Unbound Pavement Applications of Excess Foundry System Sands: Subbase/Base Material

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RMRC

Participant Job Description

Which of the following describes your job?

- Civil Engineer or Environmental Engineer
- Geologist
- Foundry Operator
- Transportation Materials Engineer
- Construction Manager

Paricipant Background

- Private sector
- Public sector
- Planner
- Designer
- Regulator
- Contractor
- Marketing

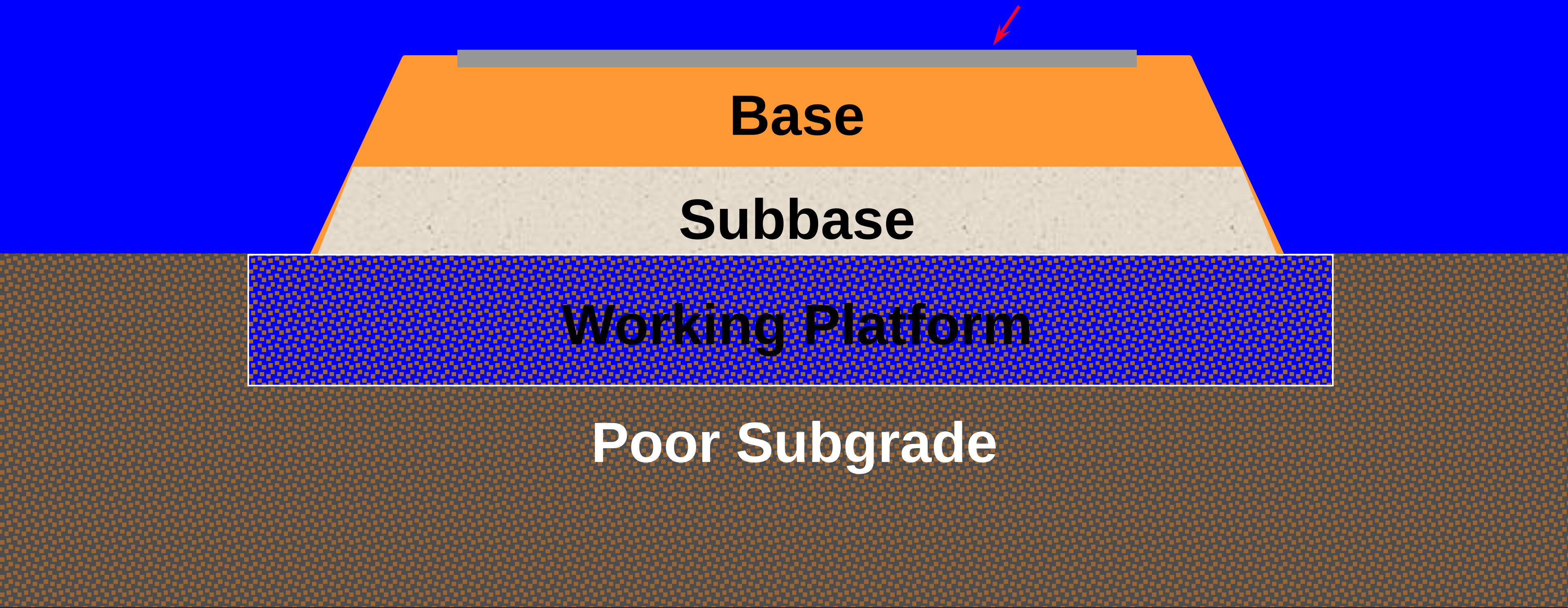
UNBOUND PAVEMENT APPLICATIONS OF ESS

Roadway structural systems

- Working Platform
- Subbase

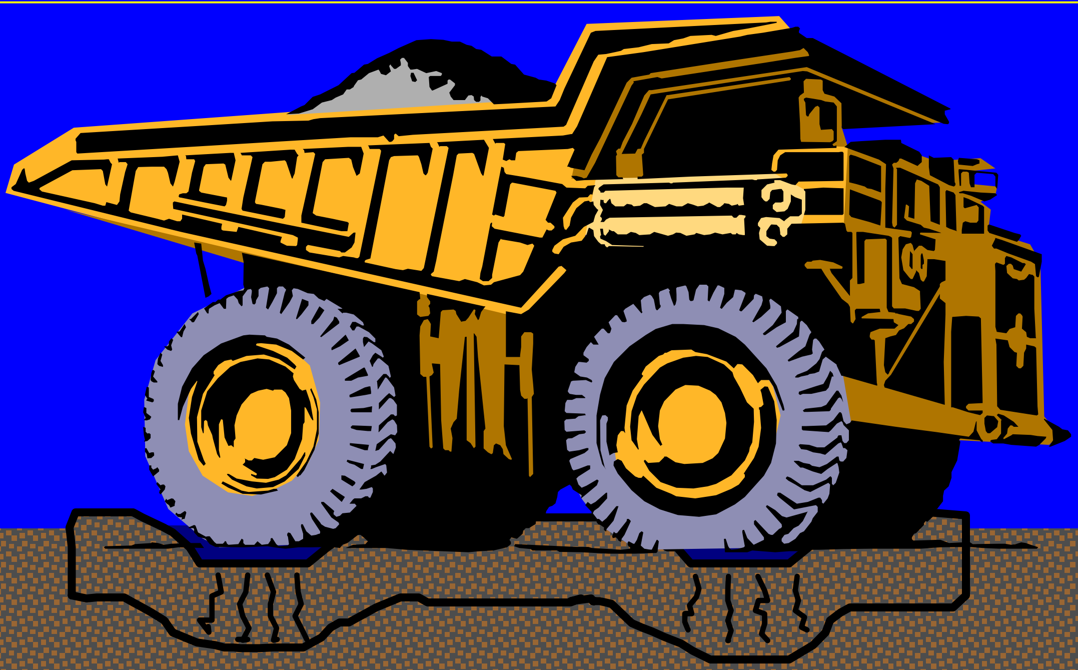
INTRODUCTION

Majority of the paved roads in the United States constructed with **FLEXIBLE PAVEMENTS**



Deformation during construction on soft subgrade :

- Impede construction equipment
- Complicate placement of subbase, base, and asphalt
- *requires working platform*



Soft Subgrade

According to Tensar (1989) the soft subgrade problems can be as bad as this!!

Questions:

- How to determine thickness of working platform to limit total deflection to a certain value under construction traffic

- How to determine the thickness of working platform constructed with foundry sands

WORKING PLATFORM EQUIVALENCY SELECTION METHOD

Equivalency as defined in this research requires that total deflection of the alternative material (δ_{ta}) equal to that of breaker run (δ_{tb}) under the same load at 1000 cycles over soft subgrade.

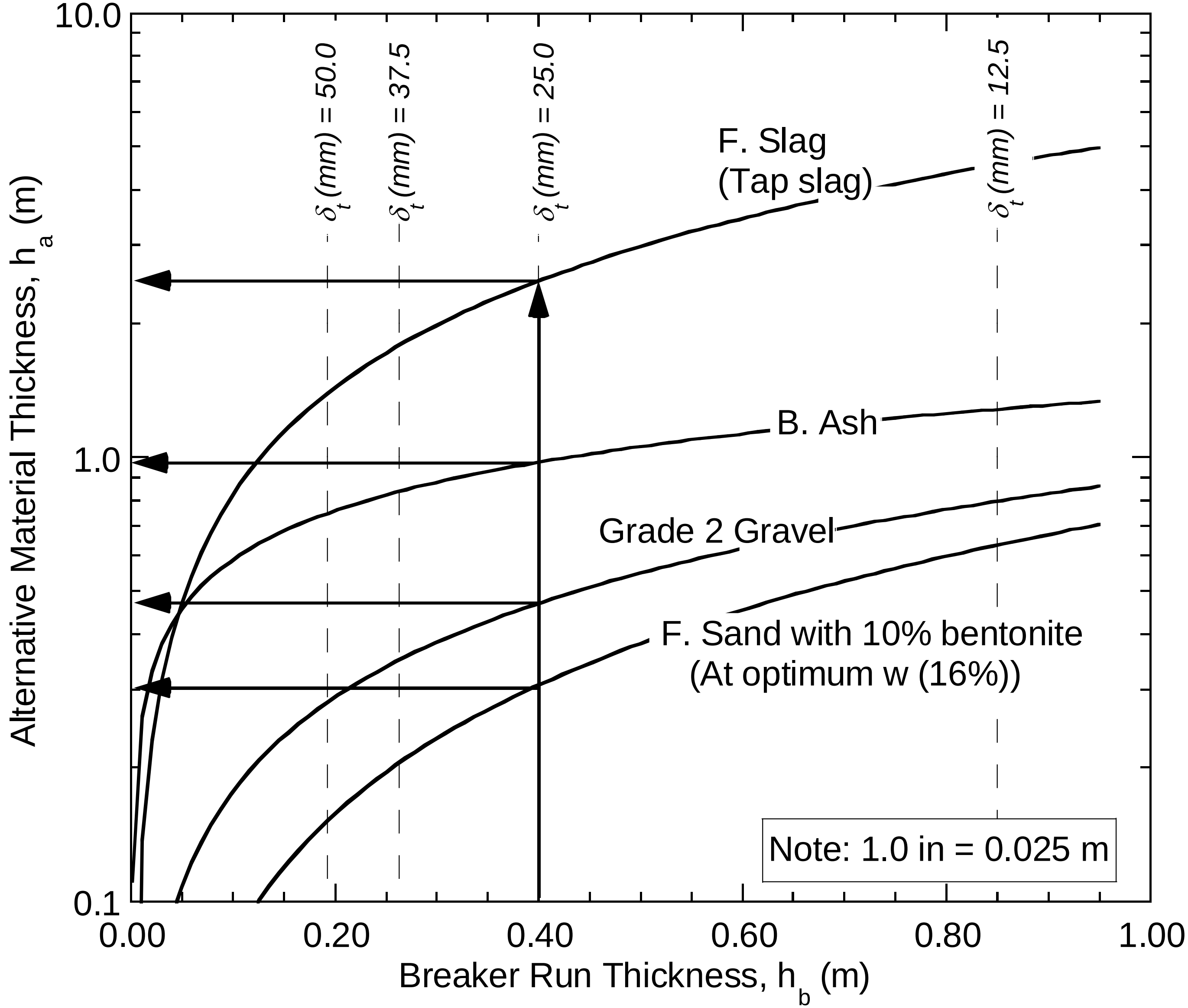
METHODOLOGY TO SELECT THICKNESS OF WORKING PLATFORM BASED ON δ_t

