Foundation Design Principles for Post-Tensioned Foundations in Houston

Robert L. Lytton
John T. Bryant
Dean R. Read

Houston Foundation Performance Association
December 10, 2008

Outline

- What's the point of design? (RLL)
- Design details
  - Soils (JTB)
  - Site conditions (JTB)
  - Loads (DRR)
  - Structures (DRR)
- Summary (RLL, JTB, DRR)

What's the Point of Design?

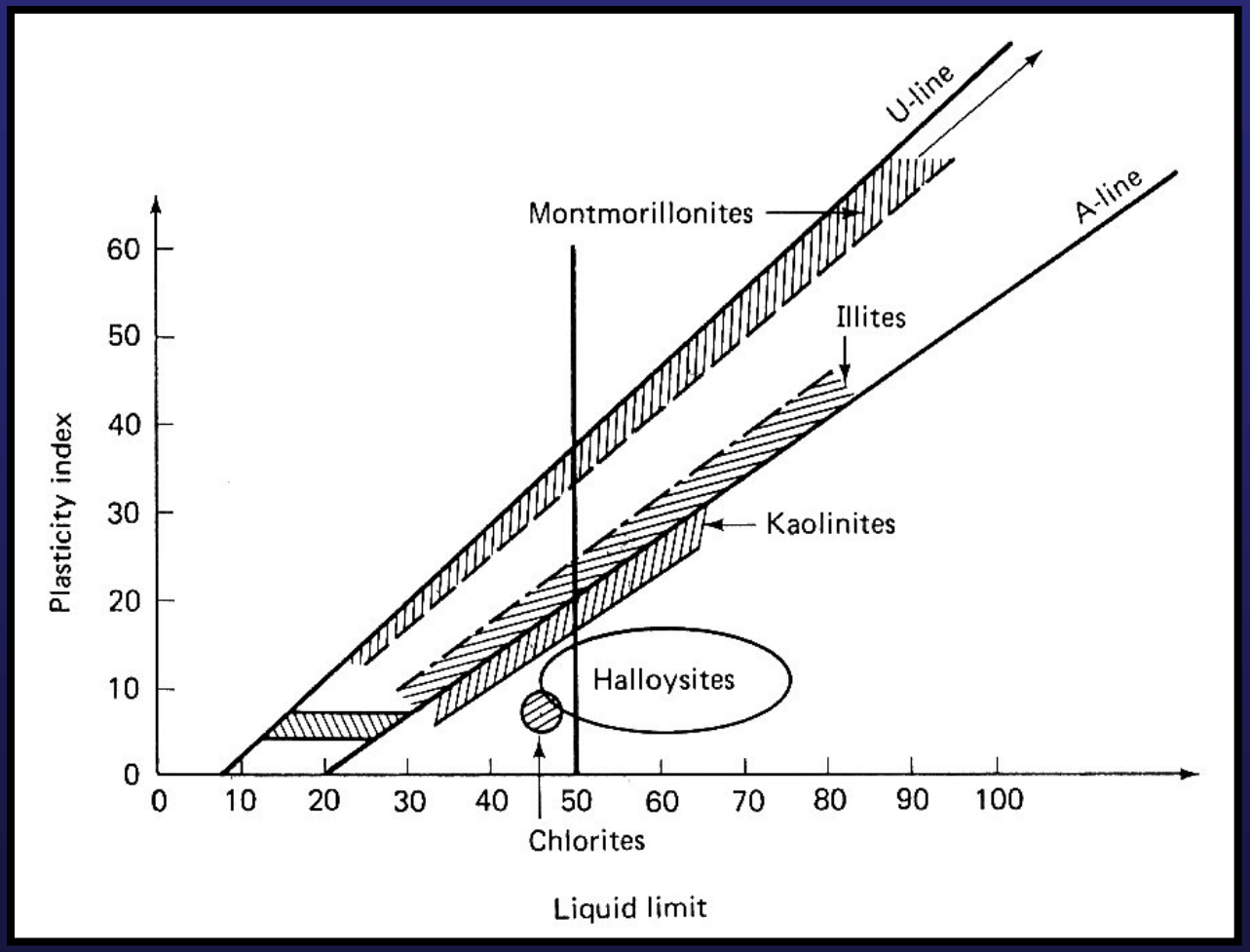
- Contributing elements
- Design conditions
- Design approaches
- Design criteria
  - Stresses/strength
  - Deflections/tolerance
  - Stiffness
- Objectives
- Constraints

Contributing Elements

- Soils
- Site conditions
- Loads
- Structures

Soils (1/2)

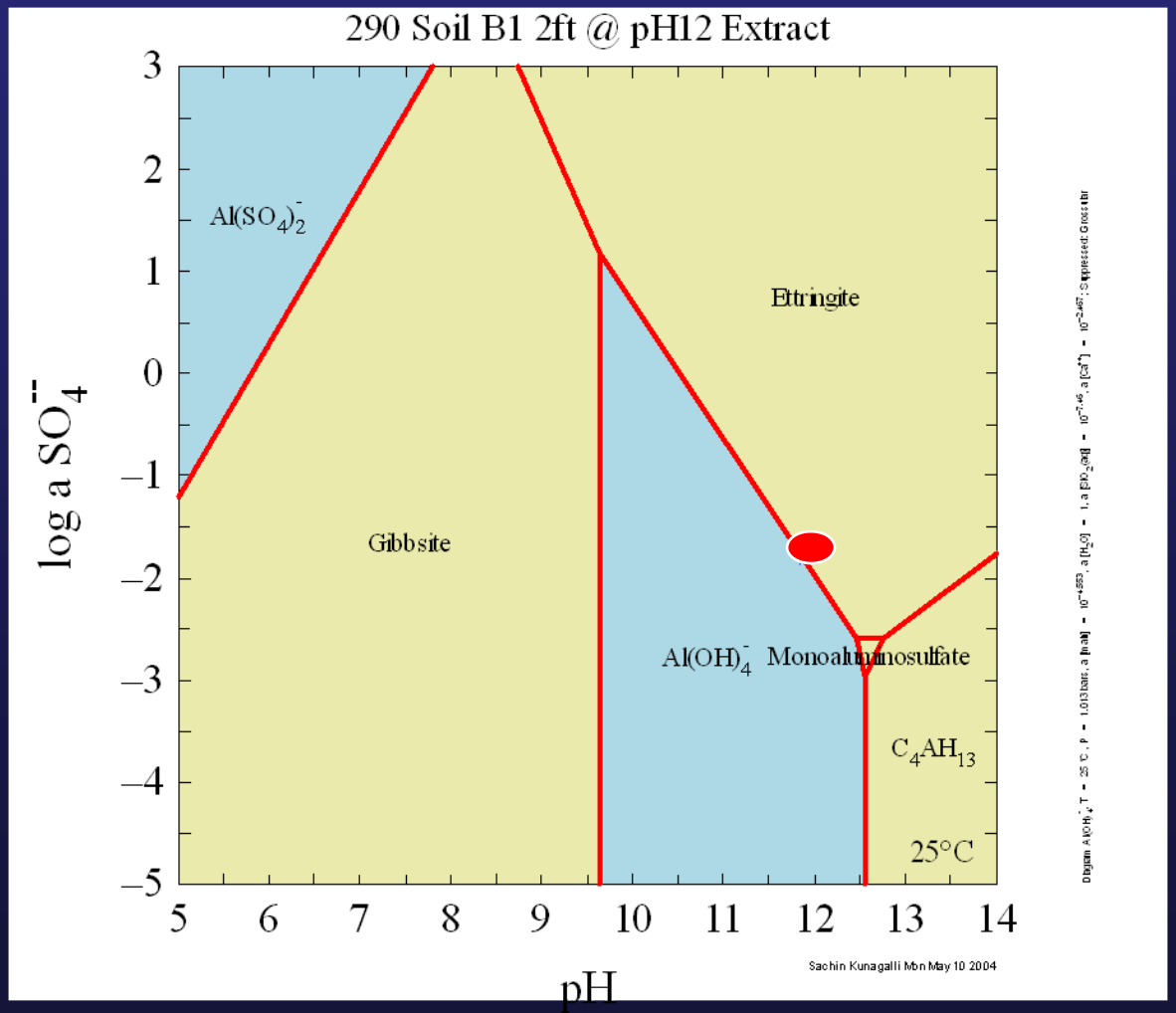
- Expansive
  - Differential movement
  - Total movement
- Minerals
  - Wide variety
  - Mixed
  - Large differences in behavior


U-line
A-line
Montmorillonites
Illites
Kaolinites
Halloysites
Chlorites
Plasticity index
Liquid limit
0
10
20
30
40
50
60
70
80
90
100

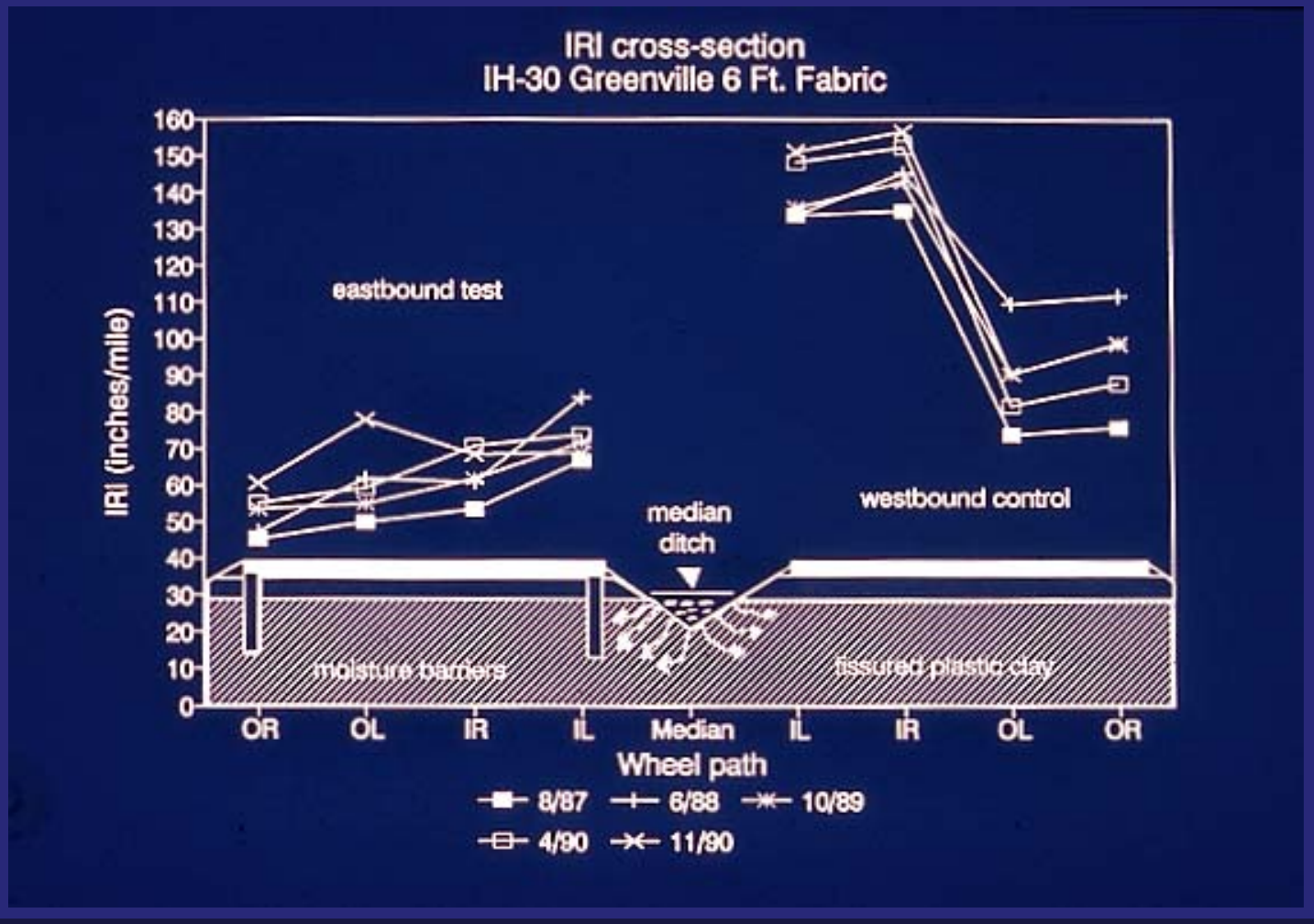
Soils (2/2)

- Chemistry
  - Sulfates
  - Chlorides
  - Stabilizing chemicals
- Stabilization against
  - Movement
  - Moisture movement

