Foundry Byproducts as Sustainable Geotechnical Construction Materials

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Participant Background

Which describes your training:

- Engineer
- Geologist
- Environmental scientist
- Other

Participant Background

Which describes your employment:

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

What is an iron foundry?

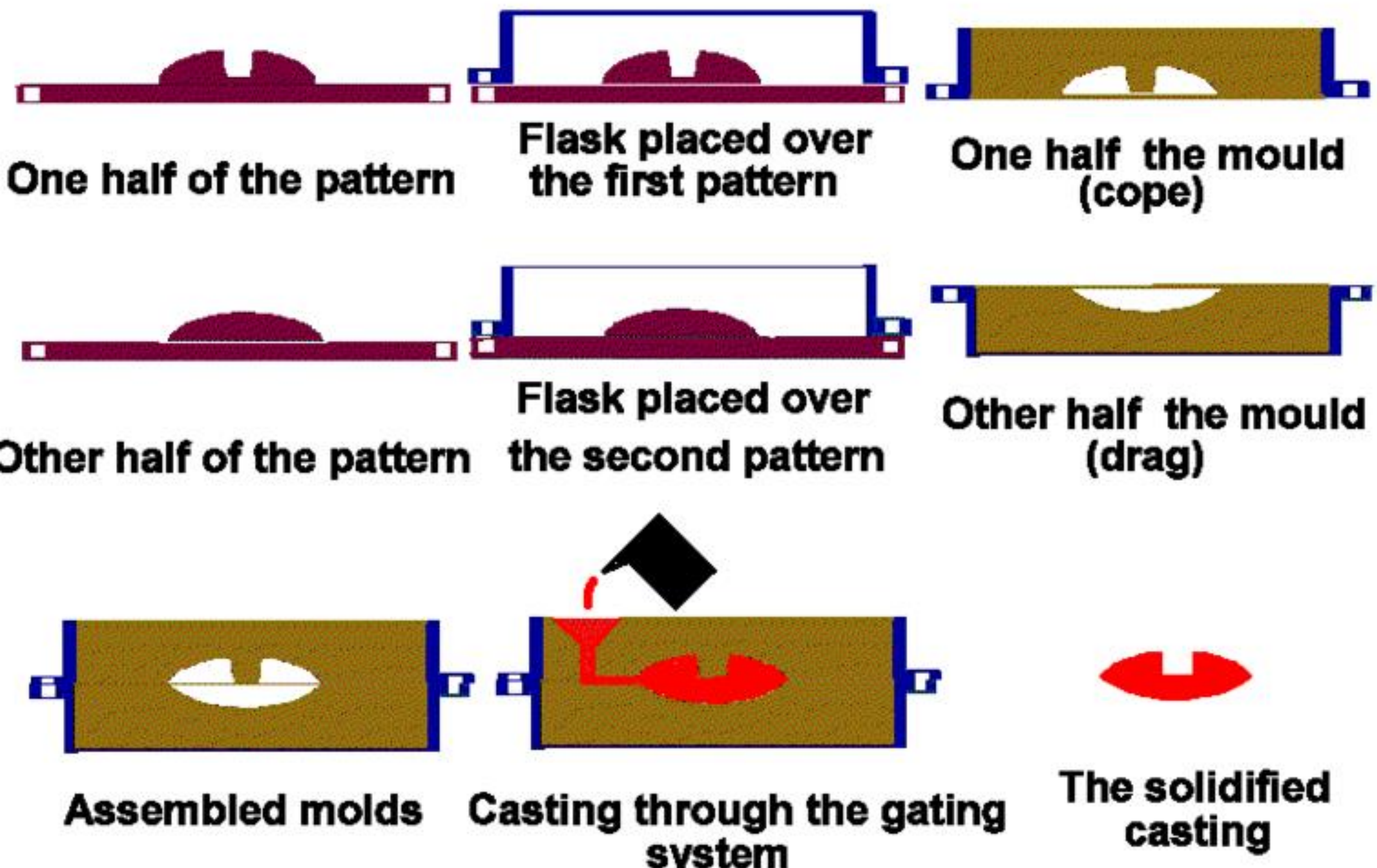
- An iron foundry is a manufacturing plant where molten iron is poured into molds to make iron products.
- Some common products include brake parts, gearboxes, propellers, and valves.
- Molds are formed with “green” sand, “no bake” sand, & “cores”
- Excess foundry sands used in construction usually are a mixture of green sand (predominant) and “core” or “no-bake” sand.

