Design of Geosynthetics for Earth Walls under Special Conditions

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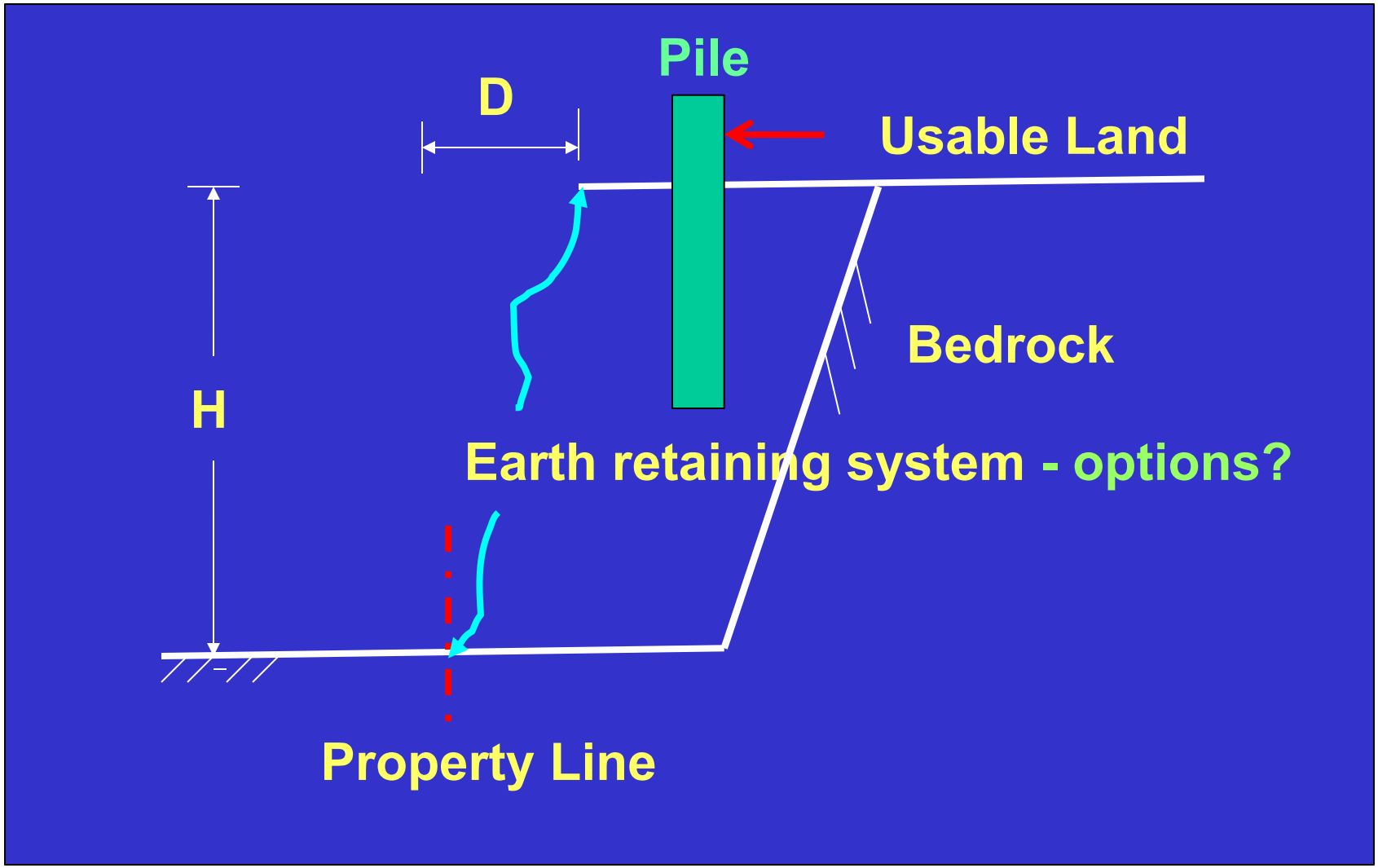
Outline of Presentation

- Introduction
- Tiered Walls
- Limited-Space Earth Walls
- Piles in Earth Walls Subjected to Lateral Loads

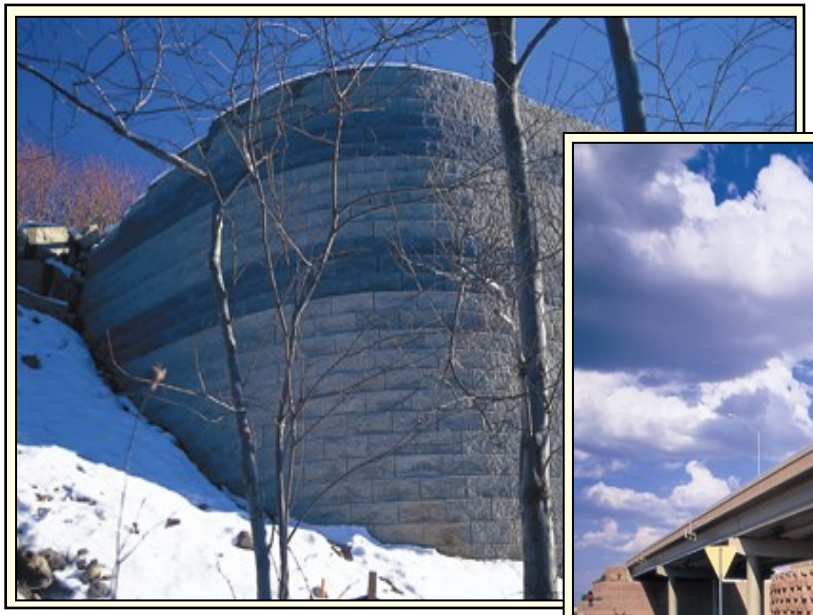
Introduction

Earth Walls under Special Conditions



Tiered Walls

Geosynthetic-Reinforced Retaining Structures



Wall

Tiered

Slope

Multi-tired Block Walls

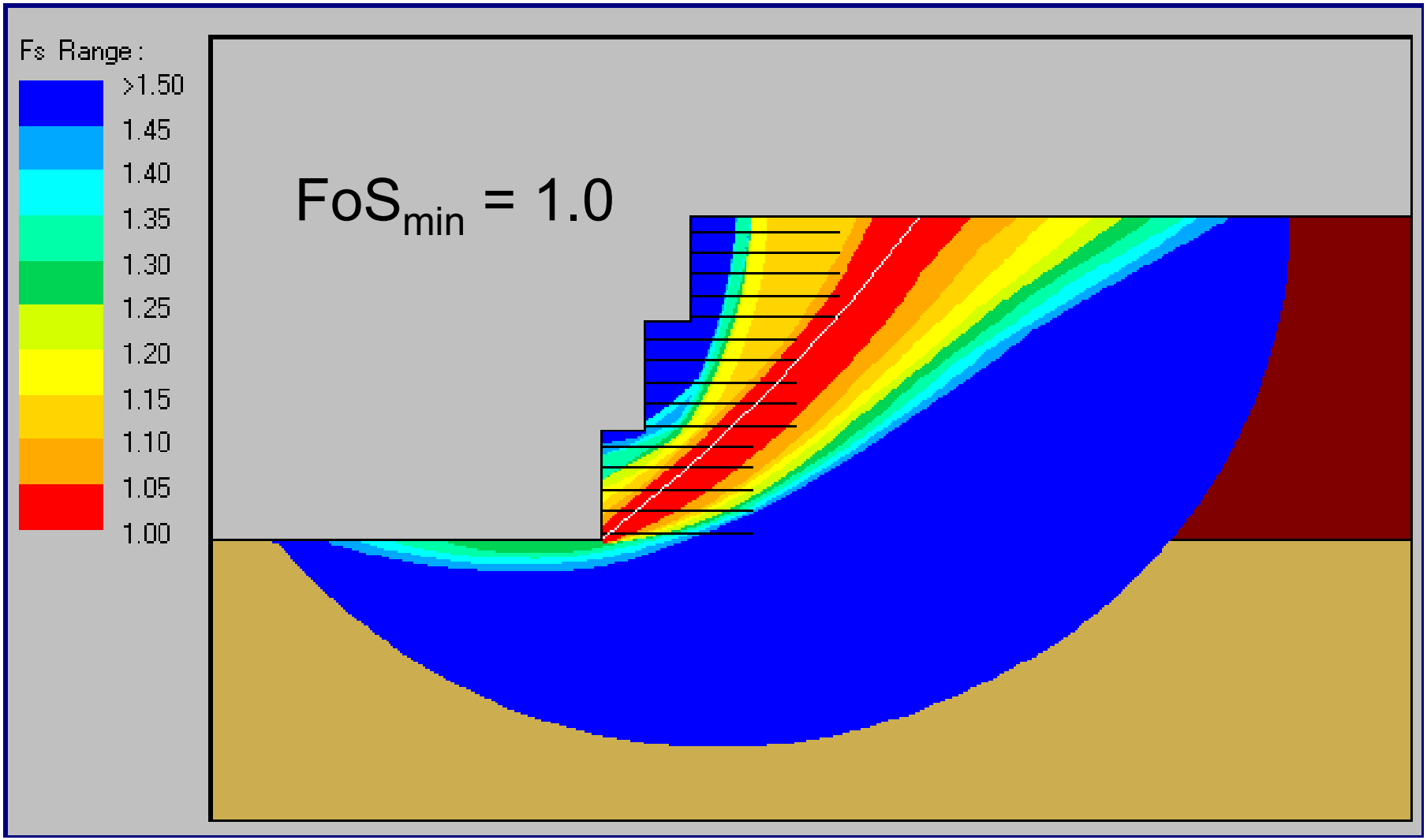
Courtesy of Leshchinsky

Question?

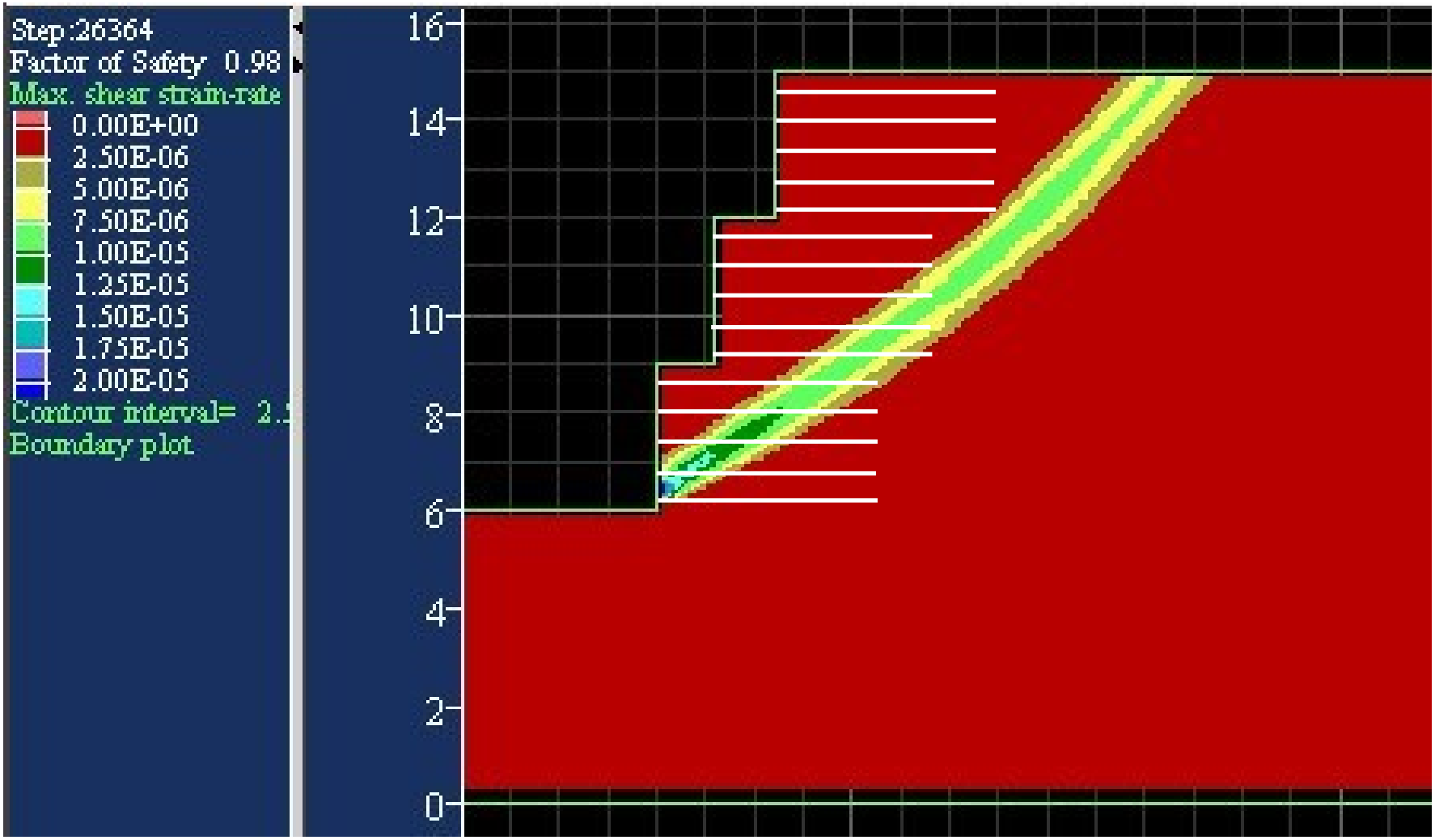
Tiered walls should be designed as

- Walls – Lateral earth pressure theory
- Slopes – Limit equilibrium theory

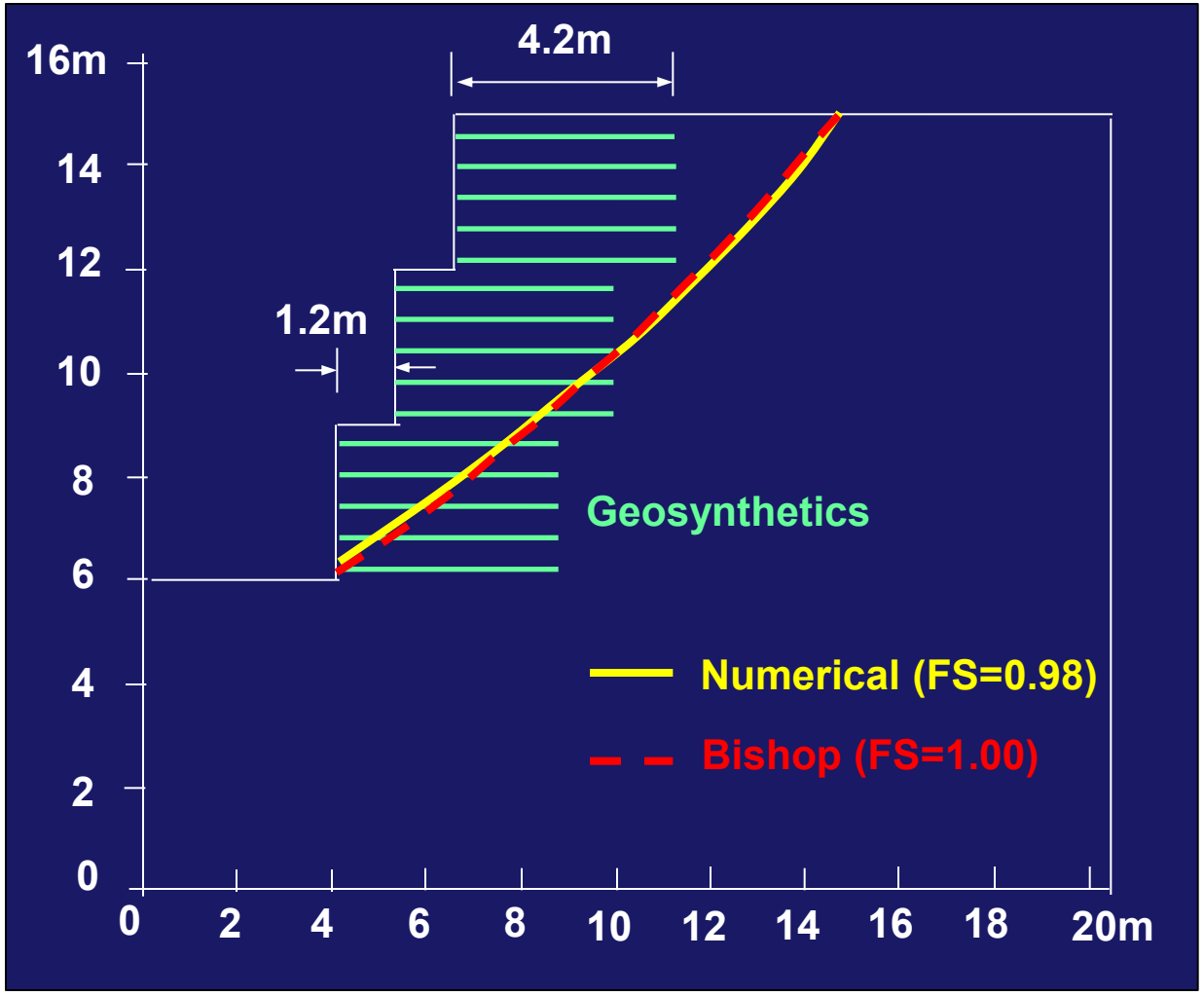
Minimal Factor of Safety and Critical Surface from ReSSA (2.0)



Minimal Factor of Safety and Critical Surface from FLAC (4.0)



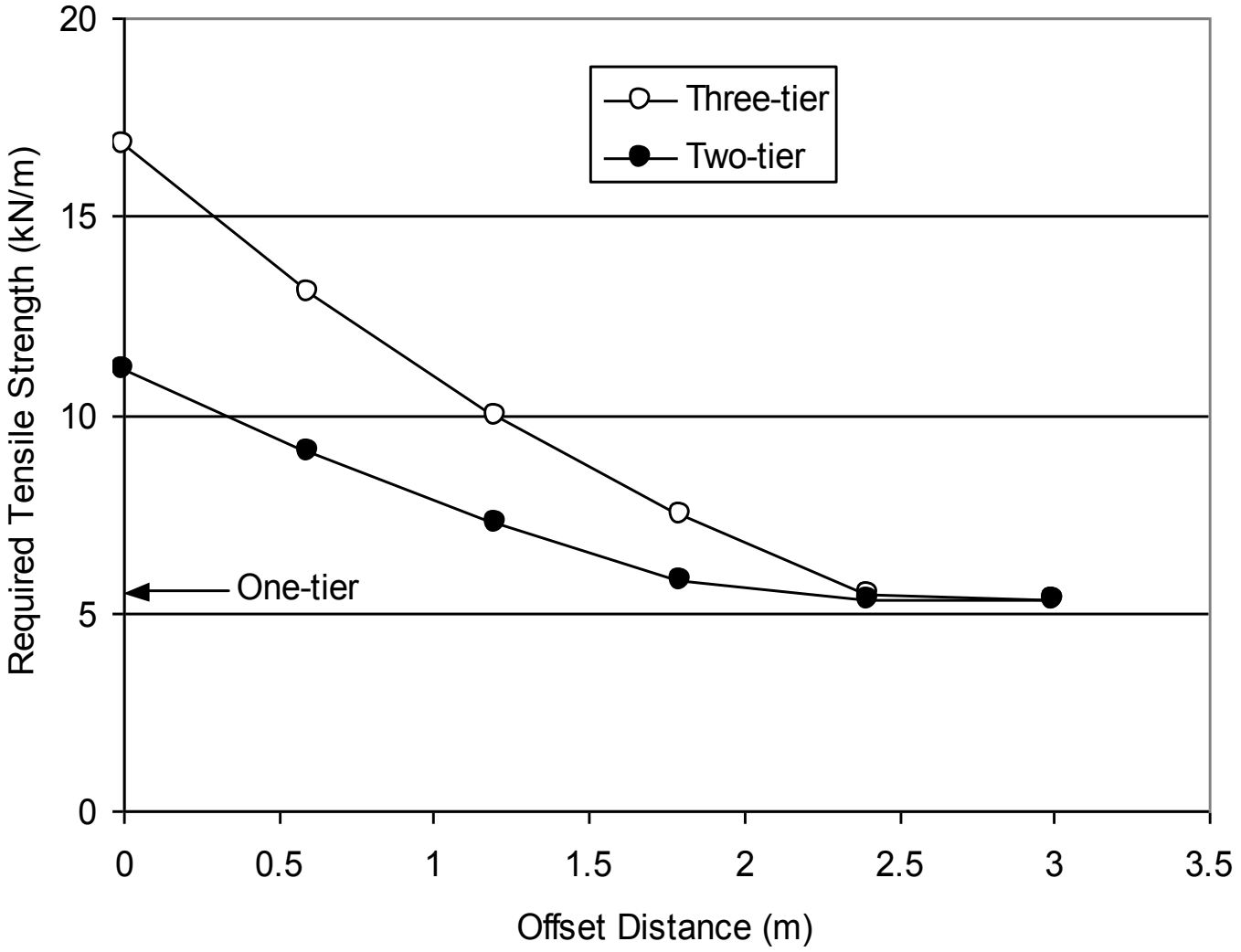
Critical Slip Surface and FS



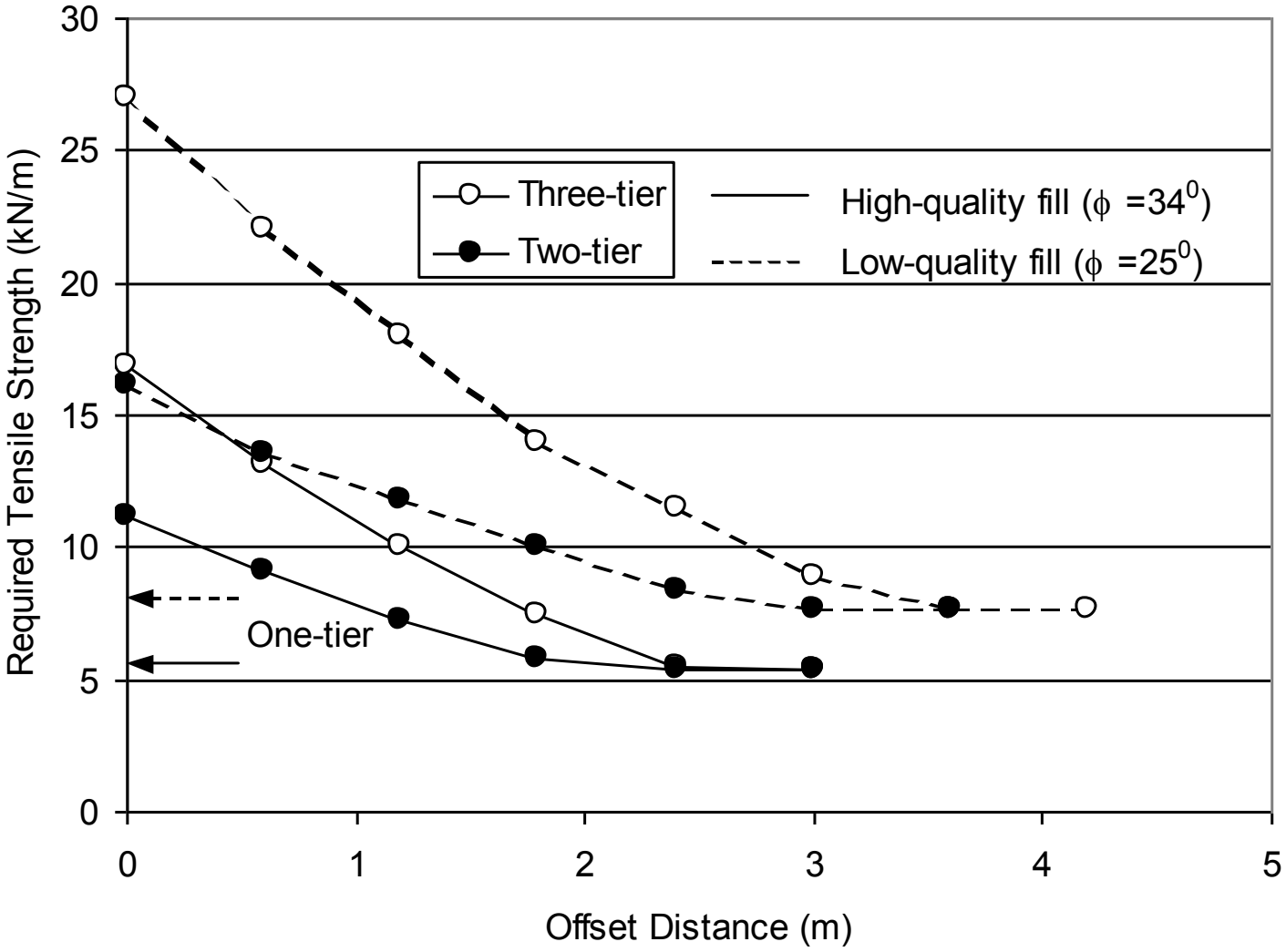
Summary of Parametric Study

Case Studied	Parameter Value	Tensile Strength (kN/m)	Fs (Numerical)	Fs (Limit equilibrium using Bishop)
Baseline	N_t = 3, H = 9m, d_{os}=1.2m, N_r = 1, L = 6.3m, J = 1000kN/m, γ=18 kN/m^3 c_r=0kPa, ϕ_r= 34^o, c_f=10kPa, ϕ_f=34^o, q=0kPa, h_w = N/A	10.0	0.99	1.00
Fill quality	c_r=0kPa, ϕ_r = 25^o	22.0	0.99	
Reinforcement length	L = 4.2m	11.4	0.98	
Reinforcement stiffness	J=100,000 kN/m	10.0	1.03	
Reinforcement type	N_r = 2	7.5 (upper 8 layers) 11.0 (lower 7 layers)	1.01	
Foundation soil	c_f=0kPa, ϕ_f = 18^o	10.0	0.86 (bearing failure)	
Water	h_w= 3m	9.25	1.01	
Surcharge	q = 20 kPa	11.6	1.02	
No. of tiers	N_t= 5, d_{os} = 0.6m	10.1	1.00	

