CIVIL ENGINEERING APPLICATIONS OF TIRE DERIVED AGGREGATE

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Presented to:

Resource Recovery Fund Board
Halifax, Nova Scotia

February 20, 2009

Tire Derived Aggregate – *TDA*

Why use TDA?

- TDA has properties that civil engineers need
  - Lightweight (1/3 soil)
  - Low earth pressure (1/2 soil)
  - Good thermal insulation (8 times better)
  - Good drainage (10 times better)
  - Compressible

Why use TDA?

- TDA is often the <u>cheapest</u> alternative if you need its unique properties

Why use TDA?

- Can use lots of tires!!!
  - 100 tires per M^3 of TDA fill
  - 1.6 million tires for landslide stabilization, St. Stephens, NB
  - 1.2 million tires for highway embankment, Portland, Maine
  - 1 million tires for leachate collection system in Delaware

Specifications

- Type A – drainage, insulation & vibration damping
  - – 100% passing 4-in. sieve
  - – Minimum of 90% passing 3-in. sieve
  - – Maximum of 5% passing 4.75-mm (no. 4) sieve

- Type B – lightweight fill
  - – 100% smaller than 18-in. max. dimension
  - – 90% smaller than 12-in. max. dimension
  - – Maximum of 50% passing 3-in. sieve
  - – Maximum of 25% passing 1.5-in. sieve
  - – Maximum of 1% passing 4.75-mm (no. 4) sieve

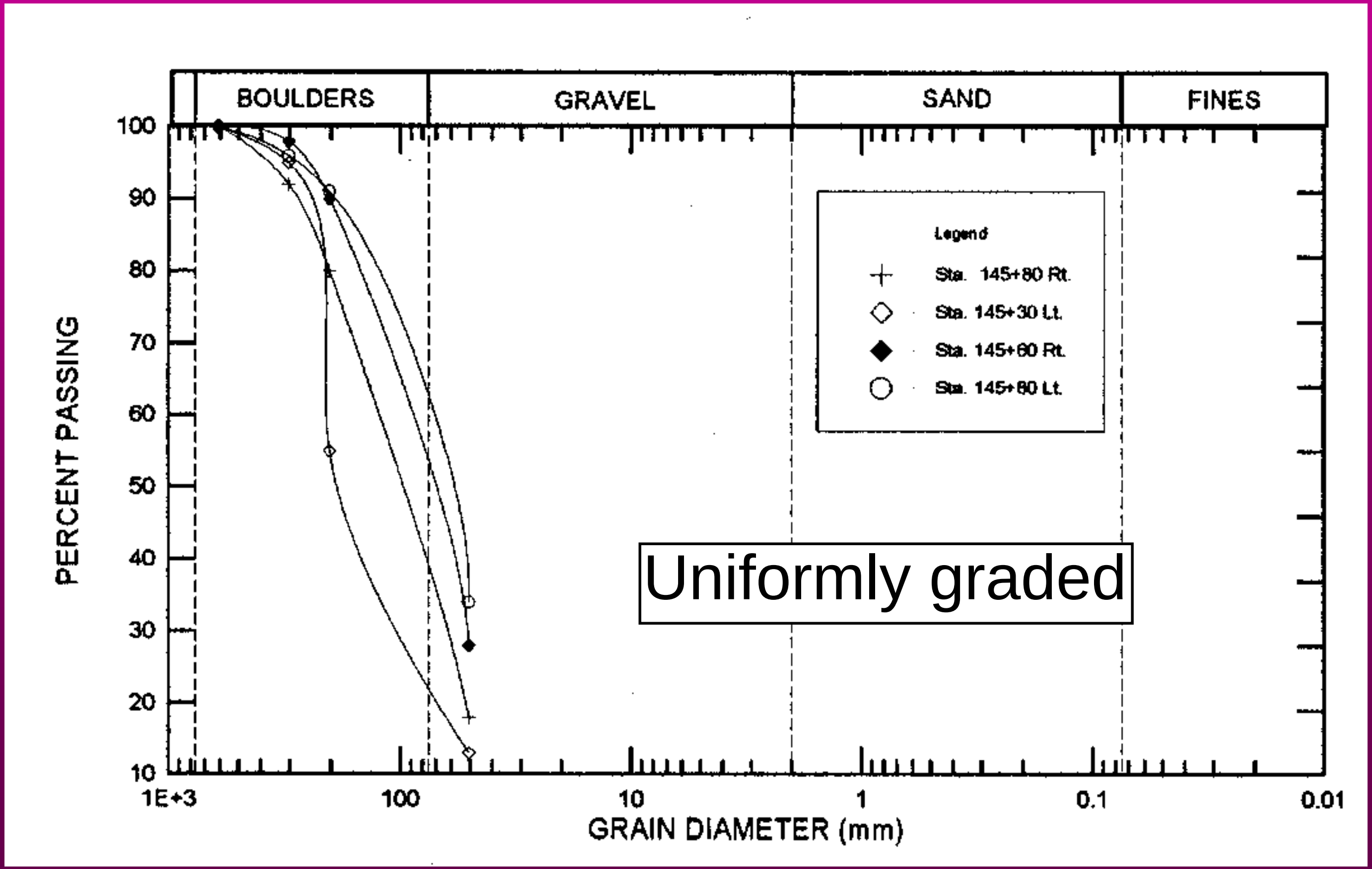
Guidelines

- ASTM D6270 “Civil Engineering Applications of Scrap Tires”
  - Revised standard approved in 2008
- Guidelines to limit heating
- Water quality

Engineering properties of TDA

- Gradation
- Unit weight
- Compressibility
- Time dependent settlement
- Shear strength
- Specific gravity Adsorption
- Resilient modulus
- Lateral earth pressure
- Permeability
- Thermal conductivity

Typical gradation 300-mm minus



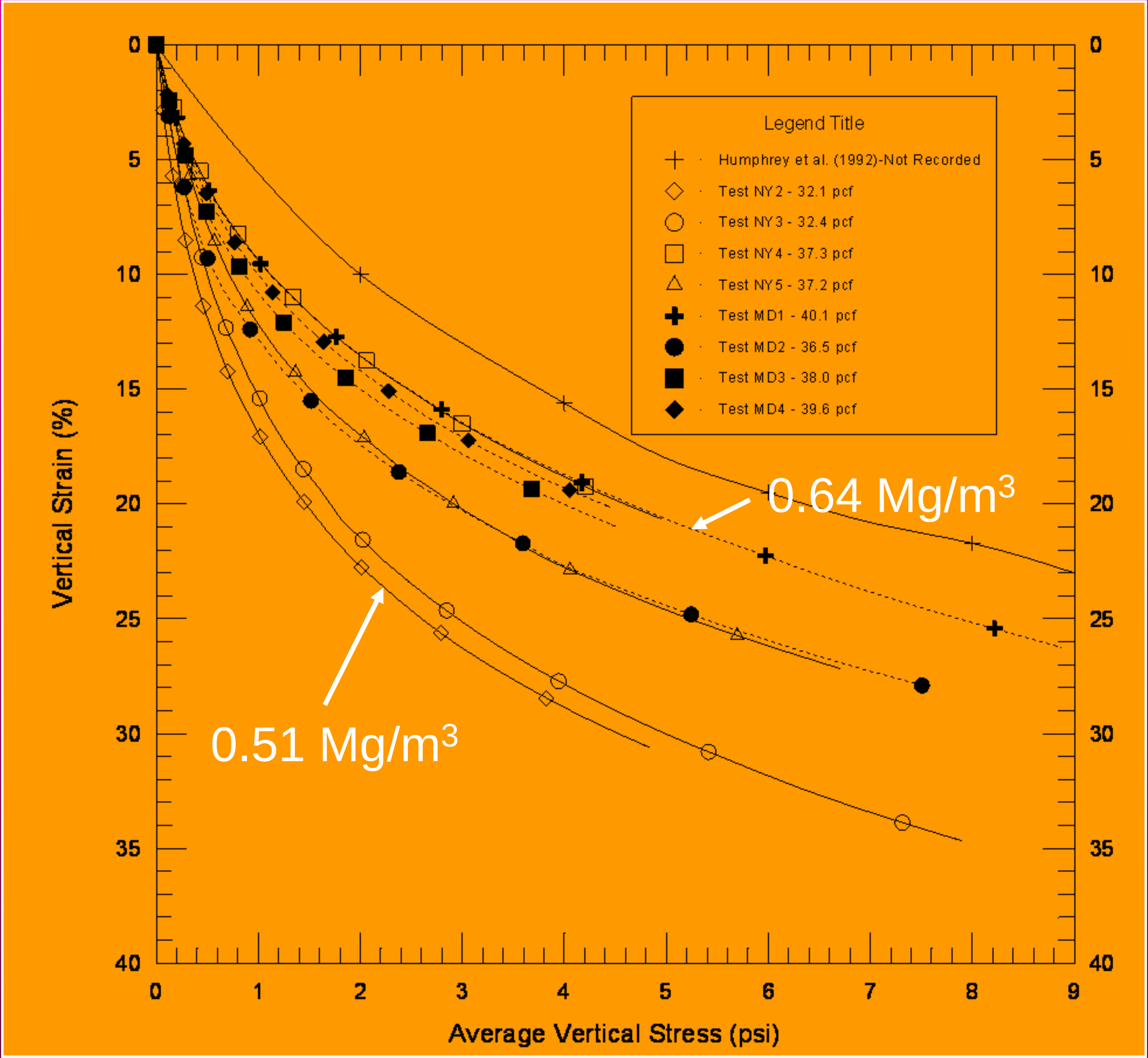
Compacted Unit Weight

- Little compactive energy needed to reach maximum density
- Water content has no effect
- Typical values
  - Loose – 0.3 to 0.5 Mg/m^3
  - Compacted – 0.6 to 0.7 Mg/m^3
  - Soil – 2 Mg/m^3
- UNIT WEIGHT INCREASES AS TDA COMPRESSED!!!

Compressibility

- Need to know compressibility:
  - Estimate overbuild
  - Estimate in-place unit weight
- Typical test results

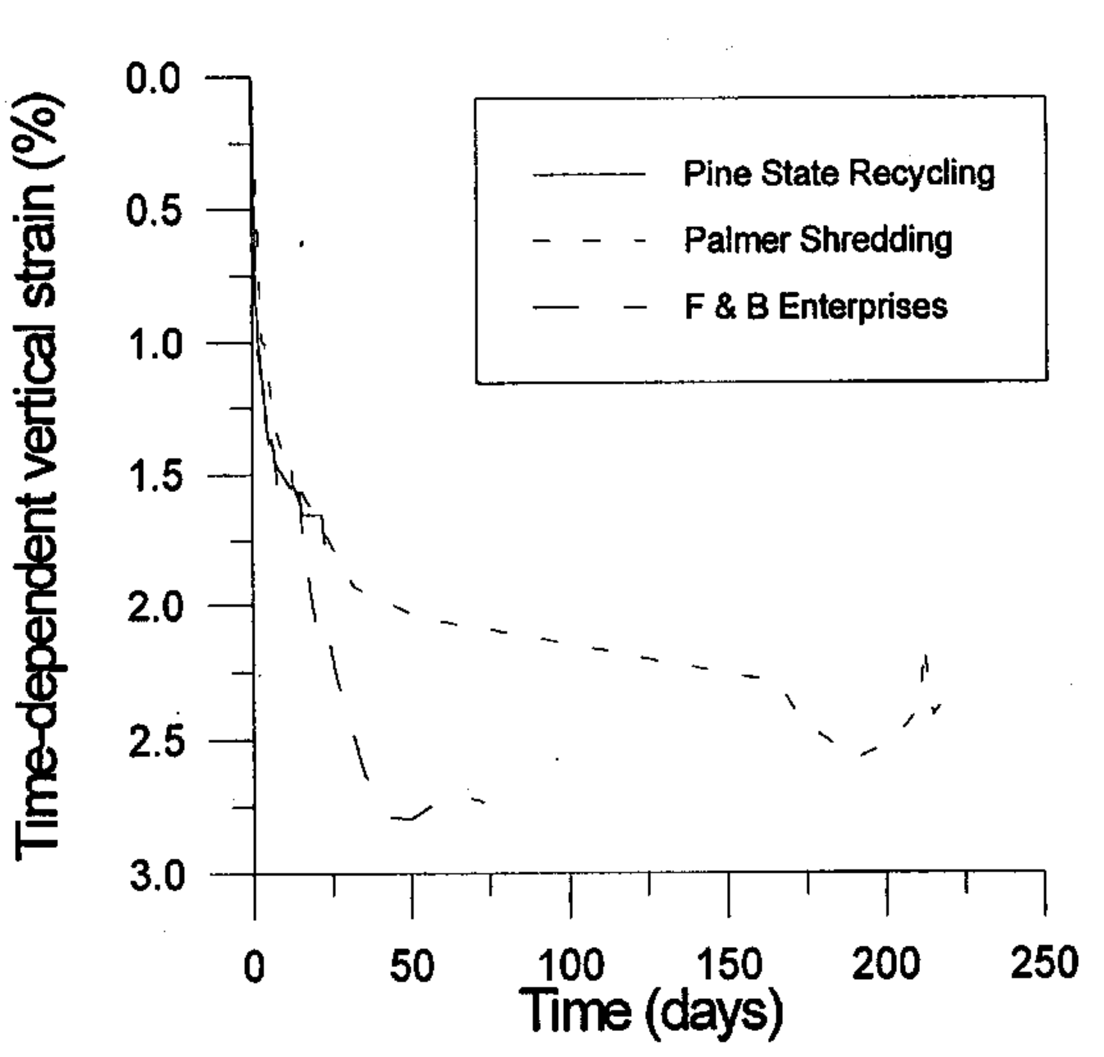
Typical results – low stress



Time Dependent Settlement

- Measured for 4.3-m thick TDA fill with 36 kPa surcharge
- Used 75 mm TDA from two suppliers and 38 mm TDA from a third supplier
- 2 to 3% strain in first two months

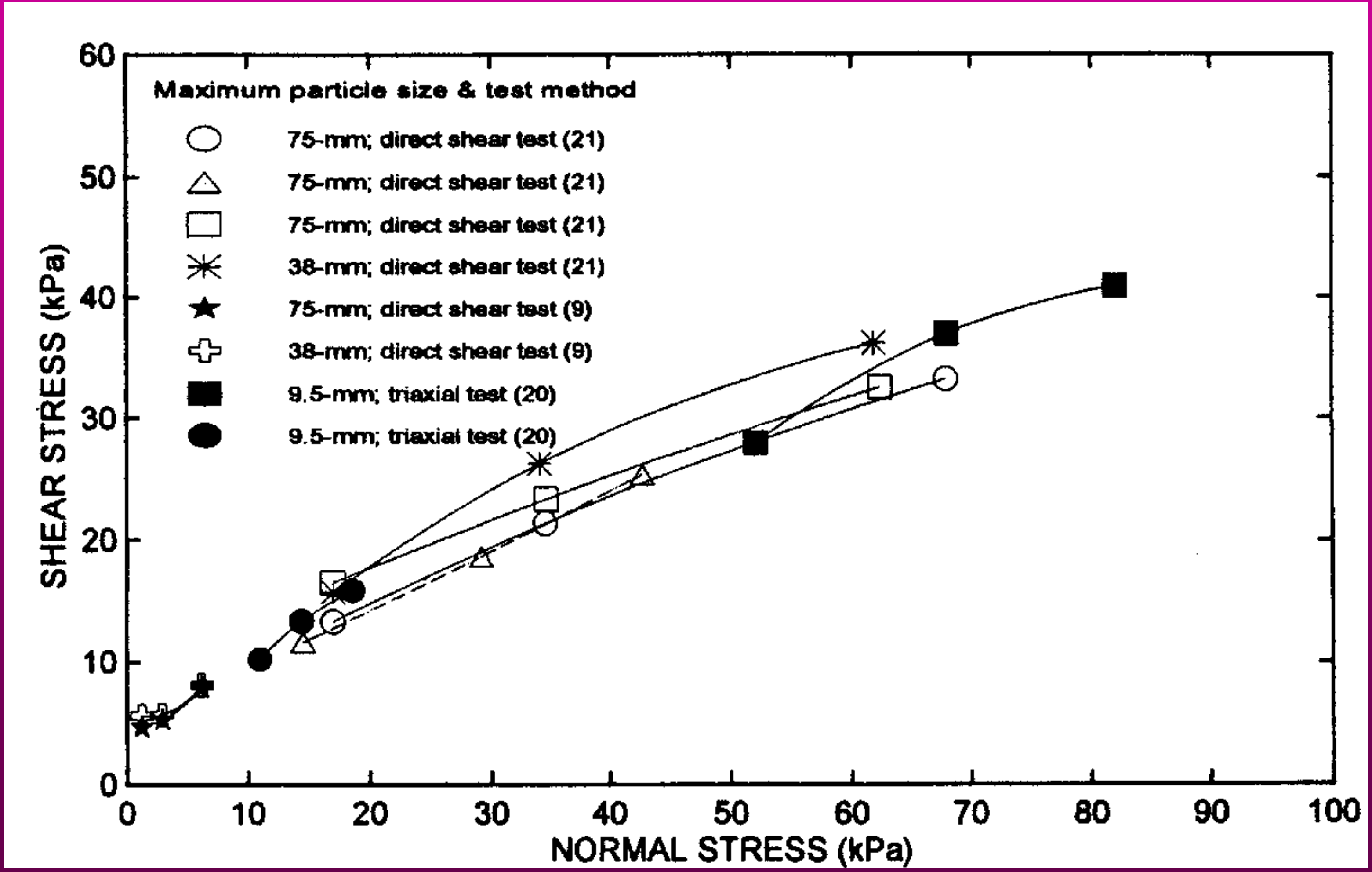
Time Dependent Settlement



Shear Strength

- Direct shear ≈ triaxial shear
- Typical shear stress vs. deformation
- Failure envelopes

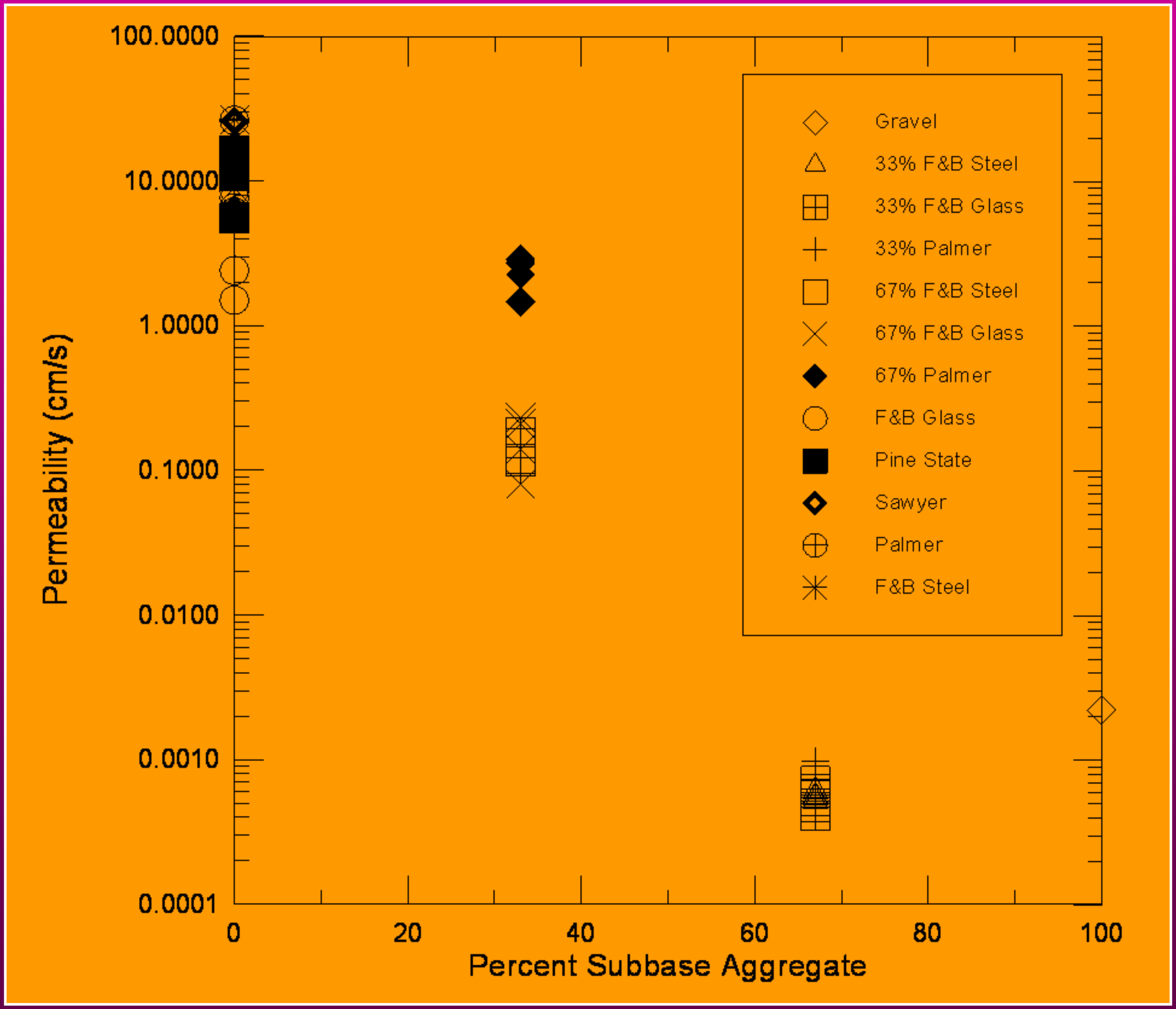
Failure envelope



Hydraulic conductivity (permeability)

