Characterizing Engineering Properties of Foundry Sands

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Participant Background

Which of the following describes your training:

- Civil Engineer or Environmental Engineer.
- Geologist
- Environmental scientist
- Other

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Participant Background

Which describes your employment:

- Private sector
- Public sector
- Designer
- Regulator
- Construction

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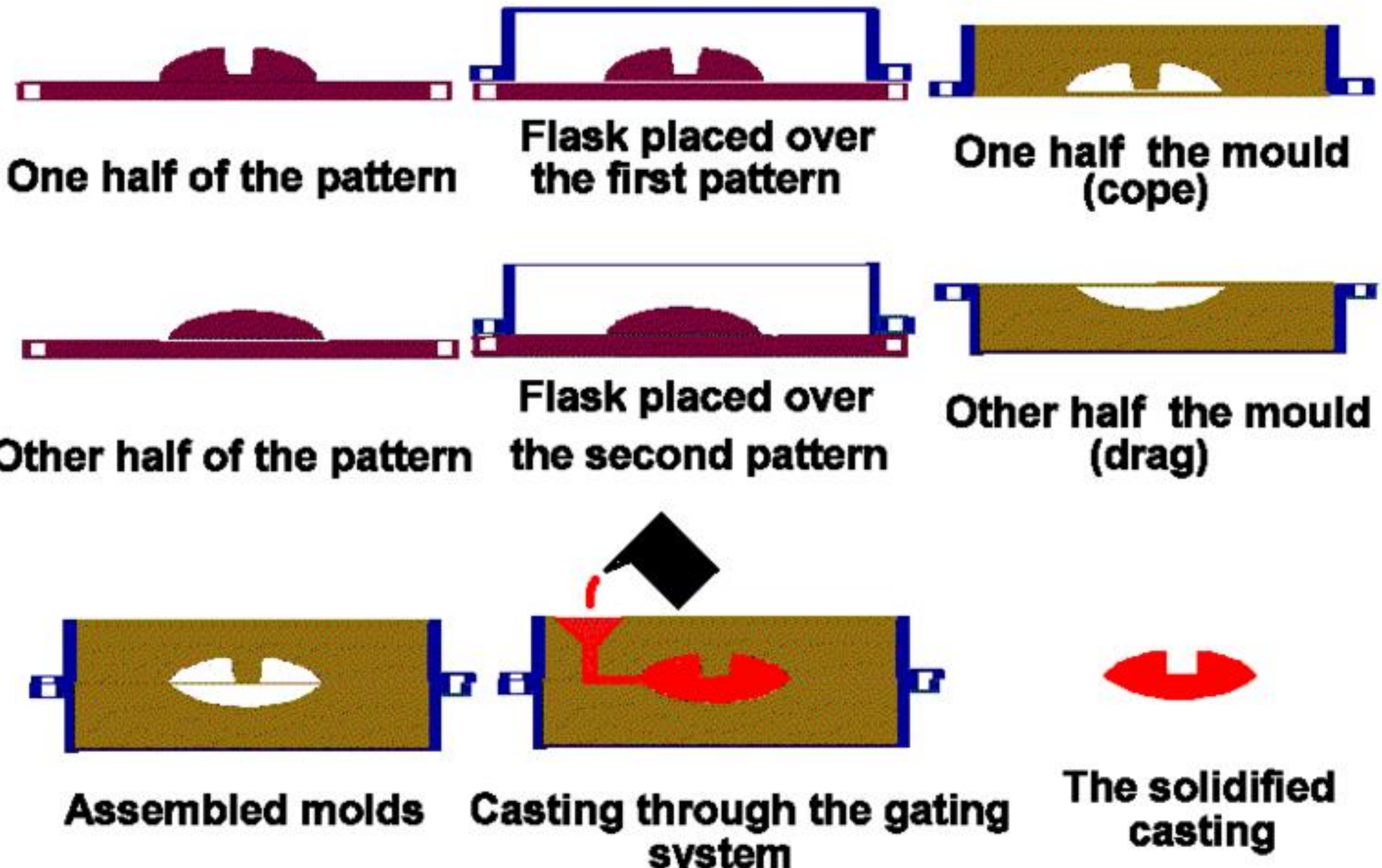
What is an iron foundry?

- An iron foundry is a manufacturing plant where molten iron is poured into molds to make iron products.

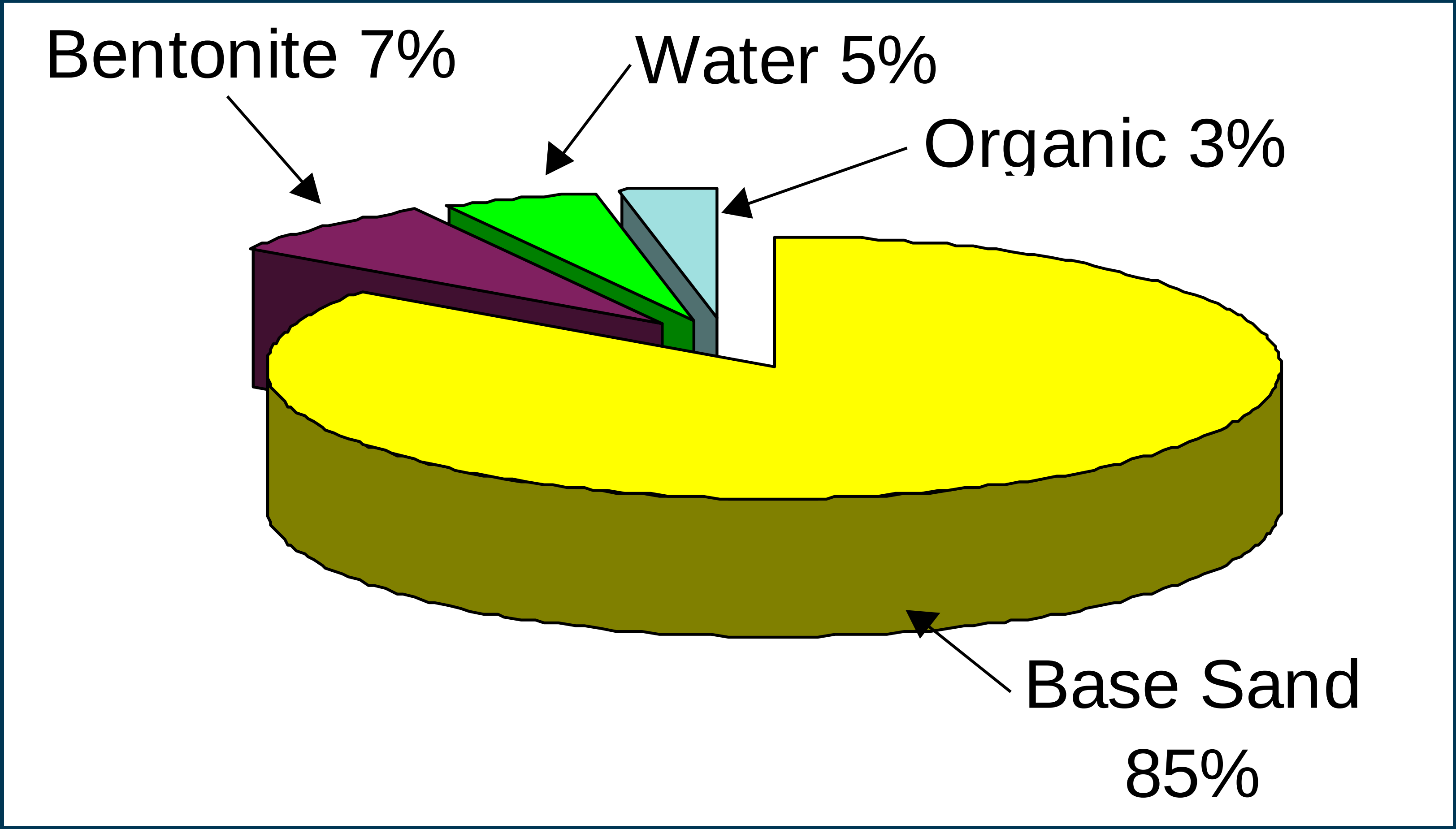
- Some common products include brake parts, gearboxes, propellers, and valves.

- Molds are formed with “green” sand, “no bake” sand, & “cores”
- Excess foundry sands used in construction usually are a mixture of green sand (predominant) and core sand or no-bake sand.