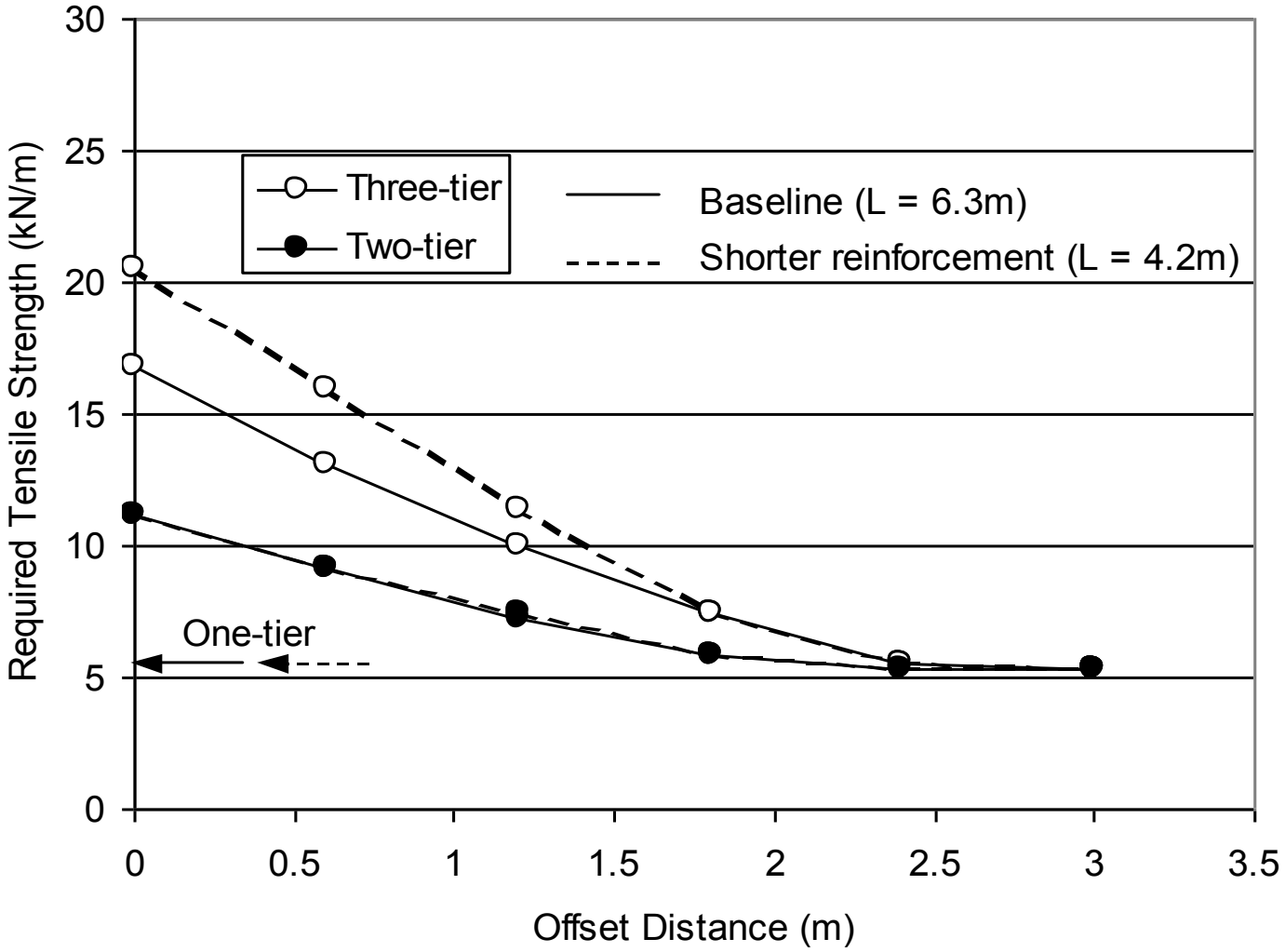
Effect of Offset Distance



Effect of Fill Quality



Effect of Reinforcement Length



Problem - ReSSA Demo

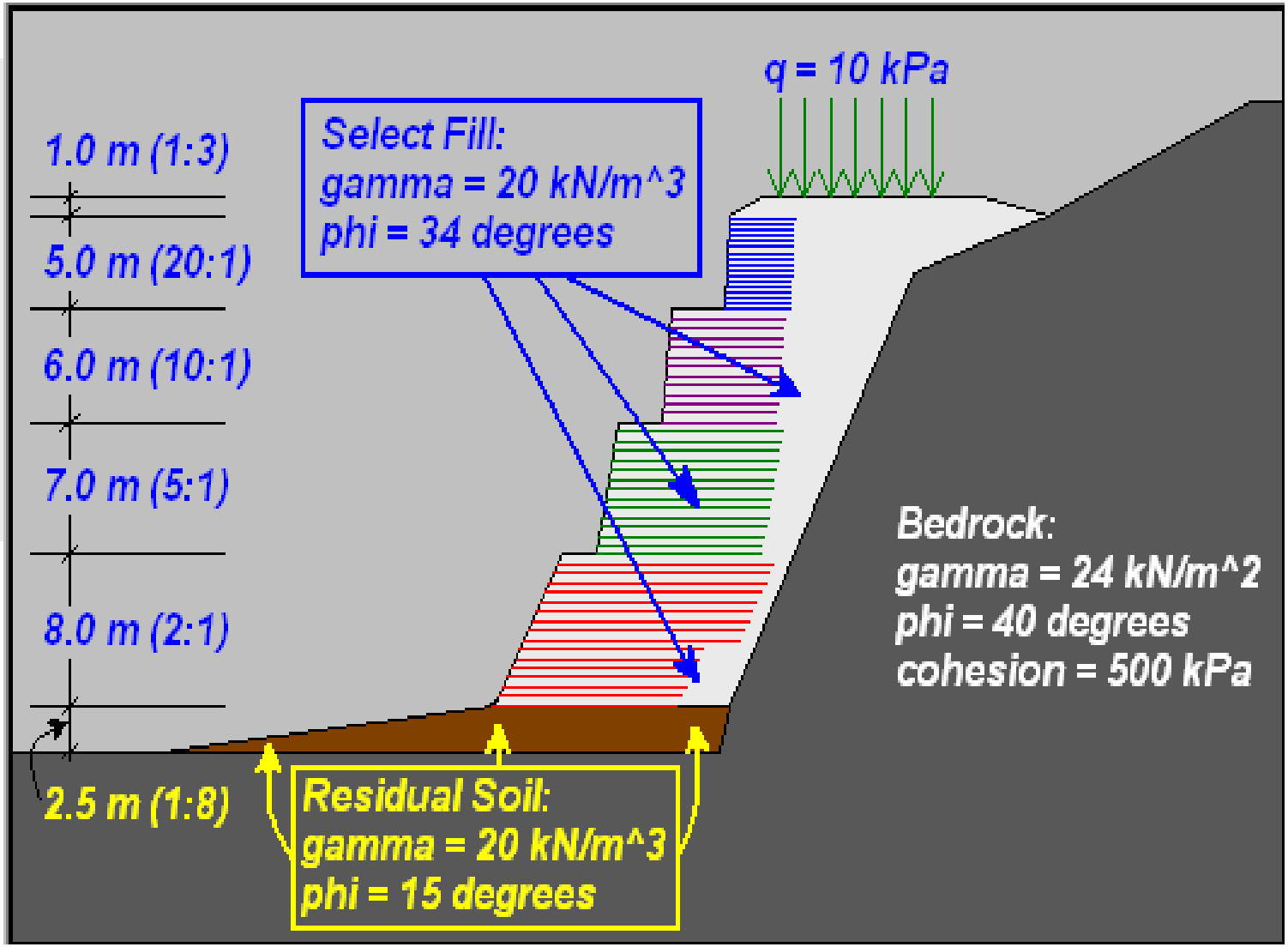
Tltds:

8 kN/m

30 kN/m

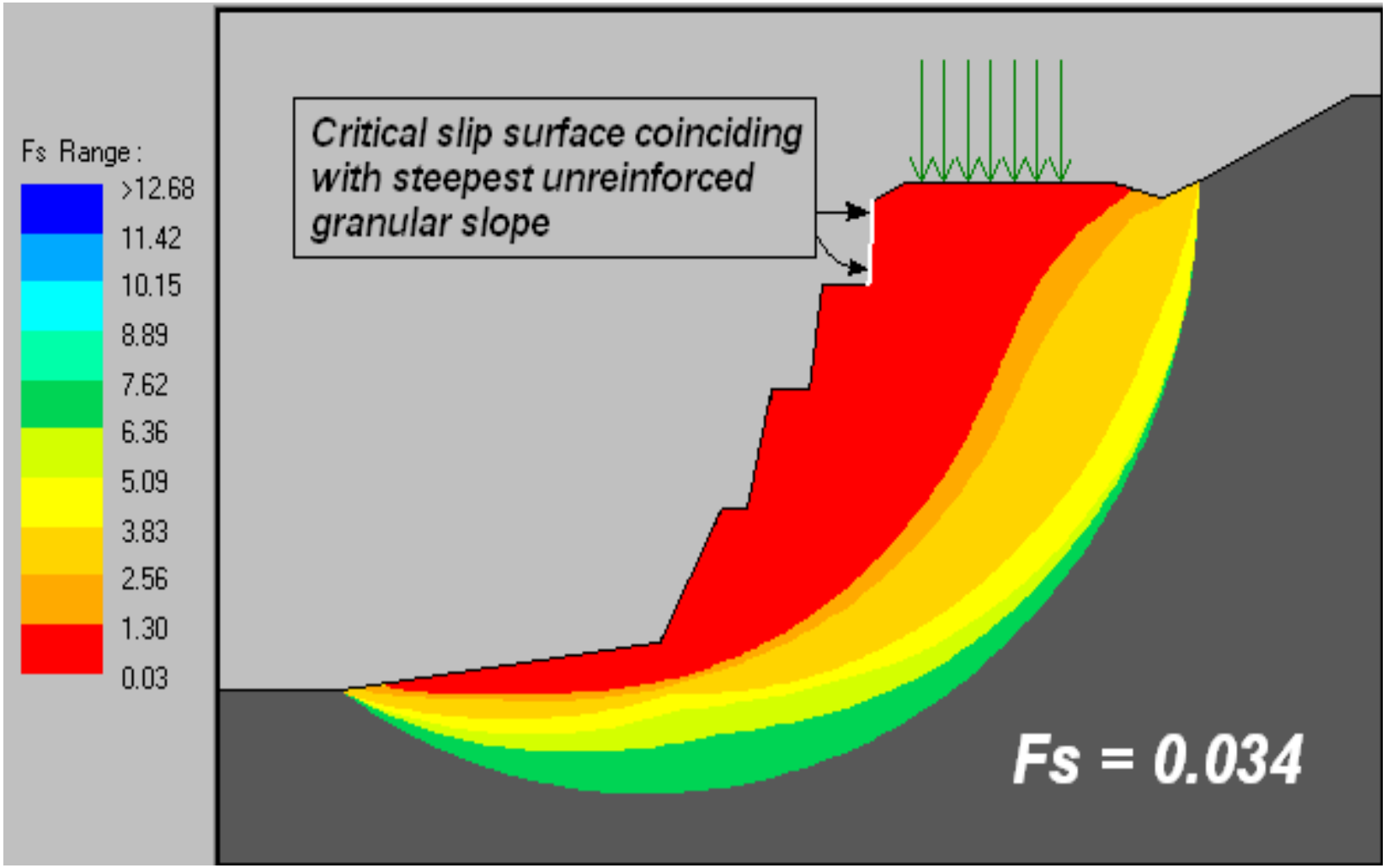
50 kN/m

80 kN/m



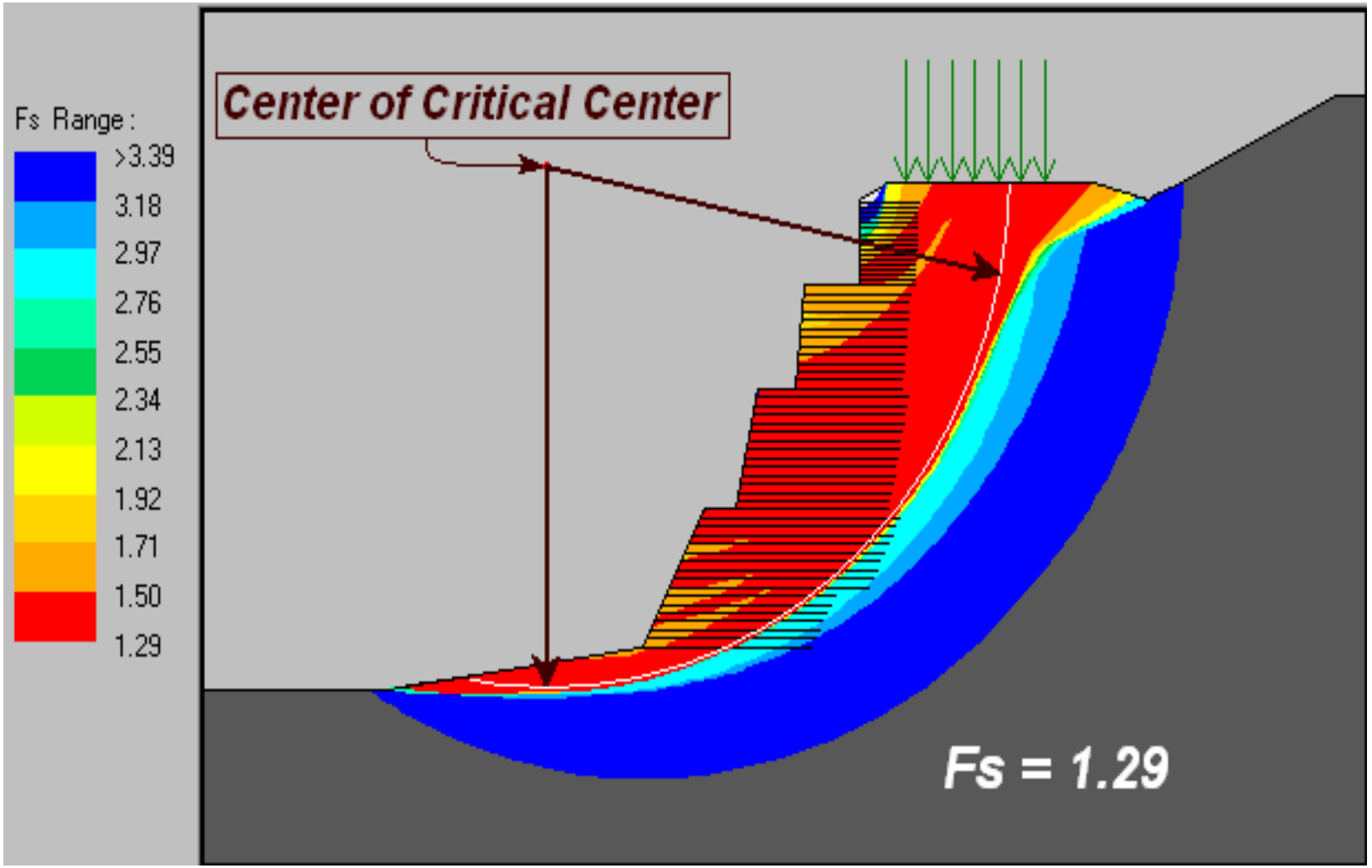
Courtesy of Leshchinsky

Safety Map: Unreinforced Problem Using Bishop



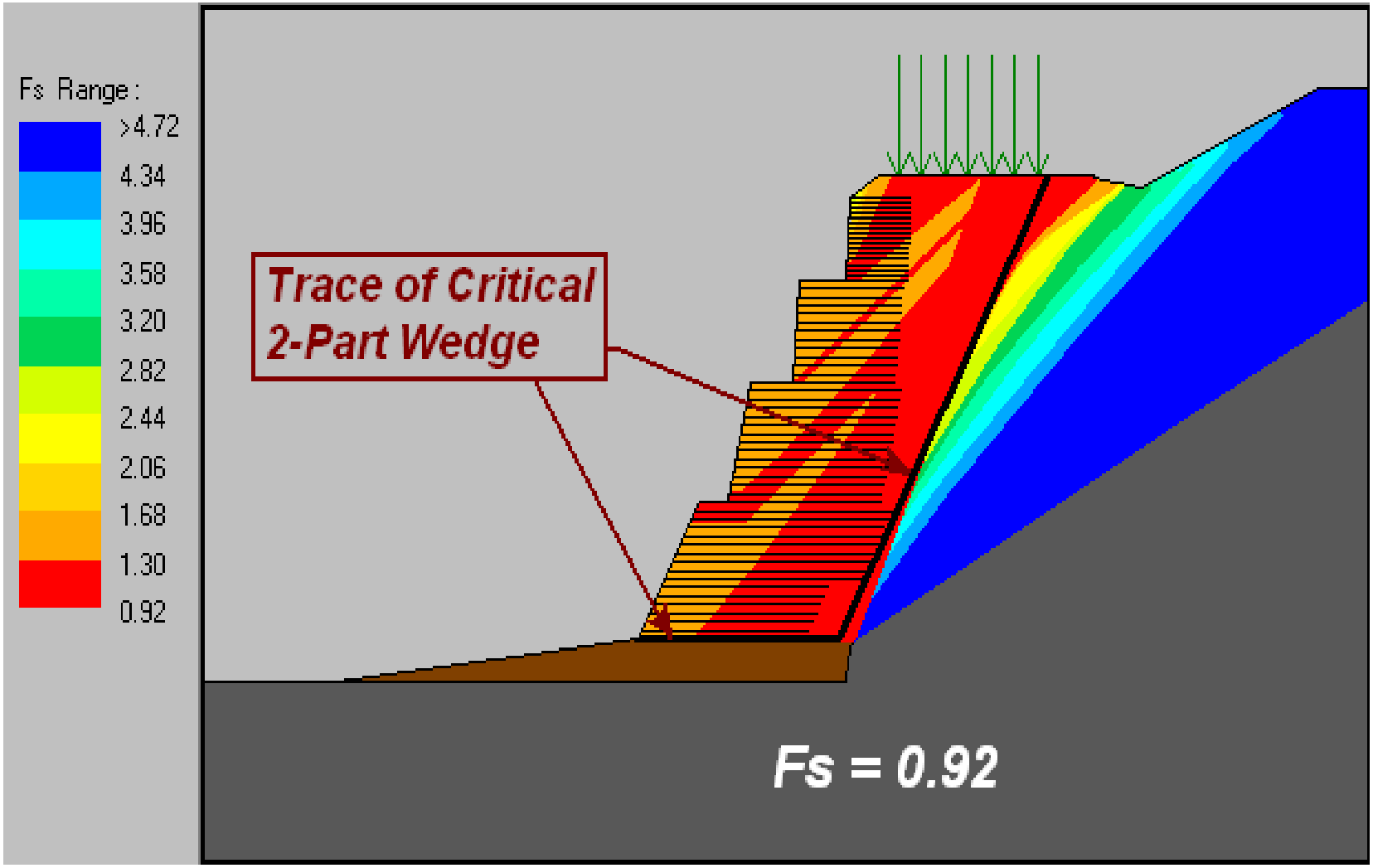
Courtesy of Leshchinsky

Safety Map: Reinforced Problem Using Bishop



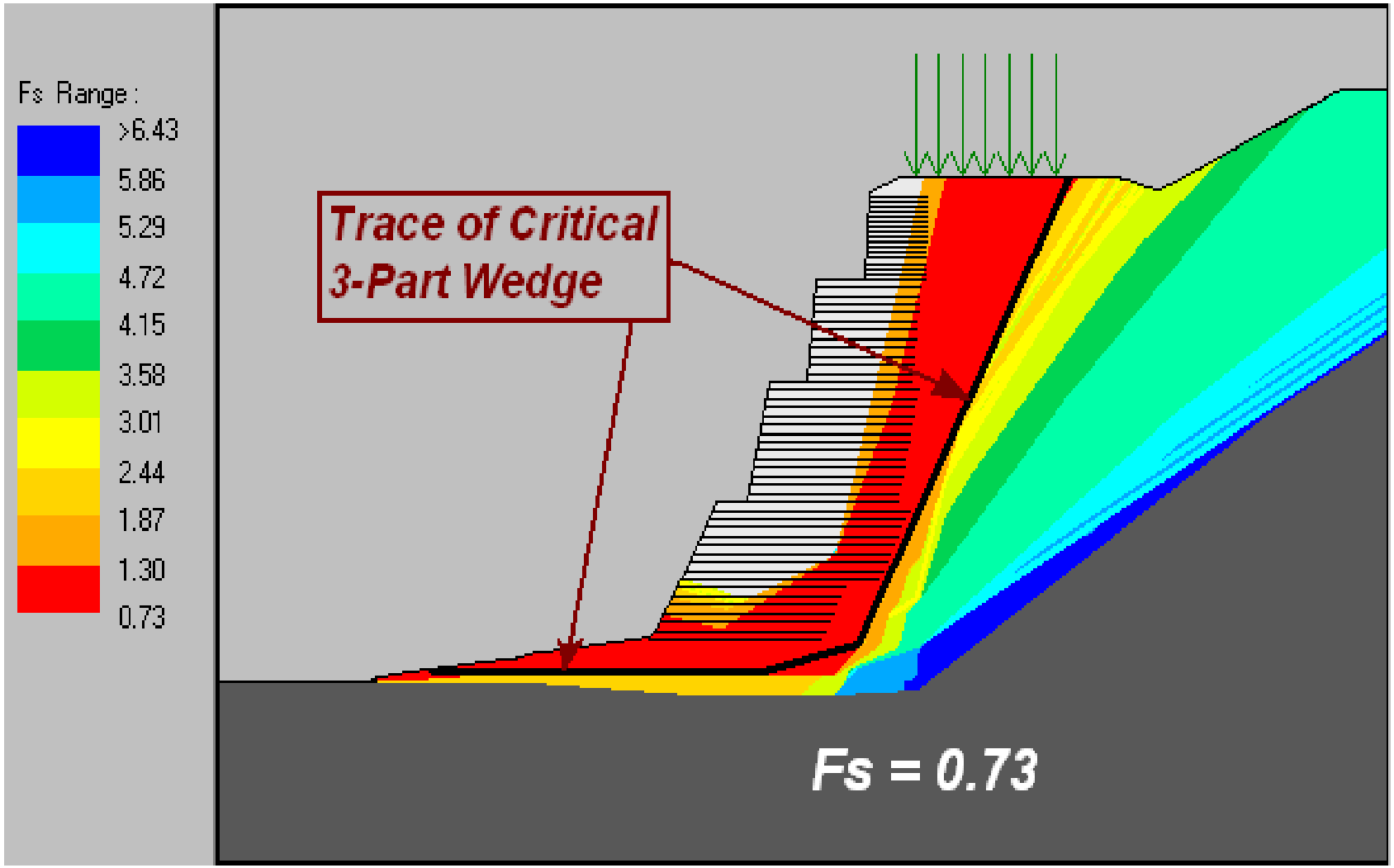
Courtesy of Leshchinsky

Safety Map: 2-Part Wedge Using Spencer



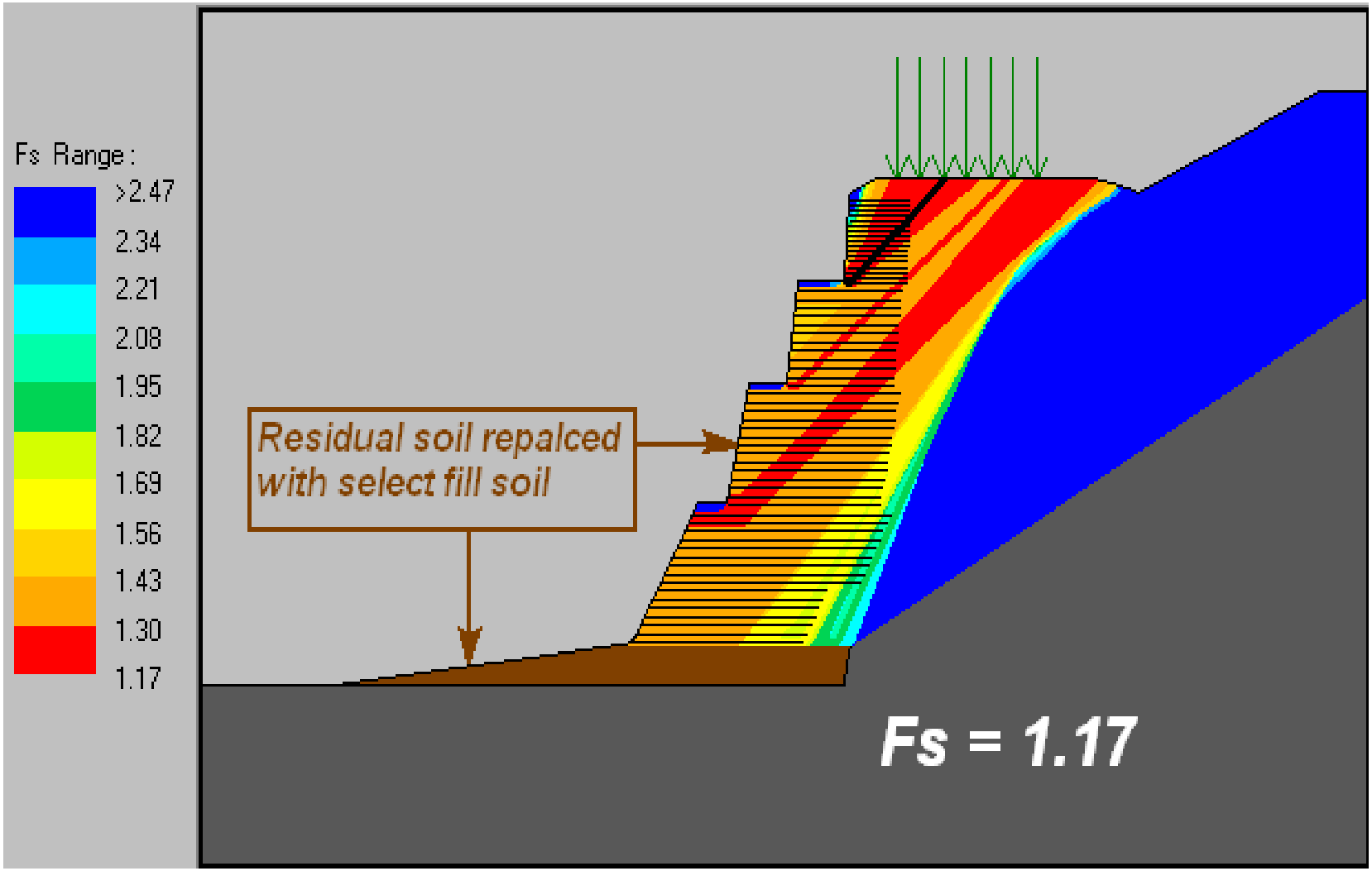
Courtesy of Leshchinsky

Safety Map: 3-Part Wedge Using Spencer



Courtesy of Leshchinsky

Safety Map: 2-Part Wedge Using Spencer – Foundation Replaced



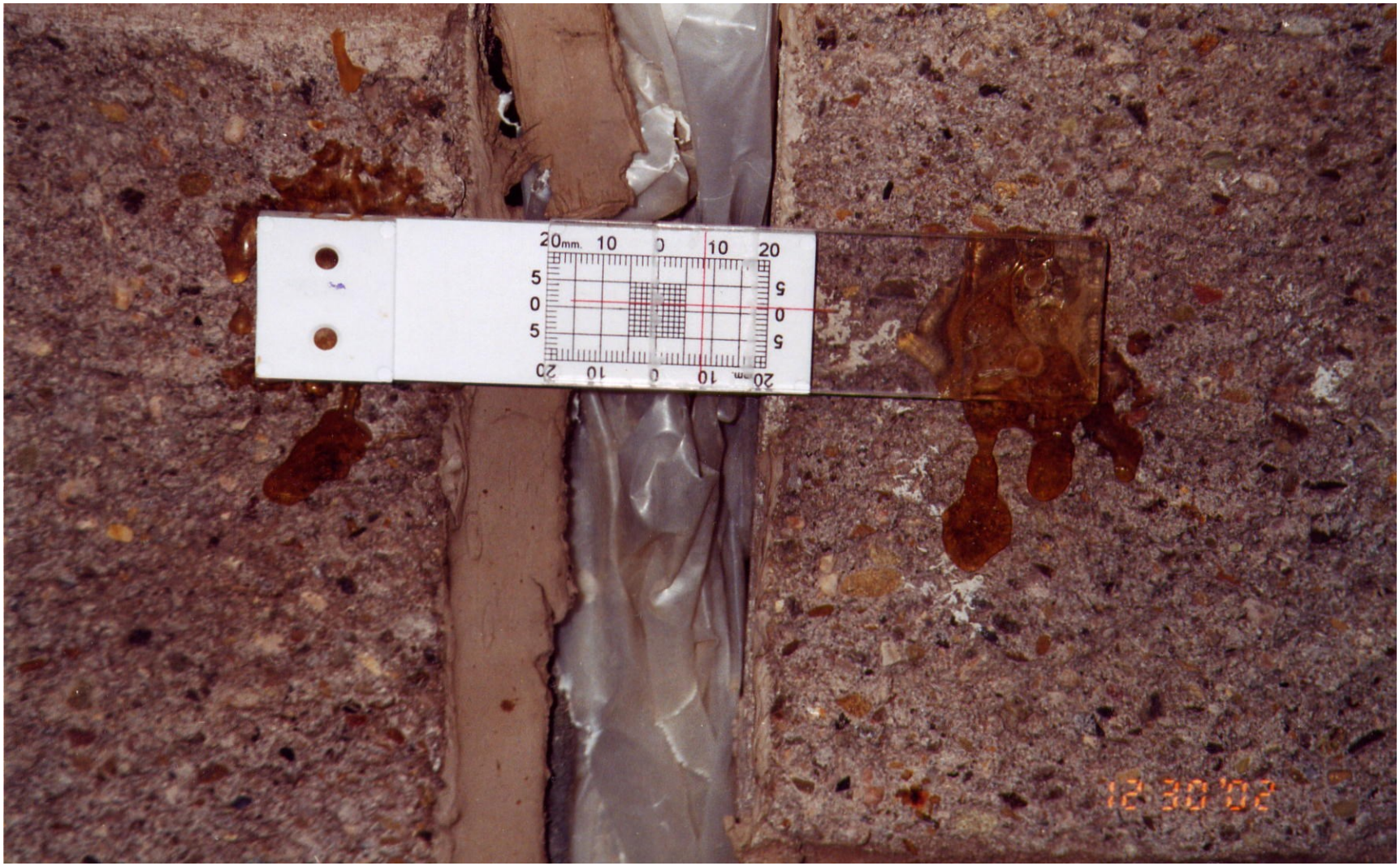
Courtesy of Leshchinsky

Case Study

Four Tiered Walls with Toe Slope

Exterior Wall Cracks

Crackmeter

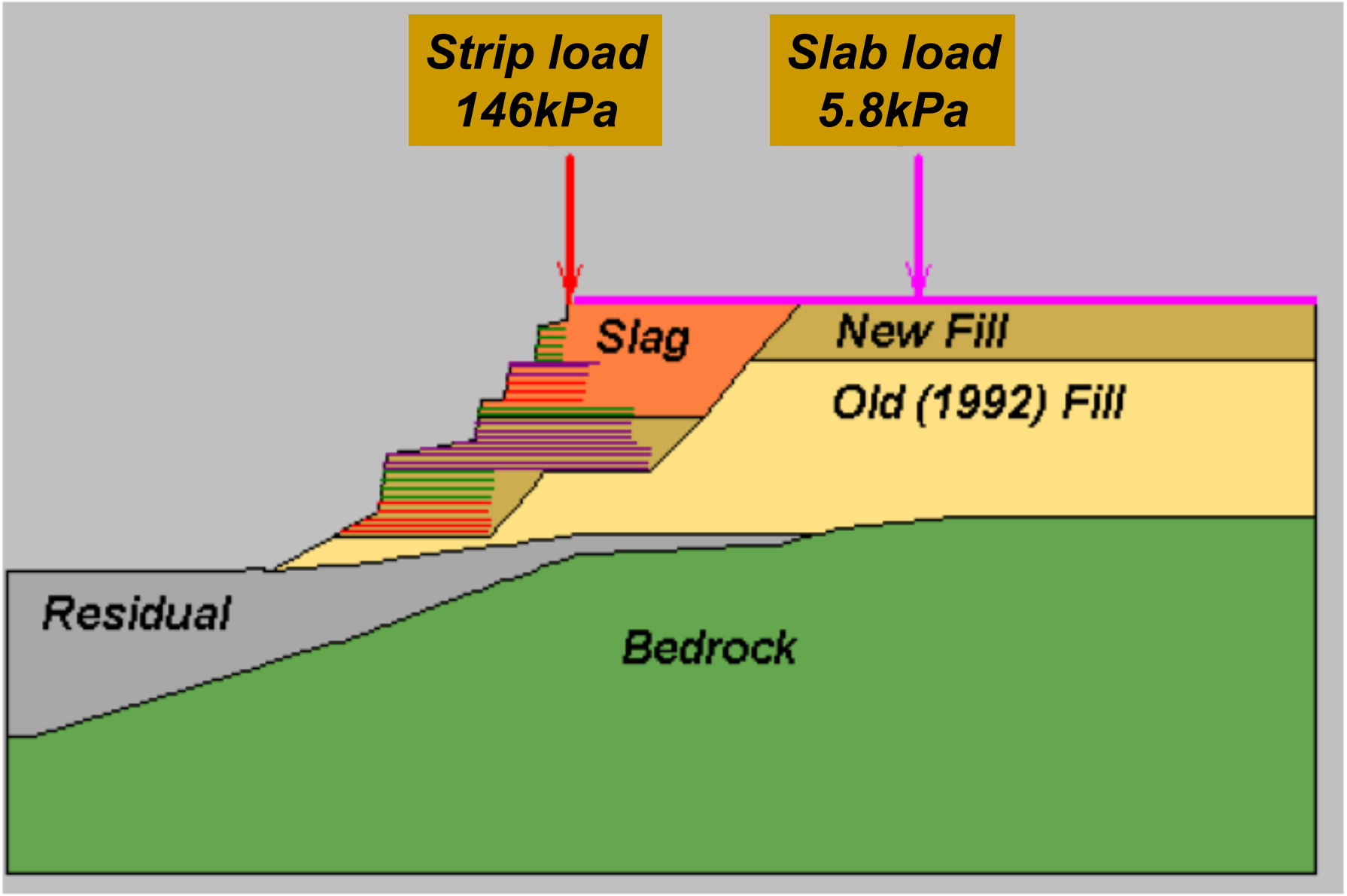


Interior Wall Crack

Interior Floor Cracks

Remediation using Micropiles

Section for Analysis



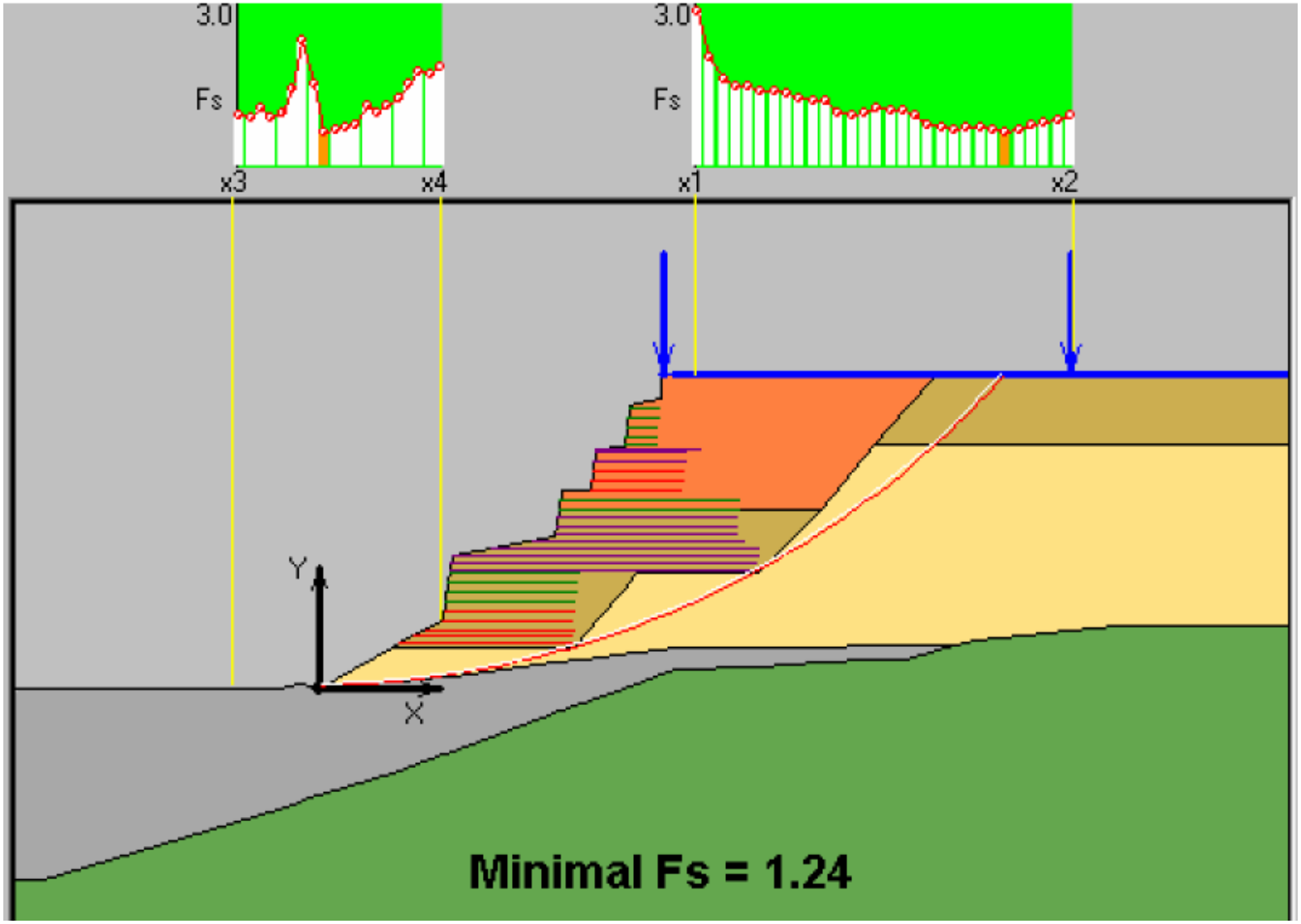
Engineering Properties of Soils and Rock

Soil	γ (kN/m^3)	ϕ (deg.)	c (kPa)
Lightweight (slag) fill	12.6	45.0	0
New fill	21.2	25.8	9
Old (1992) fill	21.2	23.9	9
Residual soil	20.4	33.0	14.4
Bedrock	21.2	45.0	96