Stability Models or Phase Diagrams
290 Soil - Depth of 24-inches



Soluble Sulfates = 18,700 ppm


IRI cross-section
IH-30 Greenville 6 Ft. Fabric
IRI (inches/mile)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
eastbound test
westbound control
median
ditch
moisture barriers
fissured plastic clay
OR
OL
IR
IL
Median
IL
IR
OL
OR
Wheel path
8/87
6/88
10/89
4/90
11/90

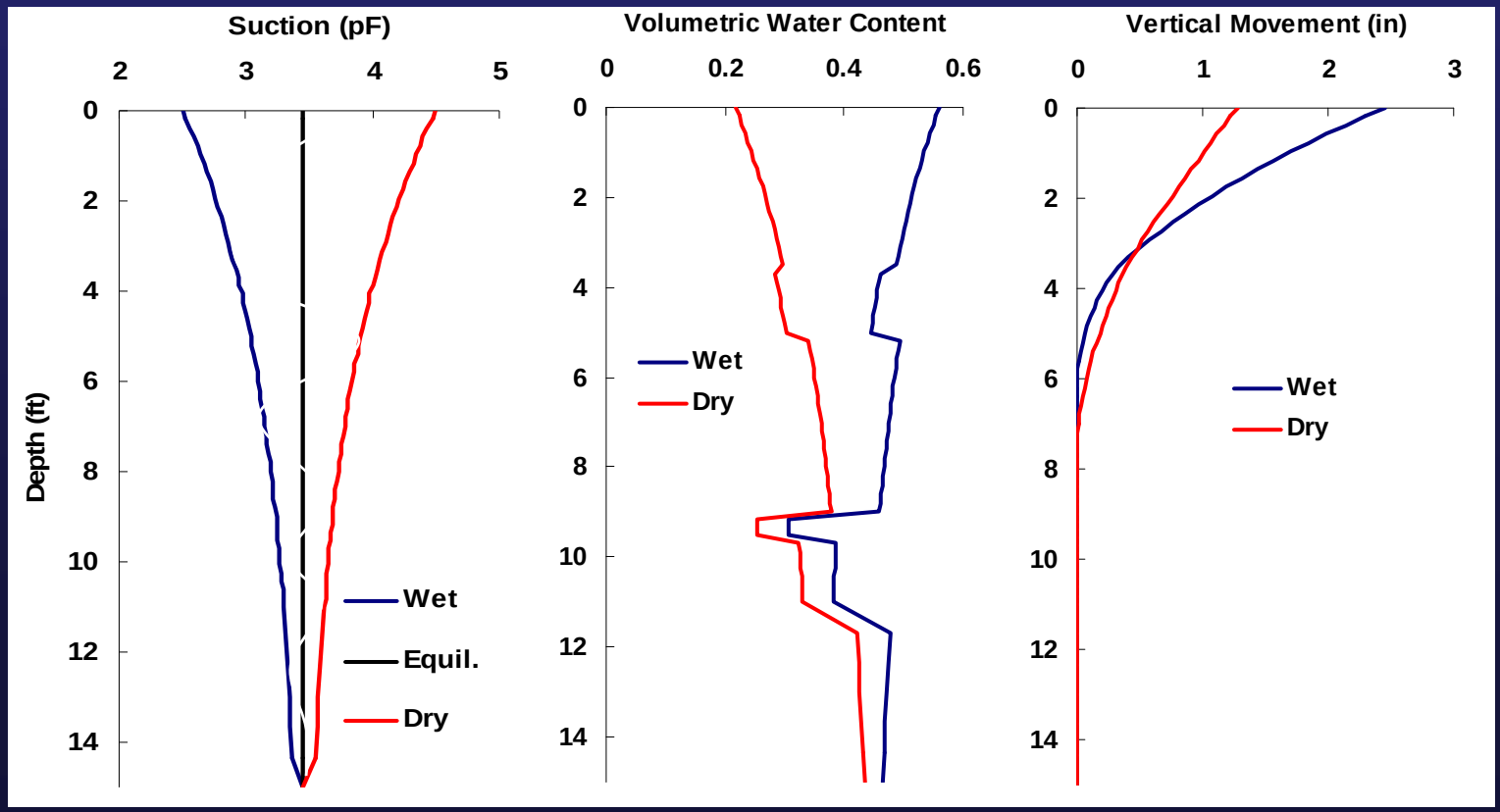
Exponential Suction Profile for Extreme Wetting and Drying Condition

$$U(Z,t) = U_e + U_o \exp\left(-\sqrt{\frac{n\pi}{\alpha}}Z\right)\cos\left(2\pi nt - \sqrt{\frac{n\pi}{\alpha}}Z\right)$$

Mitchell (1979)