Foundry Byproducts

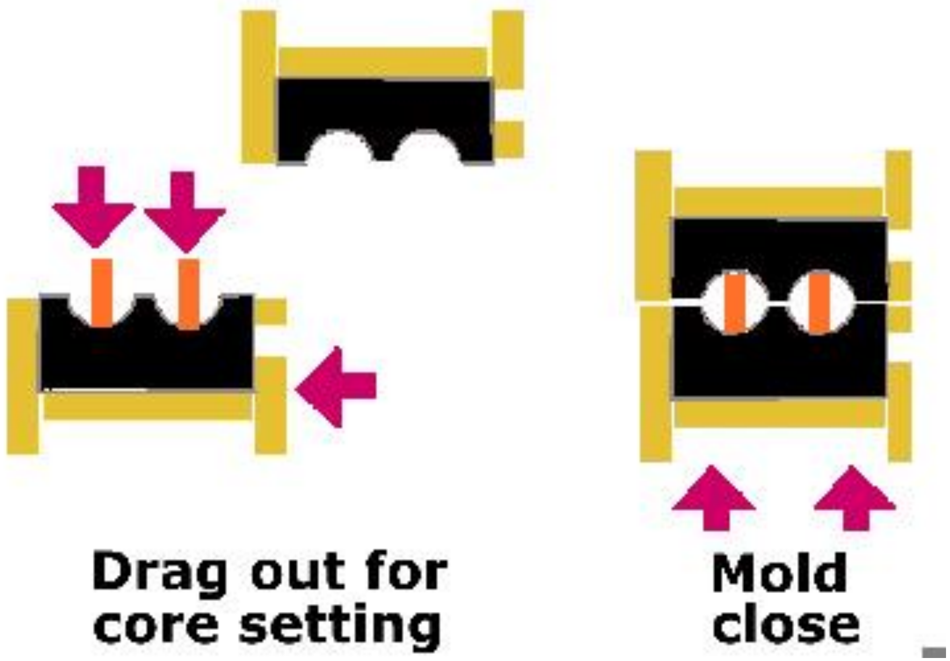
Two primary byproducts:

- Foundry sand – excess material generated at foundry as new ingredients are added to sand blend to ensure suitable properties (aka "excess sand" or "spent system sand").
- Foundry slag – impurities that float to surface of molten iron (Ca, Mg, and other elements). Amorphous "obsidian-like" when slowly air cooled or porous "tuff-like" when rapidly water cooled.

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.

Foundry Sand Being Used as Fill

Foundry sand grades and shapes easily.

Fines facilitate compaction with modest amount of moisture.

Foundry sand being spread as highway sub-base.

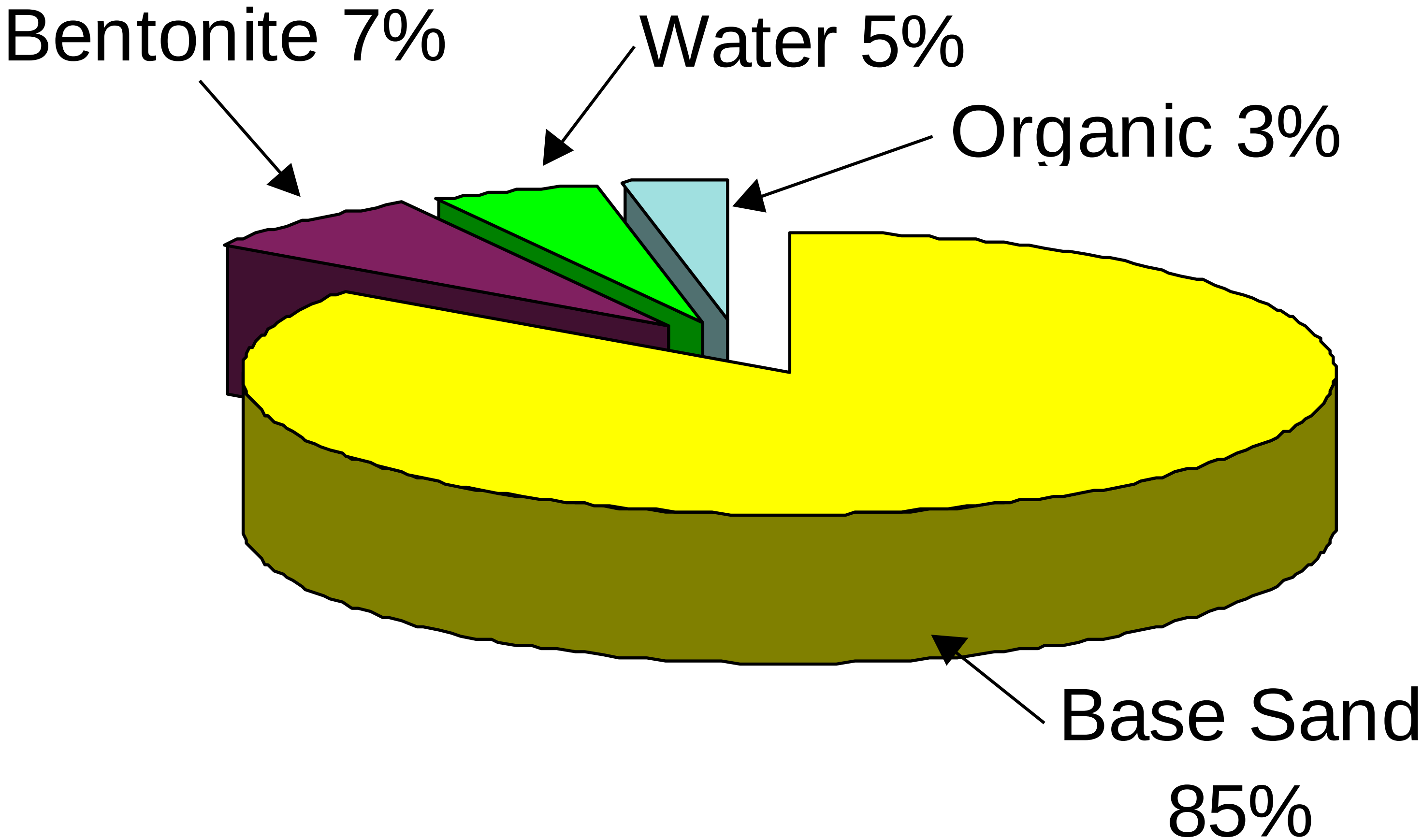
Foundry sand sub-base being compacted.

