TEXAS A&M ENGINEERING

Effects of Trees on Foundations

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Houston Foundation Performance Association
Houston, Texas, December 8, 2010

Trees and Tree Characteristics

- Trees
  - How they affect slab performance and design
  - How they affect drilled shaft performance and design
- Tree characteristics
  - What they need to survive
  - Root zones
  - Water uptake
  - Moisture active zone

Outline

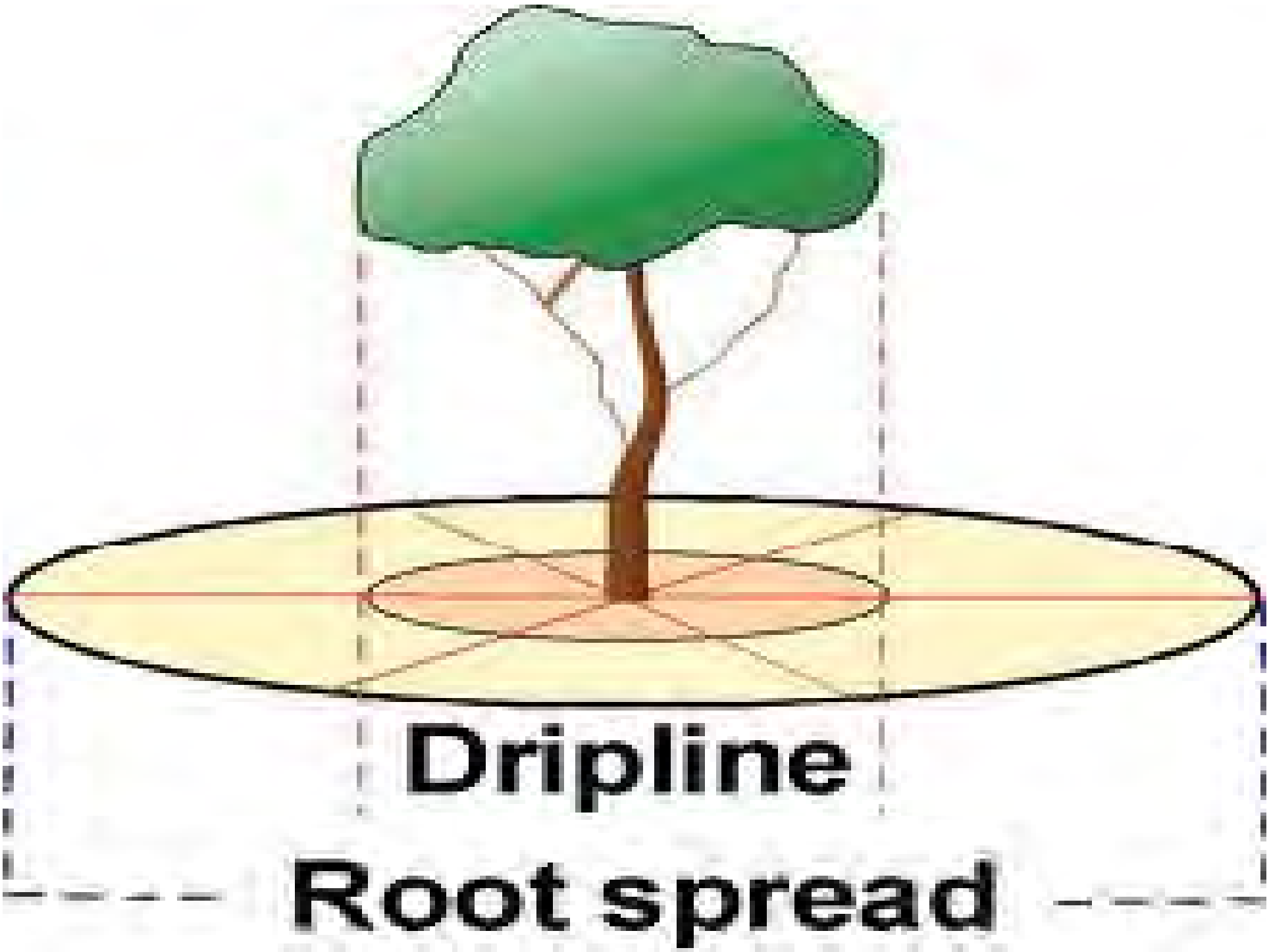
- Movement caused by trees
- Movie of movements caused by trees
- Design considerations of slabs near trees
- Design considerations of drilled shafts near trees
- Seams of moisture effects
- Summary

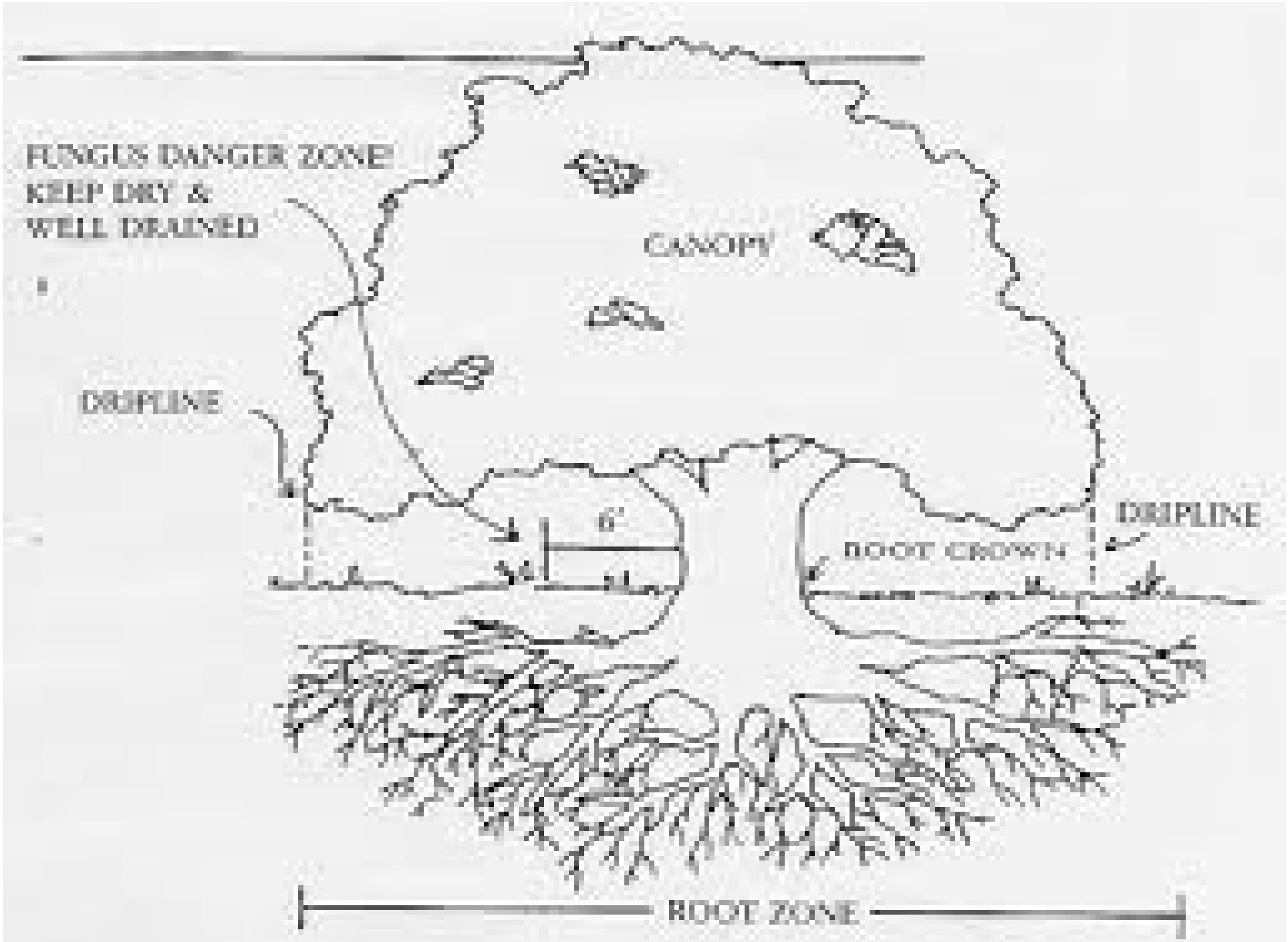
Trees – What They Need to Survive

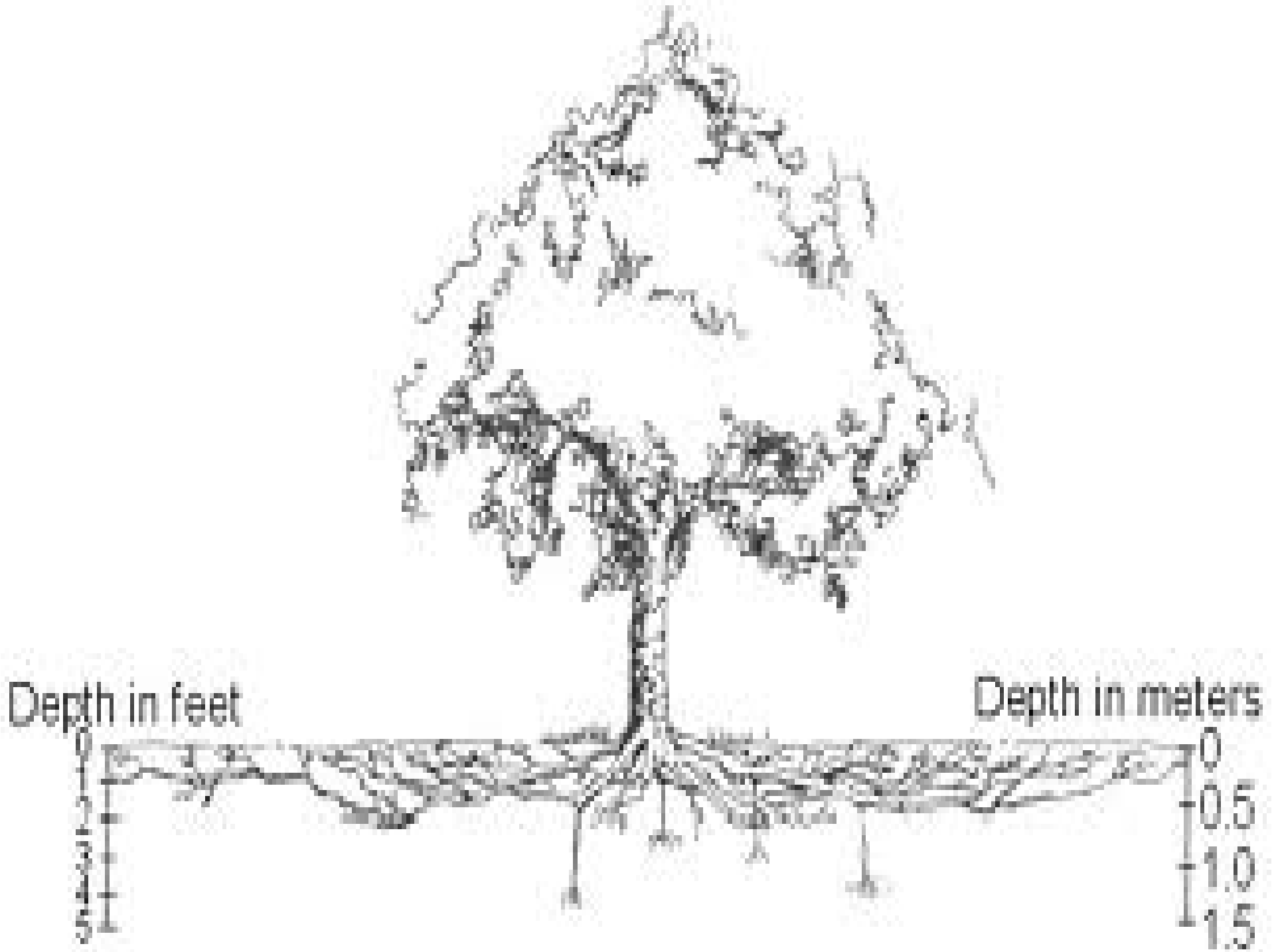
- Water
- Oxygen
- Nutrients

Characteristics of Root Zones

- Shallow roots
- Tap roots
- Root “ball”
- Root density


Dripline
Root spread


FUNGUS DANGER ZONE!
KEEP DRY &
WELL DRAINED
CANOPY
DRIPLINE
6'
ROOT CROWN
DRIPLINE
ROOT ZONE


Depth in feet
Depth in meters
0
0.5
1.0
1.5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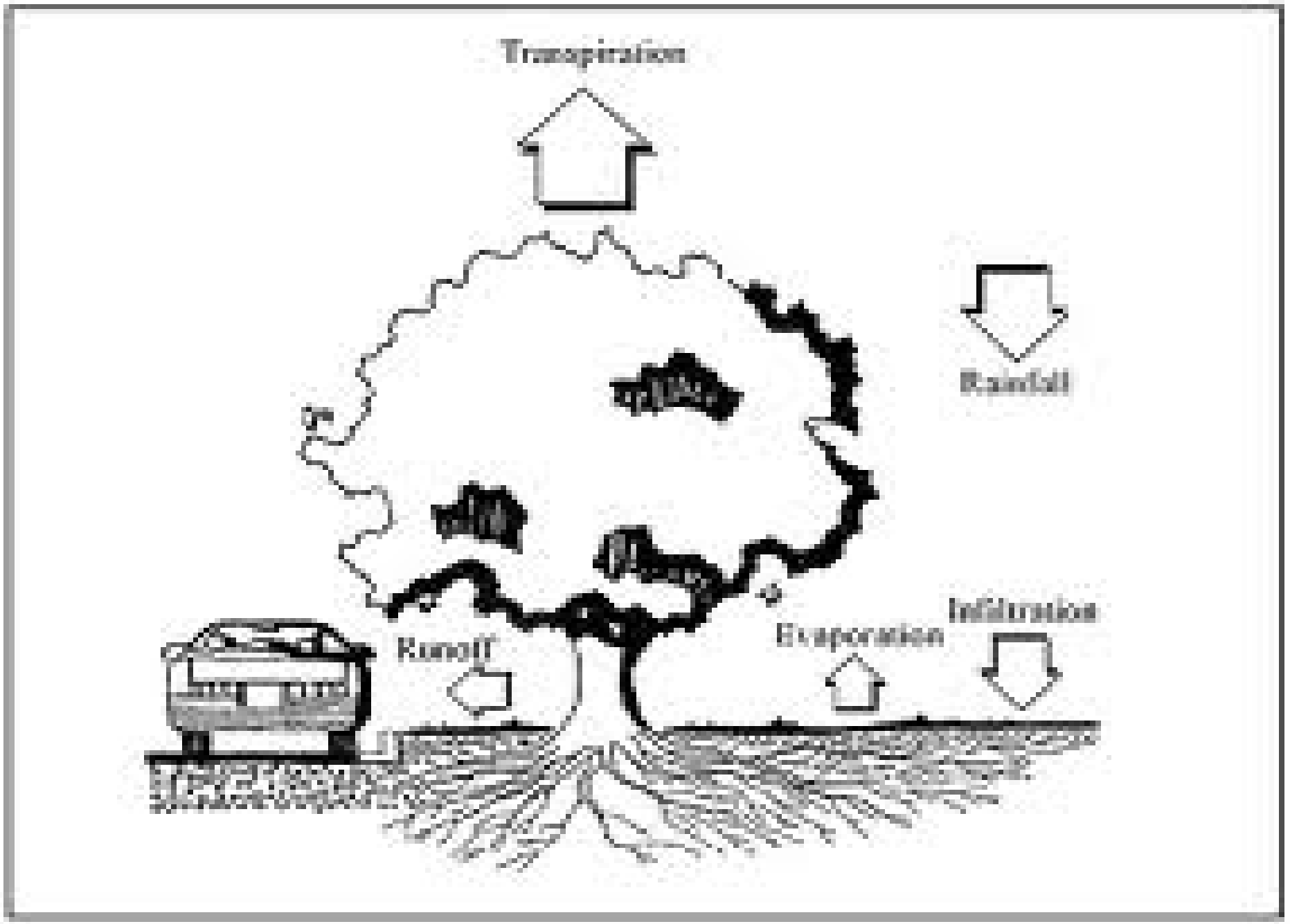
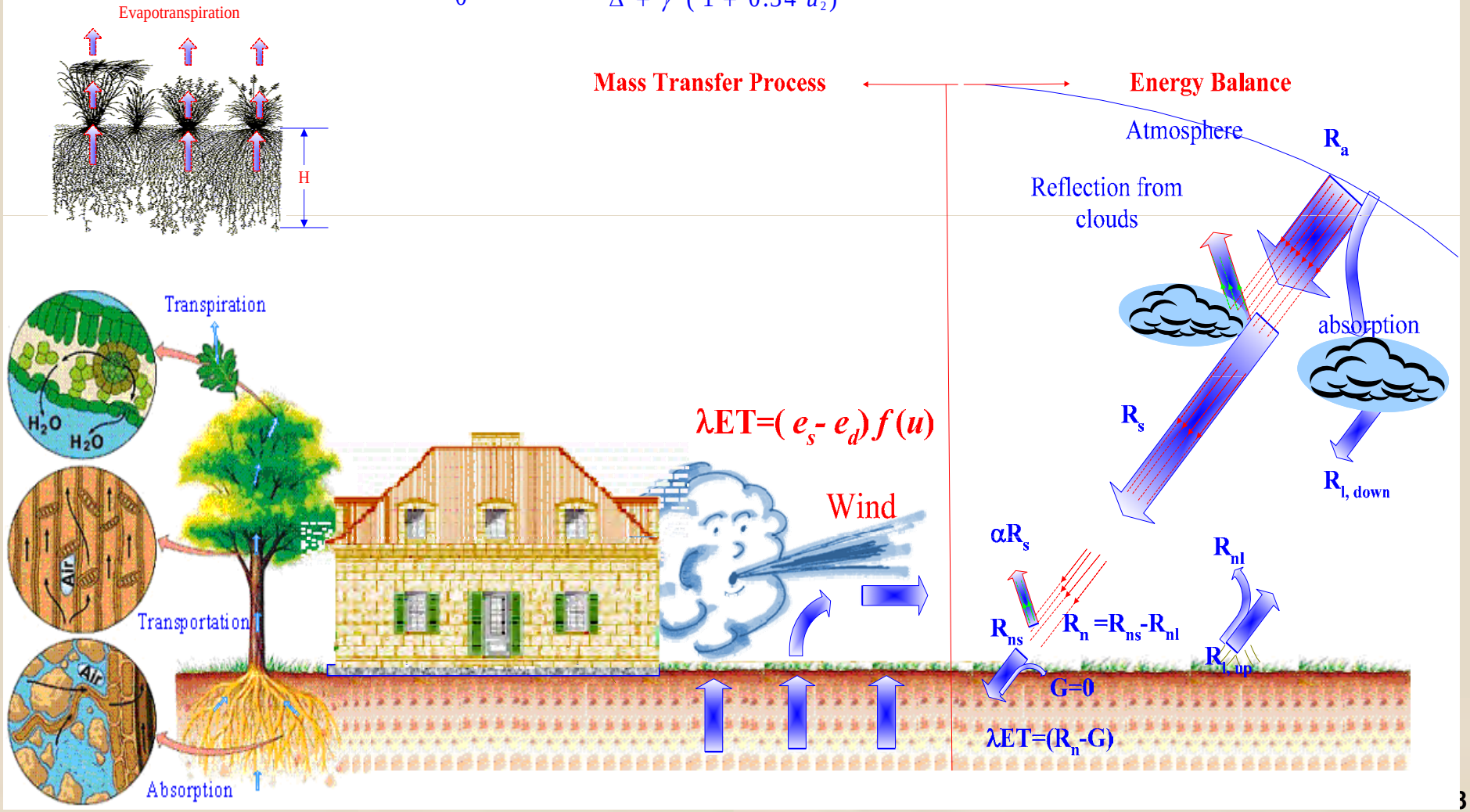


Figure 2: Main water movements in urban areas

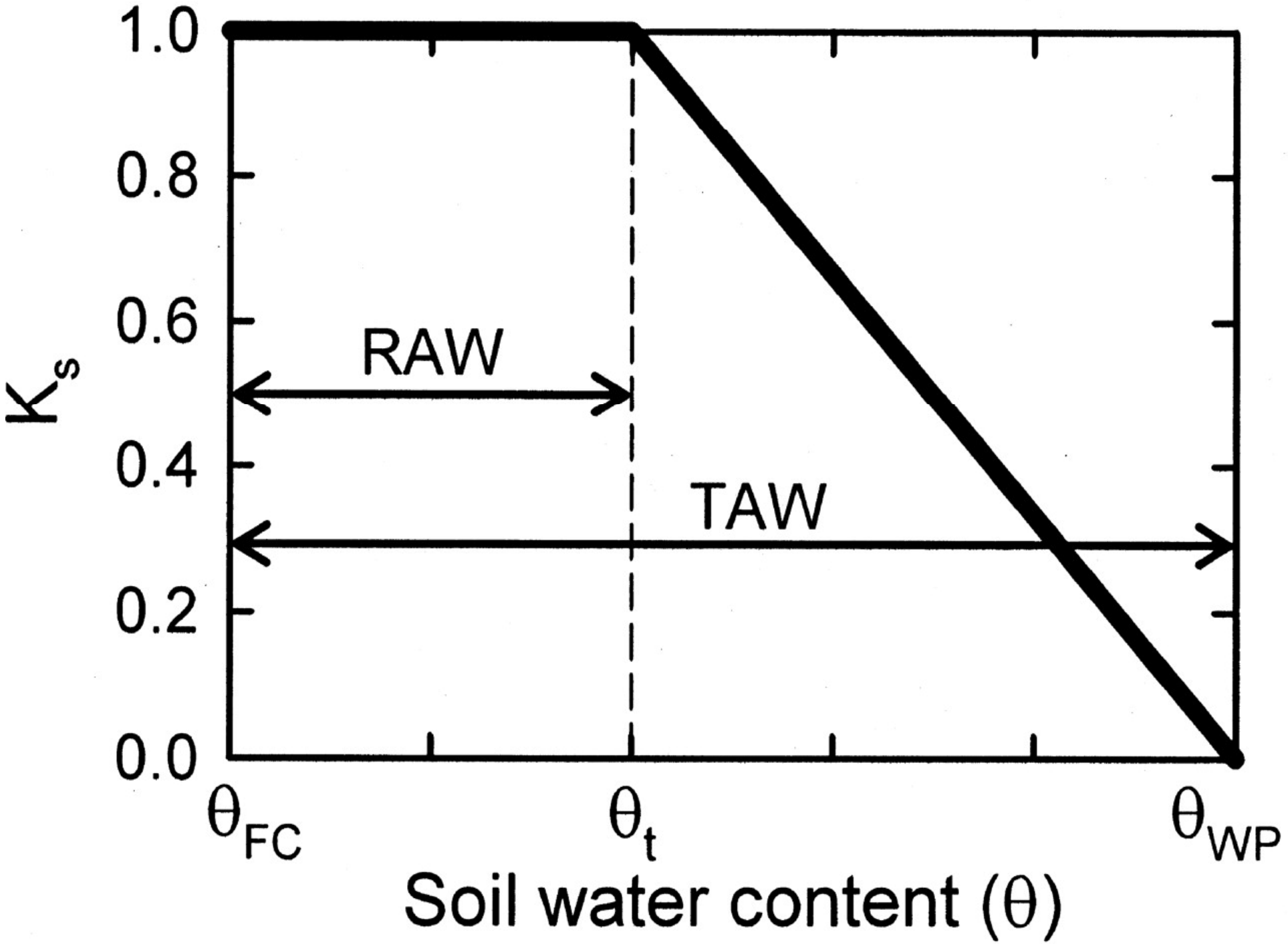
Factors Influencing Evapotranspiration

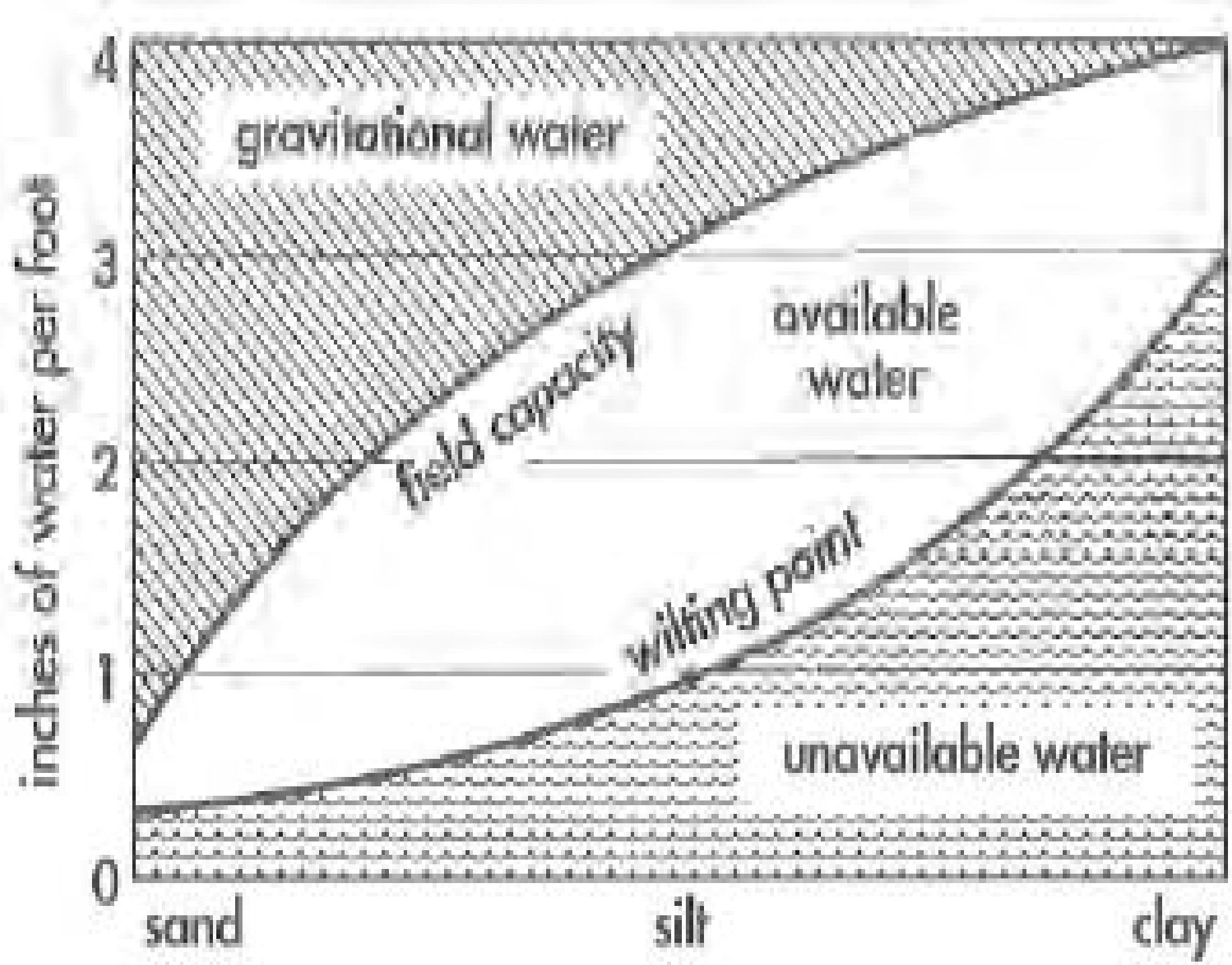
$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T+273}\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)}$$



