Laboratory Evaluation of the GeoGauge™

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November 2000

Objectives of Laboratory Evaluation

- Verify reasonableness of GeoGauge measurements for approximate elastic half space model using well established soil mechanics principles:
  - Use dry silica sand in soil bin lined with energy absorbing material to simulate radiation damping.
  - Compare GeoGauge stiffness measurements with empirical relations of Hardin & Richart.

- Determine layering and boundary effects:
  - GeoGauge measurements on successive 4 inch layers in soil bin
  - GeoGauge measurements at various lateral positions on each successive layer

- Develop laboratory test methodology for determination of a subgrade's or base coarse's potential stiffness.
  - Standard Proctor compaction with subsequent GeoGauge measurement.

Raining of Silica Sand into Test Bin

Bin Dimensions:

30”x28”x24” Deep

3/4” Styrofoam Lined

U.S. Silica F-52 Sand

Mean Size: 0.26 mm

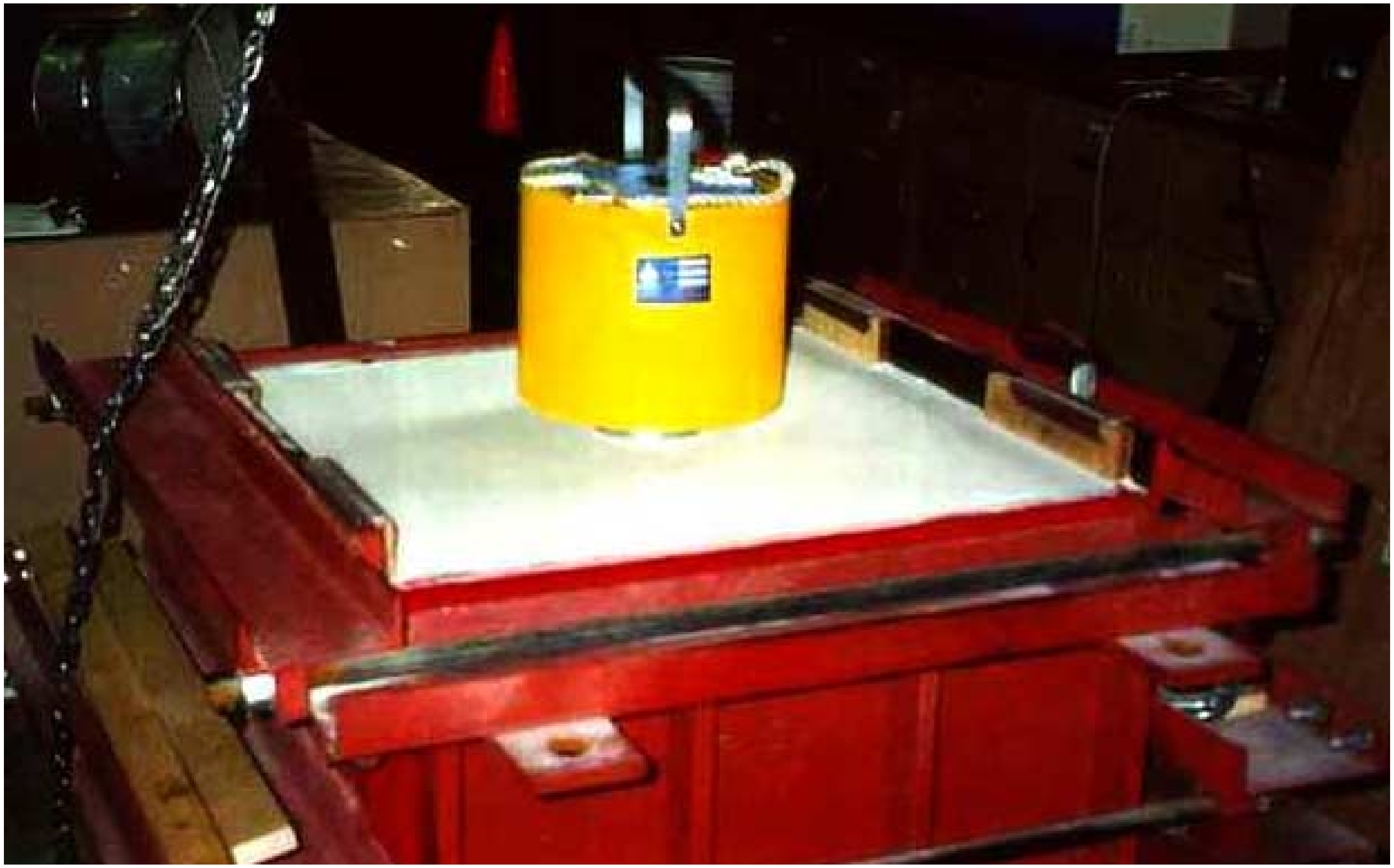
Rain Height: 18”