- Much greater than most soils
- Test method
  - Constant head permeability apparatus
- Results range from 0.58 to 23.5 cm/s
- Mixture of TDA and soil

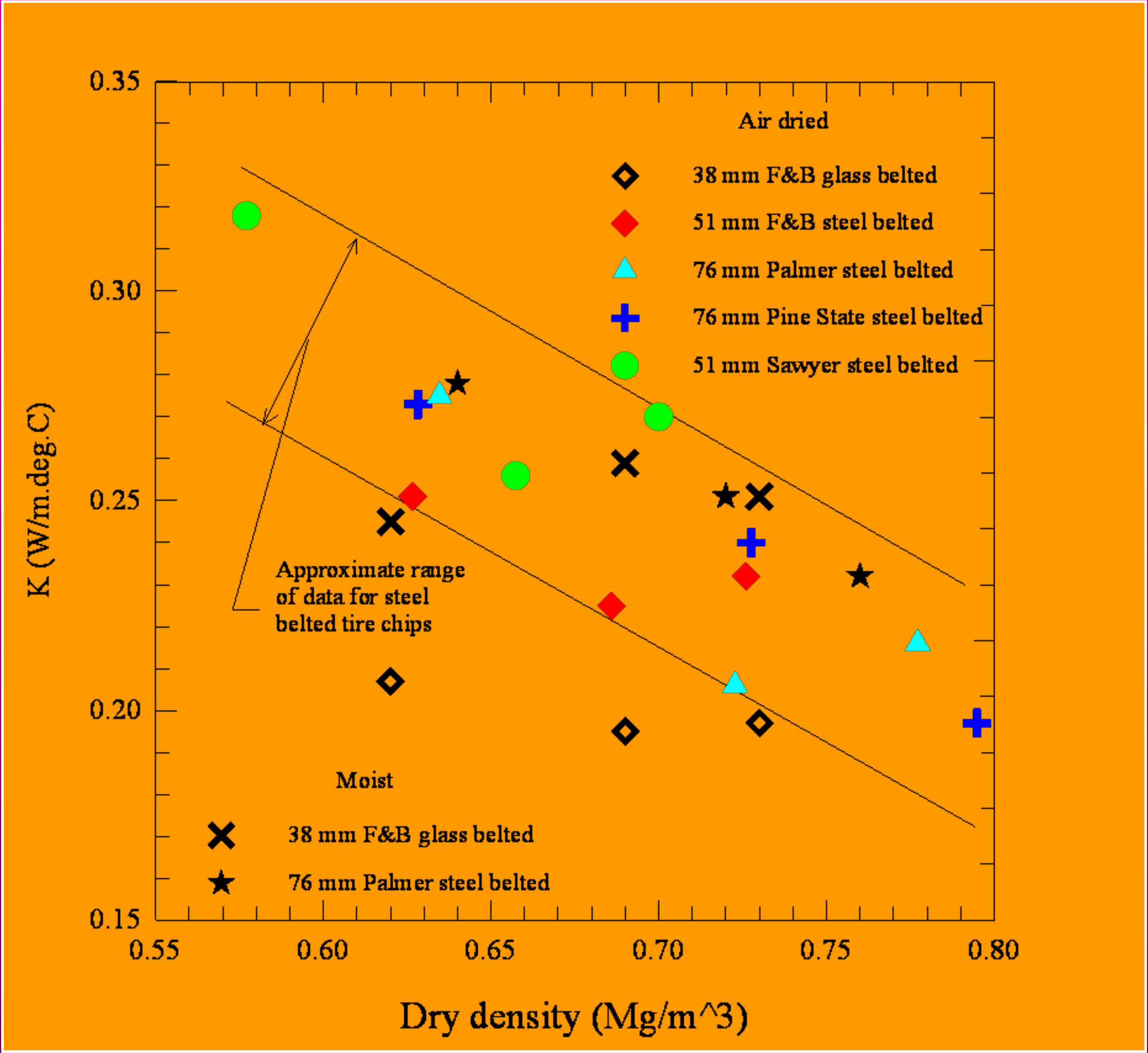
Mixture of TDA and aggregate



Thermal conductivity

- Results from Shao, et al. (1995)
  0.0563 to 0.0988 BTU/hr/ft/°F
- Results from Humphrey and Eaton
  0.1 to 0.2 BTU/hr/ft/°F
- For soils typical value is 1 BTU/hr/ft/°F

Thermal conductivity



Internal Heating
Three projects with problems

- Ilwaco, Washington
- Garfield County, Washington
- Glenwood Canyon, Colorado

Guidelines to limit embankment heating Type I fills (< 1 m thick)

- No TDA contaminated with gasoline, oil, grease, etc.
- Maximum of 50% passing 38 mm sieve
- Max. of 5% passing No. 4 (0.074-mm) sieve

Guidelines to limit embankment heating Type II fills (1 to 3 m thick)

- No TDA contaminated with gasoline, oil, grease, etc.
- Maximum of 50% passing 75-mm sieve
- Maximum of 25% passing 38-mm sieve
- Max. of 1% passing No. 4 (0.074-mm) sieve
- Limit exposed steel belt
- 3-m max. TDA layer thickness
- Minimize access of fill to water & air

WATER QUALITY EFFECTS

WATER QUALITY EFFECTS OF TDA

Statistical analysis of data

- “There are three kinds of lies: lies, damn lies, and statistics.” --- Mark Twain
- Environmental decision makers and statistics
- Computing means (averages)
  - Example: 0.15, 0.37, 0.26, 0.14 mg/L
    Mean = (0.15 + 0.37 + 0.26 + 0.14)/4 = 0.23 mg/L
  - Problem: 0.15, 0.37. 0.26, <0.10
    Mean = ?!!?*!?
  - Solution: Dennis Helsel, U.S. Geological Survey
- Variability – standard deviation

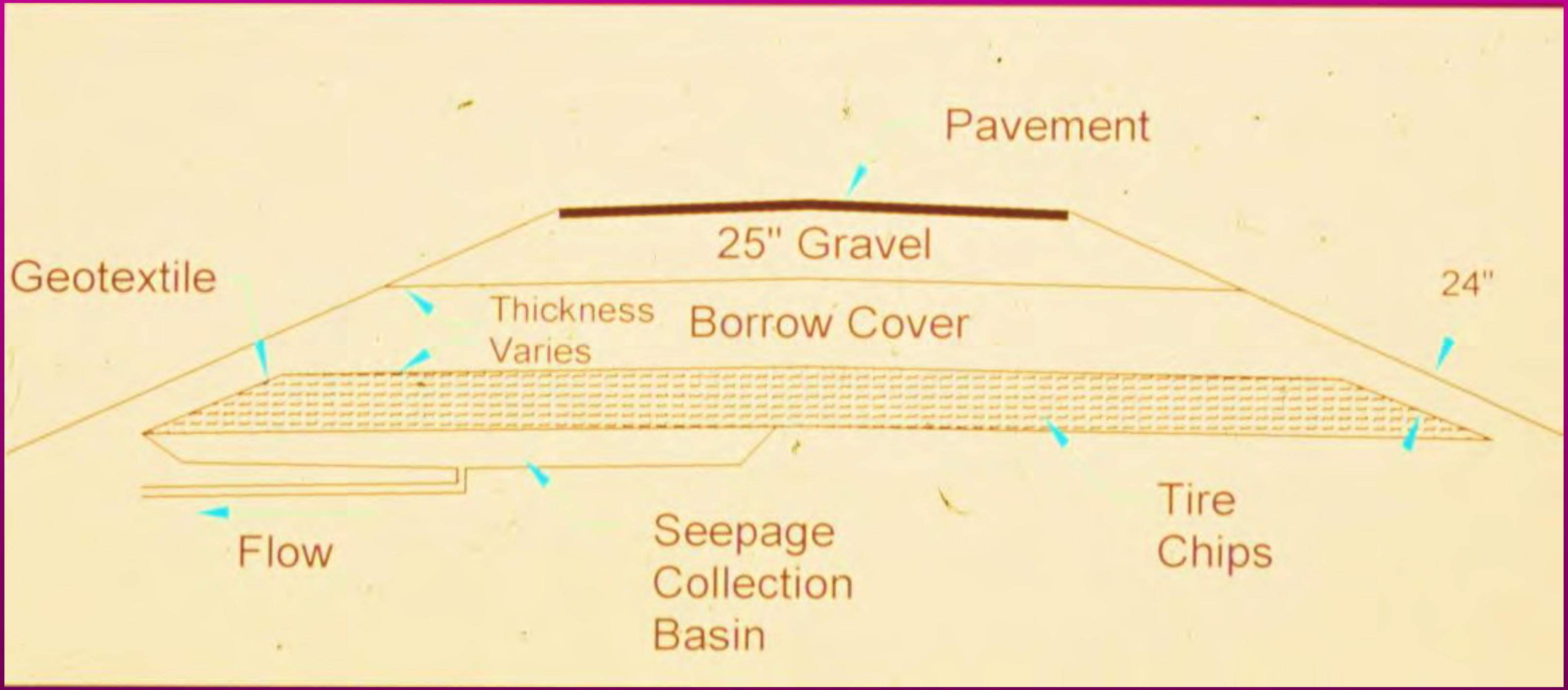
Available data

- Laboratory studies
- Direct vs. indirect measurements
- Above vs. below ground water table
- Filtered vs. unfiltered
- Effect on people – drinking water standards
- Effect on aquatic life – toxicity evaluation
- Is there a control?

Ground Water Quality

- Above groundwater table
  - Primary standards
  - Secondary standards
  - Organics
  - Toxicity evaluation

North Yarmouth Field Trial



Collection Basin
North Yarmouth, ME

Collection points
North Yarmouth, ME

Above GWT – Metals with Primary Standard

- Arsenic (As)
- Barium (Ba)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Lead (Pb)
- Mercury (Hg)
- Selenium (Se)
- Thallium (Tl)

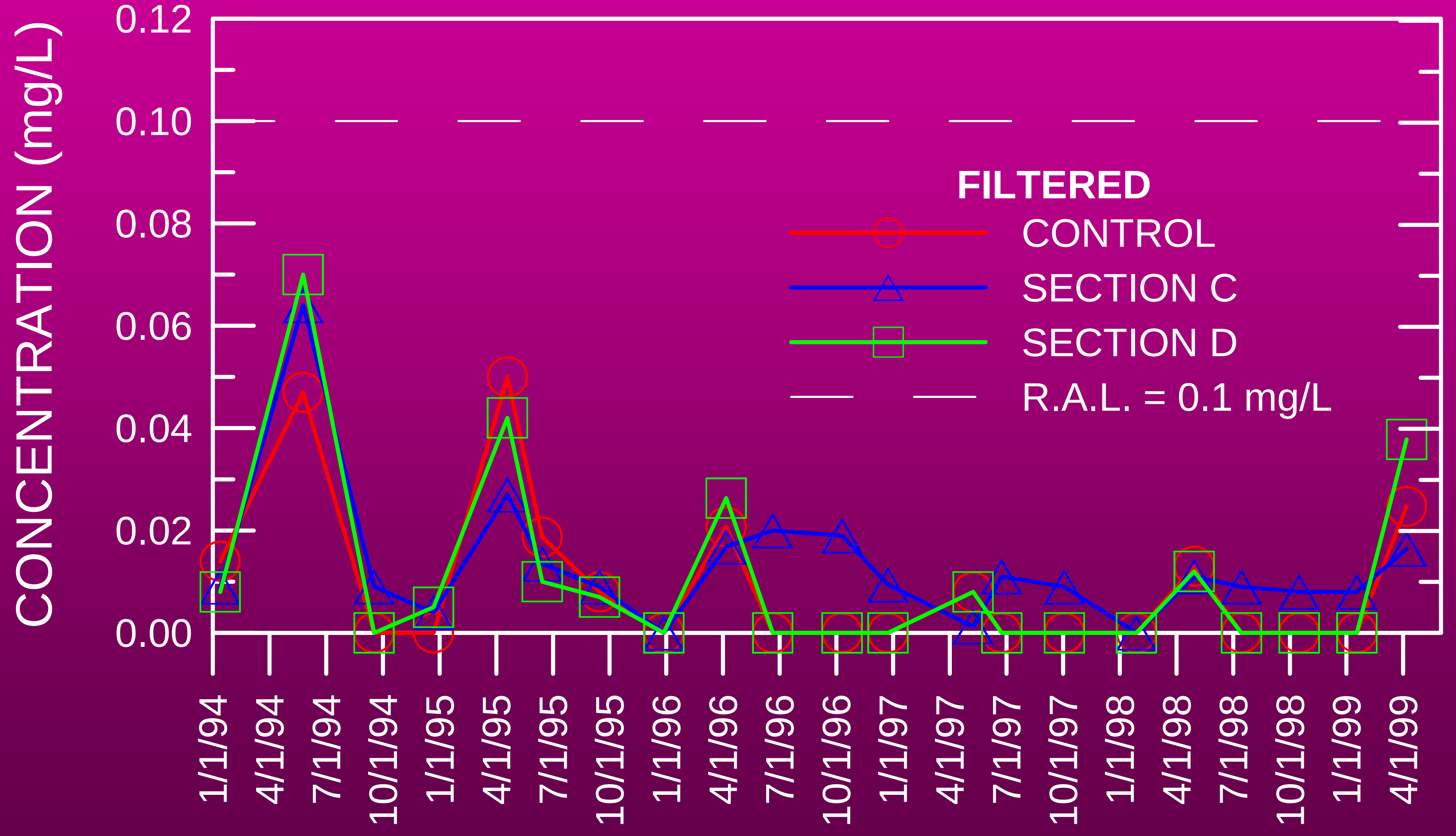
- All below primary drinking water standard

Barium (Ba)

Control	0.069 mg/L
TDA – Section C	0.034 mg/L
TDA – Section D	0.040 mg/L

Regulatory limit = 2 mg/L

Chromium Concentration



Chromium (Cr)

Control	0.012 mg/L
TDA – Section C	0.013 mg/L
TDA – Section D	0.012 mg/L

Statistically equal with 90% confidence

Regulatory limit = 0.1 mg/L

Above GWT – Metals with Secondary Standard

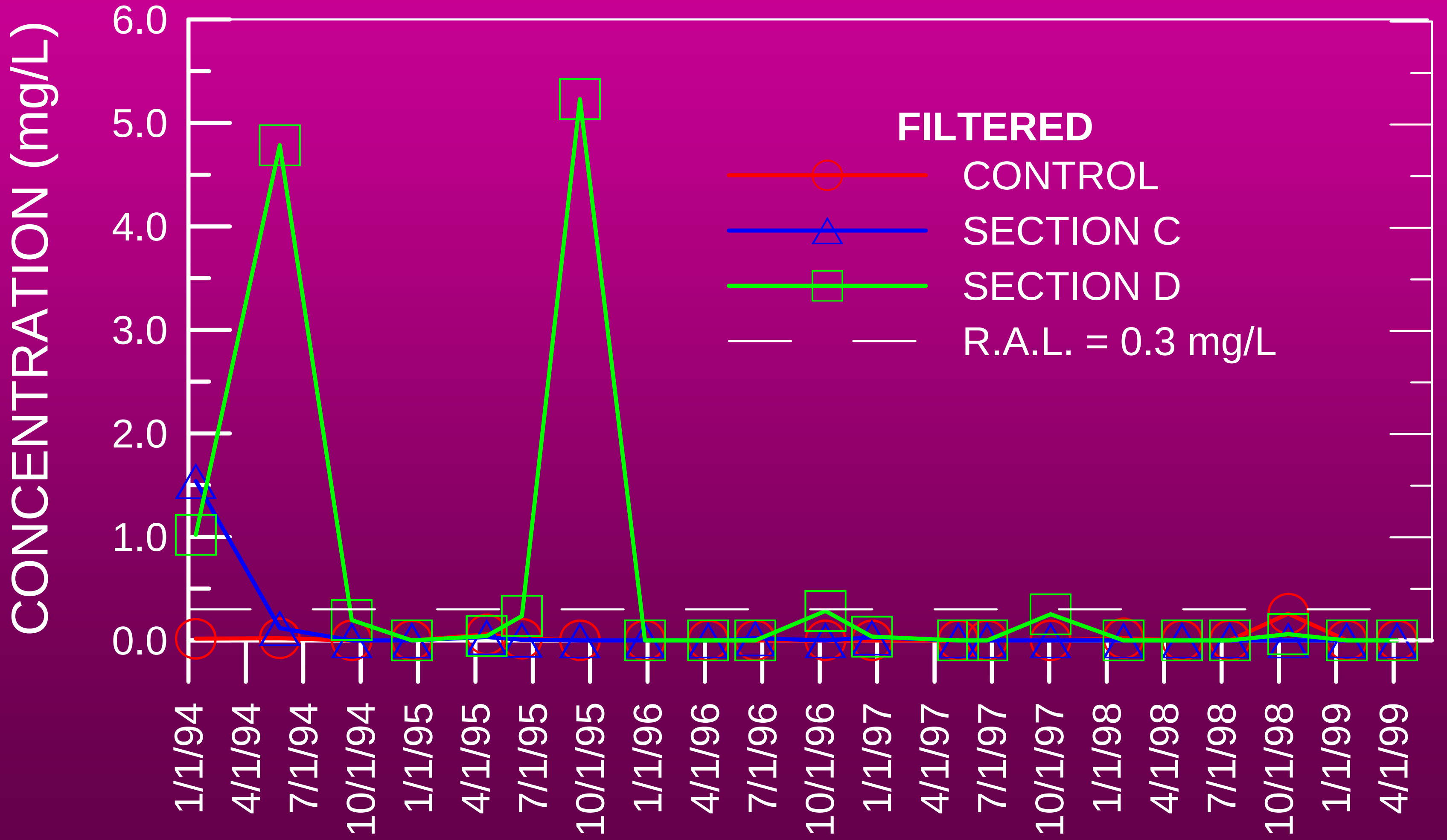
- Aluminum (Al)
- Chloride (Cl-)
- Copper (Cu)
- Fluoride (Fl)
- Iron (Fe)
- Manganese (Mn)
- Silver (Ag)
- Zinc (Zn)

Selected metals with secondary standard

	Iron (Fe)	Manganese (Mn)	Zinc (Zn)
Control	0.020	0.042	1.10
TDA – Section C	0.079	4.38	0.011
TDA – Section D	0.556	2.56	0.011
Regulatory Limit	0.3	0.05	5

Concentrations in mg/L

Iron Concentration



Volatile organics (EPA 8260)

- 82 targeted compounds
  - DL = 5 μg/L for most compounds
- Dec. 95 & April 96- all compounds below DL
- June 99
  - Control section - toluene - 70 μg/L
  - TDA section D - trace (< 5 μg/L) of 1,1-dichloroethane and 4-methyl-2-pentanone
  - TDA section C - all below DL

Semivolatile organics (EPA 8270)

- 69 targeted compounds
  - Base neutral extractable, acid extractable, polyaromatic hydrocarbons
  - DL = 5 μg/L for most compounds
- Dec. 95 & April 96 - All compounds below DL
- June 99
  - Control section - 3&4-methylphenol (100 μg/L), benzoic acid (25 μg/L) & phenol (74 μg/L)
  - TDA sections C & D - tentatively identified 2-(4-morpholinyl)-benzothiazole

