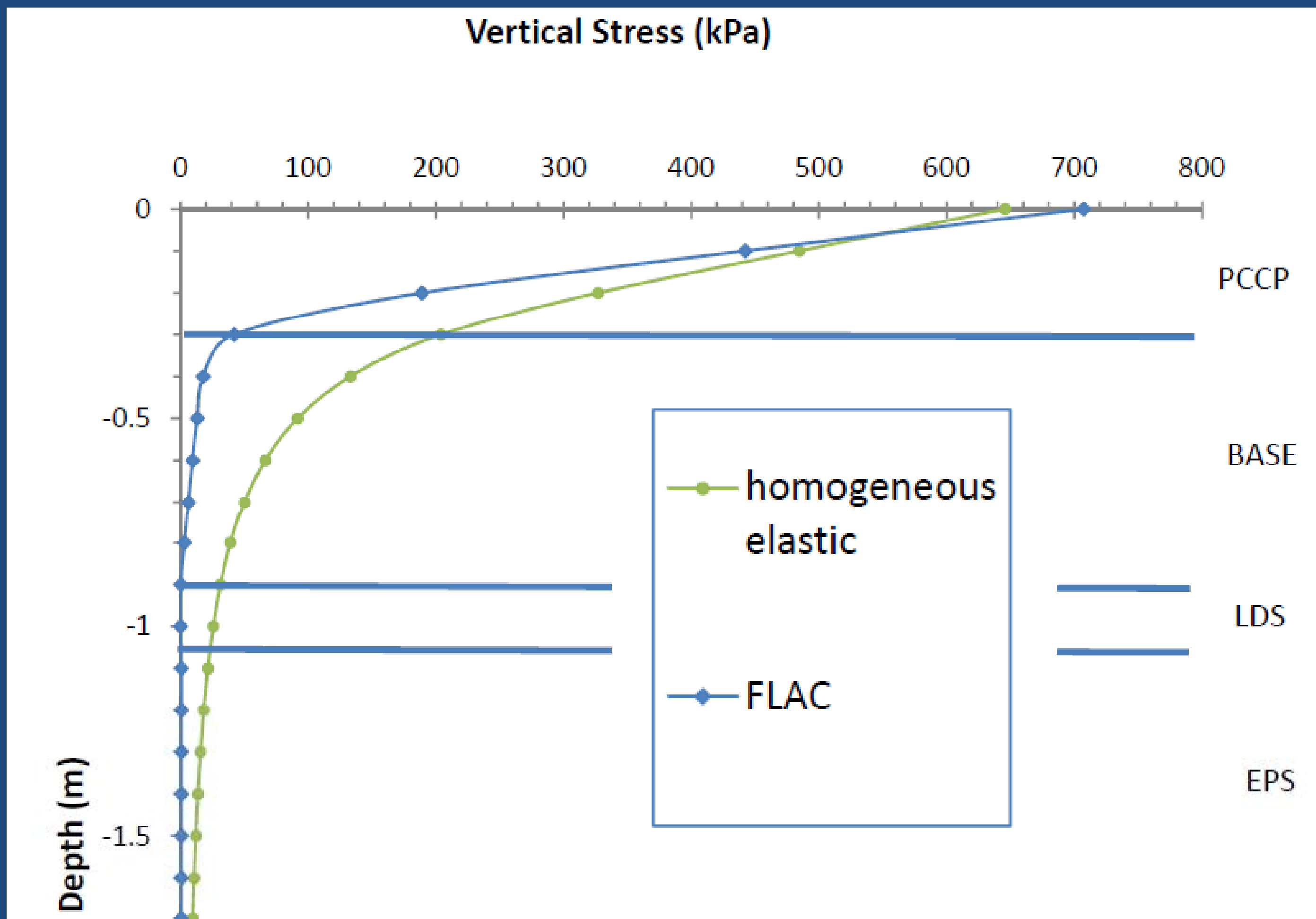


Figure 3-7 Vertical Stress Contours for 55 kN (12.5 kip) Dual Tire Load.