A chart is developed showing:

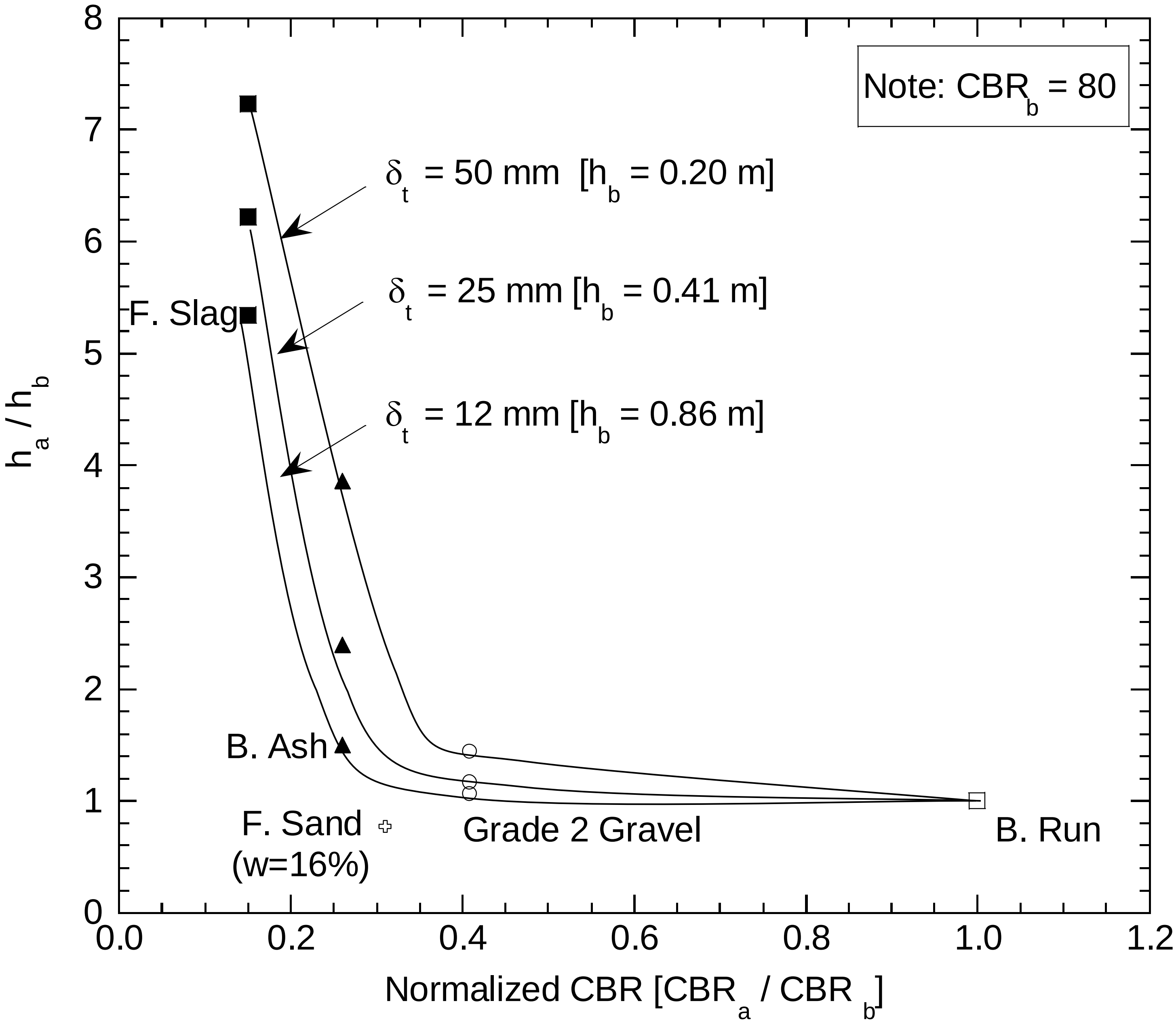
- The thickness of each working platform material to limit δ_t to a certain value

- Equivalency between breaker run and alternative materials in terms of δ_t ($\delta_{t\text{-alternative materials}} = \delta_{t\text{-breaker run}}$)

Design Chart Relating Thicknesses



Foundry Byproduct	Water Content	Thickness in meters (inches in parenthesis) to limit total deflections to 25 mm (1 in)
Foundry Sand	21%	1.81 (71)
Foundry Sand	16%	0.32 (13)
Foundry Slag	Not sensitive to water content	2.55 (100)



Note: CBR_b = 80
δ_t = 50 mm [h_b = 0.20 m]
δ_t = 25 mm [h_b = 0.41 m]
δ_t = 12 mm [h_b = 0.86 m]
F. Slag
B. Ash
F. Sand
(w=16%)
Grade 2 Gravel
B. Run
h_a / h_b
Normalized CBR [CBR_a / CBR_b]
0
1
2
3
4
5
6
7
8
0.0
0.2
0.4
0.6
0.8
1.0
1.2

Recap

- What are the requirements for a working platform over soft subgrade: (a) limit total deflections, (b) allow heavy construction traffic without getting bogged down, (c) achieve this only during construction, (d) all of the above?
- True or false: foundry sand bentonite content is not important
- True or false: foundry sand water content is important during construction