Above GWT - Toxicity Evaluation

- Seven-day survival & growth with larval fathead minnows
- Three-brood survival & reproduction with crustacean - *ceriodaphnia dubia*

- Exponent Environmental

Fathead minnows

Sample	Survival 11/8/00	Survival 1/1/02	Growth 11/8/00	Growth 1/1/02
TDA C+D	>100%	>100%	>100%	>100%
Control	>100%	>100%	>100%	>100%

Ceriodaphnia dubia

Sample	Survival 11/8/00	Survival 1/1/02	Repro-duction 11/8/00	Repro-duction 1/1/02
TDA C+D	>100%	>100%	>100%	>100%
Control	>100%	>49%	>49%	>28%

TDA above water table

North Yarmouth Field Trial

- Primary drinking water standards
  - No effect
- Secondary drinking water standards
  - Manganese & iron
  - Not significant
- Organics
  - No significant effect
- Toxicity
  - No significant effect

Overview of TDA use in Construction

- Lightweight fill
- Insulation to limit frost penetration
- Retaining wall & bridge abutment backfill
- French drains and drainage layers for roads and landfills
- Leachfields for septic tanks
- Vibration damping
- Uses of whole tires

TDA as Lightweight Fill for Embankment Construction

- Weak foundation soils
  - Increase slope stability
  - Reduce settlement

- Landslide stabilization

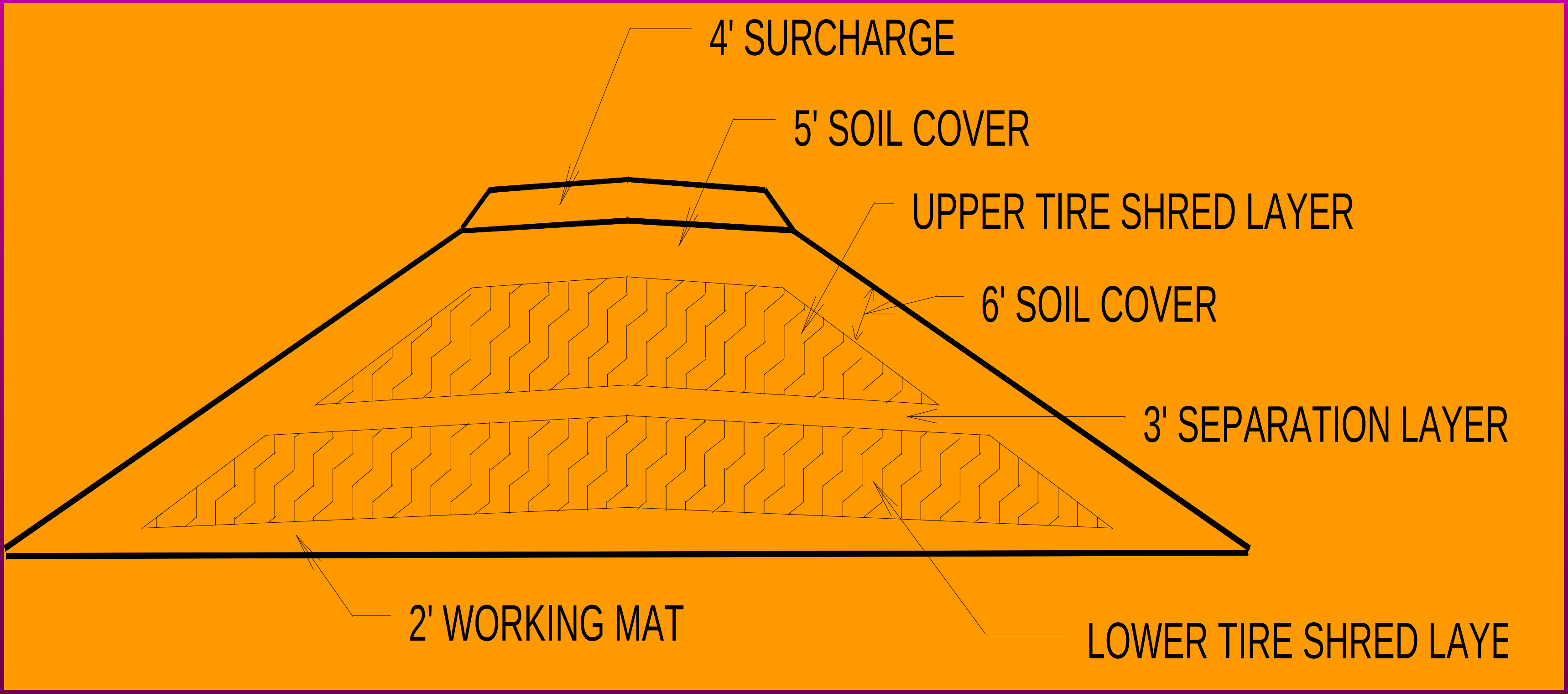
Major highway projects

- Landslide stabilization, Roseburg, OR
- Jetport Interchange, Portland, ME
- Connector Interstate, Denver, CO
- North Abutment, Merrymeeting Bridge, Topsham, ME
- Dixon Landing Interchange, Milpitas, CA
- Livingston St., Tewksbury, Mass.
- St. Stephens, New Brunswick

Portland Jetport Interchange

- PROBLEM: Embankment Constructed on weak marine clay
- SOLUTION: Use TDA for the core of the embankment (1.2 million PTE)
- CHEAPEST SOLUTION: Maine Turnpike Authority saved $300,000

Typical Cross Section



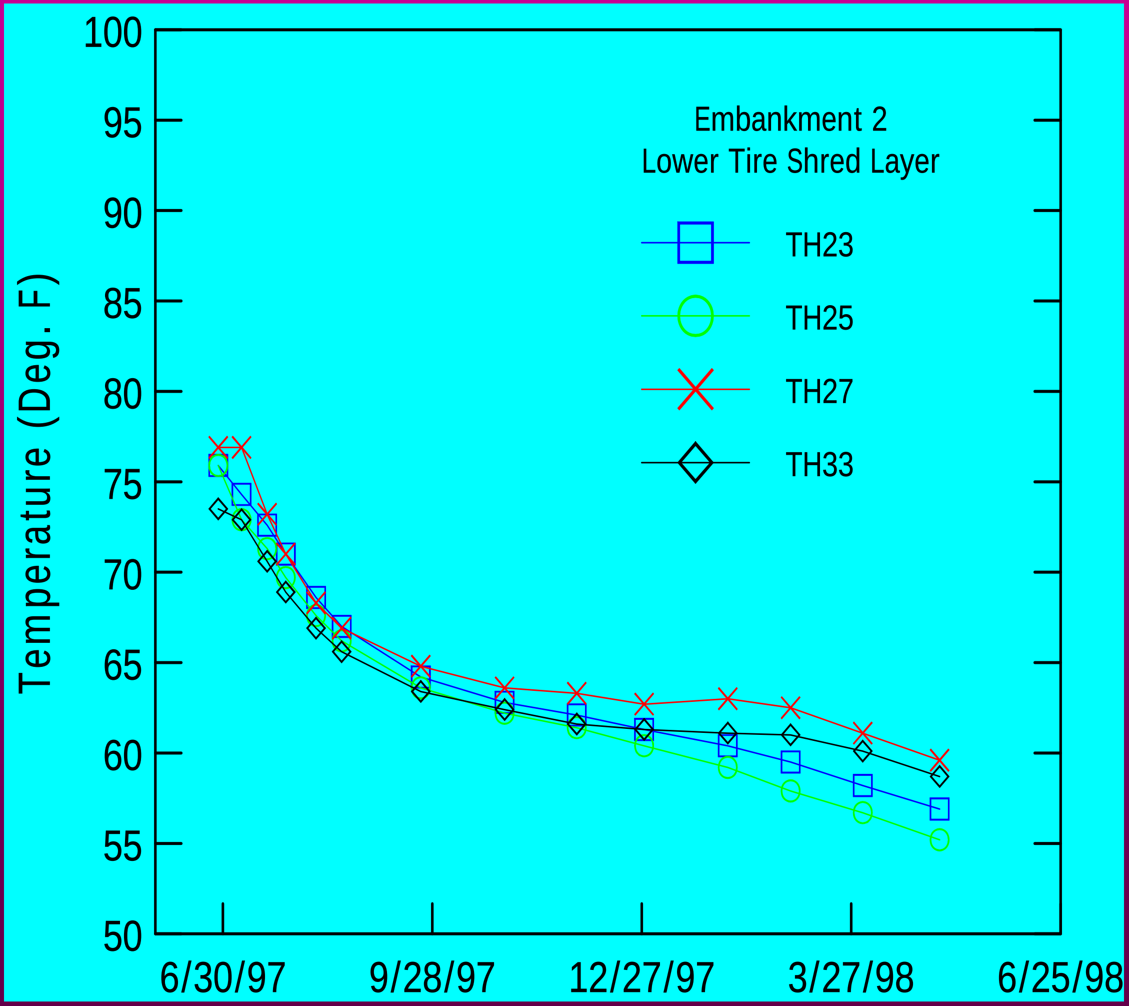
First load of TDA

Overview of construction

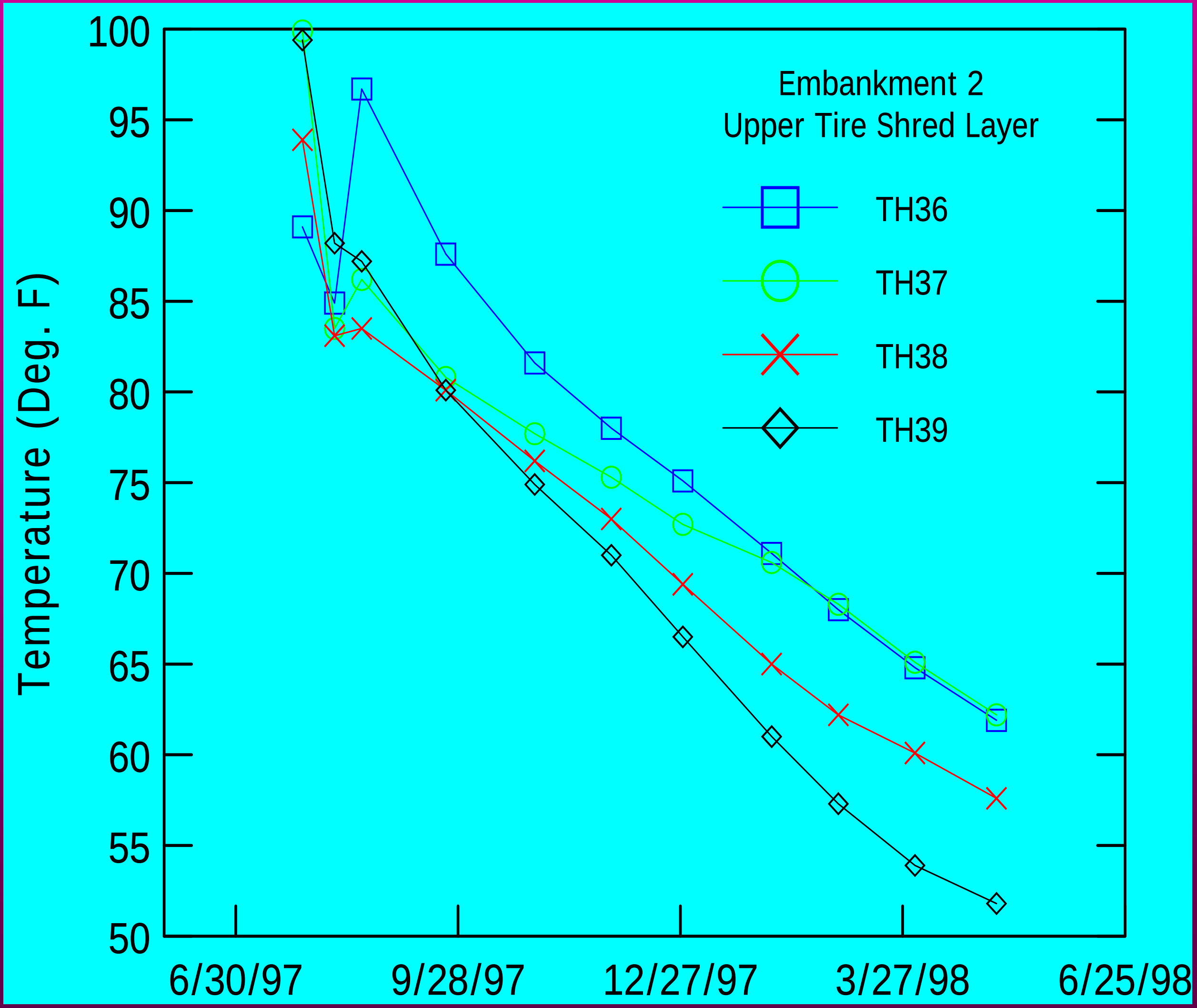
Spreading TDA with dozer

Completed embankment

Temperatures in lower layer



Temperature in upper layer



Livingston Street Reconstruction Tewksbury, Massachusetts

Lead Engineer: Stephens and Associates

- Problem:
  - 4 m of fill compressed peat layer to 2 m thick!!!!
  - Up to 1 m of settlement in 24 years
- Solution:
  - Reconstructed 240 m section with Type B TDA
  - Used 200,000 tires
  - $220,000 cost savings

Excavate to top of peat layer

Geotextile separation layer

Type B TDA

Current status

- Project completed six years ago
- Long term settlement eliminated
- No pavement cracking or rutting
- Awarded project of the year by Massachusetts Consulting Engineers Council, 2003

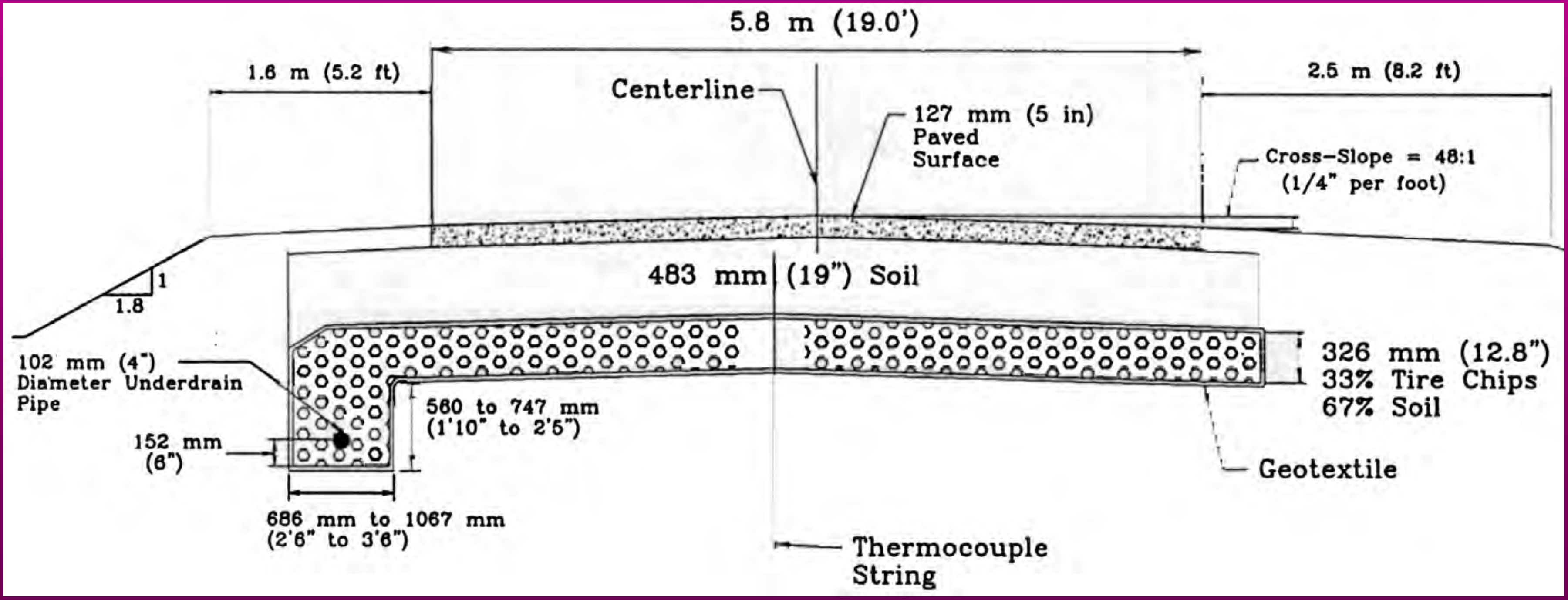
Insulation & drainage layers for roads

- Problem – loss of strength during spring thaw
- Why – frost penetration and ice lenses
- Solution – Use TDA to limit frost penetration & drain excess water

Whitter Farm Road
UMaine Campus

- Dead-end road that serves UMaine Farm
- 76 m long
- 150 or 300-mm thick layer of Type A TDA
- 100% TDA
- 67%/33% & 33%/67% TDA/soil mixtures
- 279 or 483-mm gravel cover
- 127 mm pavement

Witter Farm Road
Typical Cross Section



Excavate to grade

Excavate Edge Drain

Place Edge Drain

Compact Edge Drain (high tech)

Compact Edge Drain (low tech)