Water Uptake by Roots

- Saturated
- Field capacity
- Thresh hold
- Wilting point
- Dry


1.0
0.8
0.6
0.4
0.2
0.0
K_s
RAW
TAW
θ_{FC}
θ_t
θ_{WP}
Soil water content (θ)

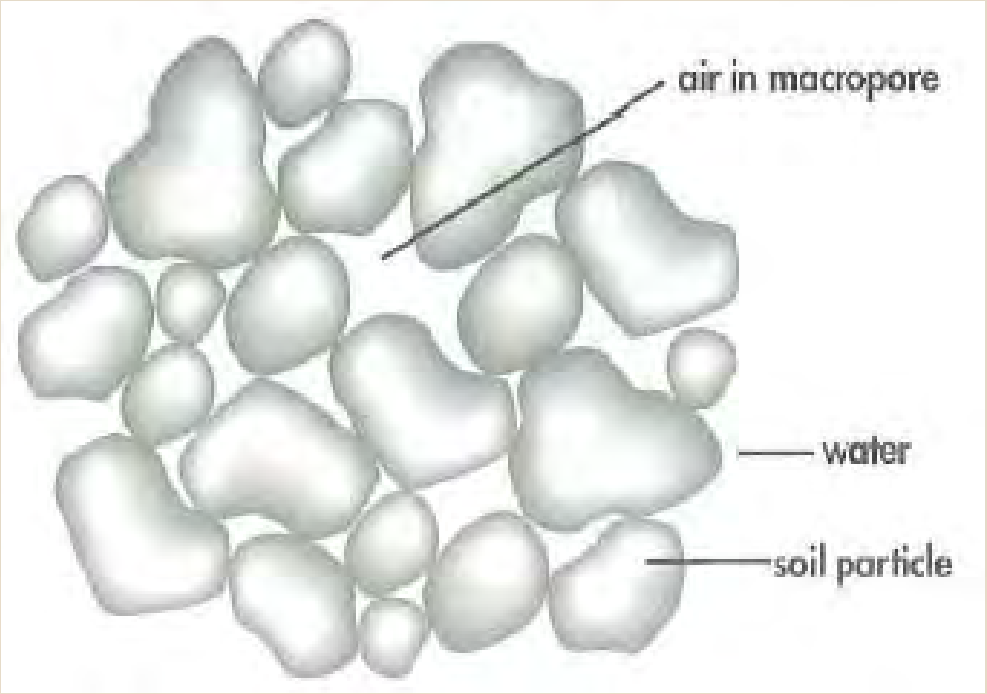

inches of water per foot
4
3
2
1
0
gravitational water
field capacity
available water
wilting point
unavailable water
sand
silt
clay

Field Capacity (or Lack Thereof)

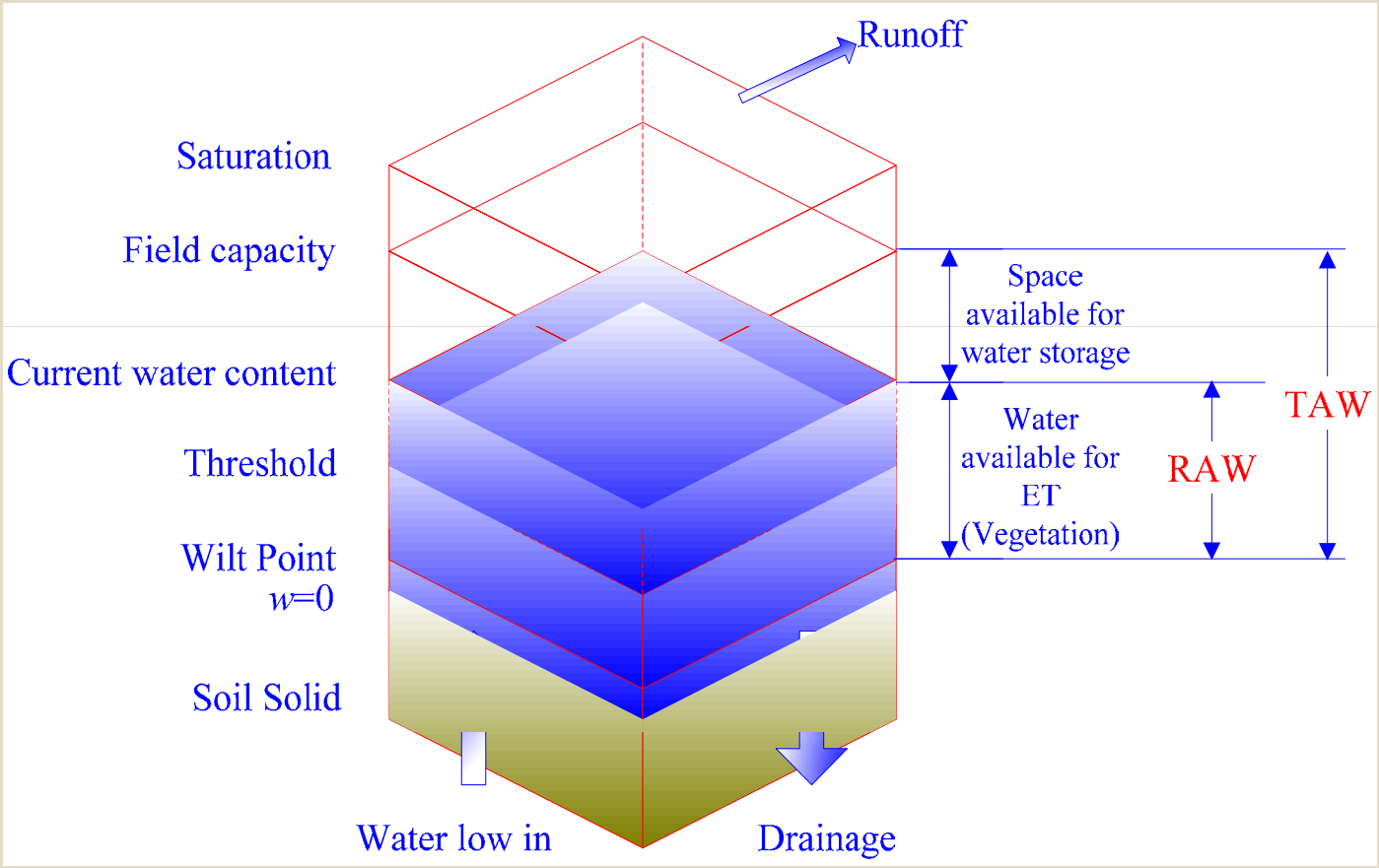
When the **gravitational water** drains away the soil is at **field capacity.**

Water that remains is held by the soil particles.

This water is absorbed by plant roots, or it evaporates. Roots can get water as long as they can overcome the adhesion that holds water to the soil particles.

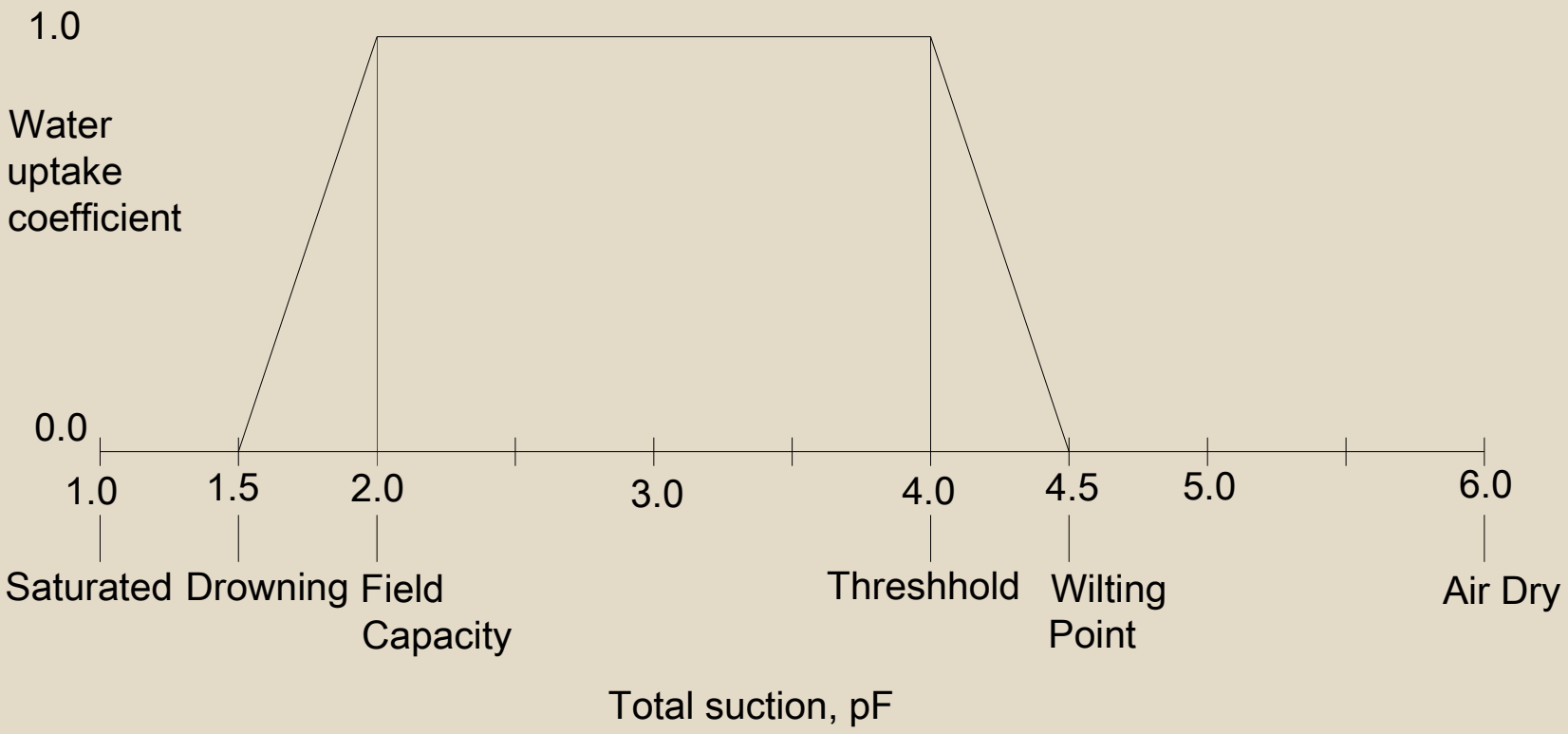


Soil Water Balance



TAW=the total available soil water in the root zone (mm)

RAW= the readily available soil water in the root zone (mm)


1.0
Water uptake coefficient
0.0
1.0
1.5
2.0
3.0
4.0
4.5
5.0
6.0
Saturated
Drowning
Field Capacity
Threshhold
Wilting Point
Air Dry
Total suction, pF

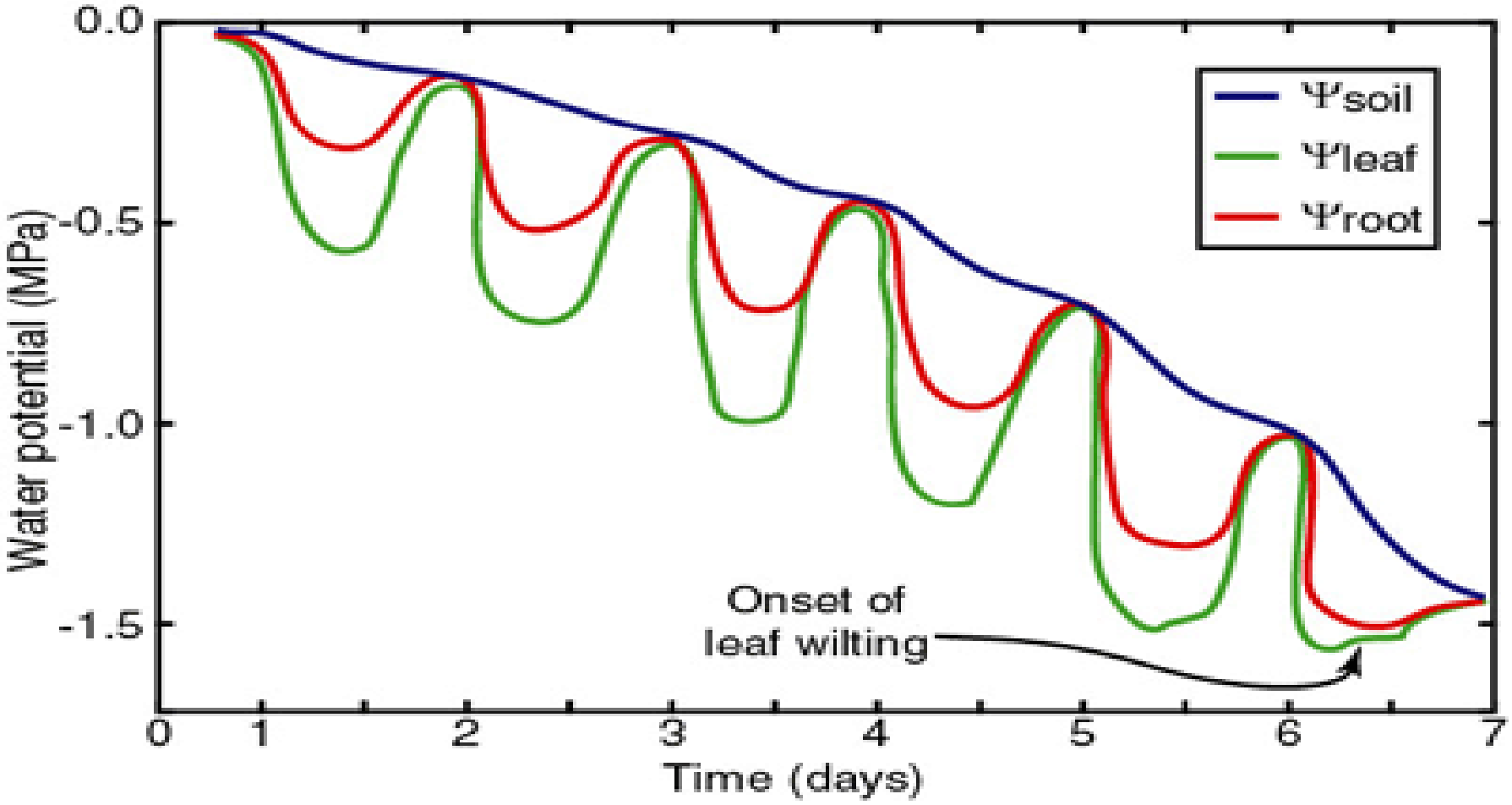
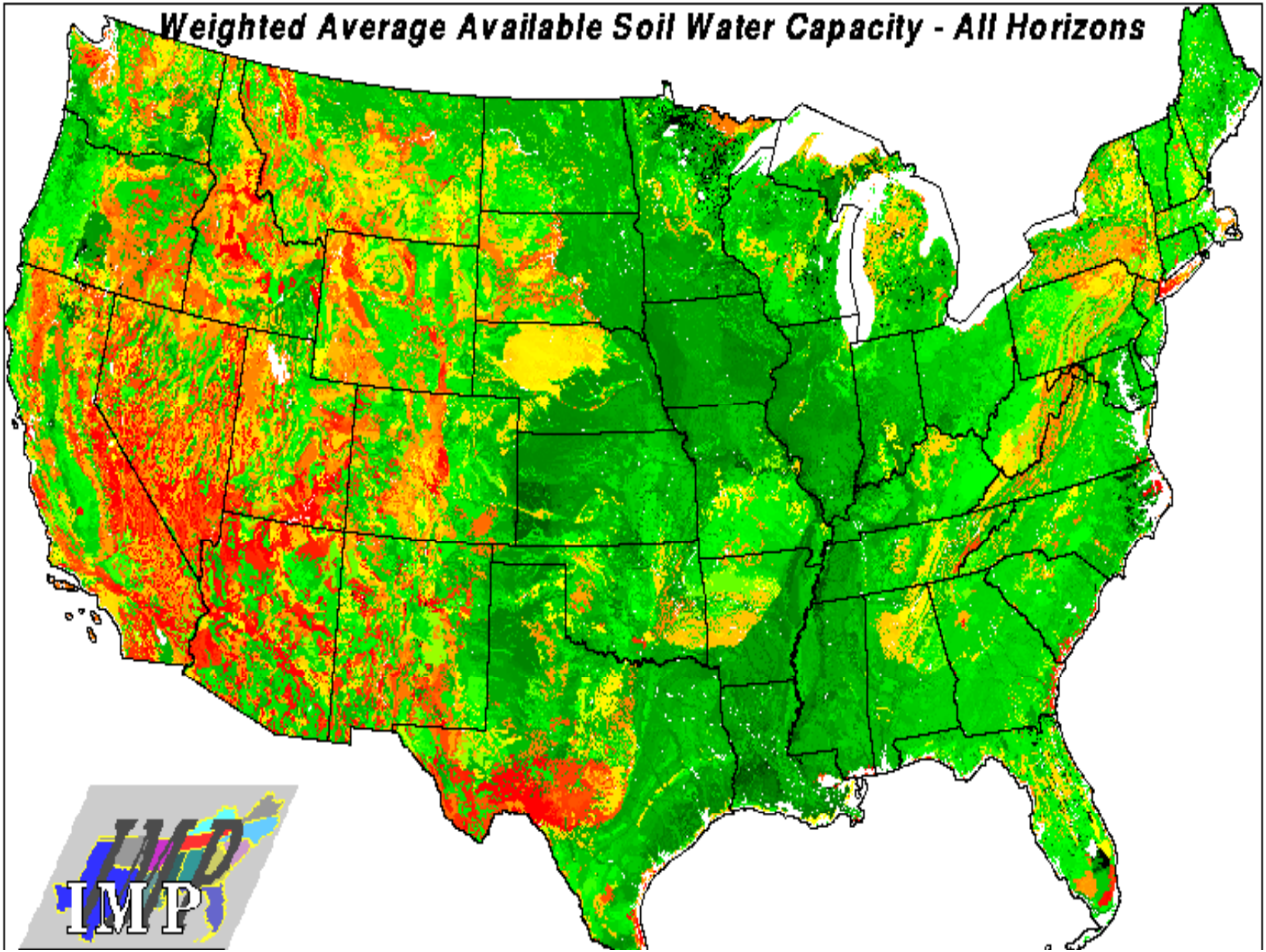


Figure 10.2. Schematic representation of daily changes in the water potential in the soil, root and leaf of a plant in an initially wet soil that dries out over a one week period. Shown are curves for the soil water potential, root xylem water potential and leaf (mesophyll) water potential, as adapted by Noble (1983; his figure 9.13) freely adapted from an article by Slatyer (1967, p 276).