A METAL CASTING POURED IN A SAND MOLD

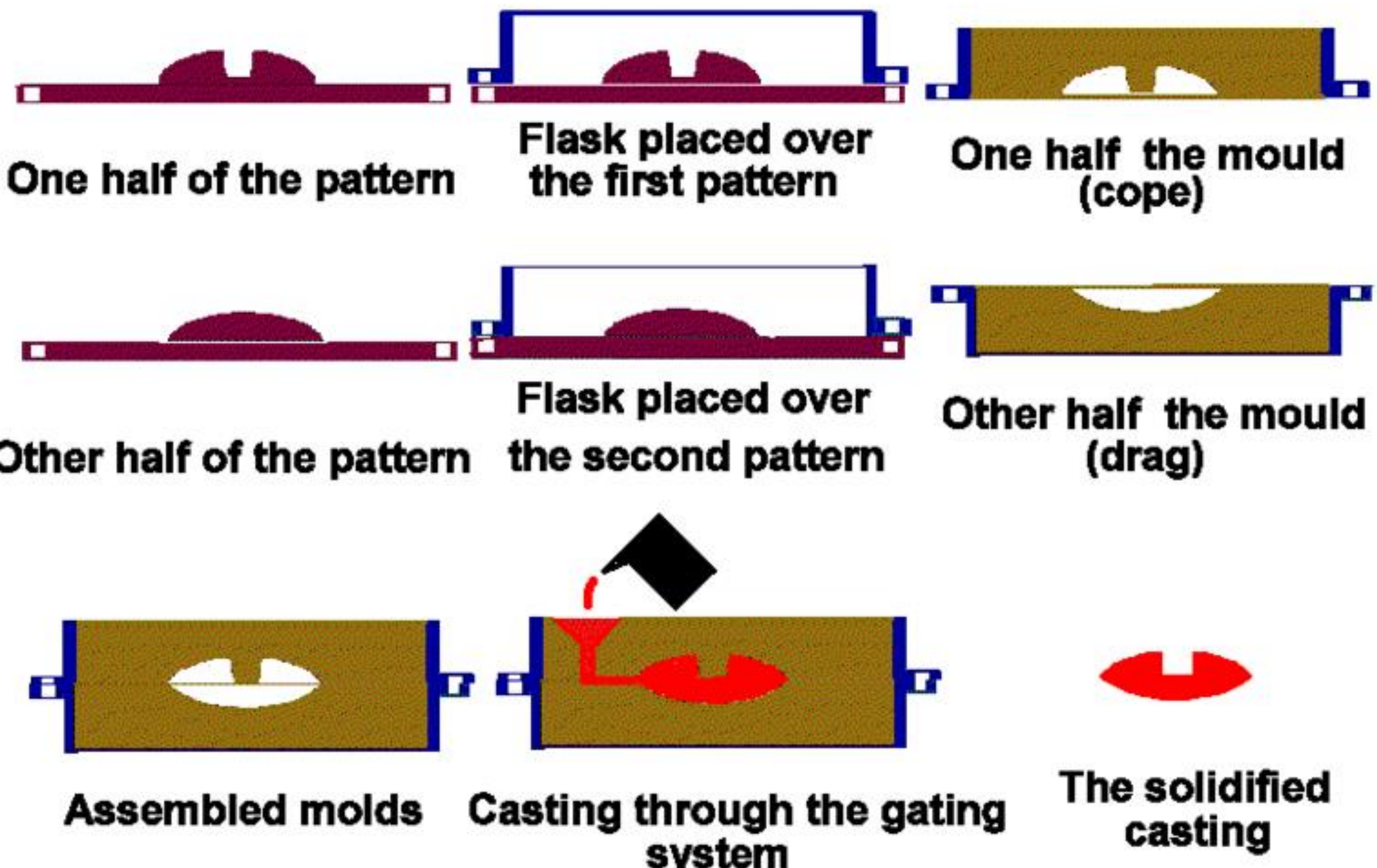


What is foundry sand?

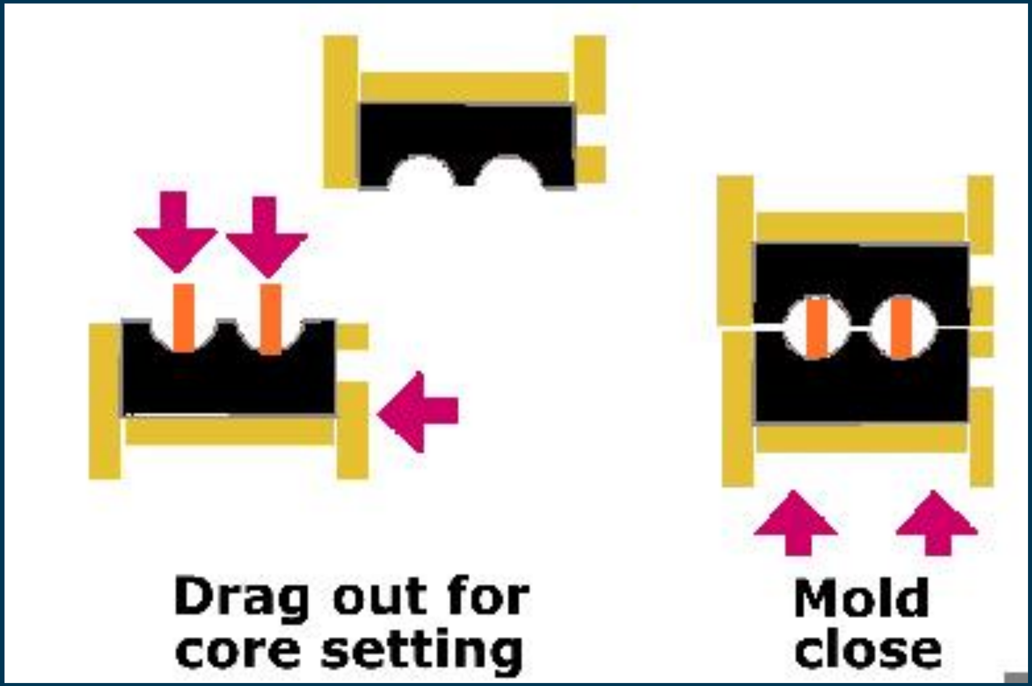


Foundry sands are sand-bentonite mixtures.

A METAL CASTING POURED IN A SAND MOLD



What is a core?



Black portion is green sand mold.

Orange is core, which is prepared with a polymeric binder. Cores form internal cavities.

Green sand can be reconstituted into a new mold. Cores generally are used one time.

Cores generally need to be crushed prior to use in construction applications.

Why is foundry sand discarded?

- High temperature and pressure degrade the sand over time.
- Sand becomes contaminated with debris (flashing, dust, core pieces etc).
- New ingredients (sand, bentonite, are added to ensure sand has suitable properties.
- Addition of new ingredients results in too much sand in the system, or “excess” sand. Thus, some of the sand is removed and discarded.
- Discarded sand is sometimes referred to as “excess system sand,” or ESS.


CAT

Foundry sand grades and shapes easily.

Compacts well with modest amount of moisture.

Foundry sand being spread as sub-base at STH 60 field site.

Foundry slag being compacted at STH 60

Recap

- What are the basic types of iron foundry sands that might be encountered in a reuse application: (a) green sand, (b) core sand, (c) no-bake sand, or (d) all of the above?
- True or false: bentonite is added to sand to make "green" sand cohesive.
- True or false: Sand is bonded using polymeric adhesives to create cores.
- Foundry sand is discarded because (a) the sand has the incorrect color, (b) excess sand accumulates at the foundry, or (c) the sand contains gravel?

Infrastructure Applications

- Subbase and working platforms for roadways and paved areas
- Retaining wall backfill, embankment fill, and structural fill
- HMA and CLSM fine aggregate
- Pond liner (e.g., runoff)

Participant Experience

Check if you have designed or constructed the following:

- Roadway
- Structural fill
- Retaining wall
- Embankment

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Participant Experience

Check if you have used foundry sand in the following:

- Roadway construction
- Structural fill
- Retaining walls
- Embankments
- Top soil applications

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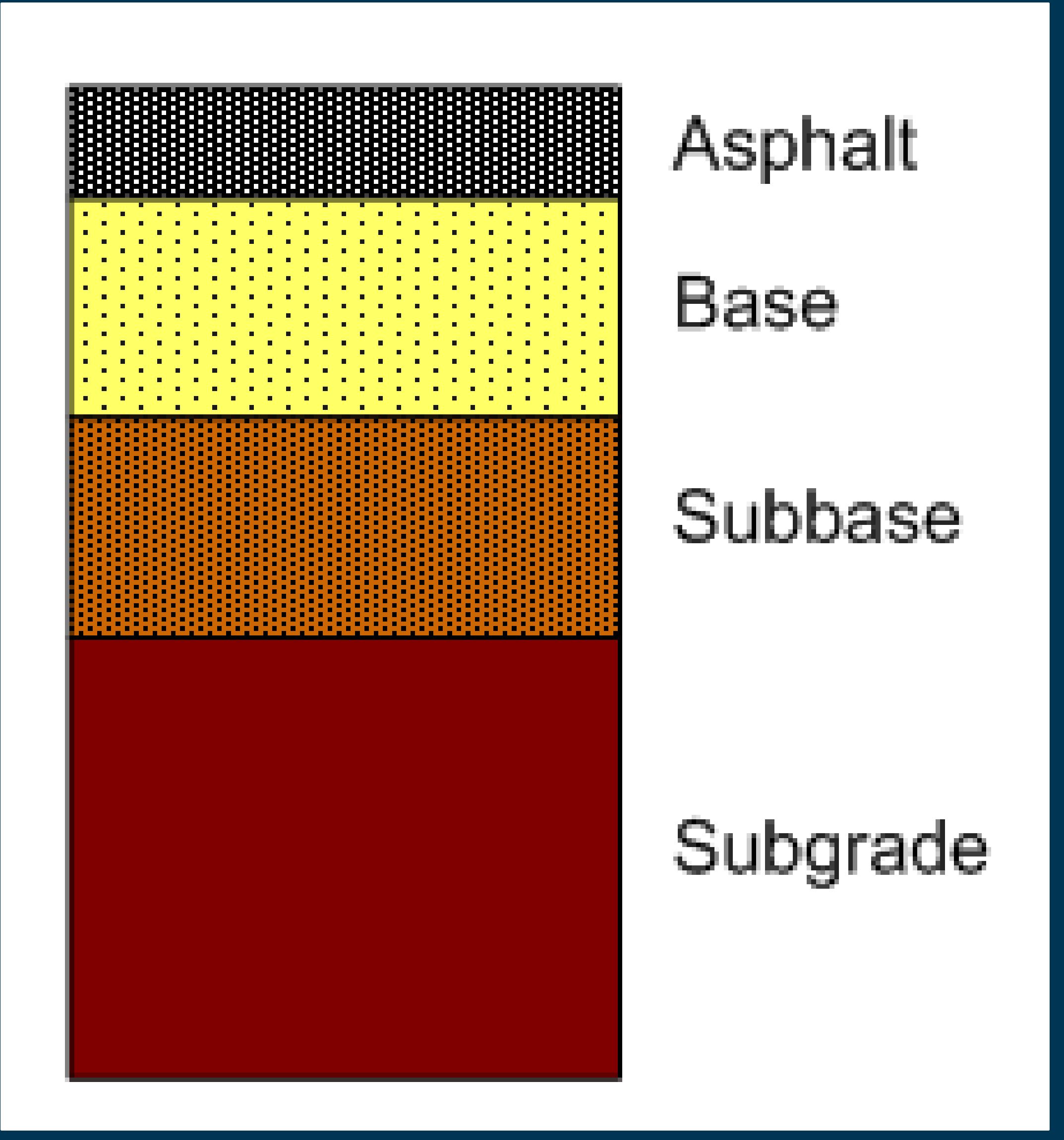
Subbase Applications