$$U(Z) = U_e + U_o \exp\left(-\sqrt{\frac{n\pi}{\alpha}}Z\right)$$

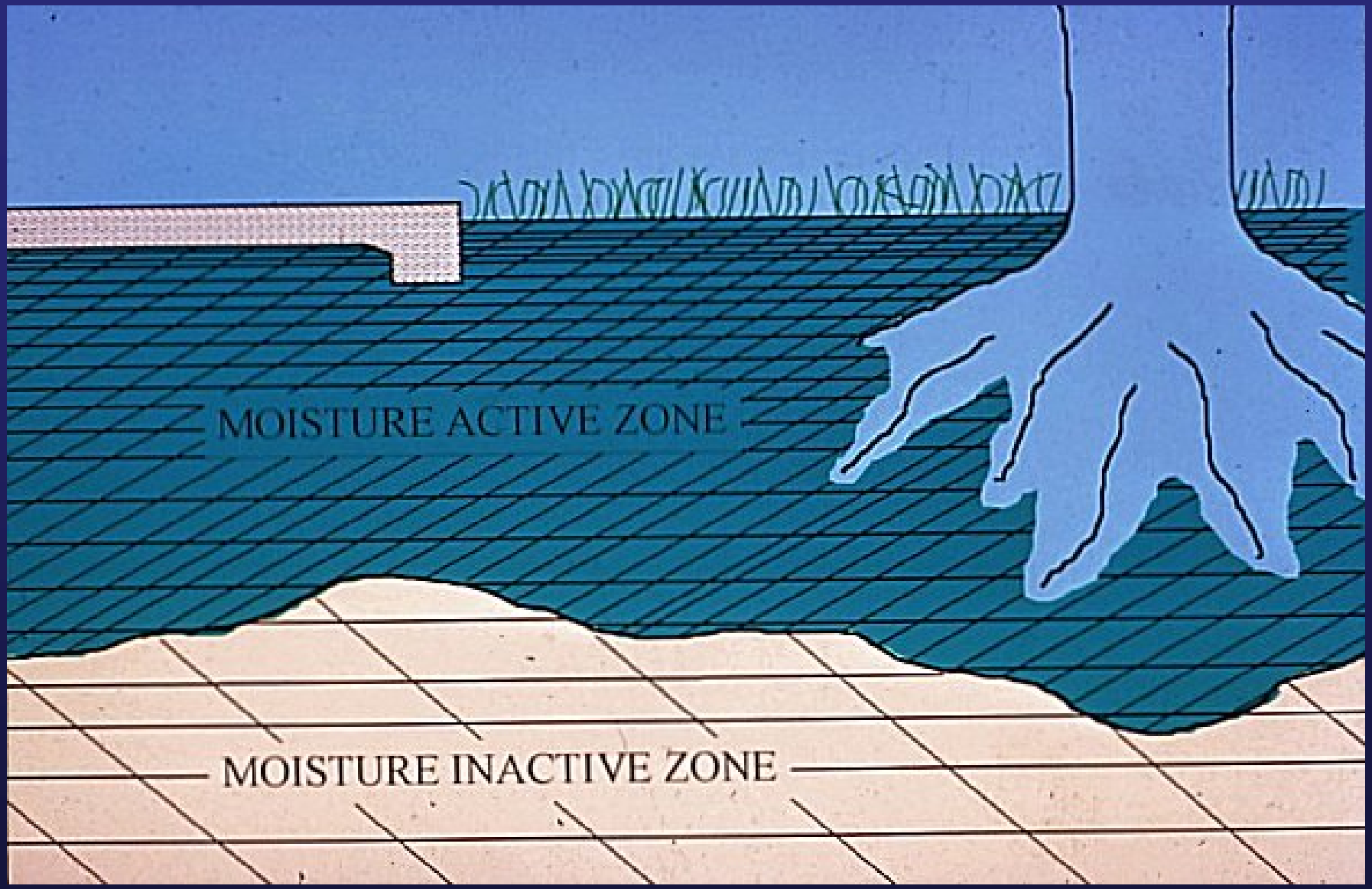
Fort Worth Interstate 820

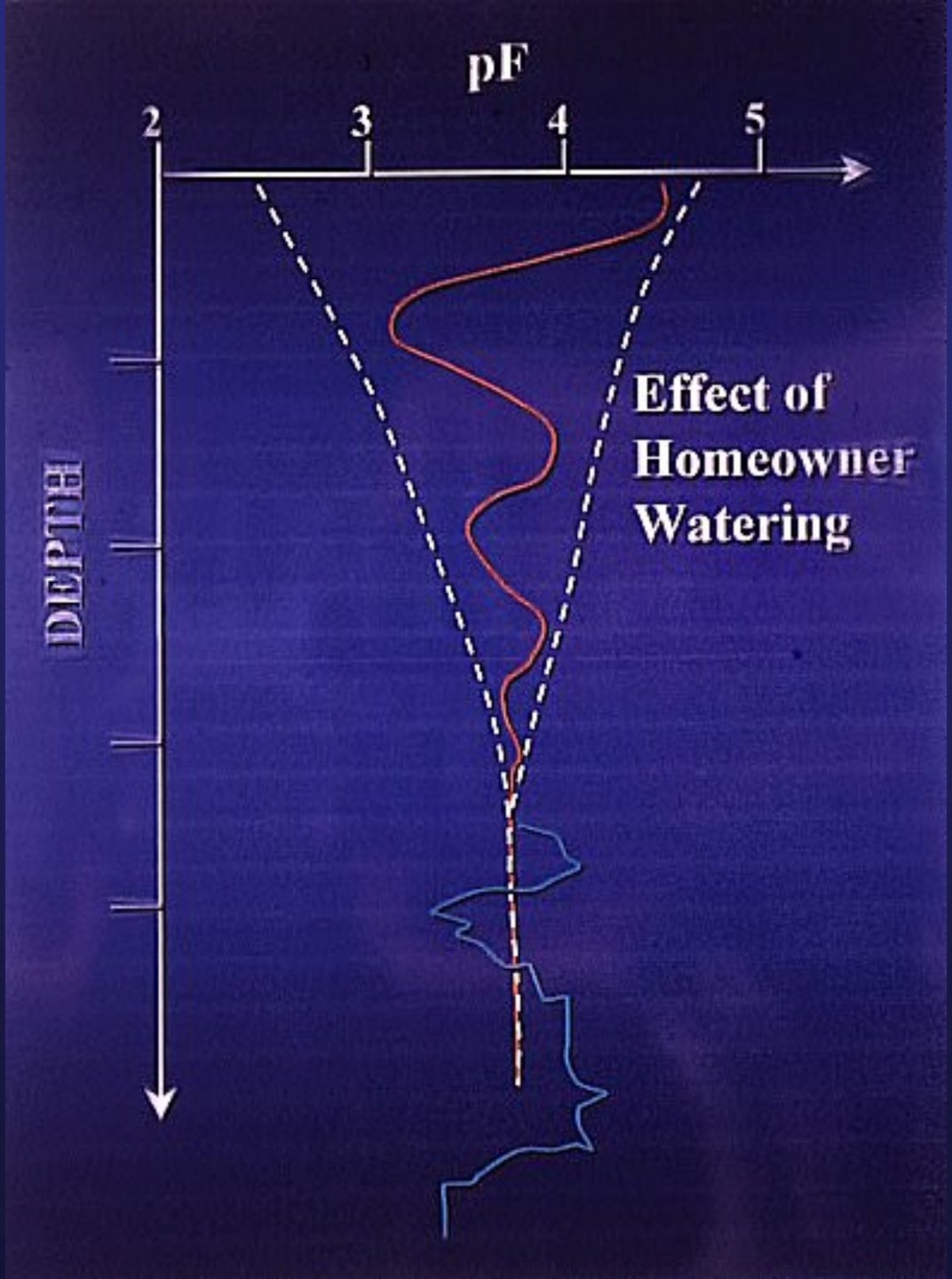


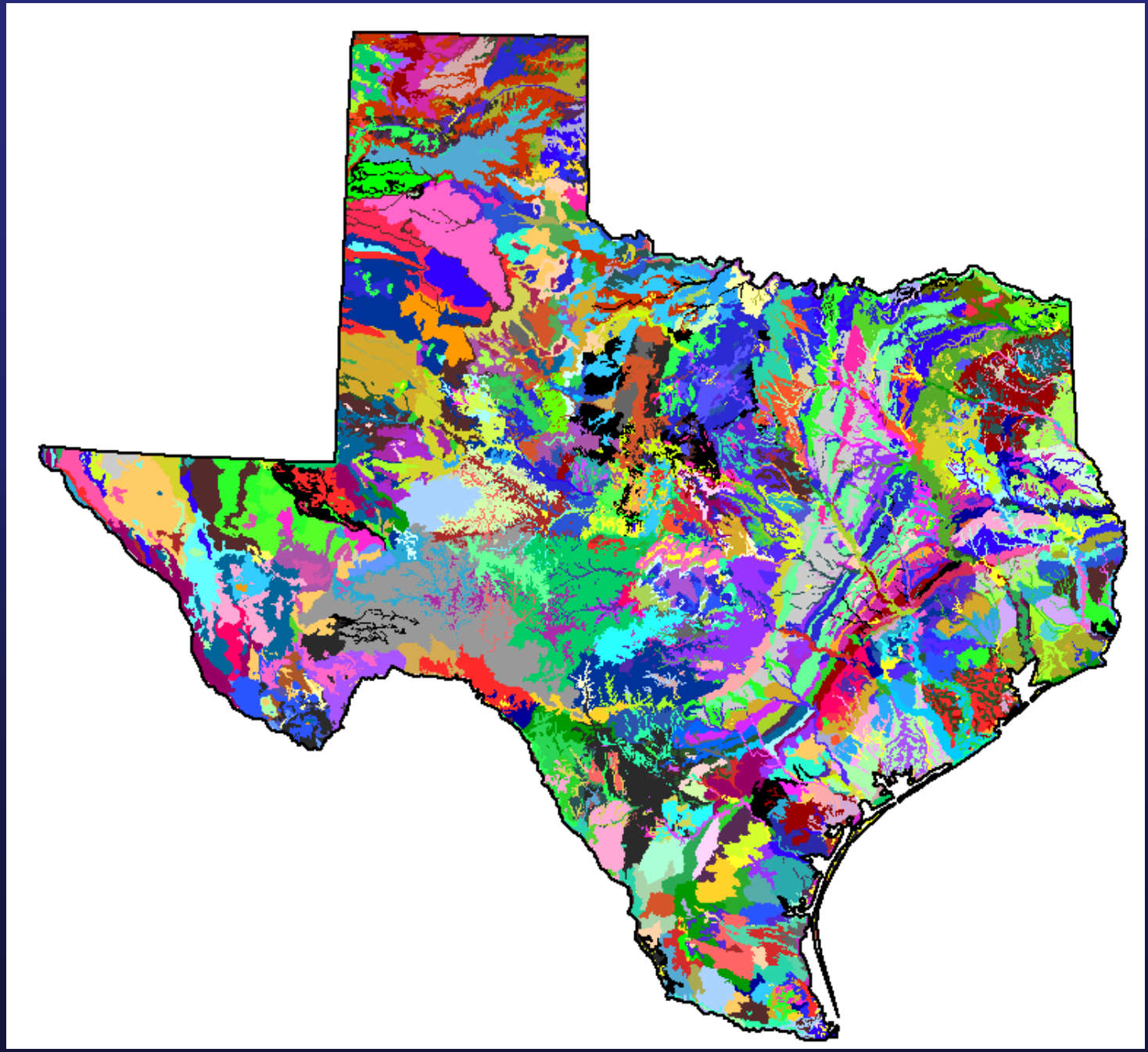
Moisture Active zone

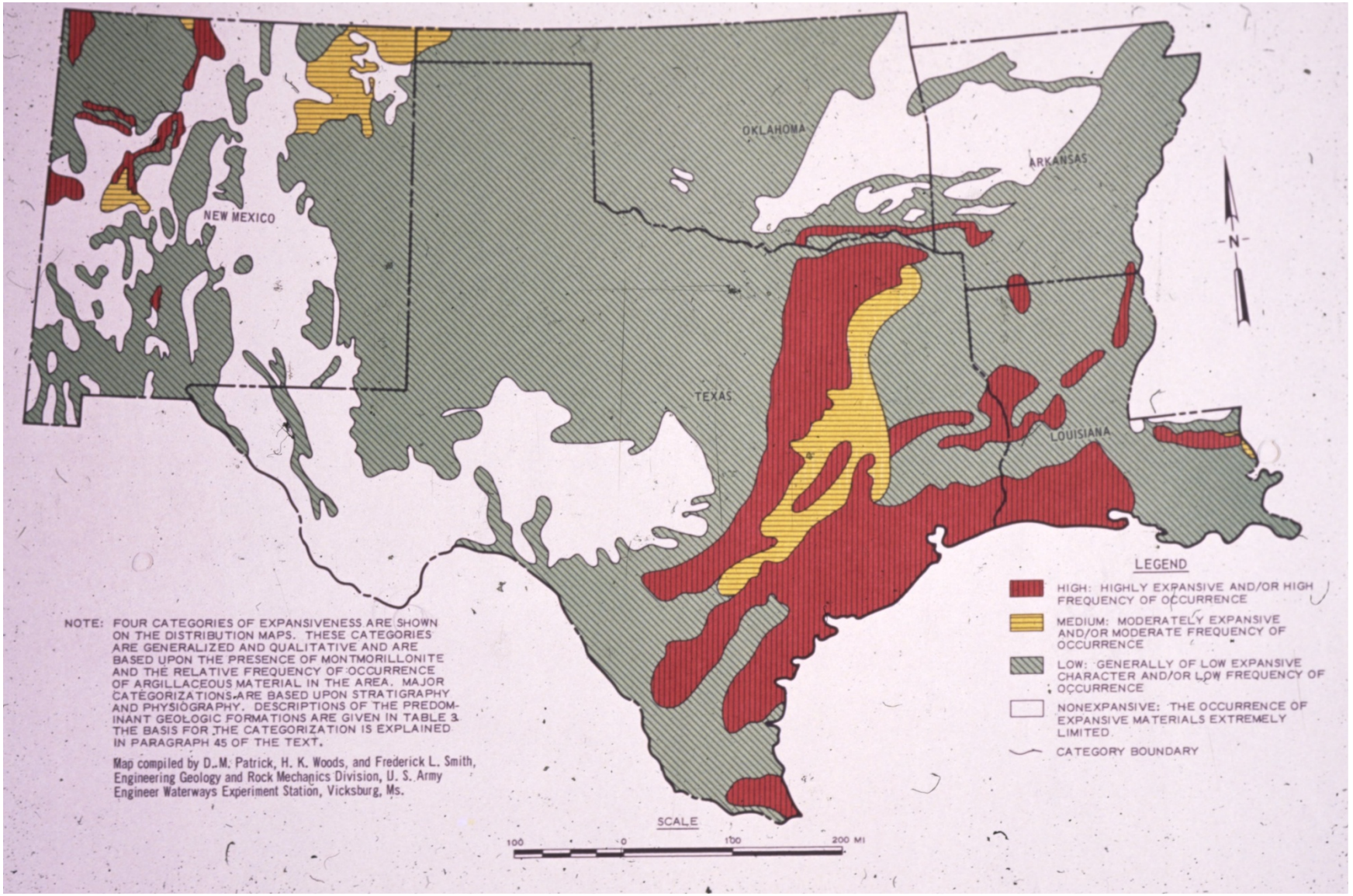
Site Conditions

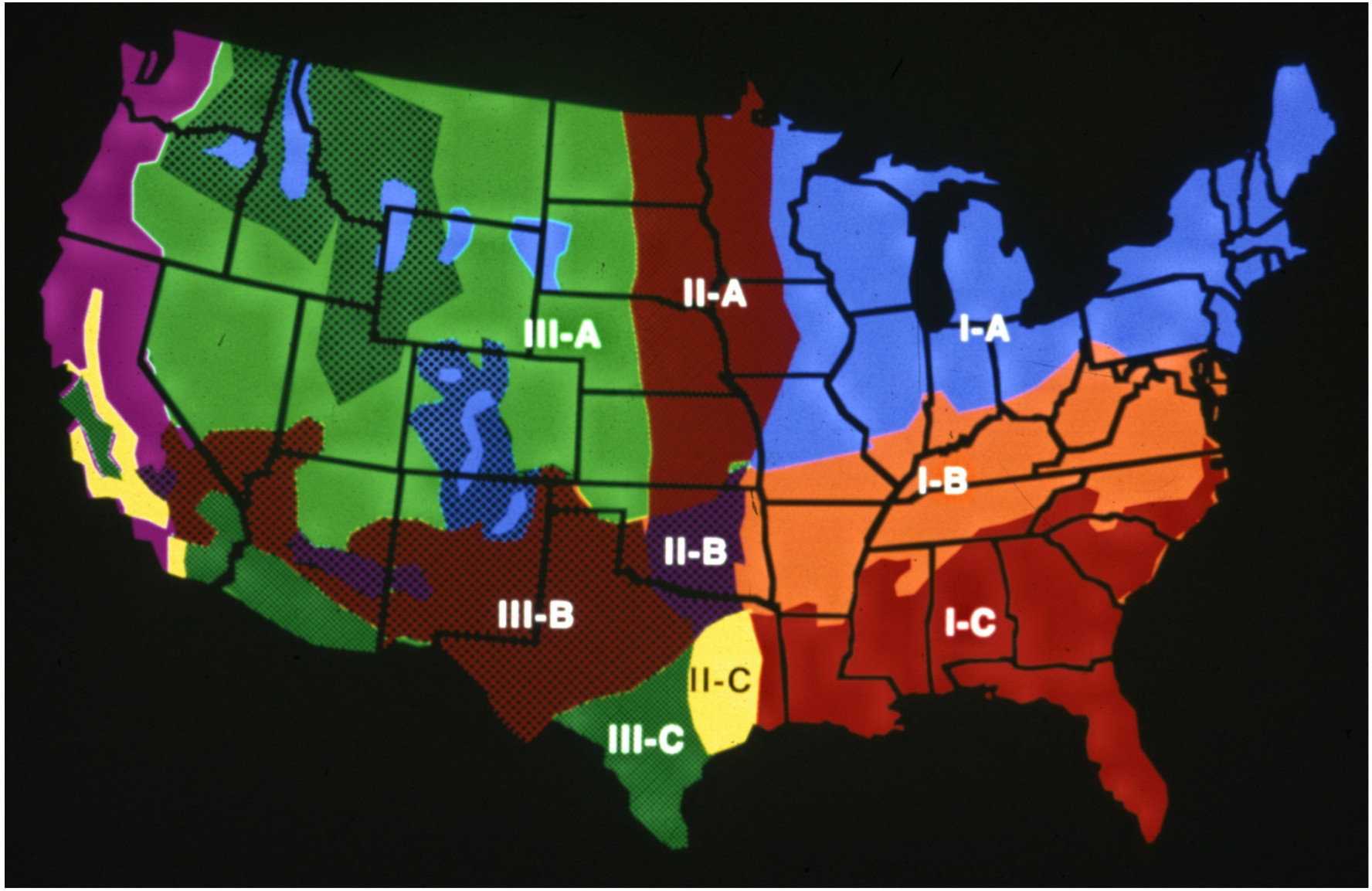
- Trees
- Slopes
  - Compaction
  - Natural soils
- Drainage
- Owner impact
- Climate