Void Ratio: 0.497

Dry Density: 110.5 pcf

Rel. Density: ~100%

GeoGauge Test on Dry Silica Sand



Half-Space Test Results

- GeoGauge Data (8 measurements) at Center-Line
  - Mean Stiffness: 6.19 MN/m (35300 lb/in.)
  - Standard Deviation: 0.04 MN/m
  - Coefficient of Variation: 0.7%

Analysis

Stiffness Solution for an Annular Loading (GeoGauge)
on an Elastic Half Space (Poulos & Davis)

$$K = \frac{F}{\delta} = \frac{3.54GR}{(1-\nu)}$$

where

K = Stiffness

G = Shear Modulus

R = Footing Radius (2.25 inch for GeoGauge)

ν = Poisson's Ratio

Estimate of Shear Modulus

(Hardin & Richart)

$$G = \frac{2630(2.17 - e)^2}{(1 + e)} (\bar{\sigma}_o)^{0.5}$$

G = Shear Modulus

e = Void Ratio

$\bar{\sigma}_o$ = Bulk Effective Stress

$$\bar{\sigma}_o = \frac{\bar{\sigma}_v + 2\bar{\sigma}_h}{3} = \frac{\bar{\sigma}_v + 2K_o\bar{\sigma}_v}{3} = \frac{\bar{\sigma}_v}{3}(1 + 2K_o)$$

where

$\bar{\sigma}_v$ = Vertical Effective Stress

$\bar{\sigma}_h$ = Horizontal Effective Stress

K_o = Lateral Earth Pressure Coefficient

$$K_o = \left(1 + \frac{2}{3}\sin\phi\right)\left(\frac{1 - \sin\phi}{1 + \sin\phi}\right) \qquad \text{(Jaky)}$$

where

ϕ = Effective Angle of Internal Friction

A laboratory estimate of the angle of internal friction was:

$$\phi = 33^{o}$$

With resultant estimates of:

$$K_o = 0.402$$

$$\overline{\sigma}_o = 0.601\ \overline{\sigma}_v$$

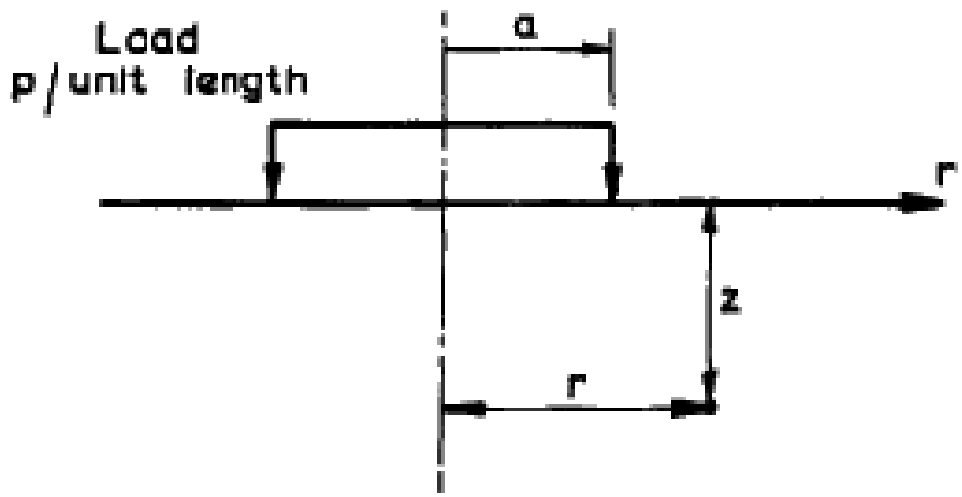
From Hooke's Law, Poisson's Ratio is: $$\nu = \frac{K_o}{1 + K_o}$$