Type of plant	Location	Wilting point (pF)	Wilting point (MPa)
Trees			
-	U.K.	4.2	1.5
-	U.S.	4.5	3.1
Post oak	Texas	4.8	6.2
Eucalyptus	Australia	4.35	2.2
Eucalyptus	Australia	4.55	3.5
Woody plants			
Burkea africana	Africa	4.50	3.1
Ochna pulchra	Africa	4.51	3.2
Terminalia sericia	Africa	4.29	1.9
Grasses			
Eragostris pallens	Africa	4.60	3.9
Digitaria	Africa	4.47	2.9


Weighted Average Available Soil Water Capacity - All Horizons
UCD
IMP

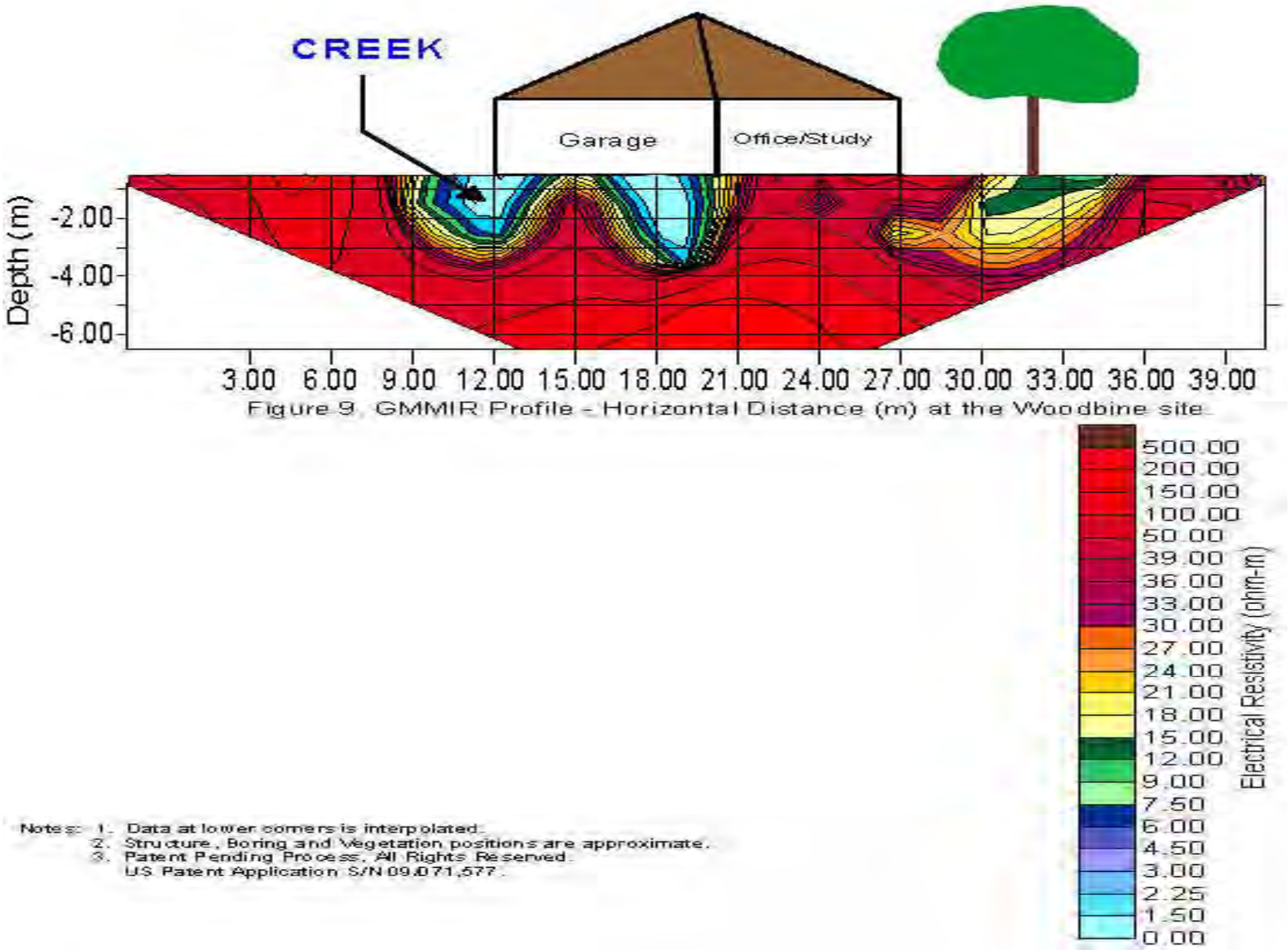
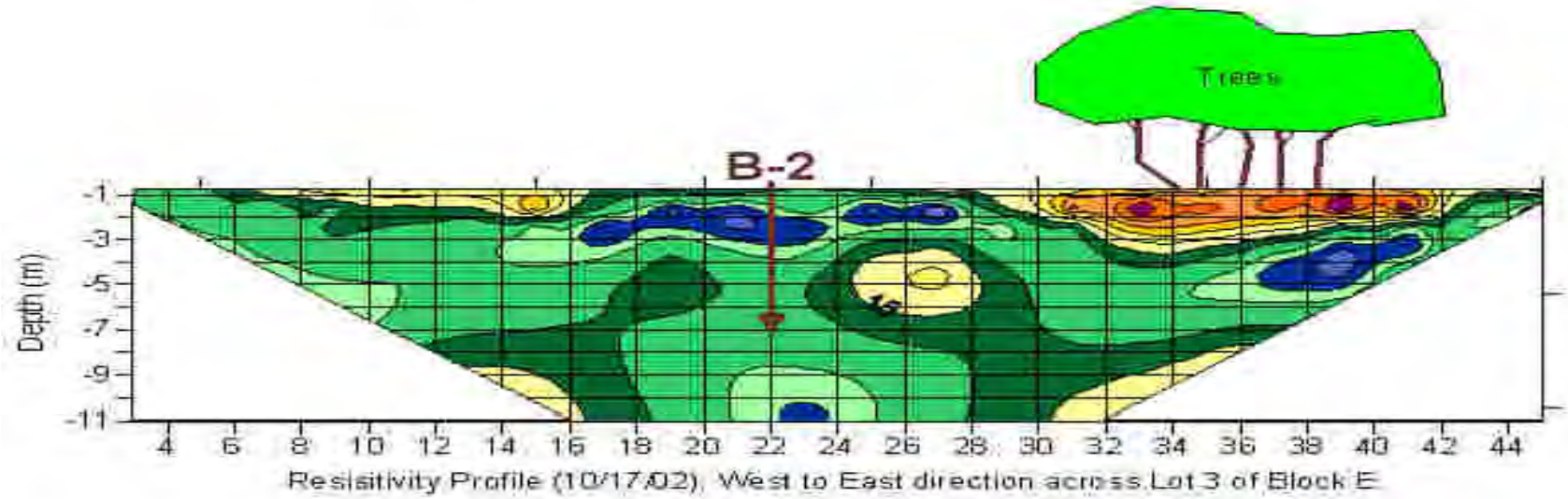
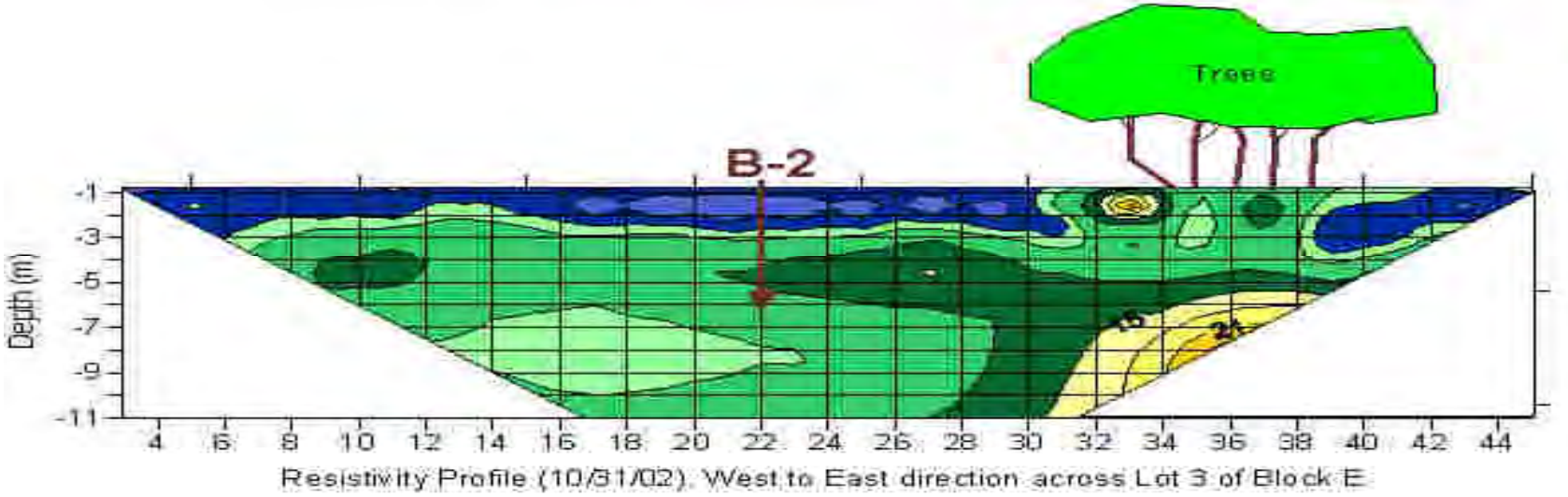


Figure 9. GMMIR Profile - Horizontal Distance (m) at the Woodbine site.

Notes: 1. Data at lower corners is interpolated.
2. Structure, Boring and Vegetation positions are approximate.
3. Patent Pending Process. All Rights Reserved.
US Patent Application S/N 09/071,577.

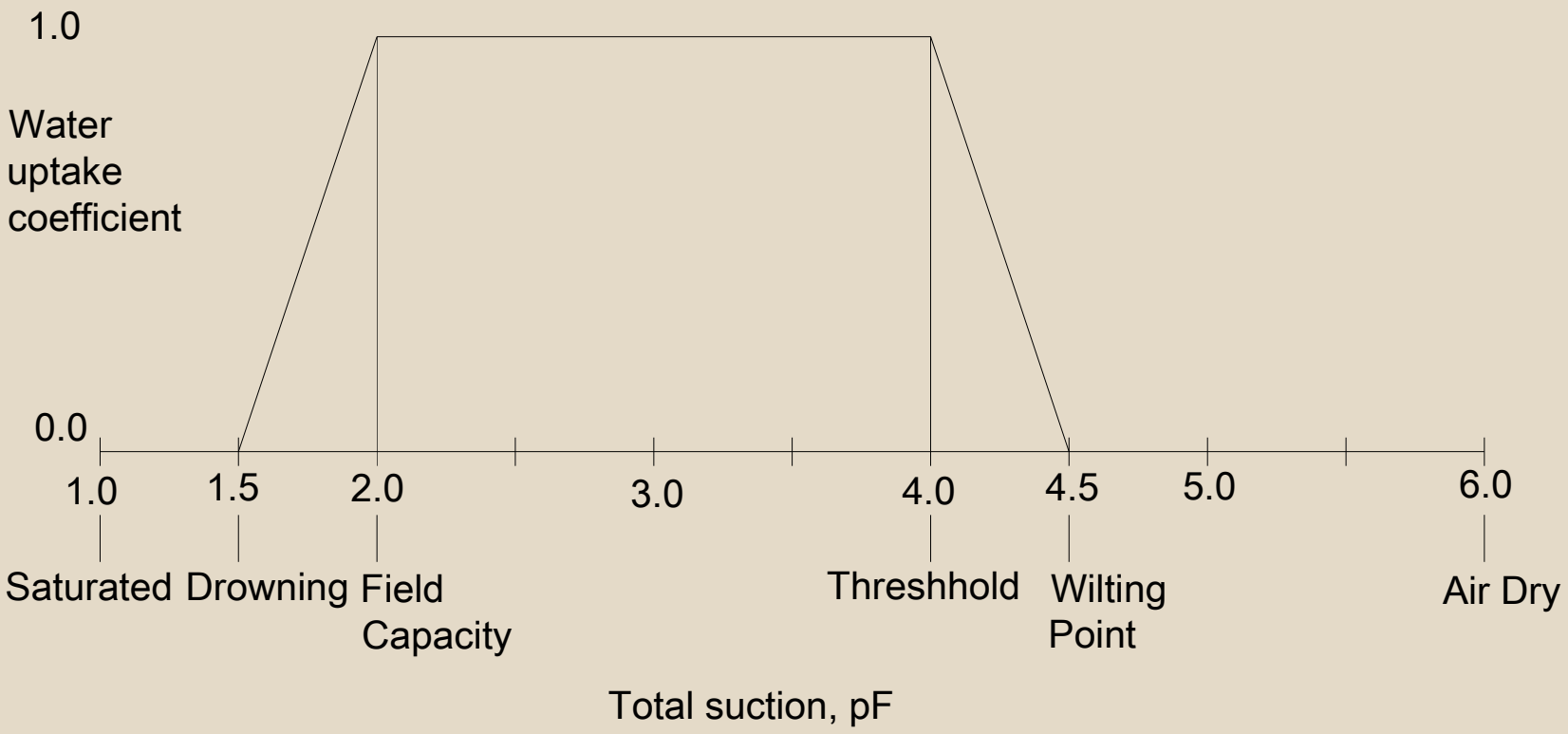
The influence of Trees and effects of a significant rainfall event on a particular lot.

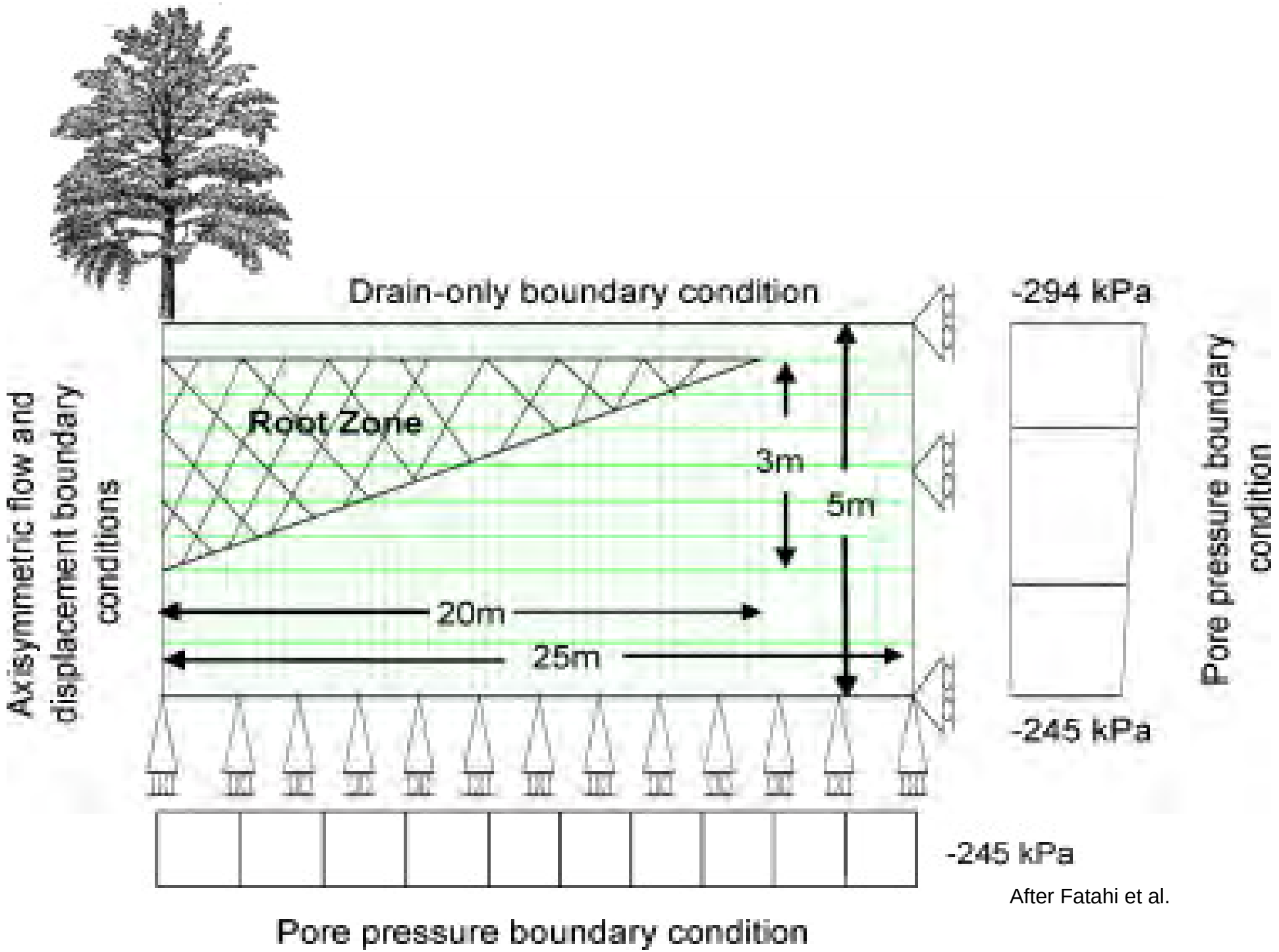




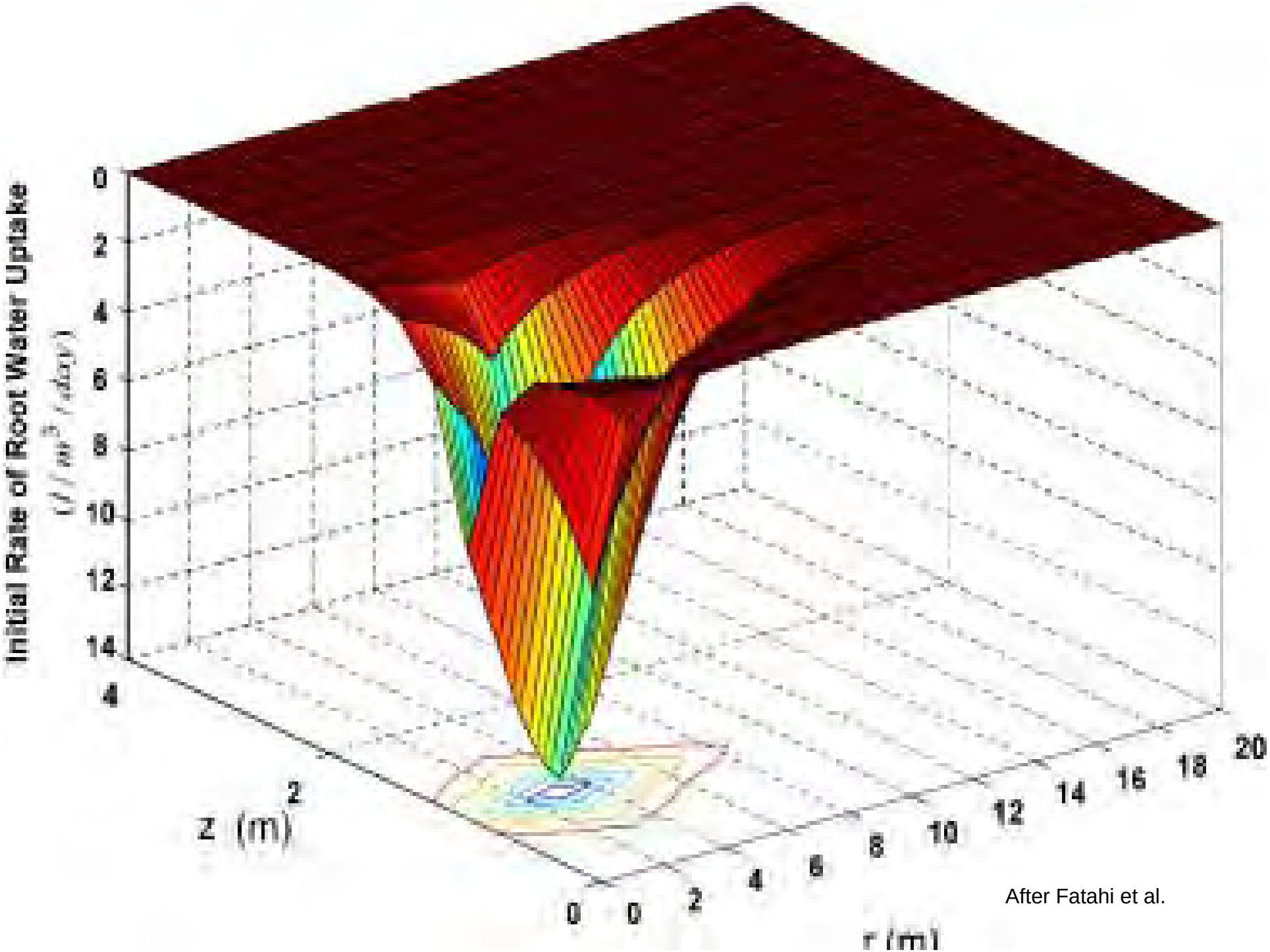
Electrical Resistivity (ohm-m)

Notes: 1. Data at lower corners is interpolated.
2. Structure, Boring and Vegetation positions are approximate.
3. Patent Process.
US Patent S/N 6,295,512.

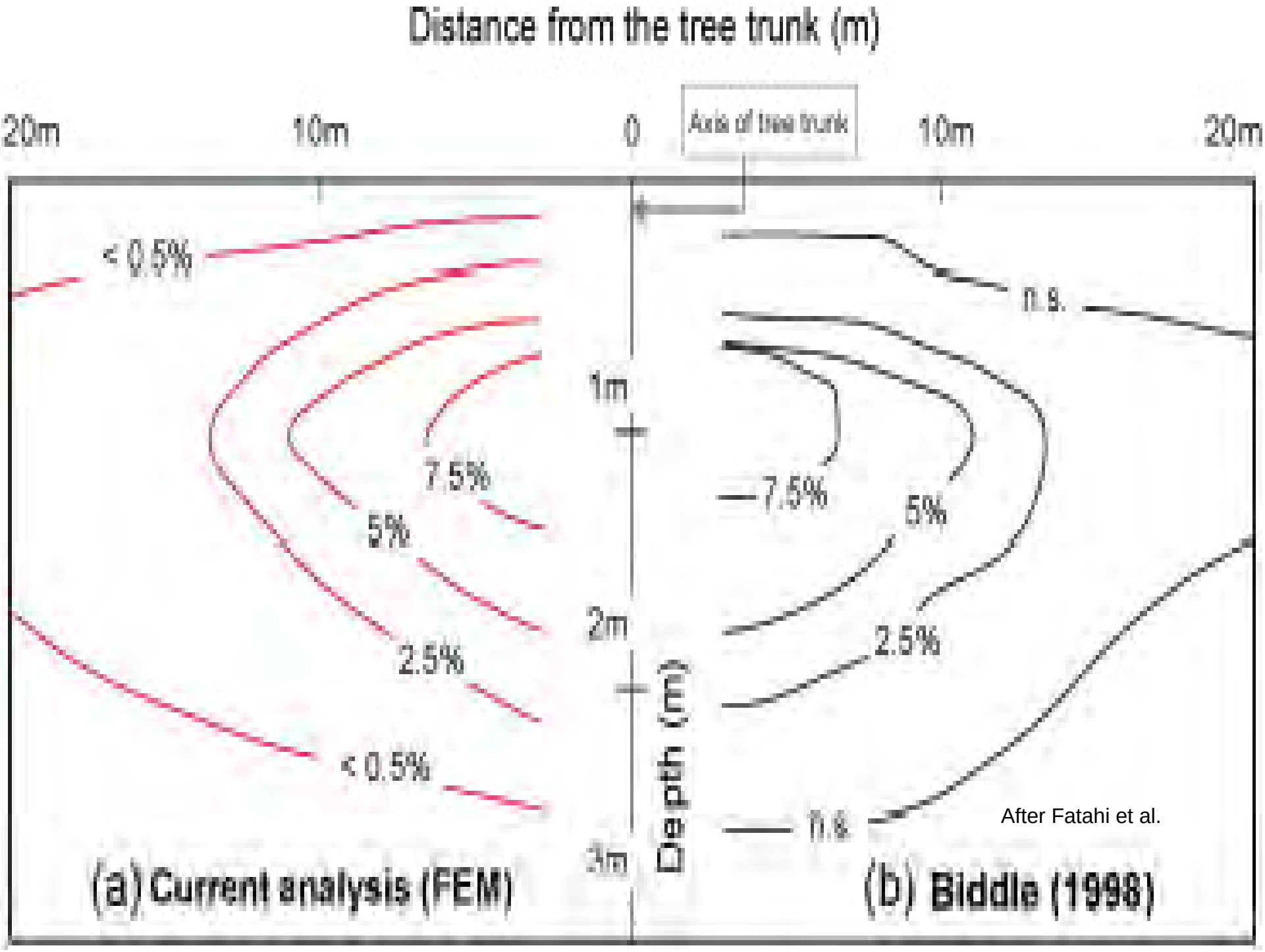

1.0
Water uptake coefficient
0.0
1.0
1.5
2.0
3.0
4.0
4.5
5.0
6.0
Saturated
Drowning
Field Capacity
Threshhold
Wilting Point
Air Dry
Total suction, pF

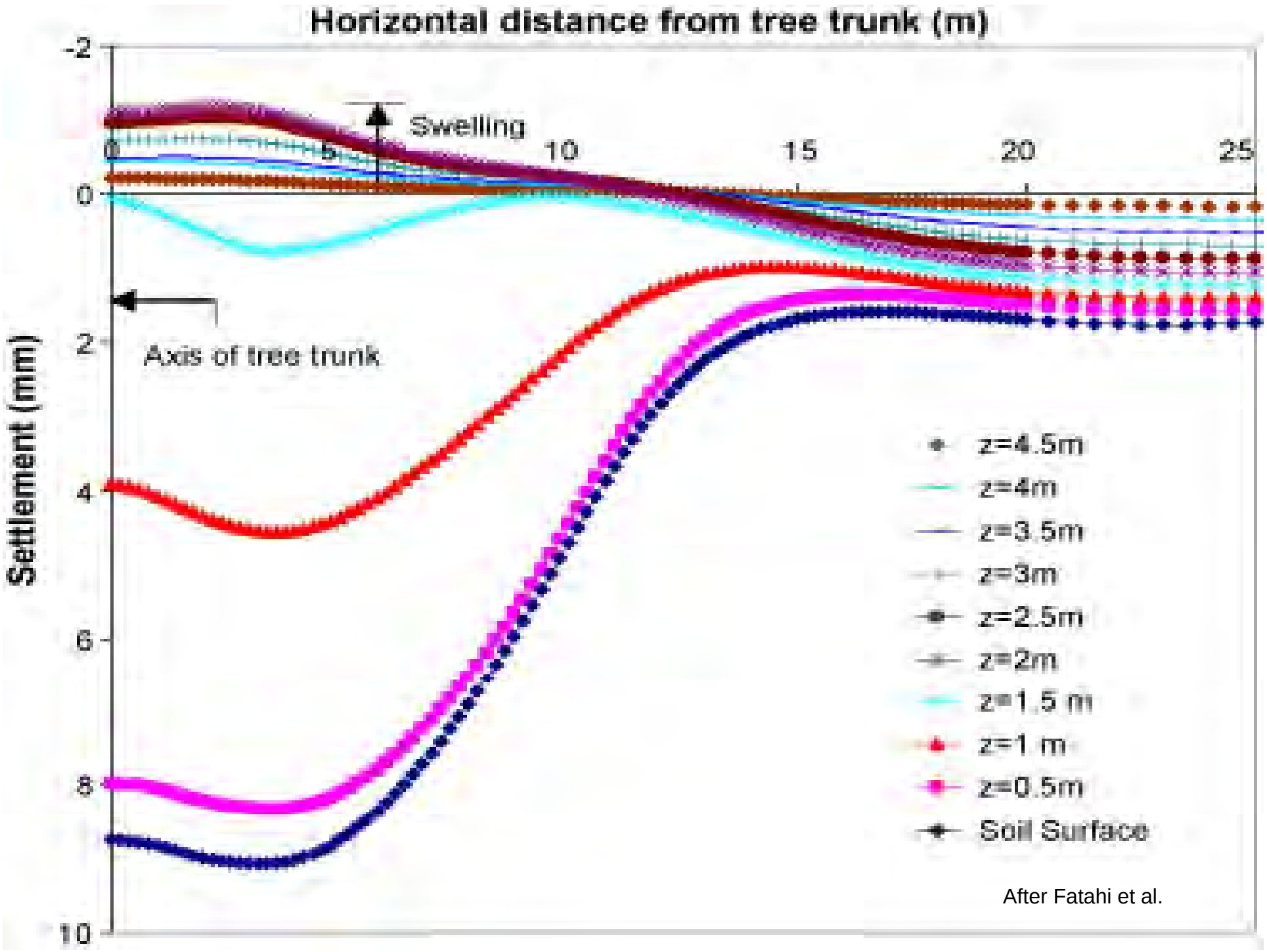


After Fatahi et al.