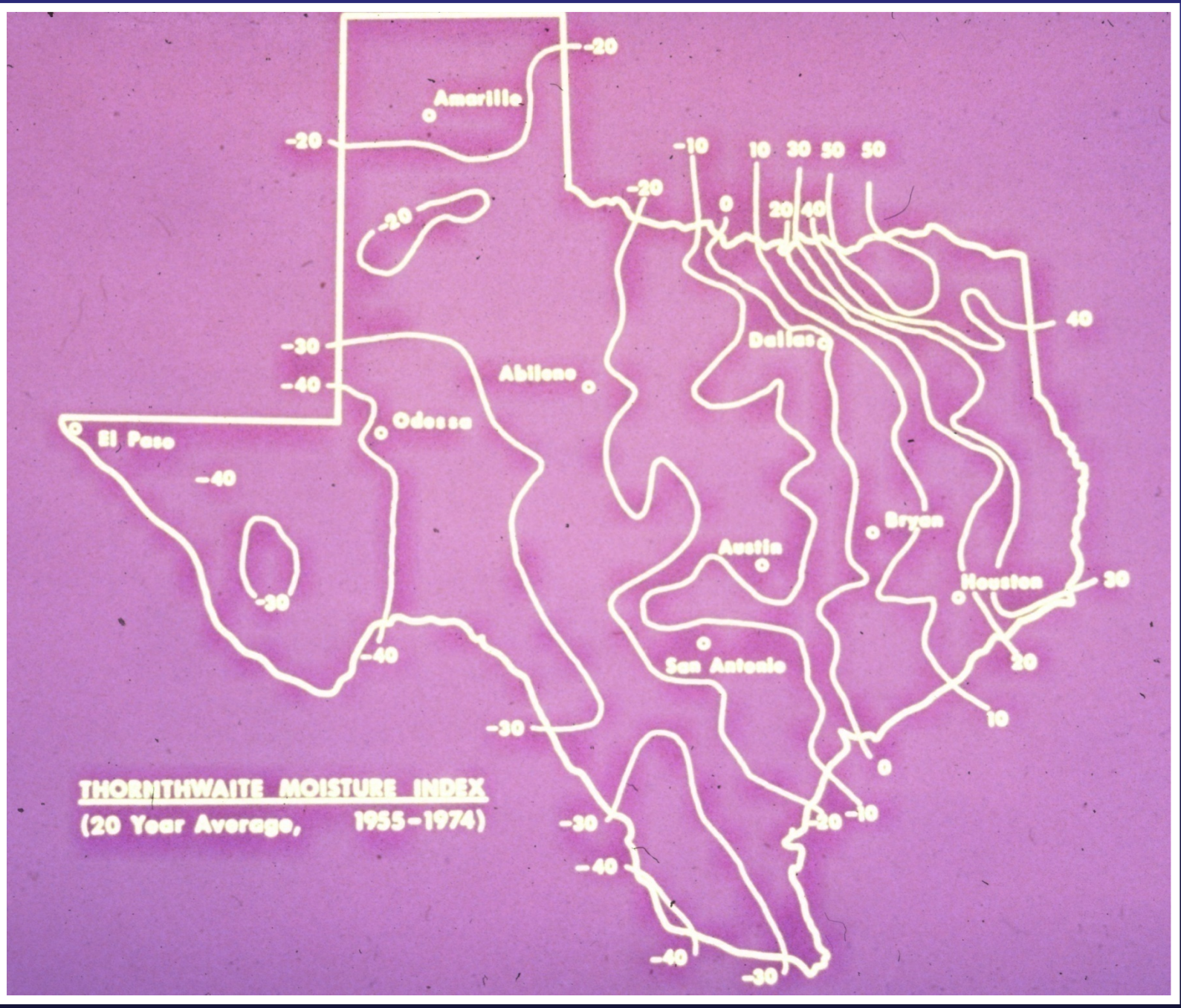

MOISTURE ACTIVE ZONE
MOISTURE INACTIVE ZONE


pF
2
3
4
5
DEPTH
Effect of
Homeowner
Watering




NEW MEXICO
OKLAHOMA
ARKANSAS
TEXAS
LOUISIANA
N
LEGEND
HIGH: HIGHLY EXPANSIVE AND/OR HIGH FREQUENCY OF OCCURRENCE
MEDIUM: MODERATELY EXPANSIVE AND/OR MODERATE FREQUENCY OF OCCURRENCE
LOW: GENERALLY OF LOW EXPANSIVE CHARACTER AND/OR LOW FREQUENCY OF OCCURRENCE
NONEXPANSIVE: THE OCCURRENCE OF EXPANSIVE MATERIALS EXTREMELY LIMITED
CATEGORY BOUNDARY
NOTE: FOUR CATEGORIES OF EXPANSIVENESS ARE SHOWN ON THE DISTRIBUTION MAPS. THESE CATEGORIES ARE GENERALIZED AND QUALITATIVE AND ARE BASED UPON THE PRESENCE OF MONTMORILLONITE AND THE RELATIVE FREQUENCY OF OCCURRENCE OF ARGILLACEOUS MATERIAL IN THE AREA. MAJOR CATEGORIZATIONS ARE BASED UPON STRATIGRAPHY AND PHYSIOGRAPHY. DESCRIPTIONS OF THE PREDOMINANT GEOLOGIC FORMATIONS ARE GIVEN IN TABLE 3. THE BASIS FOR THE CATEGORIZATION IS EXPLAINED IN PARAGRAPH 45 OF THE TEXT.
Map compiled by D. M. Patrick, H. K. Woods, and Frederick L. Smith, Engineering Geology and Rock Mechanics Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.
SCALE
100 0 100 200 MI


II-A
III-A
I-A
I-B
II-B
III-B
I-C
II-C
III-C

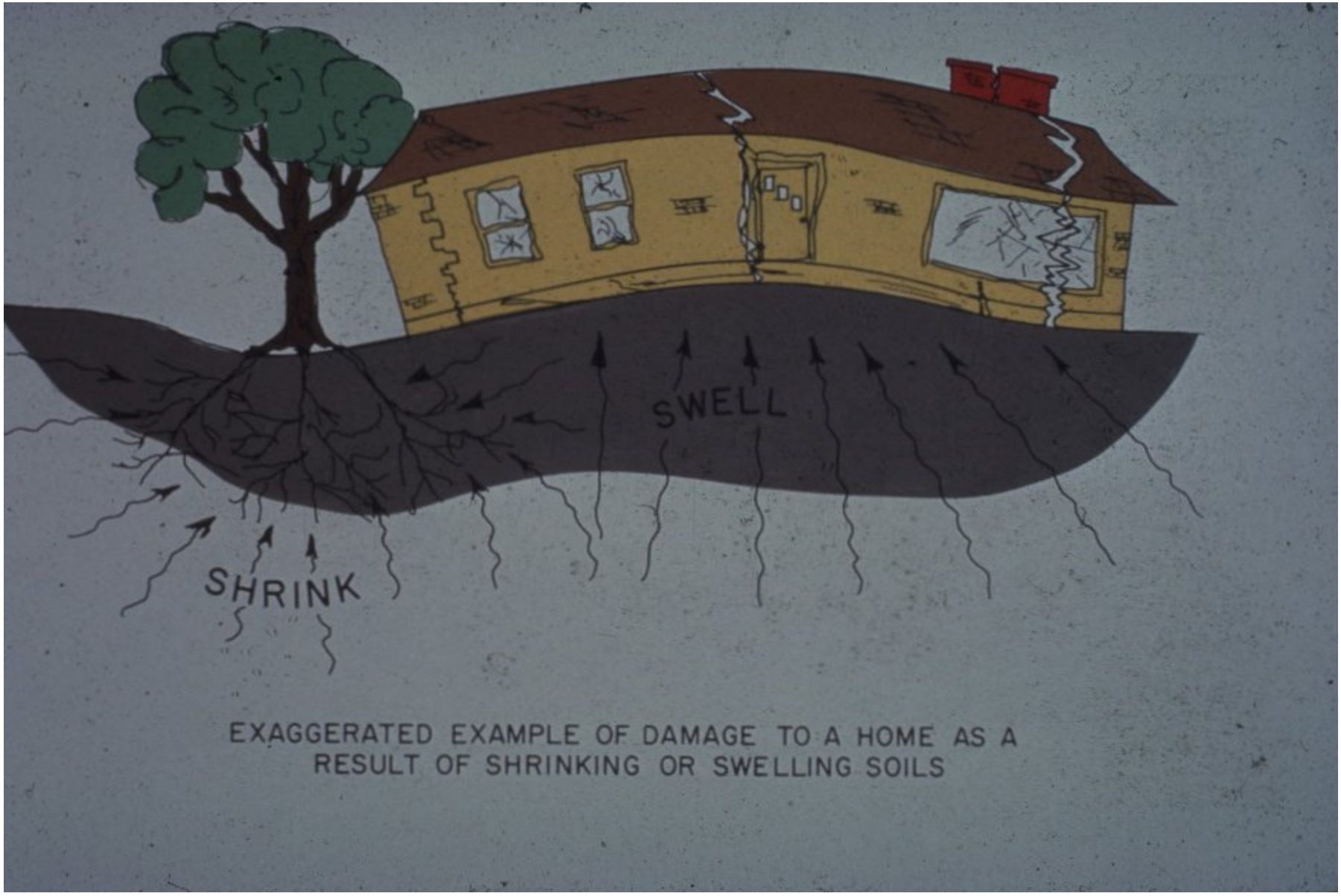

Amarillo
Abilene
Dallas
El Paso
Odessa
Austin
Bryan
Houston
San Antonio
-20
-10
10
20
30
50
40
-30
-40
0
THORNTHWAITE MOISTURE INDEX
(20 Year Average, 1955-1974)

Loads

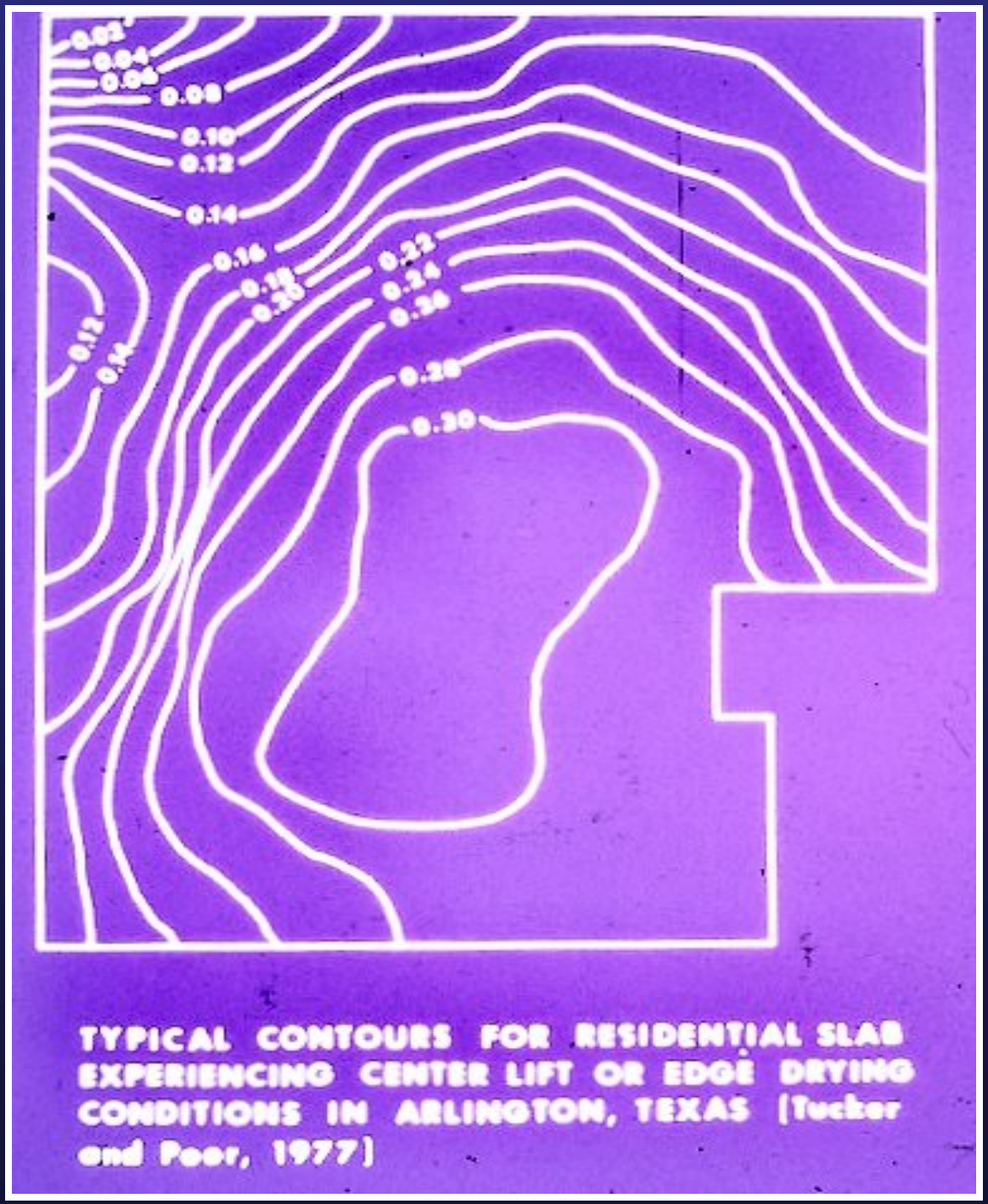
- Sustained
  - Point
  - Line
  - Distributed
- Live
  - Wind
  - Seismic