OBJECTIVES OF EES AS SUBBASE OF THE ROADWAY STRUCTURAL SYSTEMS STUDY

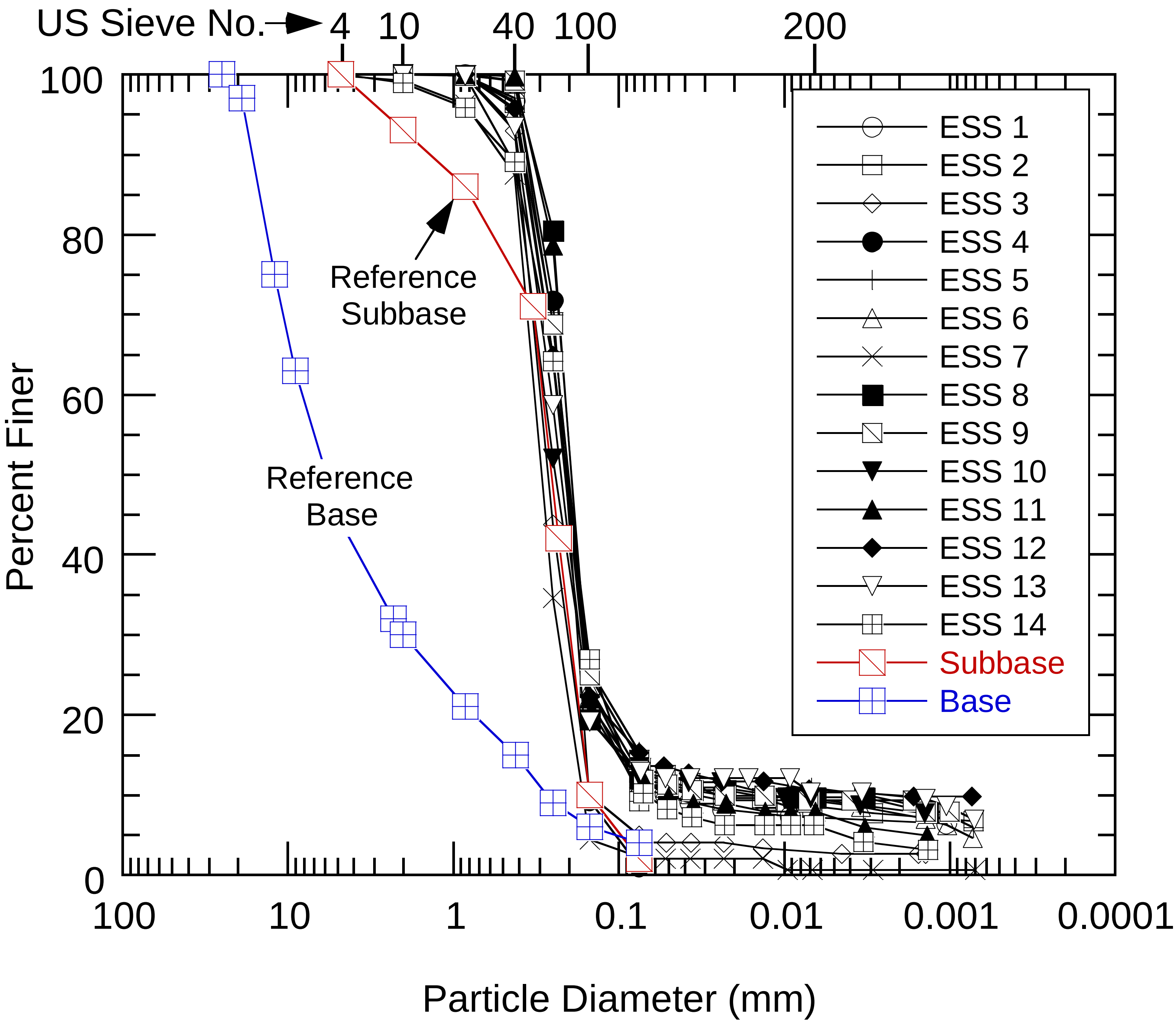
- To catalog pertinent engineering properties of ESS for use in roadway structural system (both as working platform and subbase) and correlate these properties to index properties
- To assess effect of water content and compactive effort on engineering properties.

SCOPE OF THE STUDY

- 12 clay-bonded ESS, 1 chemically bonded ESS, a base sand, and 2 reference materials (meeting WisDOT base and subbase specs) were tested in the laboratory.
- ESS from WI, IL, MI & IN
- Tests Conducted:
  - Index Properties
  - Compaction
  - CBR
  - Unconfined Compression
  - Resilient Modulus

INDEX PROPERTIES

- D_{10} : 0.002 to 0.18 mm
- P_{200} : 1.1 to 16.4%
- Clay Content (< 2 μm) : 0.8 to 10%
- Active Clay Content (methylene blue): 5.1 to 10.2%
- C_u : 1.4 to 130 and C_c : 1.1 to 69
- LL : NP to 27 PI : NP to 8 (required rehydration)
- Particle Roundness: 0.55 to 0.69 (subrounded to subangular)
- G_s : 2.52 to 2.73
- Classify as: SC, SP, or SP-SM or A-2-4 or A-3

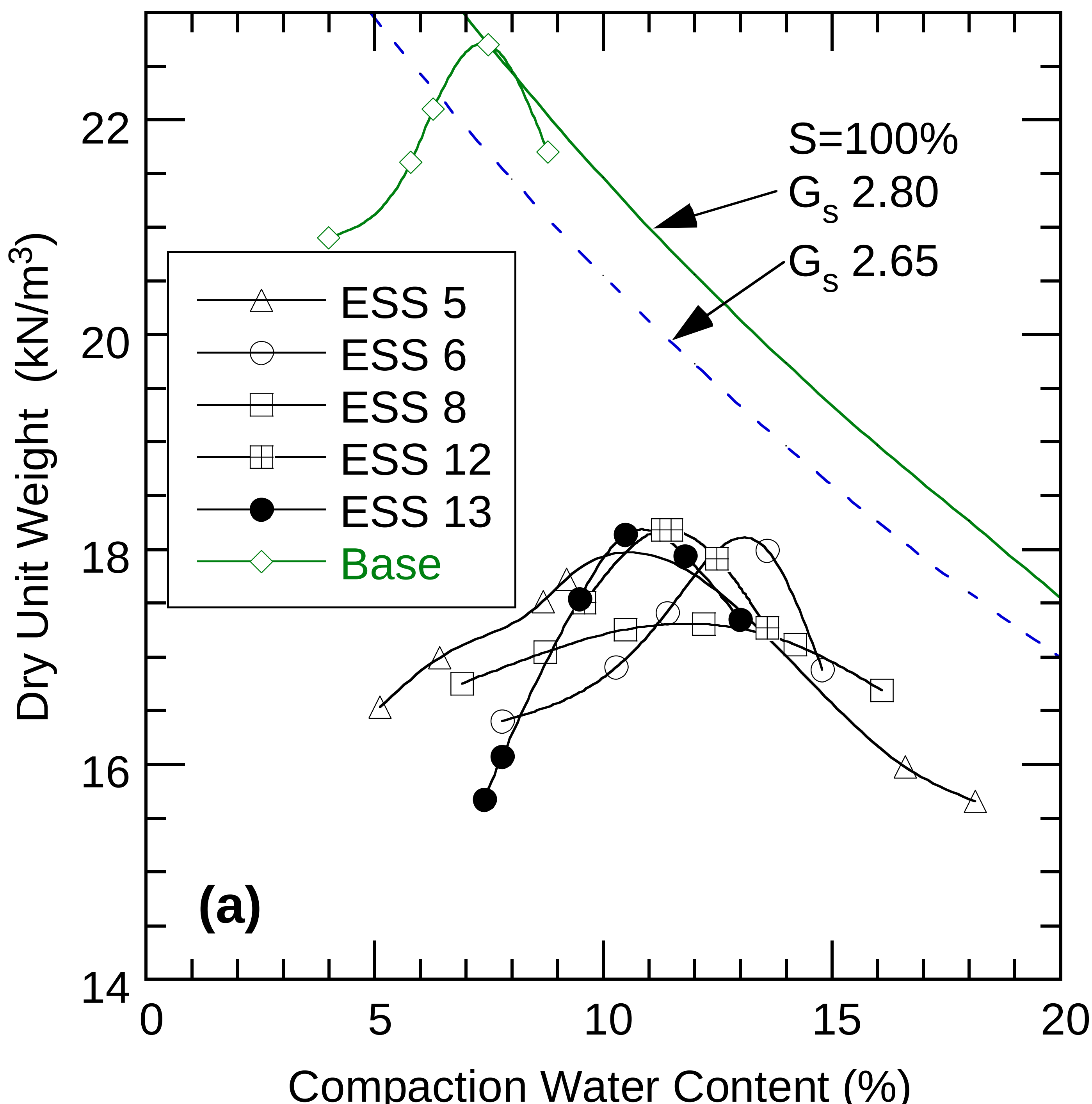

US Sieve No.
4
10
40
100
200
Percent Finer
Particle Diameter (mm)
Reference Subbase
Reference Base
ESS 1
ESS 2
ESS 3
ESS 4
ESS 5
ESS 6
ESS 7
ESS 8
ESS 9
ESS 10
ESS 11
ESS 12
ESS 13
ESS 14
Subbase
Base