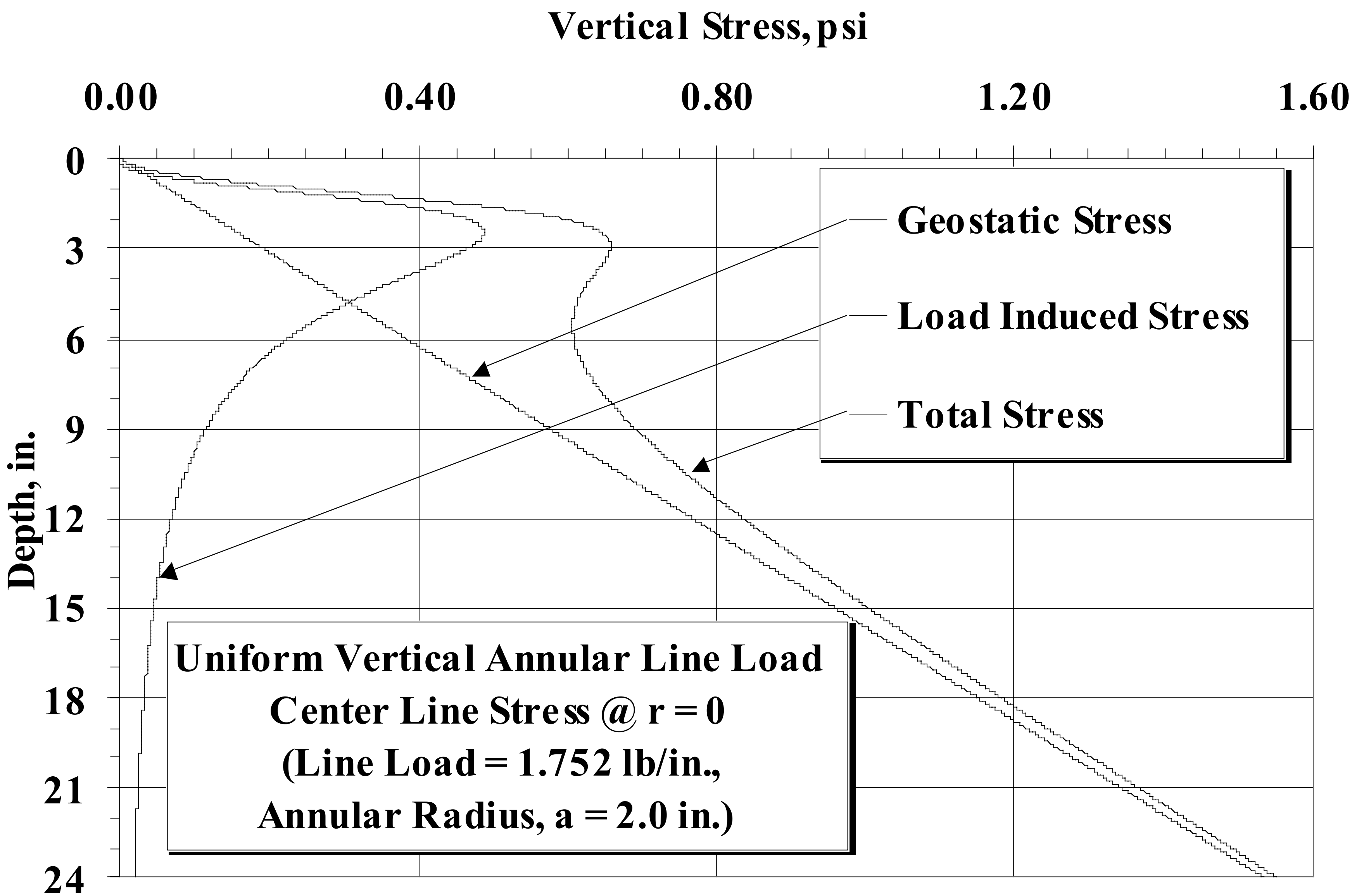
$$\nu = 0.287$$

Estimate of Vertical Effective Stress

The analytical solution for the vertical stress distribution on centerline below an annularly loaded footing is:

$$\sigma_v = \frac{3pz^3a}{\left(a^2 + z^2\right)^{5/2}} \qquad \text{(Poulos \& Davis)}$$




Vertical Stress, psi
0.00
0.40
0.80
1.20
1.60
Depth, in.
0
3
6
9
12
15
18
21
24
Geostatic Stress
Load Induced Stress
Total Stress
Uniform Vertical Annular Line Load
Center Line Stress @ r = 0
(Line Load = 1.752 lb/in.,
Annular Radius, a = 2.0 in.)

$$\bar{\sigma}_v = 0.63 \text{ psi}$$

(approximate average over 0 to 9 inch depth)