Foundation Structures

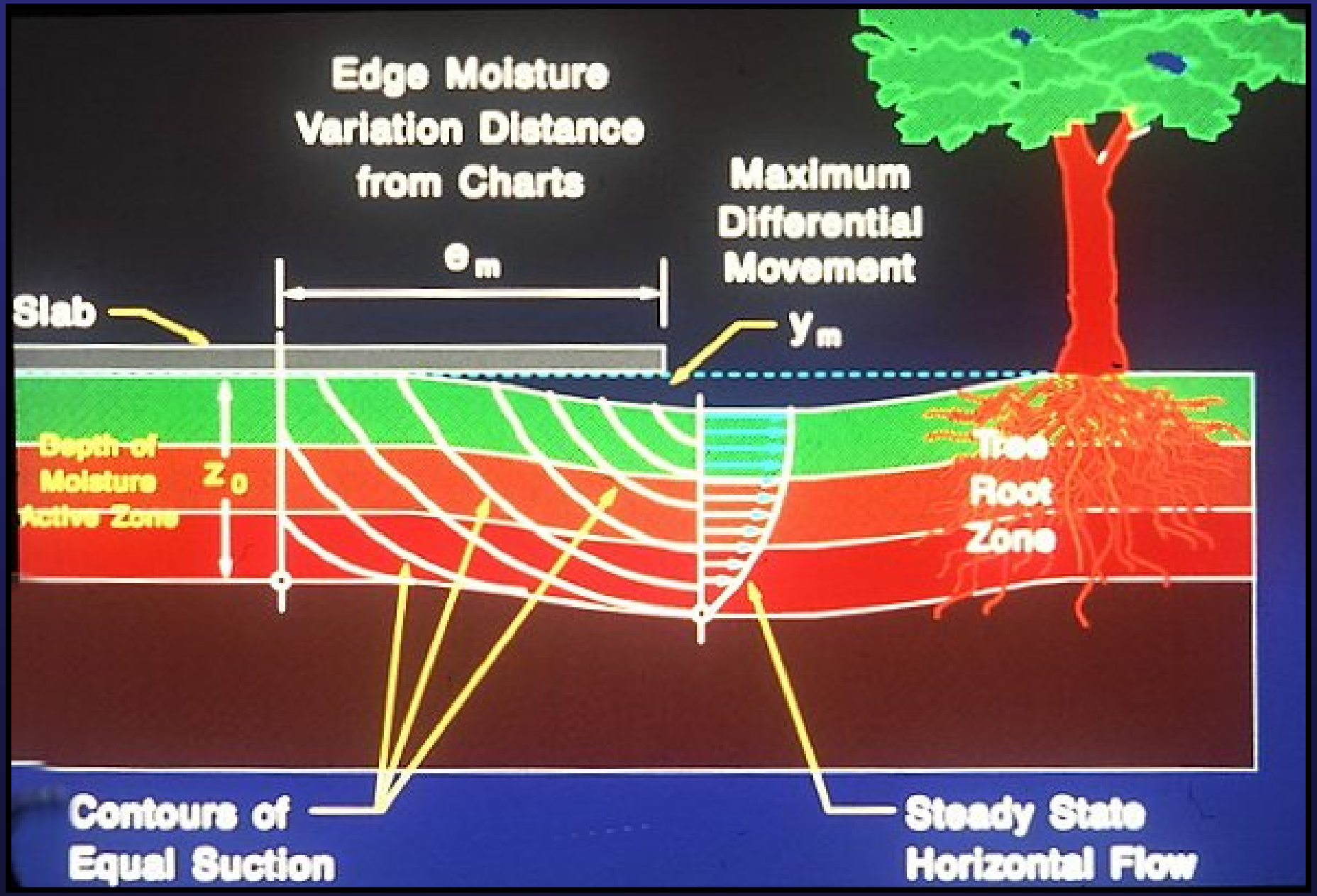
- Interaction with moving soil
- Point support
  - Drilled pier
  - Spread footings
- Beams, strip footings
- Plate (uniform thickness)
- Stiffened plate

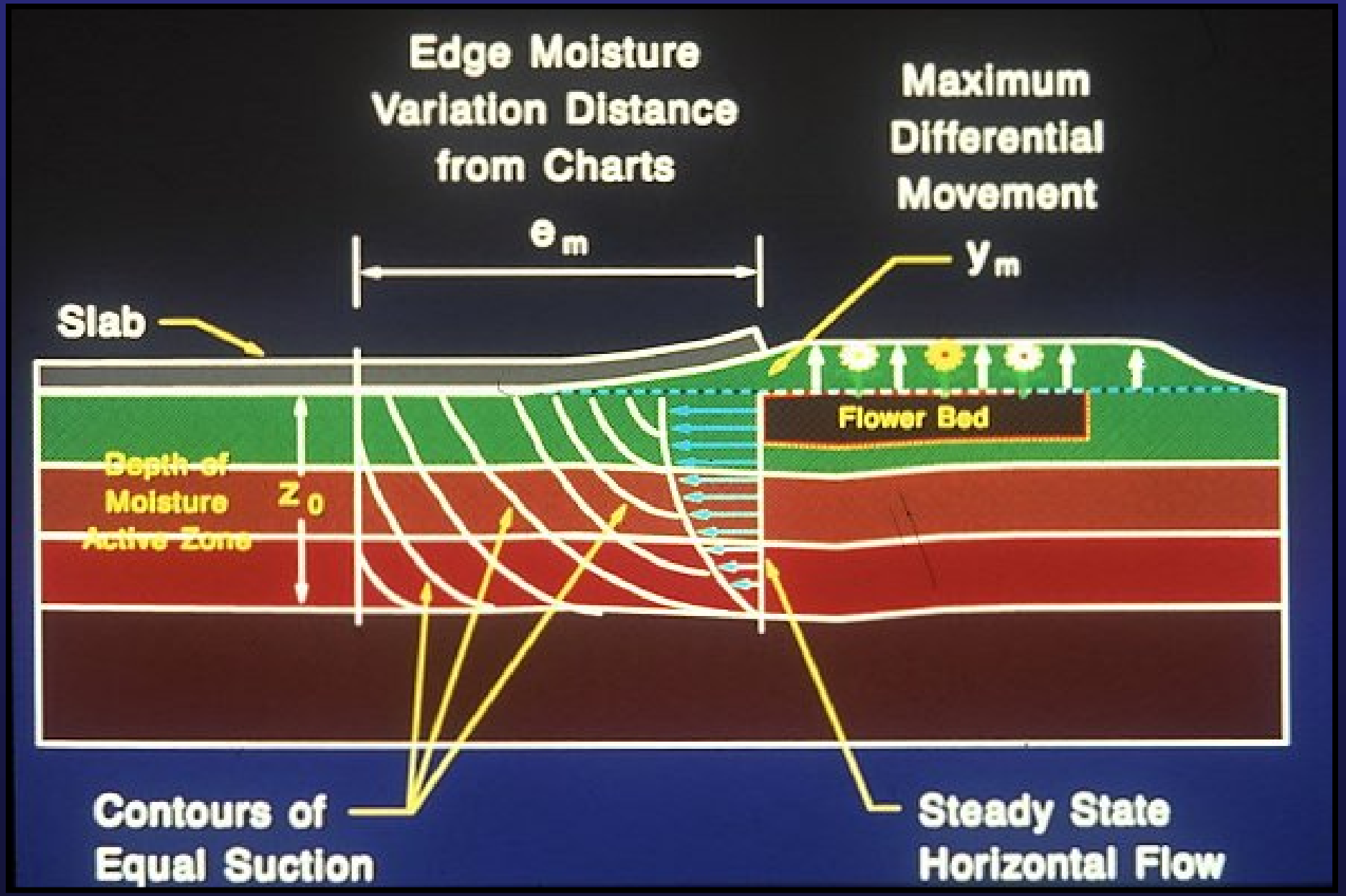


EXAGGERATED EXAMPLE OF DAMAGE TO A HOME AS A RESULT OF SHRINKING OR SWELLING SOILS



TYPICAL CONTOURS FOR RESIDENTIAL SLAB EXPERIENCING CENTER LIFT OR EDGE DRYING CONDITIONS IN ARLINGTON, TEXAS (Tucker and Poor, 1977)


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


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

Design Conditions (1/2)

- Costs
  - Design and inspection
  - Construction (labor costs)
  - Sales
  - Repairs, buy back
  - Litigation

Design Conditions (2/2)

- Timing
  - Site investigation
  - Design and inspection
  - Construction
- Risk and reliability
  - General rule:

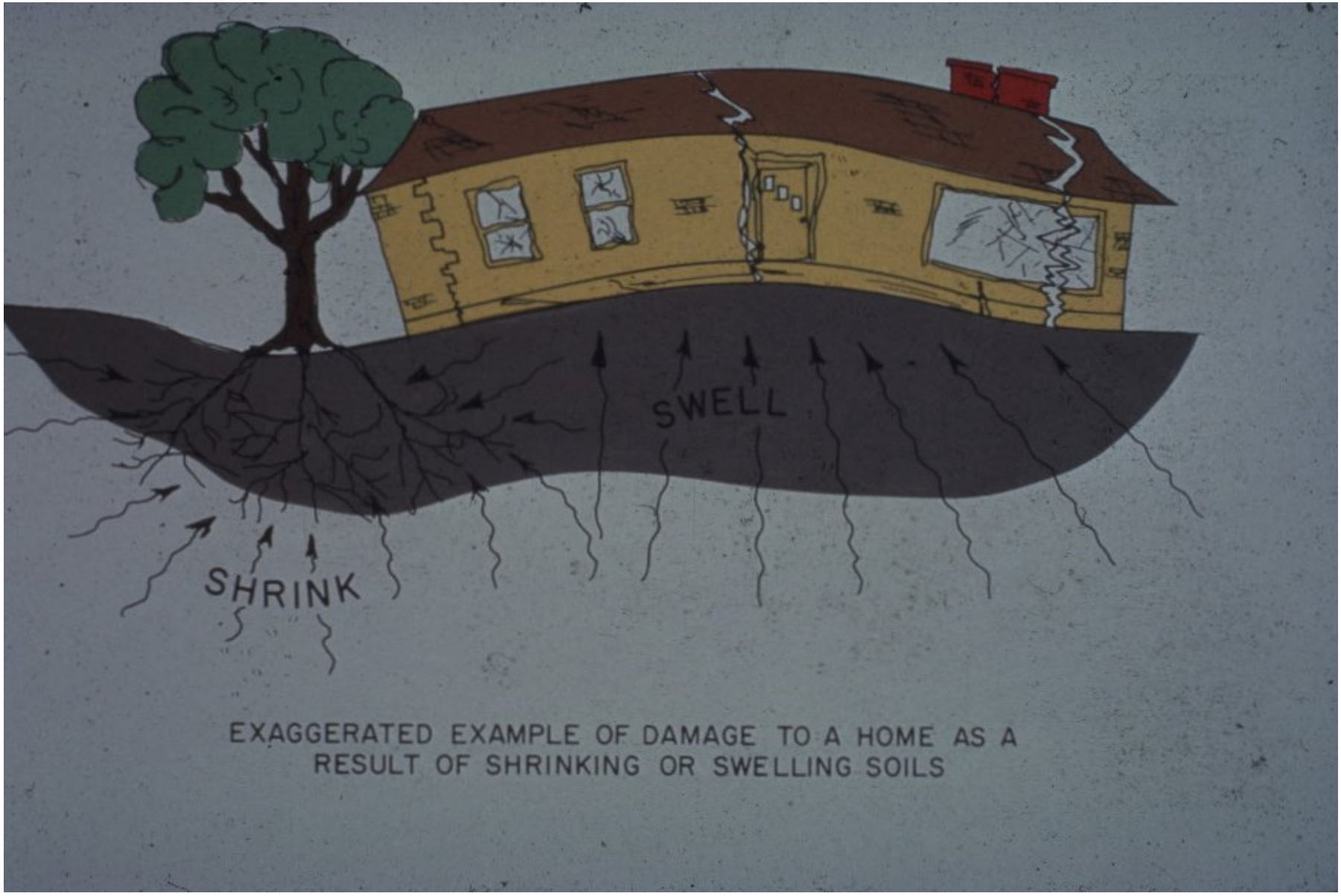
    Lighter ➡ larger risk

Design Approaches

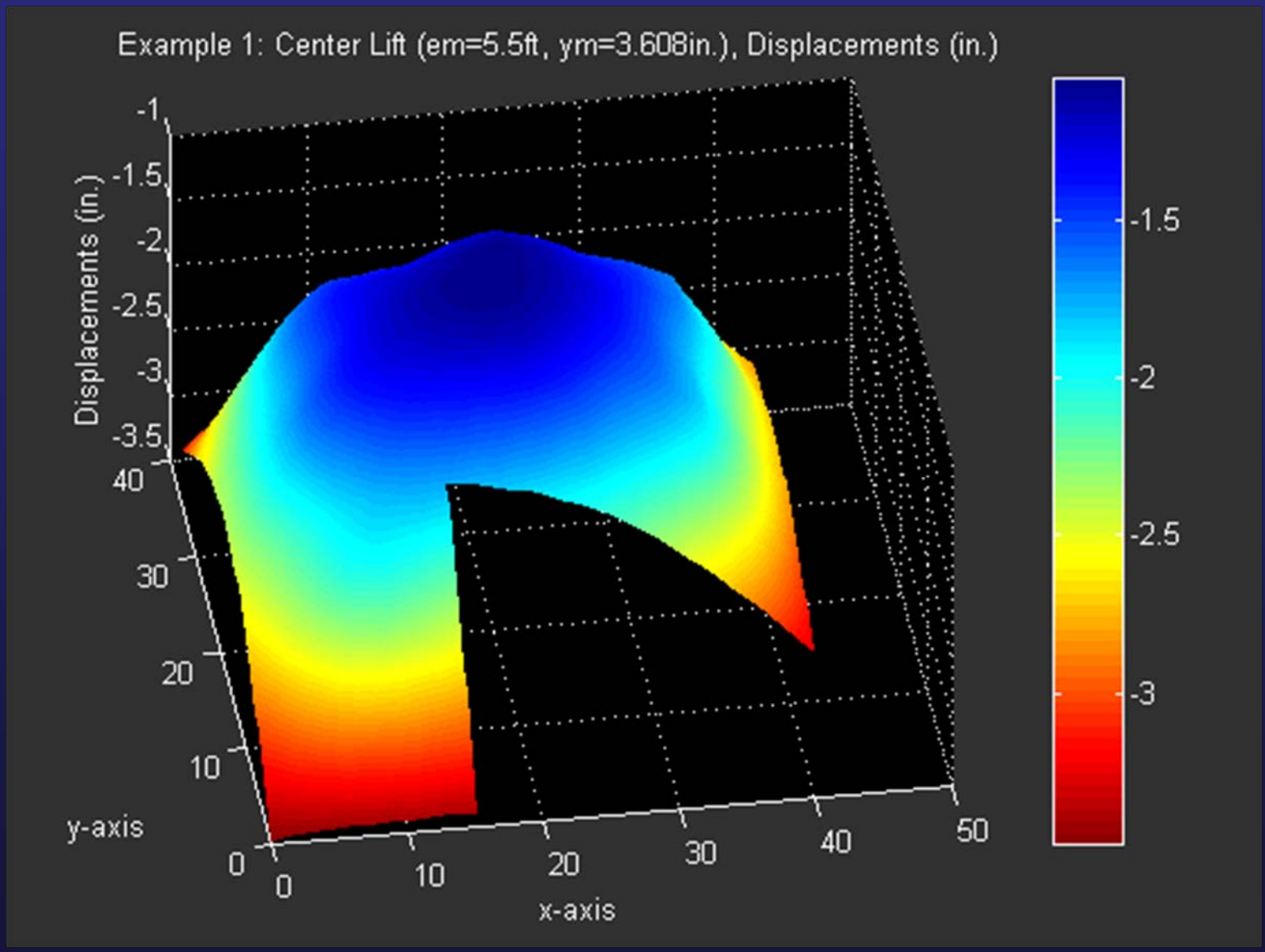
- Local experience
- Empirical
- Mechanics
  - Soil
    - Moisture energy profiles
    - Volume change
  - Structure
    - Beam
    - Plate
- Mechanistic-empirical

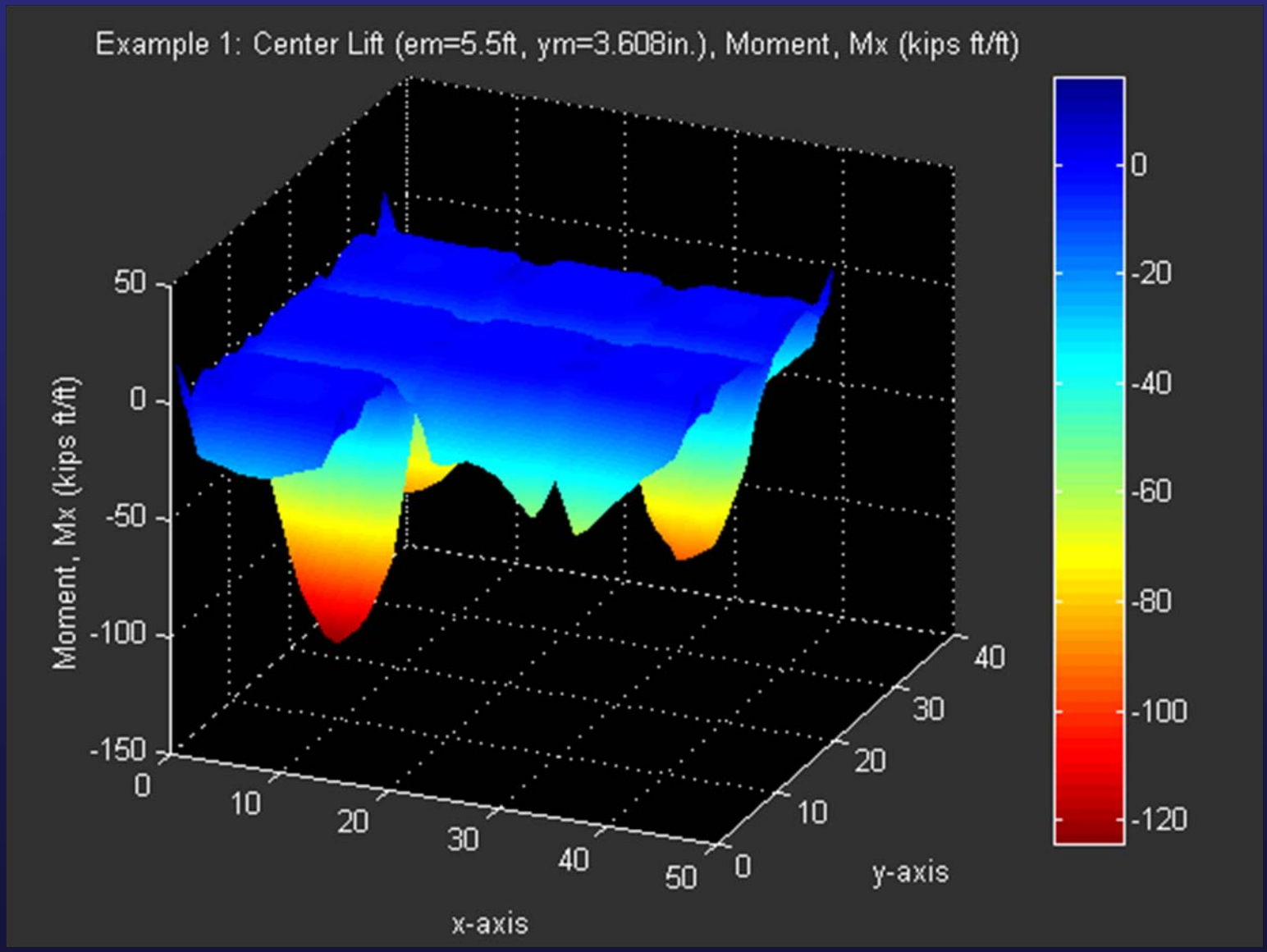
Design Criteria I: Stresses / Strength

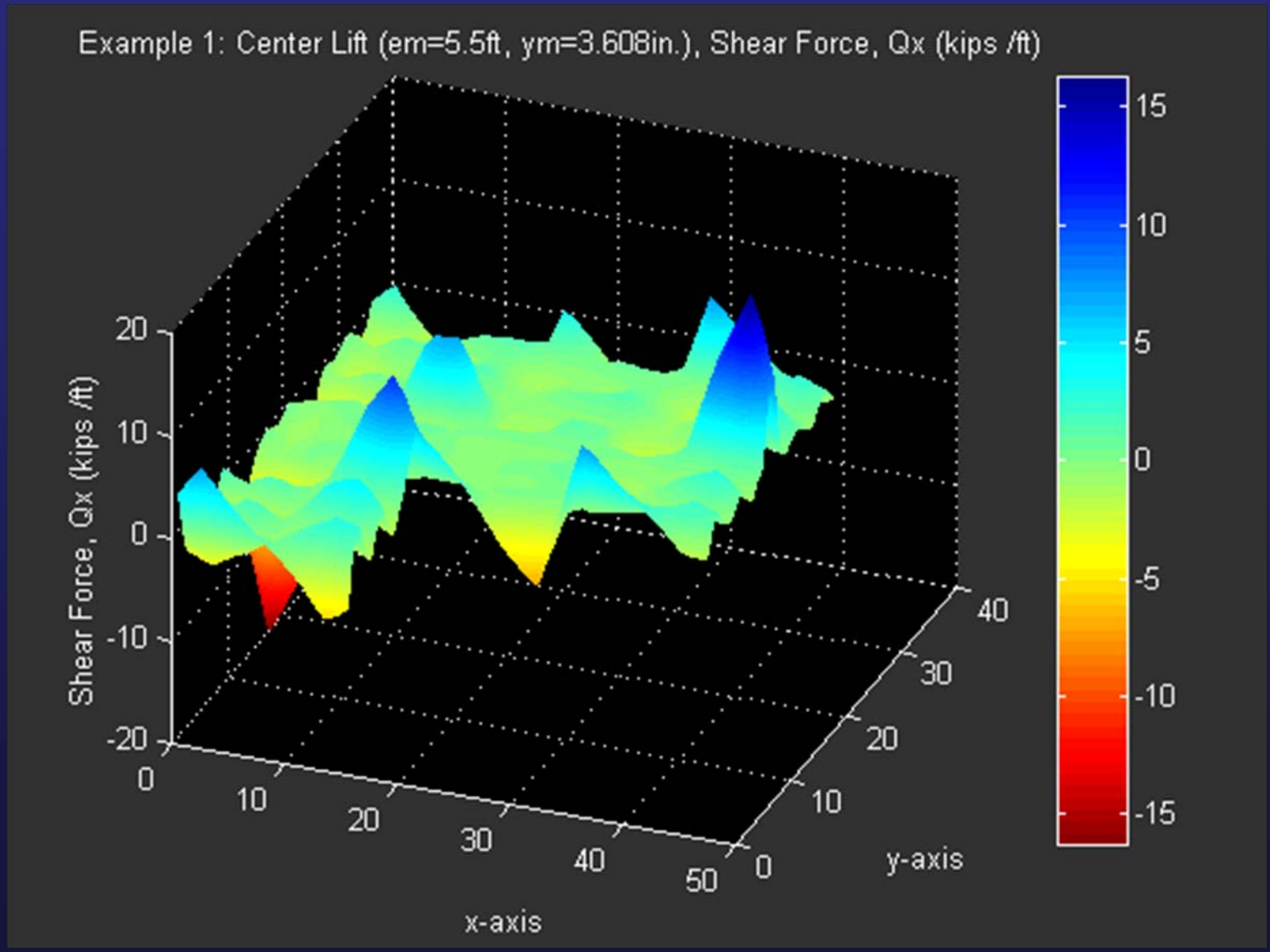
- Tension
- Compression
- Shear
- Torsion (twisting moments)