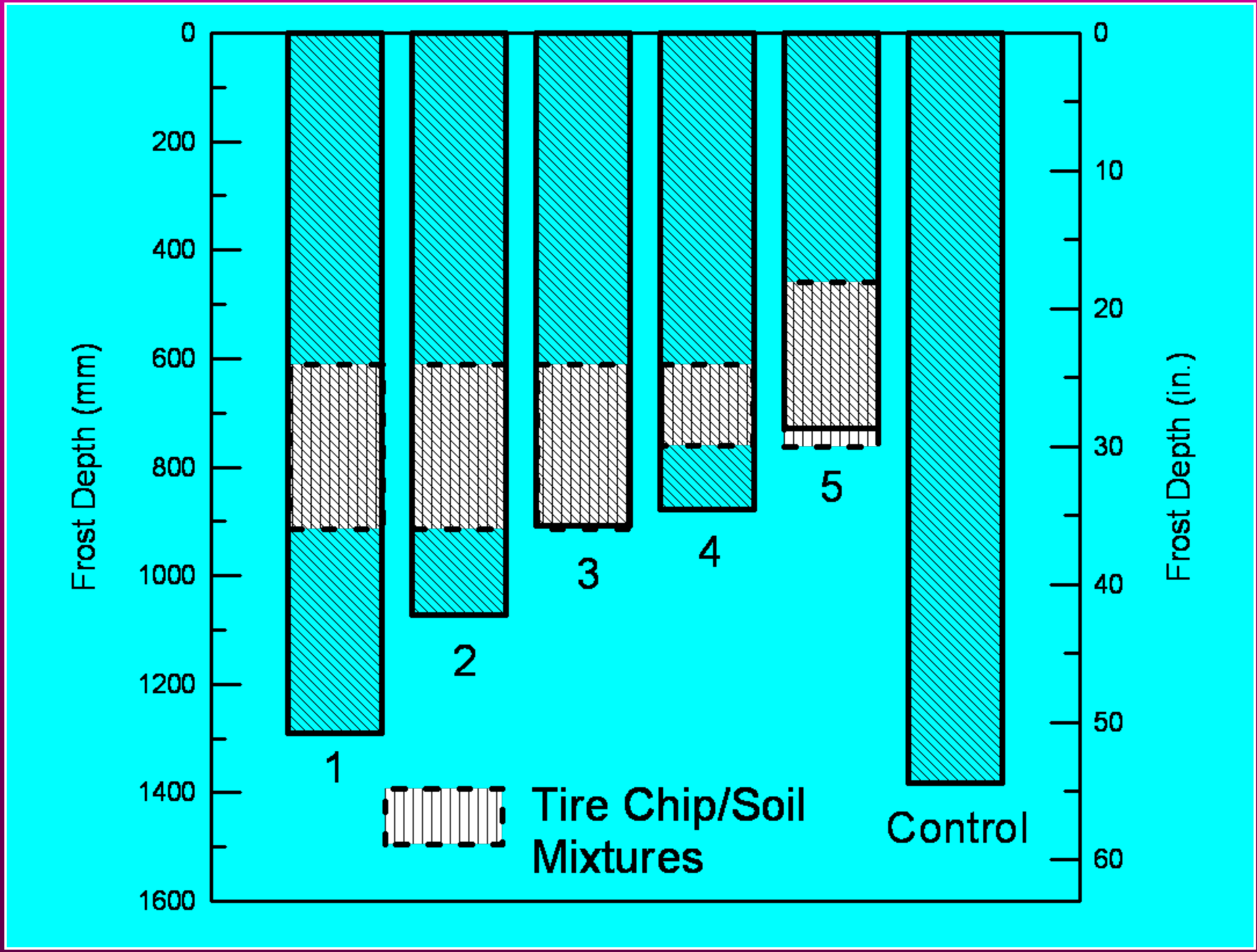
Place TDA

Place & Compact Soil Cover

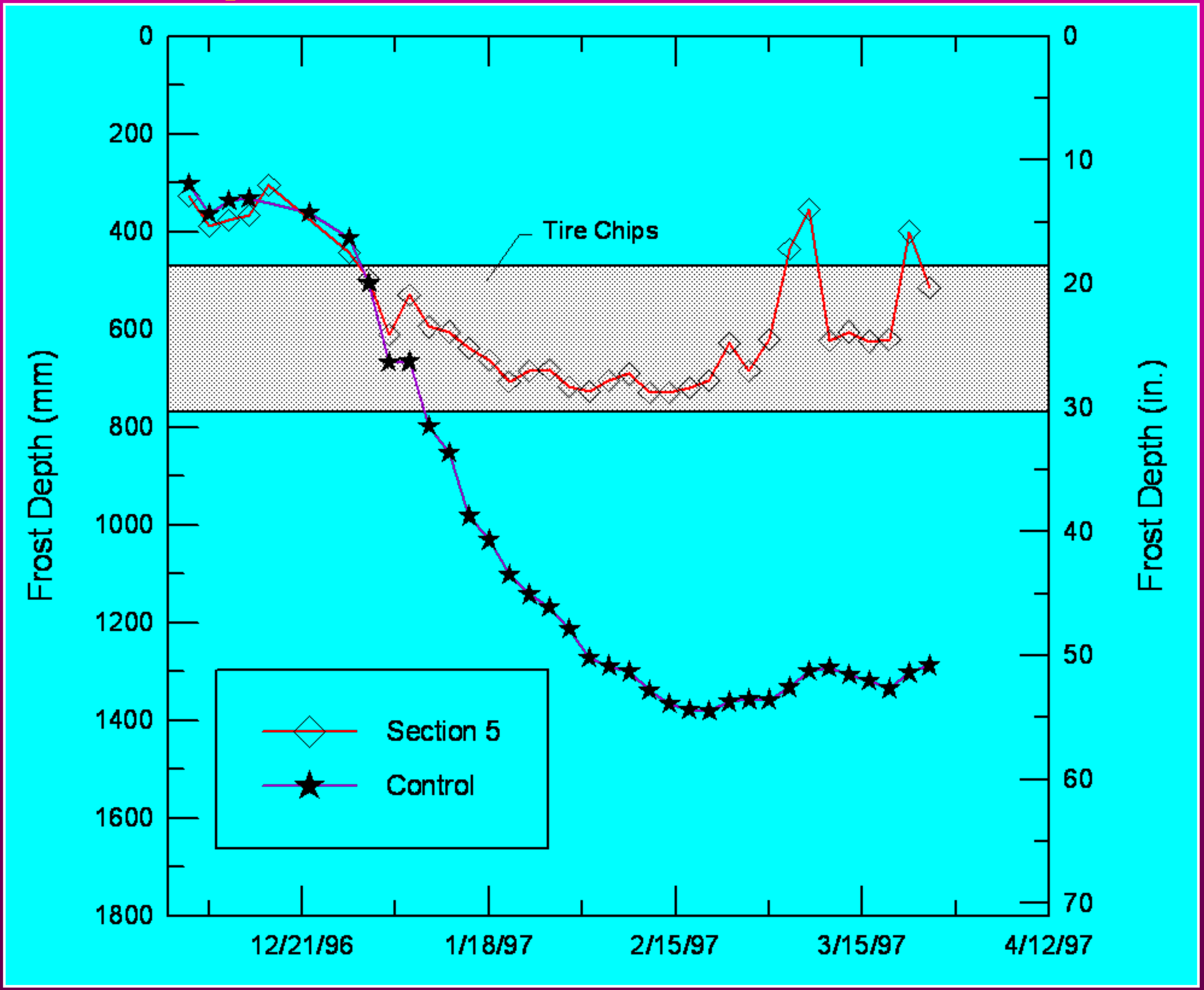
Place Pavement

Completed Project

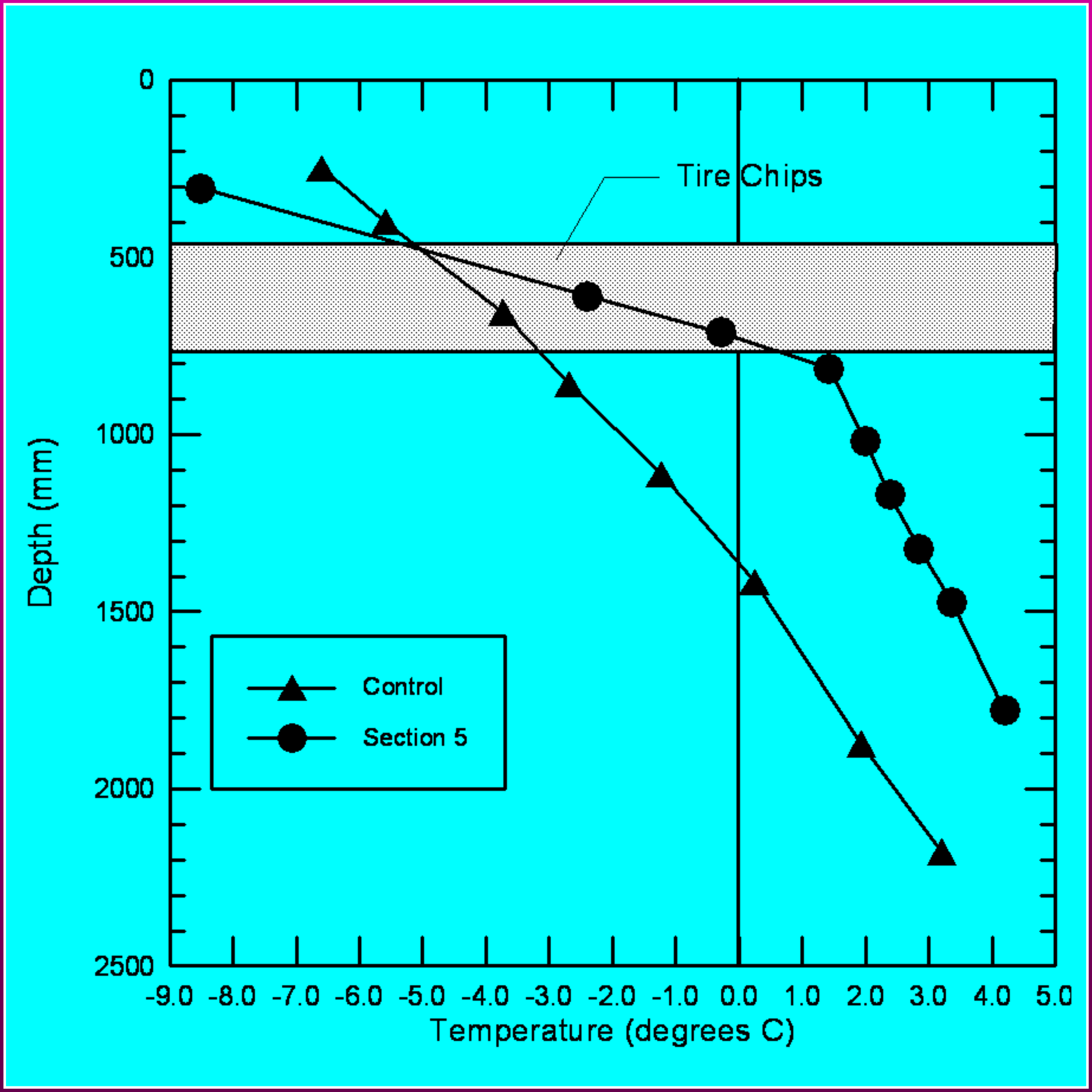
Maximum frost penetration



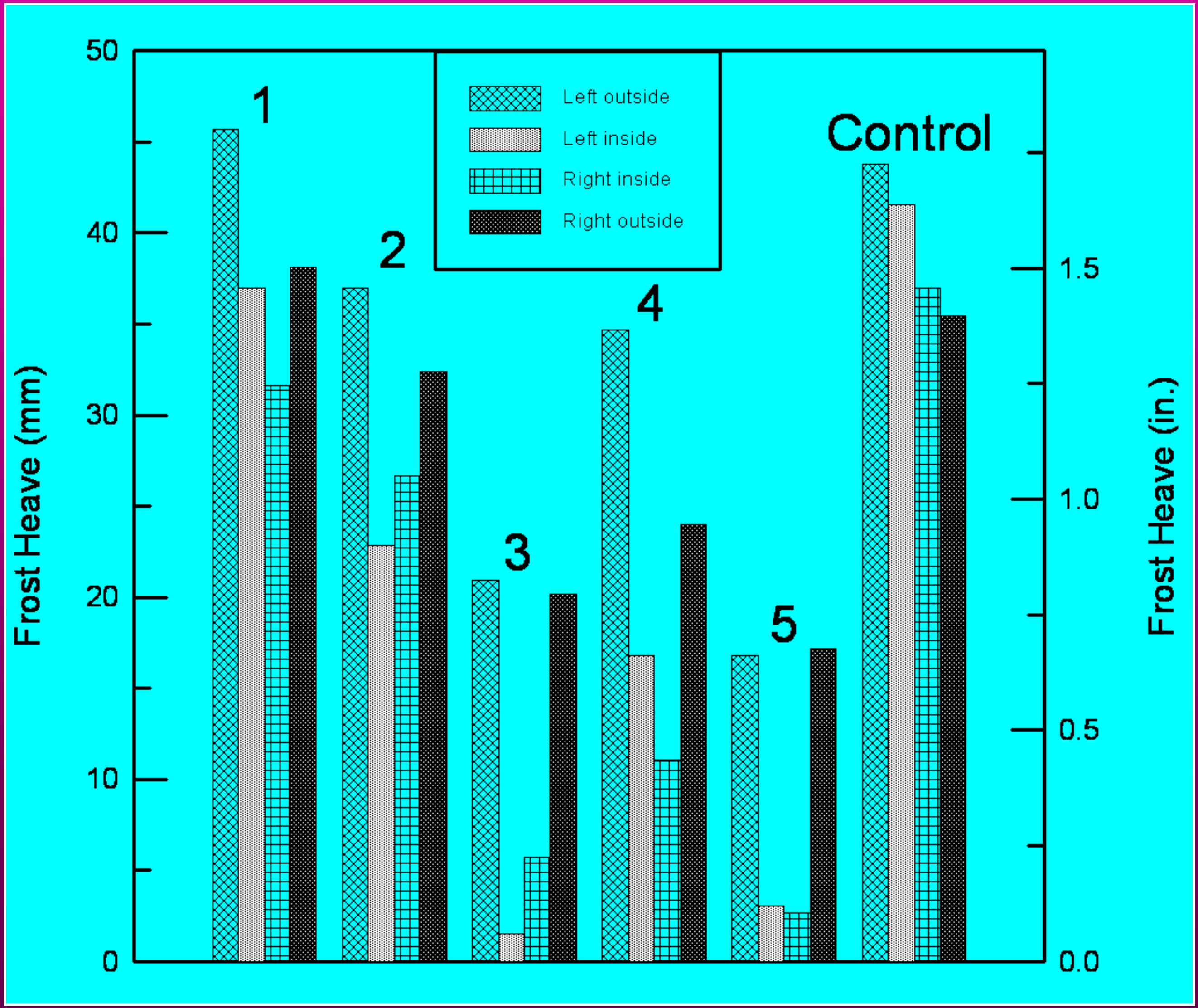
Frost penetration vs. date



Temperature profile on 2/14/97



Frost heave

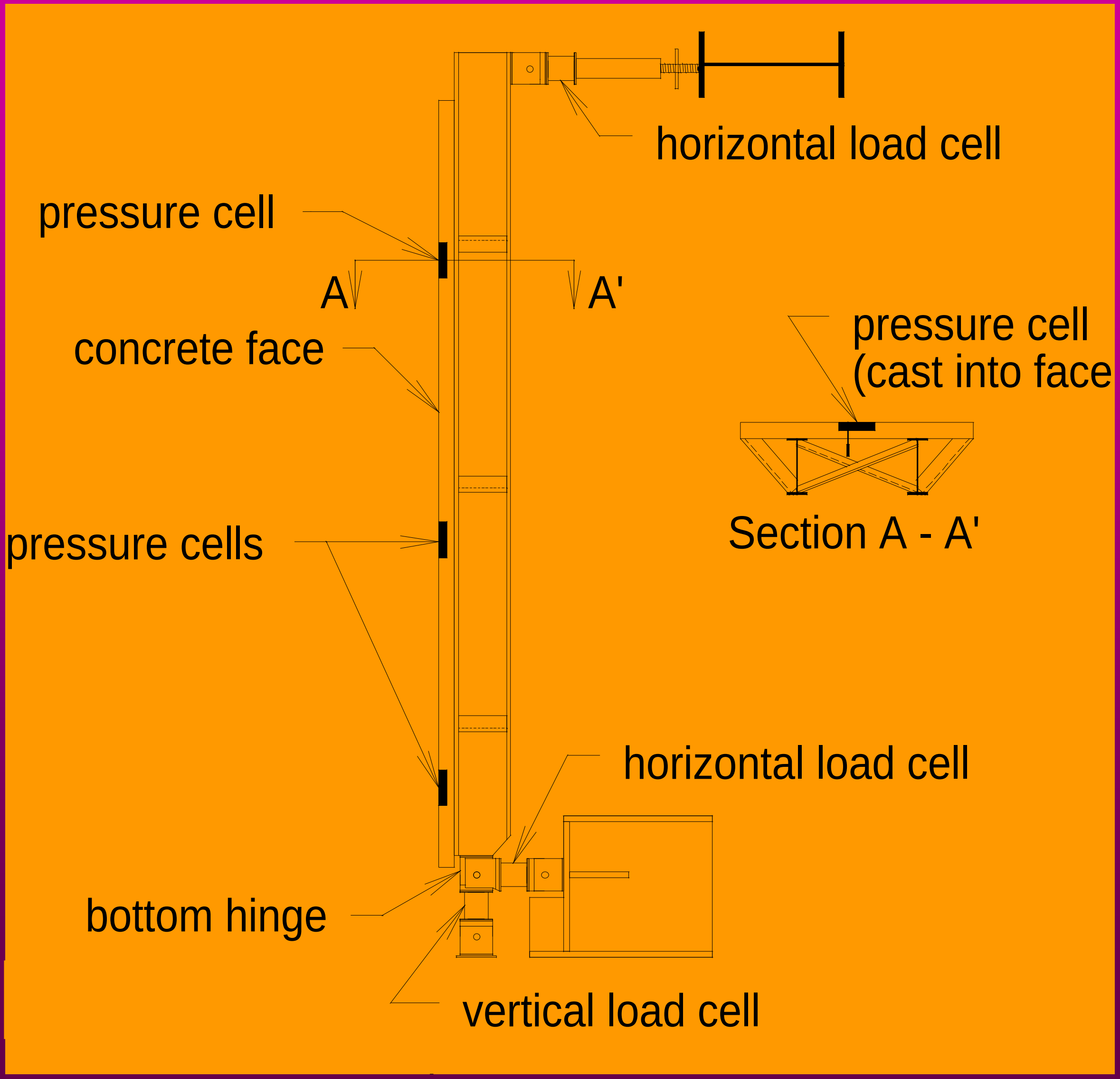


Left outside
Left inside
Right inside
Right outside
1
2
3
4
5
Control
Frost Heave (mm)
Frost Heave (in.)
0
10
20
30
40
50
0.0
0.5
1.0
1.5

Why use TDA for retaining wall backfill?

- Low unit weight
  (0.8 Mg/m^3)
- Free draining
  ($k > 1$ cm/s)
- Good thermal insulation
  (8 x better than soil)
- 100 tires per m^3!