$$K = \frac{F}{\delta} = \frac{3.54GR}{(1-\nu)} = 33800 \text{ lb/in.}$$

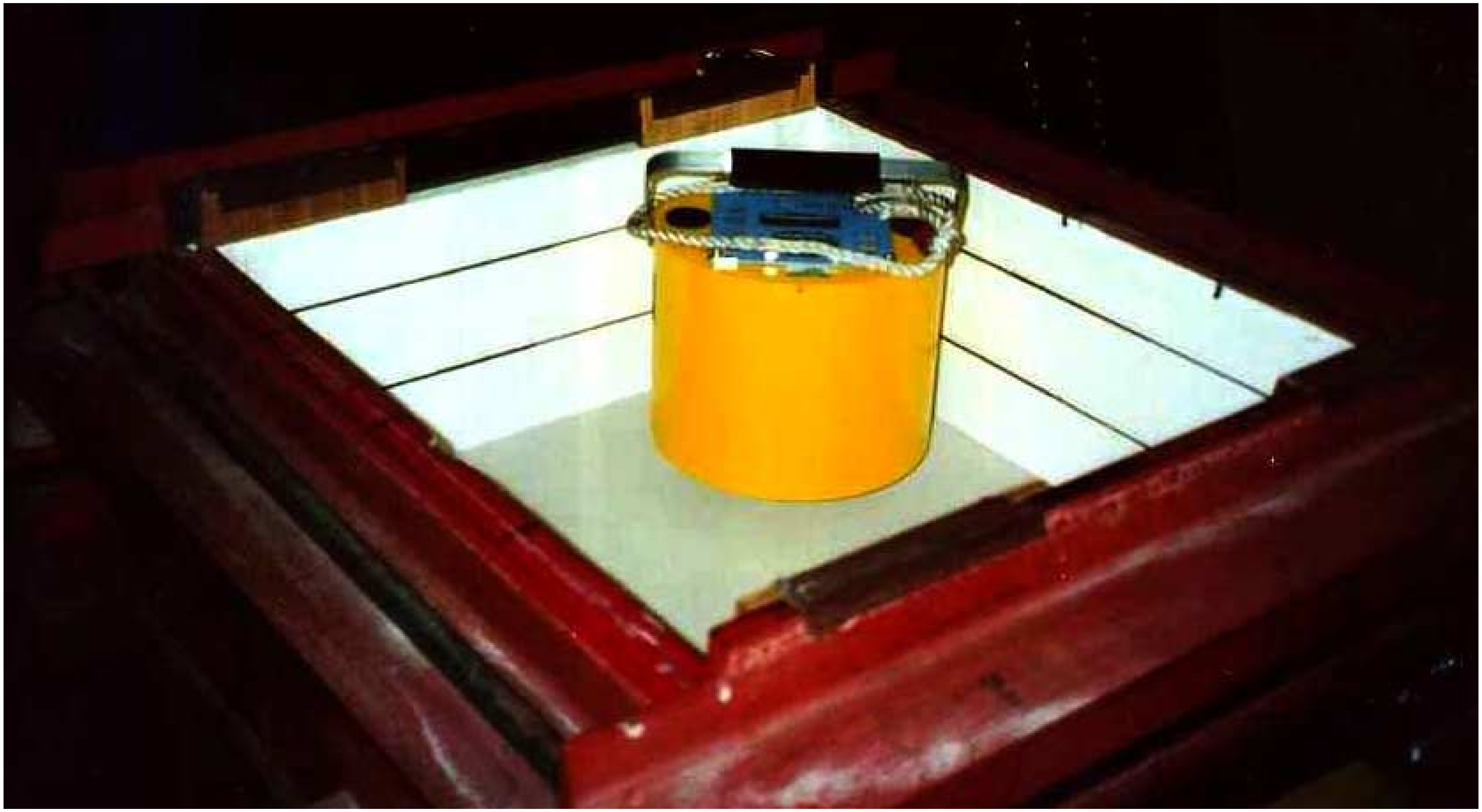