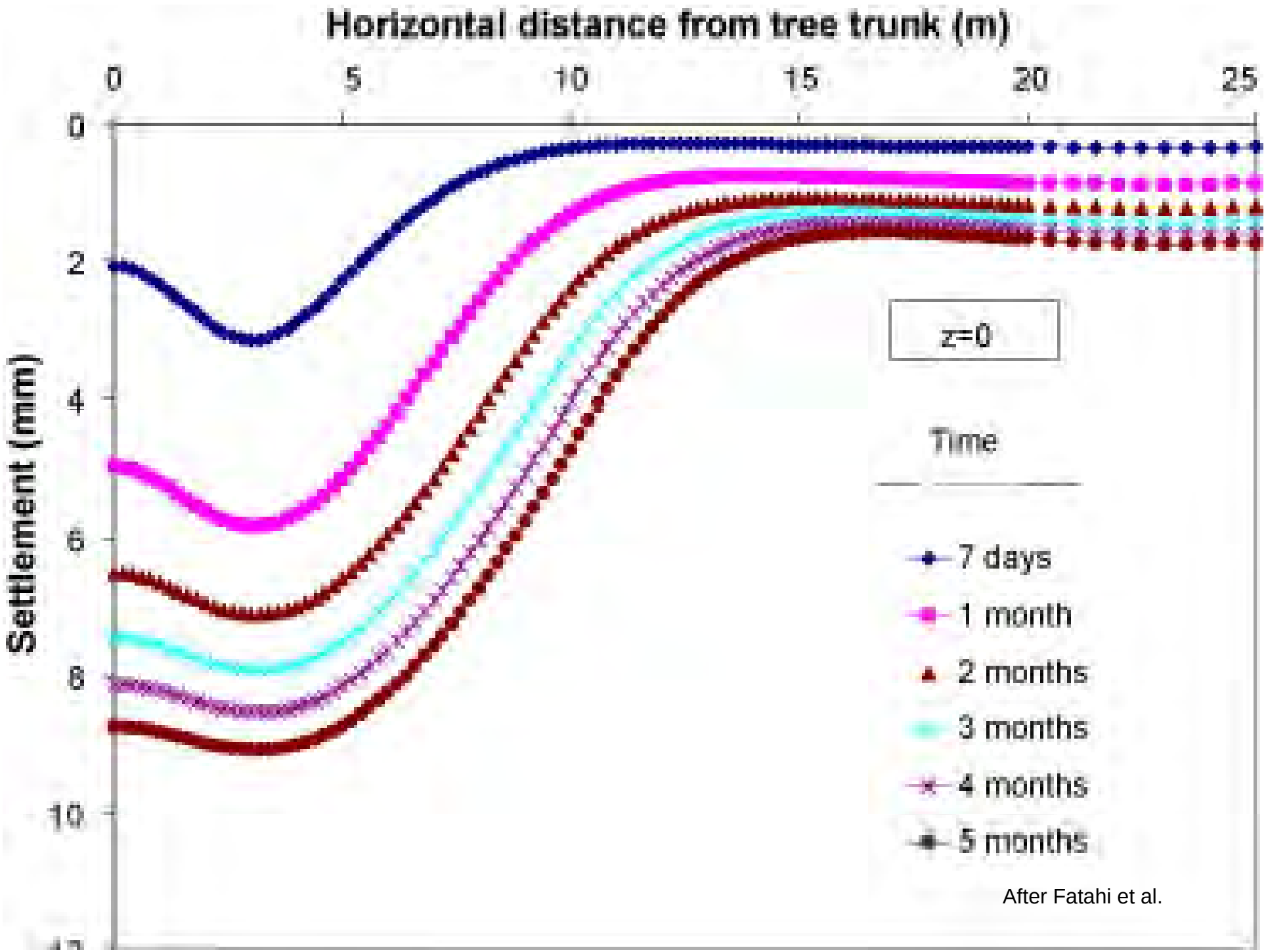


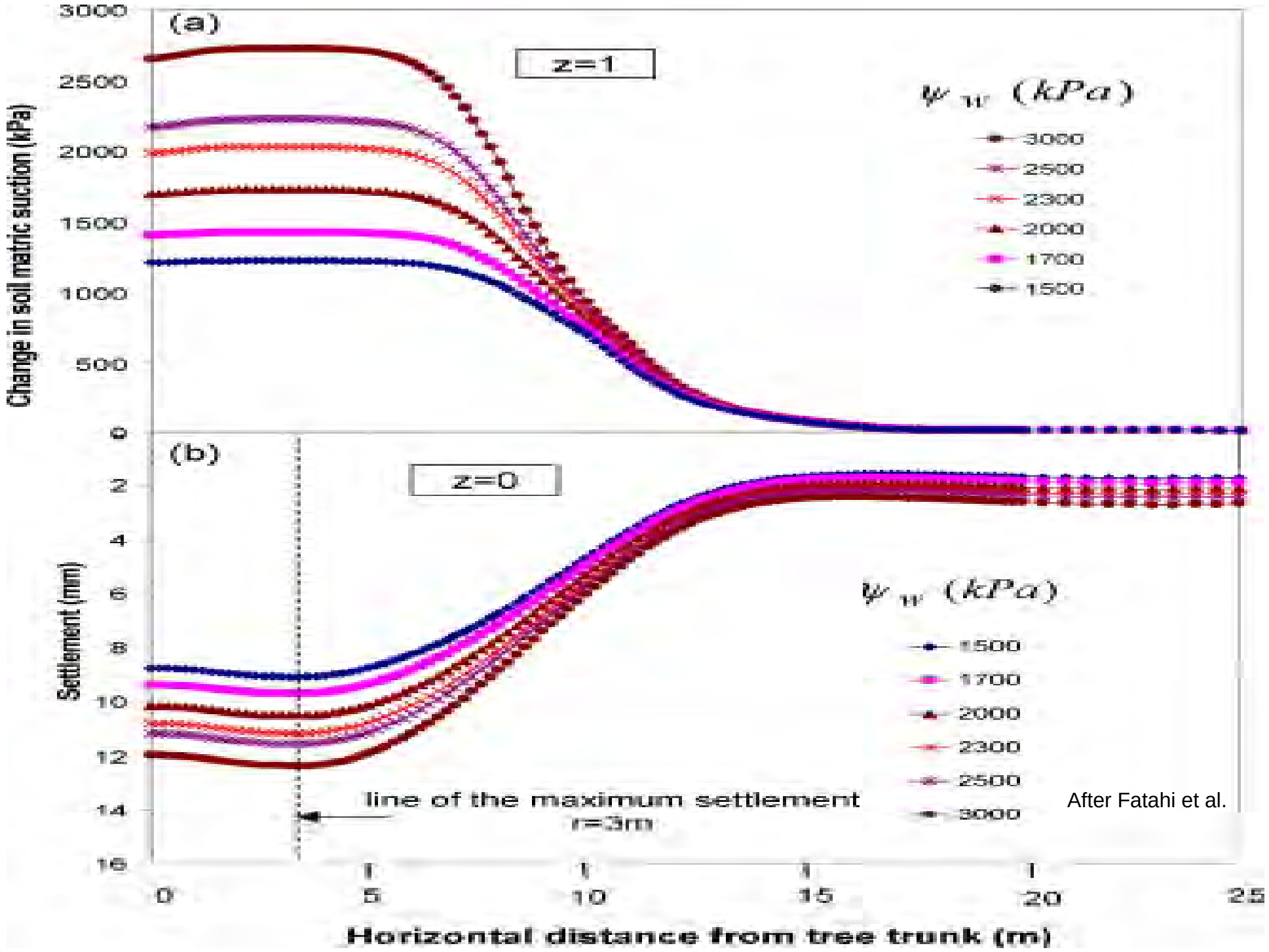
After Fatahi et al.


Distance from the tree trunk (m)
20m
10m
0
Axis of tree trunk
10m
20m
< 0.5%
7.5%
5%
2.5%
< 0.5%
n.s.
7.5%
5%
2.5%
n.s.
1m
2m
3m
Depth (m)
(a) Current analysis (FEM)
(b) Biddle (1998)
After Fatahi et al.

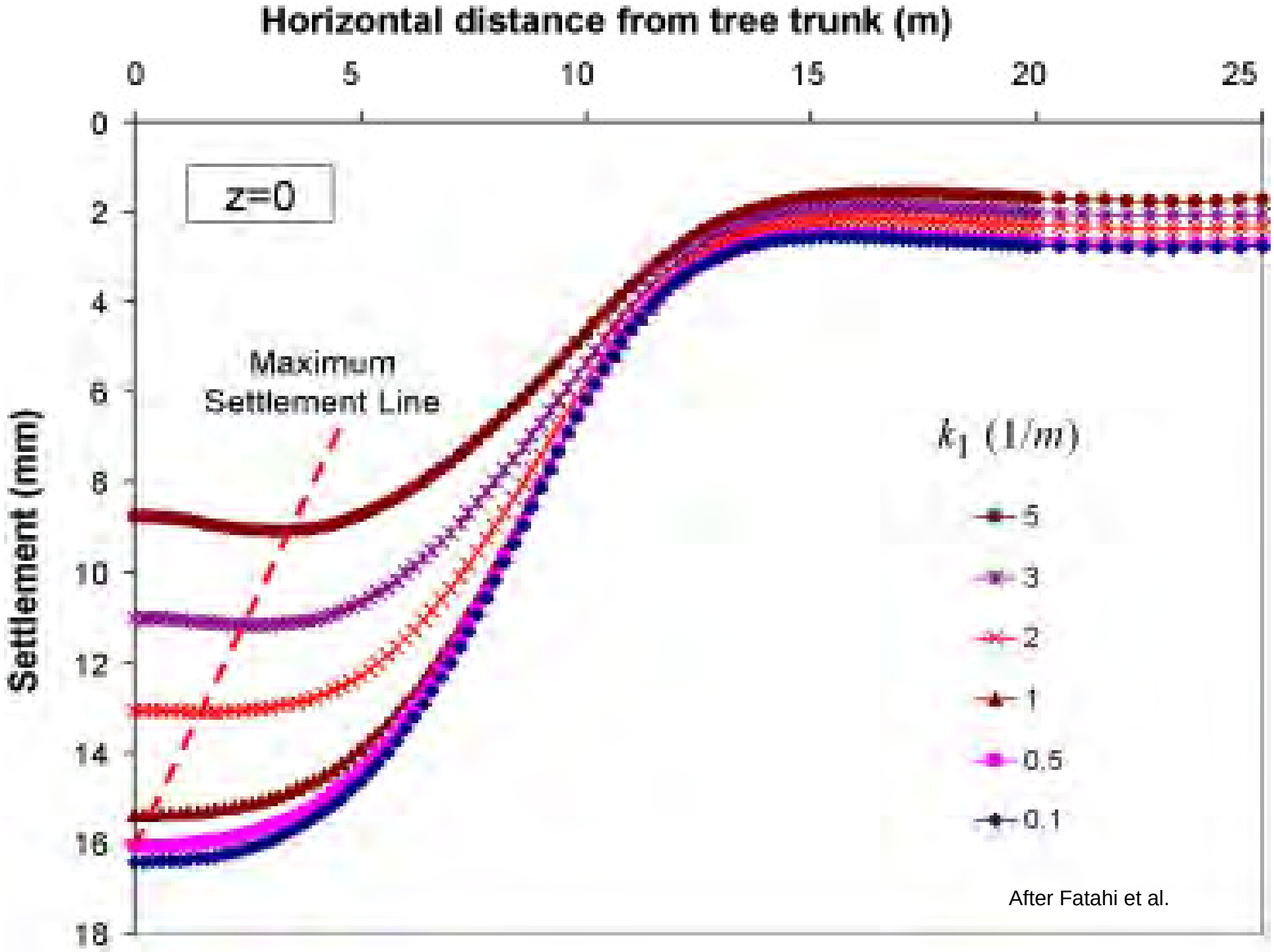


After Fatahi et al.


Horizontal distance from tree trunk (m)
0
5
10
15
20
25
Settlement (mm)
0
2
4
6
8
10
z=0
Time
7 days
1 month
2 months
3 months
4 months
5 months
After Fatahi et al.



After Fatahi et al.

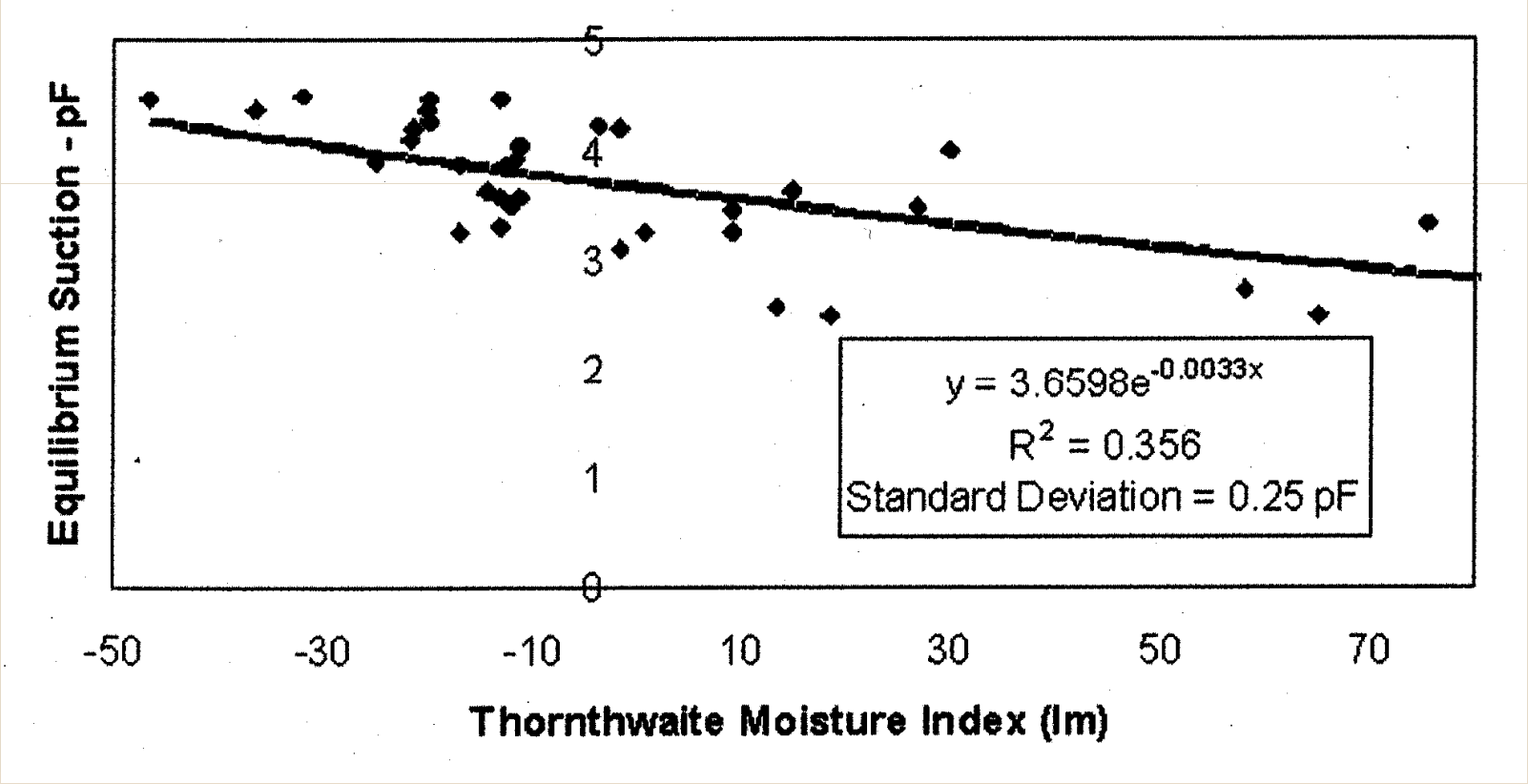

Horizontal distance from tree trunk (m)
0
5
10
15
20
25
Settlement (mm)
0
2
4
6
8
10
12
14
16
18
z=0
Maximum
Settlement Line
k_1 (1/m)
5
3
2
1
0.5
0.1
After Fatahi et al.