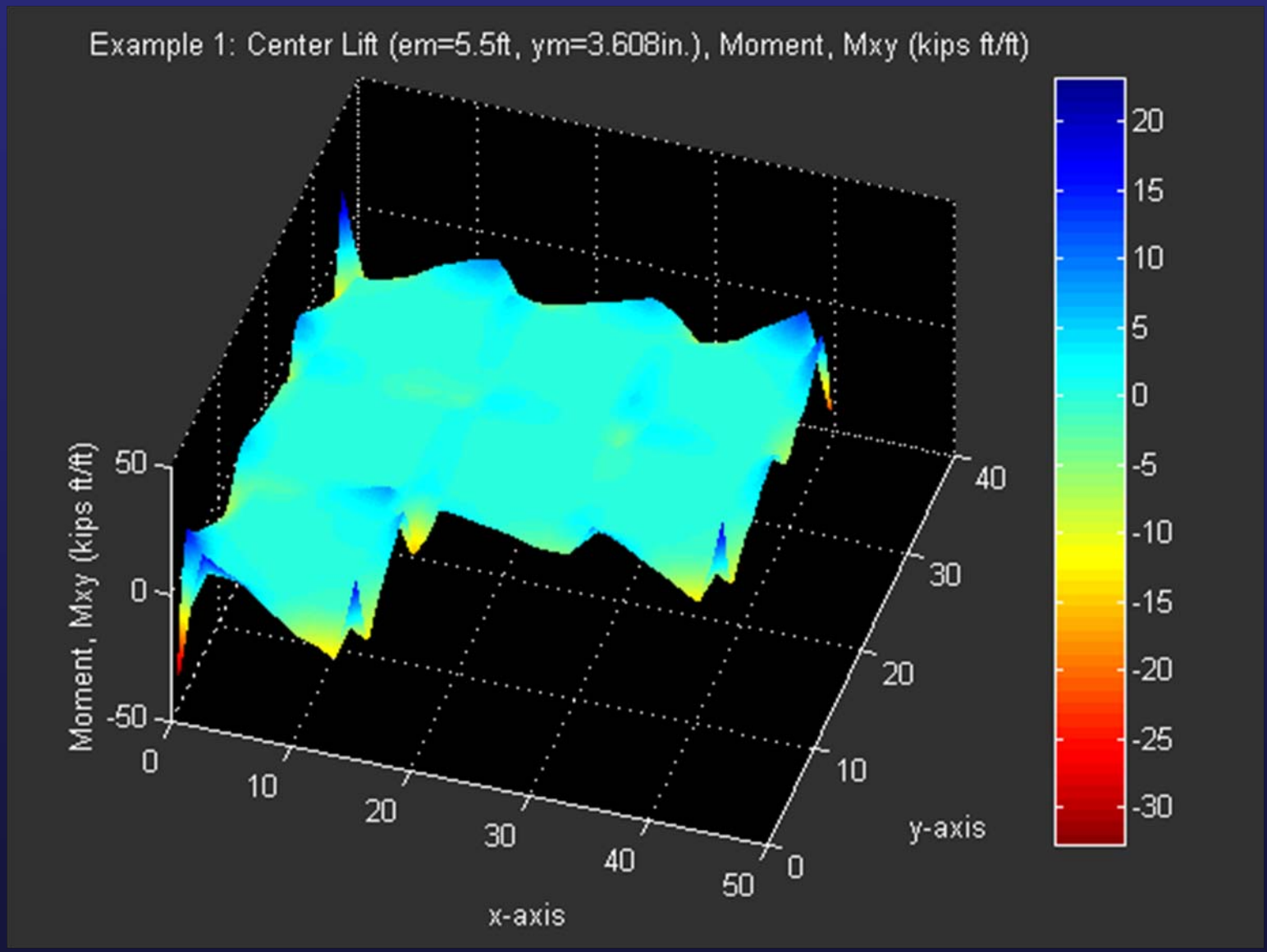


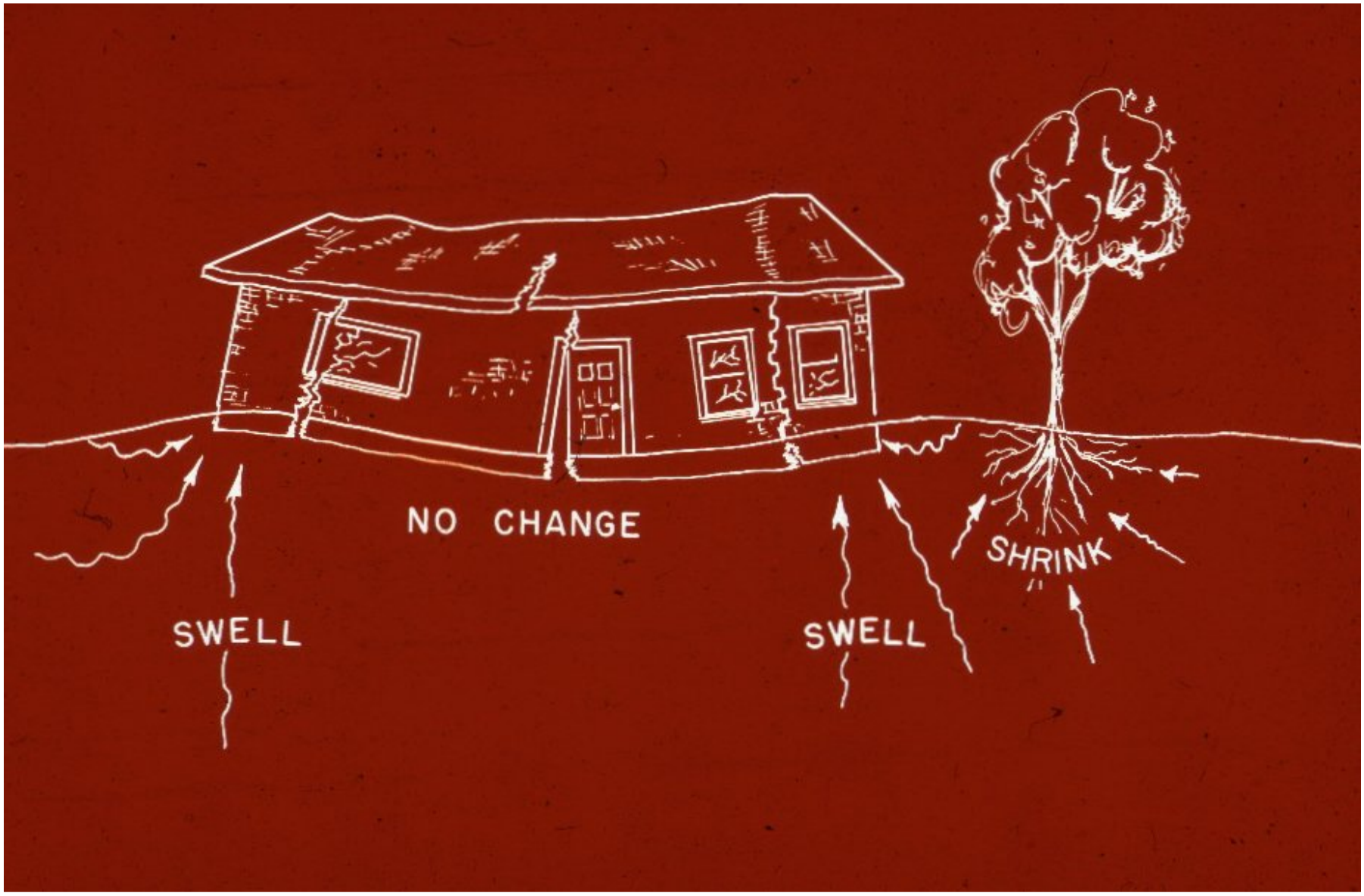
EXAGGERATED EXAMPLE OF DAMAGE TO A HOME AS A RESULT OF SHRINKING OR SWELLING SOILS

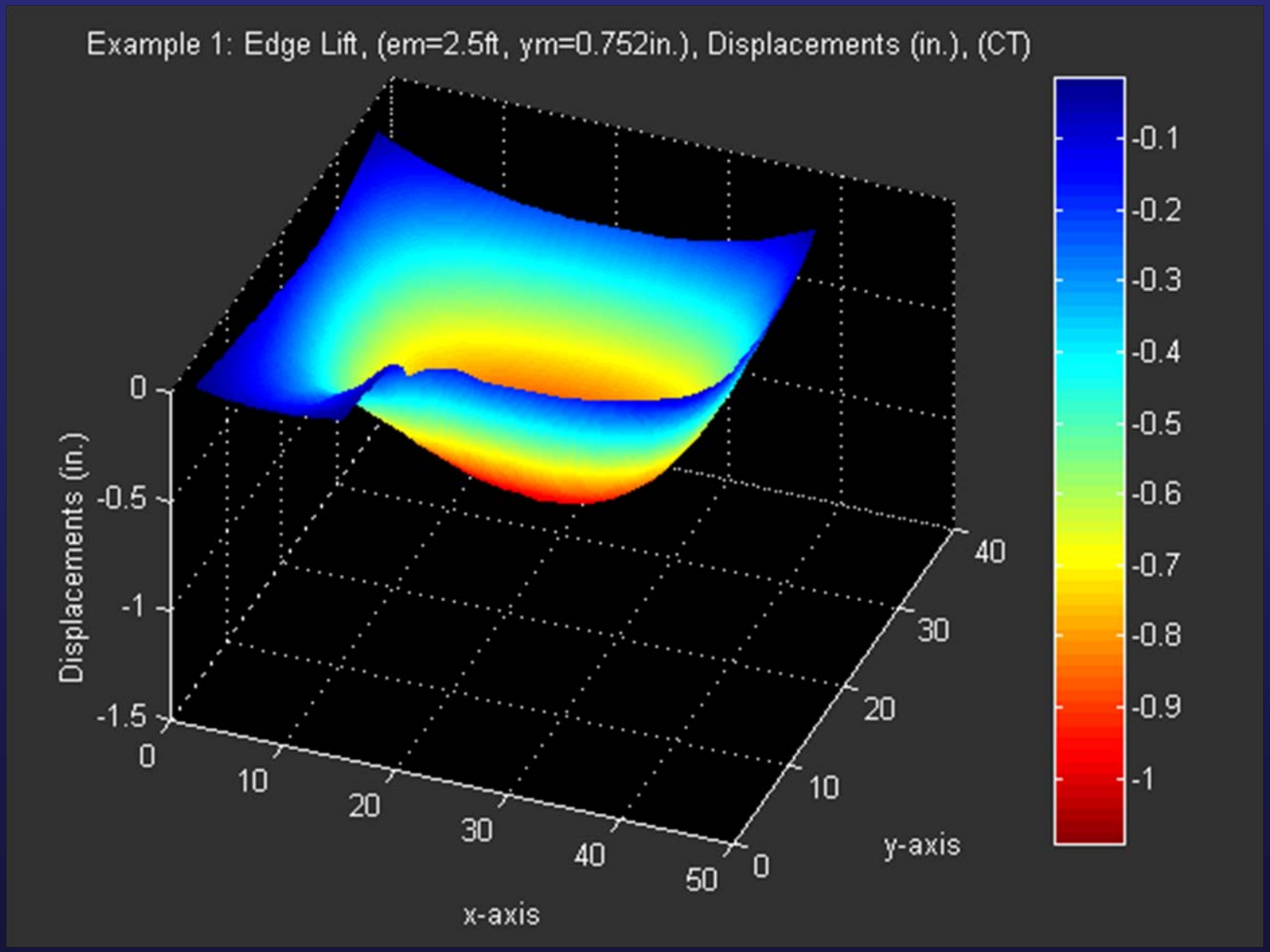

Example 1: Center Lift (em=5.5ft, ym=3.608in.), Displacements (in.)
Displacements (in.)
-1
-1.5
-2
-2.5
-3
-3.5
y-axis
40
30
20
10
0
0
10
20
30
40
50
x-axis
-1.5
-2
-2.5
-3

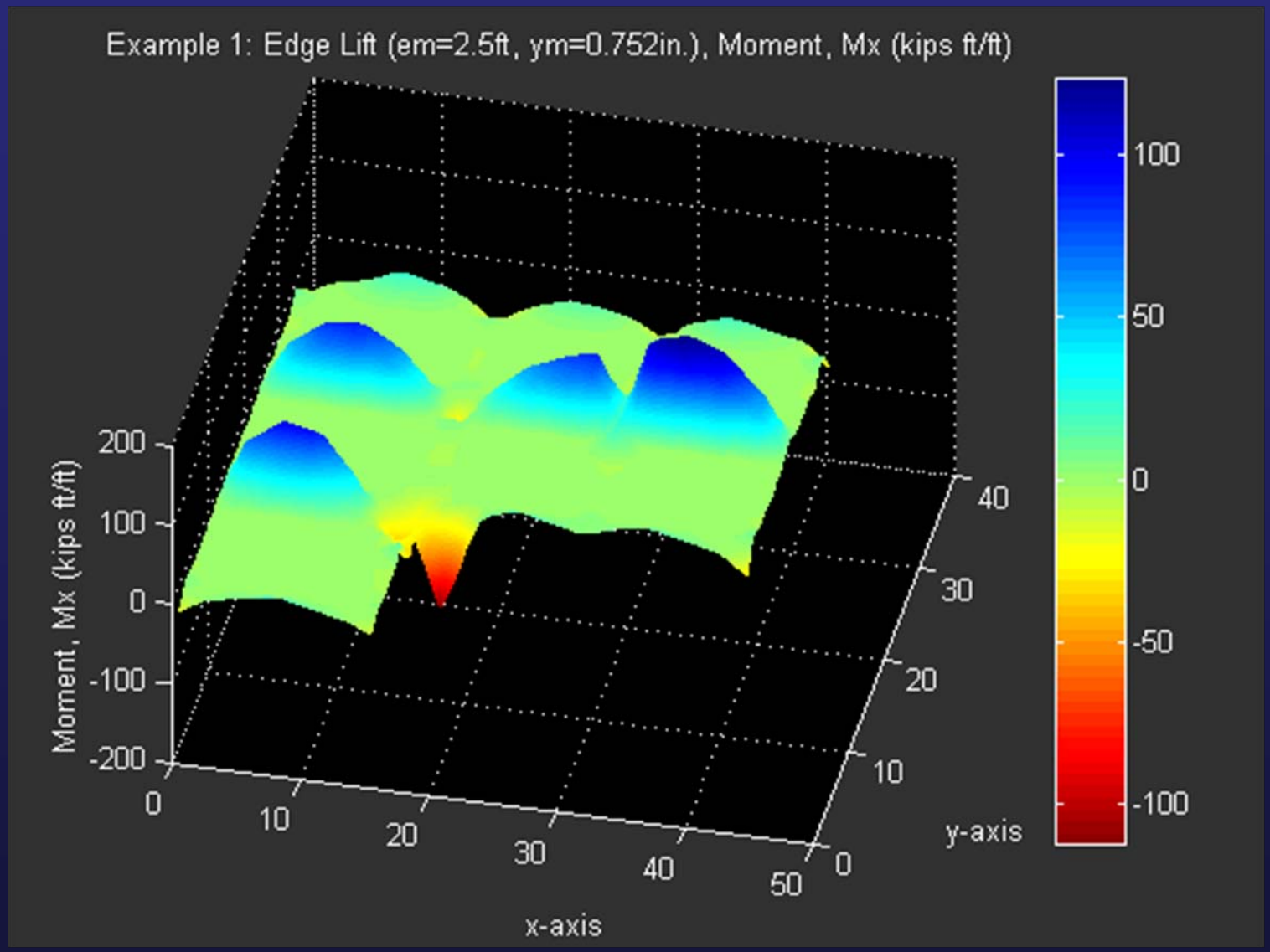

Example 1: Center Lift (em=5.5ft, ym=3.608in.), Moment, Mx (kips ft/ft)
Moment, Mx (kips ft/ft)
50
0
-50
-100
-150
0
10
20
30
40
50
x-axis
0
10
20
30
40
y-axis
0
-20
-40
-60
-80
-100
-120