Recap

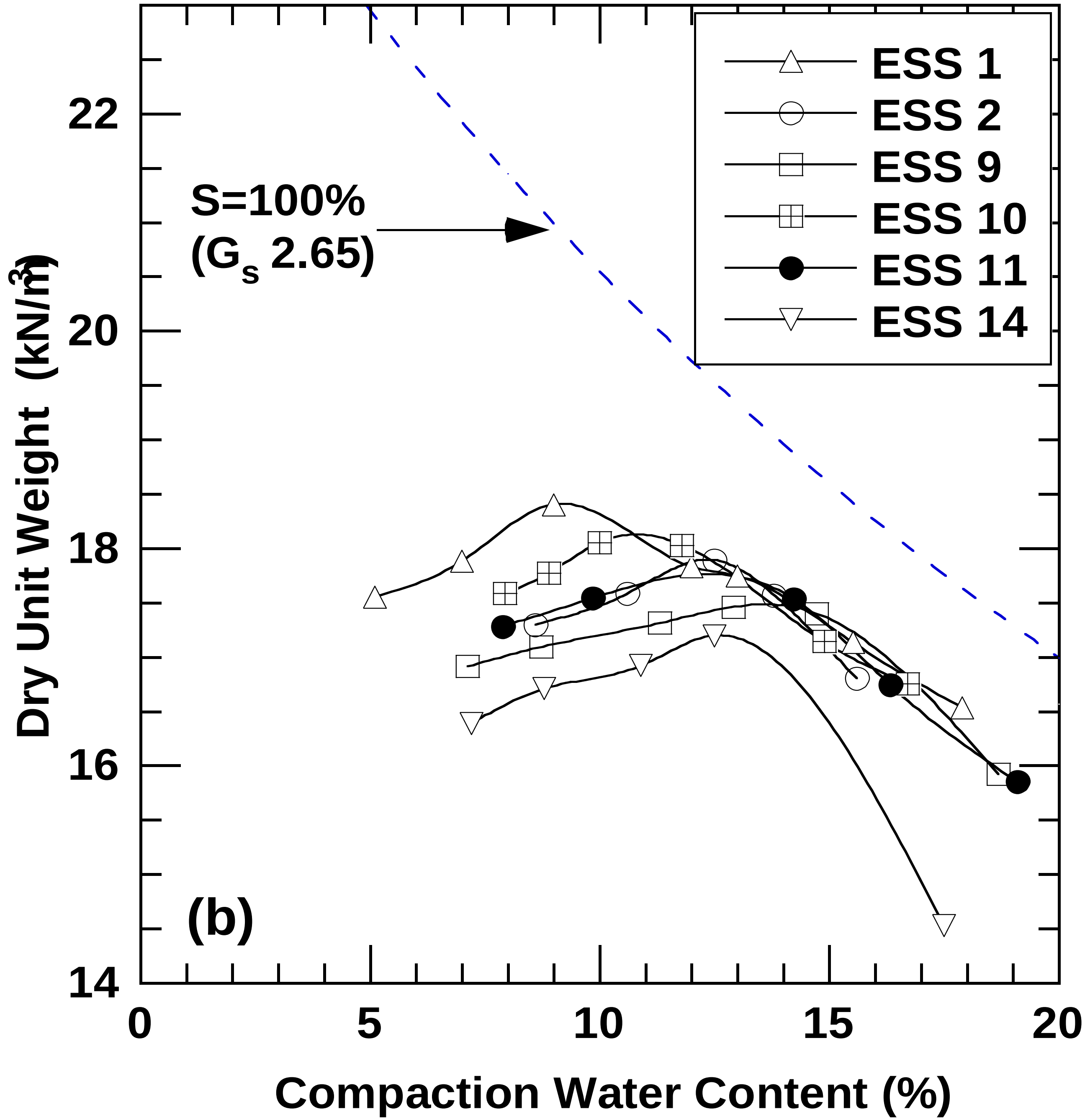
- What is the primary characteristic that varies between foundry sands : (a) sand roundness, (b) fines and clay content, or (c) color?
- True or false: Foundry sands have similar grain size distribution characteristics.
- True or false: Foundry sands are essentially like poorly graded sand or sand with fines.
- True or false: Foundry sand meet the subbase specifications exactly.

COMPACTION CHARACTERISTICS

- Some ESS behave as granular material and some cohesive.
- Hydration of compaction samples for 1 week is needed to reactivate the thermally deactivated clay
- Standard Proctor Maximum Dry Unit Weights: 17.26 to 18.39 kN/m^3
- Optimum Moisture Contents: 9.1 to 13.8%
- Vibratory Table Maximum Dry Unit Weights: 16.55 to 17.60 kN/m^3



S=100%
G_s 2.80
G_s 2.65
ESS 5
ESS 6
ESS 8
ESS 12
ESS 13
Base
(a)
Dry Unit Weight (kN/m^3)
14
16
18
20
22
0
5
10
15
20
Compaction Water Content (%)



ESS 1
ESS 2
ESS 9
ESS 10
ESS 11
ESS 14
S=100%
(G$_s$ 2.65)
(b)
Dry Unit Weight (kN/m^3)
Compaction Water Content (%)
22
20
18
16
14
0
5
10
15
20

CBR

- CBR: 4 to 40 at optimum moisture content with an average 20 (20-30 considered very good for subbase)
- Can be estimated empirically from standard Proctor maximum density, percent fines, and roundness:

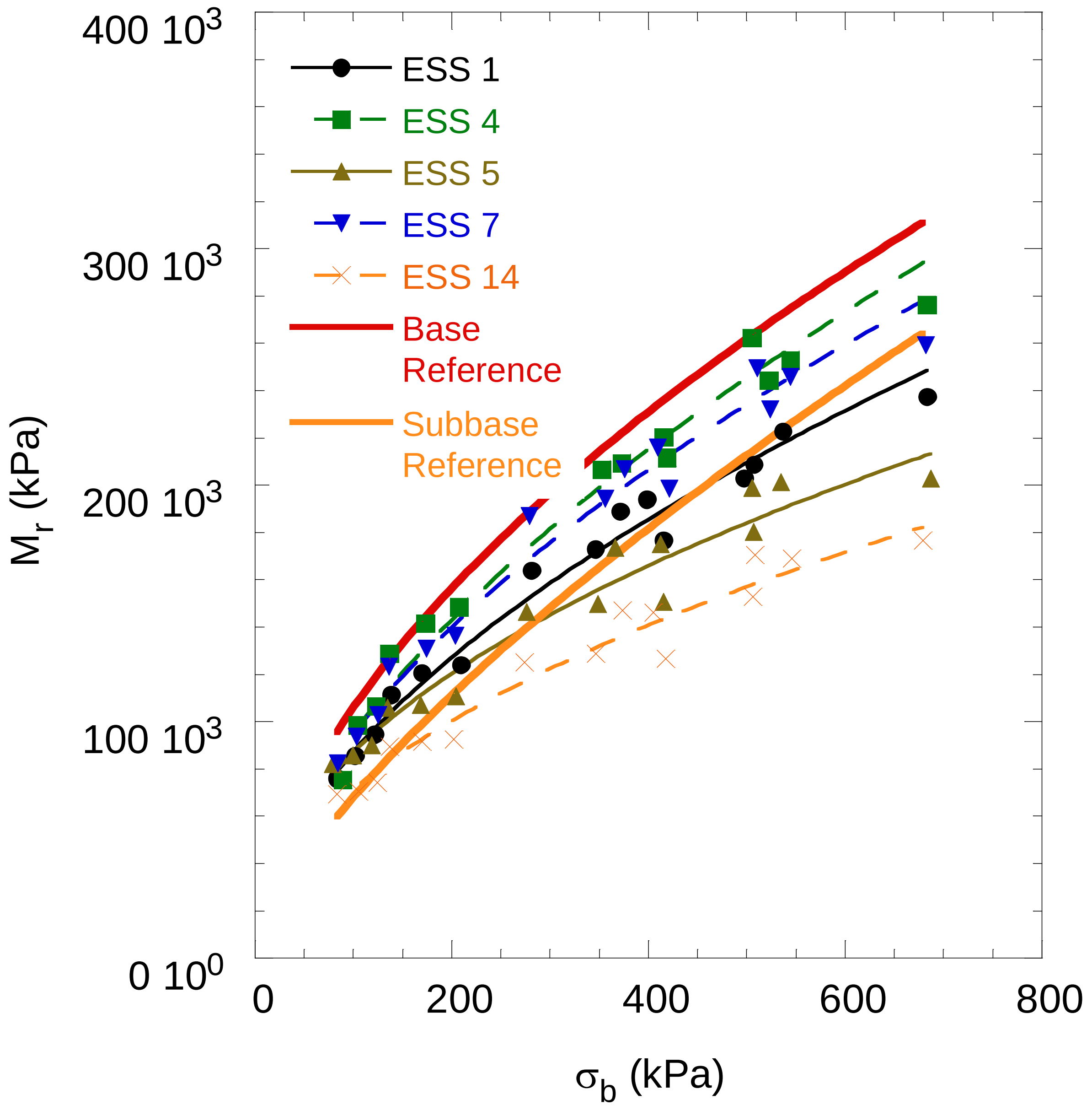
$$CBR = 32.4\gamma_{dm} - 1.93P_{200} - 264R_o - 361$$