UMaine instrumented front wall



Construction of UMaine wall test facility

Construction Continues

Overall view of UMaine wall test facility

Interior of UMaine wall test facility

Loading TDA

Compacting TDA in UMaine wall test facility

Surcharge Blocks

Test facility fully loaded

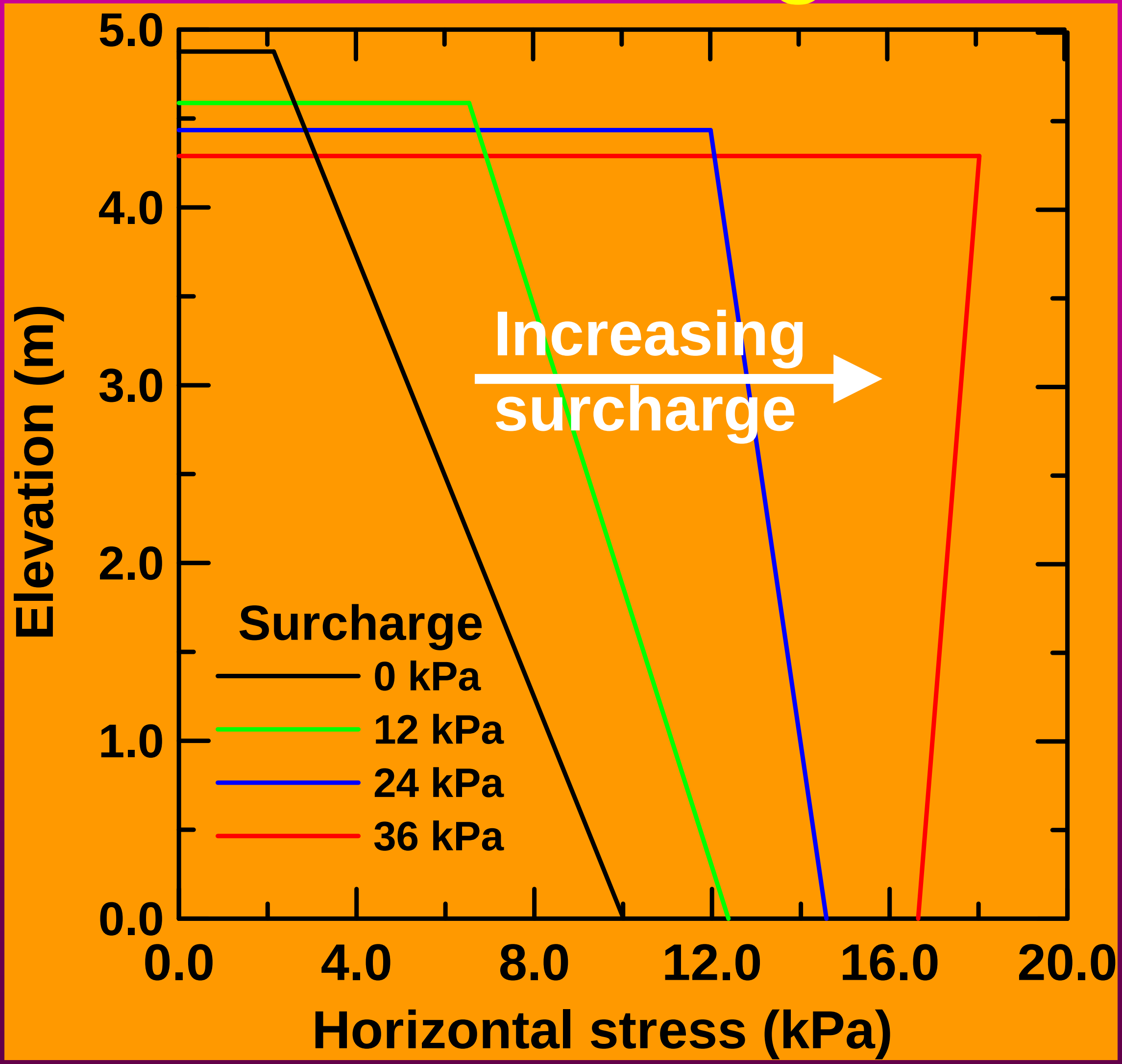
Surcharge blocks

Removable backwall

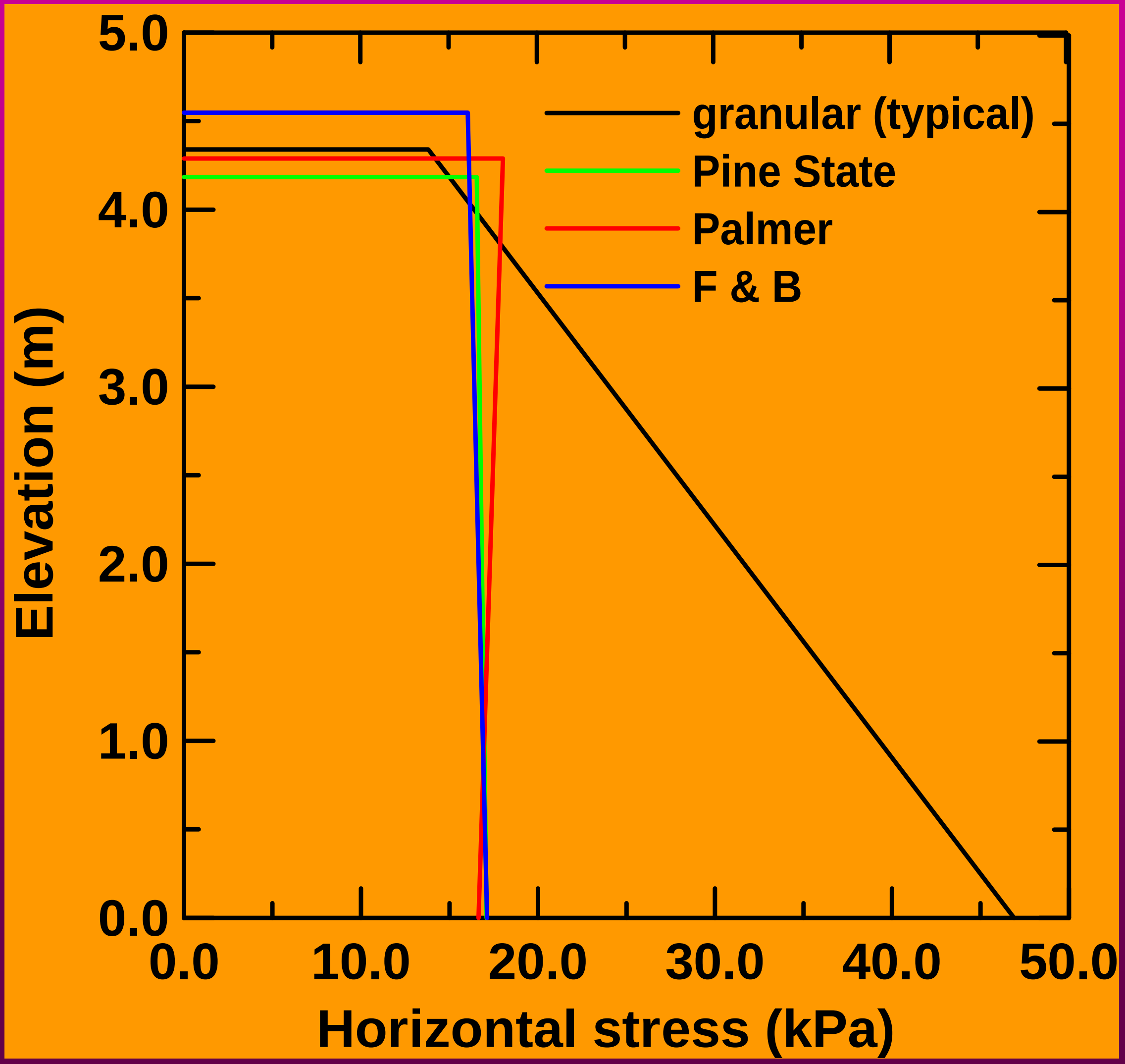
Load cells on UMaine wall test facility

Load Cells

At-rest stress distribution at four surcharges



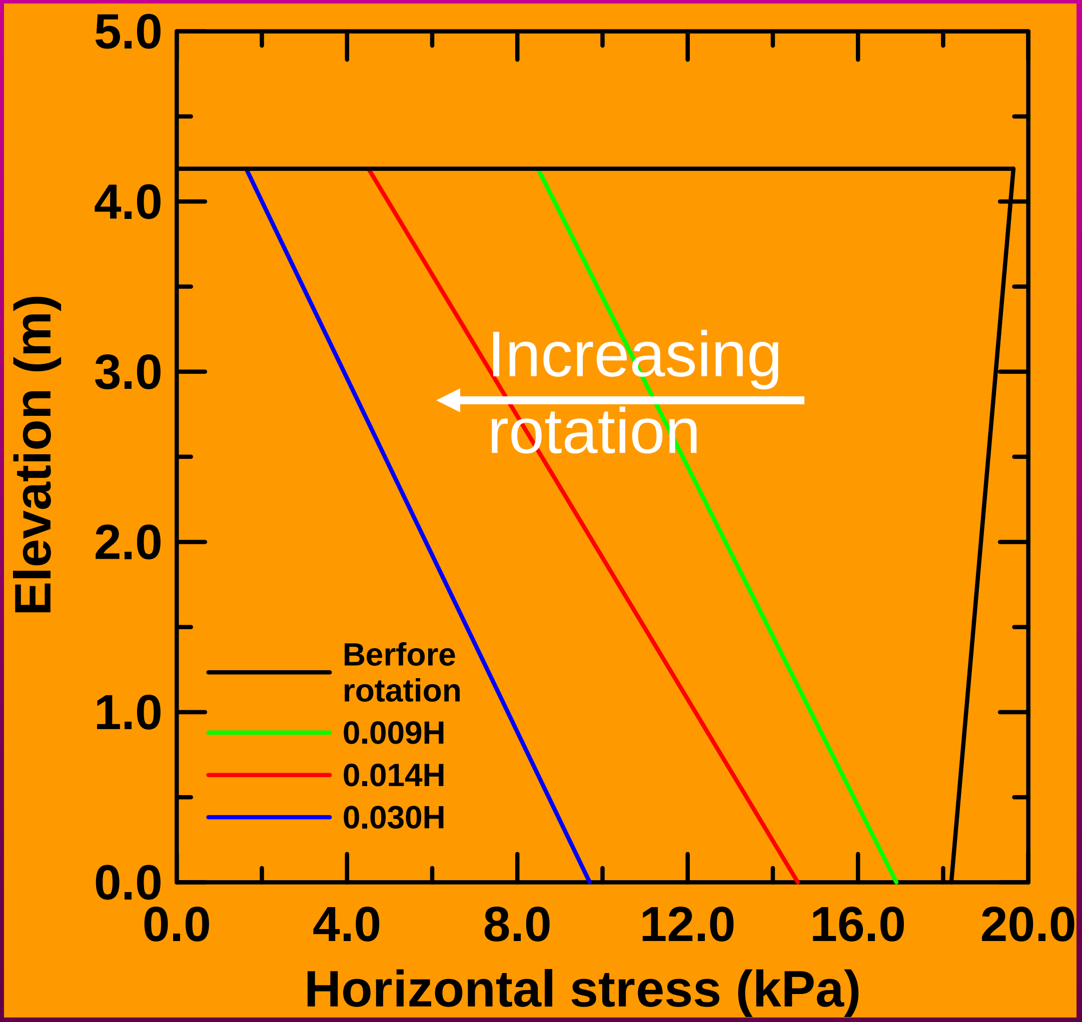
At-rest stress distribution at 35.9 kPa surcharge



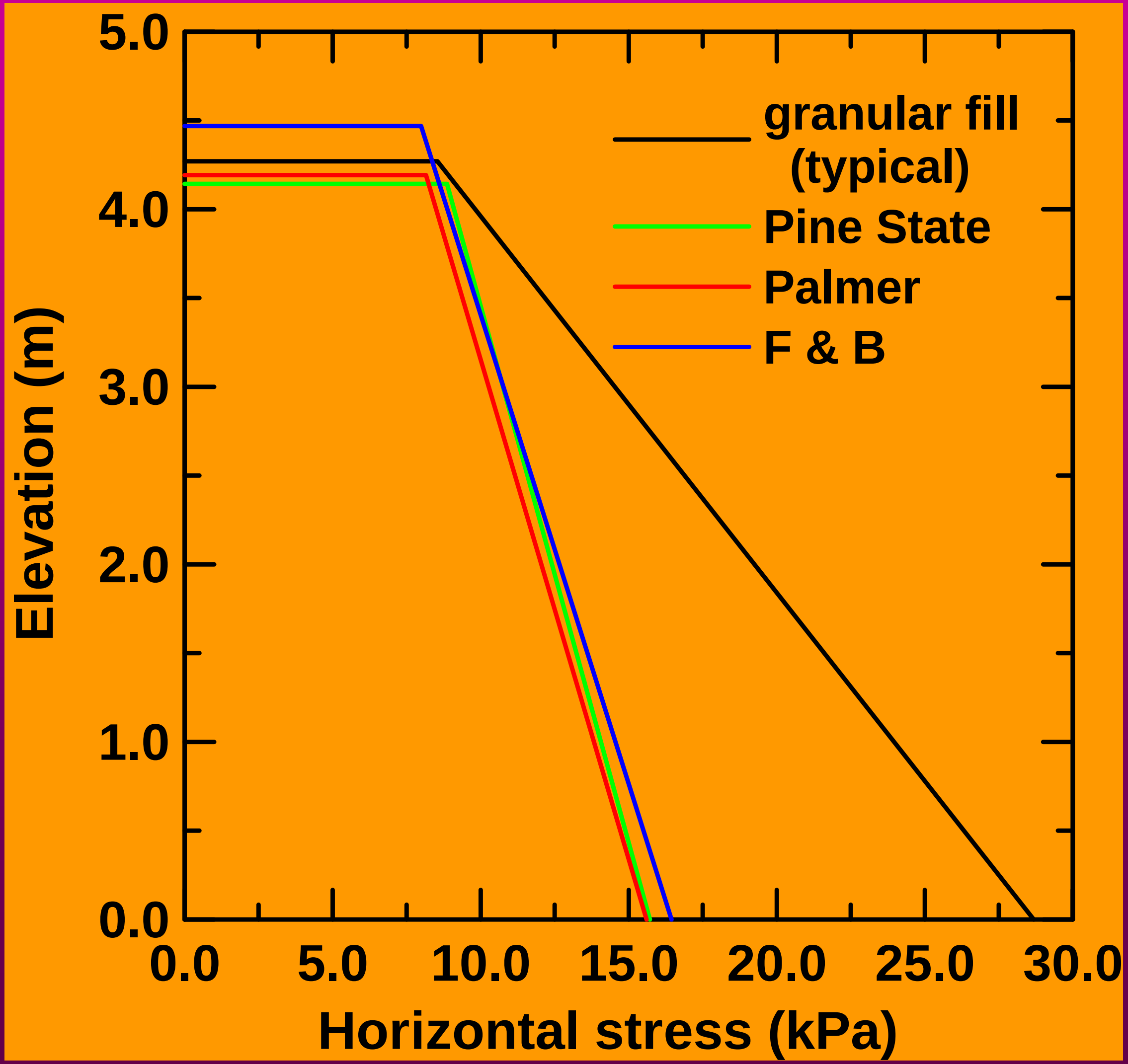
Rotating wall away from backfill

Screw Jacks

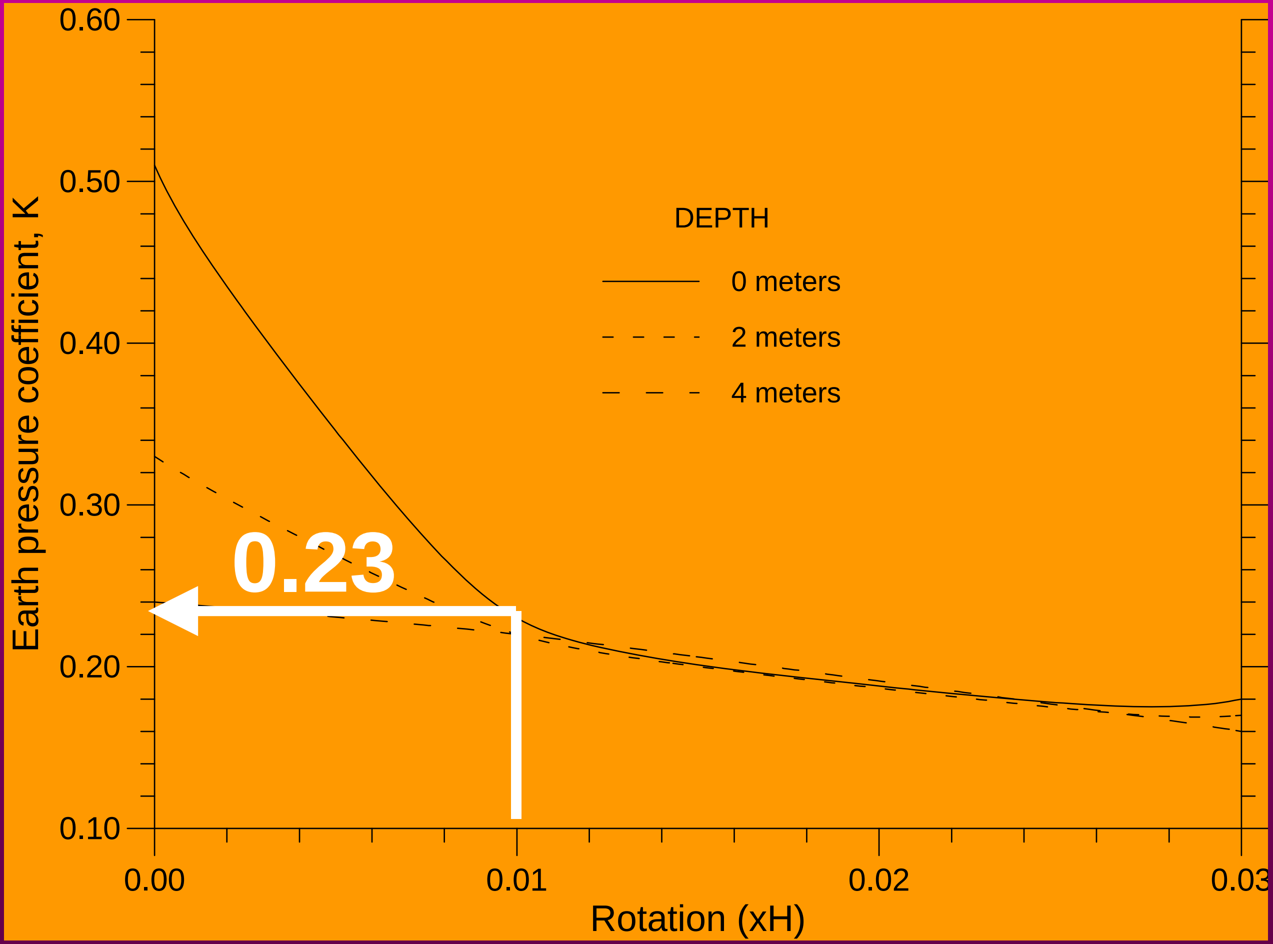
Stress distribution for wall rotations of zero to 0.03H



Stress at 35.9 kPa surcharge and 0.01H rotation



Effect of rotation on earth pressure coefficient



Backwall completely removed

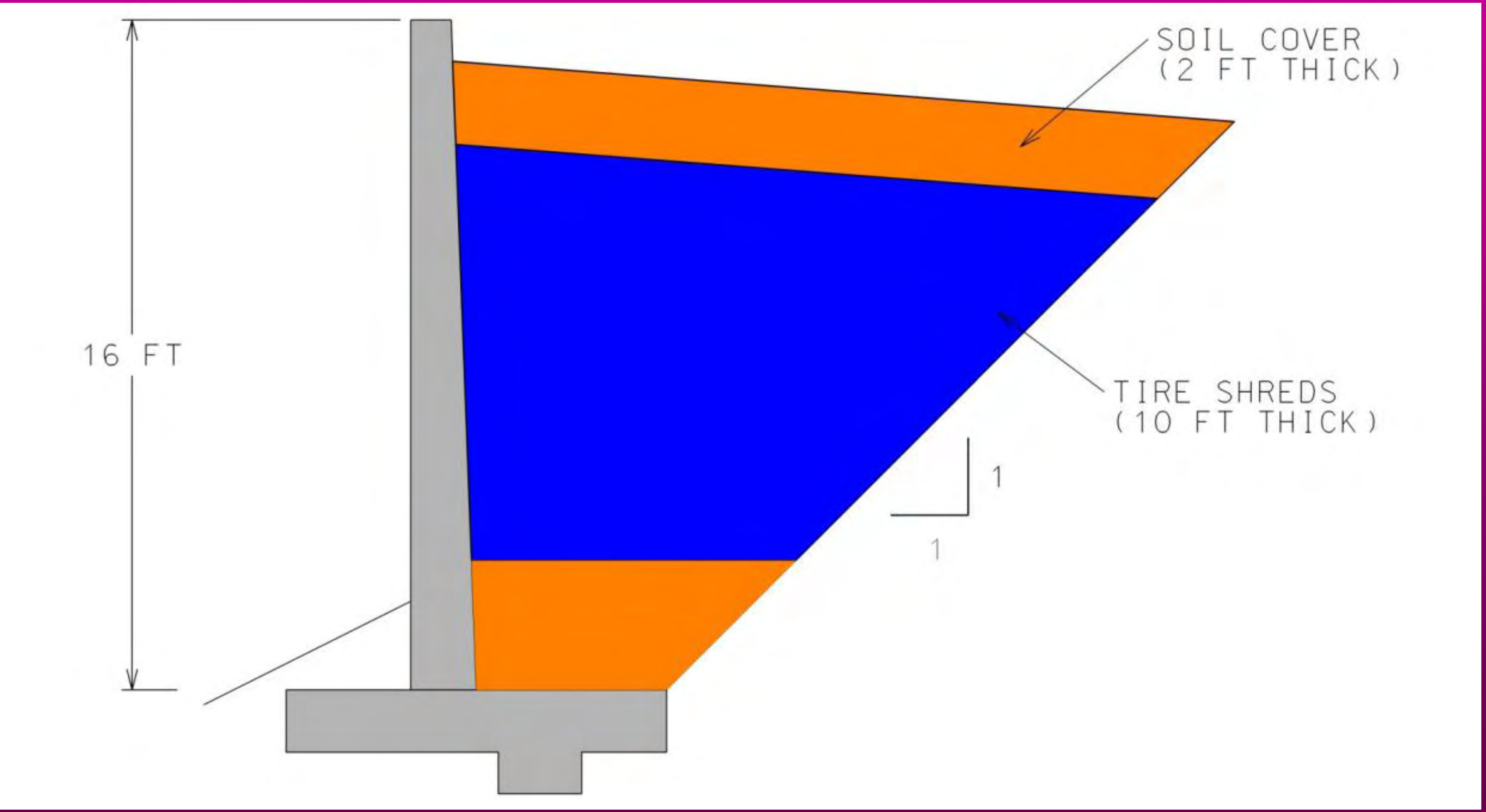
Close-up of TDA

Removing TDA at Completion of Test

Wall 119 in Riverside, CA

- Freeway widening
- Objective: show that reduced earth pressures can reduce overall wall construction costs
- Length: 79 m
- Tires used: 75,000 PTE