% Error

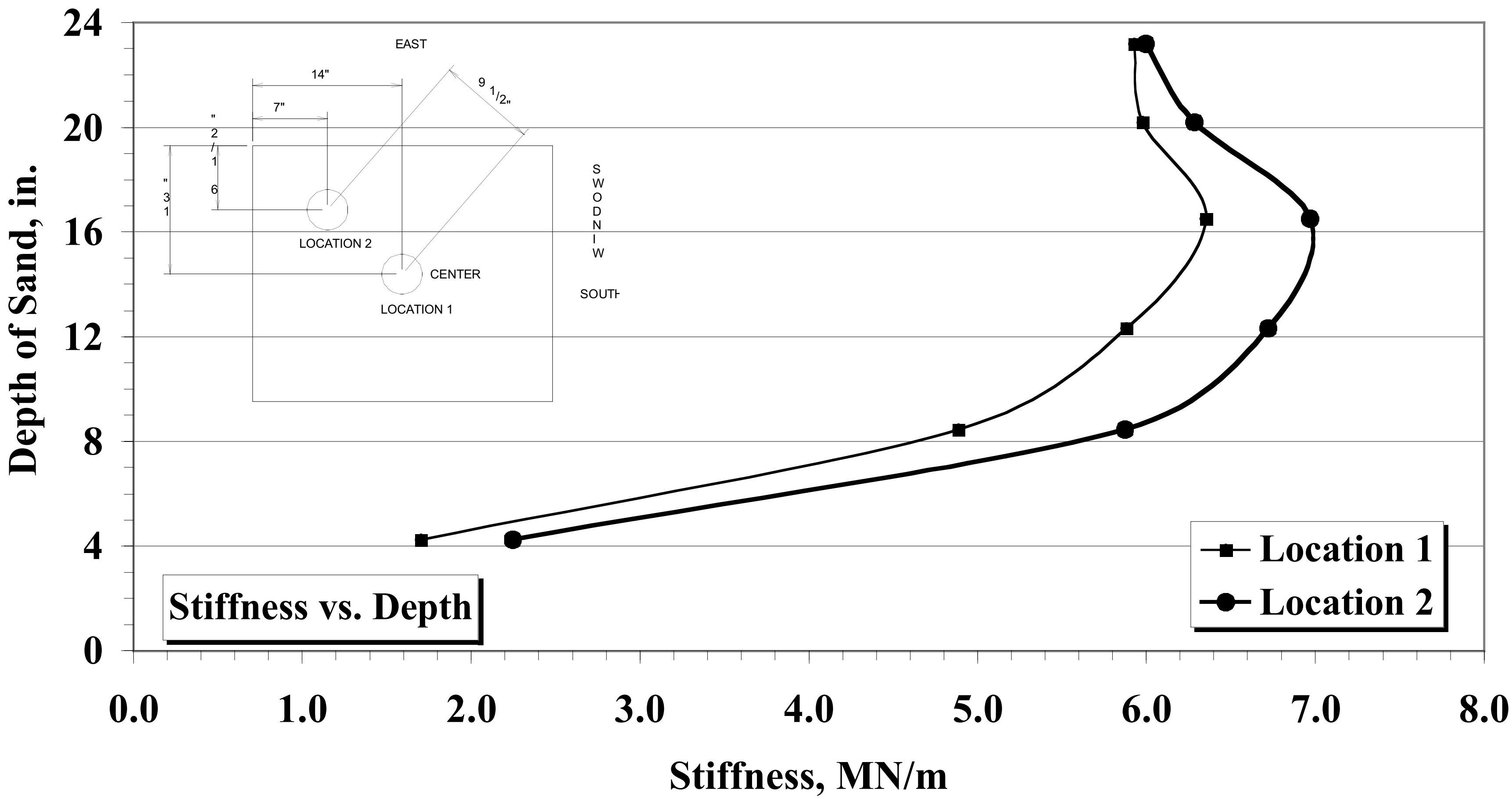
Experimental: 35300 lb/in.