- Comparable to reference subbase
- Modified Proctor gives markedly higher CBR

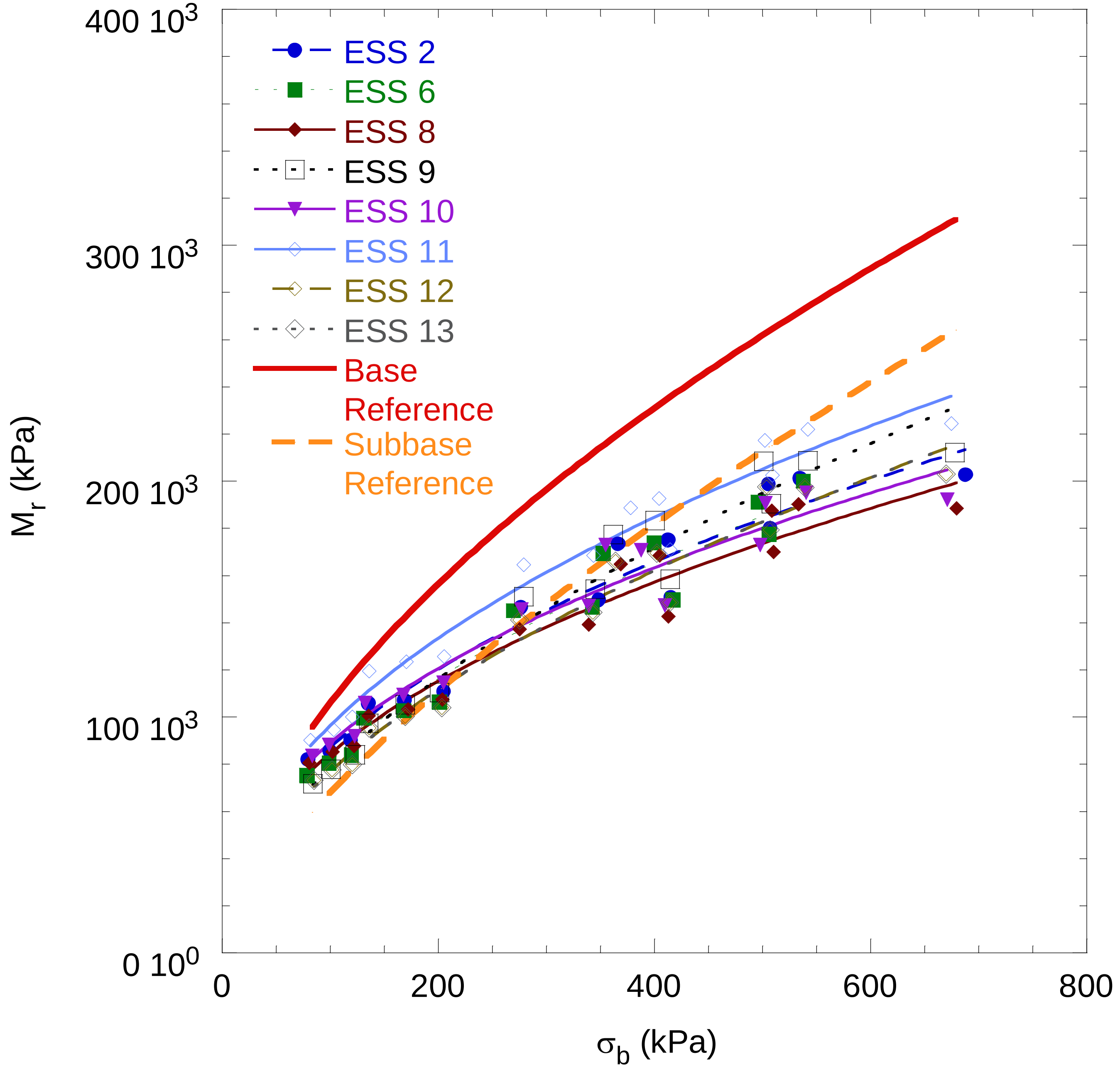
Recap

- True or false: Compaction curves for foundry sands appear very different than those for soils.
- True or false: Standard compaction procedure for soils can be used for foundry sands
- True or false: CBR values for all foundry sands rate as “good quality” for subbase purposes