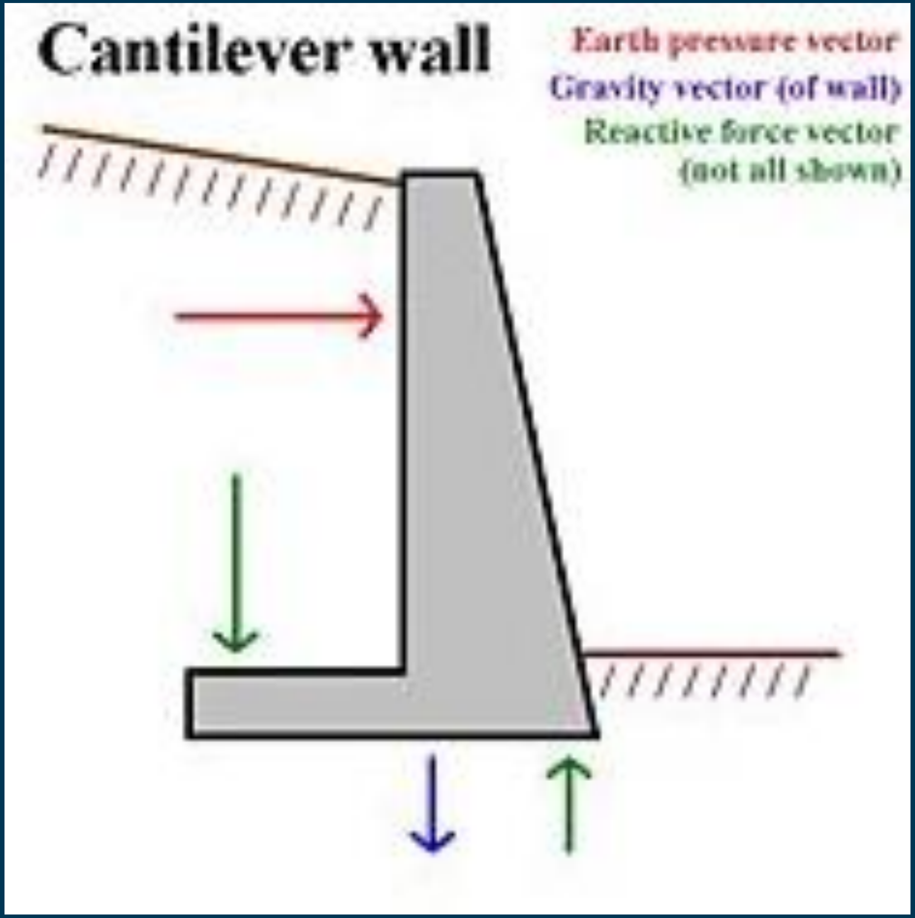
- California bearing ratio (CBR)
- Resilient modulus

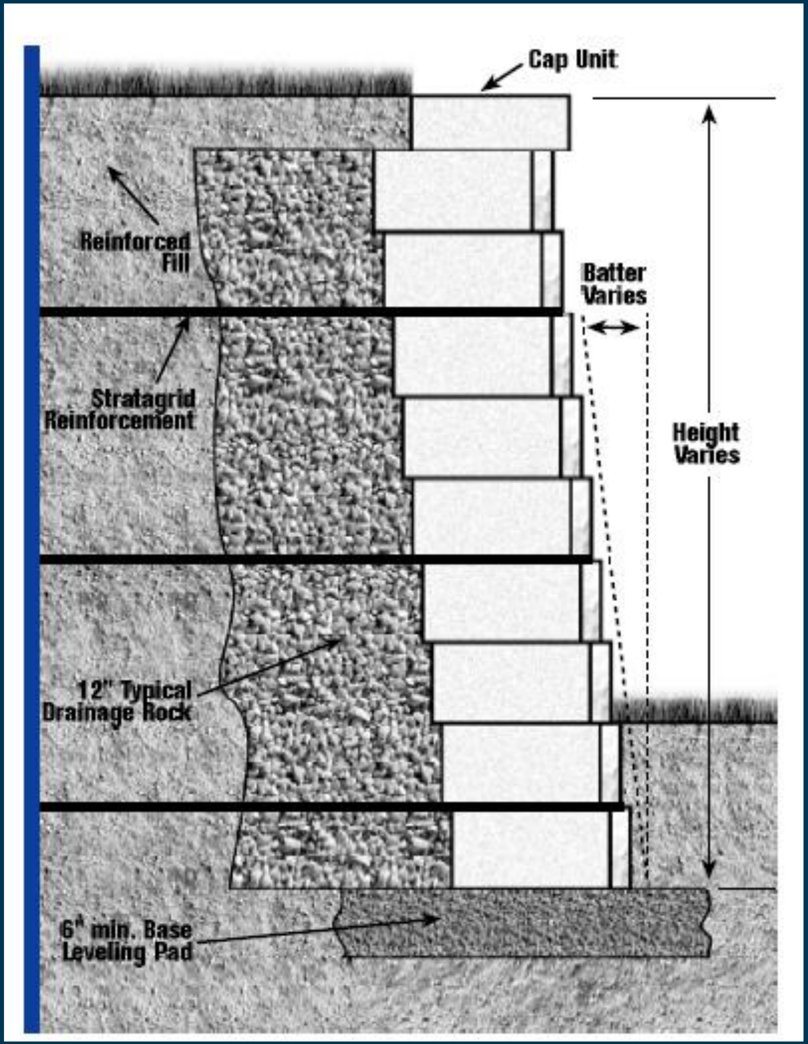
Objective: provide designers with typical engineering properties for foundry sands that can be used in preliminary design.



Conventional Wall

MSE Wall

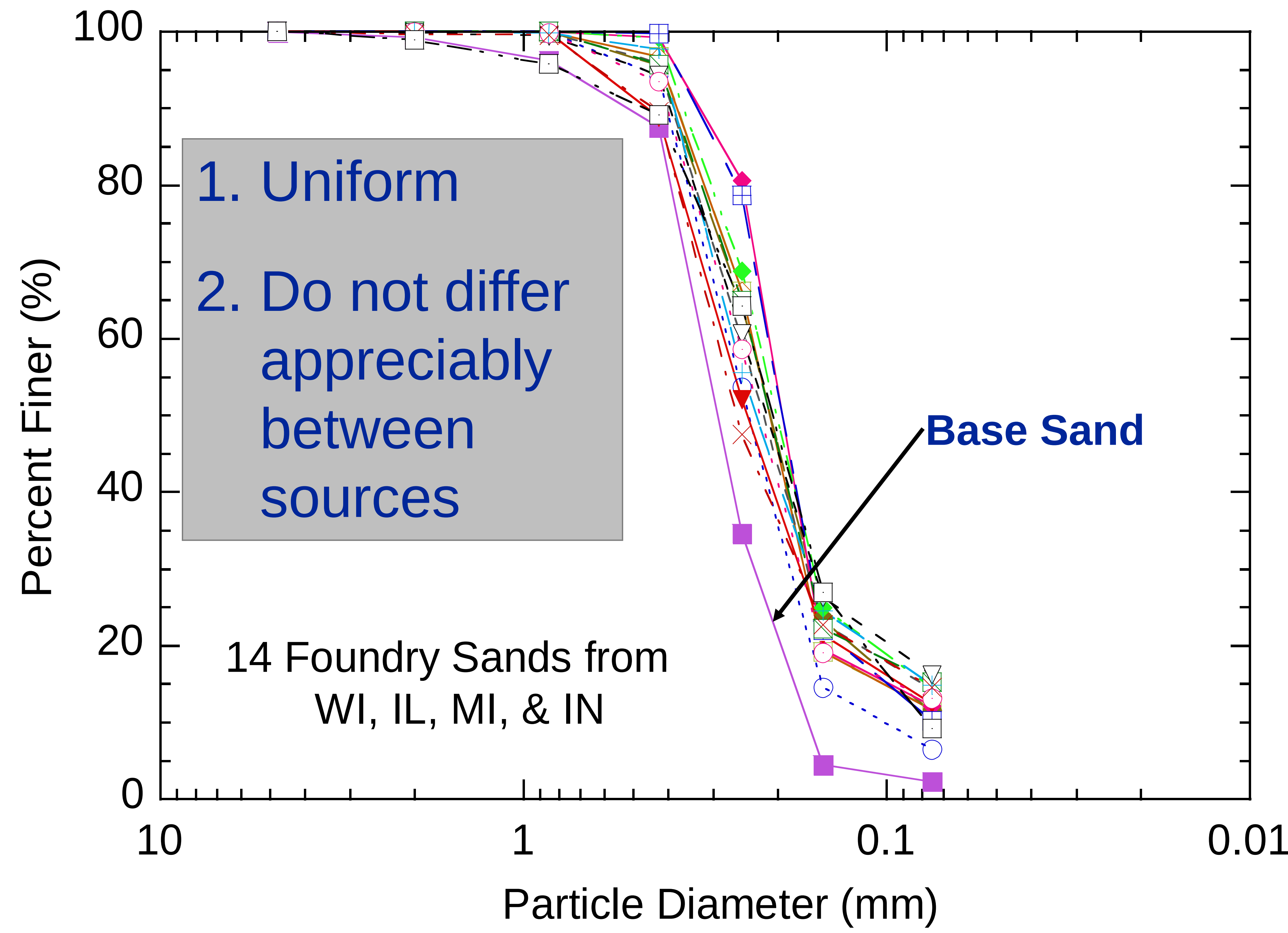




Index and Compaction Characteristics

Particle Characteristics:

- Fine Sand
- Fines (finer than 75 micron): ~ 10 – 12%
- 2 μicron clay: ~ 3 to 10%
- Roundness: surrounded to subangular
  (R = 0.5 to 0.7)
- Specific gravity (G_s): 2.52 to 2.73 (base sand = 2.66)

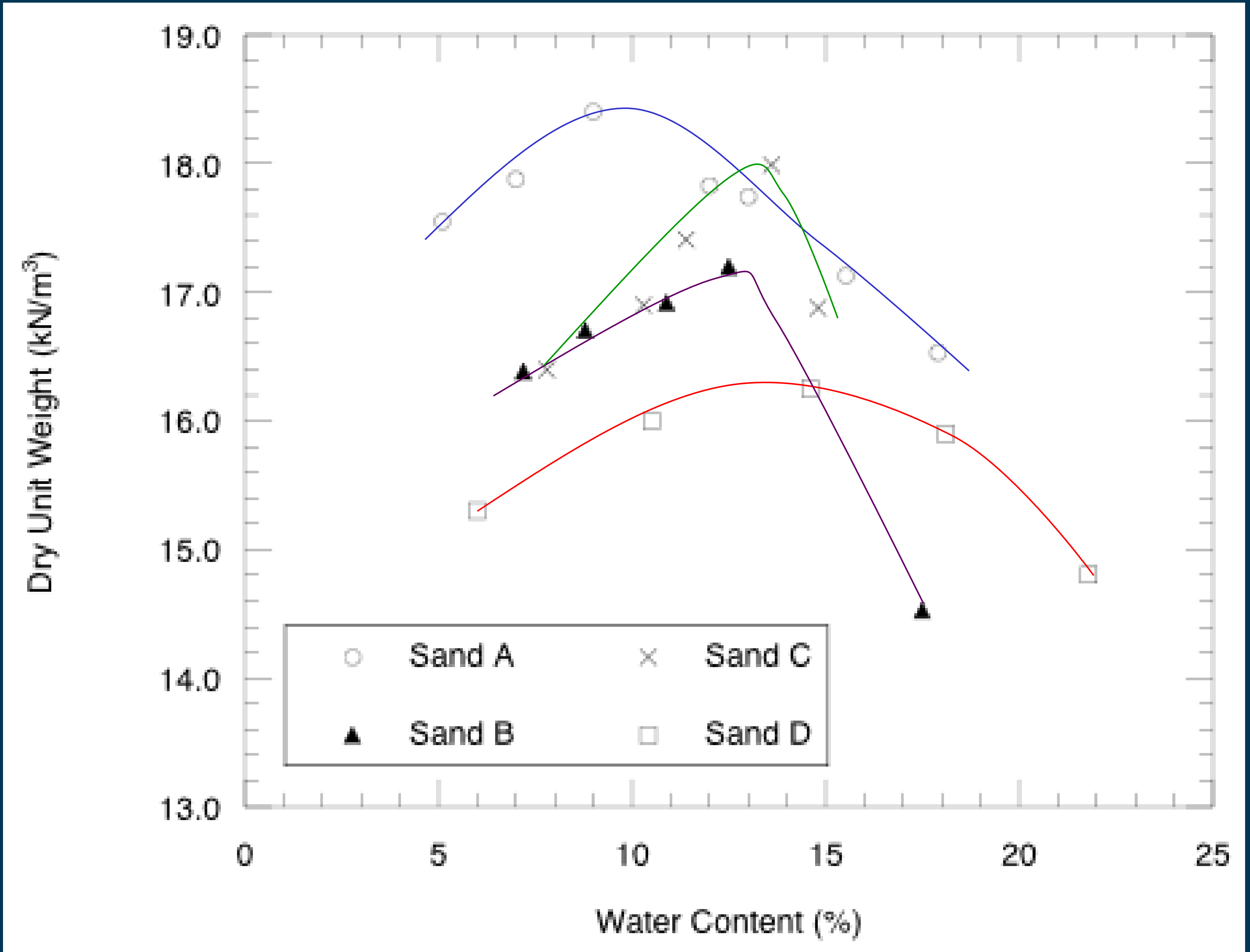


1. Uniform
2. Do not differ appreciably between sources
Base Sand
14 Foundry Sands from WI, IL, MI, & IN
Percent Finer (%)
Particle Diameter (mm)
100
80
60
40
20
0
10
1
0.1
0.01

Index Characteristics

- Plasticity: Plasticity index (PI) between non-plastic (NP) and 5
- Unified soil classification: clayey sand (SC), poorly graded sand (SP), silty sand (SM), or SP-SM
- AASHTO classification: A-2-4 or A-3
- Roundness: Subrounded to subangular (R = 0.5 to 0.7)

Compaction Curves



Recap – Applications & Characteristics

- Foundry sands can be used in lieu of virgin materials in the following applications: (a) roadway subbase, (b) retaining wall backfill, (c) flowable fill (CLSM), or (d) all of the above.
- What is the primary characteristic that varies between foundry sands: (a) sand roundness, (b) fines and clay content, or (c) color?
- True or False: compaction curves for foundry sands appear very different than those for soils.

Engineering Properties of Interest

- Geotechnical properties

  - strength (retaining structure backfill, embankment)

  - compressibility & stiffness (embankment, subbase)

  - interaction with geosynthetic materials

  - hydraulic conductivity (water retention liner)

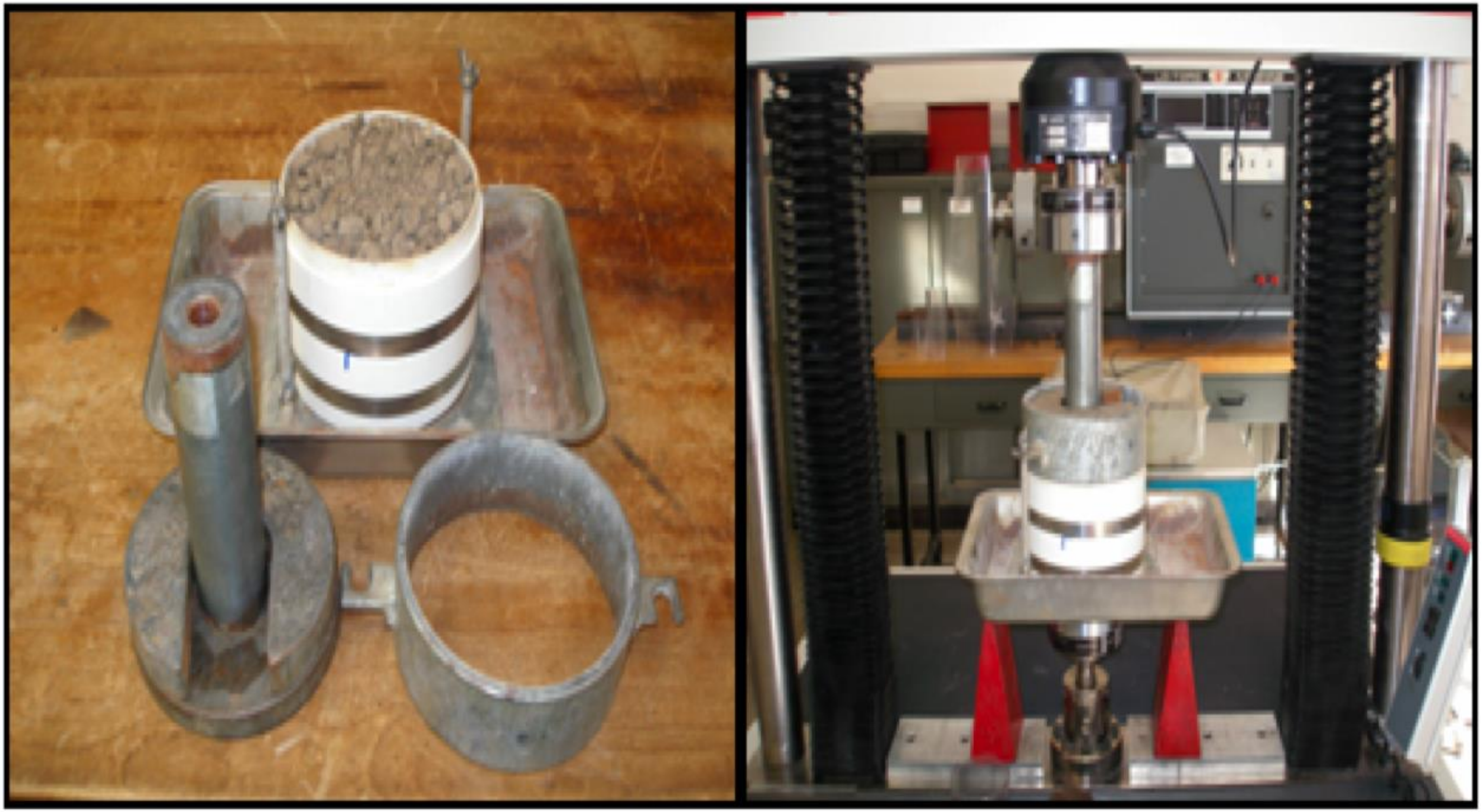
- Interactions with binders (HMA, CSLM)