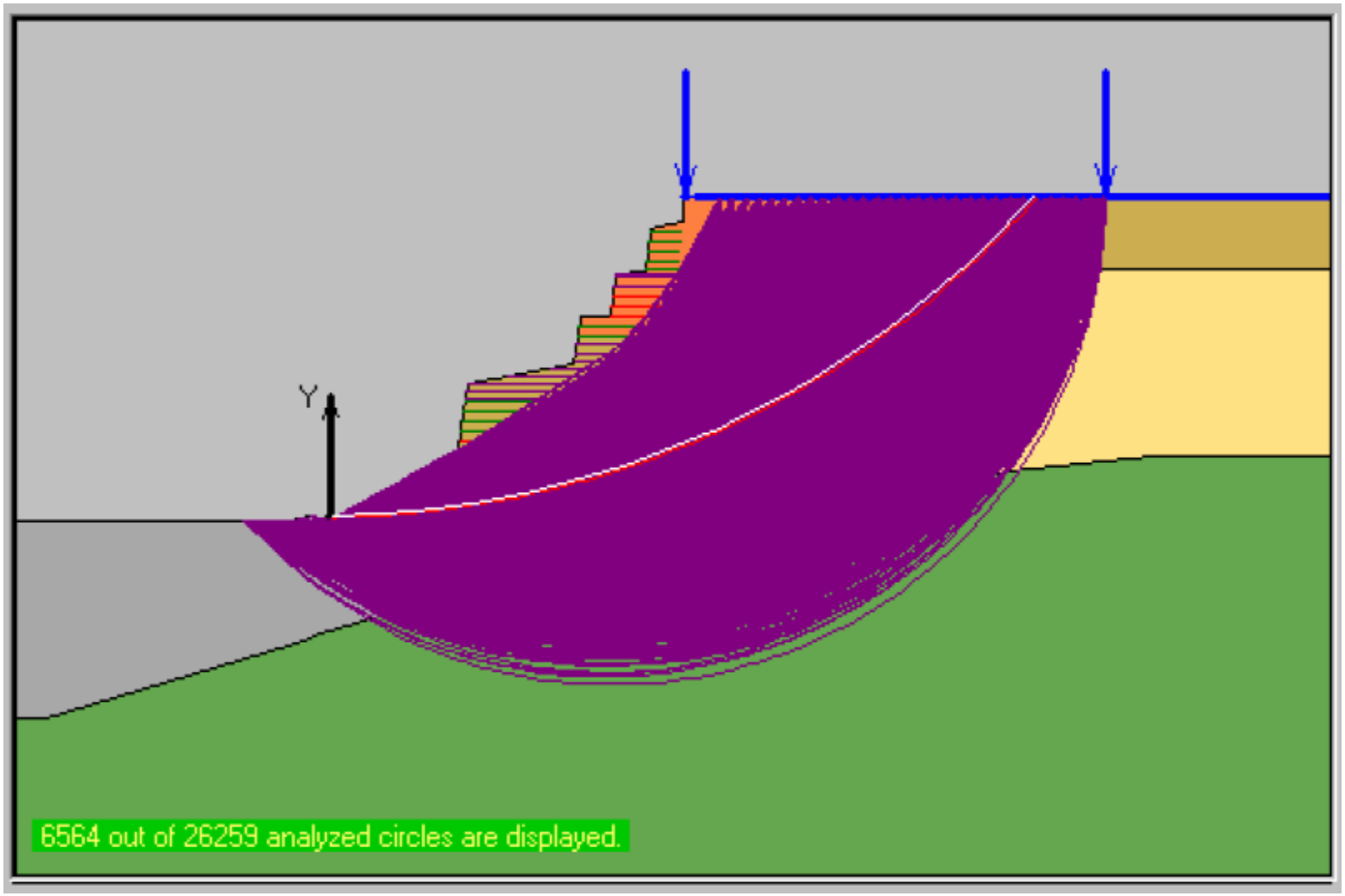
Long-Term Design Strength of Geogrids

Geogrid Type	T_{ltds} (kN/m)
Type 1	37.9
Type 2	17.7
Type 3	55.6

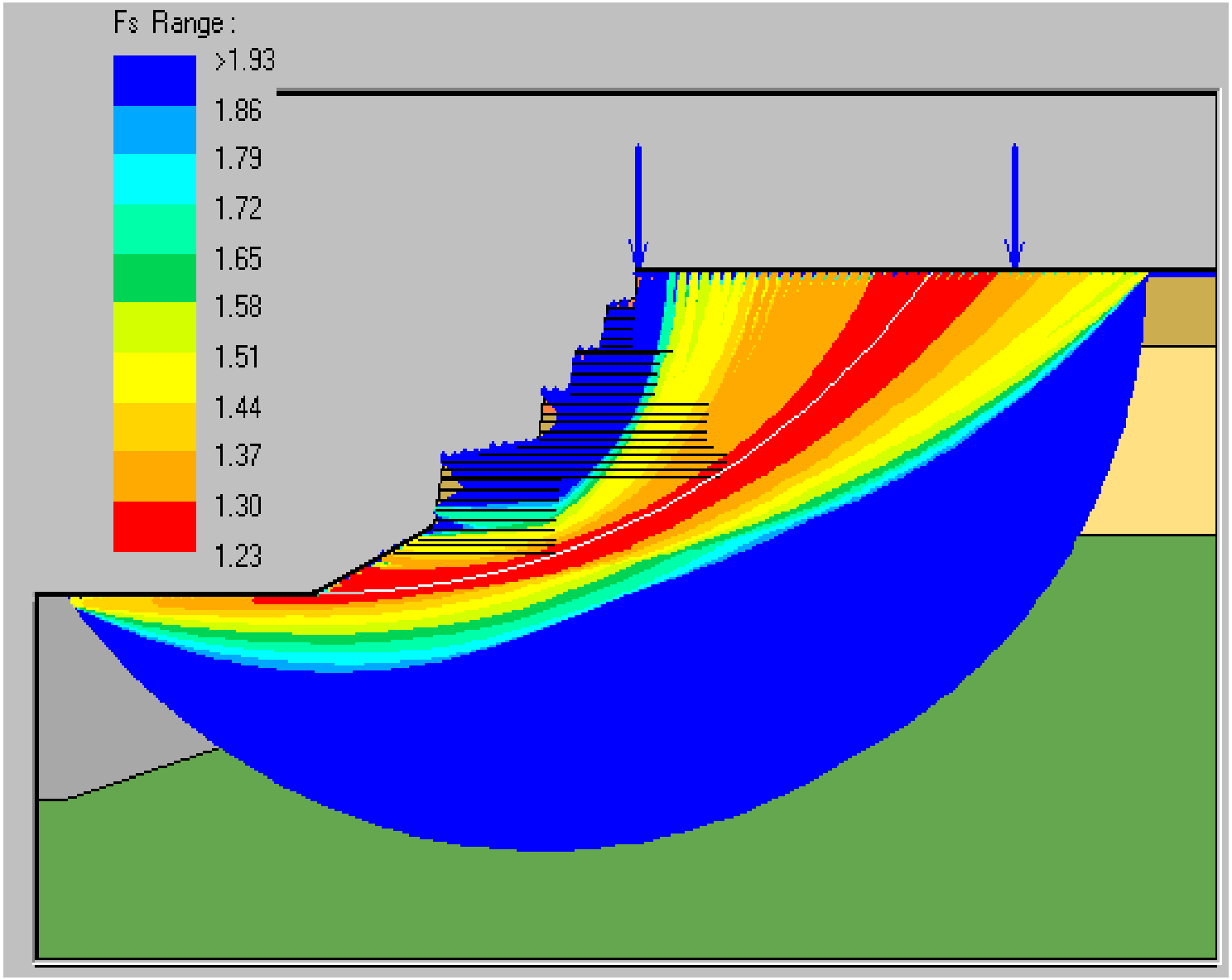
Limit Equilibrium Analysis – Bishop's



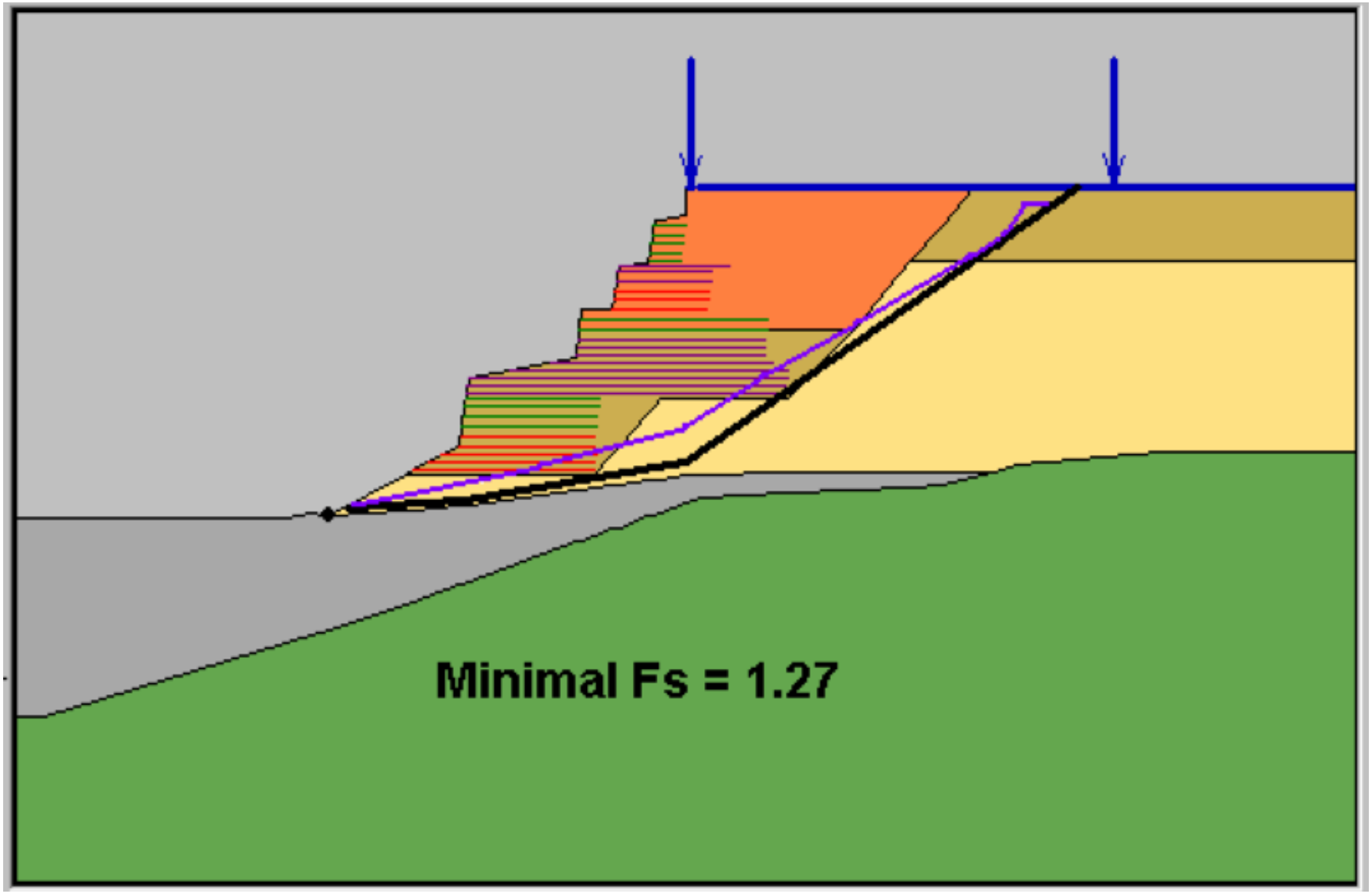
Searched Slip Surfaces



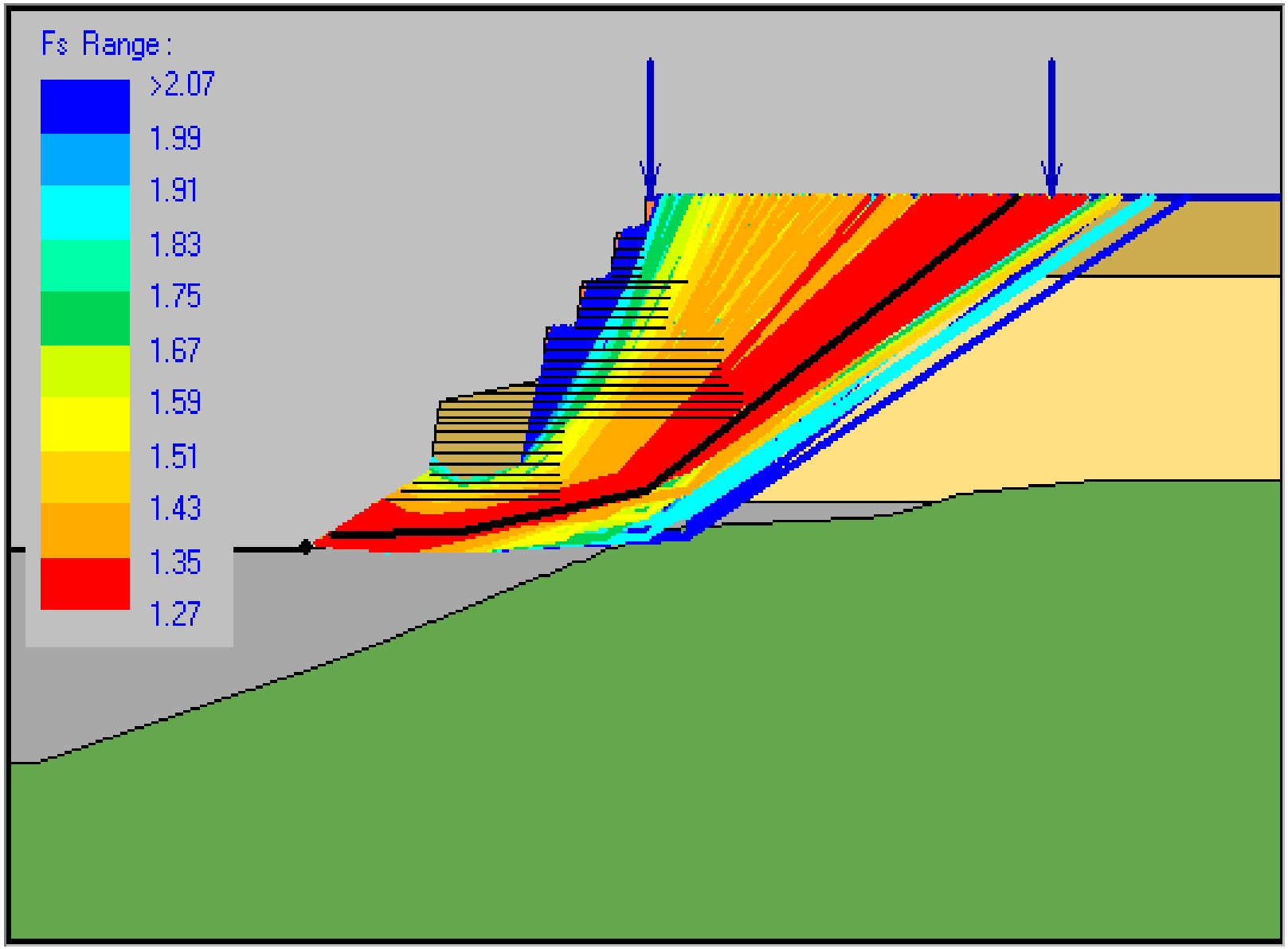
Bishop Analysis: Safety Map



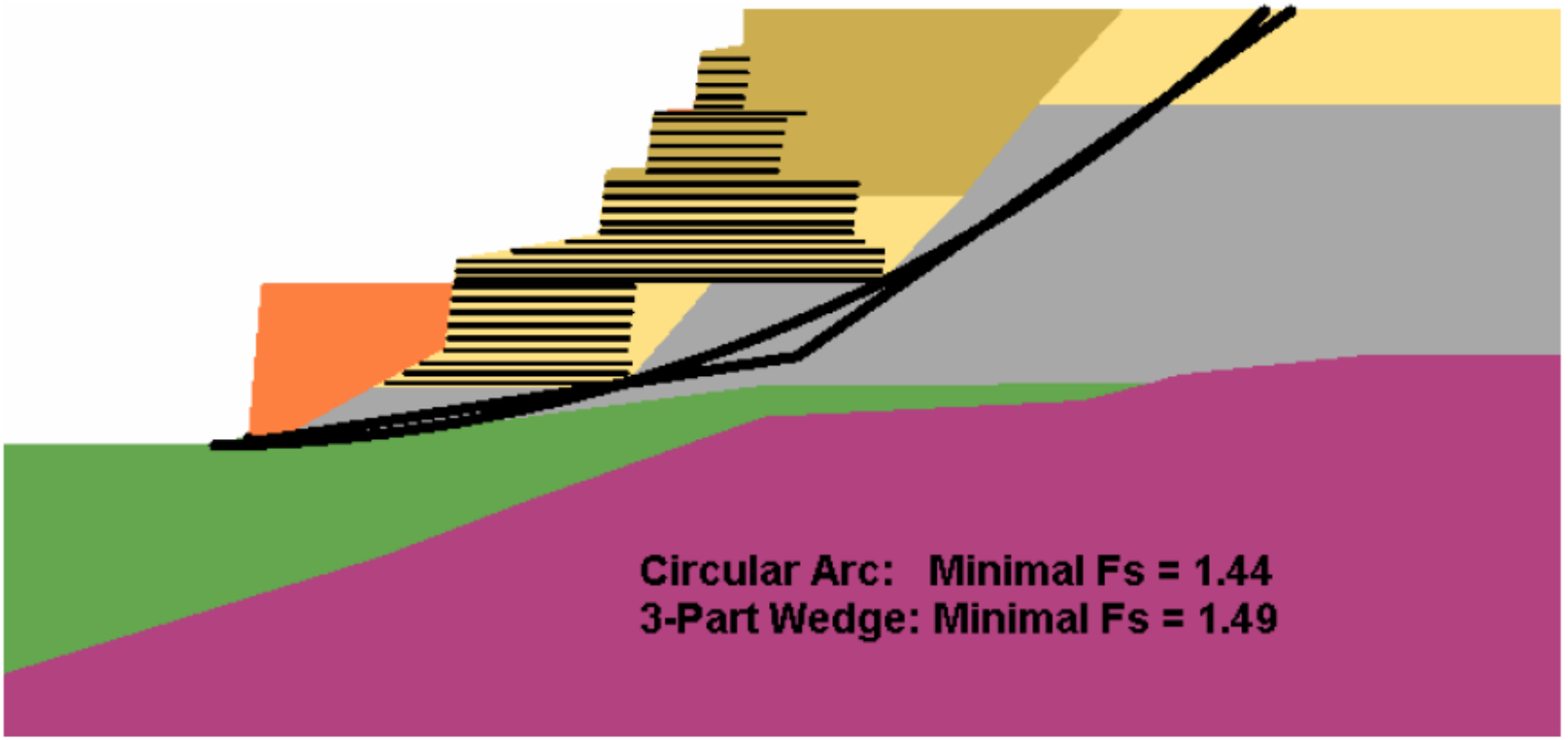
Limit Equilibrium Analysis – Spencer



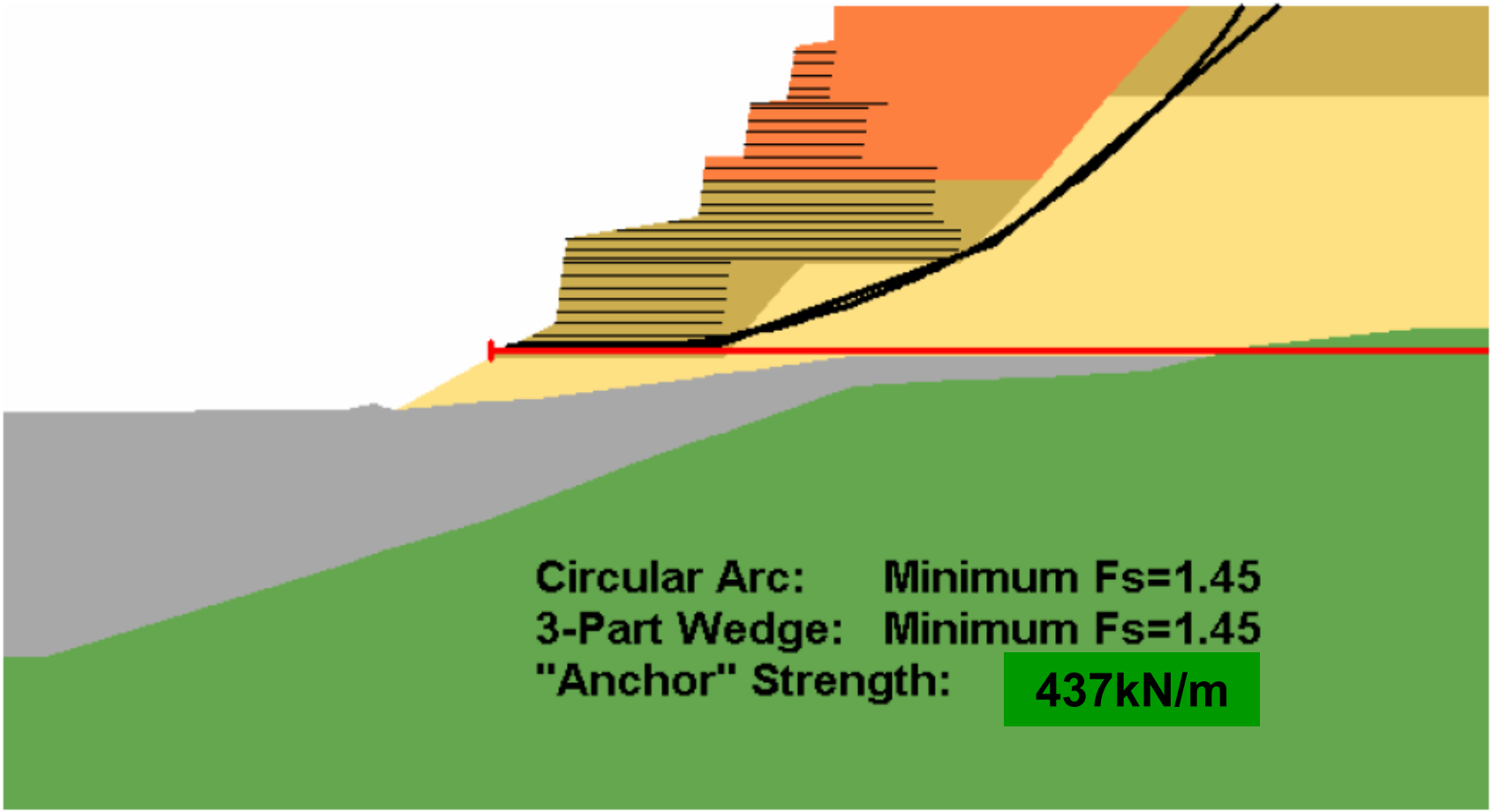
Spencer Analysis: Safety Map



Toe Berm



Anchors along Toe of Wall



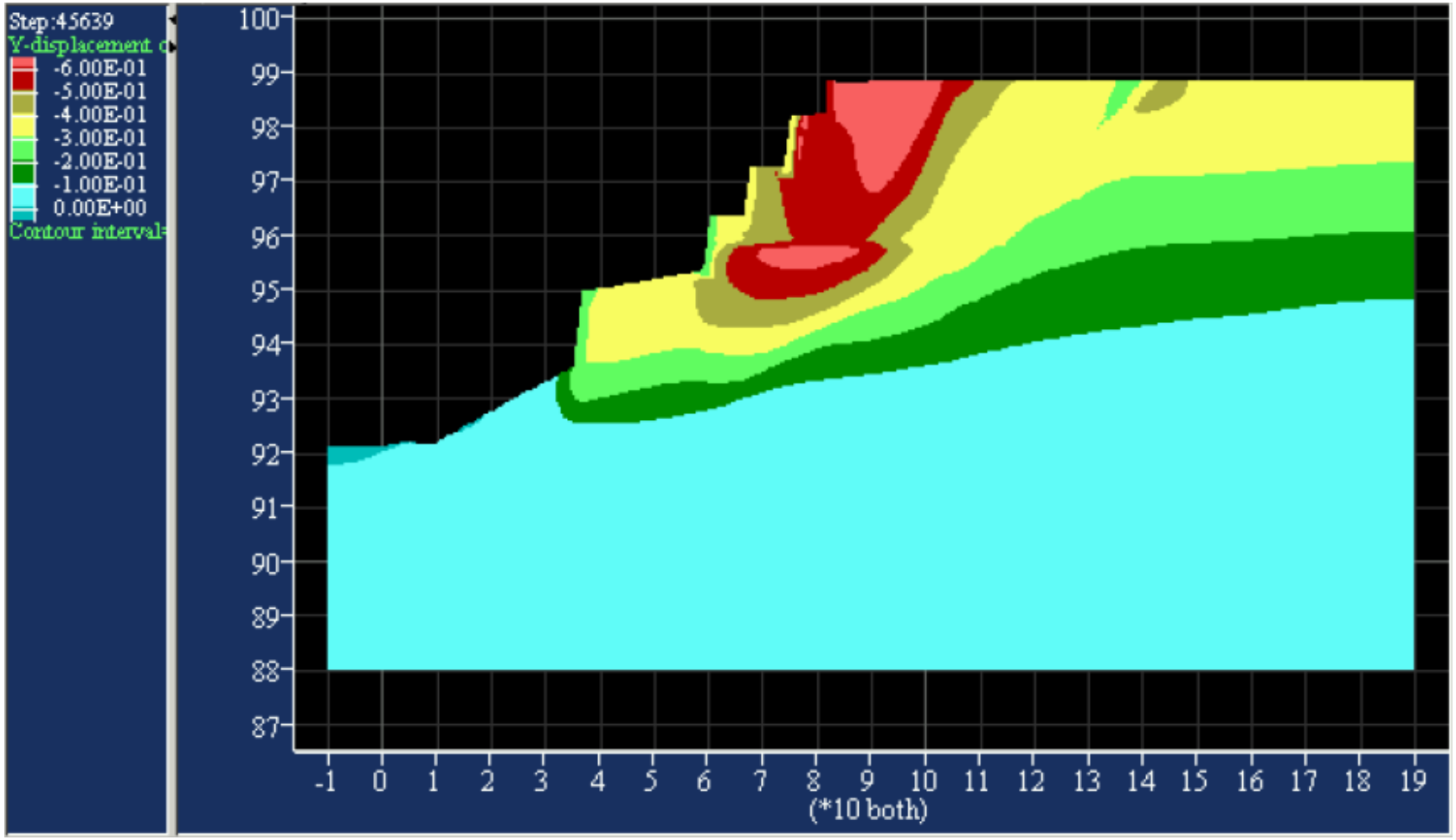
Elastic Moduli and Poisson's Ratios

Soil	E (MPa)	v
Lightweight (slag) fill	51.7	0.25
New fill	10.3	0.30
Old (1992) fill	10.3	0.30
Residual soil	20.7	0.30
Bedrock	480	0.20
Facing block	480	0.25
Concrete footing	480	0.25

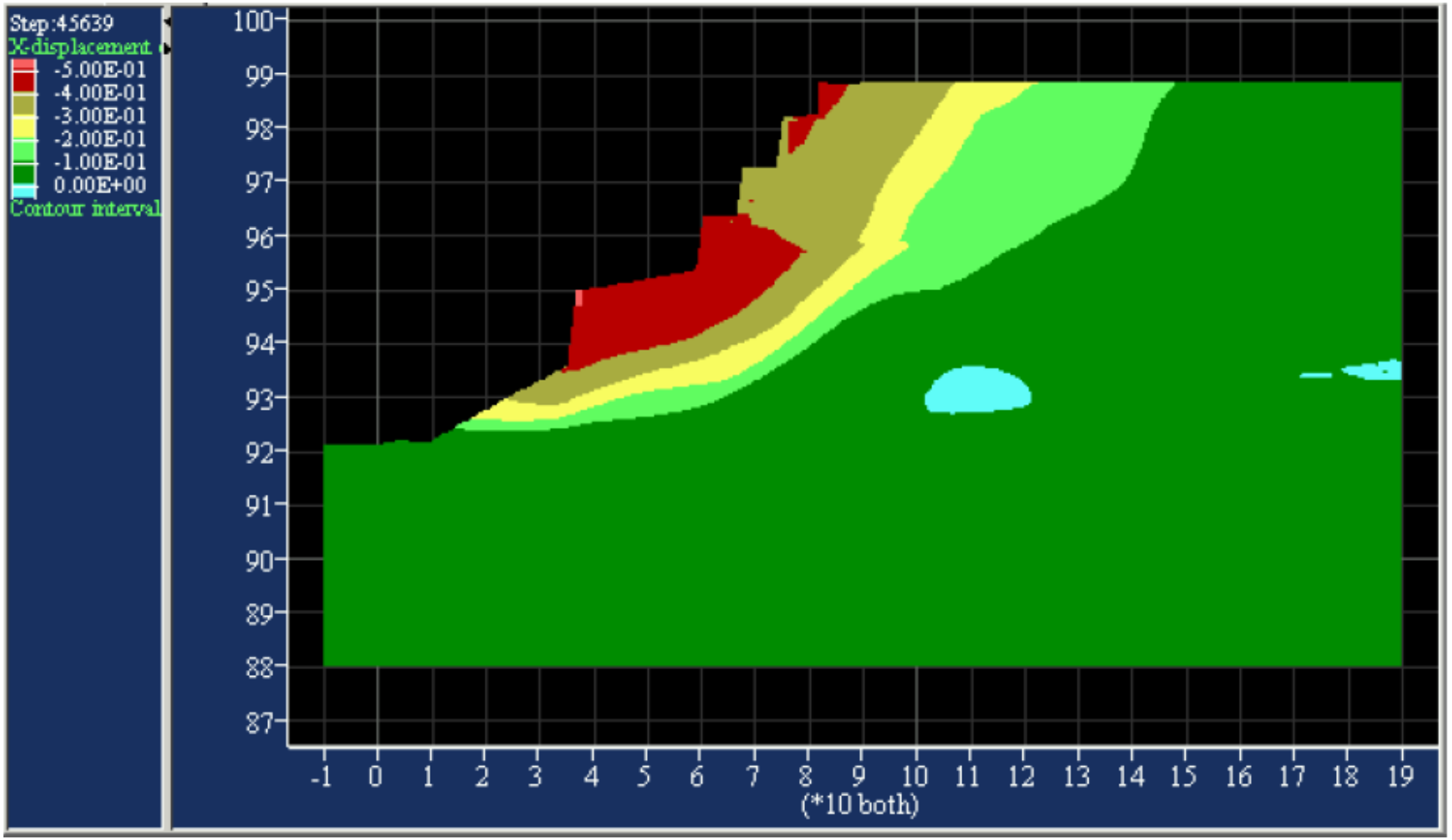
Tensile Stiffness of Geogrids

Geogrid Type	J (kN/m)
Type 1	319
Type 2	539
Type 3	619

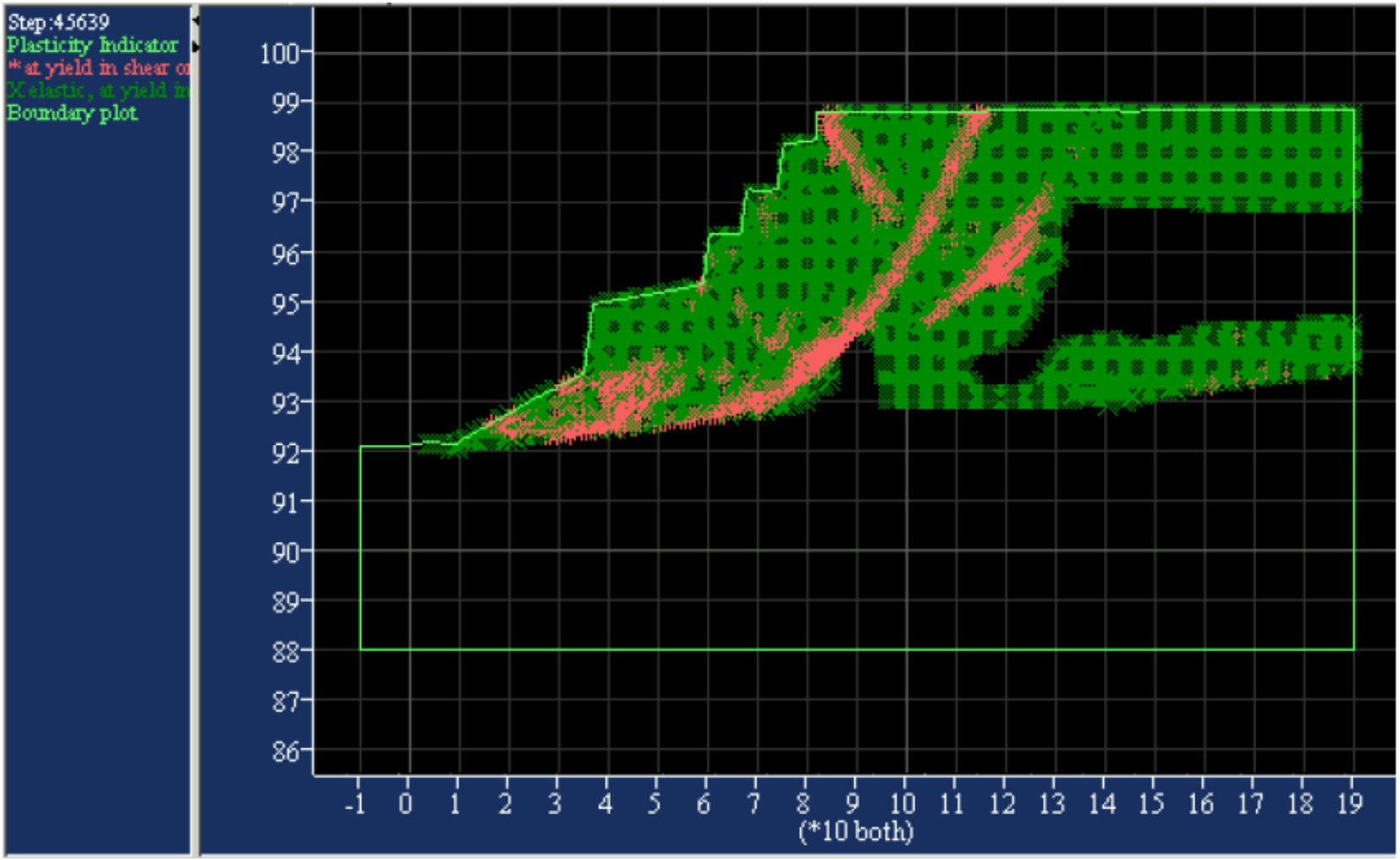
Vertical Displacement Contours



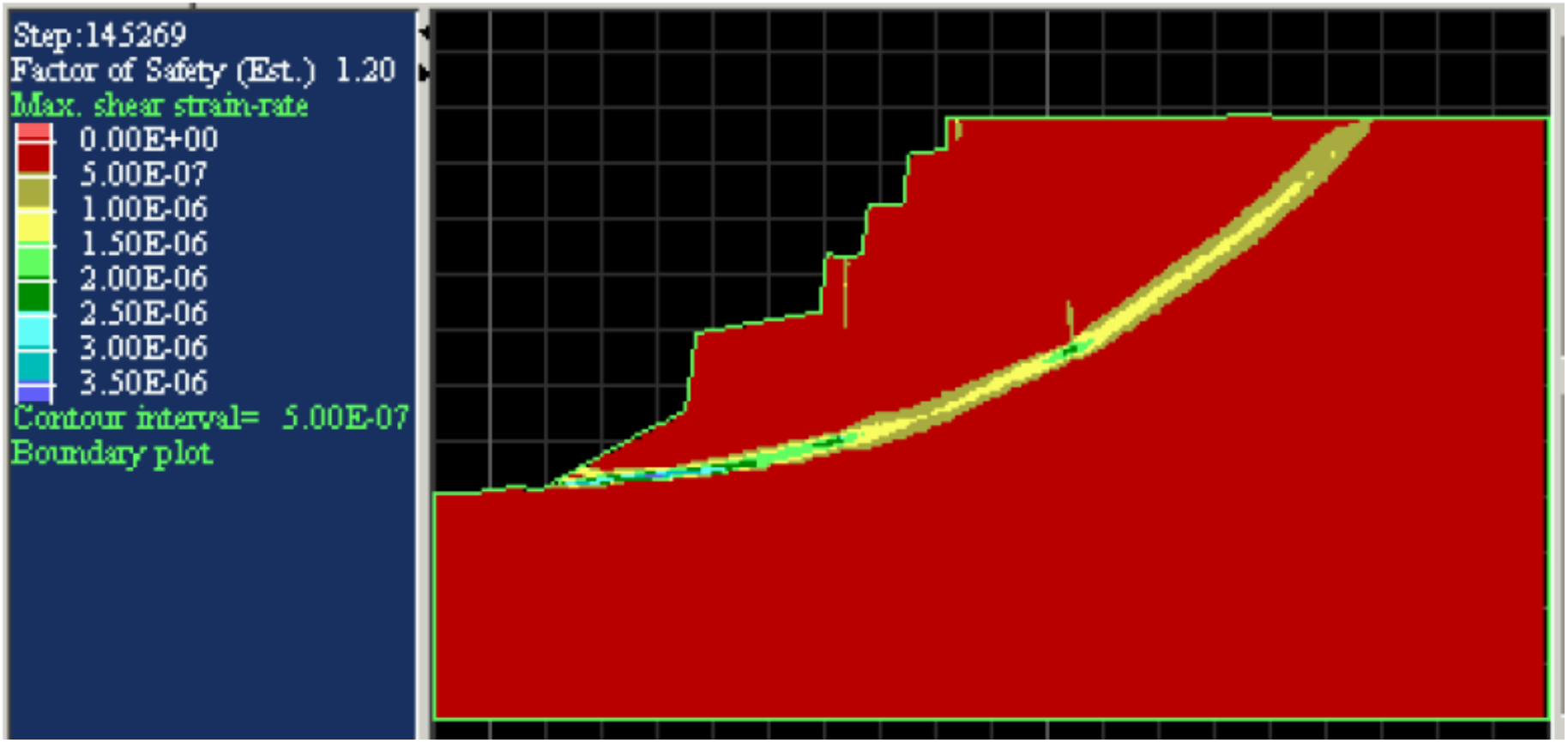
Horizontal Displacement Contours



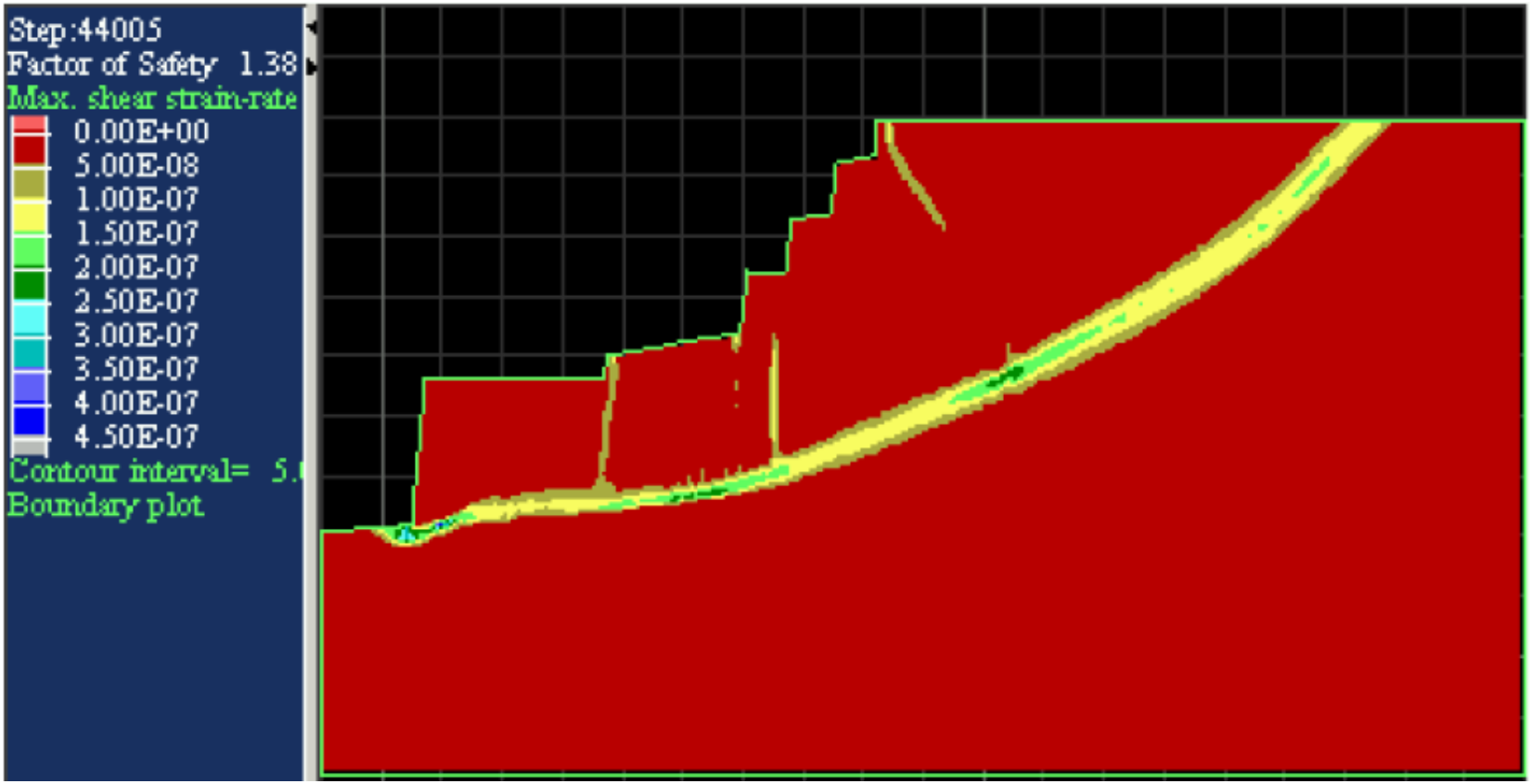
Plasticity Zones



Critical Slip Surface and FS



Toe Berm and Anchor Remedy



Results of Analyses

- Limit equilibrium and numerical analyses yield nearly identical Factor of Safety (FoS)

- FoS = 1.20 (with cohesion)
  FoS = 1.05 (without cohesion)

- The deformation profiles predicted by FLAC are in good agreement to those from the measured

Recommendations

- Cohesion should not be considered for a long-term stability

- FoS $\geq$ 1.3 is enough for slope stability but may not be enough to support sensitive structures