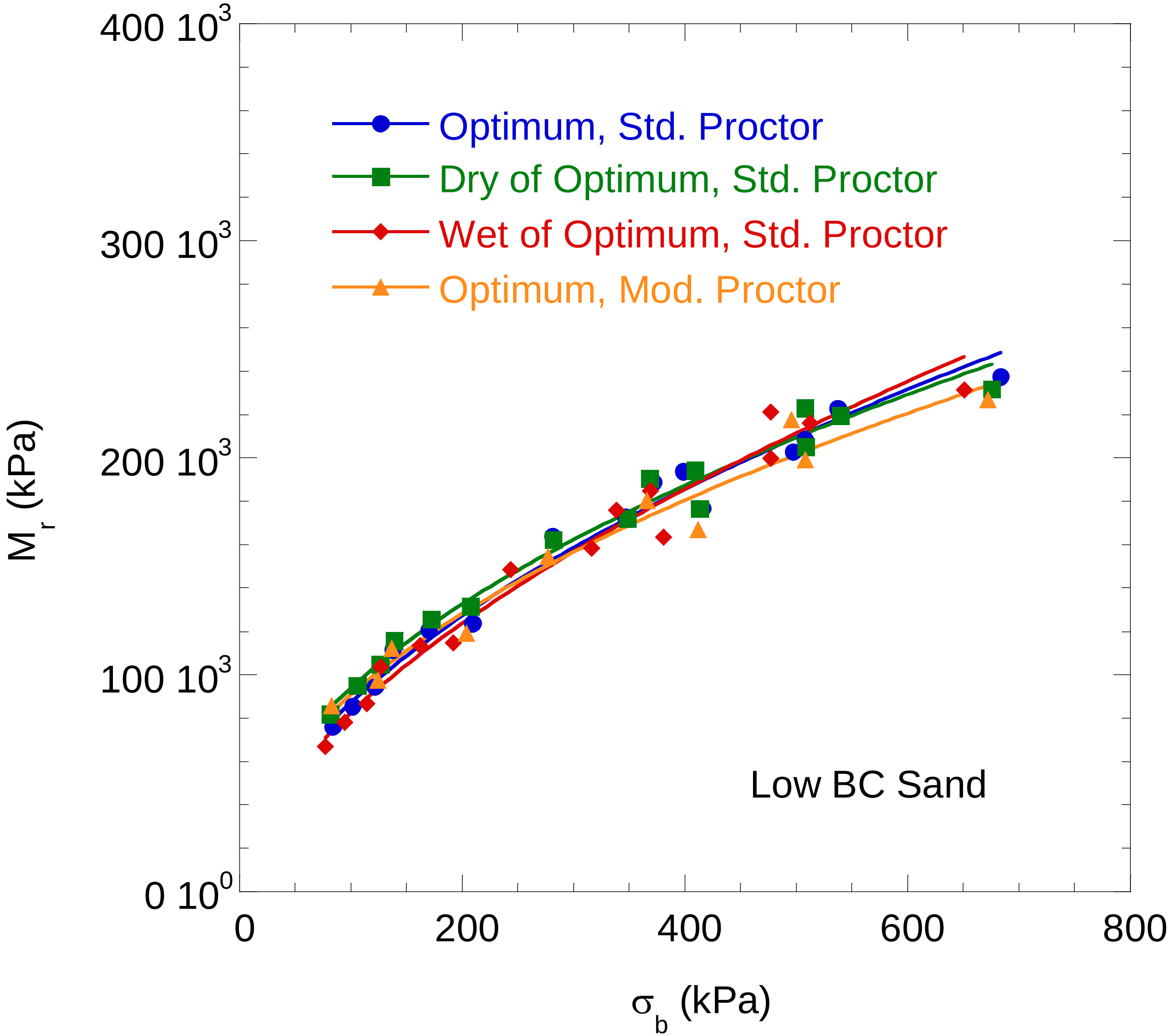
Resilient Modulus: BC < 6%



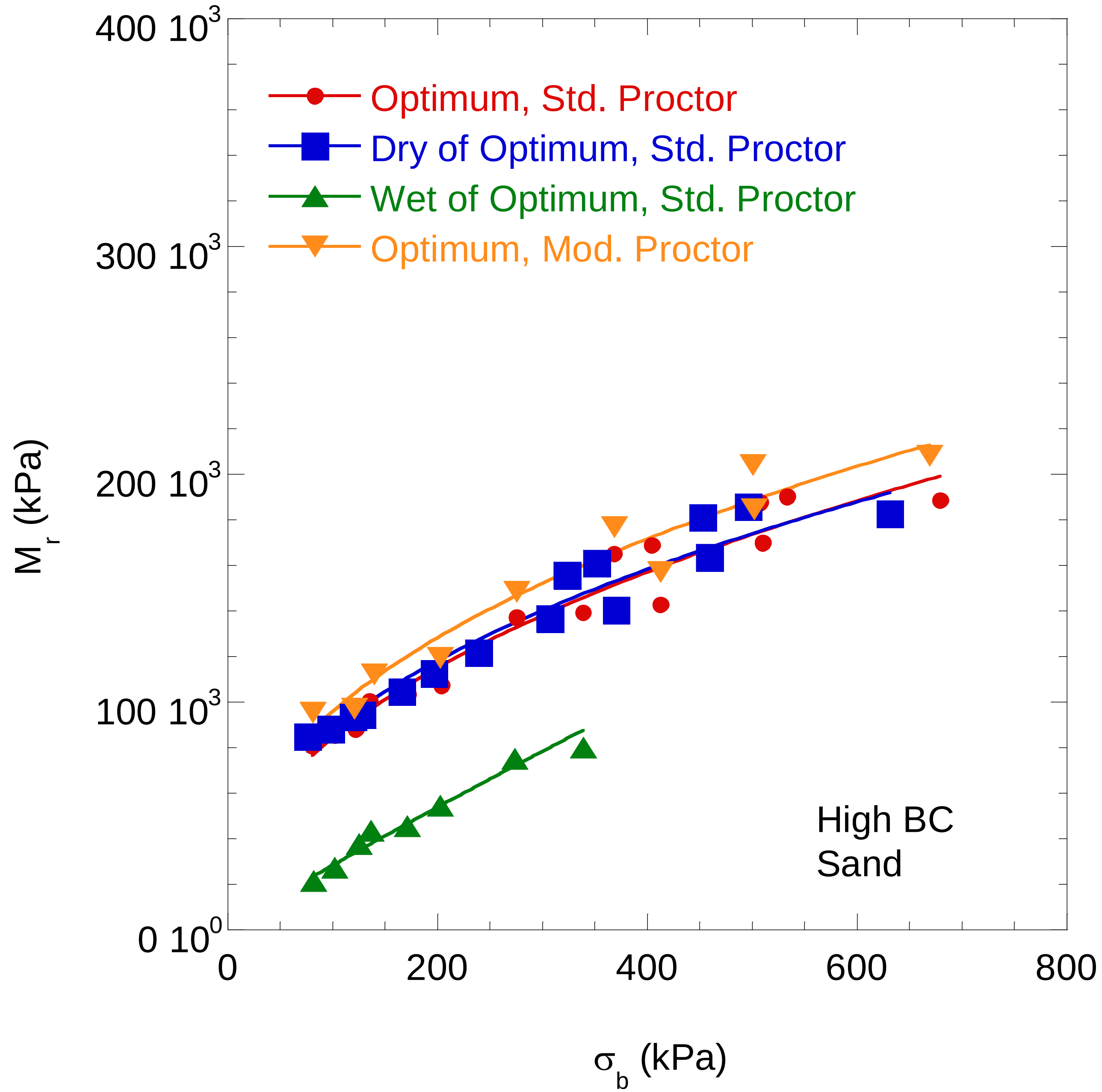
Resilient Modulus: BC > 6%



Effect of Compaction Condition: BC < 6%



Effect of Compaction Condition: BC > 6%



RESILIENT MODULUS

Power function best represented the data

$$M_r = K_1 \left(\sigma_b \right)^{K_2}$$

where σ_b is bulk stress ($\sigma_b = \sigma_d + 3\ \sigma_c$)

RESILIENT MODULUS RELATIONSHIPS

$$K_1 = 612\gamma_{dm} - 111\ CBR$$

$$K_2 = 0.696 - 2.22x10^{-5} K_1$$

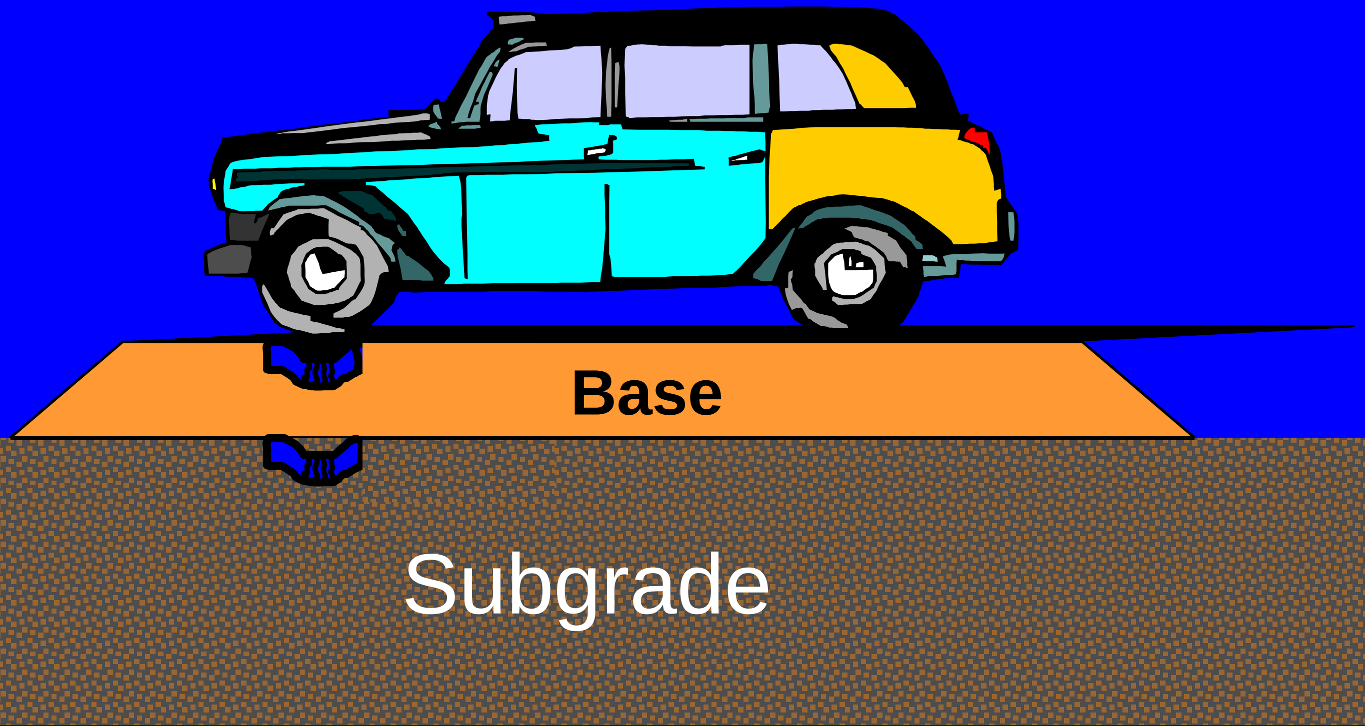
$$K_2 = 0.049P_c - 3.61D_{10}$$

RESILIENT MODULUS

- Resilient modulus close to reference base material's for foundry sands with BC < 6%
- Resilient modulus comparable to reference subbase material's for foundry sands with BC > 6% (for optimum and dry of optimum conditions)
- At low σ_b (<200 kPa) which is typical in pavements, M_r of ESS is higher than reference subbase material's

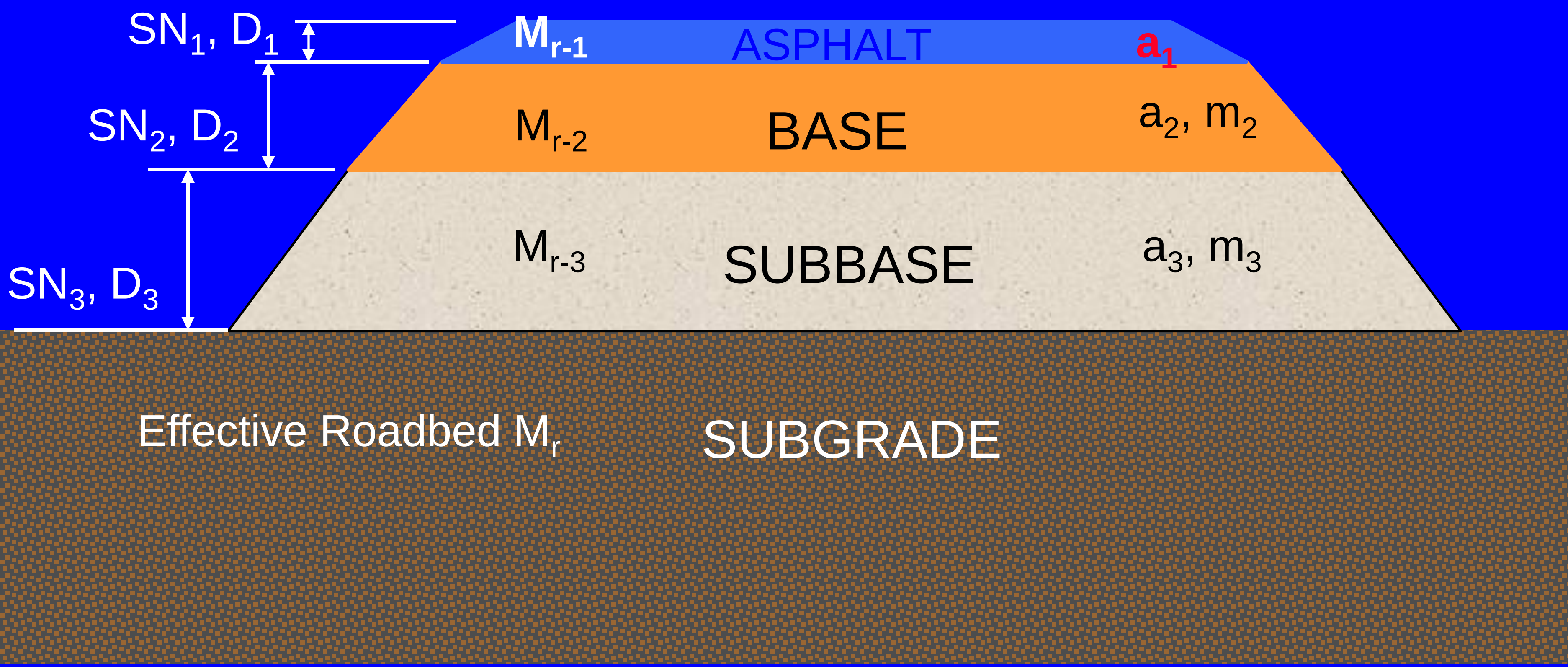
Deformation after construction:
(Accumulation of plastic shear strain and consolidation of the subgrade)