Theoretical: 33800 lb/in.

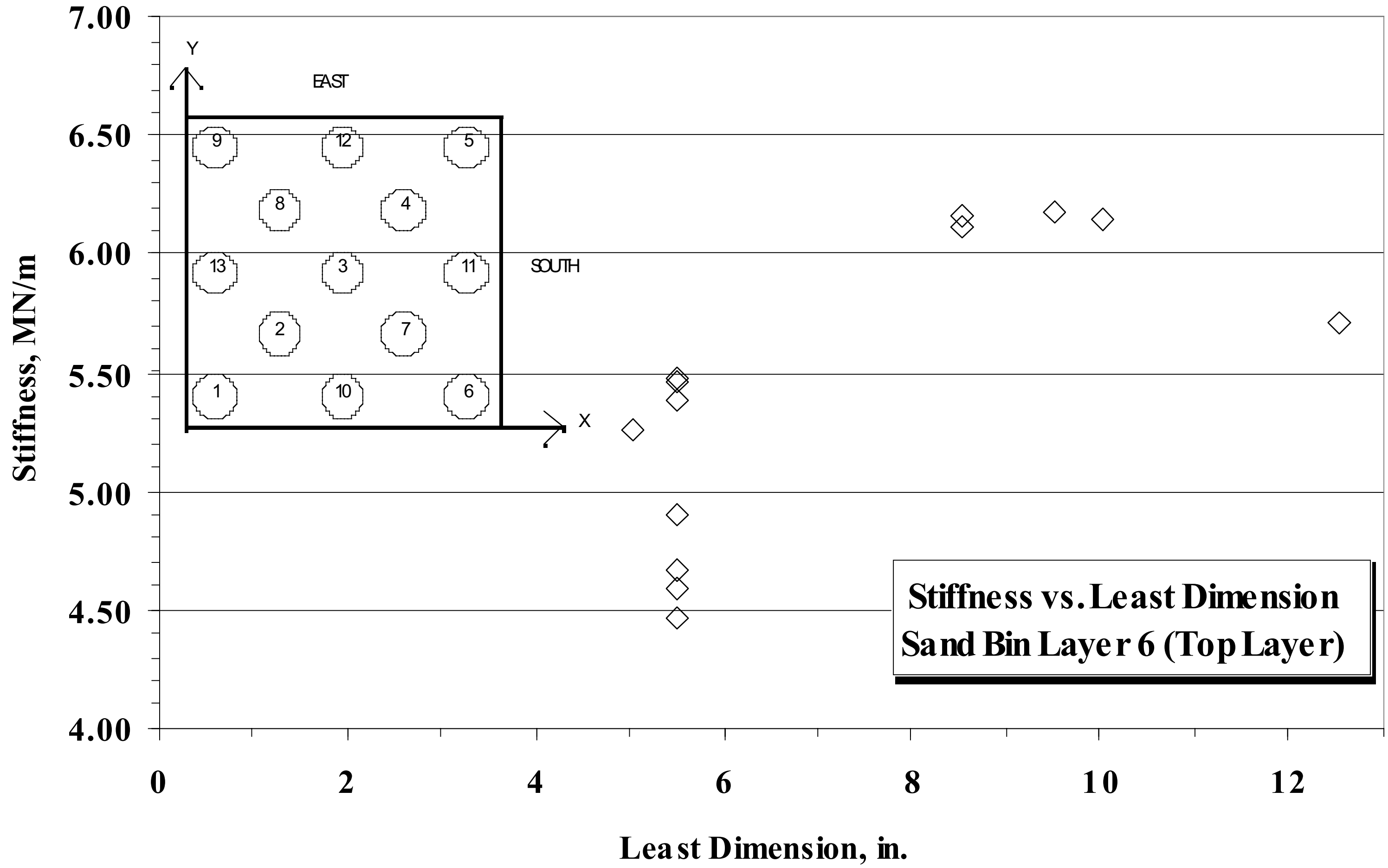
Error: 4.4 %

Layering and Boundary Effects on Dry Silica Sand





24
20
16
12
8
4
0
Depth of Sand, in.
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Stiffness, MN/m
Stiffness vs. Depth
Location 1
Location 2
EAST
14"
7"
LOCATION 2
CENTER
LOCATION 1
SOUTH



Stiffness vs. Least Dimension
Sand Bin Layer 6 (Top Layer)
Stiffness, MN/m
Least Dimension, in.
7.00
6.50
6.00
5.50
5.00
4.50
4.00
0
2
4
6
8
10
12
Y
X
EAST
SOUTH
9
12
5
8
4
13
3
11
2
7
1
10
6

Compaction of Cohesive Silty Sand

AASHTO: A-2-4; Unified: SM

Bin Dimensions:

15”x15”x12” Deep

1.5” Plywood Lined

Marshall Hammer

w/ 4” Square Foot

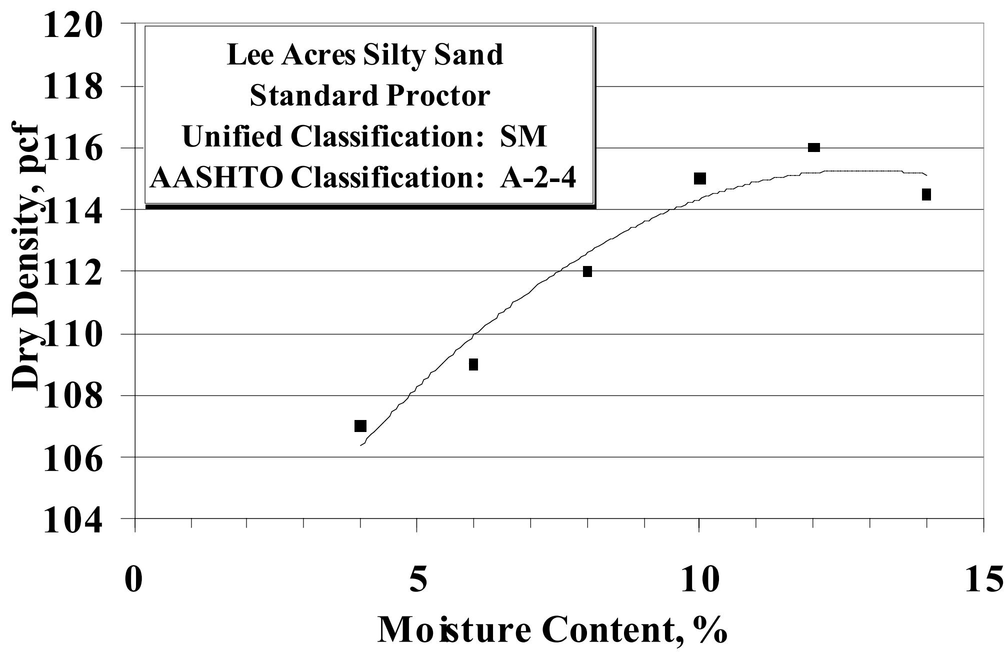
Standard Proctor
Compaction Energy

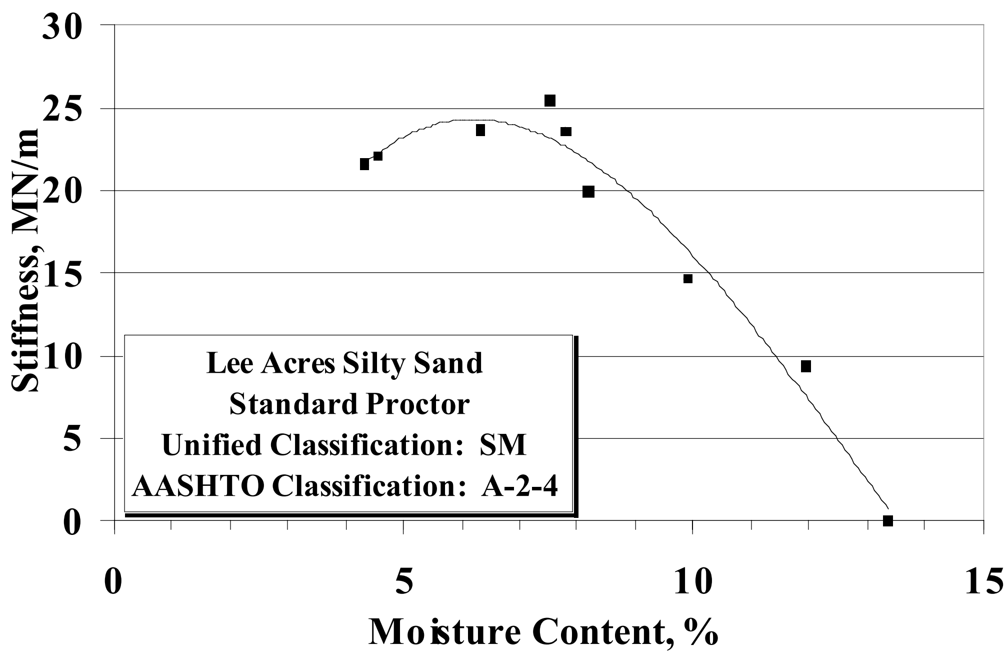
6 ea. ~ 2-1/8” Lifts

GeoGauge Stiffness Measurement

Moisture Content Evaluation

(~ 2 kg at Center-Line (Full Depth))


Lee Acres Silty Sand
Standard Proctor
Unified Classification: SM
AASHTO Classification: A-2-4
Dry Density, pcf
120
118
116
114
112
110
108
106
104
0
5
10
15
Moisture Content, %


Lee Acres Silty Sand
Standard Proctor
Unified Classification: SM
AASHTO Classification: A-2-4
Stiffness, MN/m
30
25
20
15
10
5
0
0
5
10
15
Moisture Content, %

Conclusions to Date

- GeoGauge Laboratory Measurements Verifiable by Rational Soil Mechanics Concepts
- Effects of Horizontal and Lateral Boundaries Minimal at ~12 inch Distance
- Optimum Moisture Content for Stiffness Below Optimum Moisture Content for Density