Wall 119 cross section



Rt. 91 wall during construction

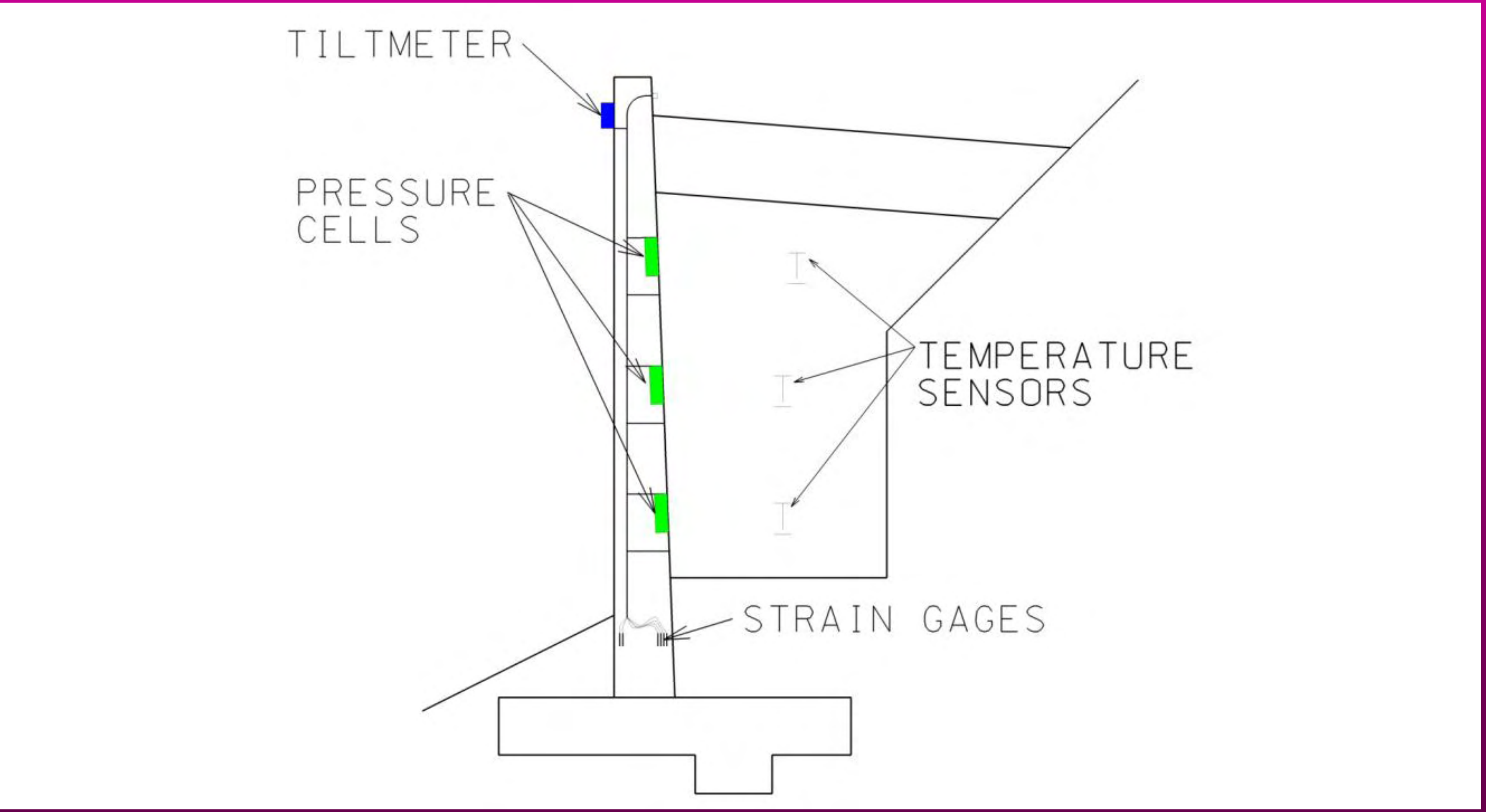
Placing TDA

Compacting TDA

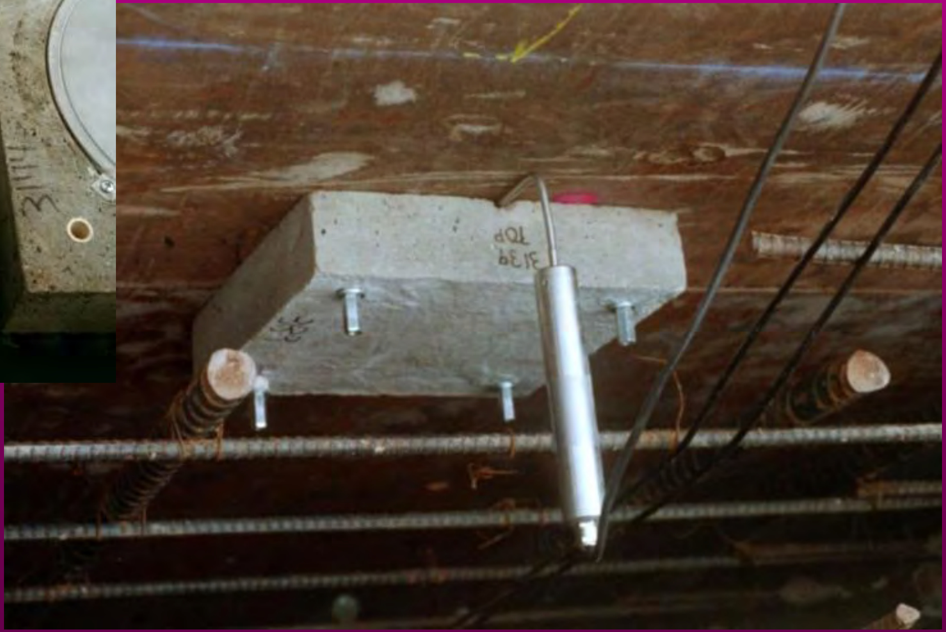
Close-up of TDA

Placing soil cover

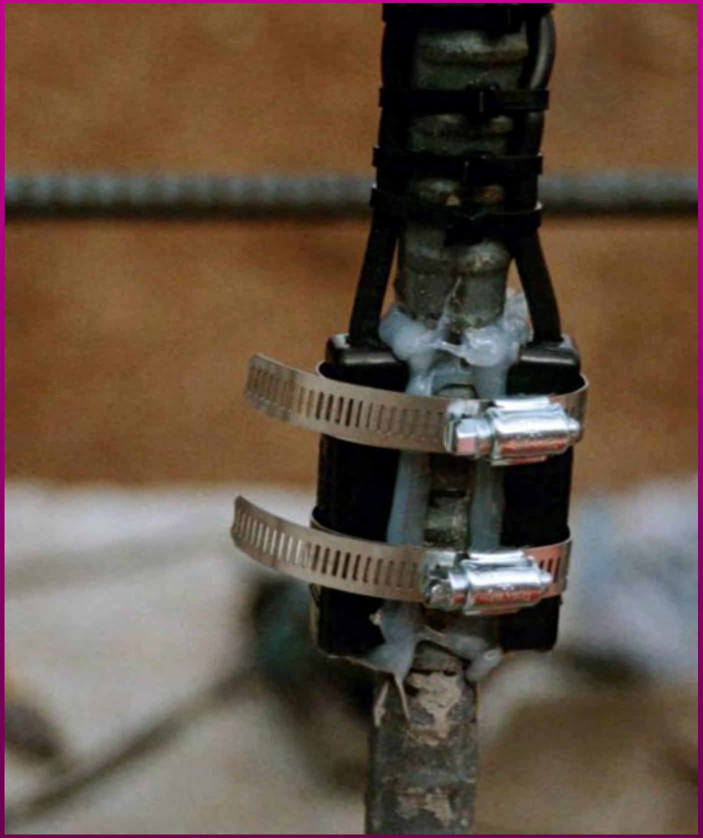
Rt. 91 wall instrumentation



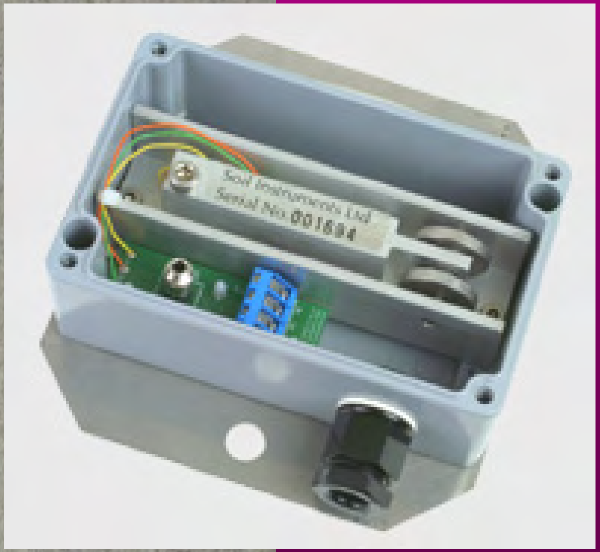
Rt. 91 pressure cells



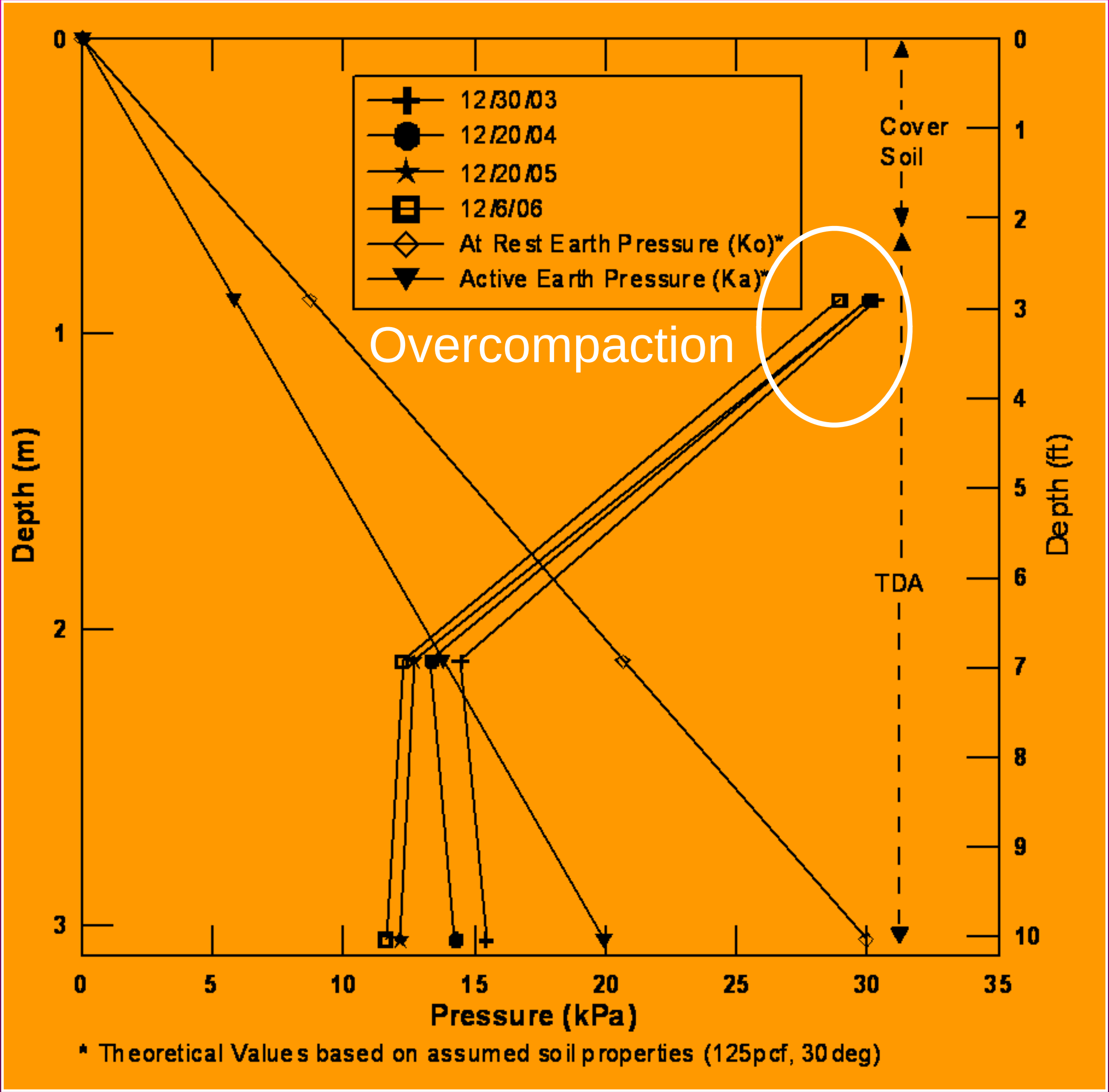
Rt. 91 strain gages



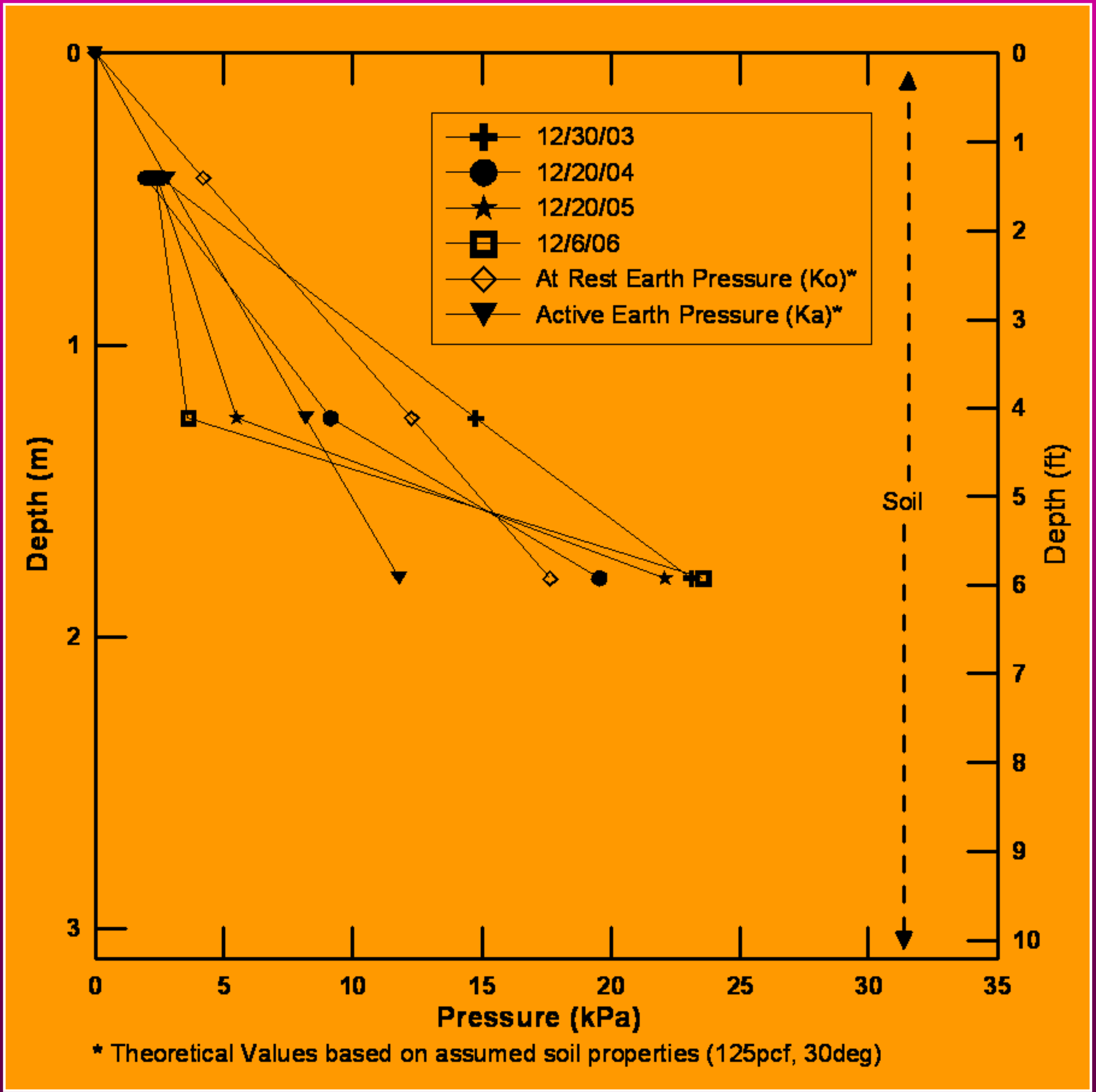
Rt. 91 tilt meters



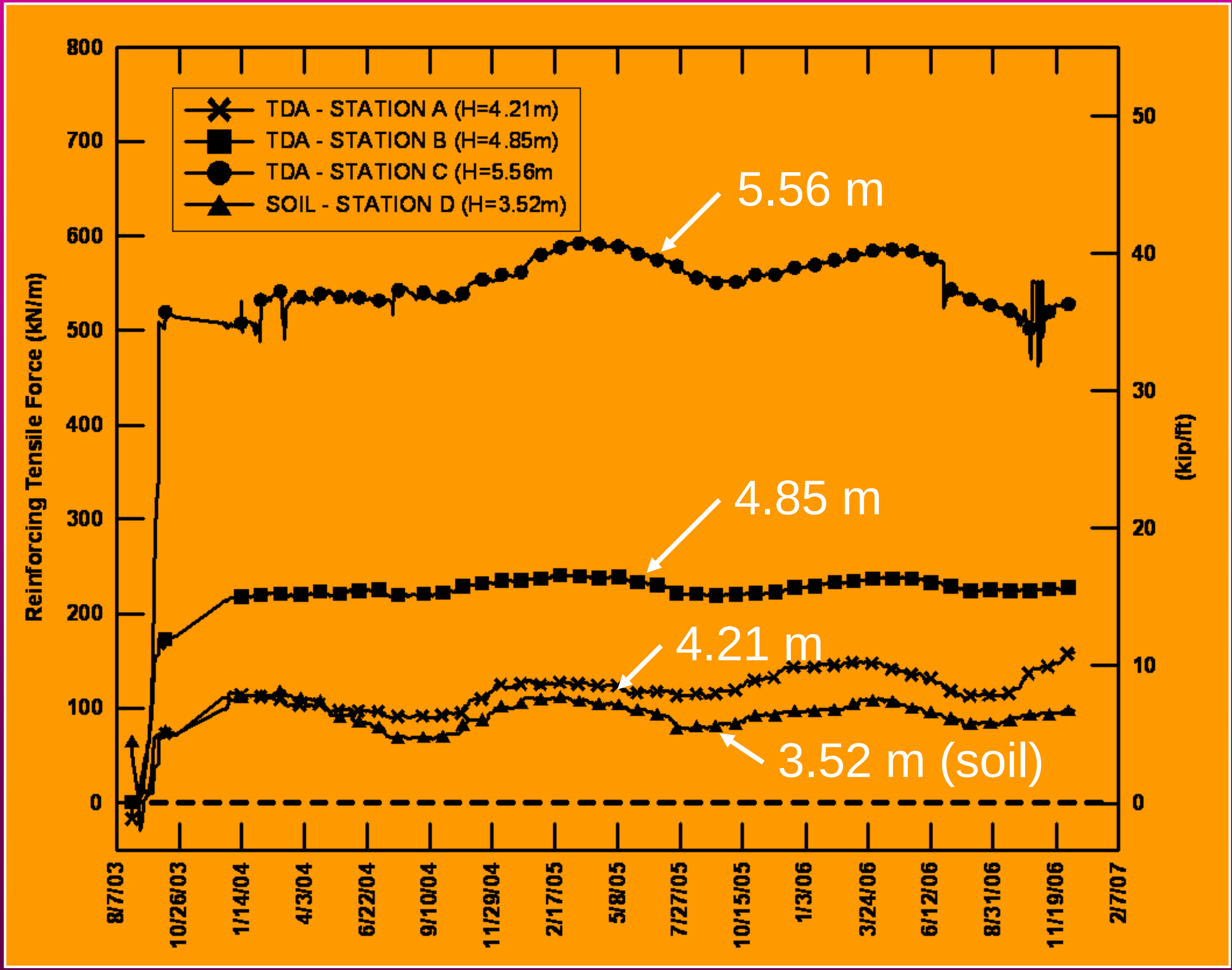
Pressure distribution for TDA



Pressure distribution for soil



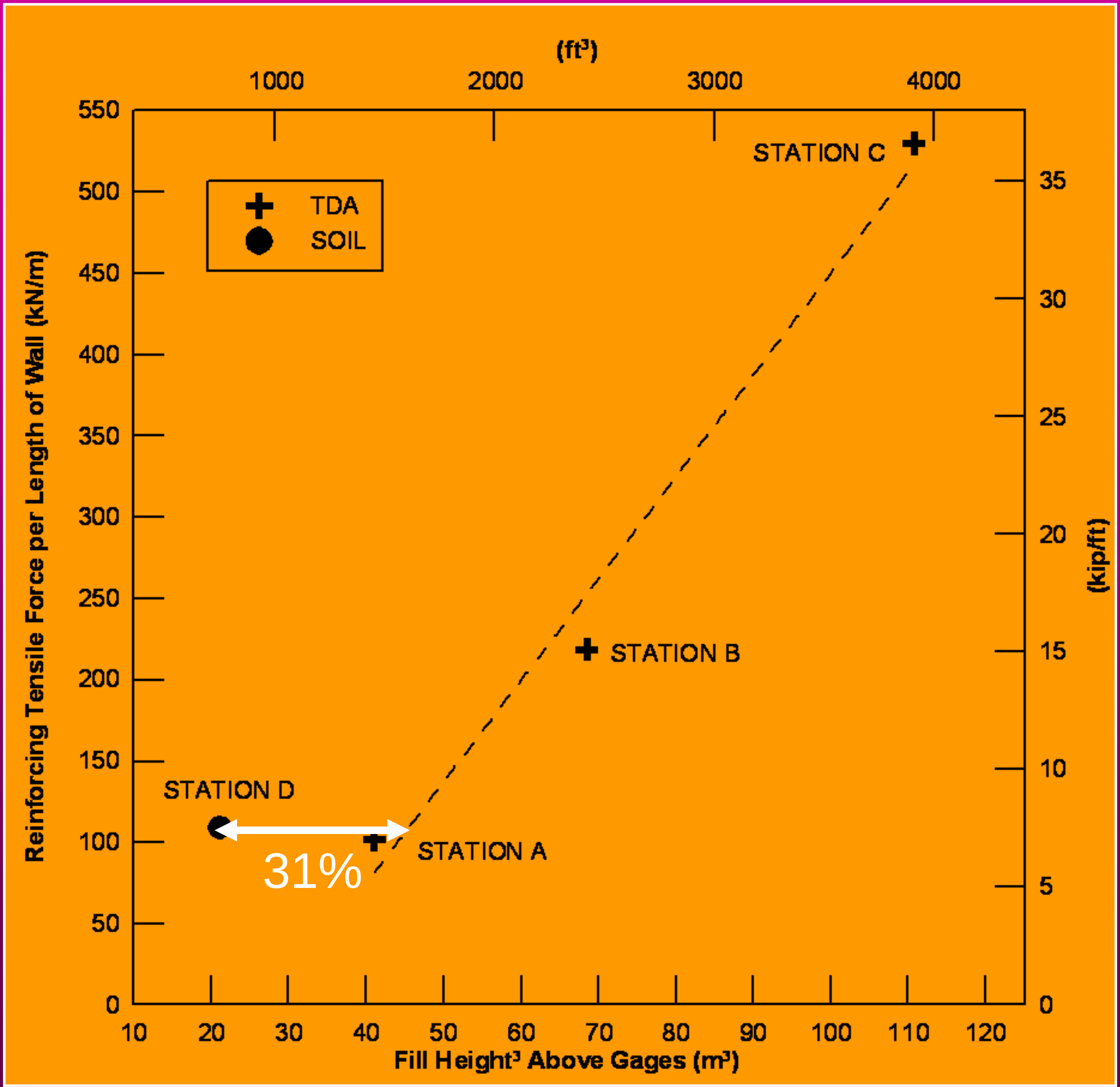
Development of force in tensile reinforcement