- Cracking or rutting of the asphalt under repeated traffic loading



$$SN = SN_1 + SN_2 m_2 + SN_3 m_3$$

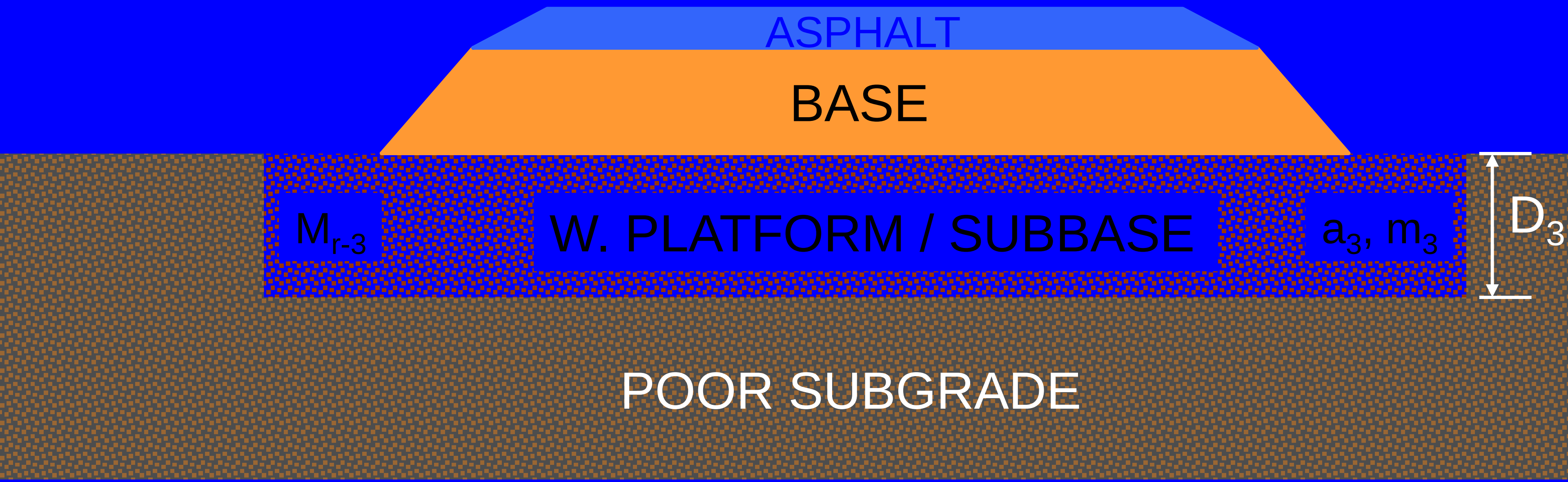
$$SN_i = a_i \times D_i, \quad a_i = f\,(M_{r\text{-}i})$$

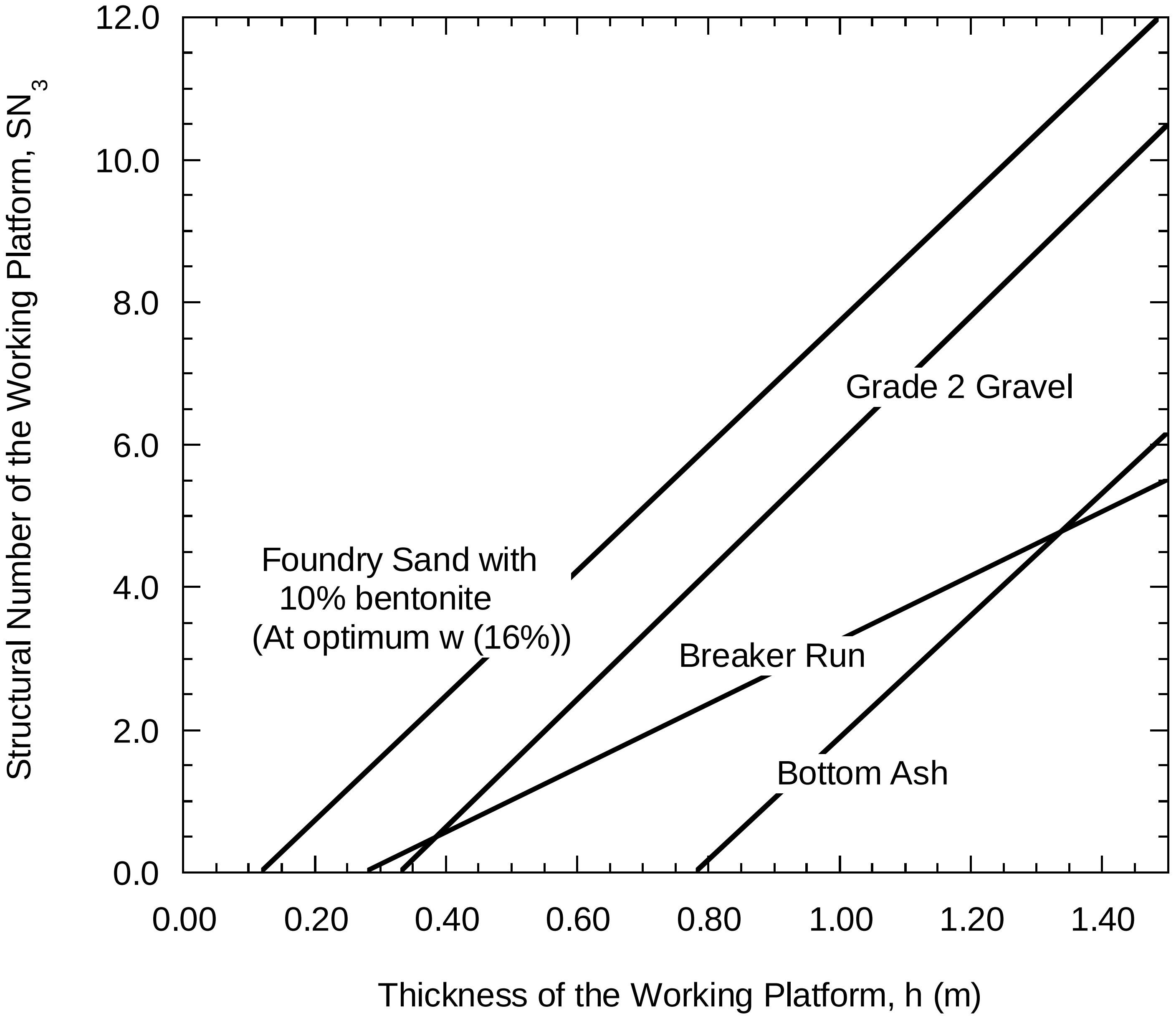


Structural Contribution as a Subbase

$$a_3 = 0.227 \log M_{r-3} - 0.839$$

$$SN_3 = a_3 \times D_3$$





Structural Number of the Working Platform, SN_3
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Thickness of the Working Platform, h (m)
Foundry Sand with
10% bentonite
(At optimum w (16%))
Grade 2 Gravel
Breaker Run
Bottom Ash