Pavement Applications - Subbase

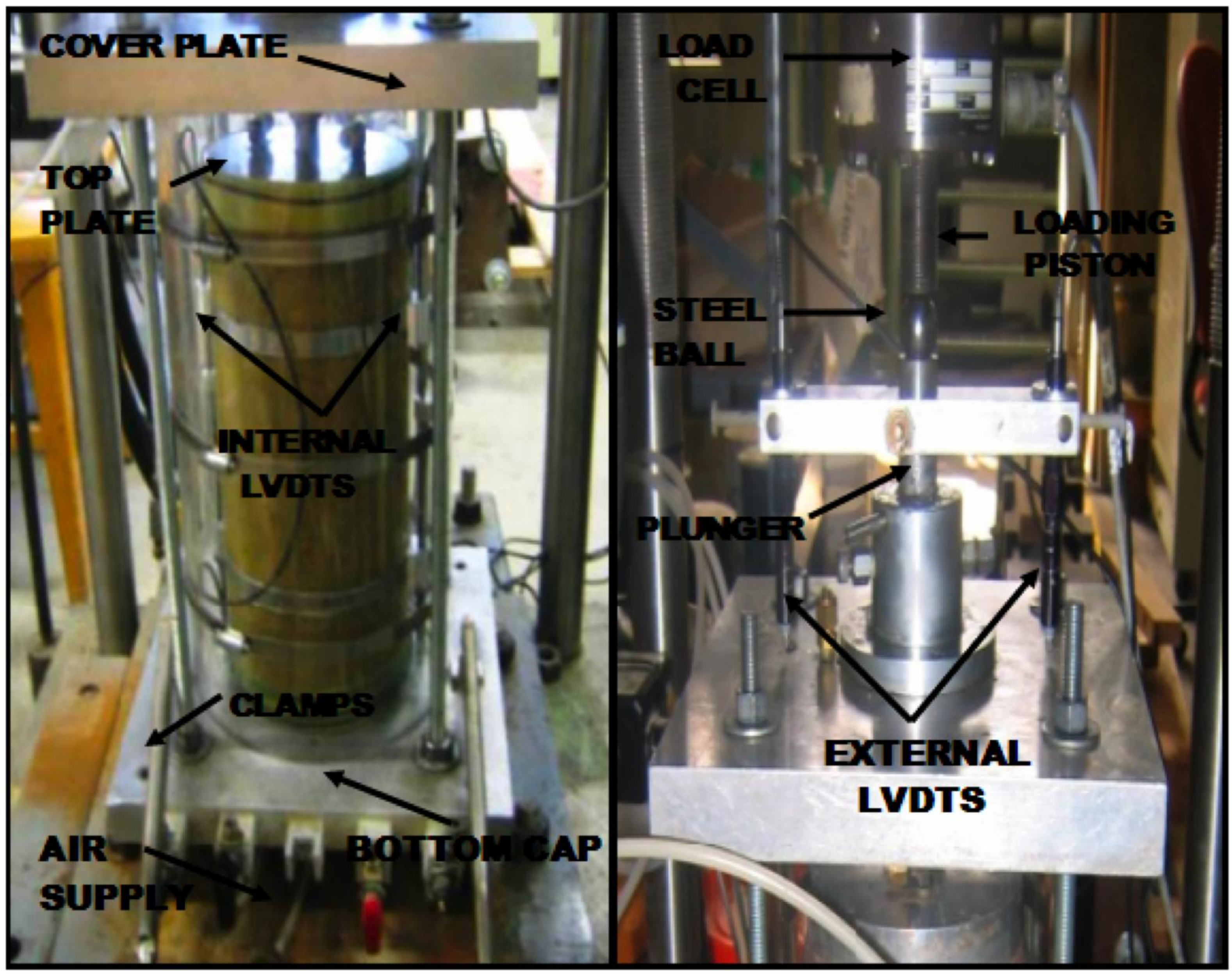
- California bearing ratio (CBR) – measure of bearing strength of unbound pavement materials (subgrade, subbase, or base).
- Resilient modulus – stiffness of unbound or bound pavement material that accounts for effect of long-term cyclic pavement loads

Modern mechanistic pavement design employs resilient modulus. However, CBR is still used in lower volume roadway designs.

CBR Test



Resilient Modulus Test



CBR of Foundry Sands

ESS #	Penetration Curve Type	P_{200}	PI	Max CBR
1	Brittle	10.7	NP	40
2	Ductile	12.7	3	8.7
3	Brittle	4.3	NP	10
4	Brittle	1.1	NP	18
5	Ductile	14.3	1	19
6	Ductile	11.3	2	22
7	Brittle	2.7	NP	10
8	Ductile	12.1	8	27
9	Ductile	13.2	4	28
10	Ductile	12.4	5	4.3
11	Ductile	10.2	3	8.1
12	Ductile	16.4	6	16
13	Ductile	13.2	3	32
14	Brittle	10.0	NP	33
Reference Base				80
Reference Subbase				17

- Higher CBR obtained with a greater fraction of non-plastic fines.
- Plastic fines reduce CBR
- Higher CBR at optimum water content and with greater density.

Estimating CBR of Foundry Sands

Non-Plastic (NP) Sands:

$$CBR = -361 + 32.4\gamma_d - 1.93P_{200} - 264R$$

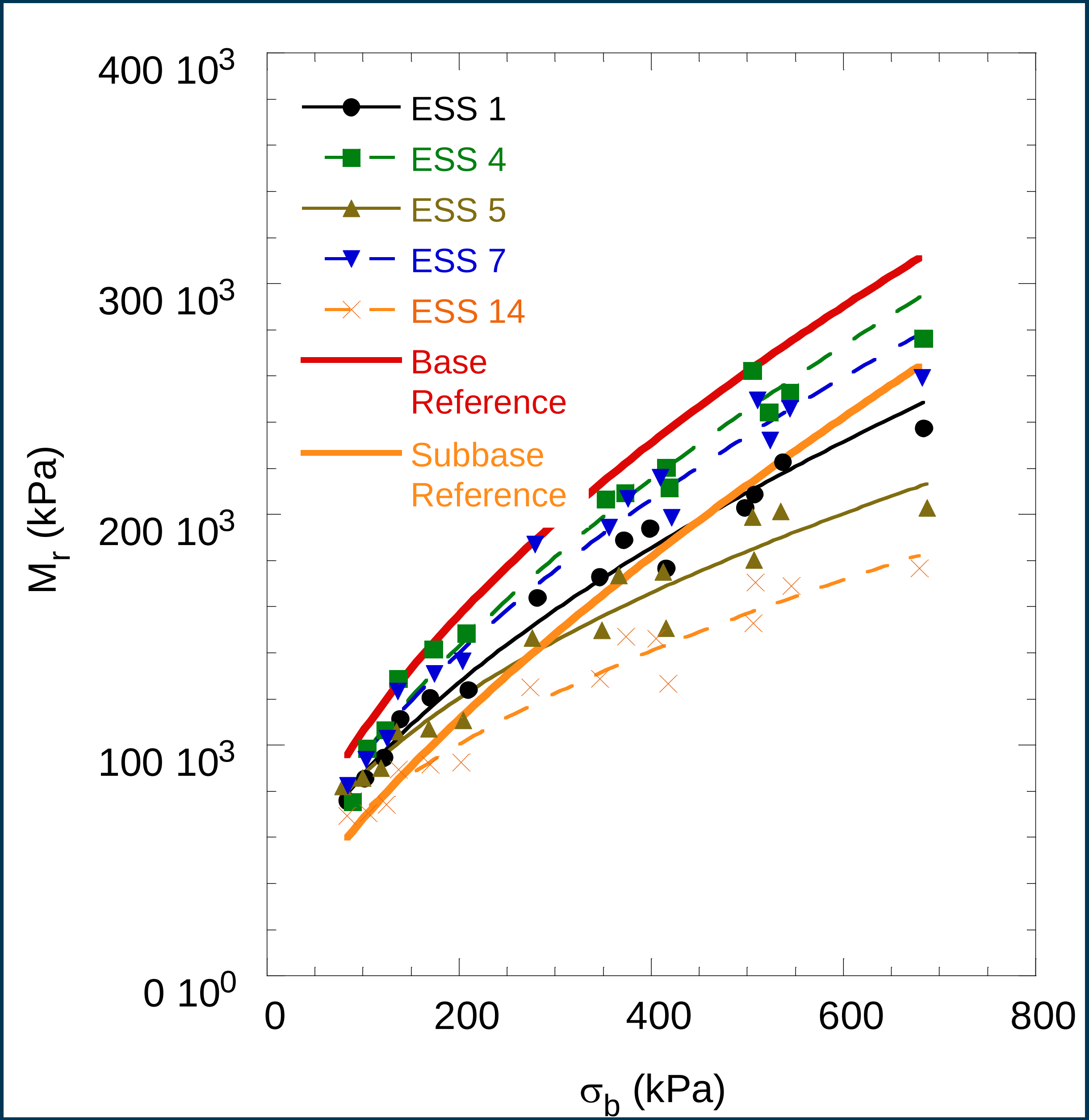
Plastic Sands (PI > 0):

$$CBR = -7.6\gamma_d + 4.25\,BC + 178R$$

γ_d is dry density in kN/m^3, P_{200} is fines content in %, R is Krumbein roundness, BC = bentonite content (%)