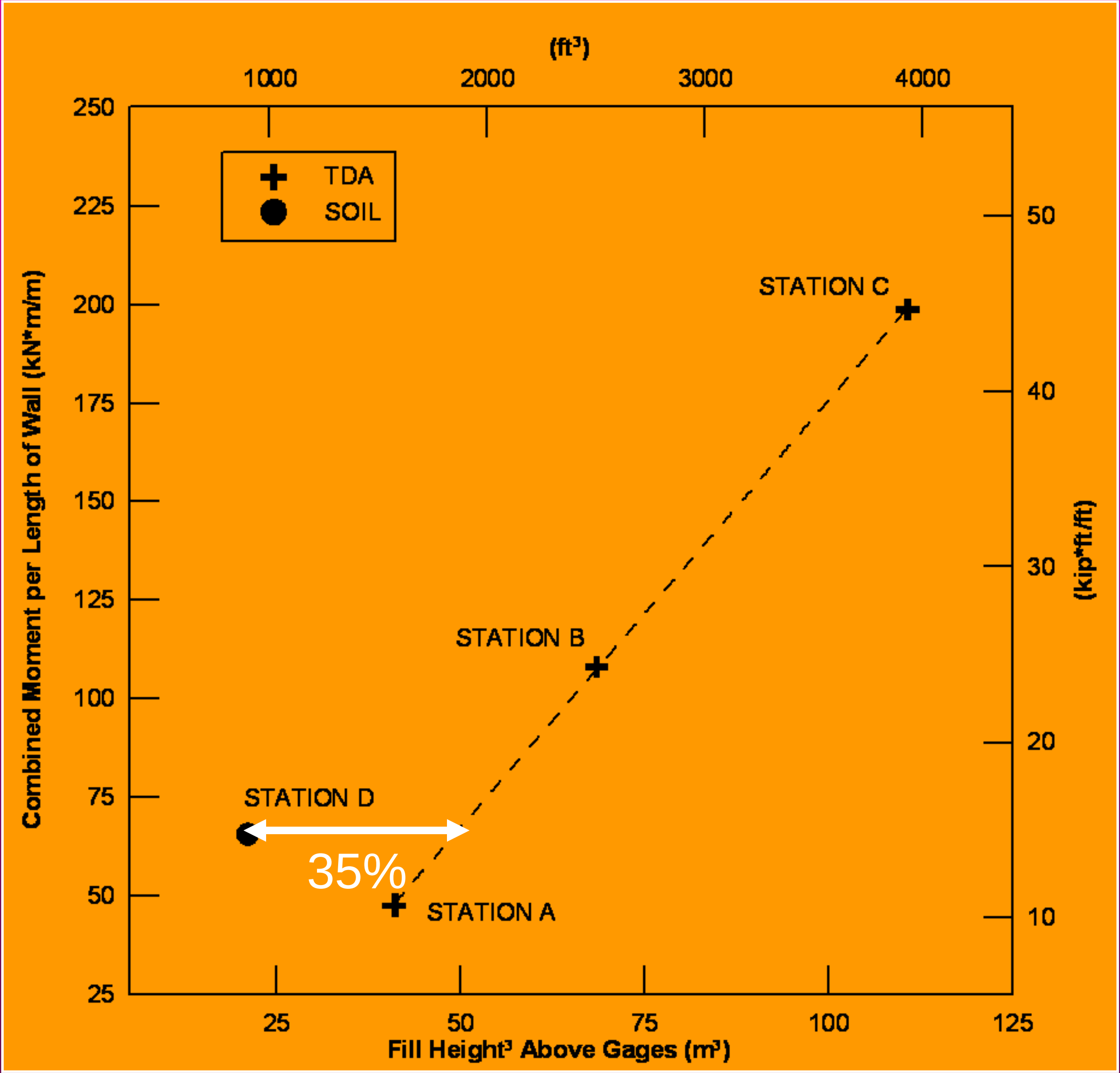
Scaling for wall height

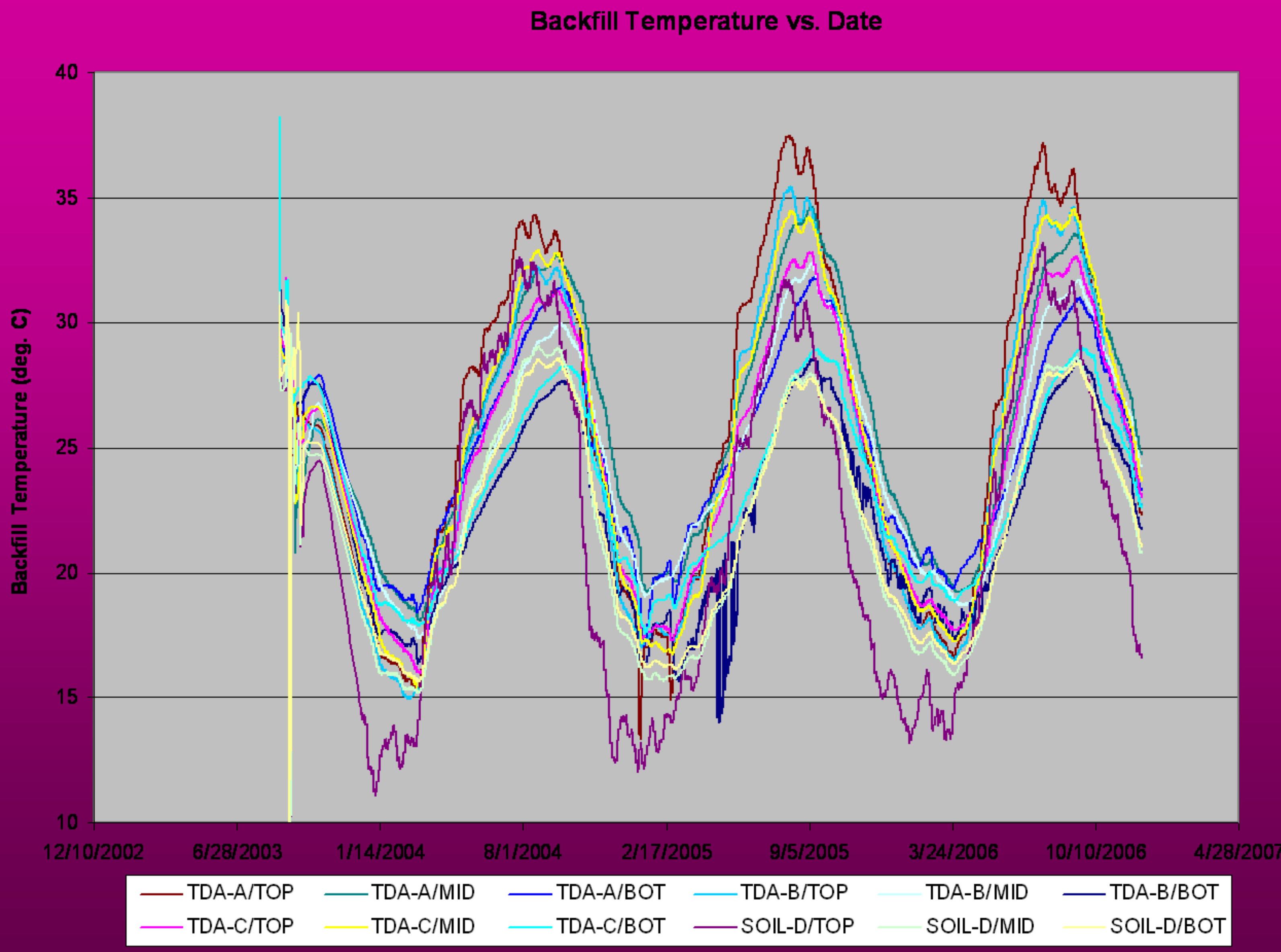
- Resultant force = $0.5K\gamma H^2$
- Moment arm = $(1/3)H$
- Overturning moment = $(1/6)\ \gamma H^3$
- Tensile force and moment in wall stem scales as function of H^3

Force in tensile reinforcement



Moment in wall stem





Backfill Temperature vs. Date
Backfill Temperature (deg. C)
40
35
30
25
20
15
10
12/10/2002
6/28/2003
1/14/2004
8/1/2004
2/17/2005
9/5/2005
3/24/2006
10/10/2006
4/28/2007
TDA-A/TOP
TDA-A/MID
TDA-A/BOT
TDA-B/TOP
TDA-B/MID
TDA-B/BOT
TDA-C/TOP
TDA-C/MID
TDA-C/BOT
SOIL-D/TOP
SOIL-D/MID
SOIL-D/BOT

Wall 207 Riverside, California

- Four instrumented sections
  - – Section A (control) 24 ft high
  - – Section B (TDA) 23 ft high
  - – Section C (TDA) 13 ft high
  - – Section D (Control) 13 ft high

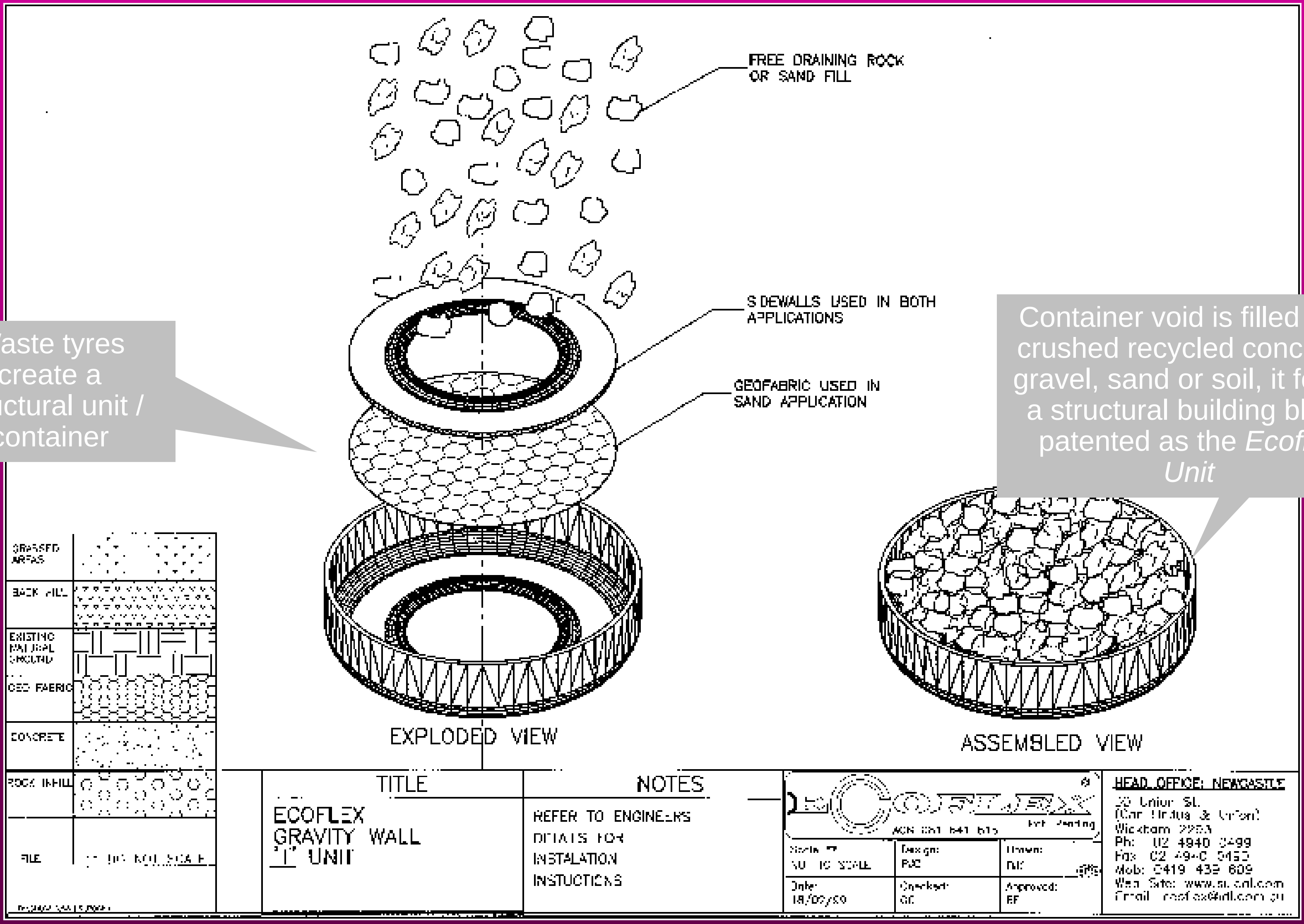
Recommendations based on five wall projects

- Recommendations apply to the following conditions:
  - Cast in place concrete cantilever retaining walls
  - Wall heights: 13 to 24 ft
  - Soil cover thickness: 2 to 6 ft
  - Single TDA layer up to 10 ft thick

Recommendations based on five wall projects

- In-place unit weight of TDA = 50 pcf
- Use earth pressure coefficient of 0.3
- Use equivalent fluid pressure of 15 pcf
- For typical wall – 24% reduction in tensile steel

Ecoflex System



Waste tyres create a structural unit / container

Container void is filled with crushed recycled concrete, gravel, sand or soil, it forms a structural building block patented as the *Ecoflex Unit*

Epave System

Ecopave System

Epave System

Ecowall Systems

Ecowall System

E-rosion Systems

TDA FOR LANDFILL CONSTUCTION

Why use TDA for landfill construction?

- High permeability
- Cost savings
- Recycling (> 90,000 tires/acre)

Where can you use TDA in a landfill?

- Leachate collection system
- Protection layer
- Gas collection trenches
- Leachate recirculation trenches
- Cover system
- Gas collection layer

Use of TDA in Leachate Collection System

Key players:

Pasquale S. Canzano, P.E.

Delaware Solid Waste Authority

John J. Wood, P.E.

Camp Dresser and McKee

Joseph R. Matteo

Magnus Environmental Corp.

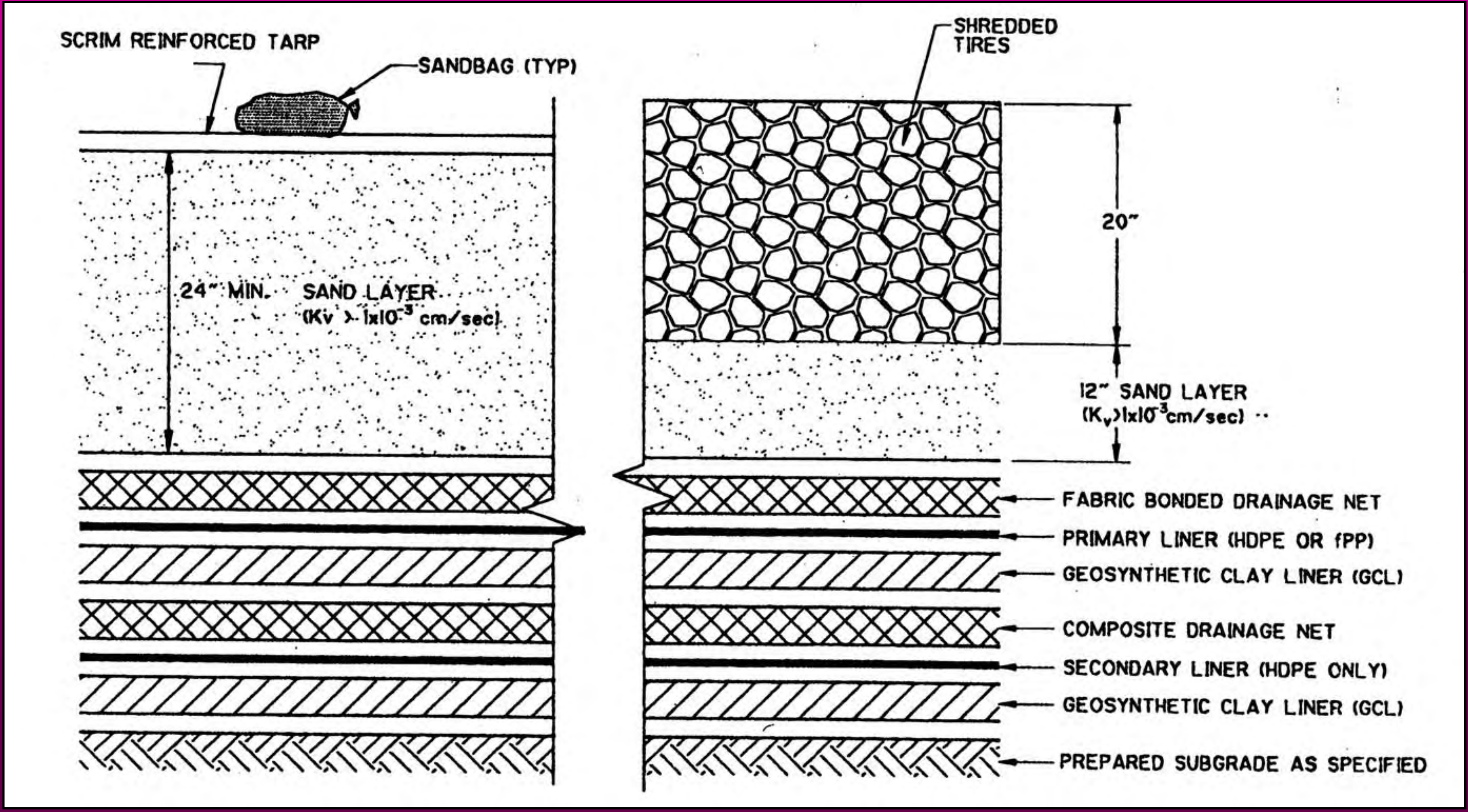
Dana N. Humphrey,P.E.