- FoS $\geq$ 1.5 should be designed if structures are supported

Limited-Space Earth Walls

(Courtesy of Daryl Wurster)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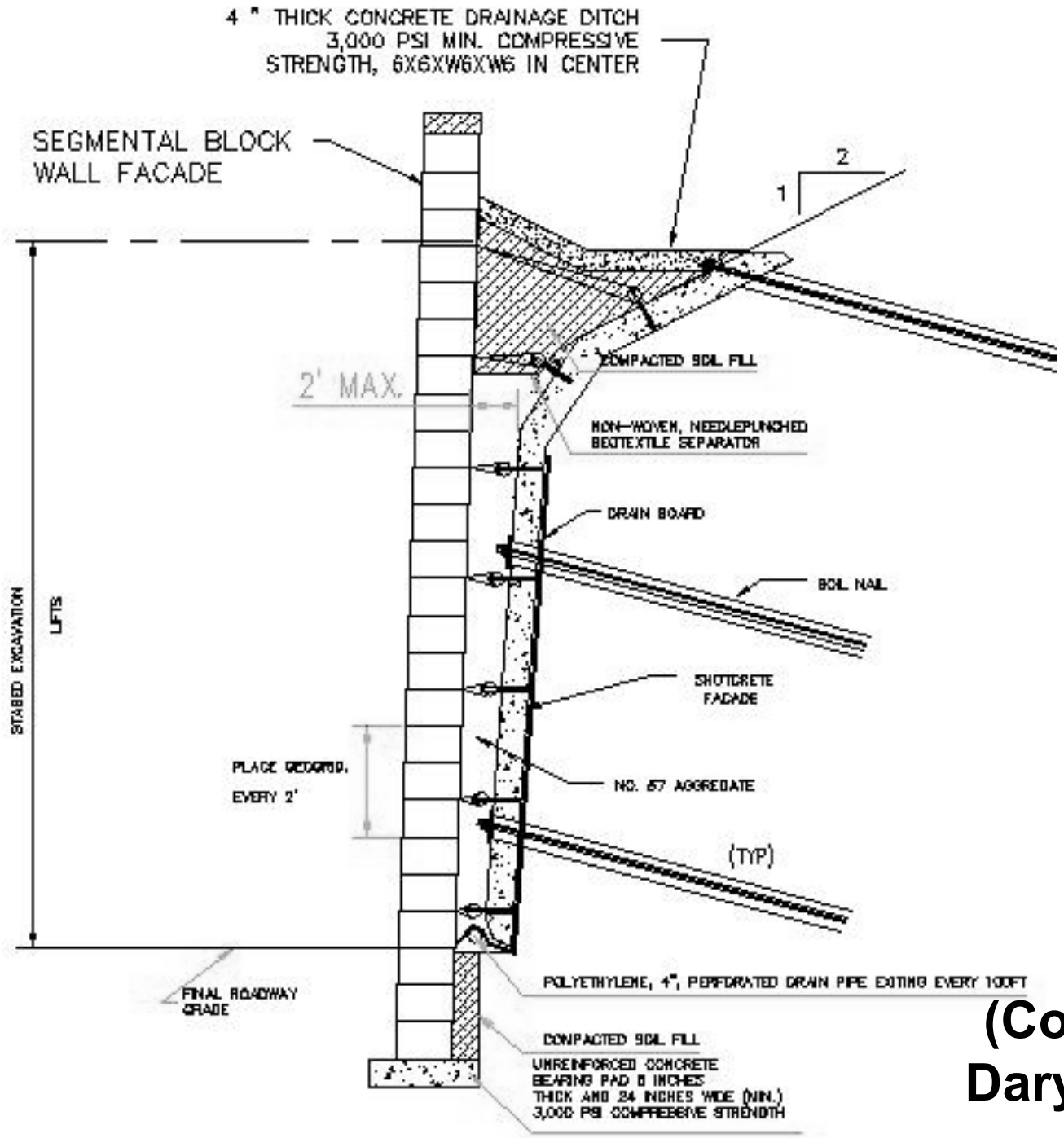

(Courtesy of Daryl Wurster)


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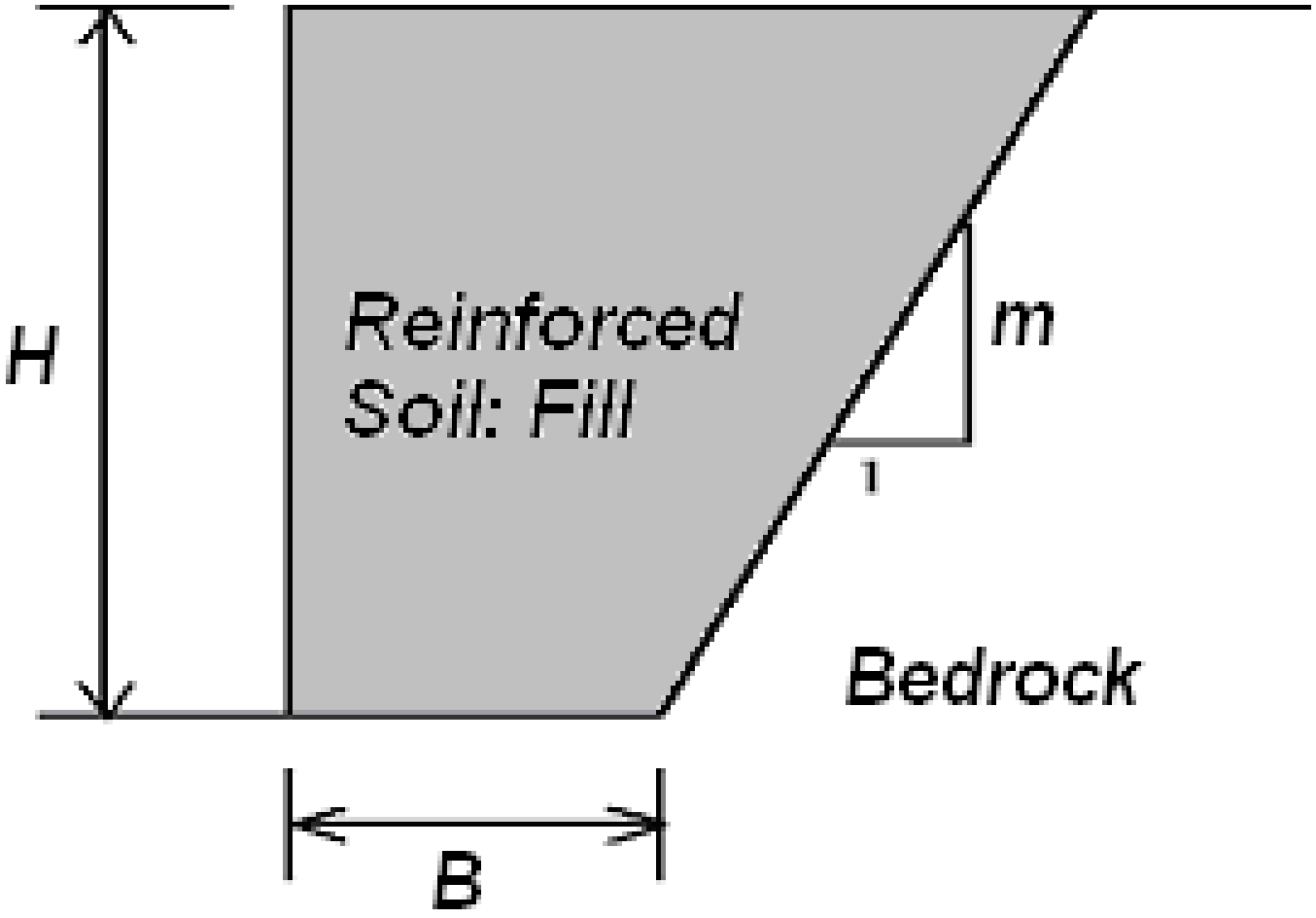
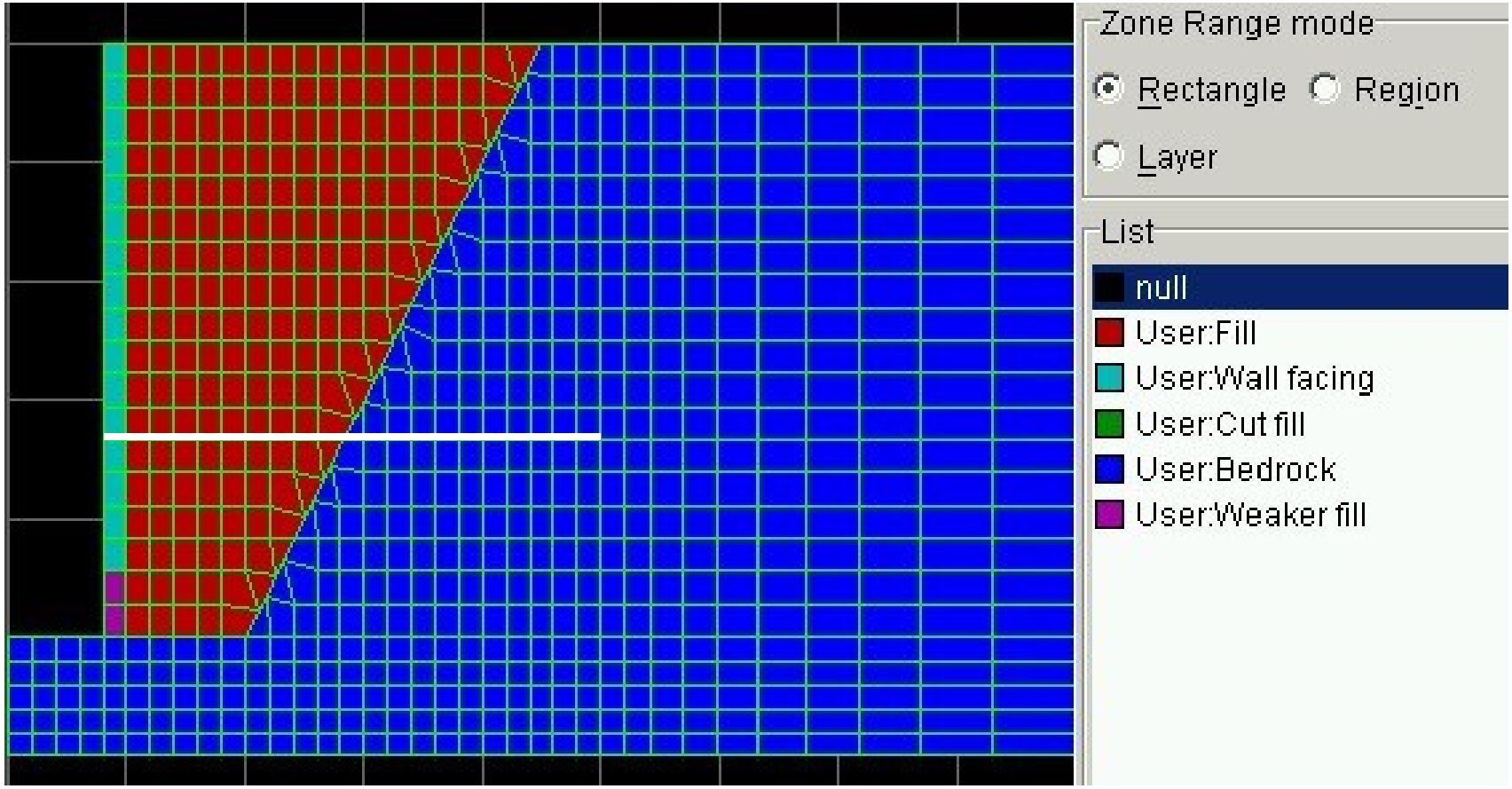
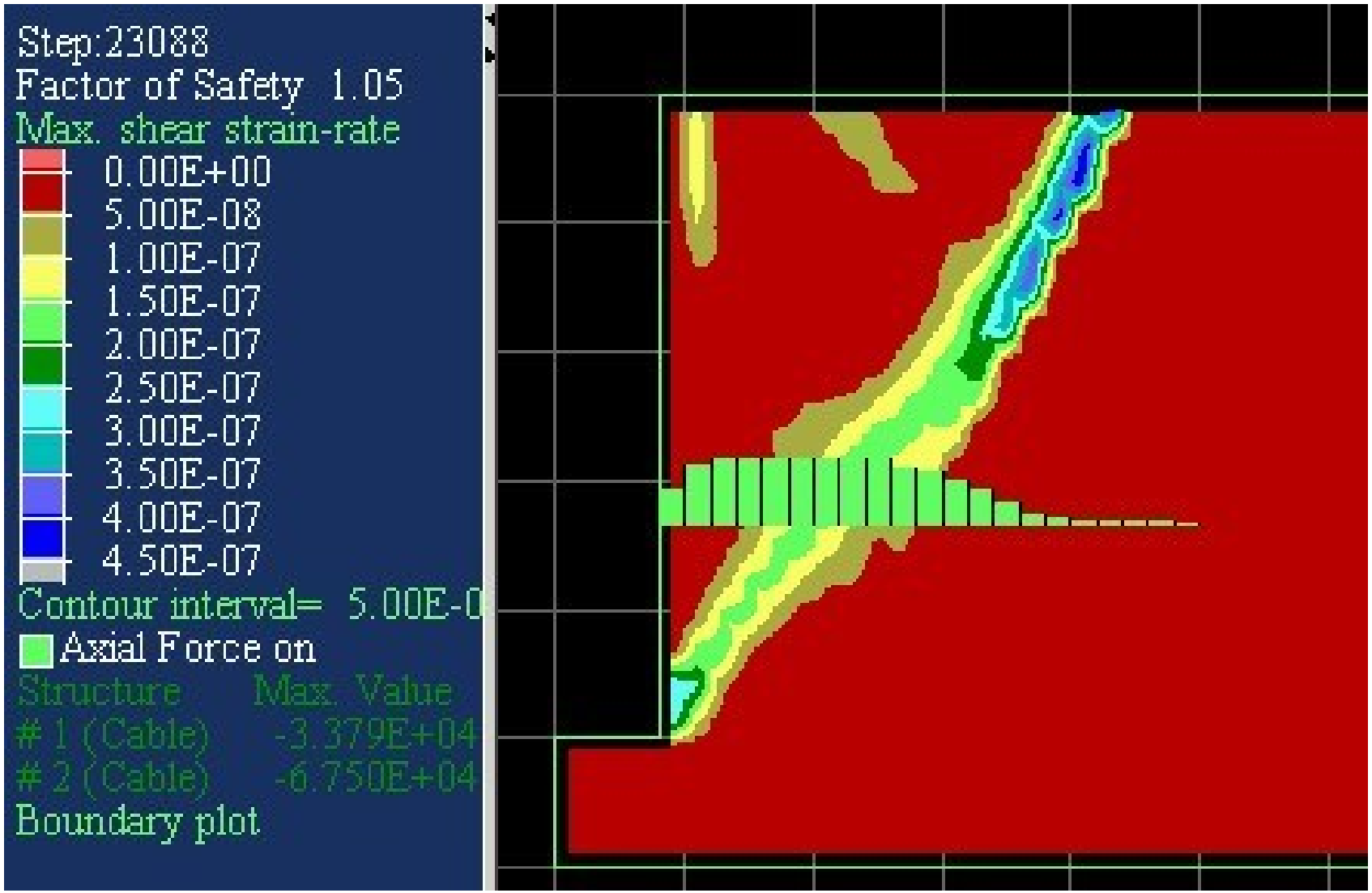
Definitions



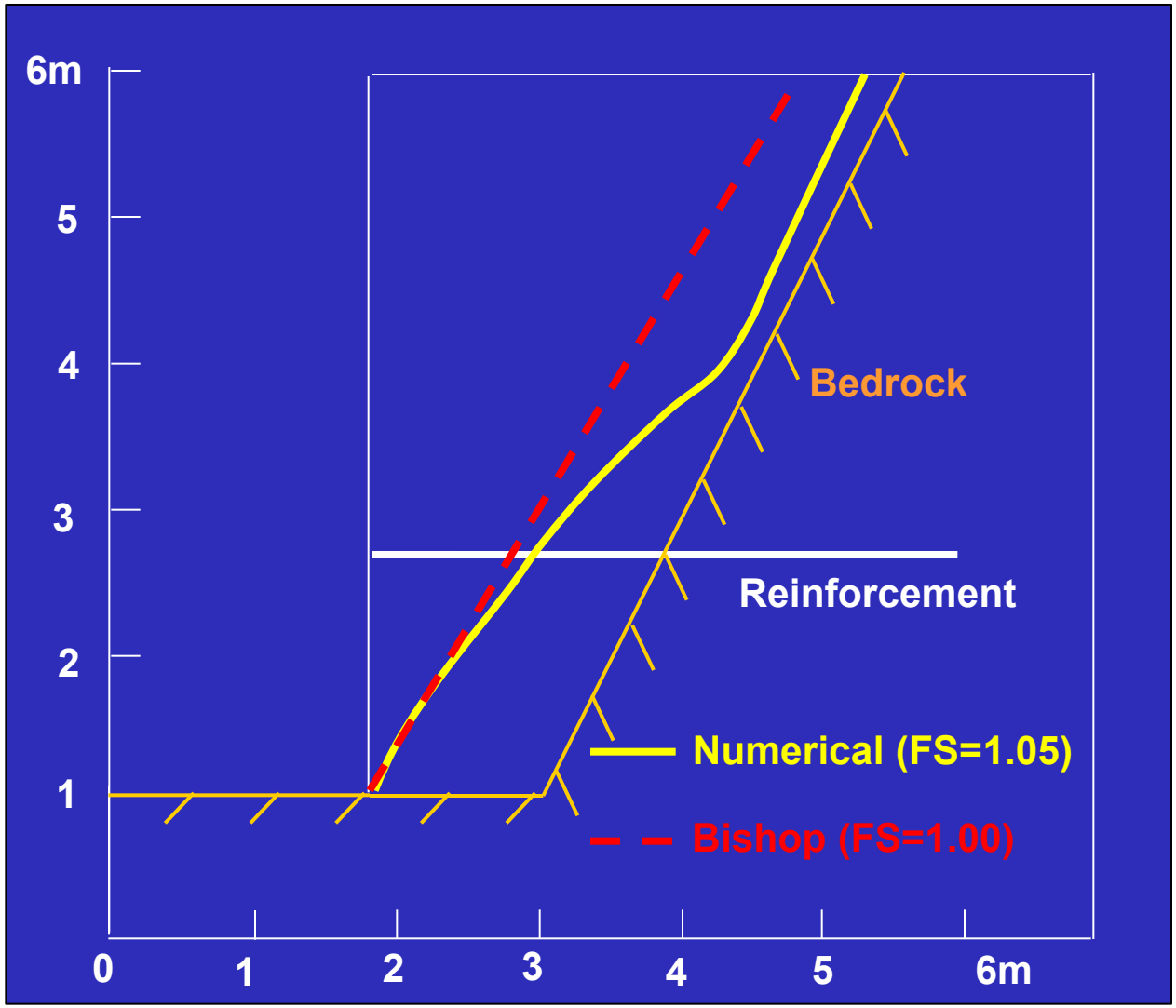
Numerical Model



Factor of Safety and Tension



Critical Slip Surface and FS



Lateral Earth Pressure Coefficient

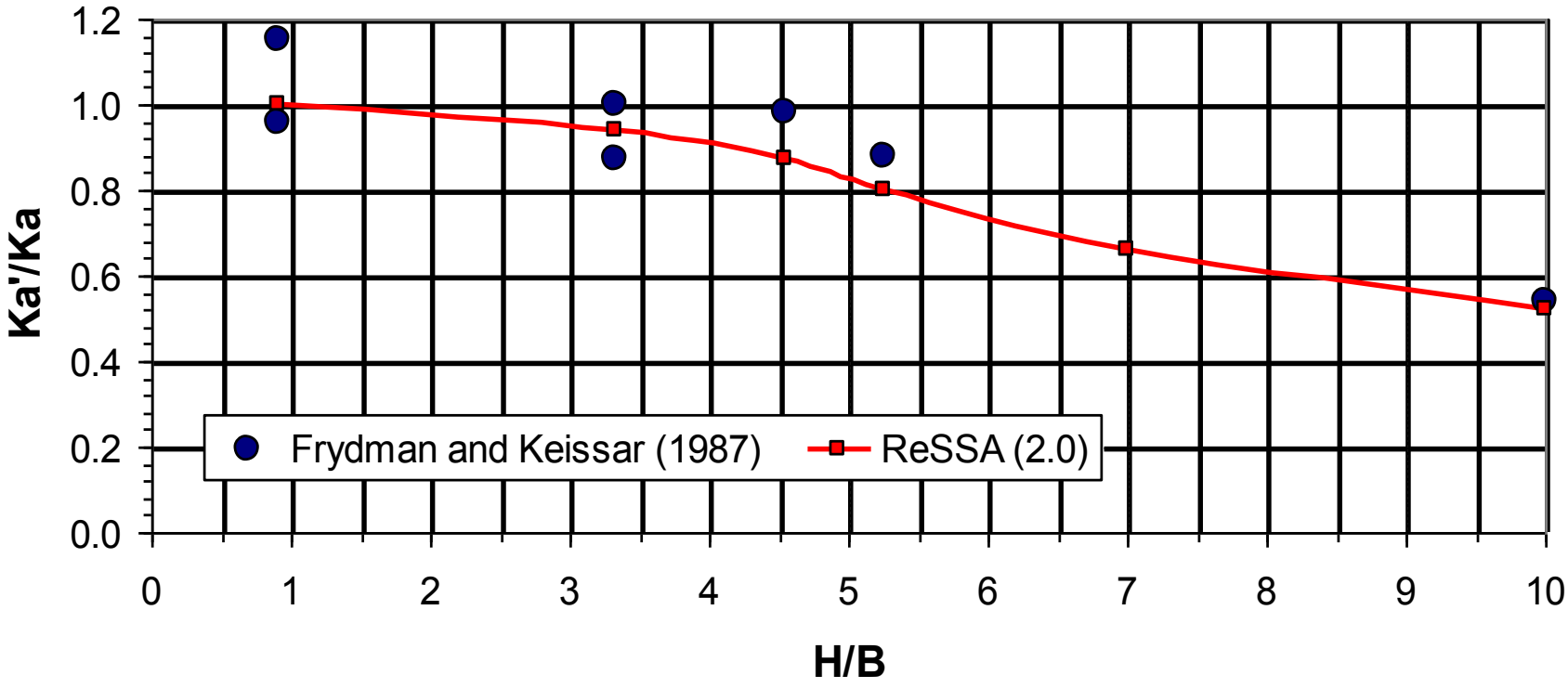
Lateral earth pressure in limited space

$$P_a^{'} = K_a^{'} \times \frac{1}{2}\gamma H^2 = T$$

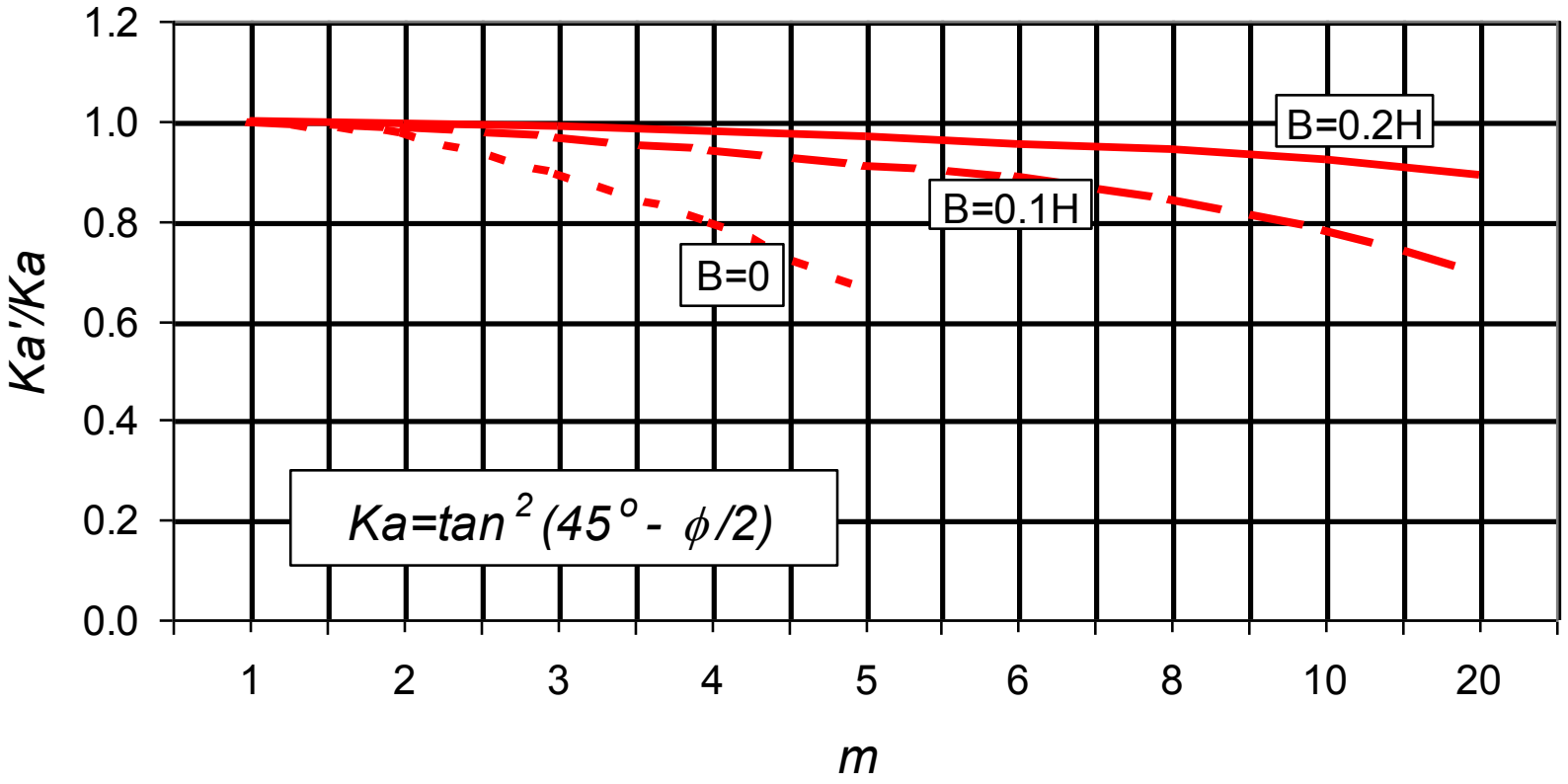
Lateral earth pressure coefficient in limited space

$$K_a^{'} = \frac{2T}{\gamma H^2}$$

LE/Numerical vs. Centrifugal Test Results (ϕ=36° and m=∞)