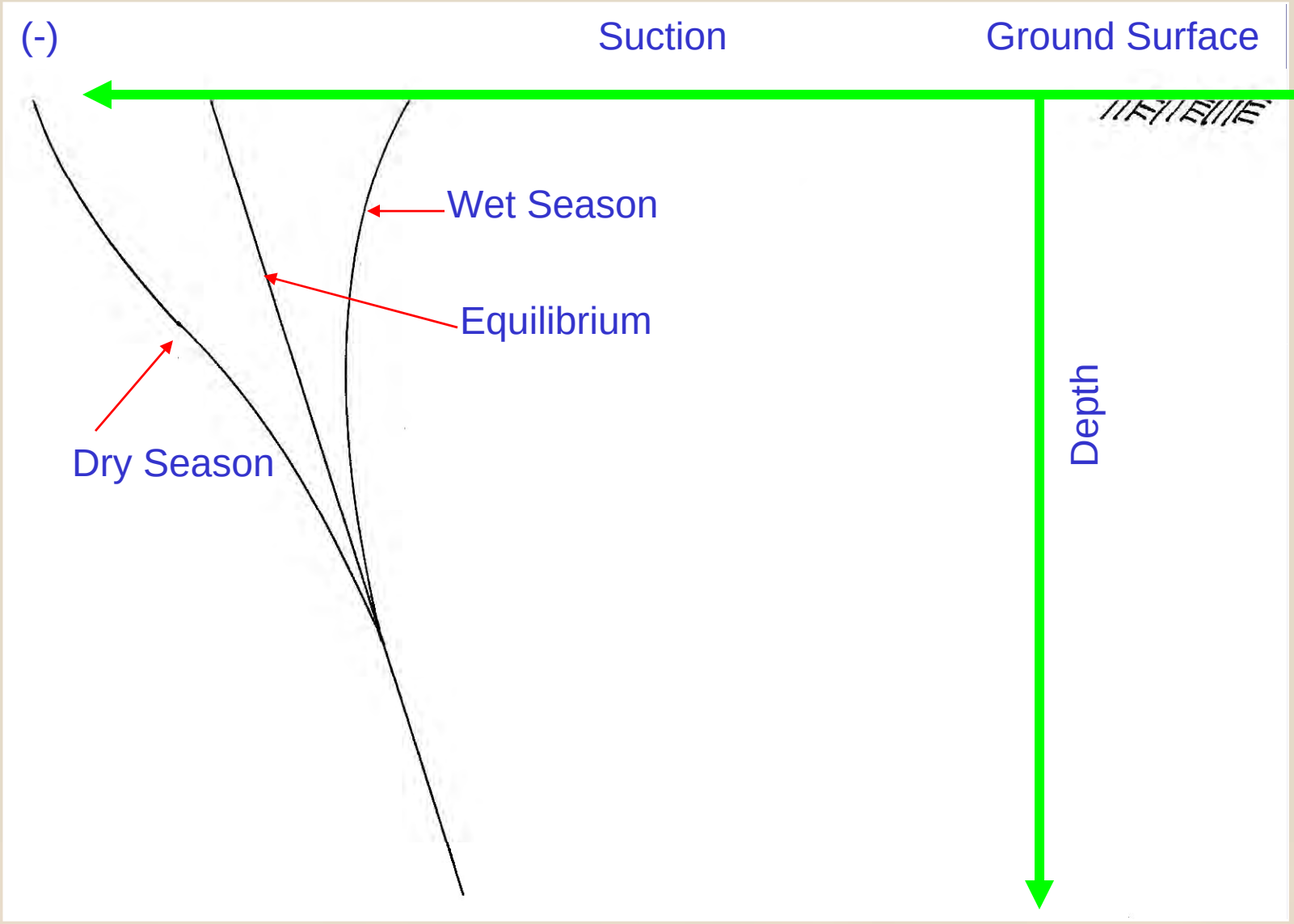

MOISTURE ACTIVE ZONE
MOISTURE INACTIVE ZONE

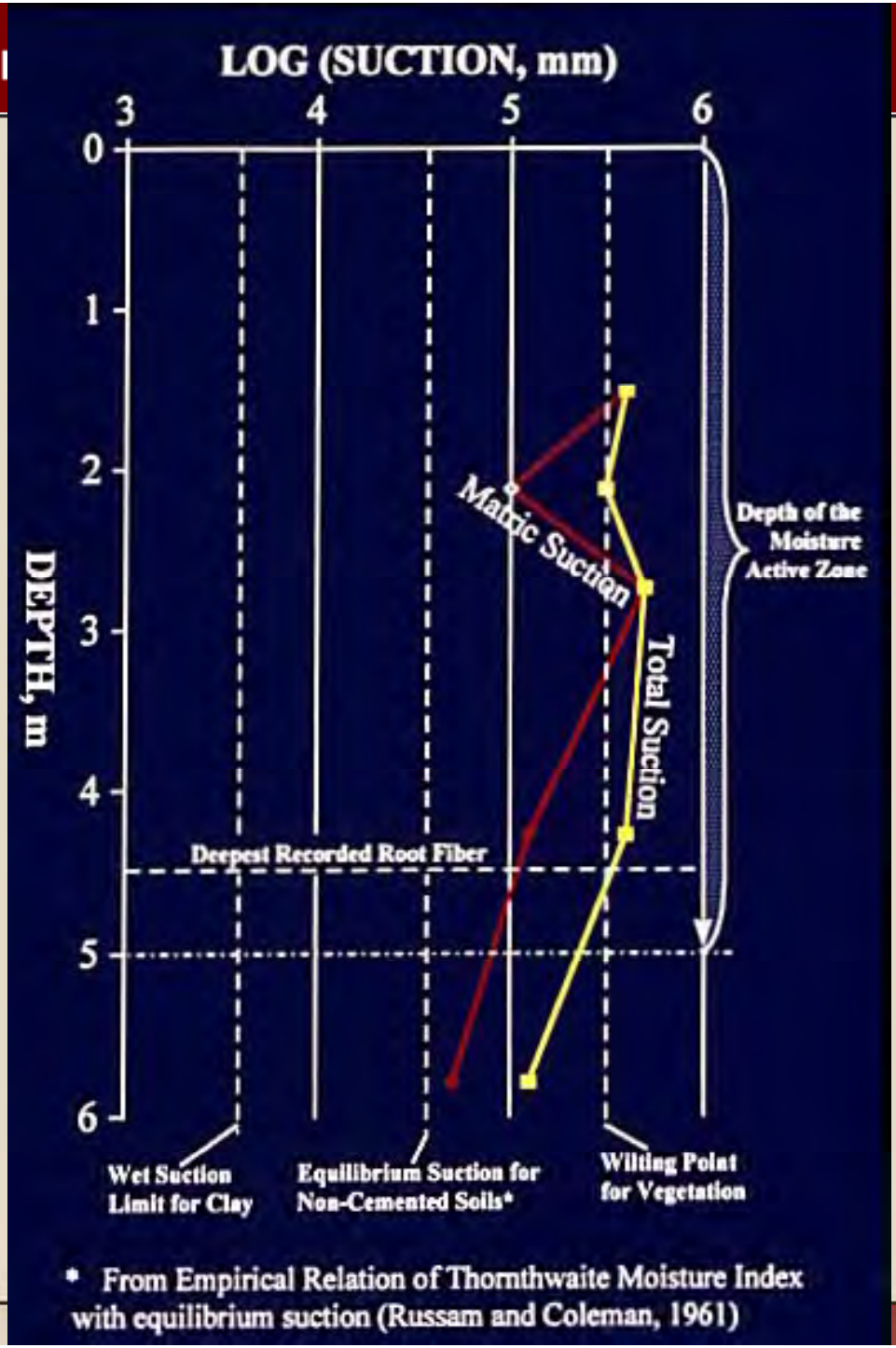
Moisture Active Zone

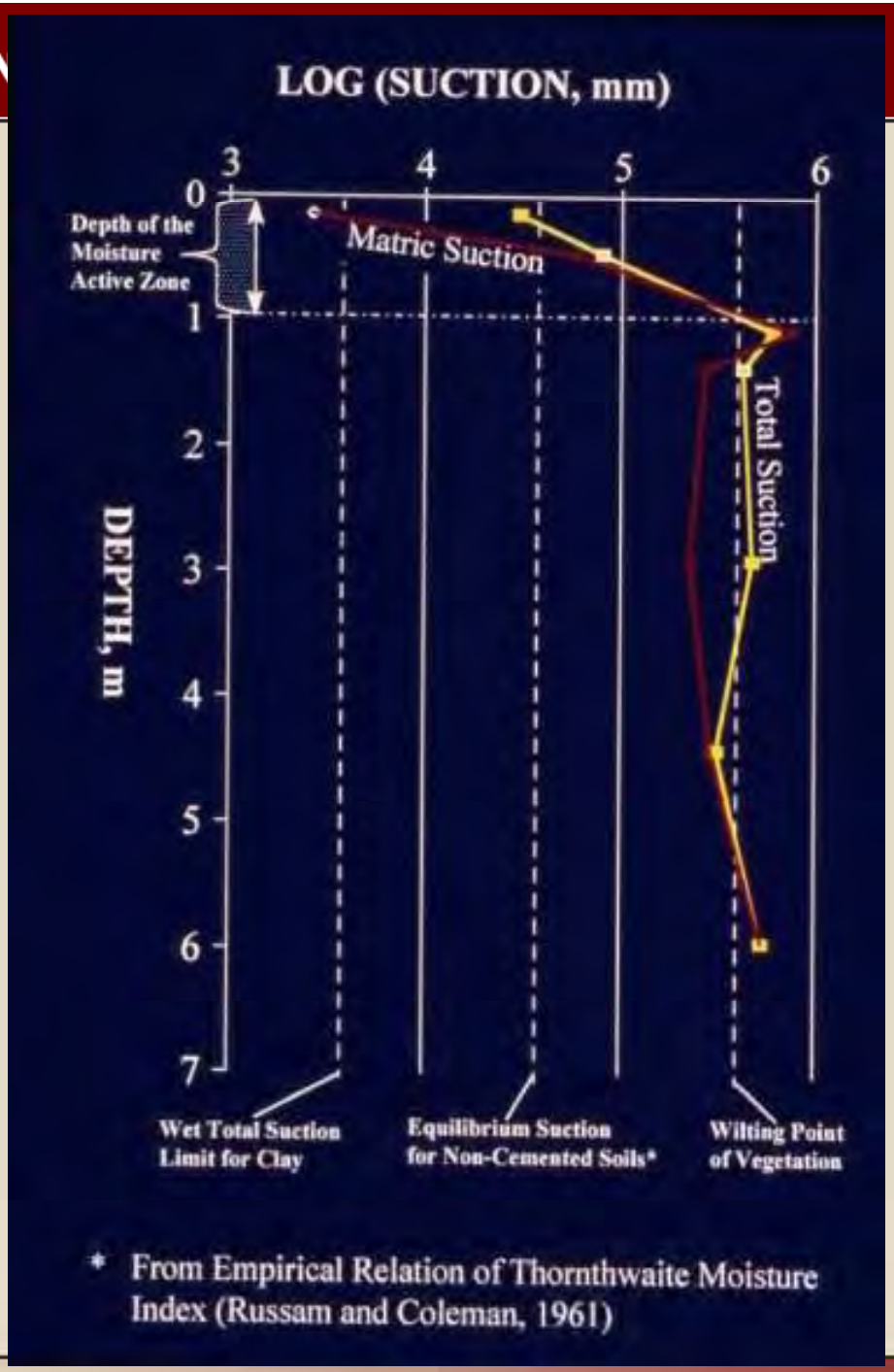
- Root zone (deepest root fiber)
- Cemented soil (suction above wilting point)
- High osmotic suction zone (above wilting point)
- Water in seams
- Water table

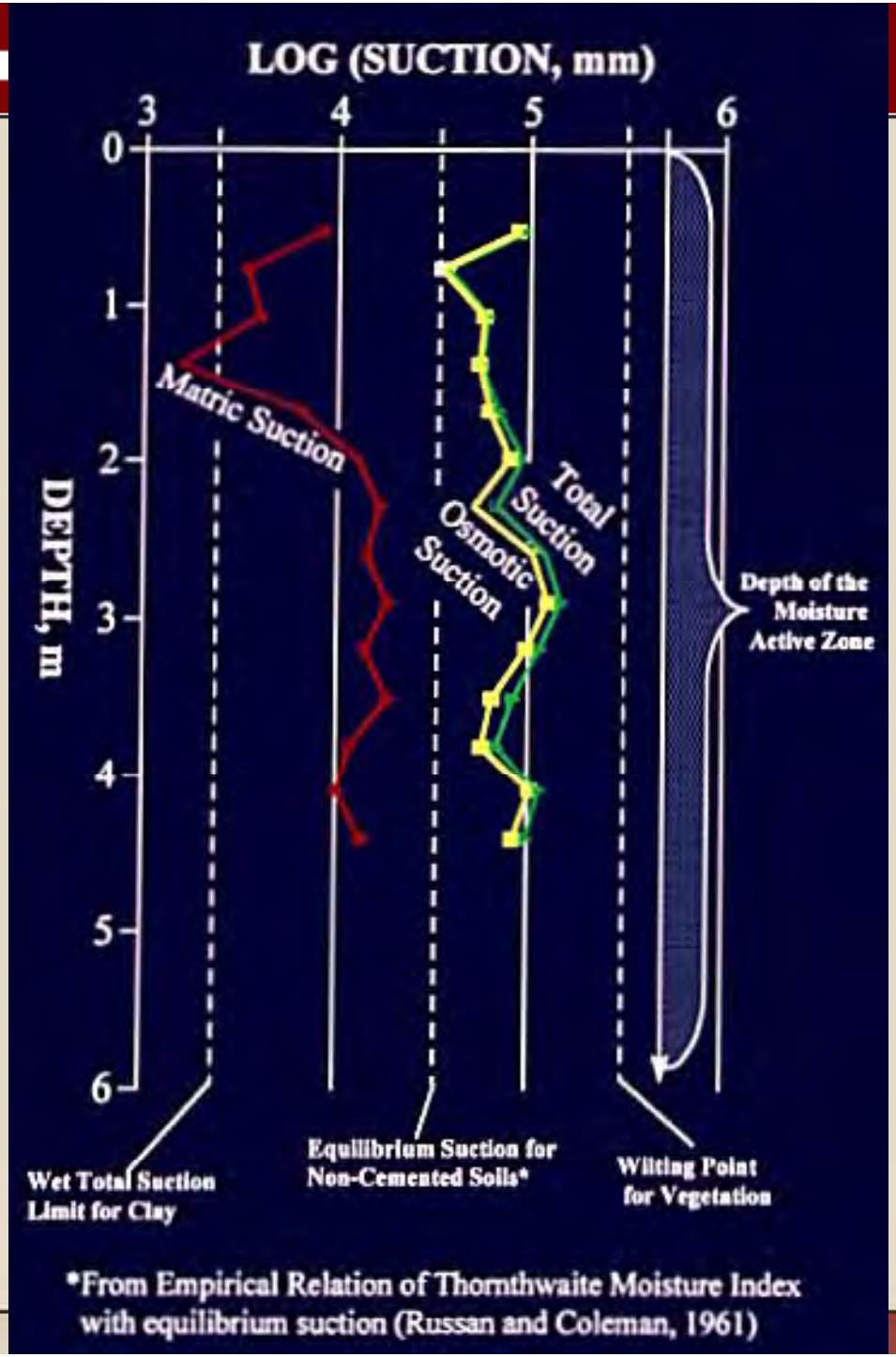
Equilibrium Soil Suction vs. TMI




(-)
Suction
Ground Surface
Wet Season
Equilibrium
Dry Season
Depth


LOG (SUCTION, mm)
3
4
5
6
0
1
2
3
4
5
6
DEPTH, m
Matric Suction
Total Suction
Depth of the Moisture Active Zone
Deepest Recorded Root Fiber
Wet Suction Limit for Clay
Equilibrium Suction for Non-Cemented Soils*
Wilting Point for Vegetation
* From Empirical Relation of Thornthwaite Moisture Index with equilibrium suction (Russam and Coleman, 1961)


LOG (SUCTION, mm)
3
4
5
6
0
1
2
3
4
5
6
7
DEPTH, m
Depth of the Moisture Active Zone
Matric Suction
Total Suction
Wet Total Suction Limit for Clay
Equilibrium Suction for Non-Cemented Soils*
Wilting Point of Vegetation
* From Empirical Relation of Thornthwaite Moisture Index (Russam and Coleman, 1961)


LOG (SUCTION, mm)
3
4
5
6
0
1
2
3
4
5
6
DEPTH, m
Matric Suction
Total Suction
Osmotic Suction
Depth of the Moisture Active Zone
Wet Total Suction Limit for Clay
Equilibrium Suction for Non-Cemented Soils*
Wilting Point for Vegetation
*From Empirical Relation of Thornthwaite Moisture Index with equilibrium suction (Russan and Coleman, 1961)

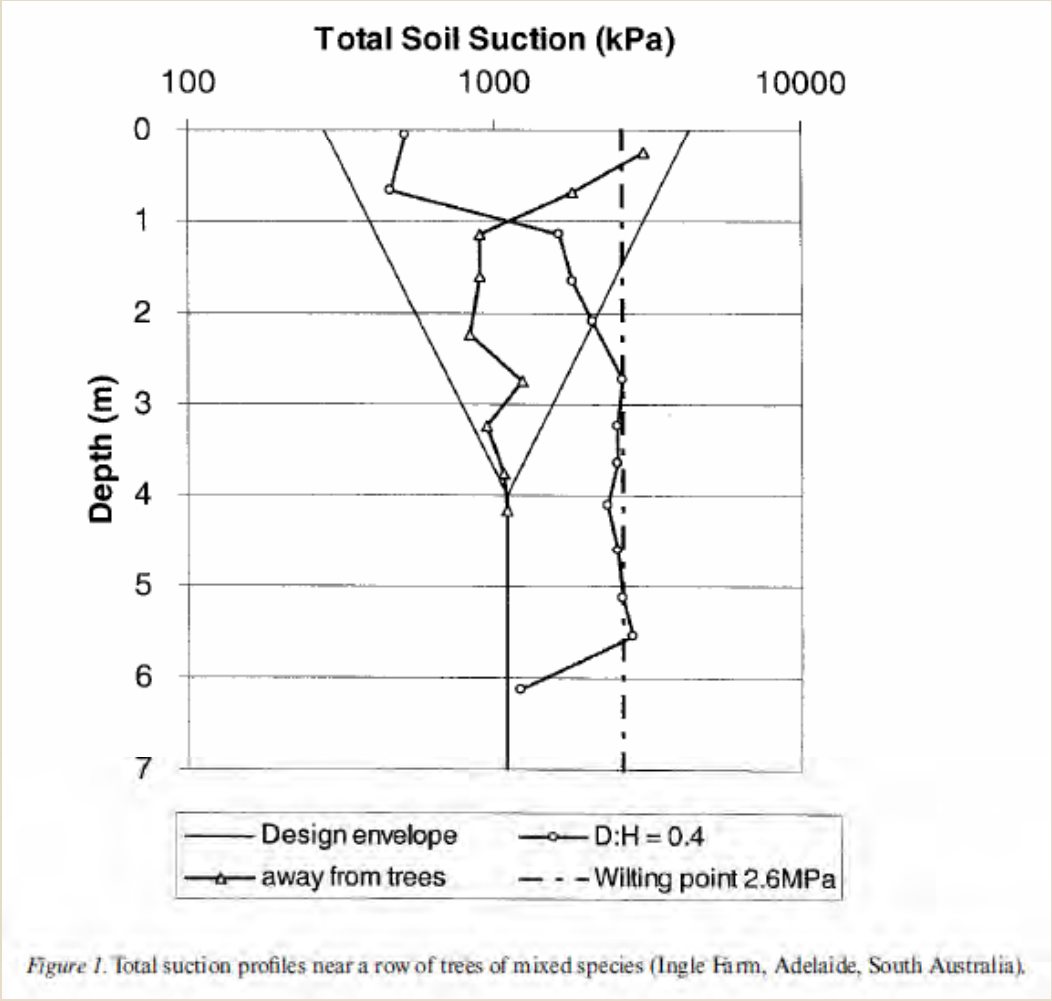


Figure 1. Total suction profiles near a row of trees of mixed species (Ingle Farm, Adelaide, South Australia).

After D. A. Cameron

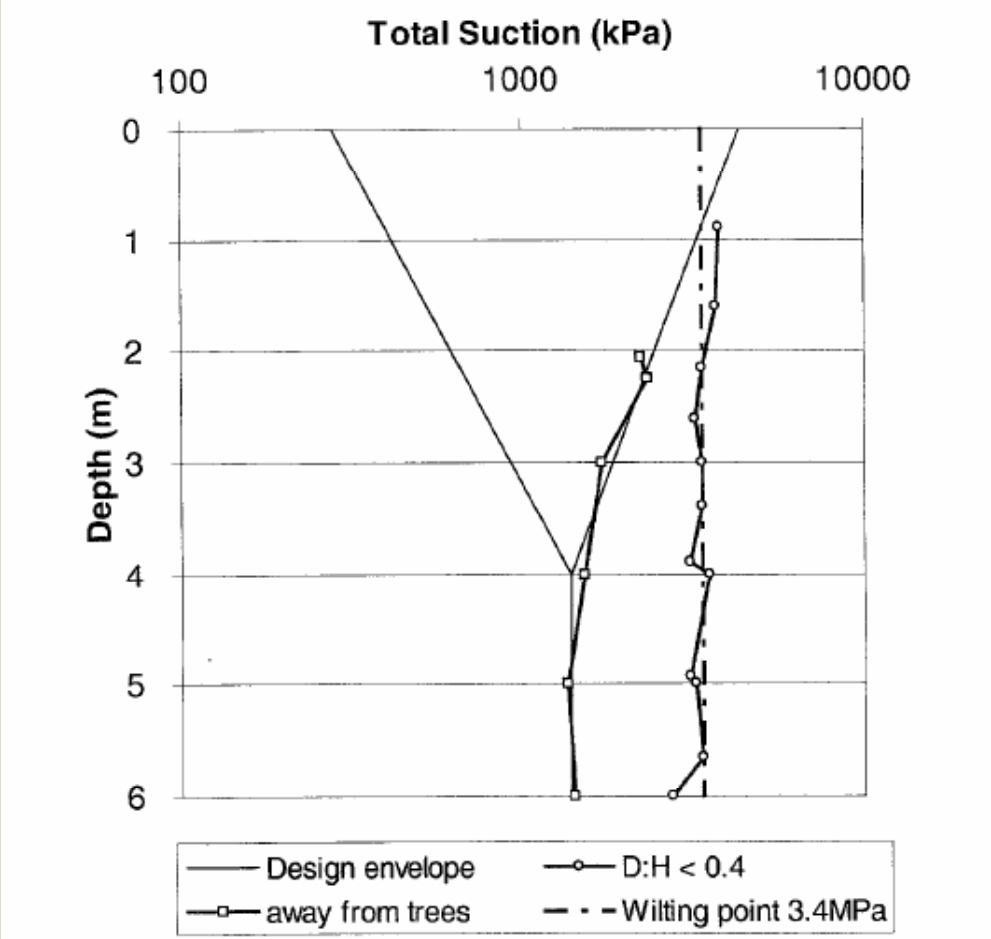


Figure 2. Total suction profiles near a row of large eucalypts (Klemzig, Adelaide, South Australia).

After D. A. Cameron

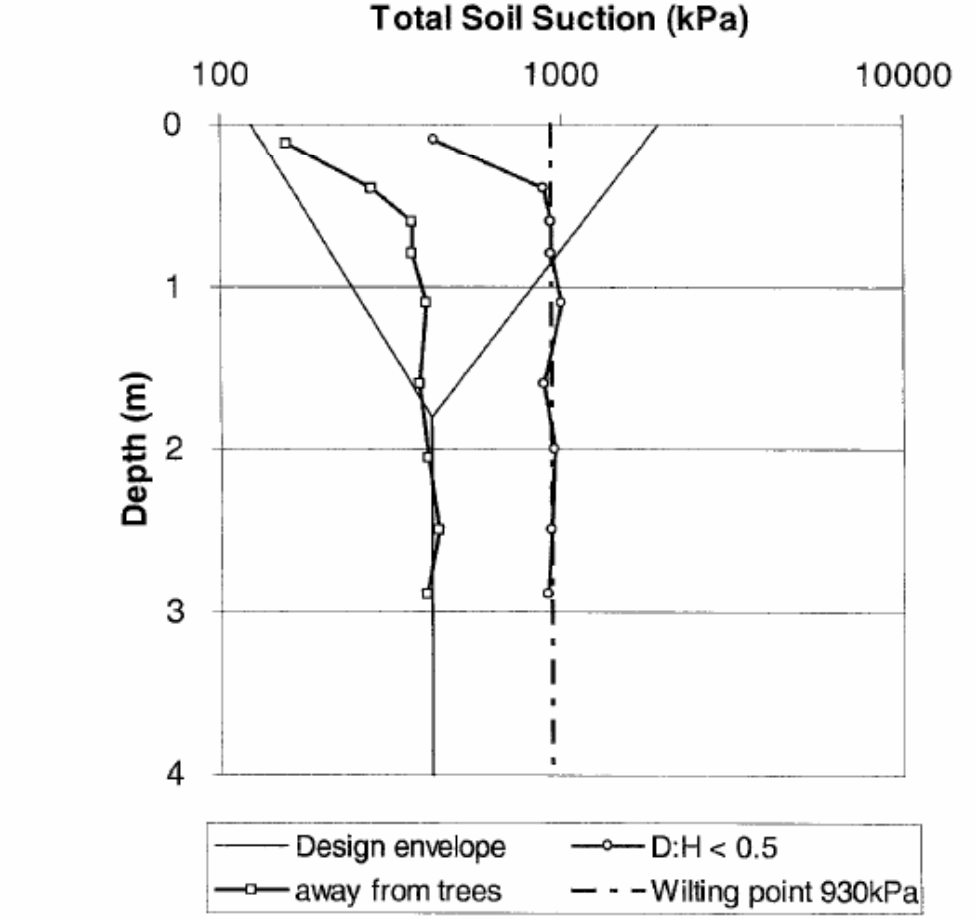


Figure 3. Total suction profiles near a row of large eucalypts (Williamstown, Victoria).

After D. A. Cameron

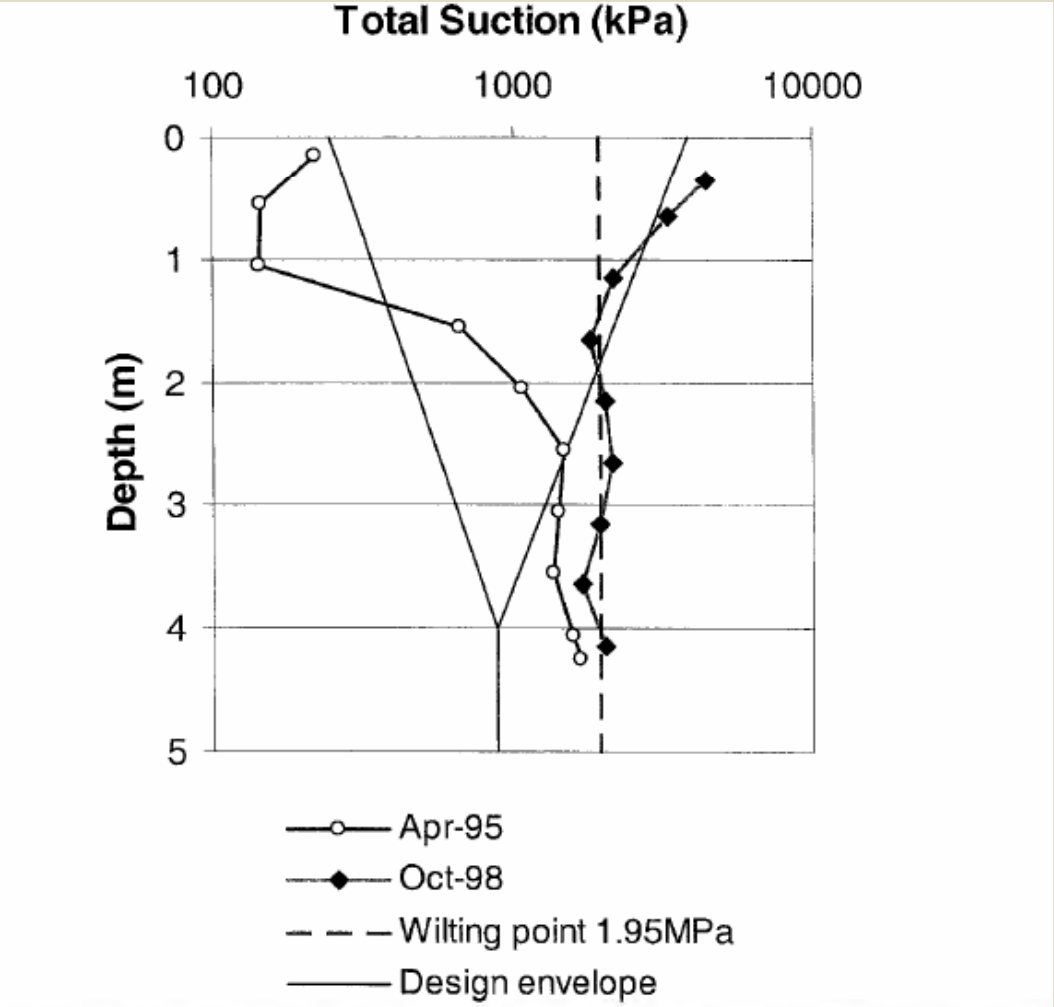
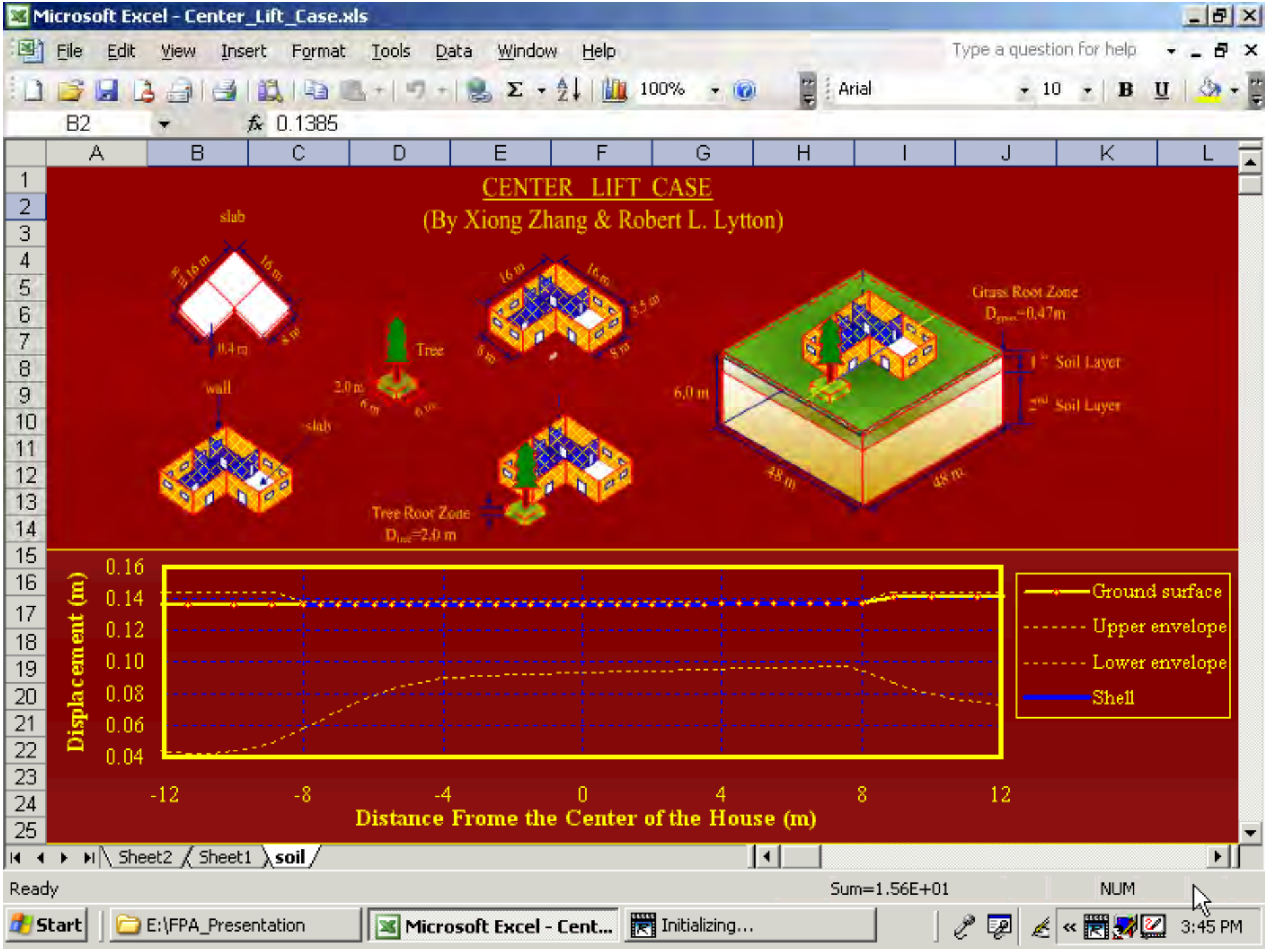


Figure 5. Total suction profiles near a roadside plantation of native trees (Hallett Cove, South Australia).