University of Maine

TDA in the leachate collection layer

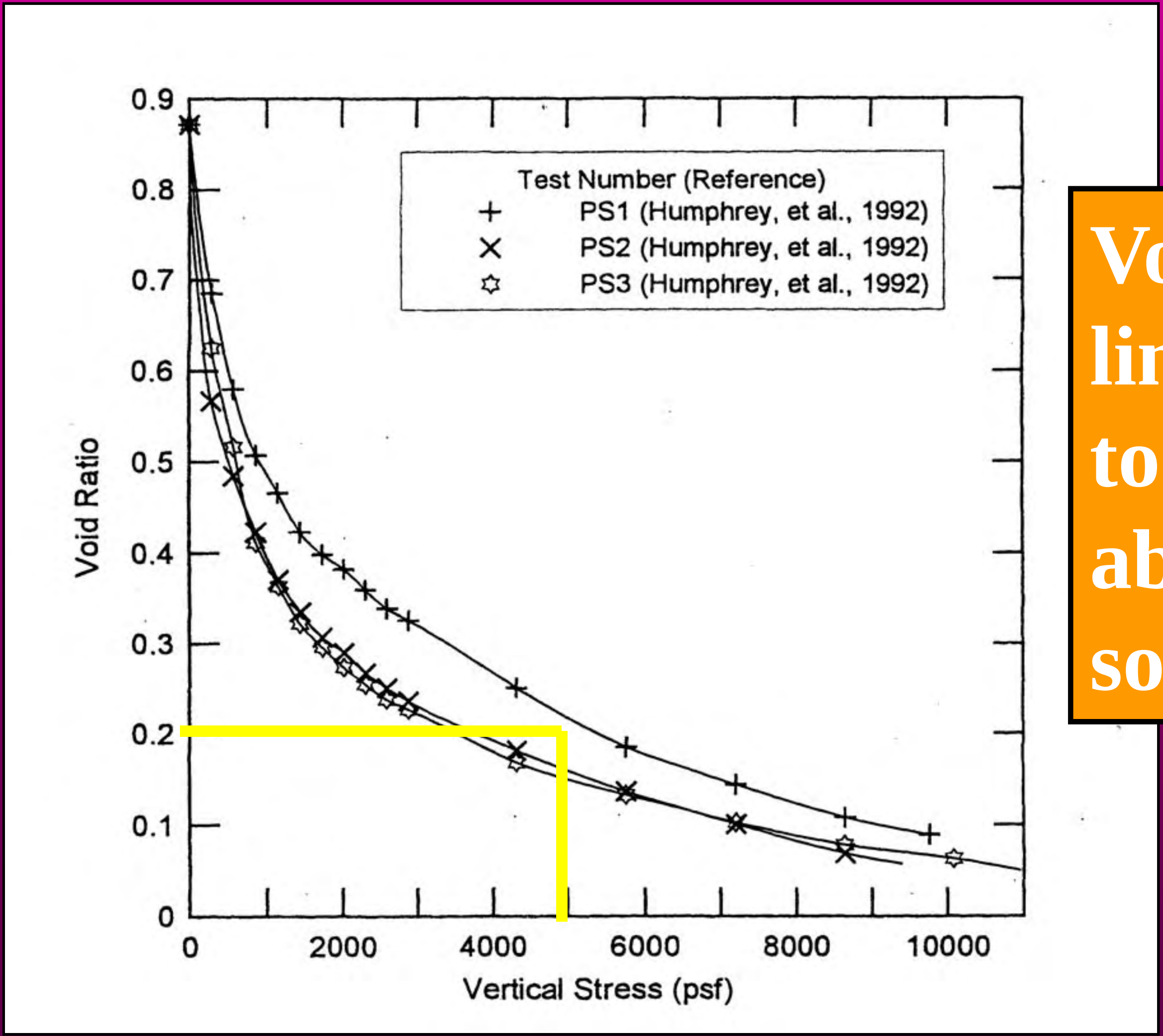
- Use TDA in drainage layer
  - Drainage is important!
- Need to maintain a permeability similar to sand
- Used more than 1 million tires

Replace of a portion of the sand in the leachate collection layer



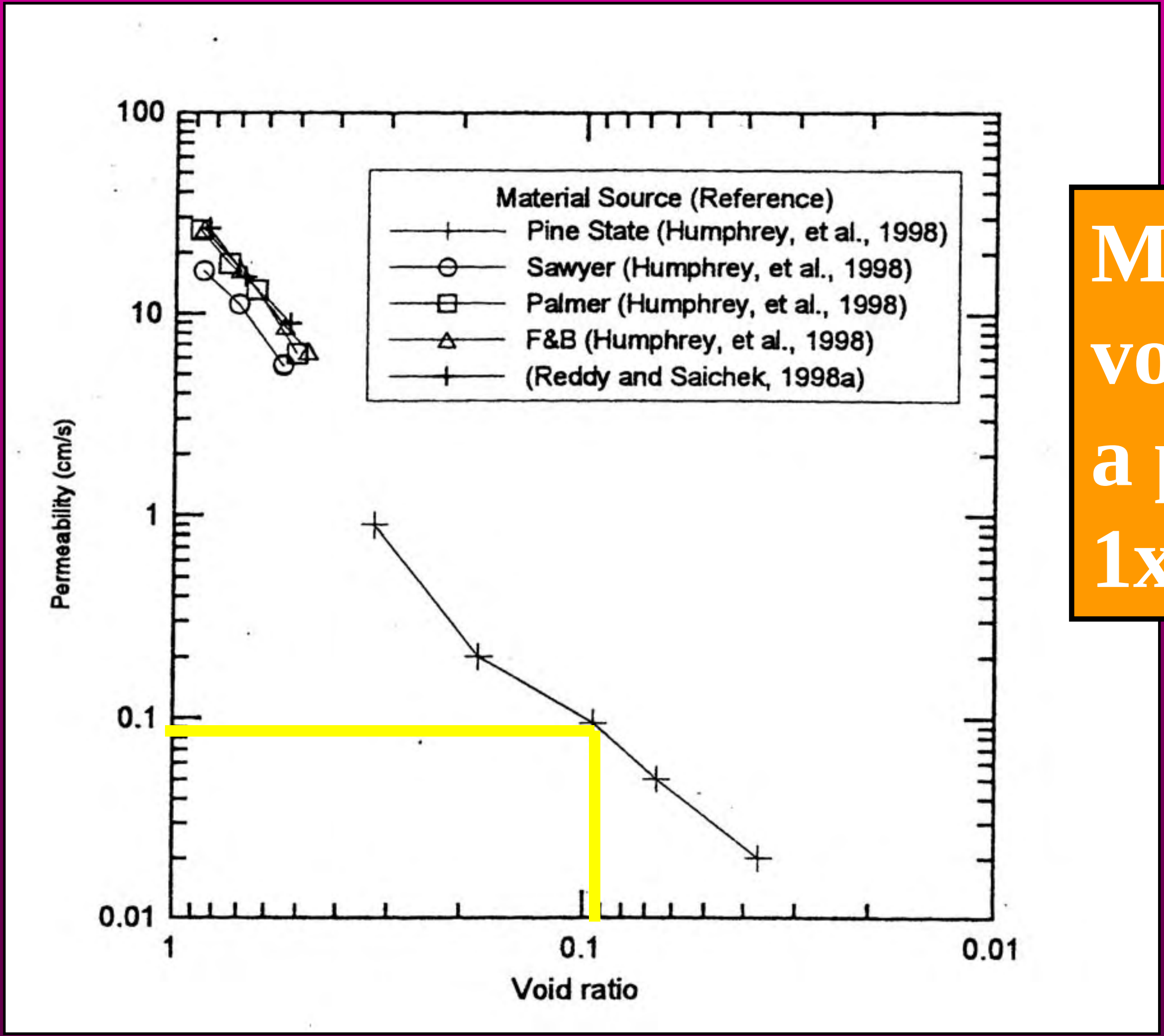
Size of TDA

Effect of vertical stress on void ratio



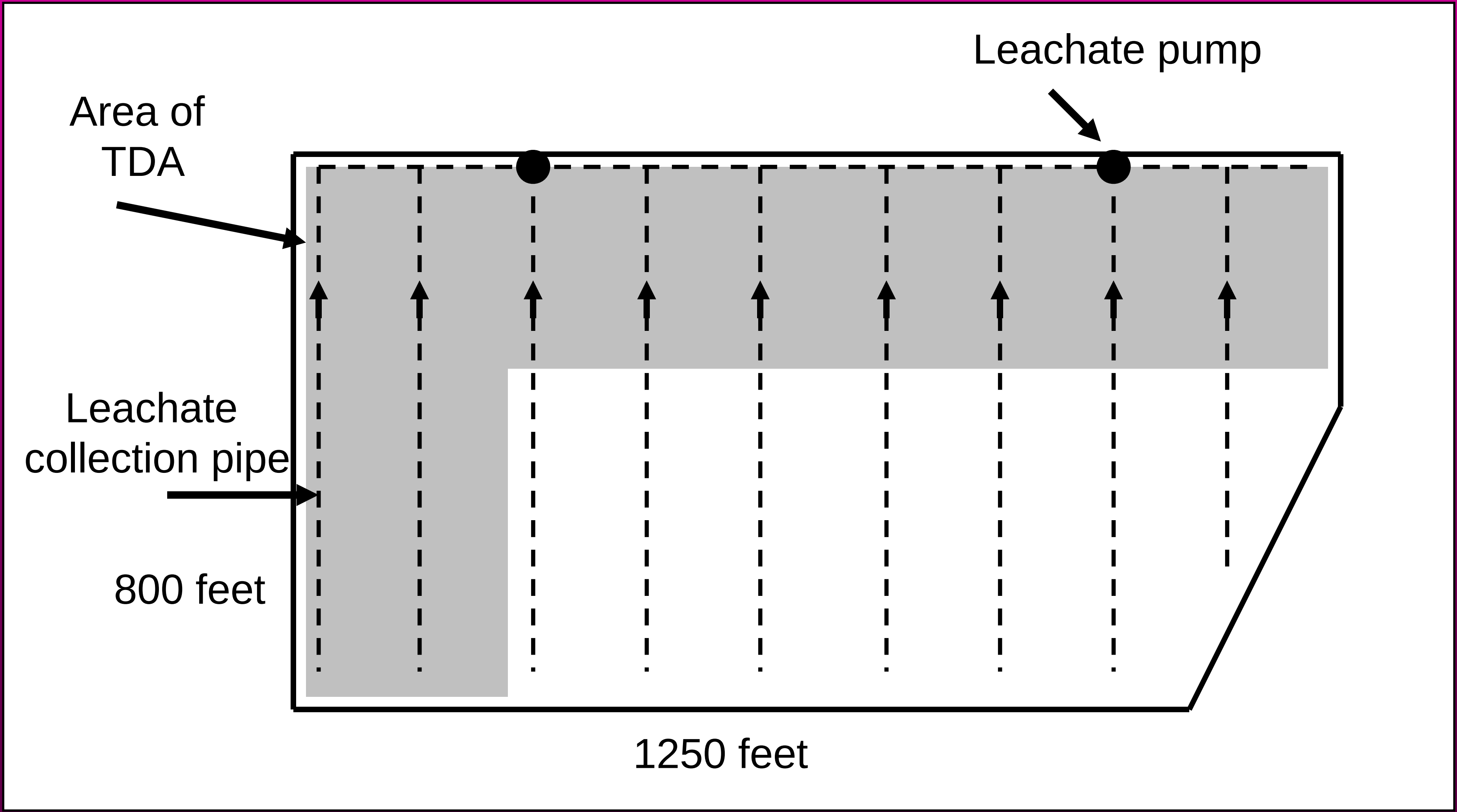
Void ratio of 0.2 limits vertical stress to 5,000 psf or about 67 feet of solid waste

Relationship between permeability and void ratio



Material with a void ratio of 0.2 has a permeability of 1x1^{-1} cm/sec

Use of TDA



Leachate pump
Area of TDA
Leachate collection pipe
800 feet
1250 feet

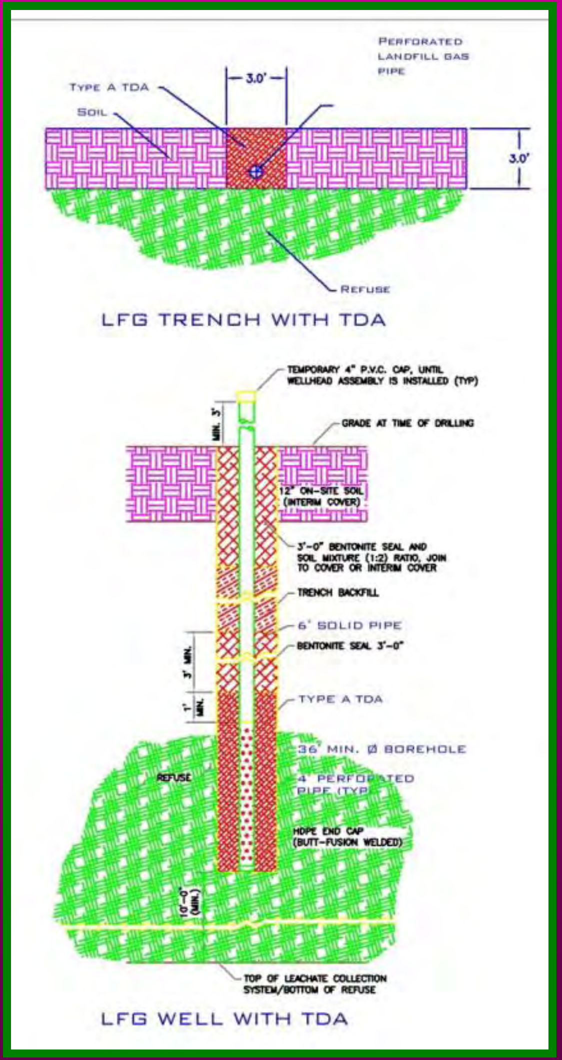
Results of bid process

Contractor	Sand ($/cy)	Tire Shreds ($/cy)
A	$ 8.33	$ 7.88
B	$ 11.25	$ 12.75
C	$ 11.60	$ 20.93
D	$ 11.25	$ 12.75
E	$ 9.00	$ 10.50
F	$ 18.00	$ 54.00
G	$ 15.00	$ 12.00
Average	$ 12.06	$ 18.69

Results of bid process excluding one contractor

Contractor	**Sand ($/cy)**	**Tire Shreds ($/cy)**
A	$ 8.33	$ 7.88
B	$ 11.25	$ 12.75
C	$ 11.60	$ 20.93
D	$ 11.25	$ 12.75
E	$ 9.00	$ 10.50
F	$ 18.00	$ 54.00
G	$ 15.00	$ 12.00
Average	$ 11.07	$ 12.80

Landfill Gas Collection Trenches, Replace Gravel w/Type A TDA



- Type A for Gravel Replacement
- Oversize Auger for Vertical Wells
- Geotextile separator between TDA and Soil or Fine Material

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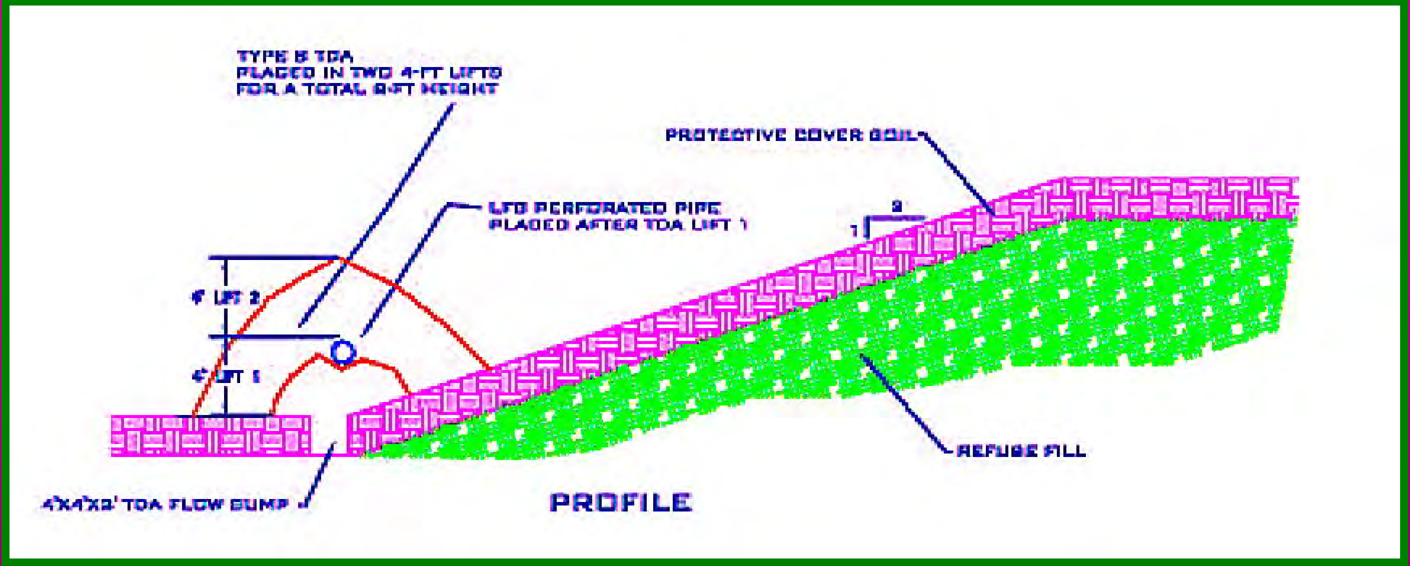
Gas Collection System, Trench-less, Type B TDA



- High Permeability
- Cost savings
- Recycling (100 Tires = 1.5 cy)

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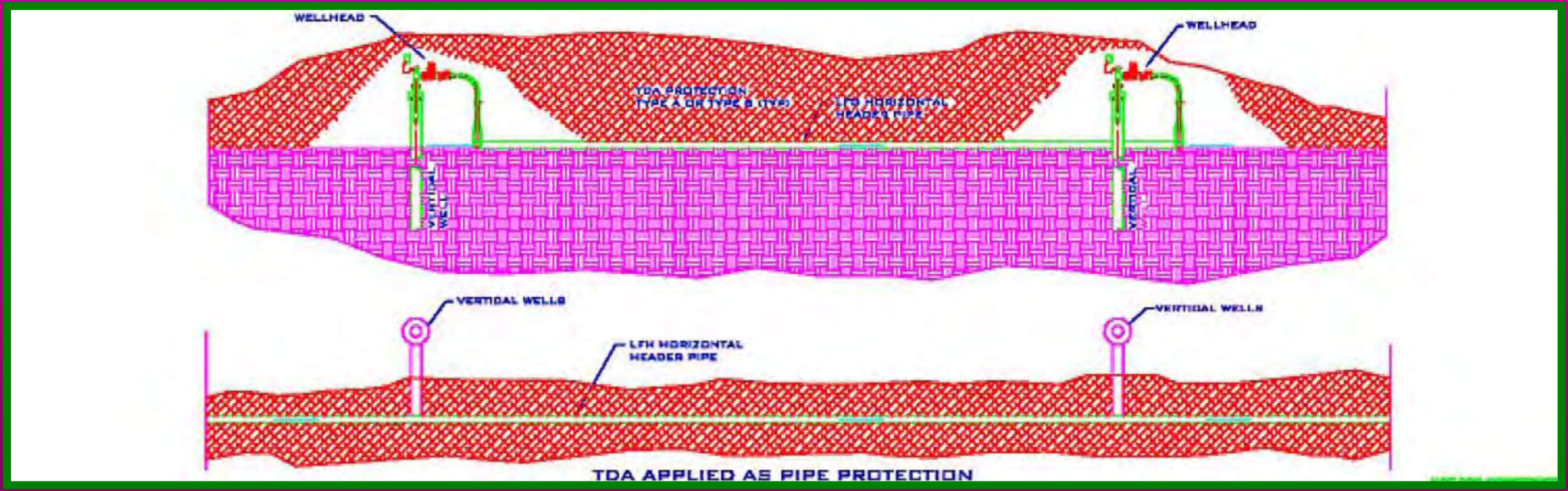
Gas Collection System, Pipe Protection, Type B TDA



- Header Pipe Protection
- Cost savings
- Recycling (100 Tires = 1.5 cy)

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Gas Collection System, Pipe Protection, Type B TDA

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Conclusions

- TDA has properties that engineers need
- TDA is cost effective
- Small projects use large number of tires
- Specifications and guidelines available
- Negligible environmental effects


QUESTIONS?