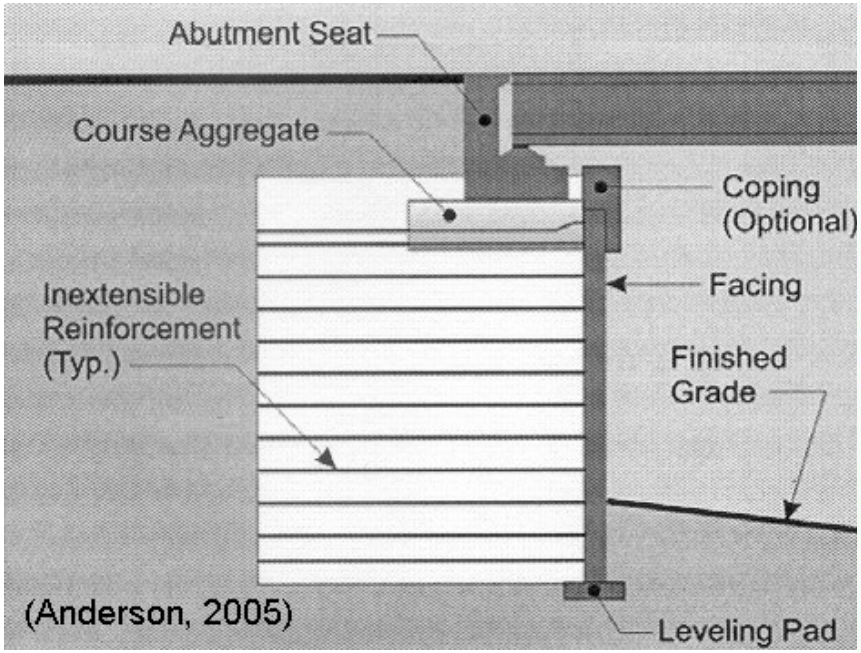


Ratio of Lateral Earth Pressure Coefficient

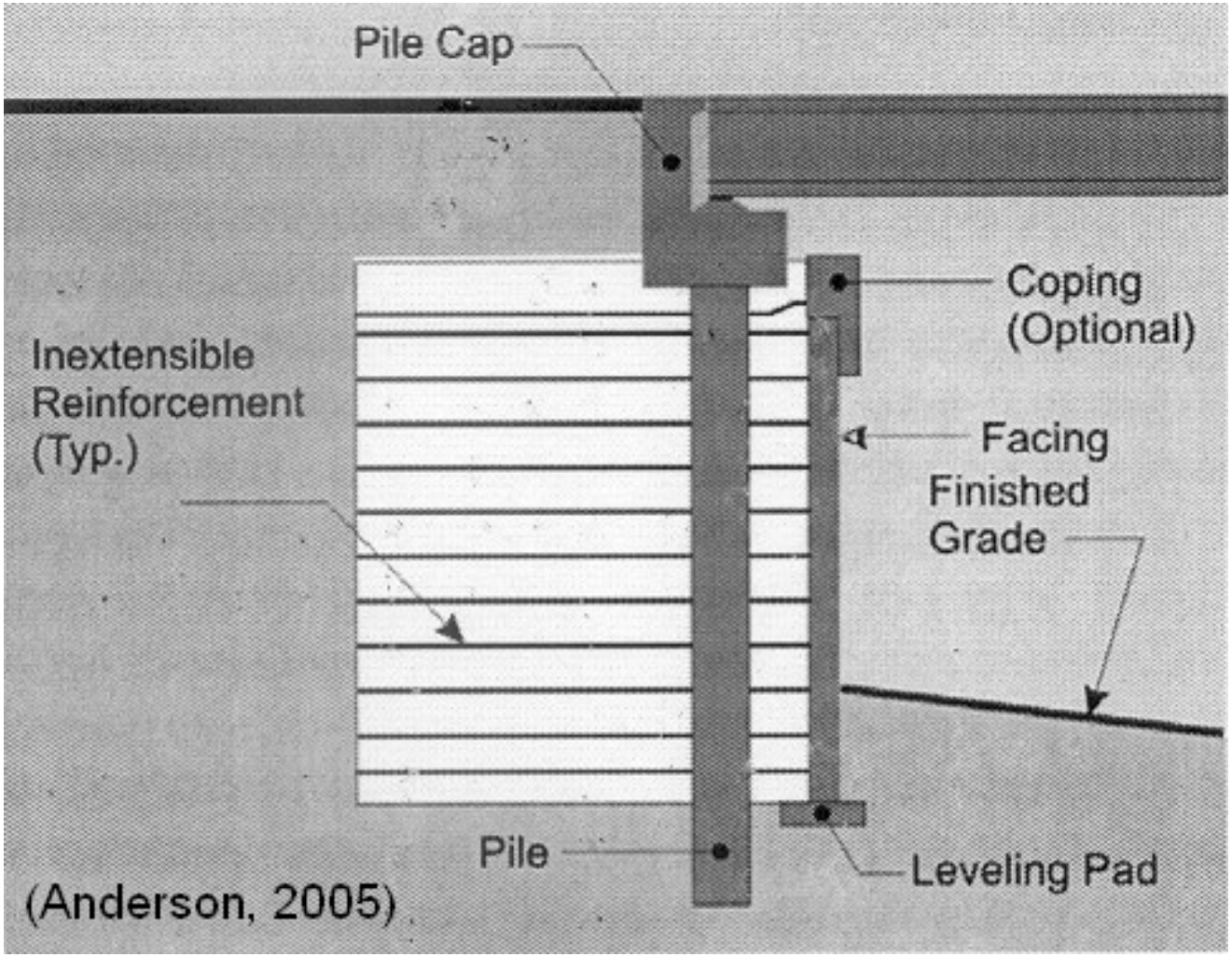


Piles in Earth Walls Subjected to Lateral Loads

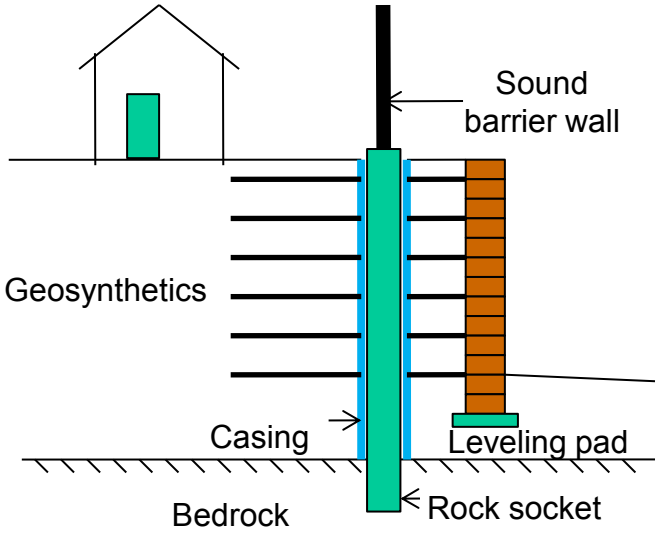
Typical True MSE Wall Abutment



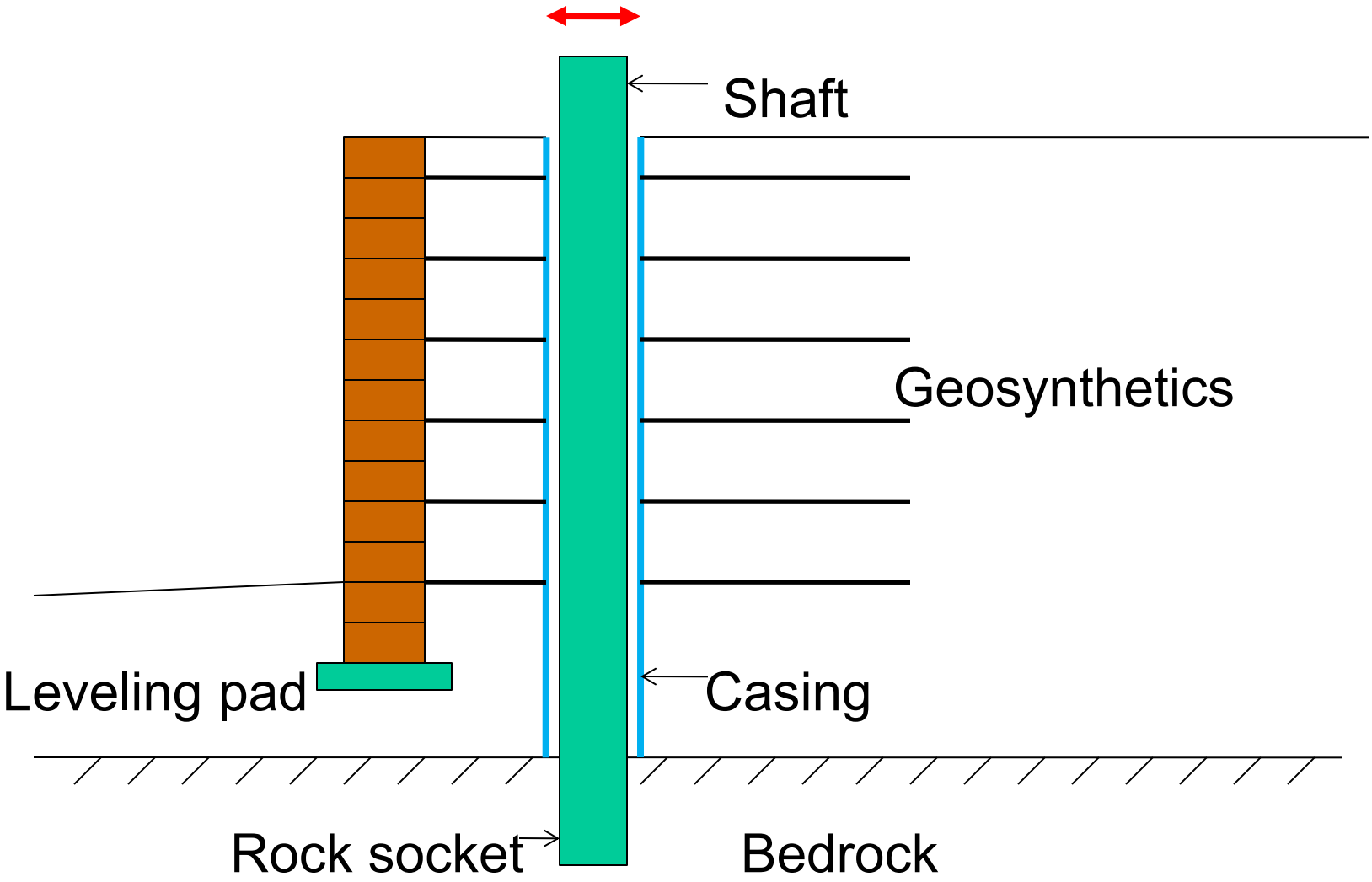
Typical Mixed MSE Wall Abutment



Sound Barrier Walls



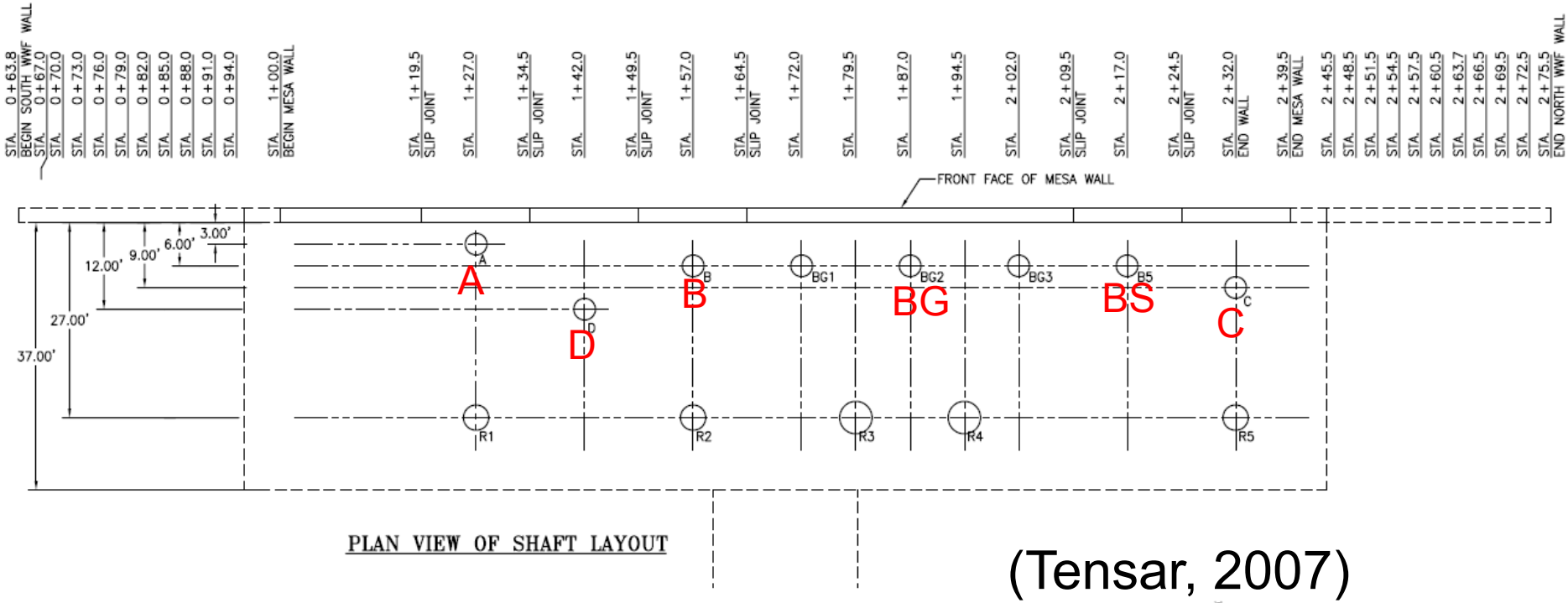
Current Practice



Construction of Wall and Shafts

- Excavation of Site
- Steel Used in Shafts
- Rock Sockets
- Setting of Steel in Rock Sockets
- Leveling Pad
- Materials
- Wall Construction
- Instrumentation

Plan View



(Tensar, 2007)

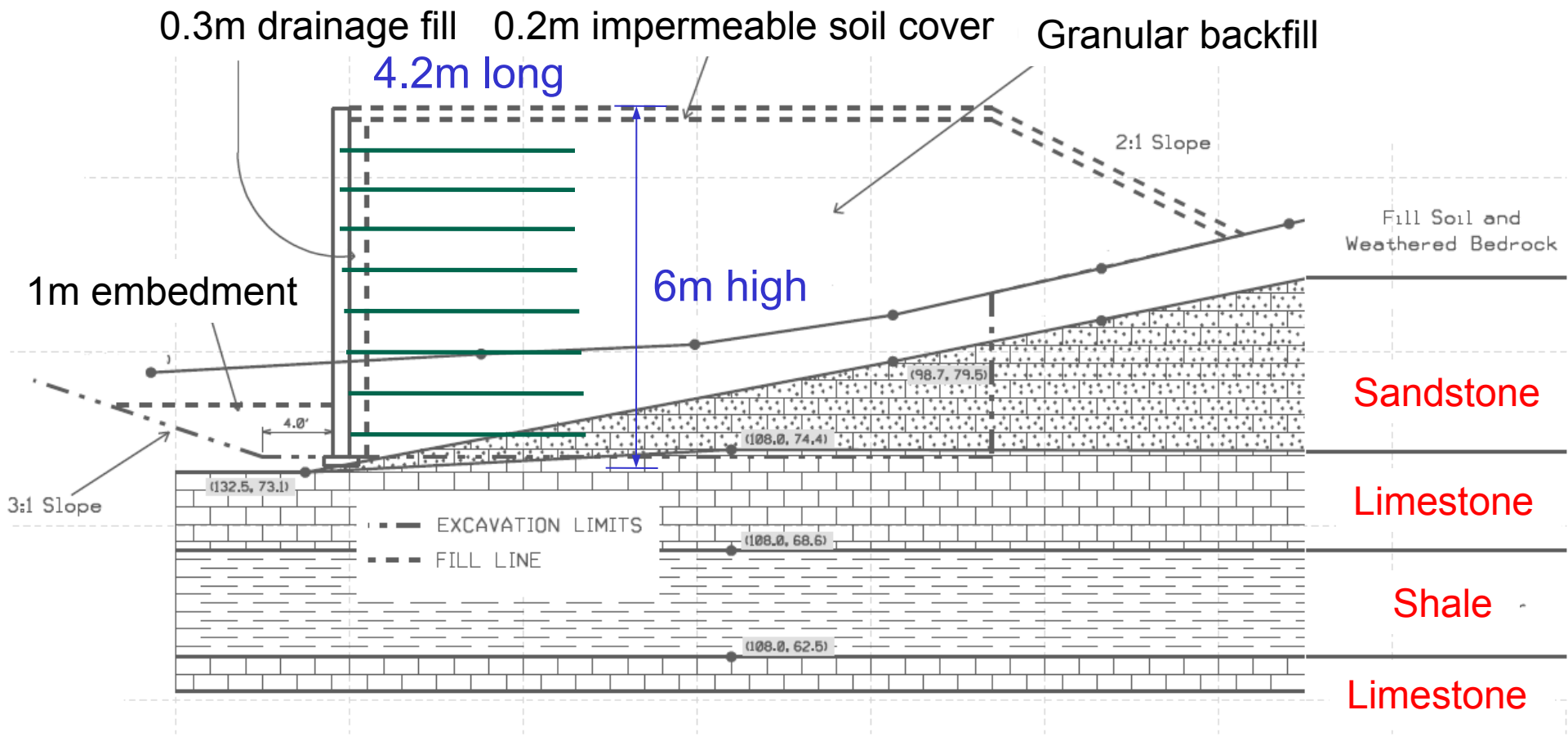
N

Diameter of test shaft = 0.9m

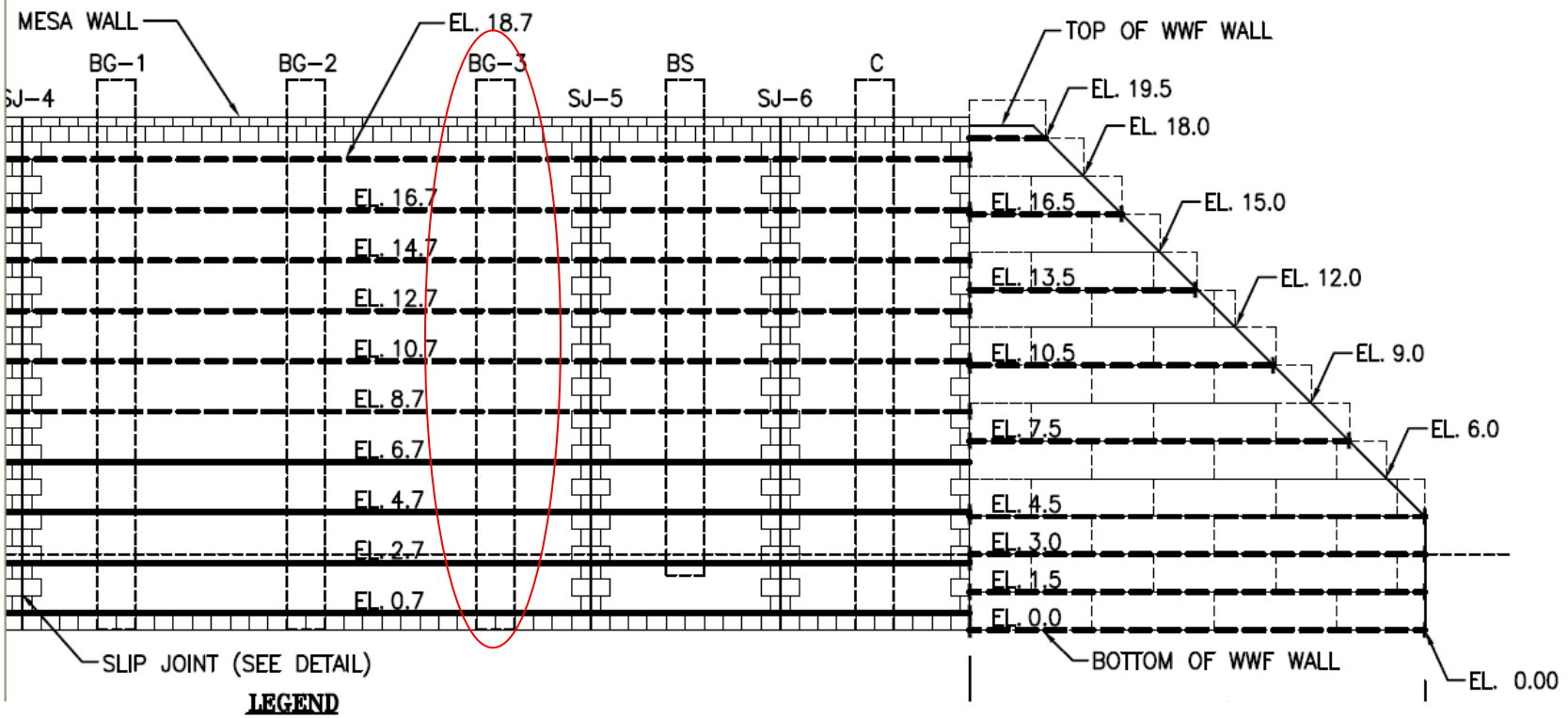
Distance to back of wall facing

Shaft A	0.9m
Shaft B	1.8m
Shaft C	2.7m
Shaft D	3.6m

Profile of Wall and Subsurface



(KDOT, 2007)



(Tensar, 2007)

Facing and Reinforcement Plans

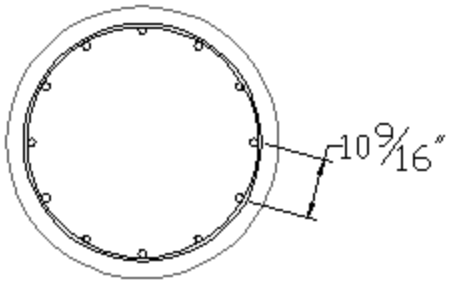
Excavation

- Loosely Cemented Silty Sandstone
- Stopped at Hard Limestone Layer

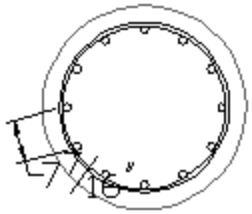
Steel Reinforcement Used in Shafts

2 x 1.2m Dia x 8.8m long Reaction Shafts

1.2m Shaft



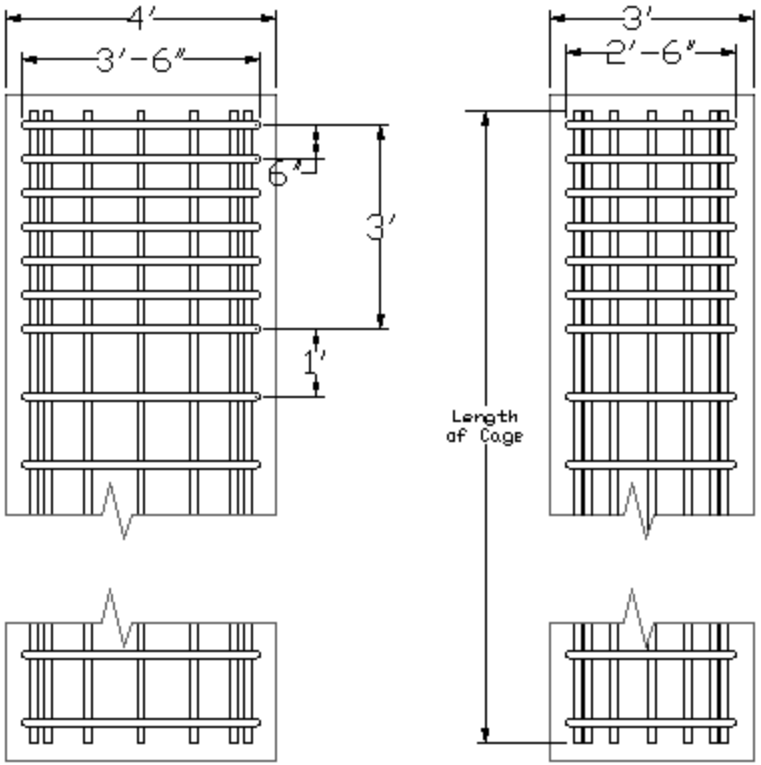
0.9m Shaft



4 x 0.9m Dia x 8.8m long Reaction Shafts

All Longitudinal Bars # 11

All Transverse Bars # 5



7 x 0.9m Dia x 7.0m long Test Shafts

1 x 0.9m Dia x 5.5m long Test Shaft

Rock Sockets

- 1.8 – 2.1m Deep on all Reaction Shafts
- 4 x 0.9m Diameter
- 2 x 1.3m Diameter

Setting Shafts in Rock Sockets

Corrugated Metal Pipe

Leveling Pad

Wall Construction

- Blocks
  - Placement, Leveling
- Backfill
  - Placement, Leveling, Compaction
- Geogrid
  - Placement, Trimming (if necessary), Connectors, Pre-tensioning
- Notes
  - Top Soil Cover
  - Slip Joints

Blocks

Placement

Leveling

Backfill


Geogrid must be trimmed to go around the drilled shafts
Geogrid
Tensar Uniaxial Geogrid
Spacing: One course every 0.6m or 3 blocks
Tensioning of Grid and Placement of CA-5

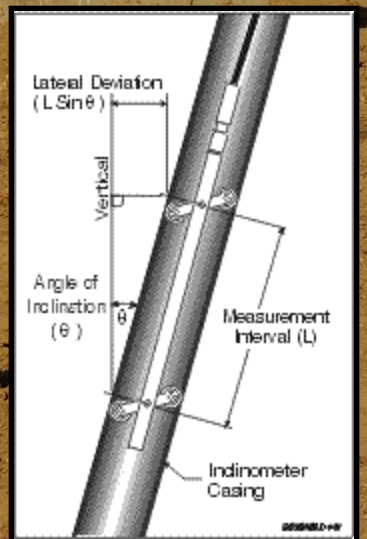

Connection

Instrumentation

- Inclinometer Casing
- Strain Gages on Geogrid
- Photo Targets Attached to Facing
- Earth Pressure Cells Behind Facing
- Data Collection System
- Tell-Tales Imbedded in Wall