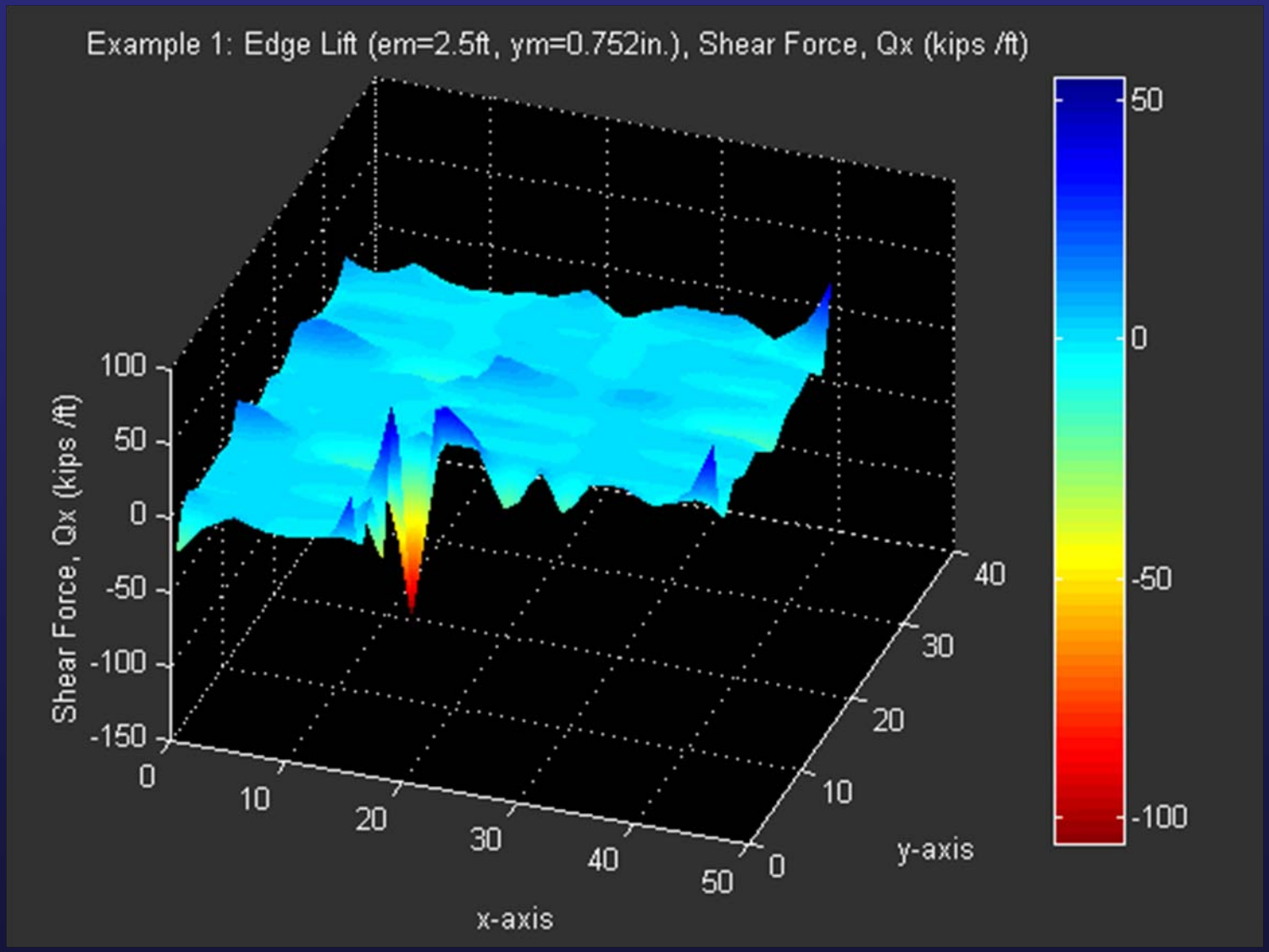

Example 1: Center Lift (em=5.5ft, ym=3.608in.), Shear Force, Qx (kips /ft)
Shear Force, Qx (kips /ft)
20
10
0
-10
-20
0
10
20
30
40
50
x-axis
0
10
20
30
40
y-axis
15
10
5
0
-5
-10
-15

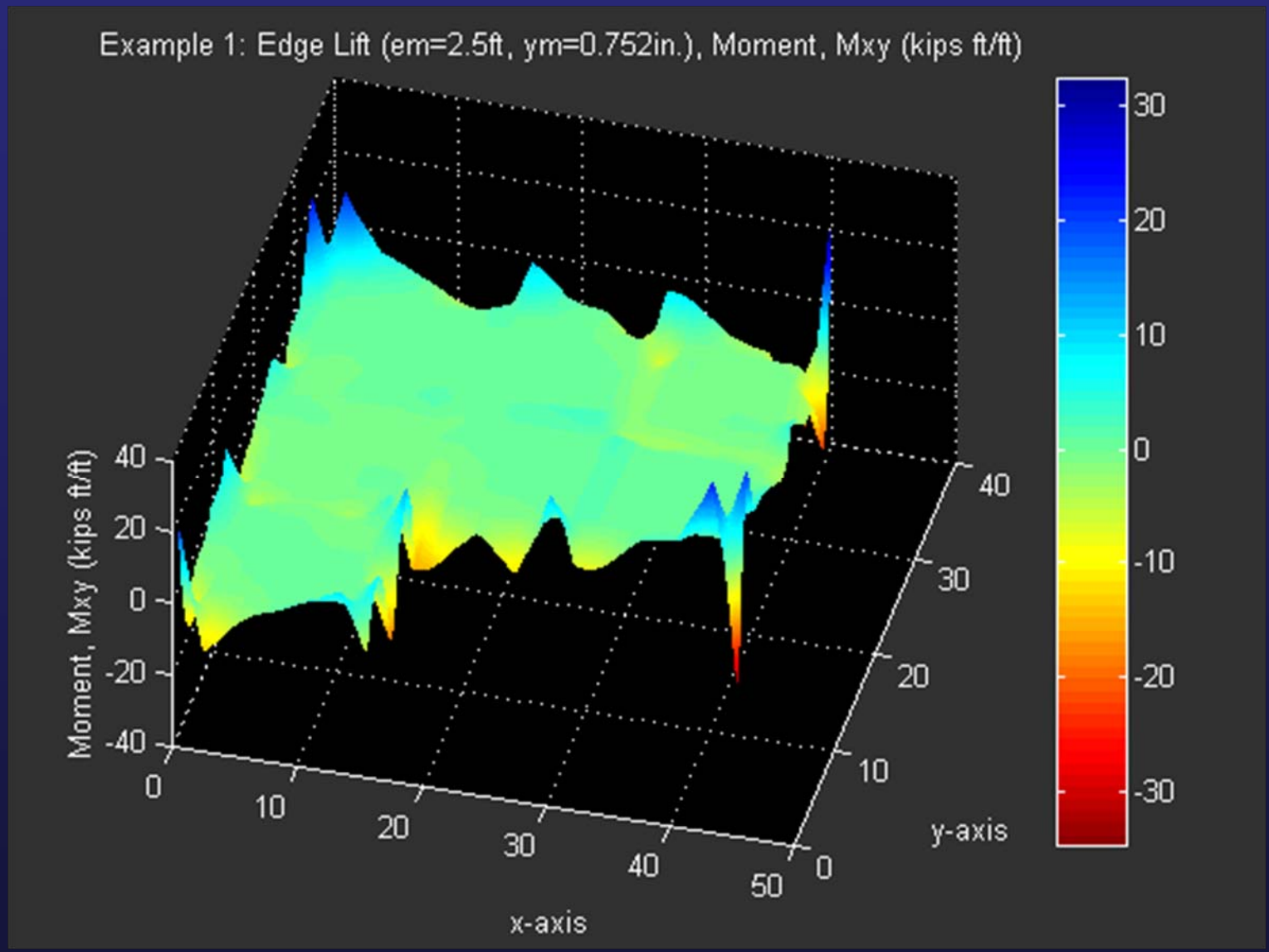

Example 1: Center Lift (em=5.5ft, ym=3.608in.), Moment, Mxy (kips ft/ft)
Moment, Mxy (kips ft/ft)
50
0
-50
0
10
20
30
40
50
x-axis
0
10
20
30
40
y-axis
20
15
10
5
0
-5
-10
-15
-20
-25
-30


NO CHANGE
SHRINK
SWELL
SWELL


Example 1: Edge Lift, (em=2.5ft, ym=0.752in.), Displacements (in.), (CT)
Displacements (in.)
0
-0.5
-1
-1.5
0
10
20
30
40
50
x-axis
0
10
20
30
40
y-axis
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1


Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Moment, Mx (kips ft/ft)
Moment, Mx (kips ft/ft)
200
100
0
-100
-200
0
10
20
30
40
50
x-axis
0
10
20
30
40
y-axis
100
50
0
-50
-100


Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Shear Force, Qx (kips /ft)
Shear Force, Qx (kips /ft)
100
50
0
-50
-100
-150
0
10
20
30
40
50
x-axis
0
10
20
30
40
y-axis
50
0
-50
-100


Example 1: Edge Lift (em=2.5ft, ym=0.752in.), Moment, Mxy (kips ft/ft)
Moment, Mxy (kips ft/ft)
40
20
0
-20
-40
0
10
20
30
40
50
x-axis
0
10
20
30
40
y-axis
30
20
10
0
-10
-20
-30

Design Criteria II: Deflections / Tolerance

- Sensitivity of foundation and super structure (Δ/L)
- Differential ($\Delta_c + \Delta_s$)
  - As built (Δ_c)
  - Soil movement (Δ_s)
- Total
- Twisting

Design Criteria III: Stiffness

- Substitute for deflection tolerance
- Enough concrete section to handle soil movement

Design Objectives

- Stay in business
- Least life cycle cost
  - Designer
  - Builder
  - Owner
- Make profit (?)

Design Constraints

- Meet all design criteria
- Acceptable level of risk
- Within acceptable time limits
- Acceptable costs per design

Post-Tensioned Design Procedure (1/3)

- Soils
  - Moisture change (realistic range)
    - Surface
    - Depth
  - Volume change
  - Lab testing
  - Moisture active zones
    - Vertical
    - Horizontal

Post-Tensioned Design Procedure (2/3)

- Site conditions
  - Trees
  - Drainage
  - Climate
  - Owner impact
  - Slopes
- Loads

Post-Tensioned Design Procedure (3/3)

- Structure
  - Slab-on-ground
    - Soil movement classes
      - None
      - Low
      - Medium and high
  - Plate-on-uneven surface
- Shape
  - Rectangular
  - Non-rectangular
- Shear

Foundation Design Principles for Post-Tensioned Foundations in Houston

Robert L. Lytton
John T. Bryant
Dean R. Read

Houston Foundation Performance Association
December 10, 2008