Permanent deformation analyses using resilient moduli of foundry sands

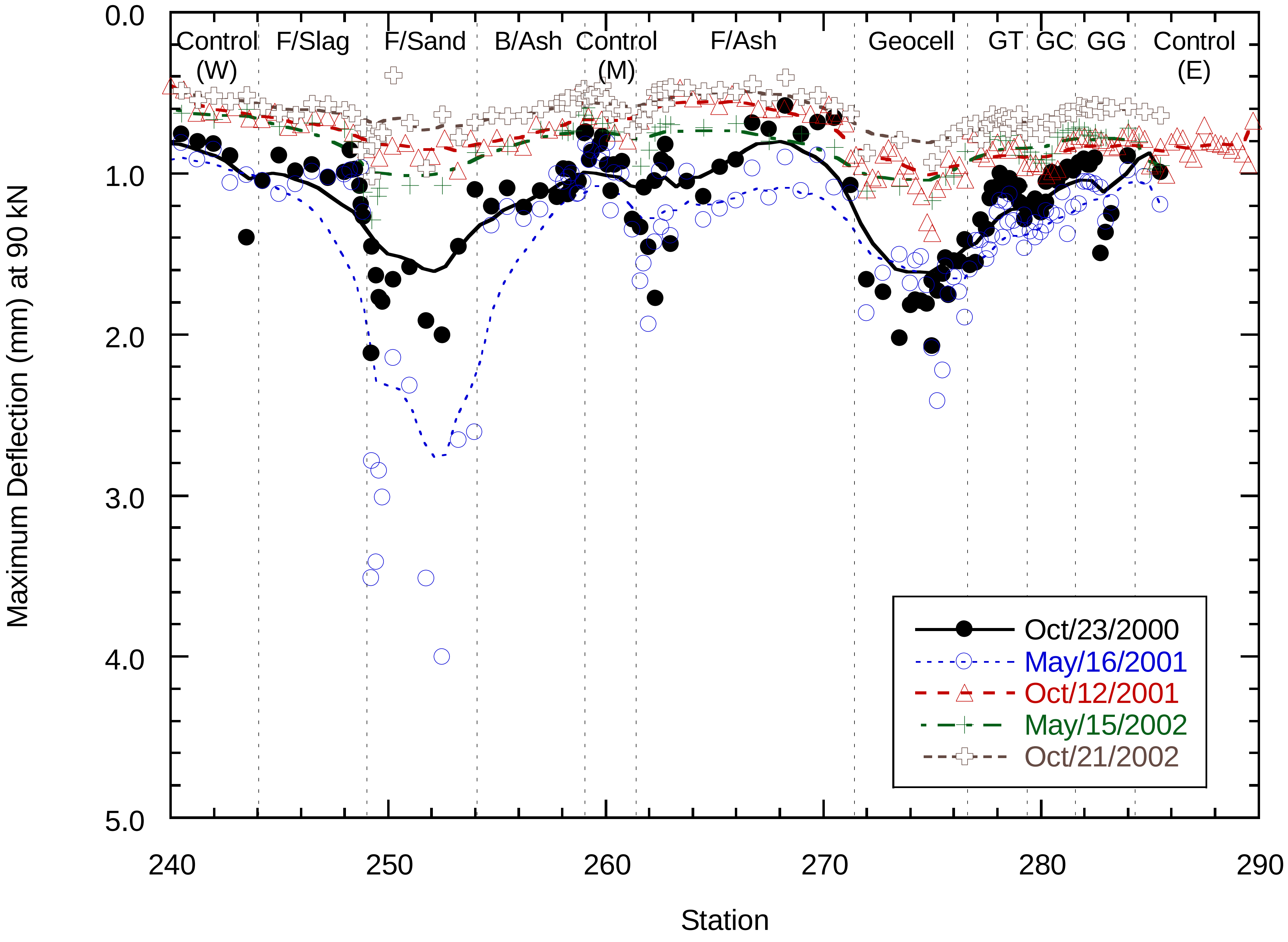
- Rate of accumulation very low ($\varepsilon \sim 5.0 \times 10^{-6}$ per load application)
- Permanent deformation very low, typically < 0.01 mm after 10 million load applications
- Permanent strain comparable to reference subbase, more than reference base
- Minimize rutting & improve performance of rigid pavements

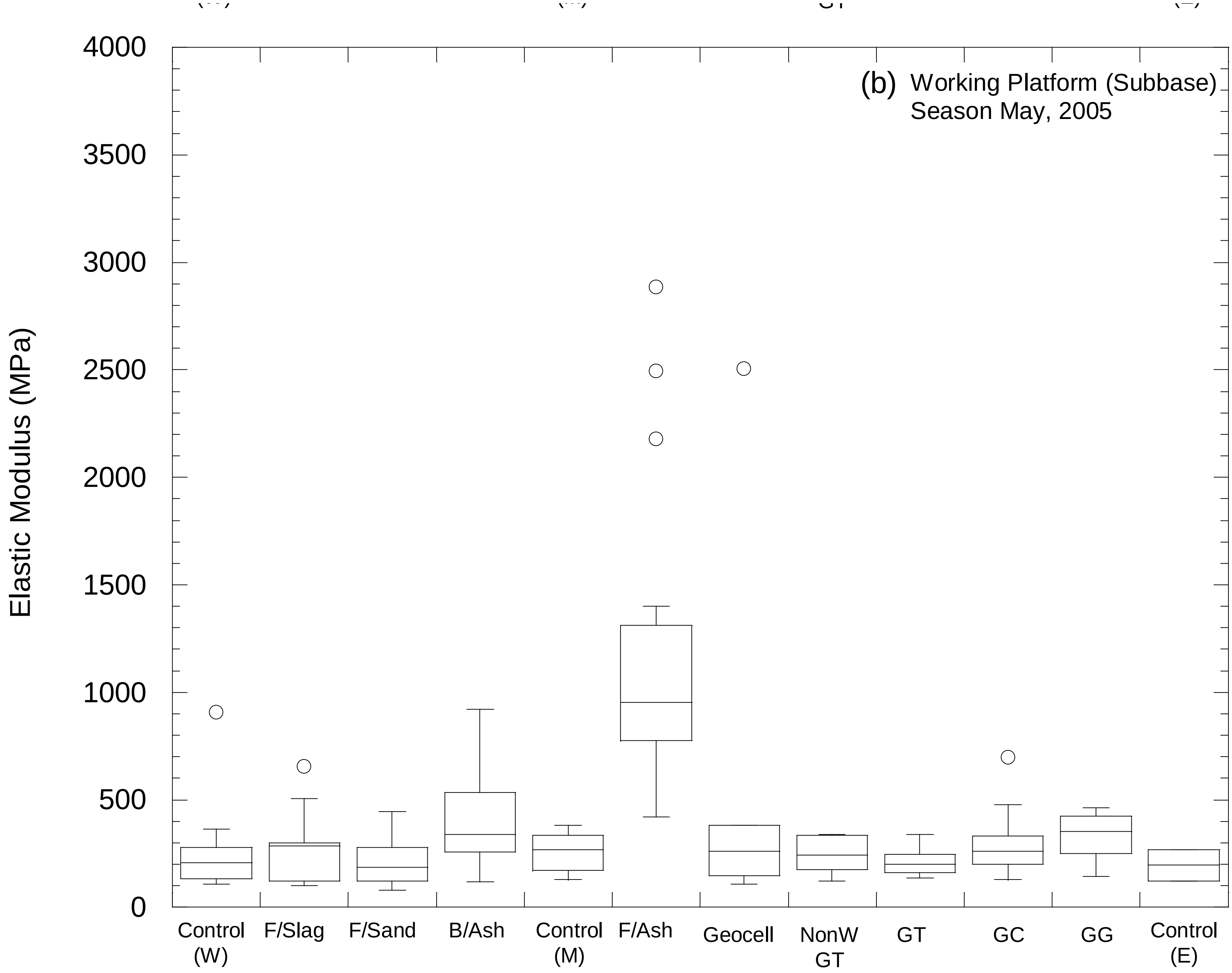
RECAP

- True or false: Excess foundry system sands do not offer a viable and economical alternative as working platform or a subbase material.
- True or false: ESS are not all the same and their properties depend on their fines and active clay content as well as particle shape.
- True or false: Large variety of ESS have resilient modulus comparable or higher than granular subbase material.


CATERPILLAR

Compaction with Padfoot Compactor


Control (W)
F/Slag
F/Sand
B/Ash
Control (M)
F/Ash
Geocell
GT
GC
GG
Control (E)
Maximum Deflection (mm) at 90 kN
0.0
1.0
2.0
3.0
4.0
5.0
240
250
260
270
280
290
Station
Oct/23/2000
May/16/2001
Oct/12/2001
May/15/2002
Oct/21/2002


(b) Working Platform (Subbase)
Season May, 2005
Elastic Modulus (MPa)
0
500
1000
1500
2000
2500
3000
3500
4000
Control
(W)
F/Slag
F/Sand
B/Ash
Control
(M)
F/Ash
Geocell
NonW
GT
GT
GC
GG
Control
(E)