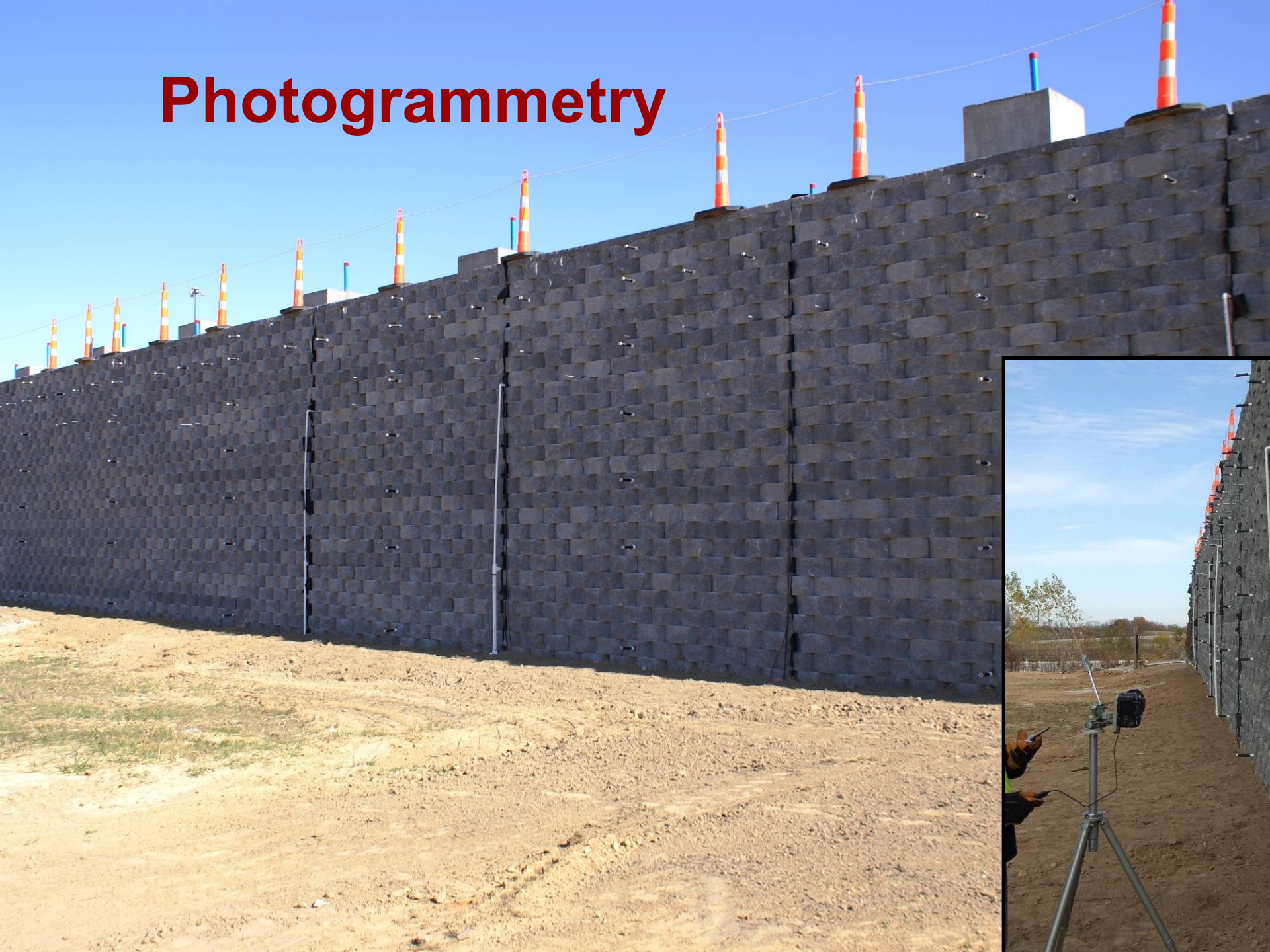
Inclinometer Casing

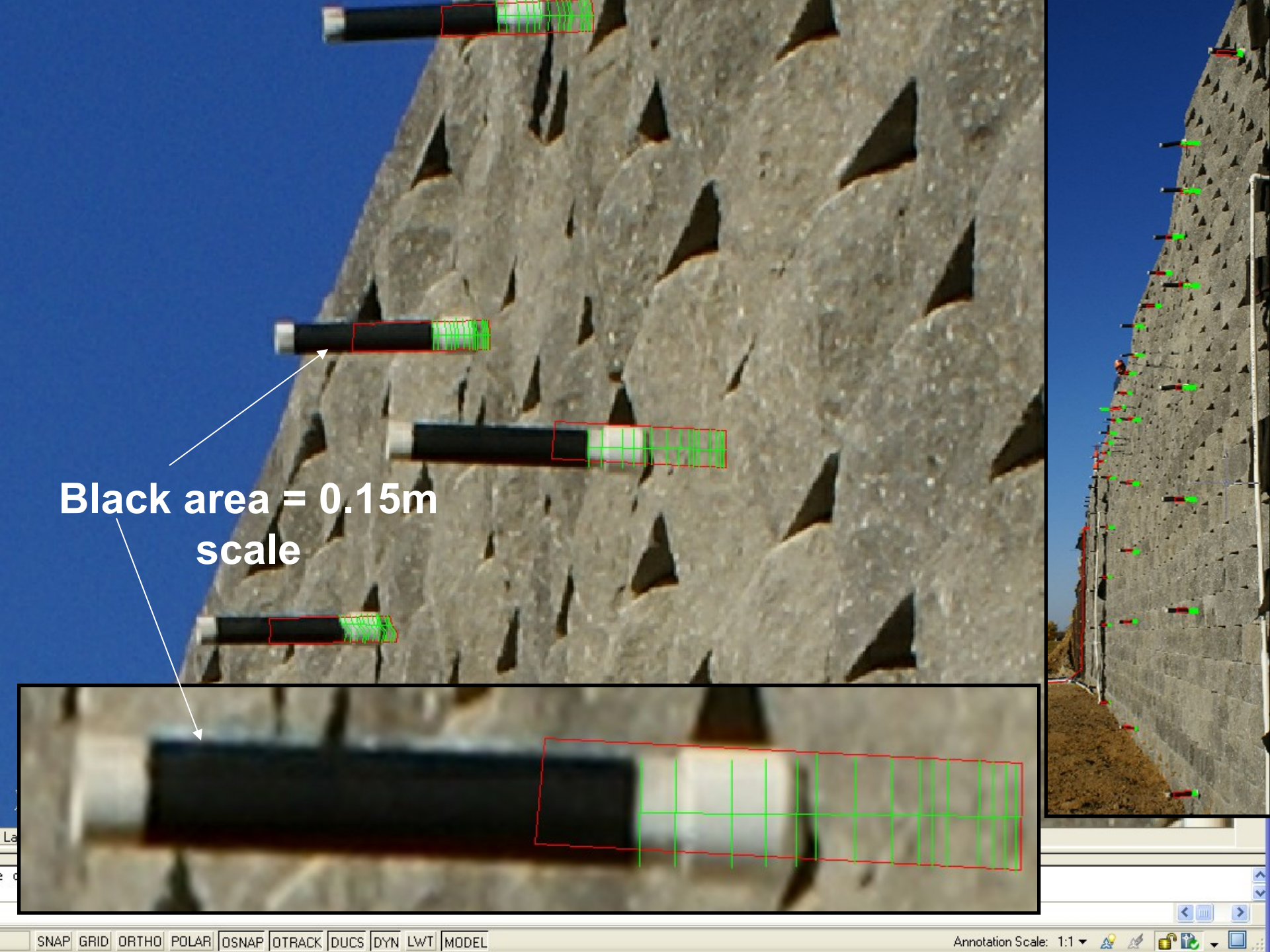
- In all drilled shafts and also two located along the facing