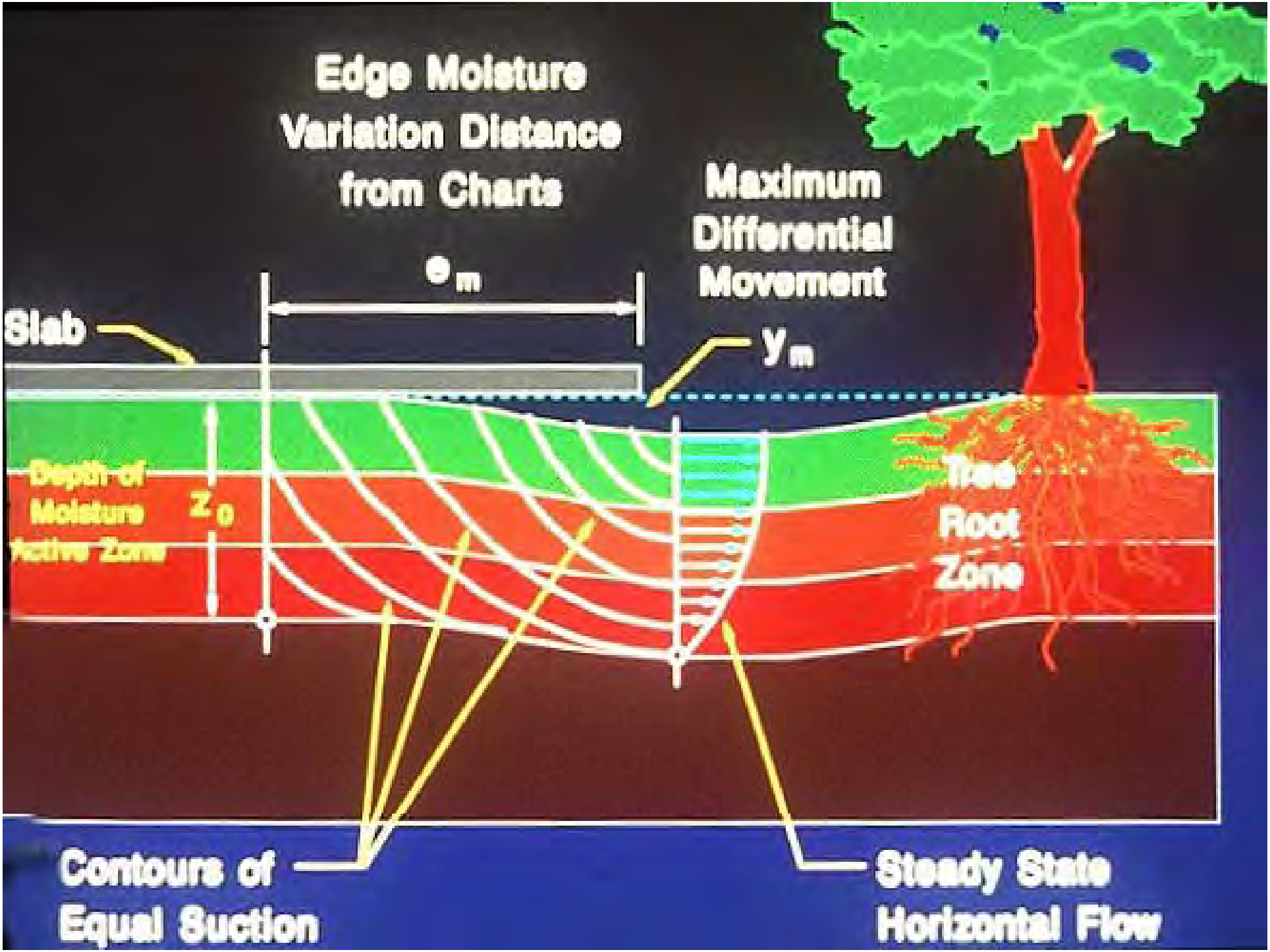
After D. A. Cameron

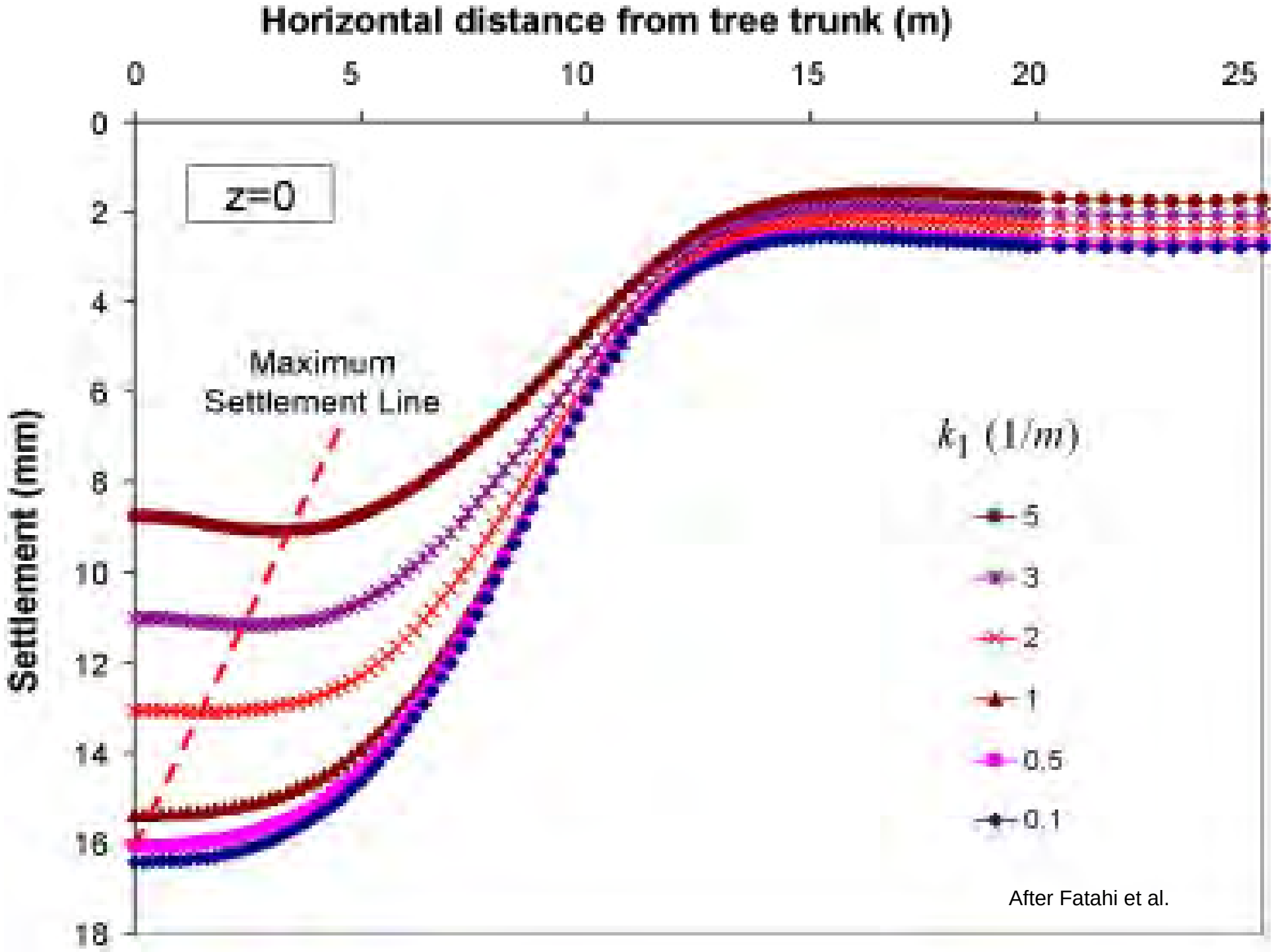

Microsoft Excel - Center_Lift_Case.xls
File Edit View Insert Format Tools Data Window Help
Type a question for help
B2
0.1385
CENTER LIFT CASE
(By Xiong Zhang & Robert L. Lytton)
slab
16 m
16 m
0.4 m
8 m
Tree
2.0 m
6 m
6 m
wall
slab
16 m
16 m
3.5 m
8 m
8 m
Tree Root Zone
D_max=2.0 m
Grass Root Zone
D_max=0.47m
1st Soil Layer
2nd Soil Layer
6.0 m
48 m
48 m
Displacement (m)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
-12
-8
-4
0
4
8
12
Distance Frome the Center of the House (m)
Ground surface
Upper envelope
Lower envelope
Shell
Sheet2
Sheet1
soil
Ready
Sum=1.56E+01
NUM
Start
E:\FPA_Presentation
Microsoft Excel - Cent...
Initializing...
3:45 PM

Design of Slabs Near Trees

- Find moisture active zone, z_m

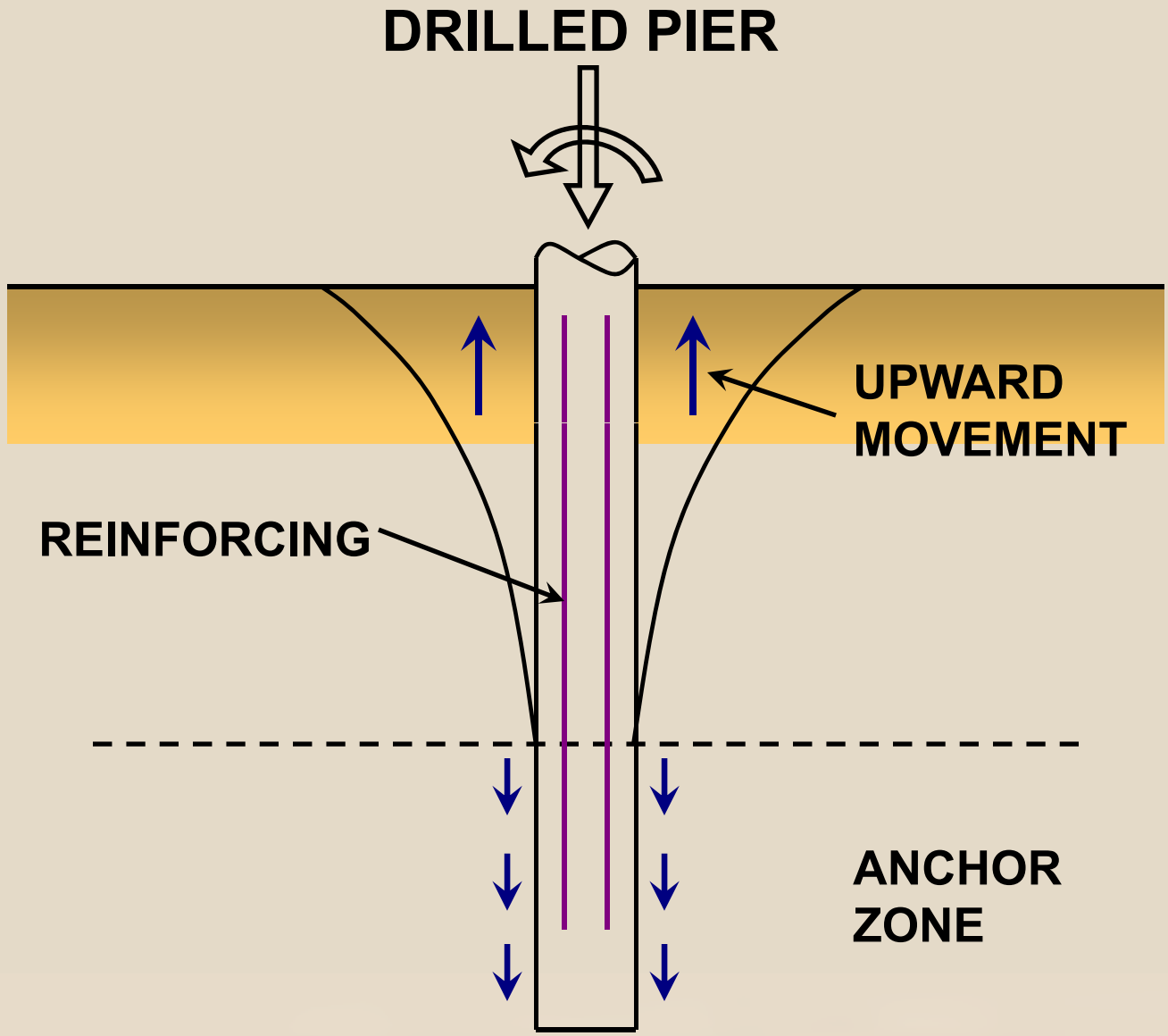
- Find edge moisture variation distance, e_m


Edge Moisture
Variation Distance
from Charts
e_m
Maximum
Differential
Movement
y_m
Slab
Depth of
Moisture
Active Zone
z_0
Tree
Root
Zone
Contours of
Equal Suction
Steady State
Horizontal Flow

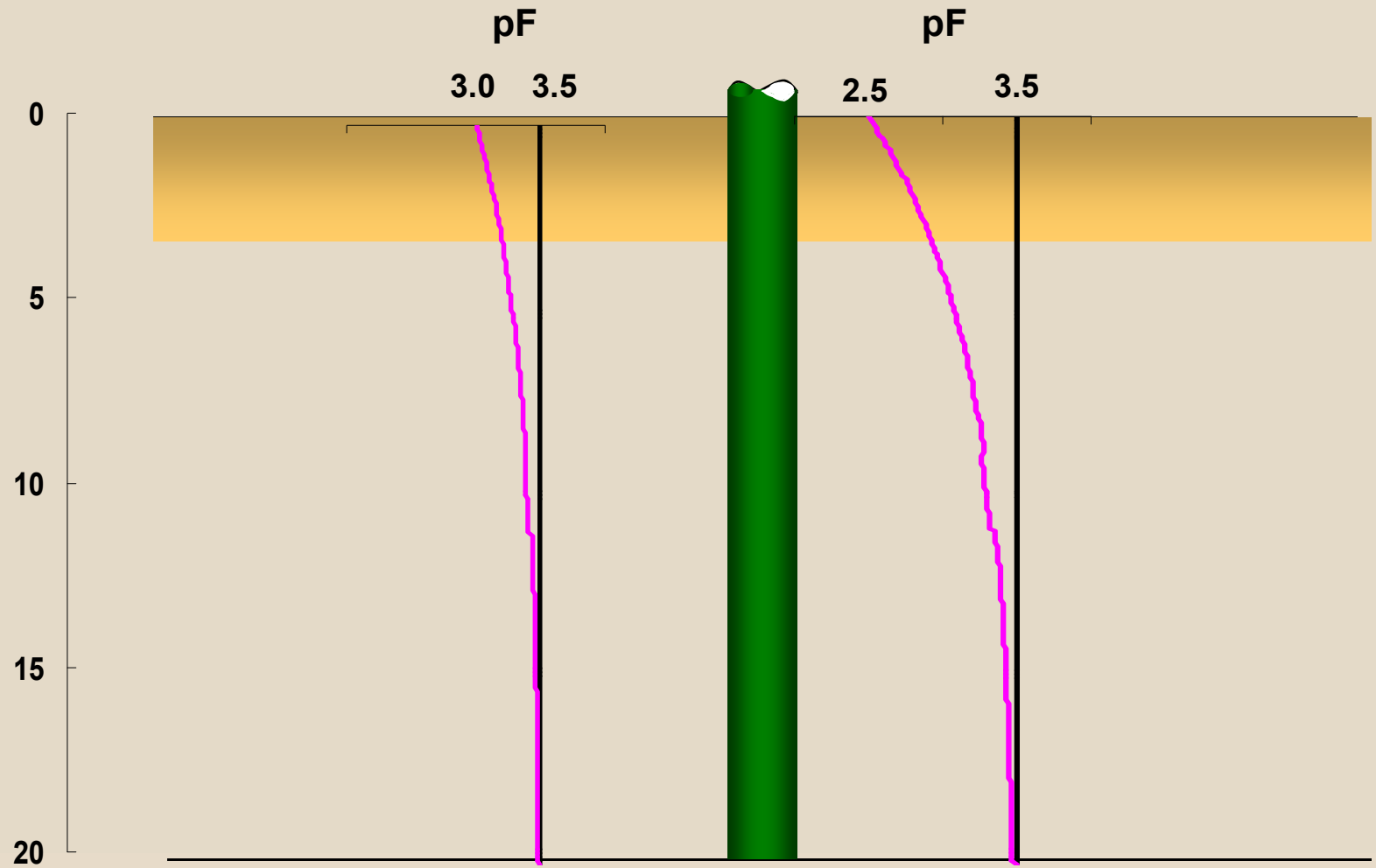

Horizontal distance from tree trunk (m)
0
5
10
15
20
25
Settlement (mm)
0
2
4
6
8
10
12
14
16
18
z=0
Maximum
Settlement Line
k_1 (1/m)
5
3
2
1
0.5
0.1
After Fatahi et al.

Design of Drilled Shafts Near Trees

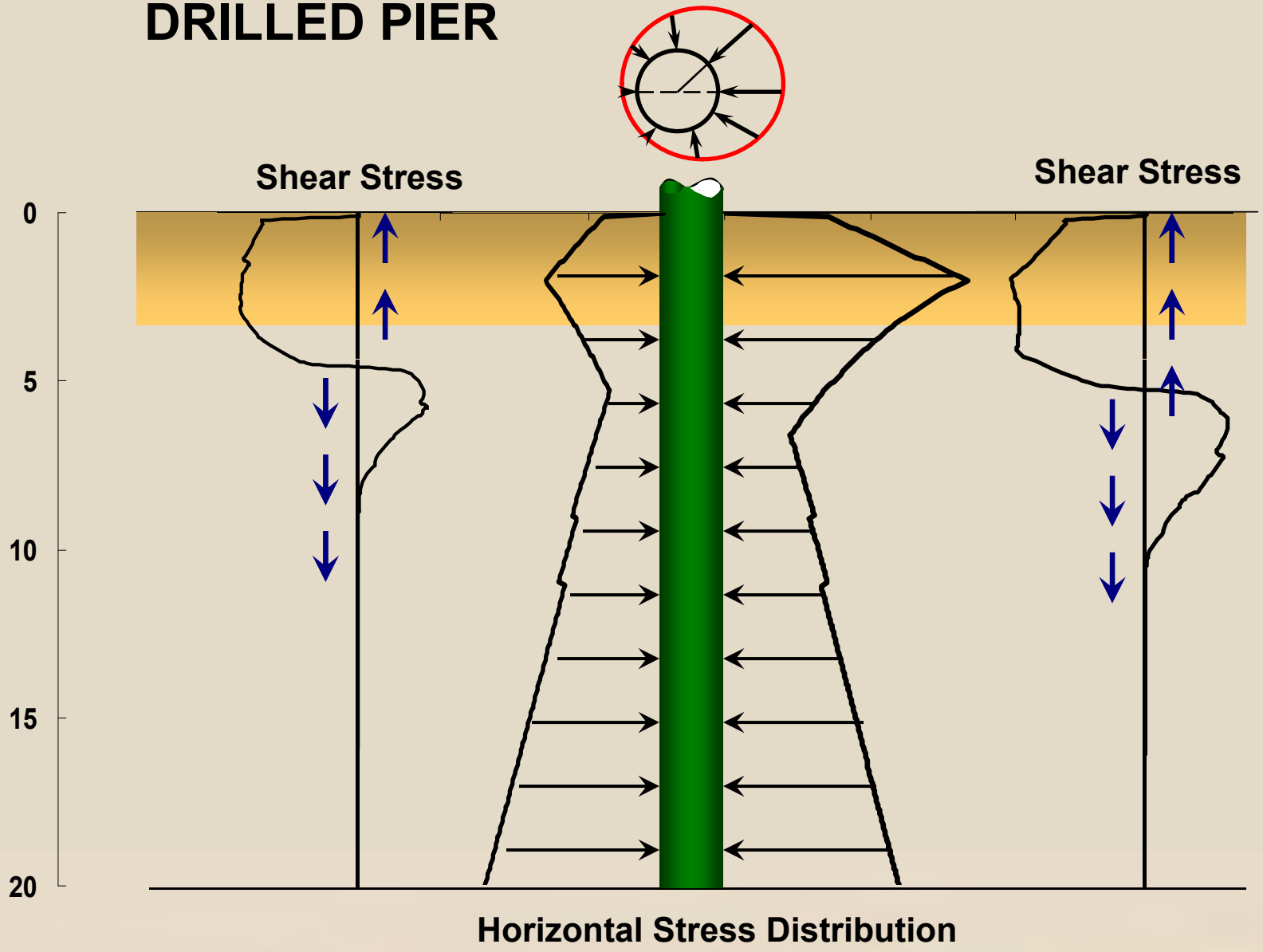
- Find moisture active zone, z_m
- Determine anchor length below z_m, L_A
- Account for unsymmetric bending
- Use tensile reinforcing (bond development length)