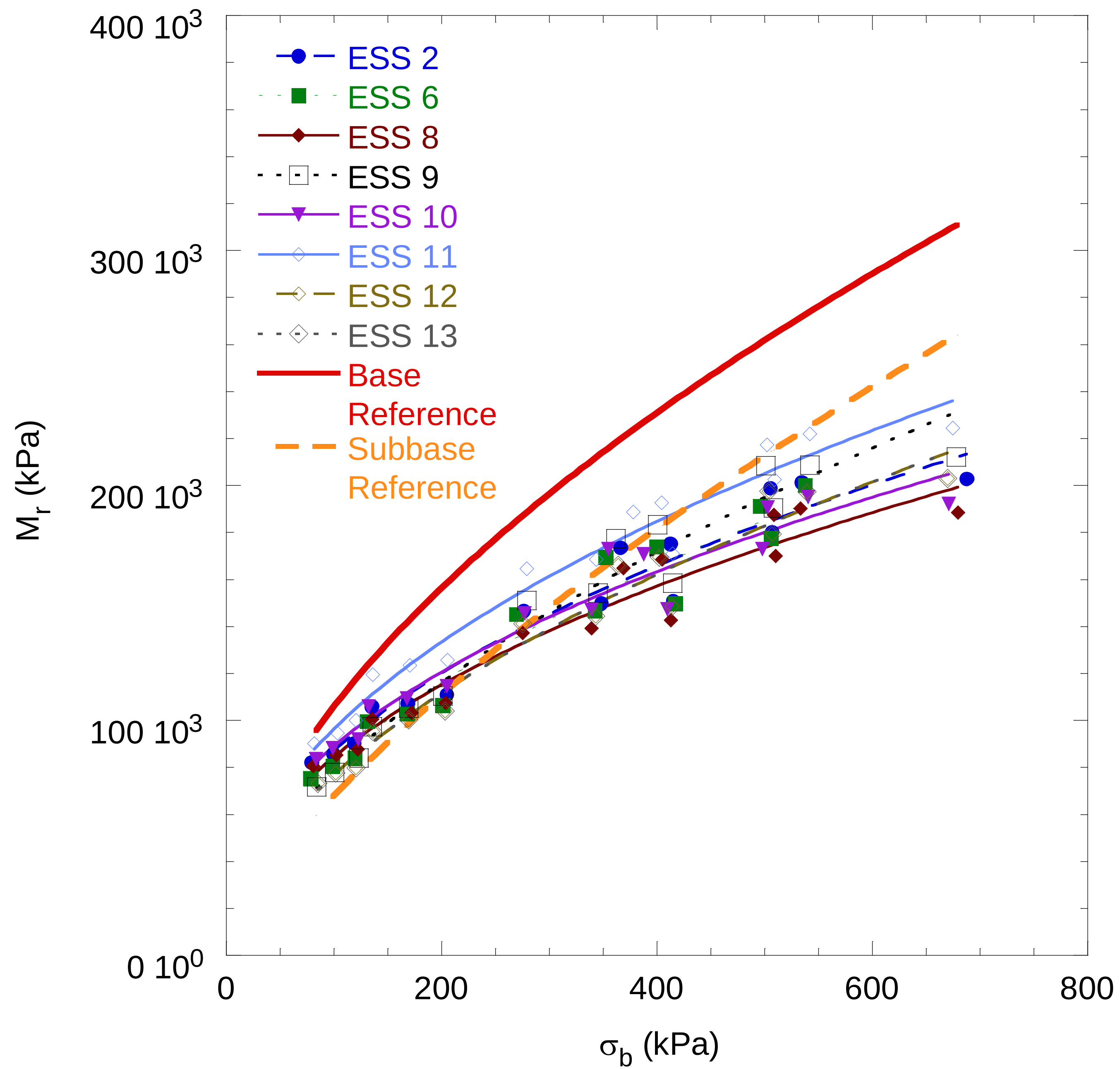
Resilient Modulus: BC < 6%

- Many foundry sands have modulus falling between conventional subbase and base.