Vertical Stress Profile



Conclusions

- I-15 Design was done using Draft European Design Codes (1998)
  - Based on performance data, this methodology is acceptable
  - EPS 19 is adequate for systems with LDS
- NCHRP 529 does not address short-term loading conditions
  - Construction loadings
  - Parking lot scenarios
  - Loading combination used in NCHRP 529 is questionable, use of impact factor with dead load is questionable

Conclusions (cont.)

- No method fully addresses vertical stress distributions for layered systems with load distribution slabs
  - Vertical stress distributions can be determined from numerical modeling
- No method address sample size and its effects on modulus
- No method fully addresses seismic design
- All methods should be considered as guidance and further research and development is warranted.
- Recommend a Combination of:
  - NCHRP 529 and European Design Codes (2011)

UDOT Reports

- Bartlett, S.F., Lawton, E.C., Farnsworth, C.B., and Newman, M.P., 2011,“Design and Evaluation of Geofoam Embankment for the I-15 Reconstruction Project, Salt Lake City, Utah, Prepared for the Utah Department of Transportation Research Division, Report No. UT-???, Oct. 2011, 184 p.

- Bartlett, S.F. and Farnsworth, C.B., 2004. “Monitoring and Modeling of Innovative Foundation Treatment and Embankment Construction Used on the I-15 Reconstruction Project, Project Management Plan and Instrument Installation Report,” UDOT Research Report No. UT-04.19, 202 p.

- Farnsworth, C. B. and Bartlett, S. F. (2008). “Evaluation of Rapid Construction and Settlement of Embankment Systems on Soft Foundation Soils.” *UDOT Research Report No. UT-08.05*, Utah Department of Transportation, Salt Lake City, Utah.

Papers

•Farnsworth C. F., Bartlett S. F., Negussey, D. and Stuedlein A. 2008, "Construction and Post-Construction Settlement Performance of Innovative Embankment Systems, I-15 Reconstruction Project, Salt Lake City, Utah," Journal of Geotechnical and Geoenvironmental Engineering, ASCE (Vol. 134 pp. 289-301).

• Newman, M. P., Bartlett S. F., Lawton, E. C., 2010, "Numerical Modeling of Geofoam Embankments," Journal of Geotechnical and Geoenvironmental Engineering, ASCE, February 2010, pp. 290-298.

• Bartlett, S. F. and Lawton E. C., 2008, "Evaluating the Seismic Stability and Performance of Freestanding Geofoam Embankment," 6th National Seismic Conference on Bridges and Highways, Charleston, S.C., July 27th – 30th 2008, 17 p.

• Bartlett, S. F., Negussey, D., Farnsworth, C. B., and Stuedlein, A., 2011, "Construction and Long-Term Performance of Transportation Infrastructure Constructed Using EPS Geofoam on Soft Soil Sites in Salt Lake Valley, Utah," EPS 2011 Geofoam Blocks in Construction Applications, Oslo Norway.

Papers (cont.)

- Bartlett, S. F., Trandafir, A. C., Lawton E. C. and Lingwall, B. N., 2011, “Applications of EPS Geofoam in Design and Construction of Earthquake Resilient Infrastructure,” EPS 2011 Geofoam Blocks in Construction Applications, Oslo Norway.

- Bartlett S. F., Farnsworth, C., Negussey, D., and Stuedlein, A. W., 2001, “Instrumentation and Long-Term Monitoring of Geofoam Embankments, I-15 Reconstruction Project, Salt Lake City, Utah,” EPS Geofoam 2001, 3rd International Conference, Dec. 10th to 12th, 2001, Salt Lake City, Utah, 23 p.

- Negussey, D., Stuedlin, A. W., Bartlett, S. F., Farnsworth, C., “Performance of Geofoam Embankment at 100 South, I-15 Reconstruction Project, Salt Lake City, Utah,” EPS Geofoam 2001, 3rd International Conference, Dec. 10th to 12th, 2001, Salt Lake City, Utah, 22 p.

Questions