DRILLED PIER
UPWARD MOVEMENT
REINFORCING
ANCHOR ZONE

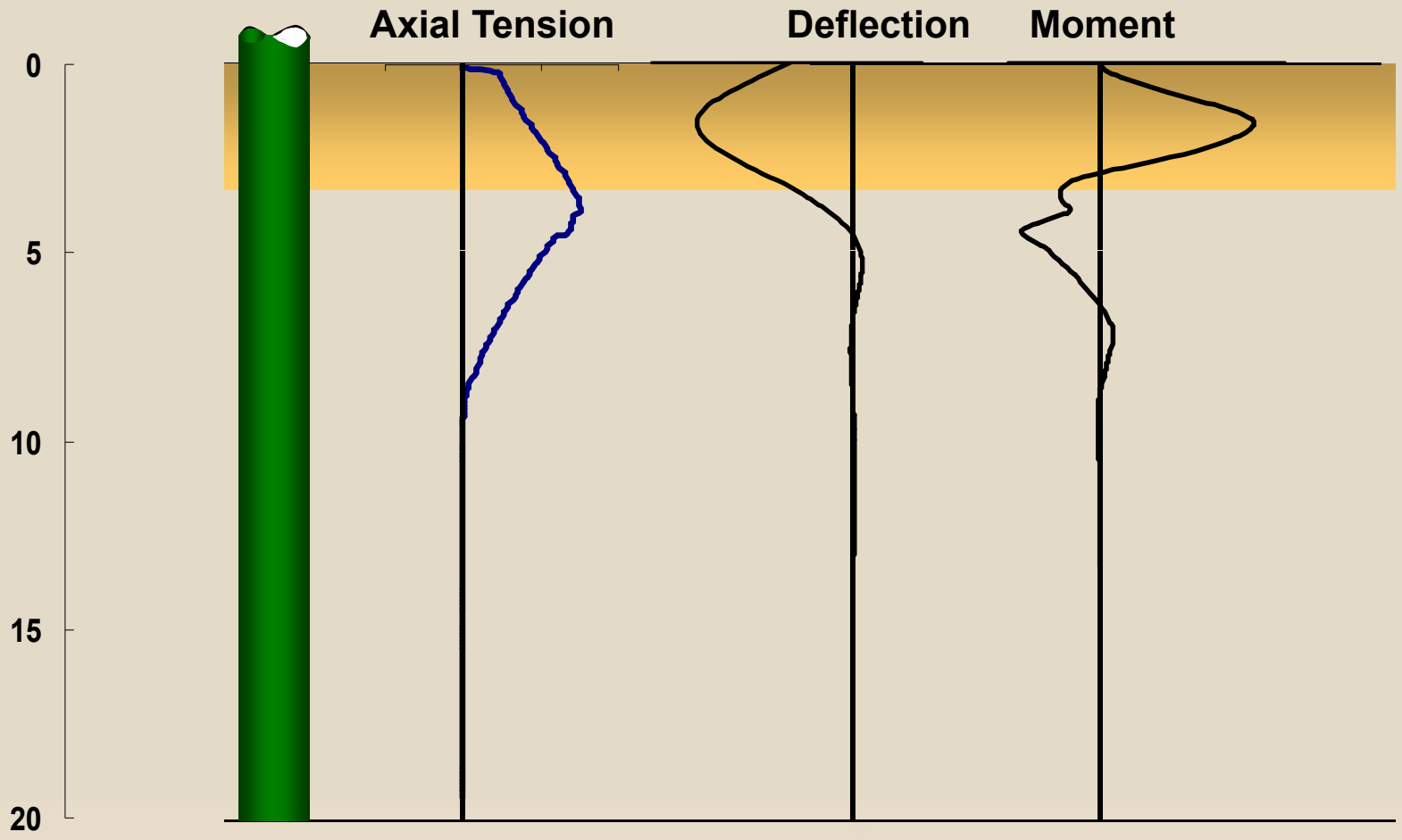
DRILLED PIER



DRILLED PIER



DRILLED PIER

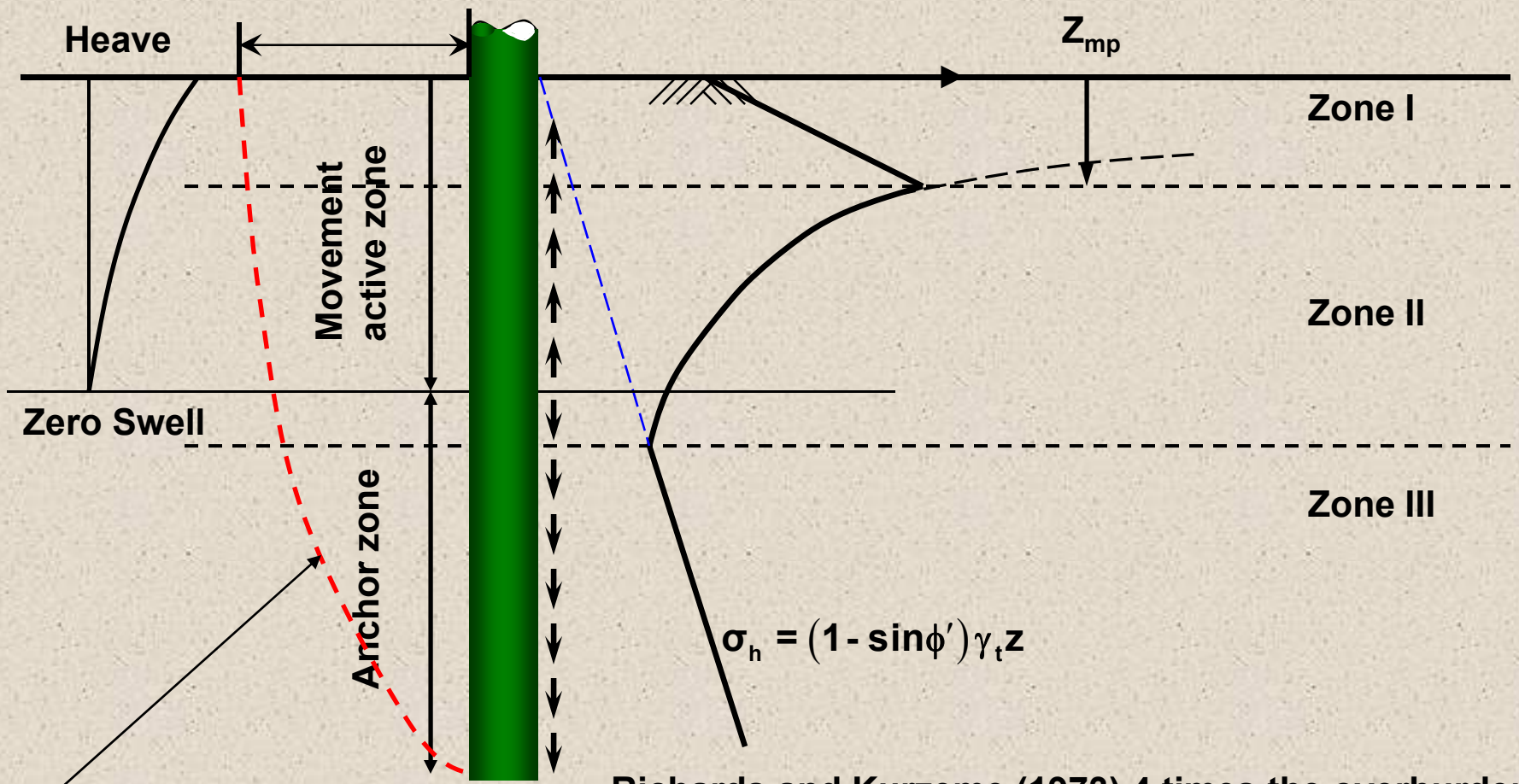


Horizontal Swelling Pressure Model

Z_{mp} = 3 - 5 ft

Joshi and Katti (1980); Komornik (1962); Brackely and Sanders (1992); Symons et al. (1989)

$$z_{mp}\tan(45+\phi'/2) = 5 - 7 \text{ ft}$$

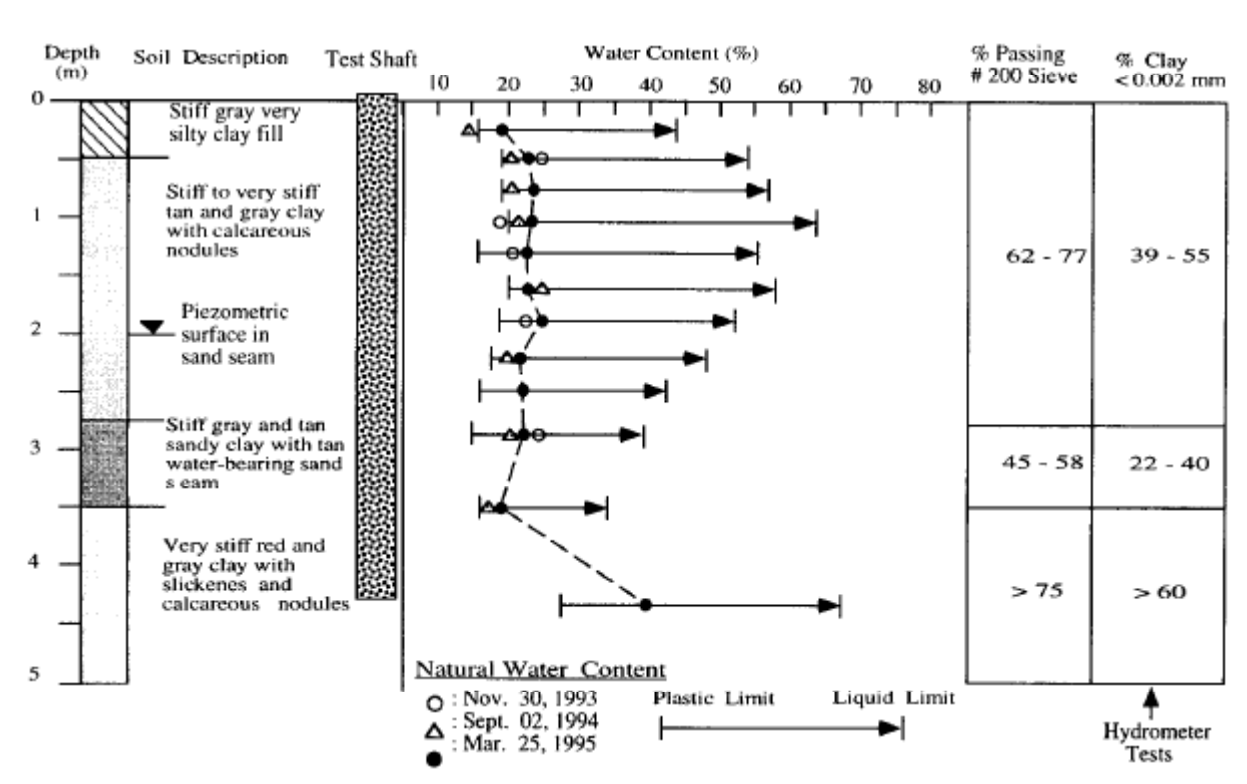


$$XZ_i = z_{mp}\tan(45+\varphi'/2)\left[1-\left(\frac{z}{H}\right)^2\right]$$

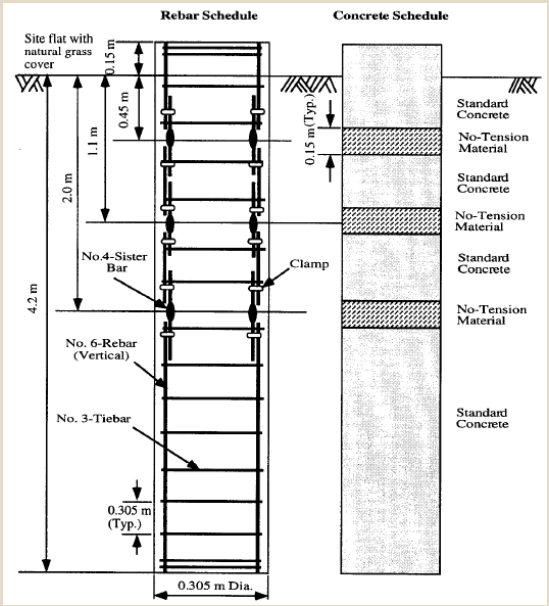
Richards and Kurzeme (1973) 4 times the overburden

Joshi and Katti (1980)	42 psi	@ 3 ft, lab
Komornik (1962)	55 psi	@ 3 ft, lab
Brackely and Sanders (1992)	12 psi	@ 3 ft, field

Kim and O'Neill (1998)
Axial behavior of the pier

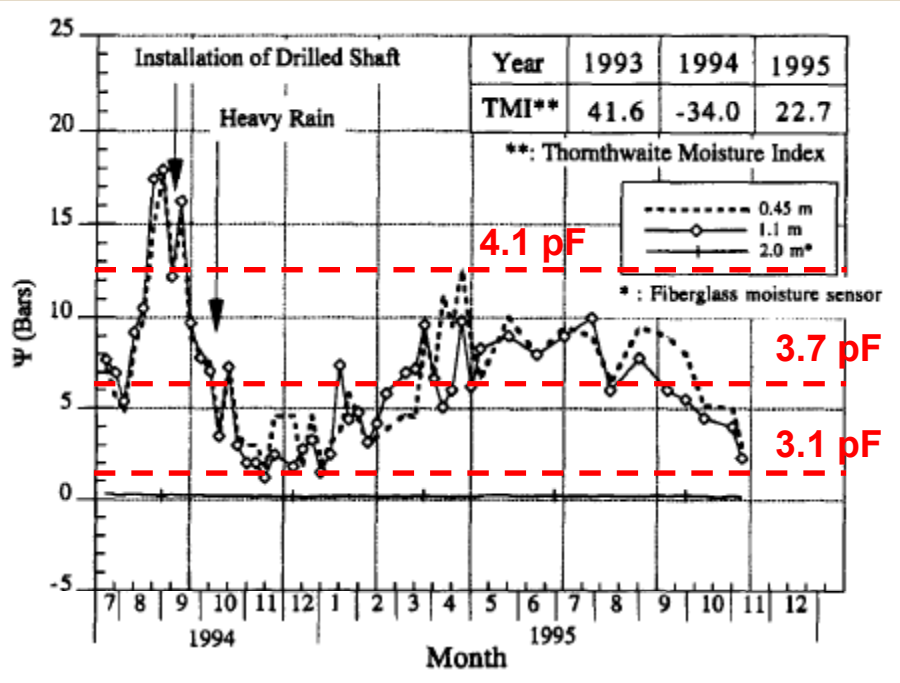


Test Site Stratigraphy (NGES-UH)

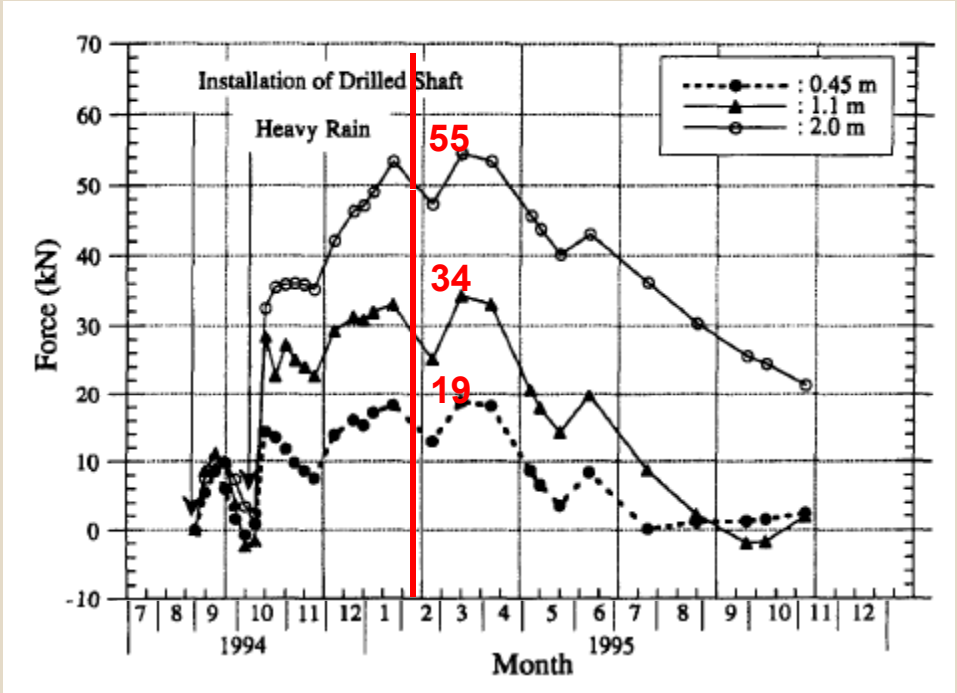


Schedule of Rebar and Concrete in Drilled Shaft

Kim and O'Neill (1998)
Axial behavior of the pier

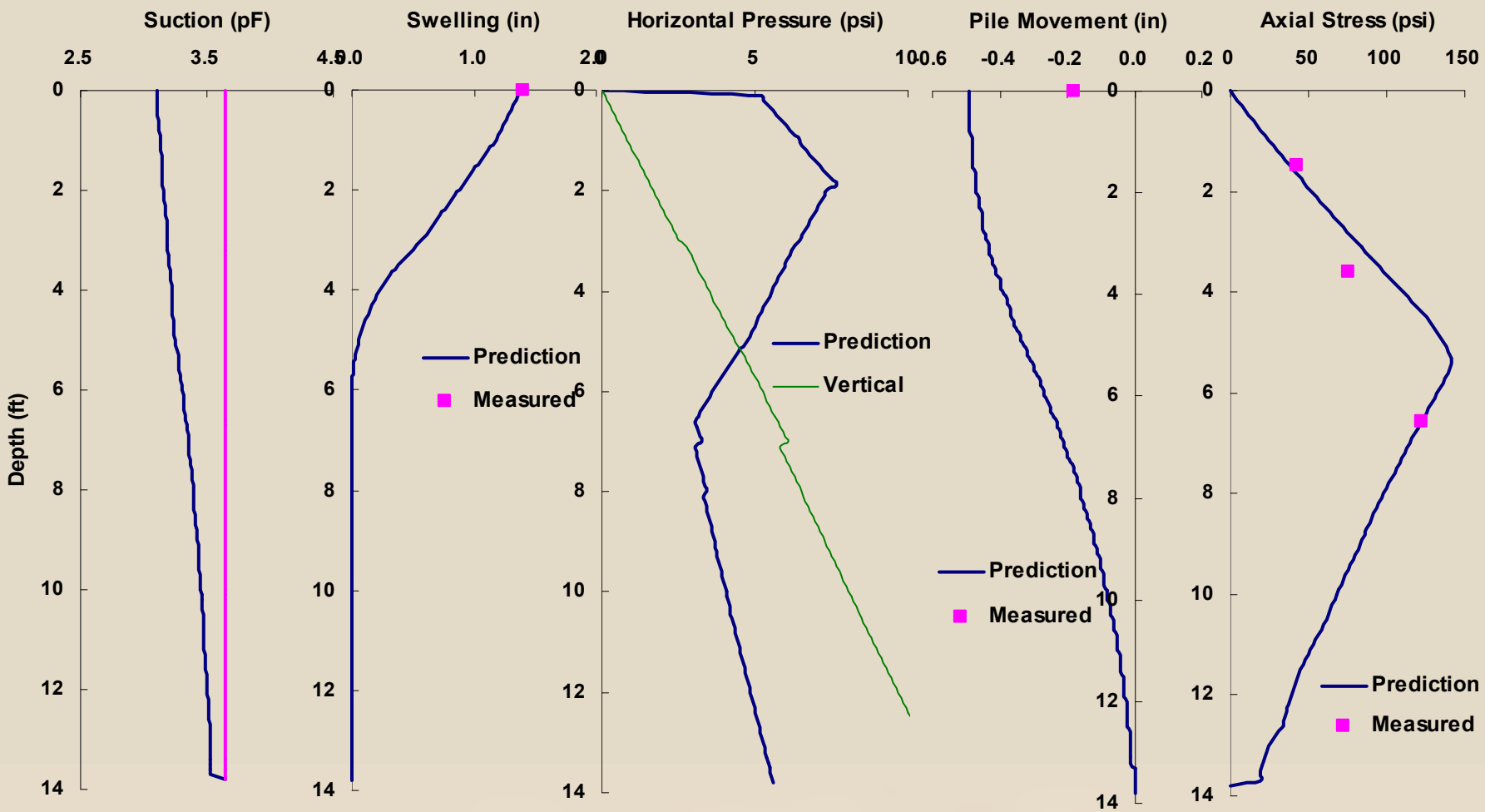


Bar versus Time(1 bar=100 kPa)

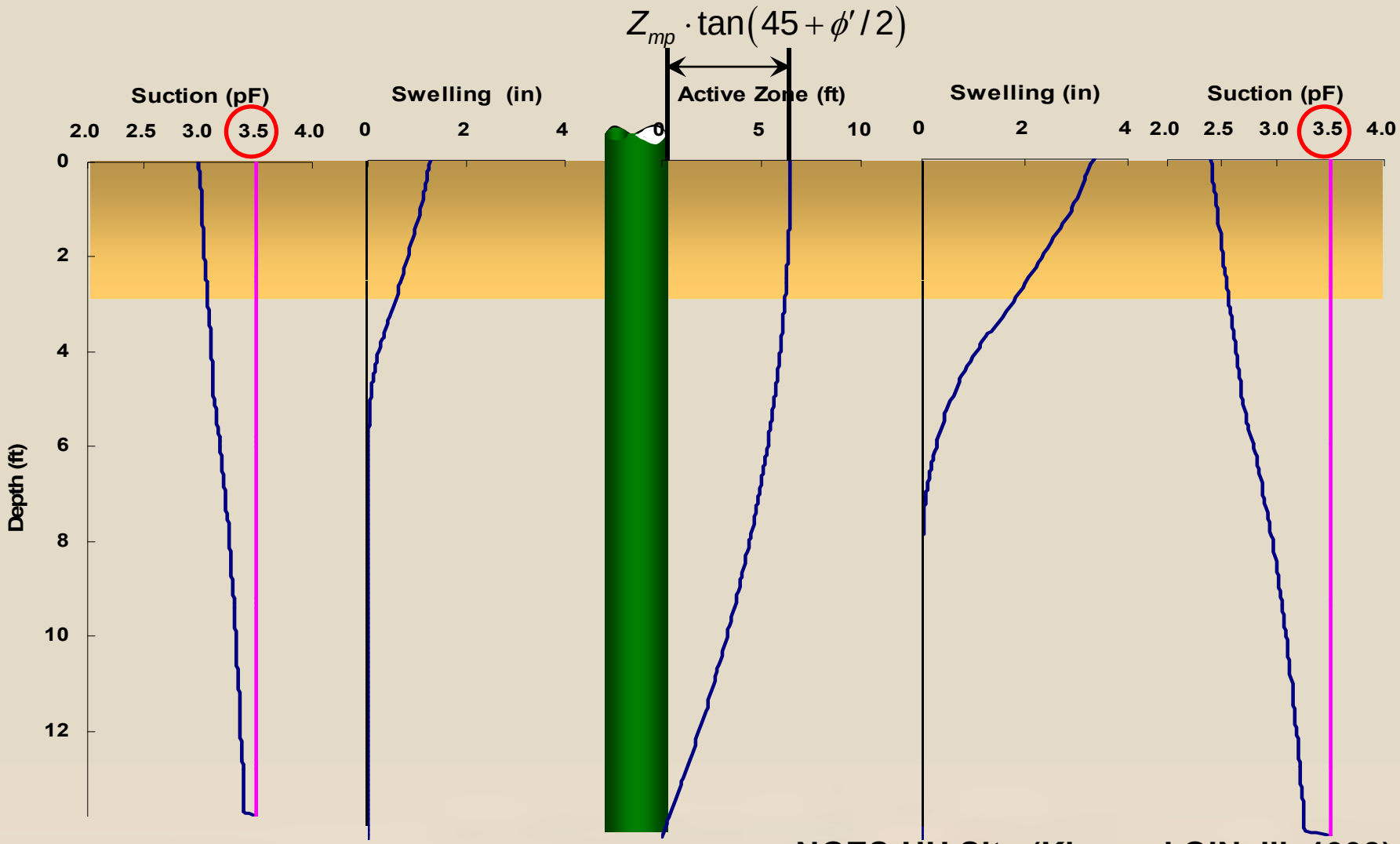


Uplift Force versus Time

Kim and O'Neill (1998)
Axial behavior of the pier

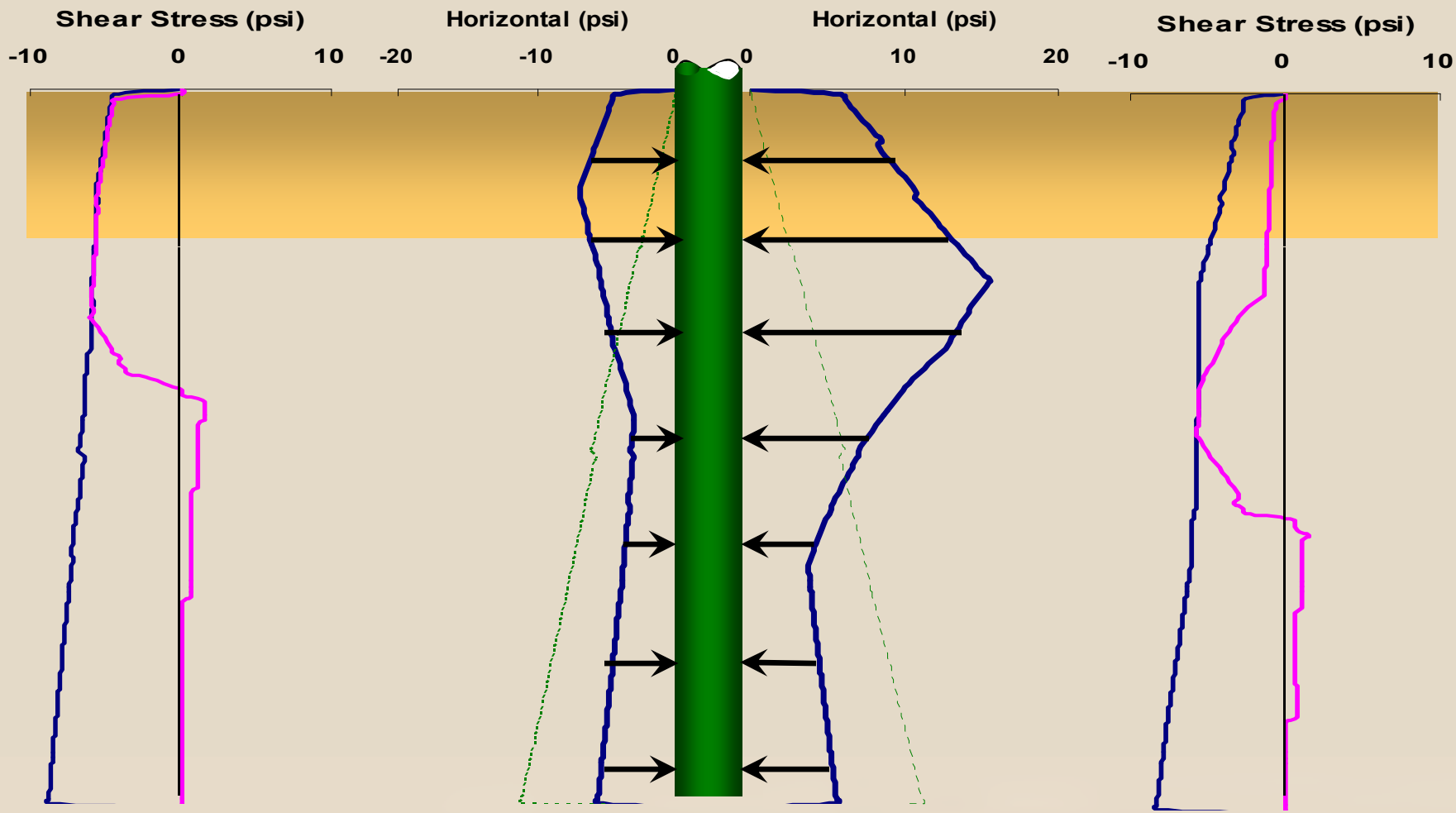


Case Study of Bending Behavior of the Pier Uneven Wetting with Same Initial Condition