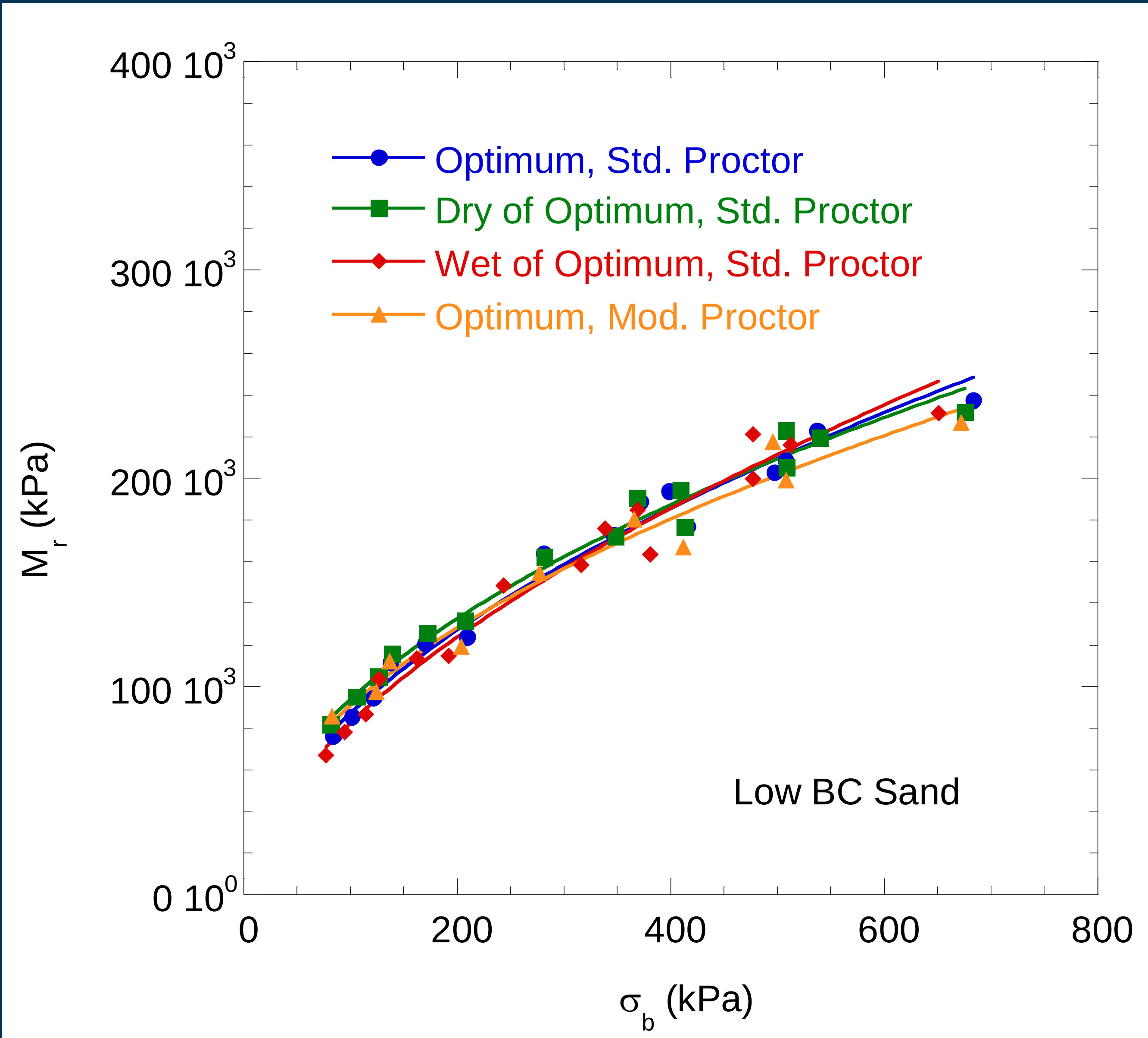
Resilient Modulus: BC > 6%

- More plastic foundry sands (higher bentonite content) have lower modulus



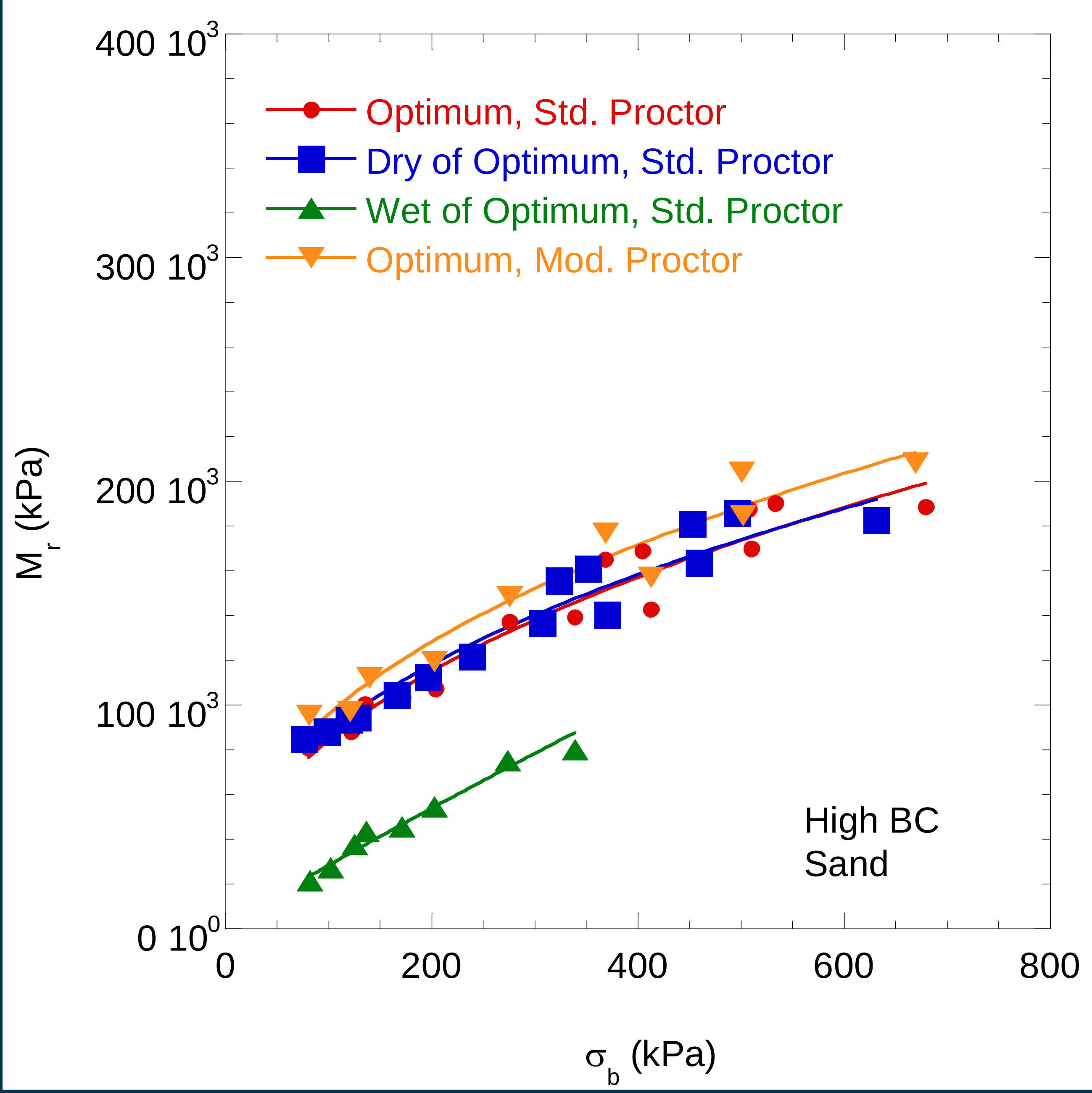
Effect of Compaction Condition: BC < 6%

Sands with BC < 6% can be compacted over a range of water contents.



Effect of Compaction Condition: BC > 6%

Plastic sands should be compacted near optimum water content.



Recap - Pavement Applications

- Can foundry sands have comparable strength and stiffness as conventional subbase and base materials?
- True or False: Foundry sands with fines and higher plasticity (more bentonite) have greater bearing strength and modulus.
- To achieve adequate bearing strength and stiffness, foundry sands should be compacted: (a) dry of optimum water content, (b) at optimum water content, or (c) wet of optimum water content?

Retaining Structure Backfill, Structural Fill, Embankment Fill

- Shear strength of foundry sands
- Interface shear strengths with geomembrane, woven geotextile, and geogrid
- Pullout with geotextile and geogrid