Strain Gages on Geogrid

Photogrammetry




Black area = 0.15m
scale

Earth Pressure Cell

Tell-Tales

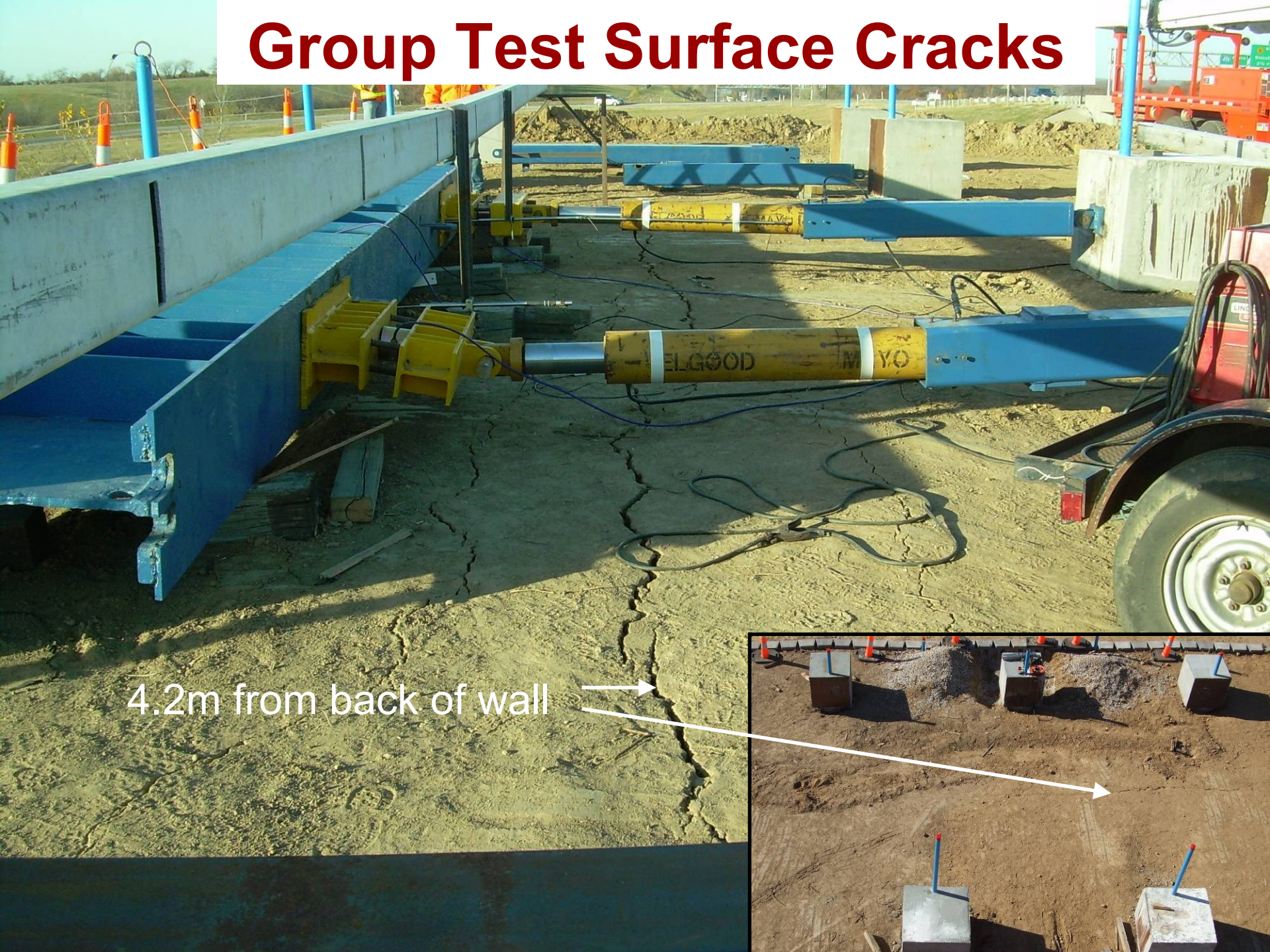
Test Setup

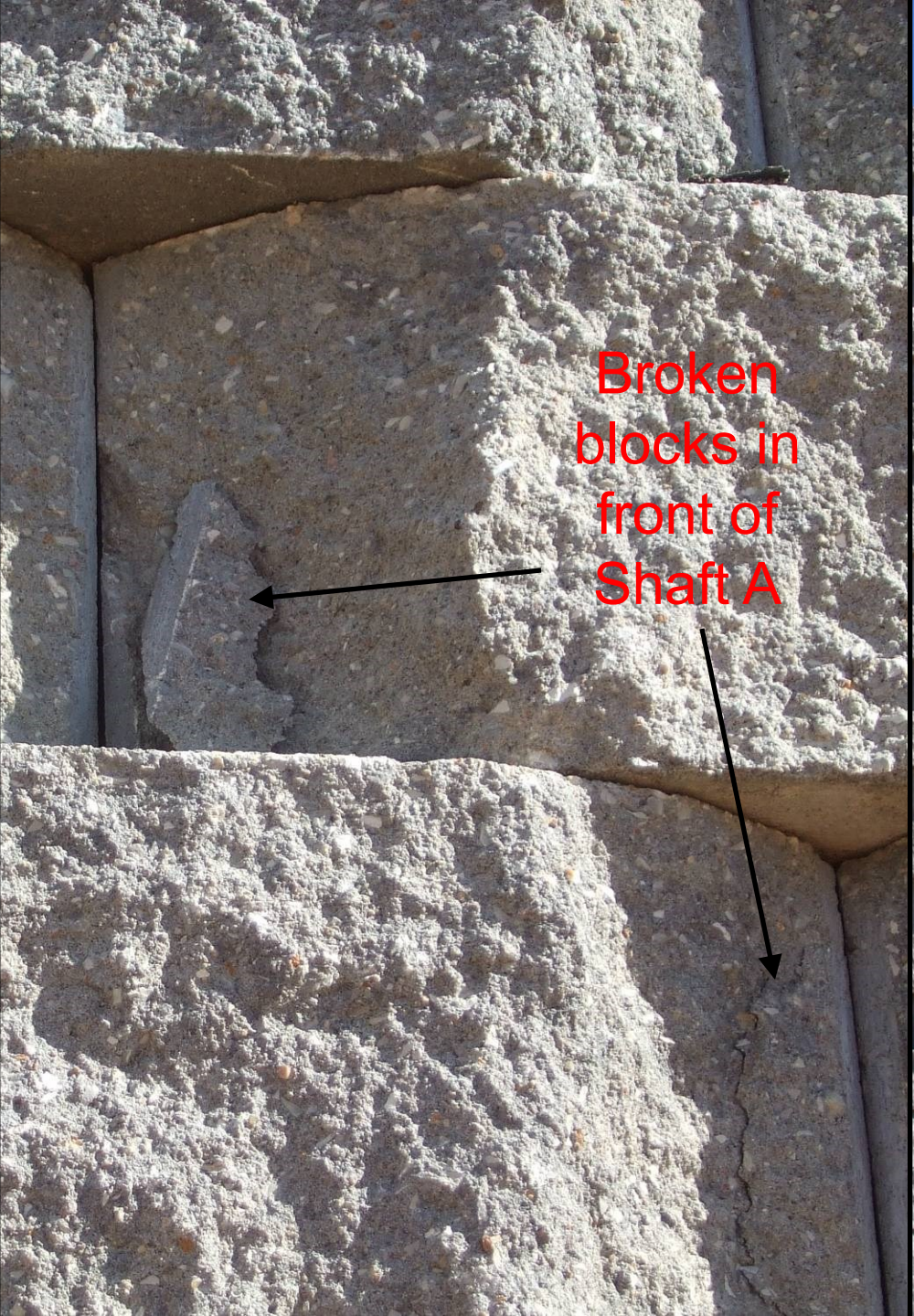
Single Shaft

Group Shaft Test

Surface Observations

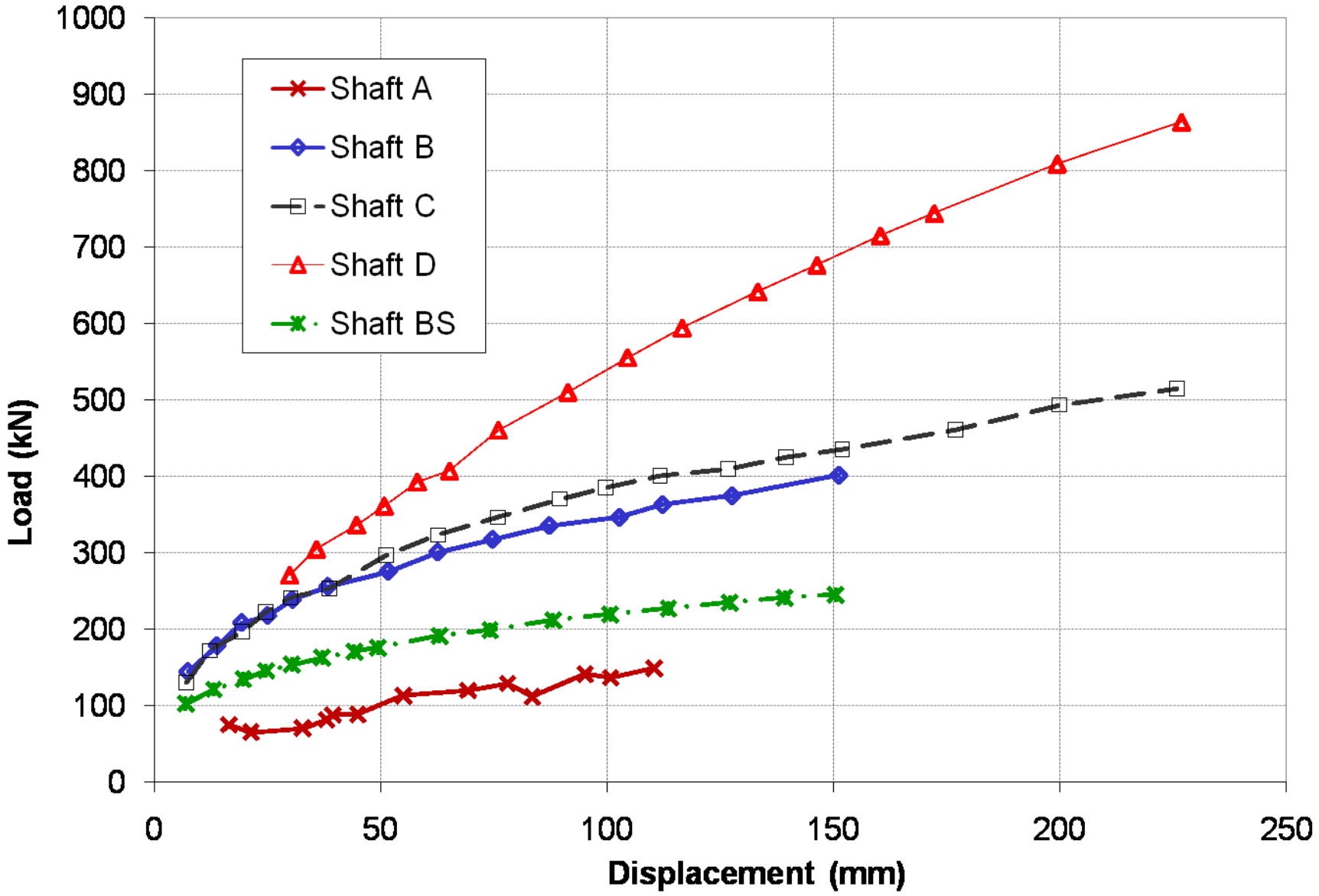
Group Test Surface Cracks



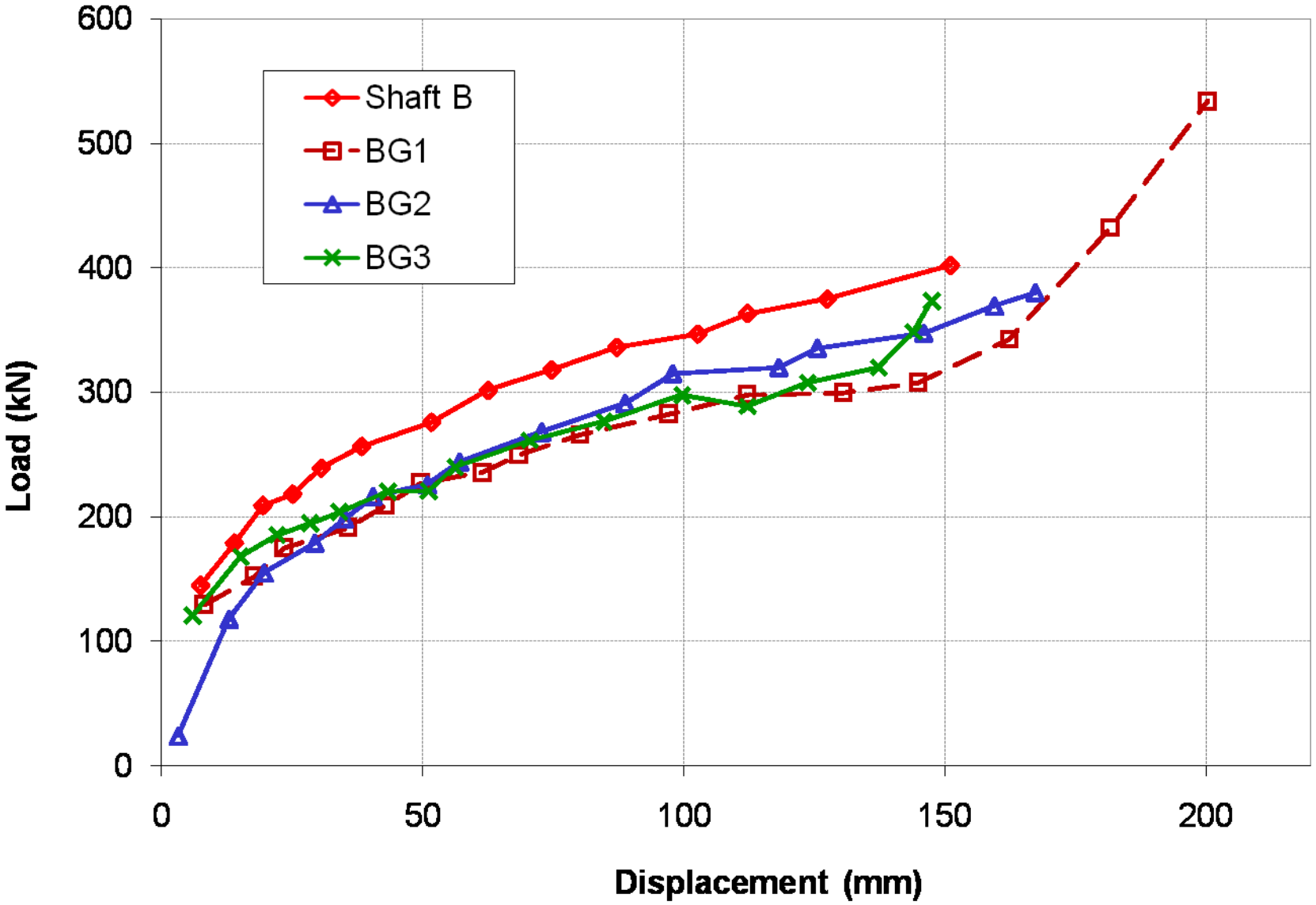

Broken
blocks in
front of
Shaft A


Opening
of
blocks in
front of
Shaft B

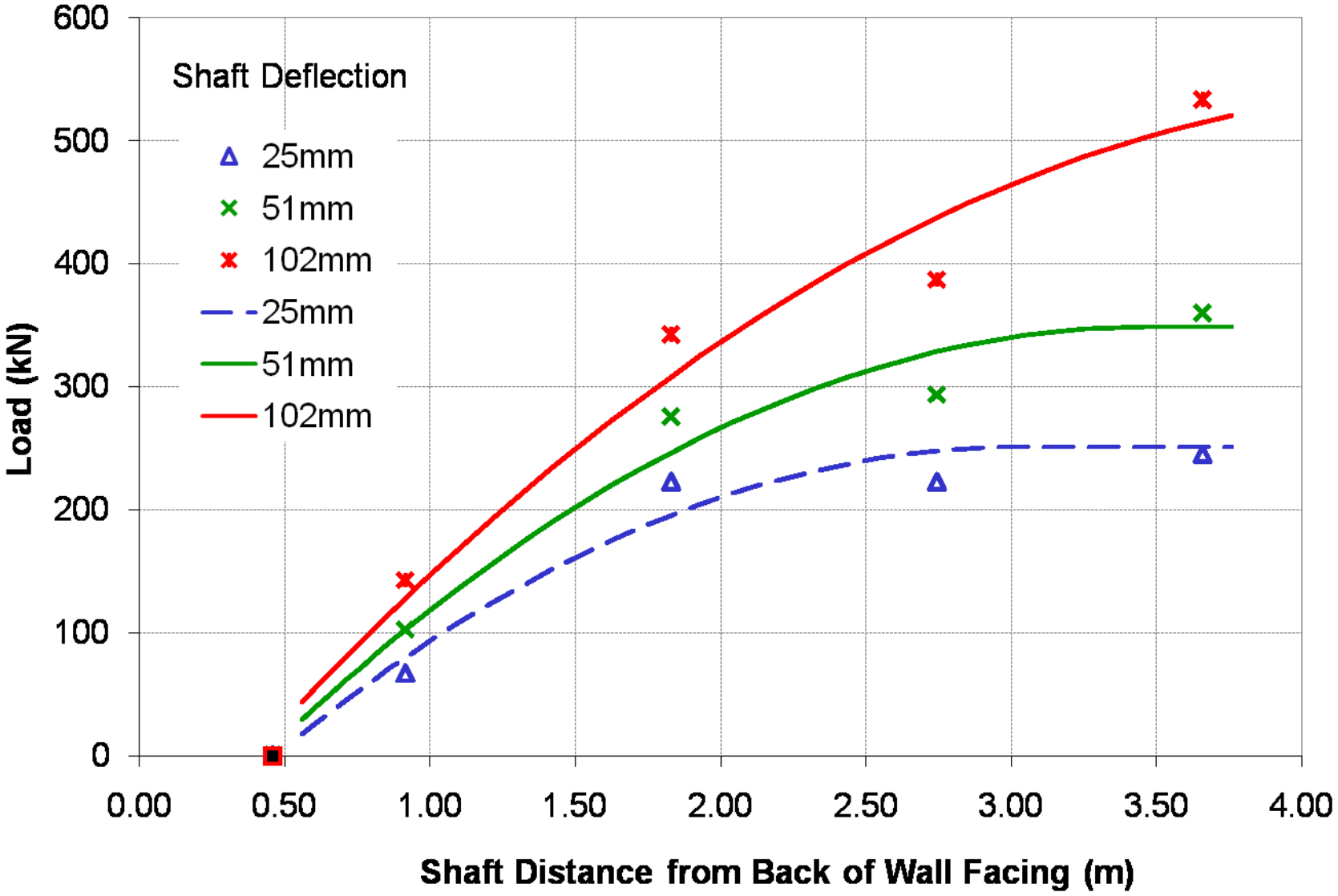
Load versus Deflection of Shaft



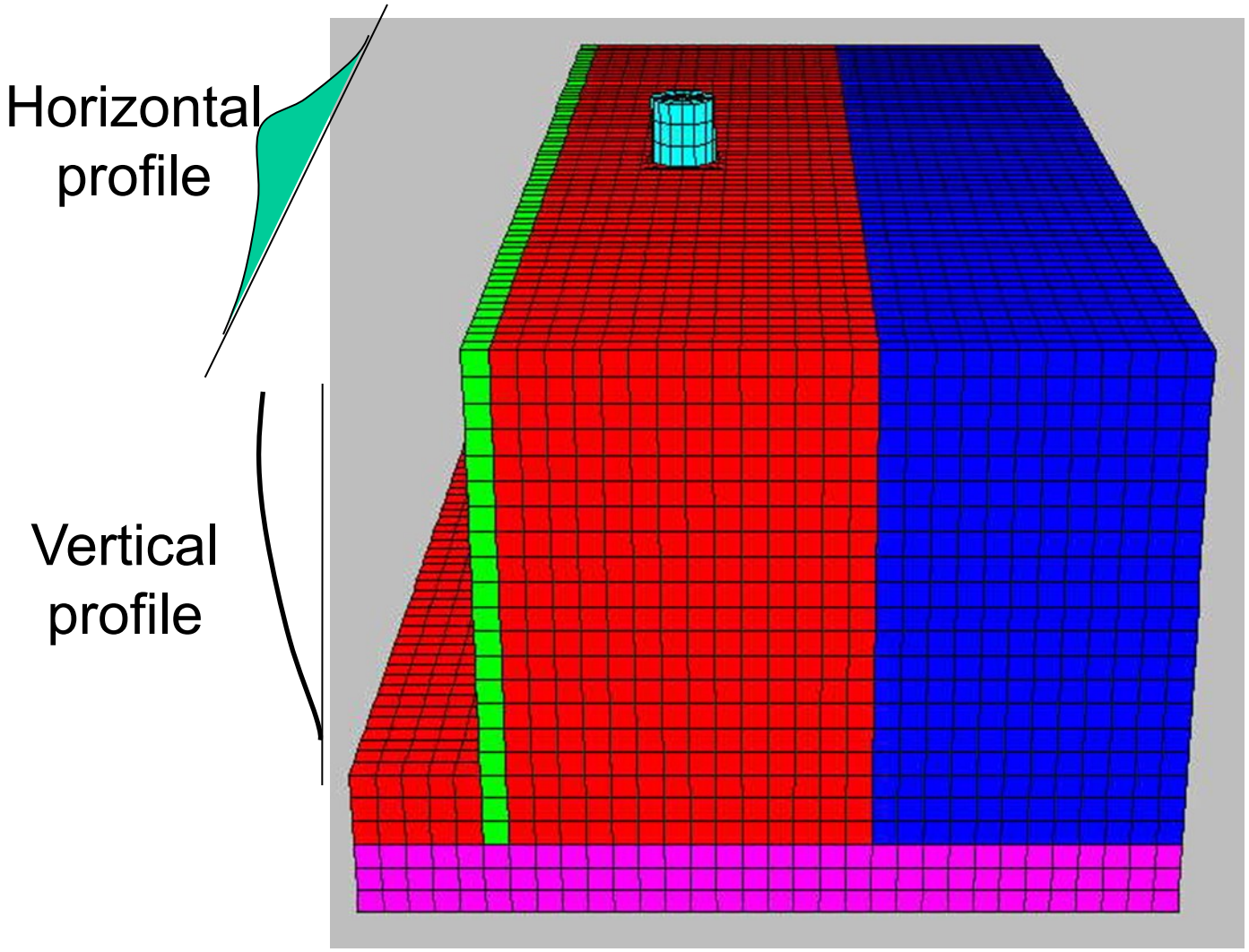
Load versus Deflection of Group Shaft



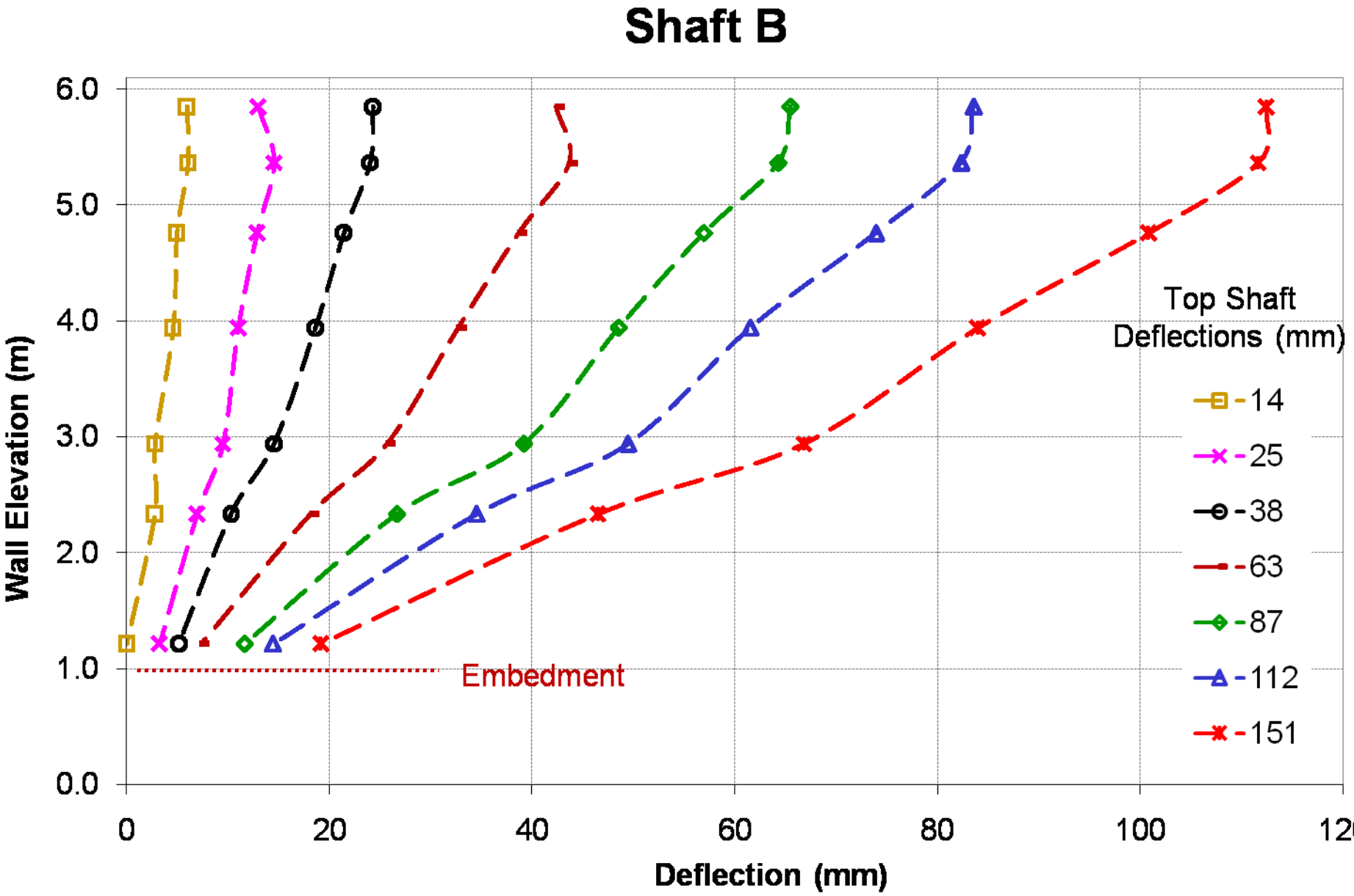
Effect of Shaft Distance on Capacity



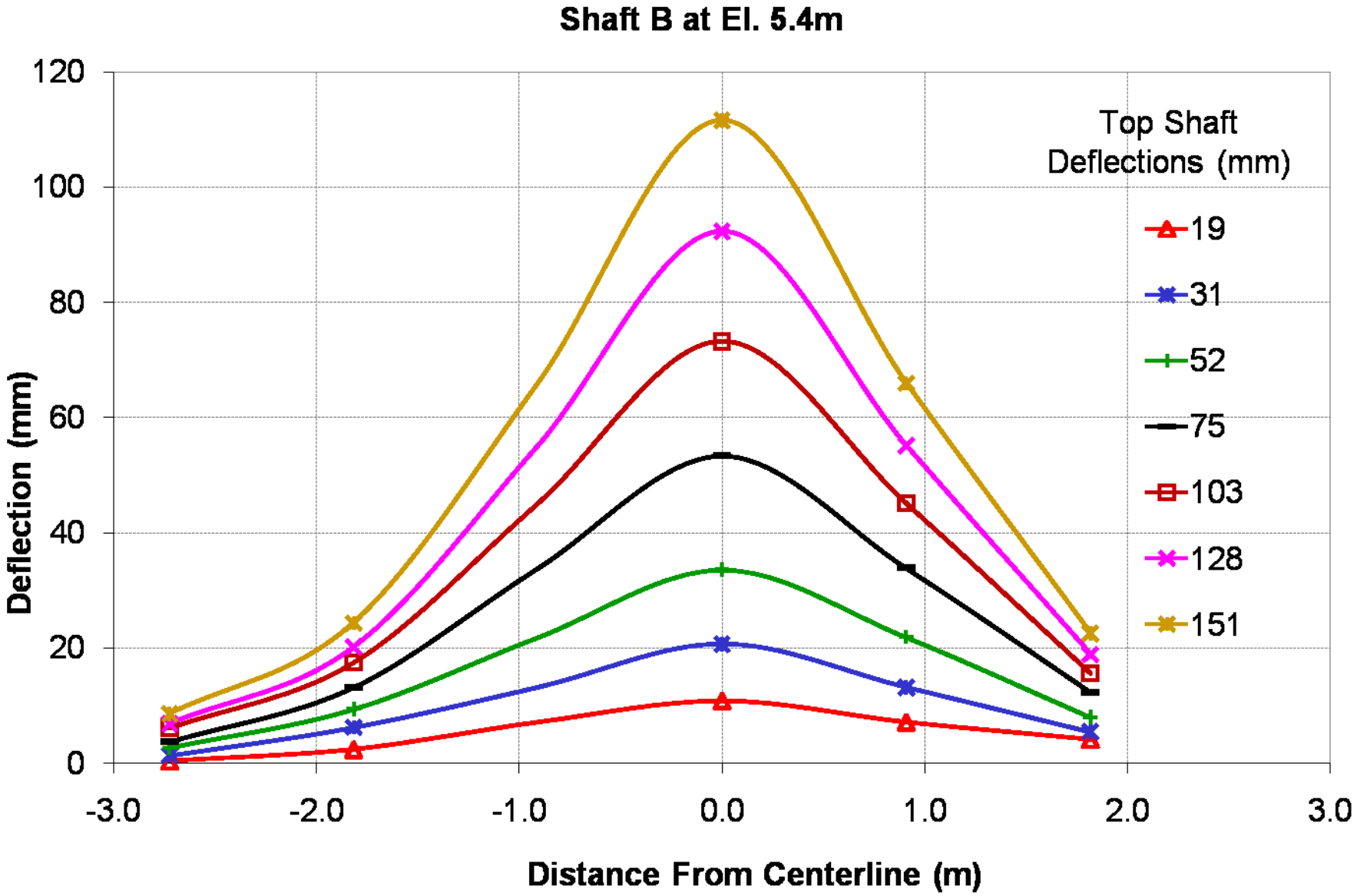
Definition of Wall Facing Deflections



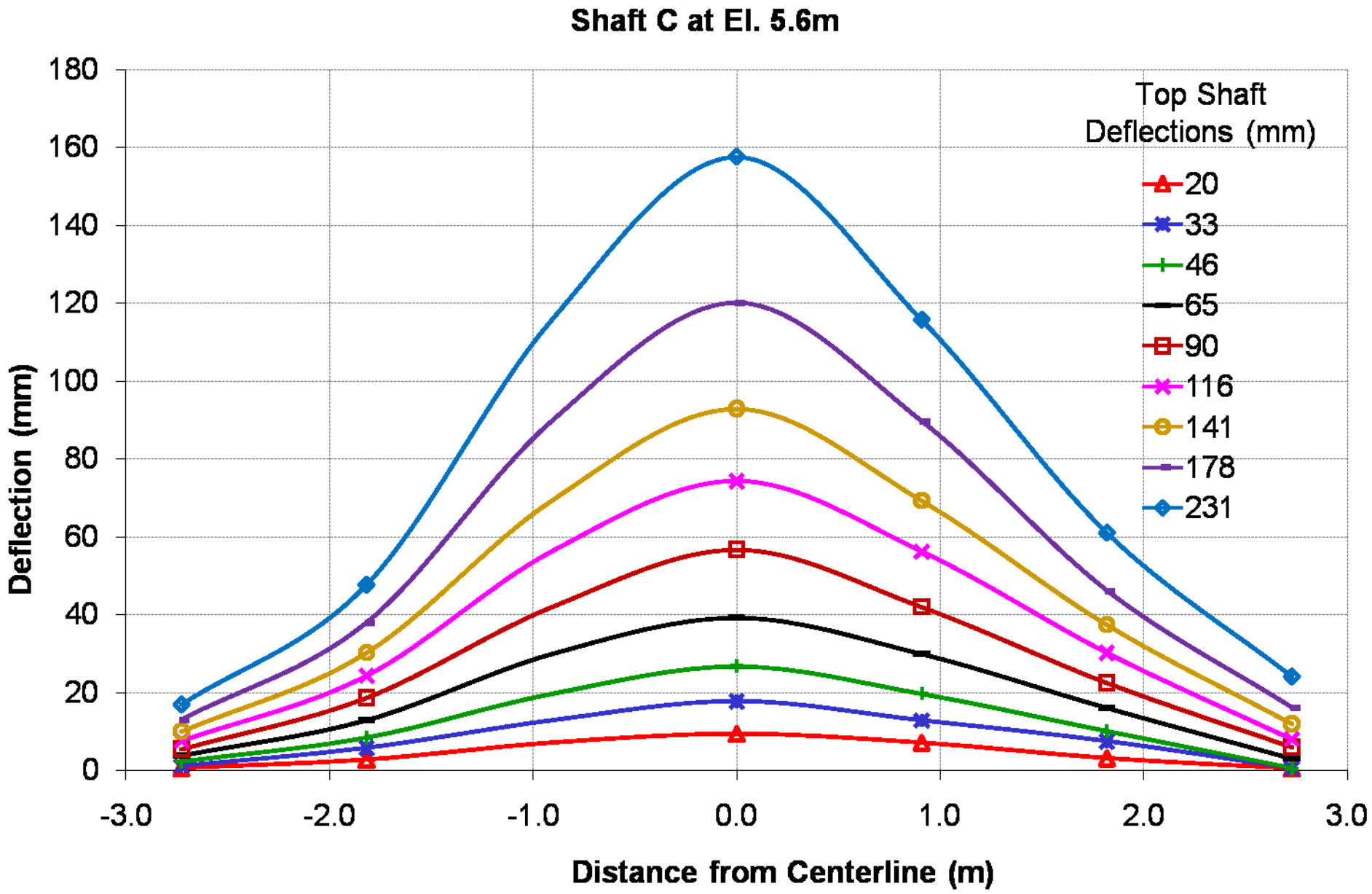
Facing Deflection – Vertical Profile



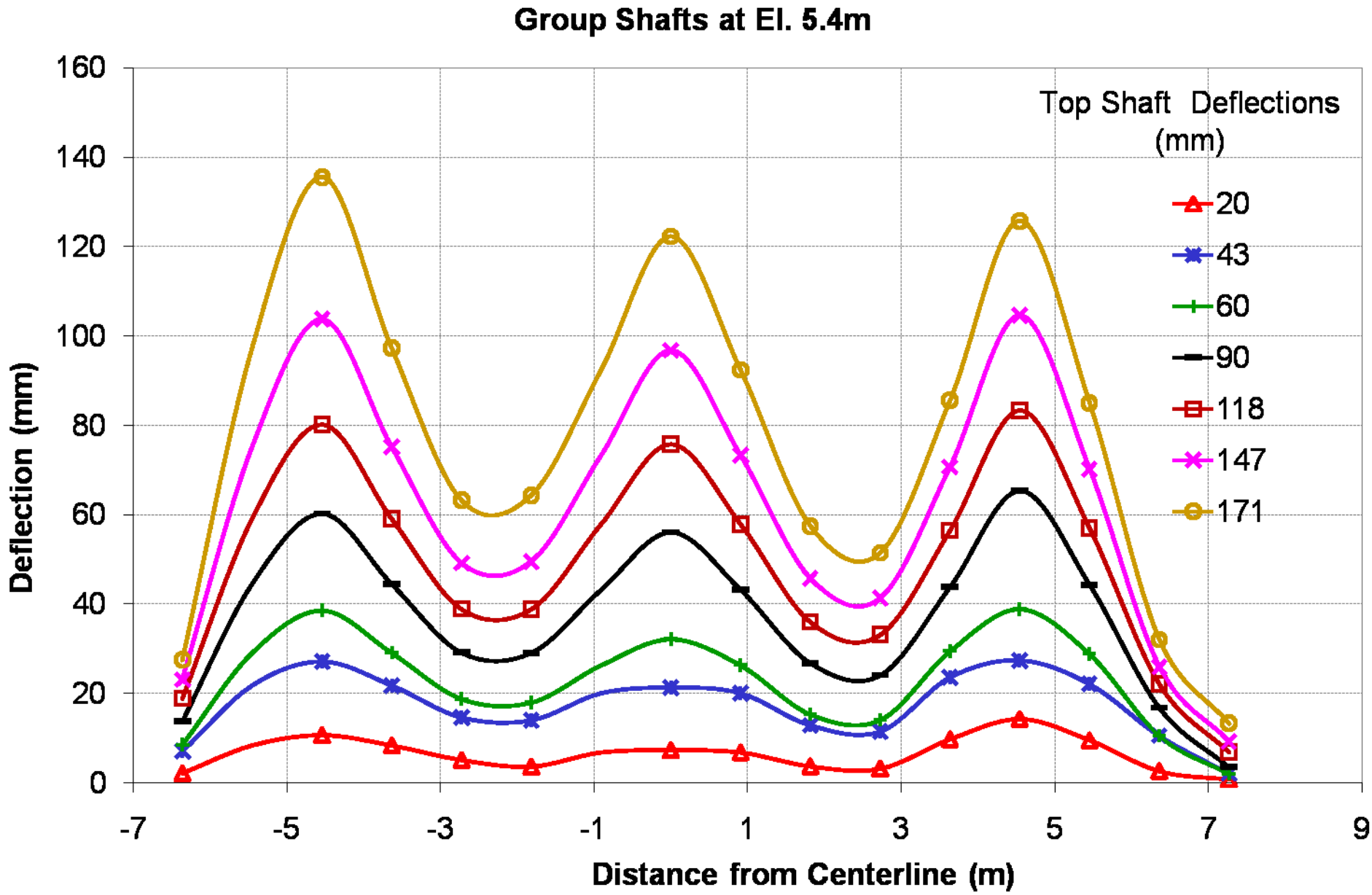
Facing Deflection – Horizontal Profile



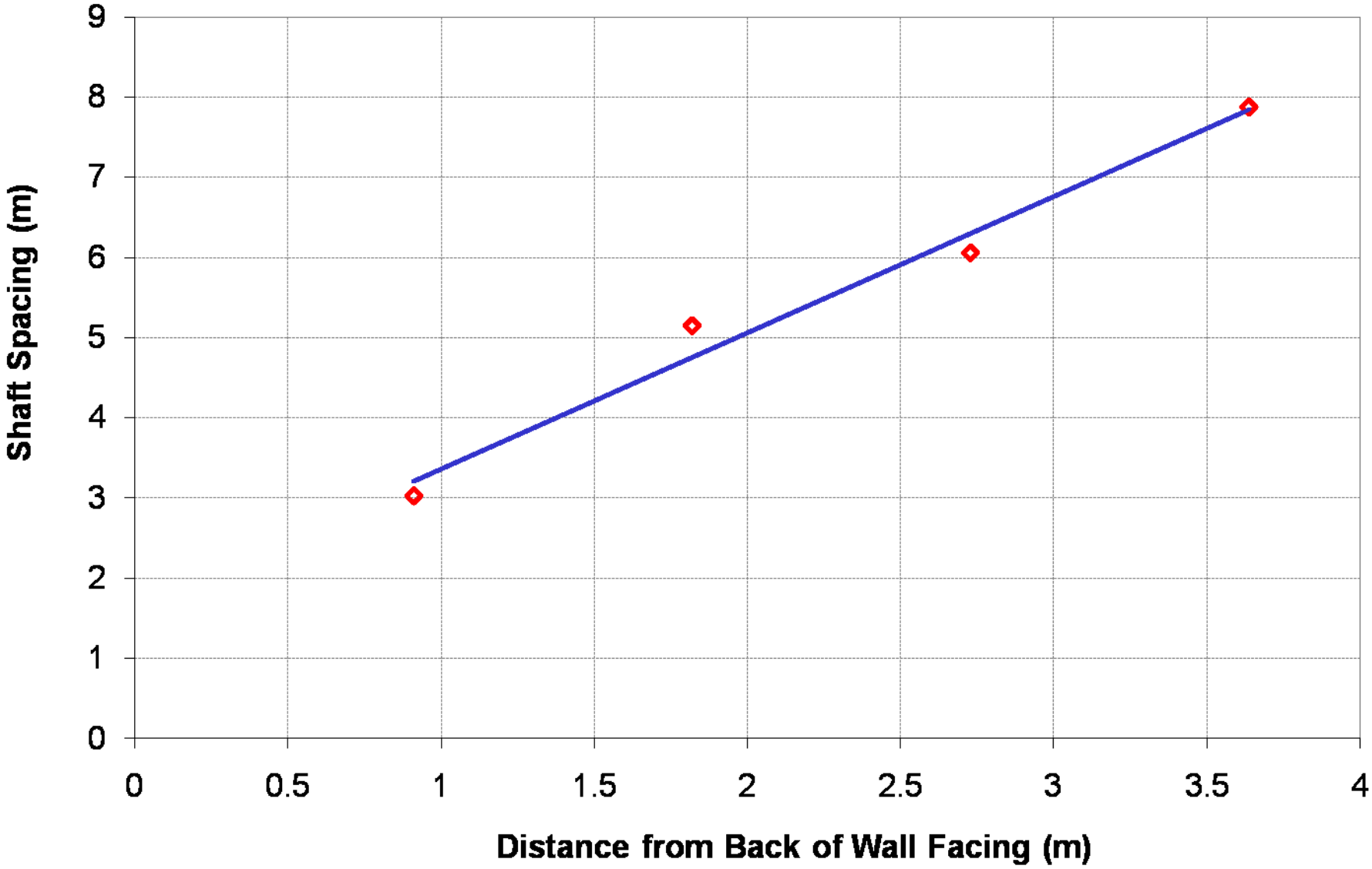
Facing Deflection – Horizontal Profile



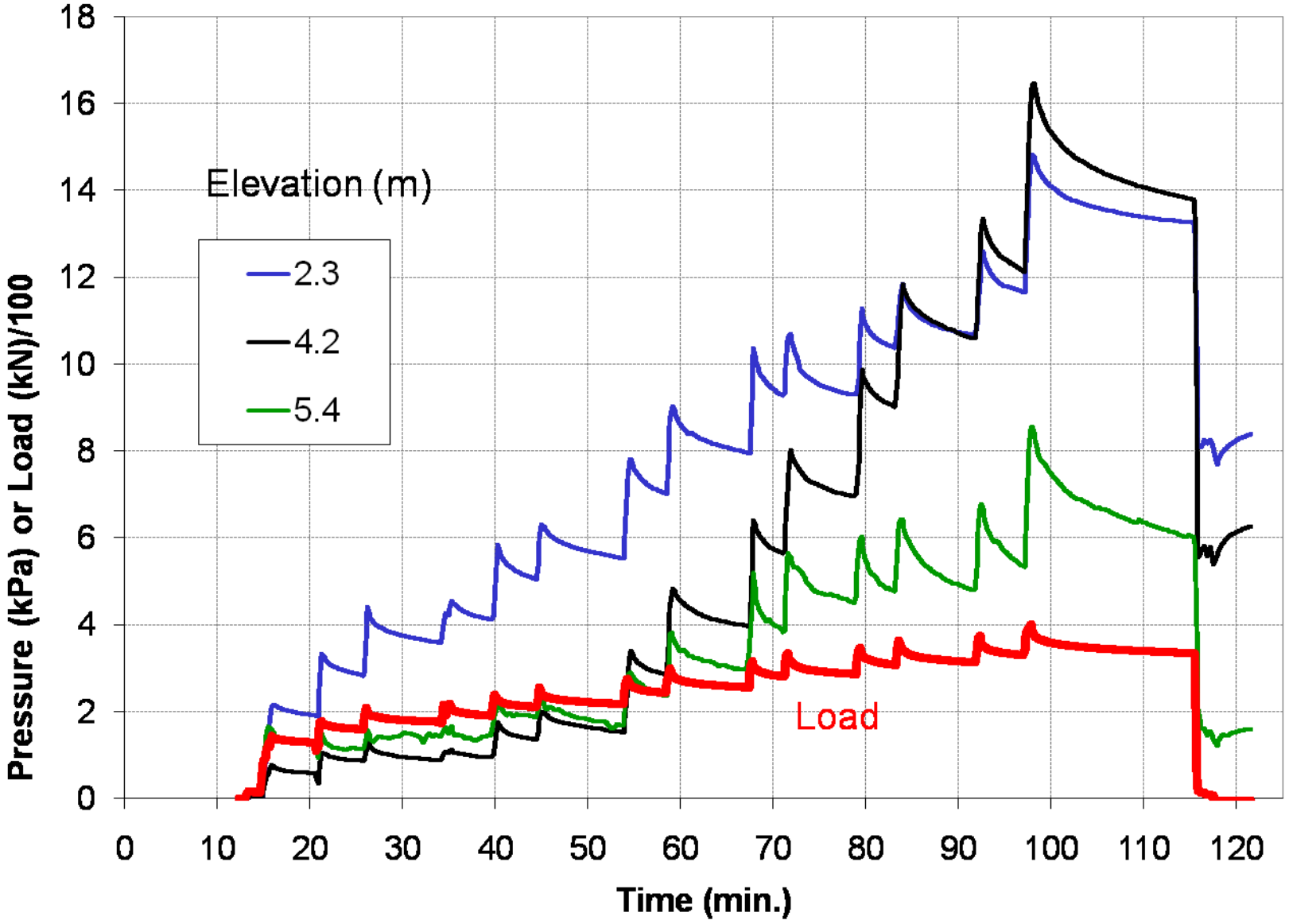
Facing Deflection – Horizontal Profile



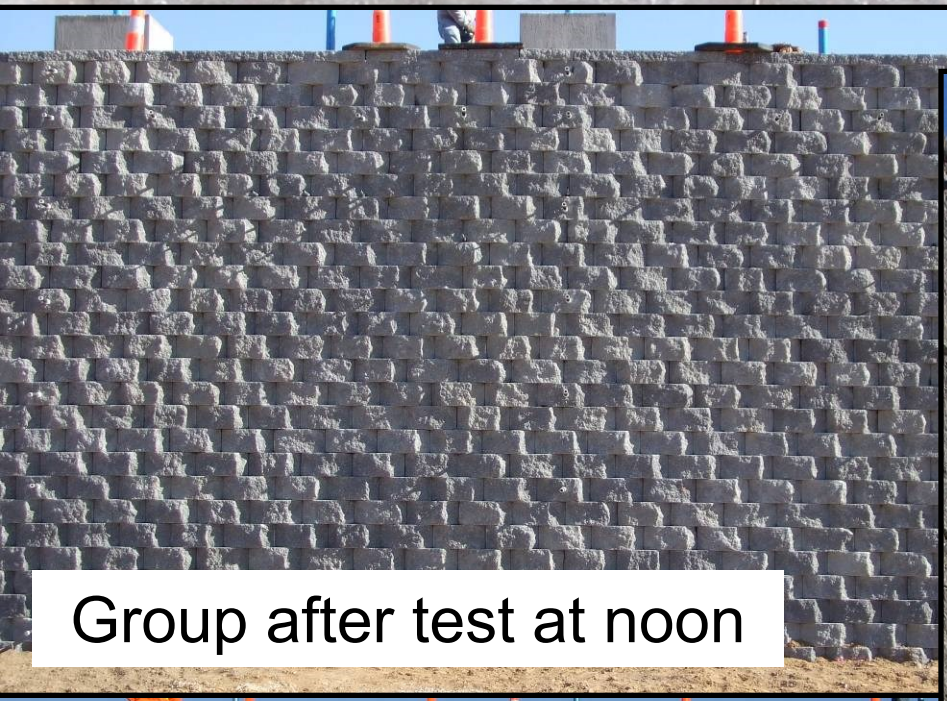
Shaft Spacing for No Group Effect



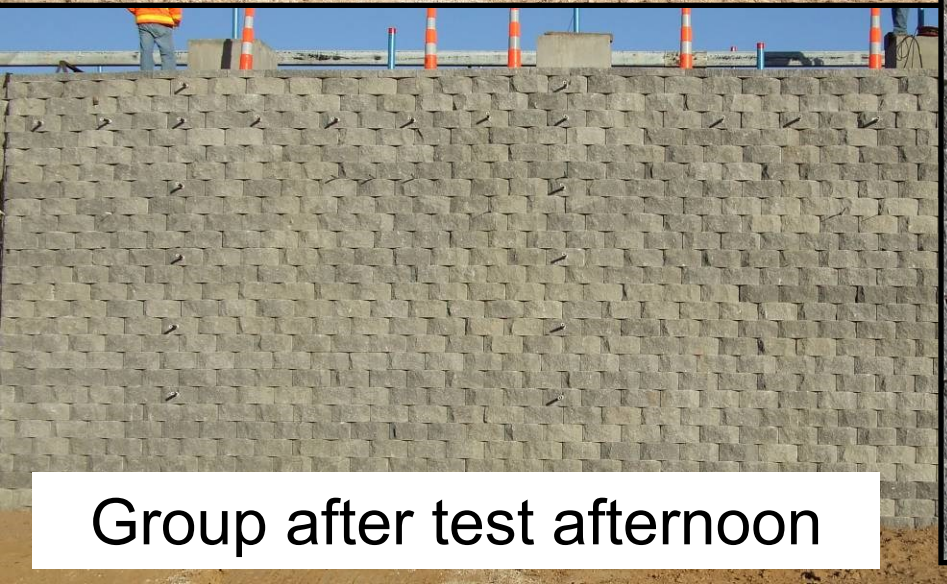
Shaft B Pressure Cell Measurements



Aesthetic



Group after test at noon



Group after test afternoon

Group after test

Strength Limit State Recommendations

Test Shaft ID	Distance (m) Center of shaft to Back of Wall Facing	Measured Load (kN)	Allowable Lateral Load (kN) Factor of Safety 2	3	Required Shaft Spacing (m) To avoid Influence
A	0.9	151	76	50	3.0
B	1.8	401	201	134	5.2
BS	1.8 (4.5m length)	245	123	82	5.2
BG	1.8 (4.5m spacing)	378	189	126	-
C	2.7	516	258	172	6.0
D	3.6	863	432	288	7.9

Service Limit State Recommendations

Shaft	Distance from Facing (m)	Lateral Load (kN)					
Displacement (mm)		13	19	25	51	102	Ultimate
A	0.9	-	62	67	102	142	151
BS	1.8 (4.5m length)	120	134	147	178	218	245
BG	1.8 (4.5m spacing)	120	156	174	236	312	378
B	1.8	178	209	223	276	343	401
C	2.7	174	196	223	294	387	516
D	3.7	-	-	245	360	534	863