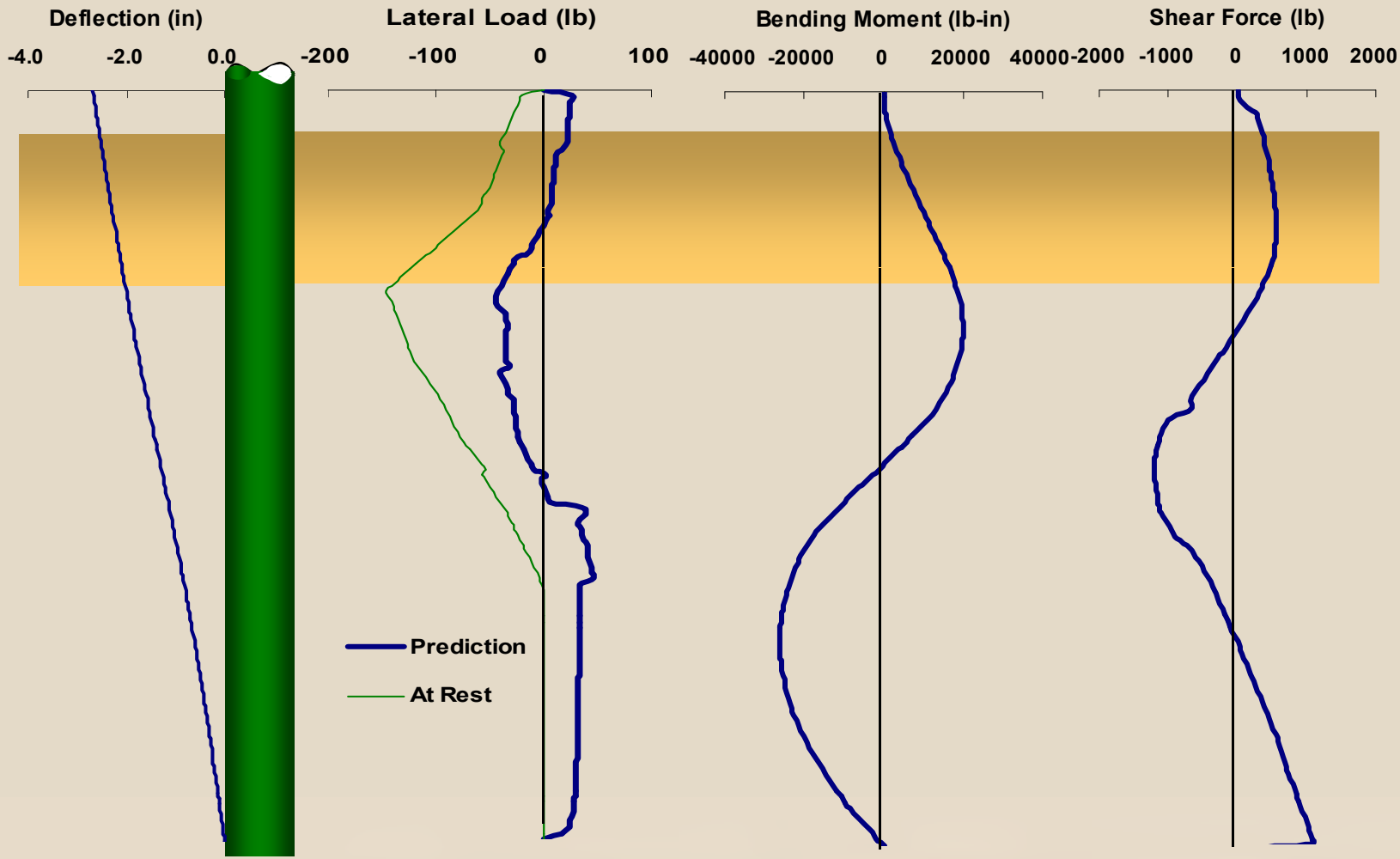
NGES-UH Site (Kim and O'Neill, 1998)

Case Study of Bending Behavior of the Pier Uneven Wetting with Same Initial Condition



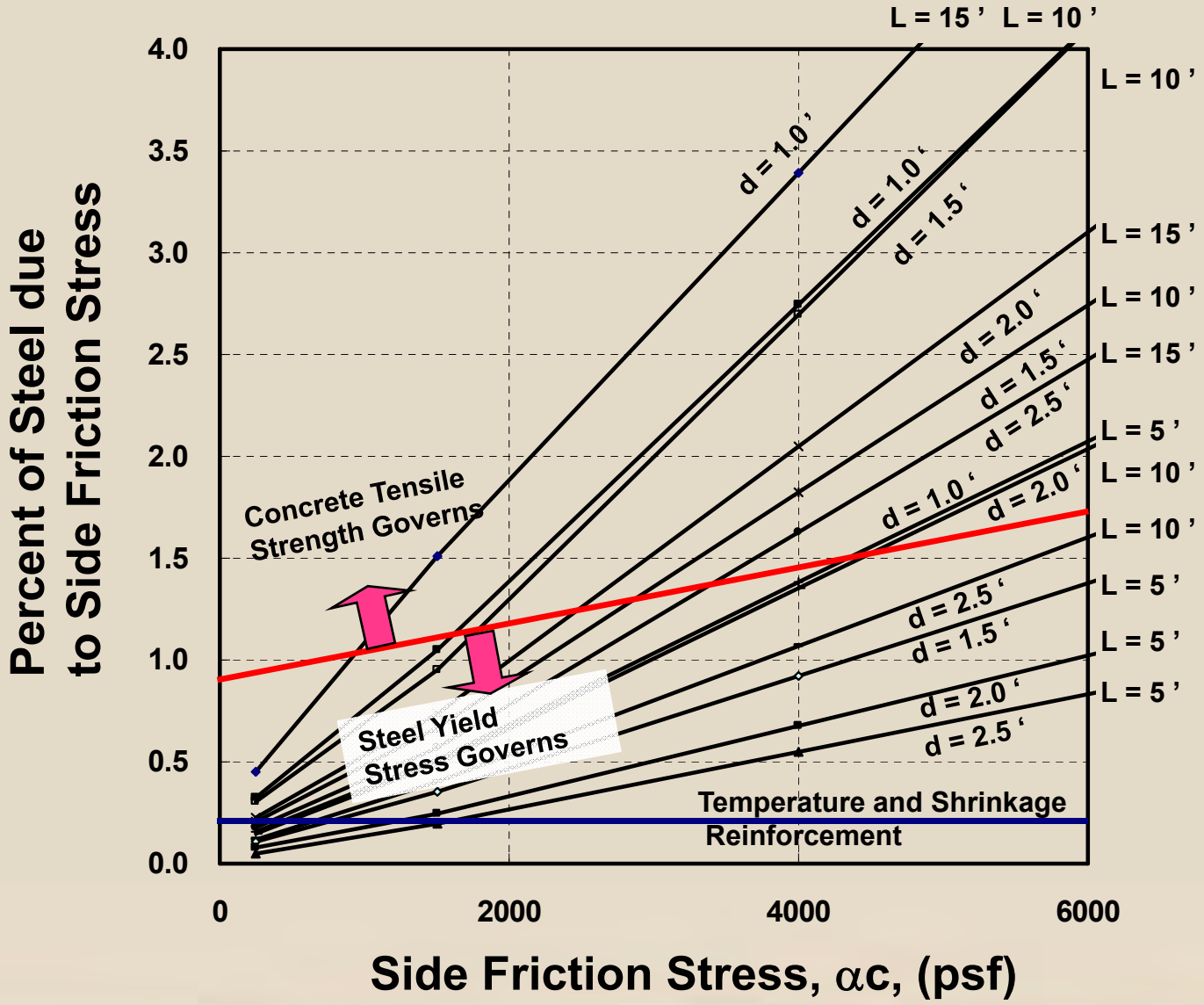
NGES-UH Site (Kim and O'Neill, 1998)

Case Study of Bending Behavior of the Pier Uneven Wetting with Same Initial Condition

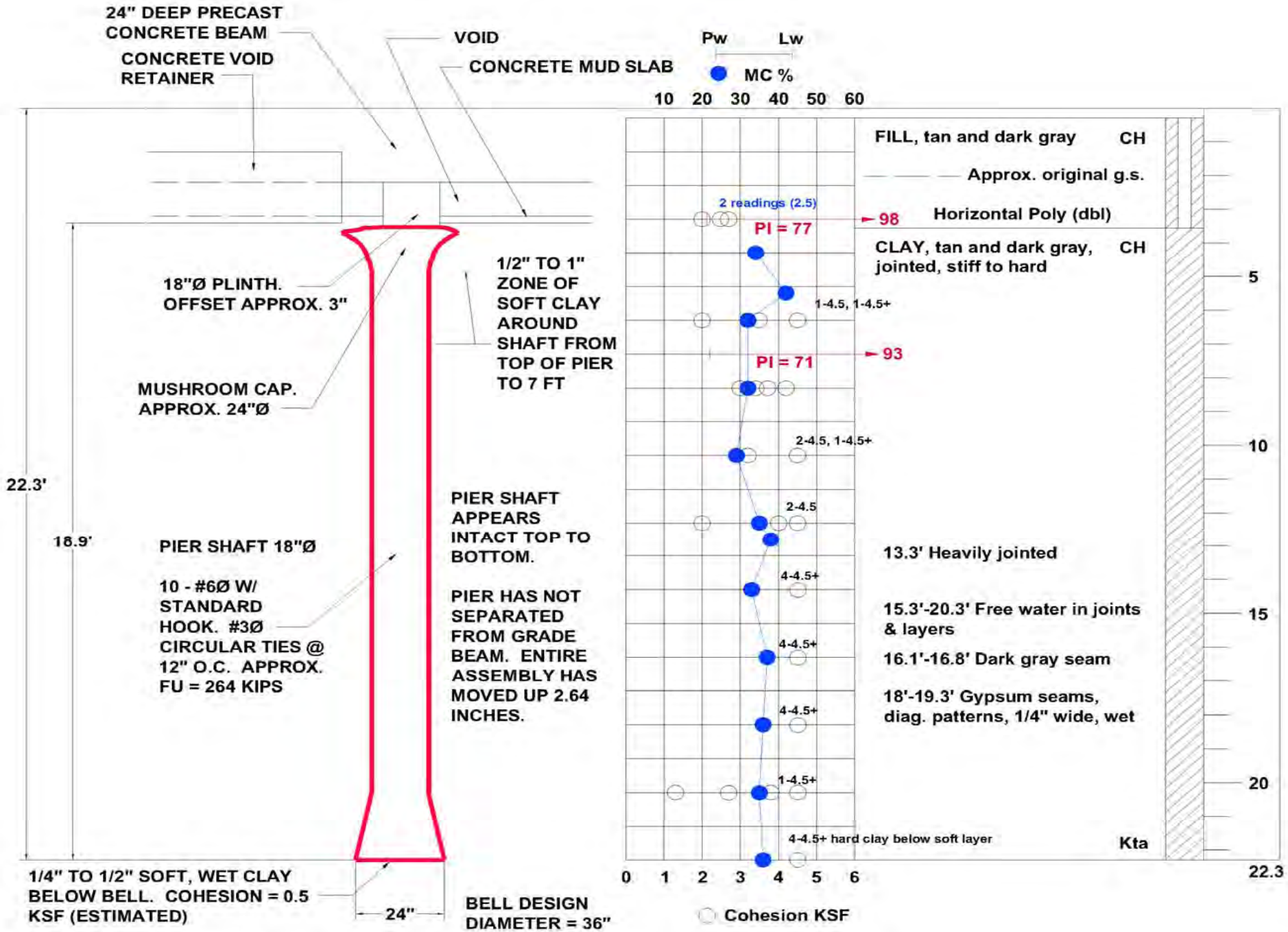


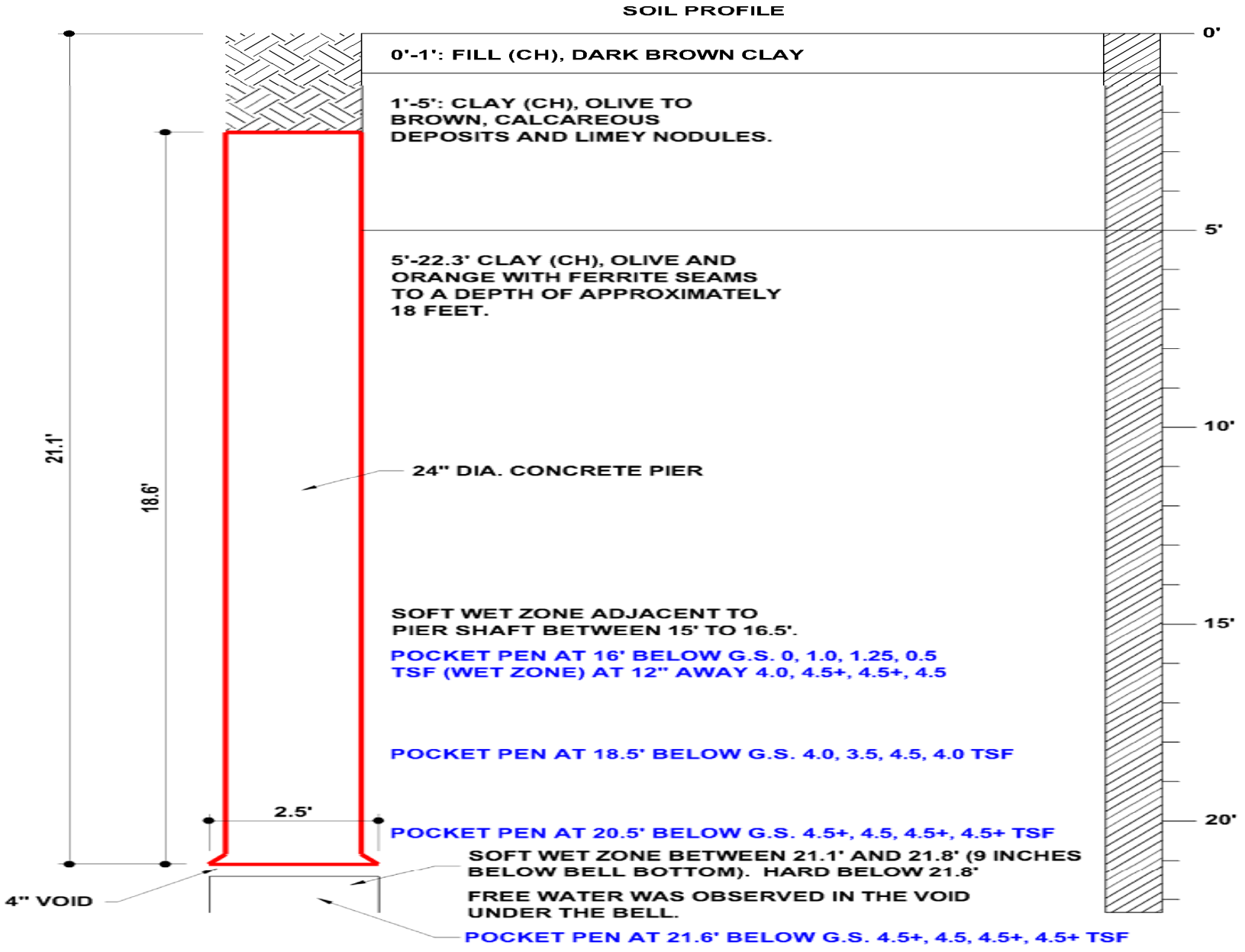
NGES-UH Site (Kim and O'Neill, 1998)

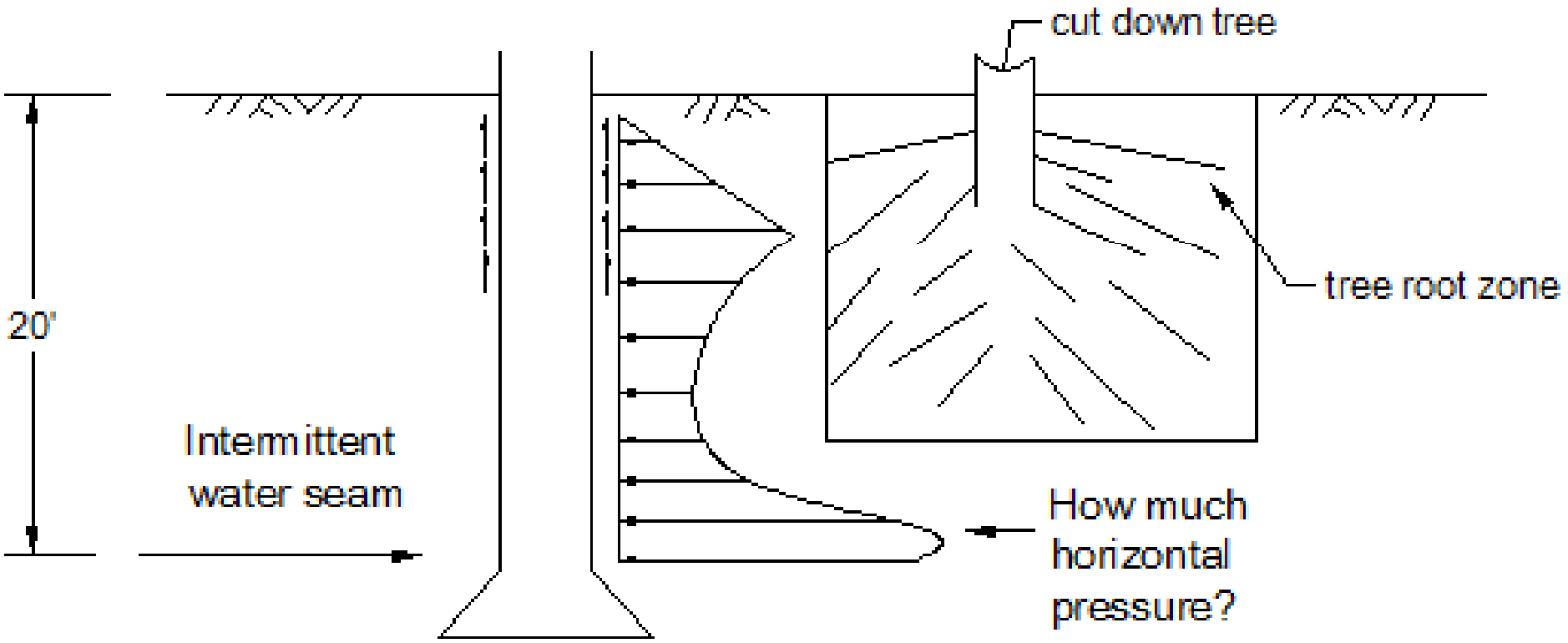
DRILLED PIER REINFORCEMENT



What about Seams of Moisture?


24" DEEP PRECAST CONCRETE BEAM
CONCRETE VOID RETAINER
VOID
CONCRETE MUD SLAB
18"Ø PLINTH. OFFSET APPROX. 3"
MUSHROOM CAP. APPROX. 24"Ø
1/2" TO 1" ZONE OF SOFT CLAY AROUND SHAFT FROM TOP OF PIER TO 7 FT
22.3'
16.9'
PIER SHAFT 18"Ø
10 - #6Ø W/ STANDARD HOOK. #3Ø CIRCULAR TIES @ 12" O.C. APPROX. FU = 264 KIPS
PIER SHAFT APPEARS INTACT TOP TO BOTTOM.
PIER HAS NOT SEPARATED FROM GRADE BEAM. ENTIRE ASSEMBLY HAS MOVED UP 2.64 INCHES.
1/4" TO 1/2" SOFT, WET CLAY BELOW BELL. COHESION = 0.5 KSF (ESTIMATED)
24"
BELL DESIGN DIAMETER = 36"
Pw
Lw
MC %
10 20 30 40 50 60
FILL, tan and dark gray CH
Approx. original g.s.
2 readings (2.5)
98
Horizontal Poly (dbl)
PI = 77
CLAY, tan and dark gray, jointed, stiff to hard CH
1-4.5, 1-4.5+
93
PI = 71
2-4.5, 1-4.5+
2-4.5
13.3' Heavily jointed
4-4.5+
15.3'-20.3' Free water in joints & layers
4-4.5+
16.1'-16.8' Dark gray seam
18'-19.3' Gypsum seams, diag. patterns, 1/4" wide, wet
4-4.5+
1-4.5+
4-4.5+ hard clay below soft layer
Kta
5
10
15
20
22.3
0 1 2 3 4 5 6
Cohesion KSF


SOIL PROFILE
0'-1': FILL (CH), DARK BROWN CLAY
1'-5': CLAY (CH), OLIVE TO BROWN, CALCAREOUS DEPOSITS AND LIMEY NODULES.
5'-22.3' CLAY (CH), OLIVE AND ORANGE WITH FERRITE SEAMS TO A DEPTH OF APPROXIMATELY 18 FEET.
24" DIA. CONCRETE PIER
SOFT WET ZONE ADJACENT TO PIER SHAFT BETWEEN 15' TO 16.5'.
POCKET PEN AT 16' BELOW G.S. 0, 1.0, 1.25, 0.5 TSF (WET ZONE) AT 12" AWAY 4.0, 4.5+, 4.5+, 4.5
POCKET PEN AT 18.5' BELOW G.S. 4.0, 3.5, 4.5, 4.0 TSF
POCKET PEN AT 20.5' BELOW G.S. 4.5+, 4.5, 4.5+, 4.5+ TSF
SOFT WET ZONE BETWEEN 21.1' AND 21.8' (9 INCHES BELOW BELL BOTTOM). HARD BELOW 21.8'
FREE WATER WAS OBSERVED IN THE VOID UNDER THE BELL.
POCKET PEN AT 21.6' BELOW G.S. 4.5+, 4.5, 4.5+, 4.5+ TSF
4" VOID
2.5'
21.1'
18.6'
0'
5'
10'
15'
20'


cut down tree
tree root zone
20'
Intermittent
water seam
How much
horizontal
pressure?

Answer:

- Change suction from

  pF 4.5 (wilting point) to pF 2.5 (higher than field capacity)

- Horizontal pressure

  10520 lb/ft2 – 4 x vertical pressure

  Enough to cause passive earth pressure

Trees and Tree Characteristics

- Trees
  - How they affect slab performance and design
  - How they affect drilled shaft performance and design
- Tree characteristics
  - What they need to survive
  - Root zones
  - Water uptake
  - Moisture active zone

Outline

- Movement caused by trees
- Movie of movements caused by trees
- Design considerations of slabs near trees
- Design considerations of drilled shafts near trees
- Seams of moisture effects
- Summary

TEXAS A&M ENGINEERING

Effects of Trees on Foundations

Robert L. Lytton

Professor, Fred J. Benson Endowed Chair
Zachry Department of Civil Engineering
Texas A&M University

Houston Foundation Performance Association
Houston, Texas, December 8, 2010