Direct Shear Strength of Foundry Sands

<u>Unsoaked</u>

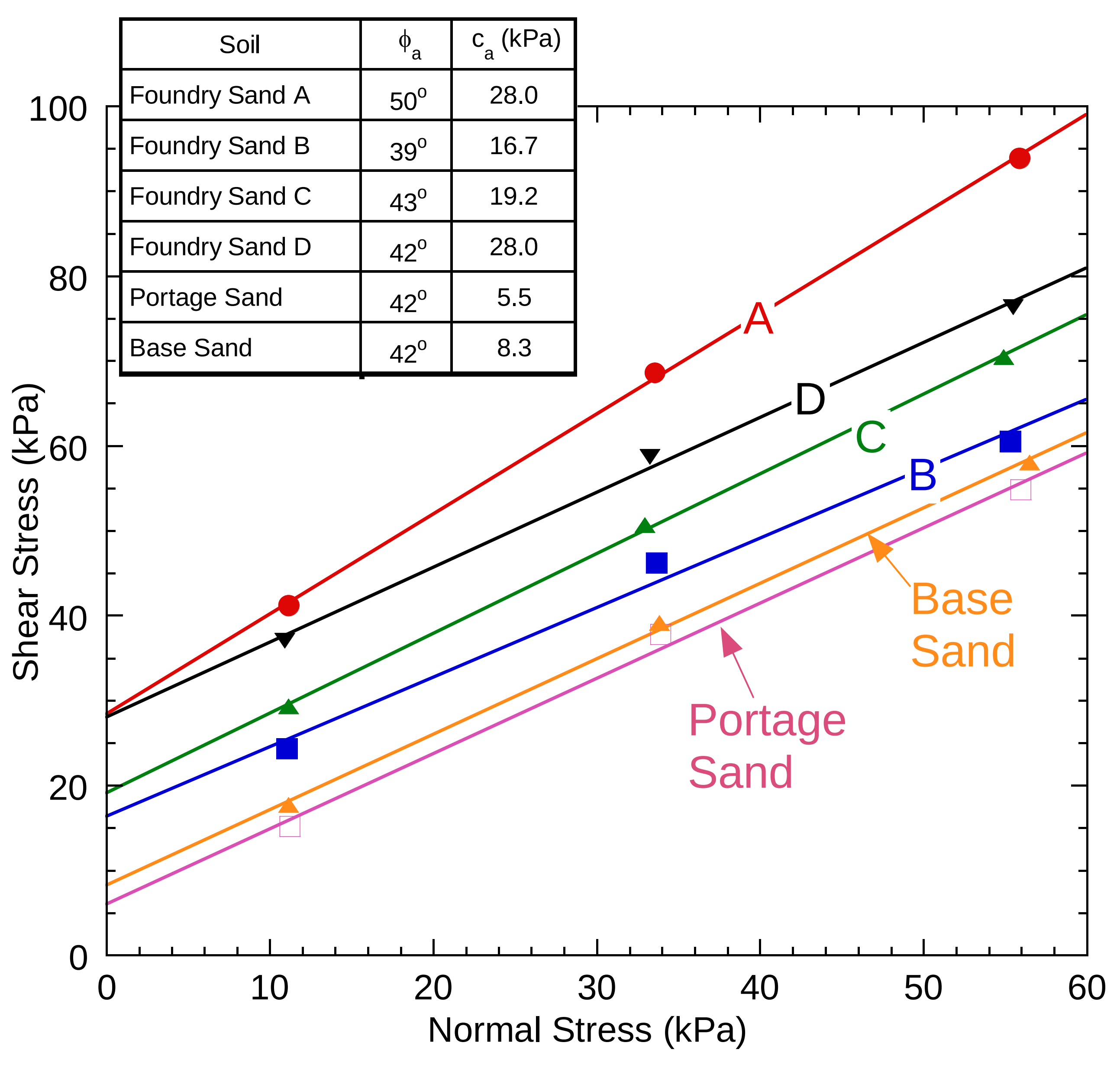
ϕ' ~ 40°

c' varies

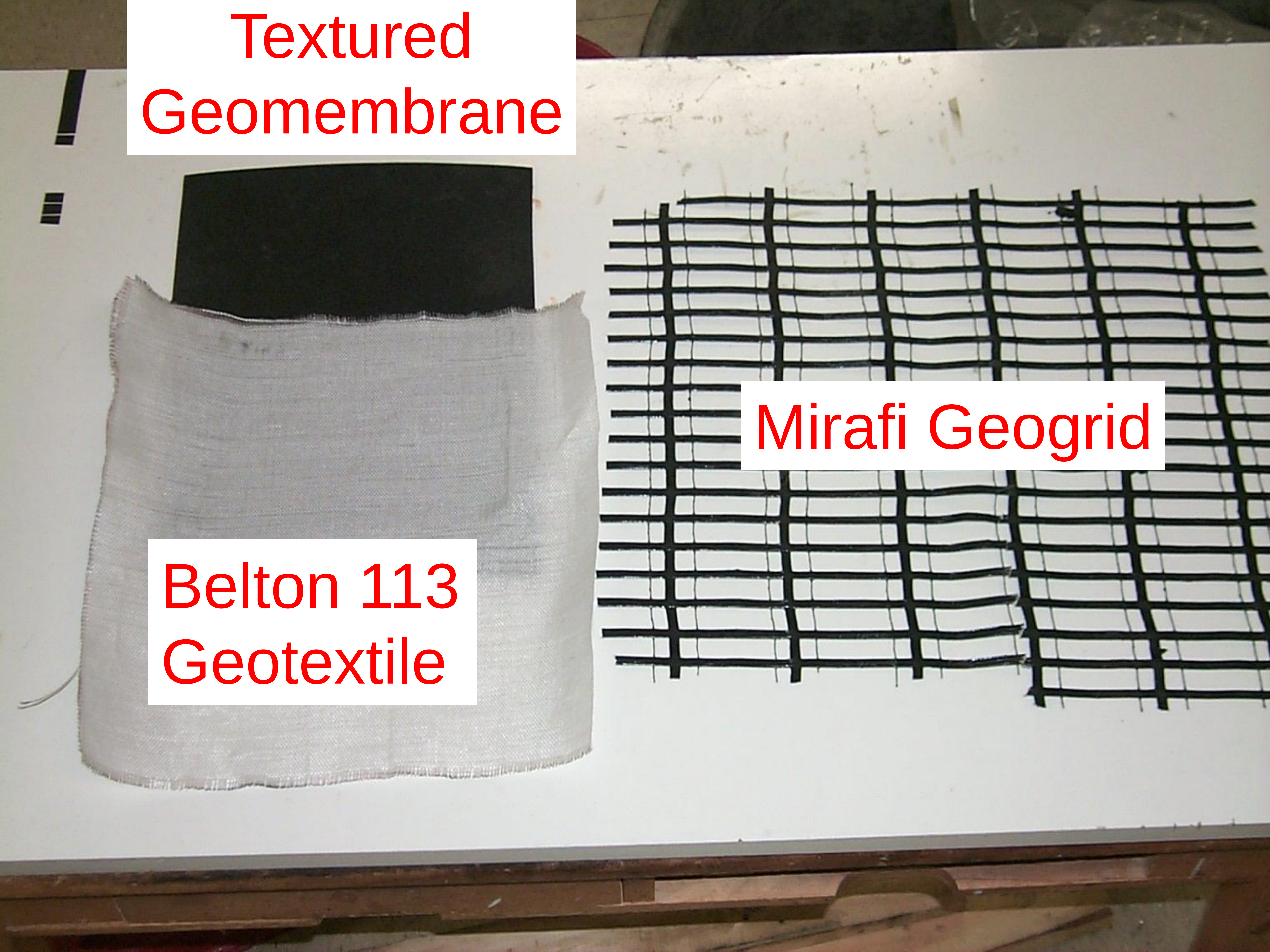
<u>Soaked</u>

ϕ' ~ 40°

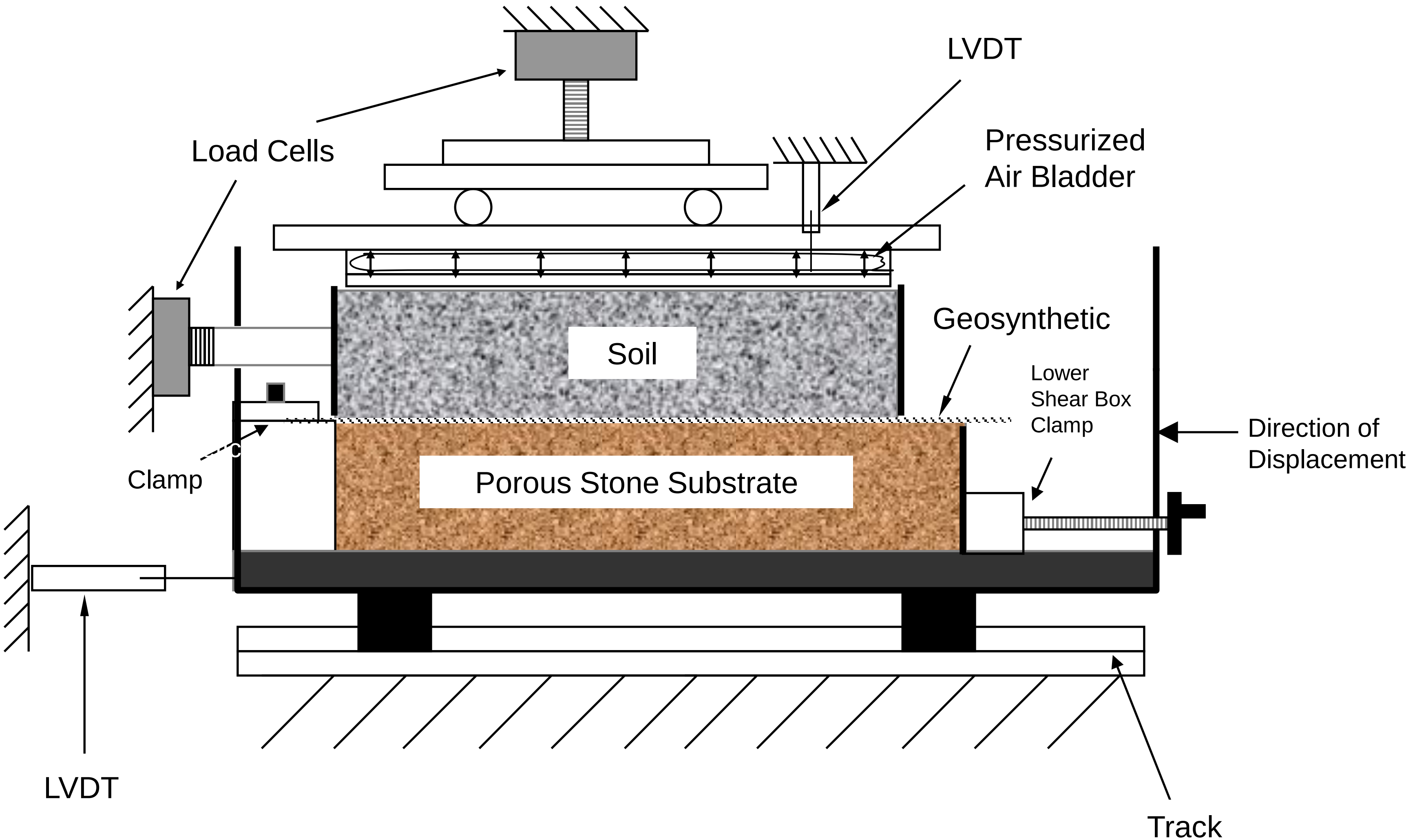
c' ~ 0



Soil	ϕ_a	c_a (kPa)
Foundry Sand A	50°	28.0
Foundry Sand B	39°	16.7
Foundry Sand C	43°	19.2
Foundry Sand D	42°	28.0
Portage Sand	42°	5.5
Base Sand	42°	8.3


Textured
Geomembrane
Mirafi Geogrid
Belton 113
Geotextile

Large-Scale (D 5321) Direct Shear Machine



Interface Direct Shear Box (300 mm x 300 mm)

Frictional Efficiencies

<u>Geotextile:</u>
Base Sand - 83%
Foundry Sands - 61 to 74%

<u>Geogrid:</u>
Base Sand - 96%
Foundry Sands - 51 to 71%

E(%) = tan♎/tan♐' x 100

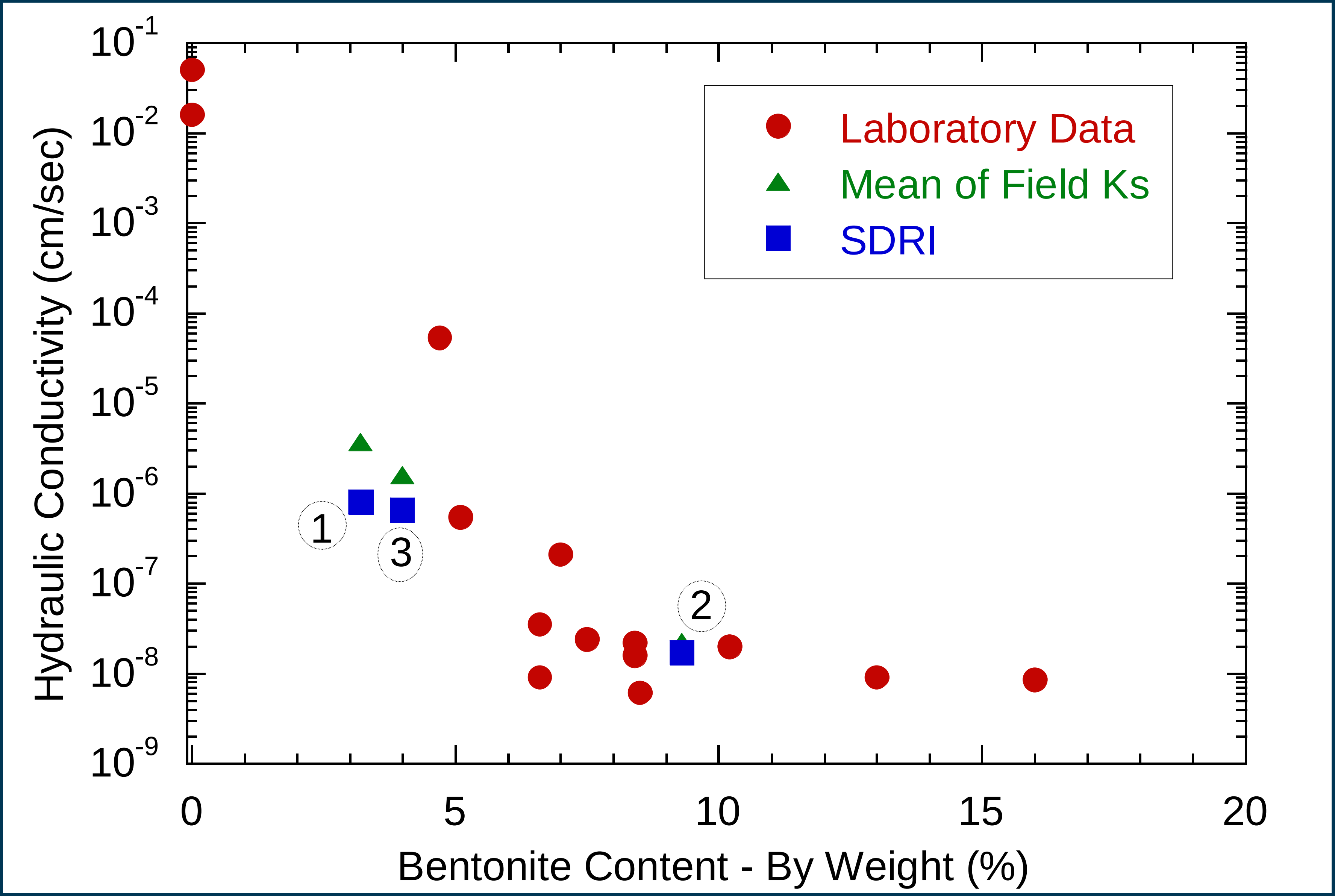
Retaining Wall and Structural Fill Design Recommendations

- $\phi' = 40^{o}$, $c' = 0$
- E = 55% (geogrid) or 65% (geotextile)
- $C_i = 1$ (low normal stresses)
- $C_i = 0.5$ (higher stresses)
- Compact near optimum water content.

Recap – Fill Applications

- True or False: the shear strength of foundry sands varies significantly between foundries.
- Frictional efficiencies between geosynthetics and foundry sands range between (a) 25-50%, (b) 50-75%, or (c) 75-100%.
- Foundry sands used for fill should be compacted (a) as dry as possible, (b) near optimum water content, or (c) 3% wet of optimum.

Hydraulic Conductivity



Hydraulic Conductivity

- Foundry sands will drain less effectively than conventional sands.
- Foundry sands with bentonite content < 6% preferred for better drainage.