Foundry Slag Used as Base Course

Recap Poll # 1 – True or False

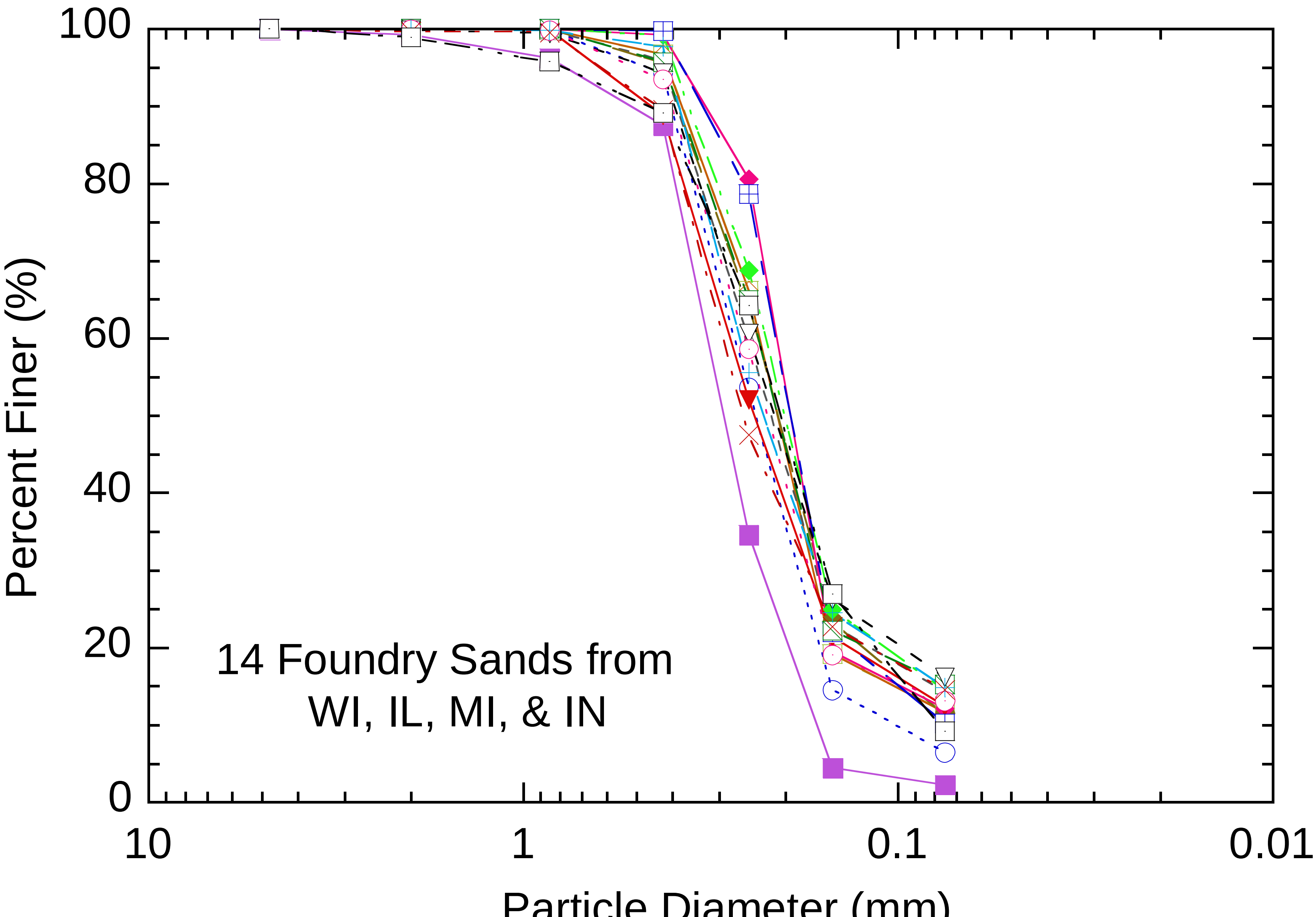
- The basic types of iron foundry sands that might be encountered in a reuse application: green sand, core sand, no-bake sand. True or false?
- Foundry sand is discarded because the sand has the incorrect color. True or false?
- Foundry slag is synonymous with foundry sand. True or false?

Foundry Sand Composition



Foundry sands are sand-bentonite mixtures.

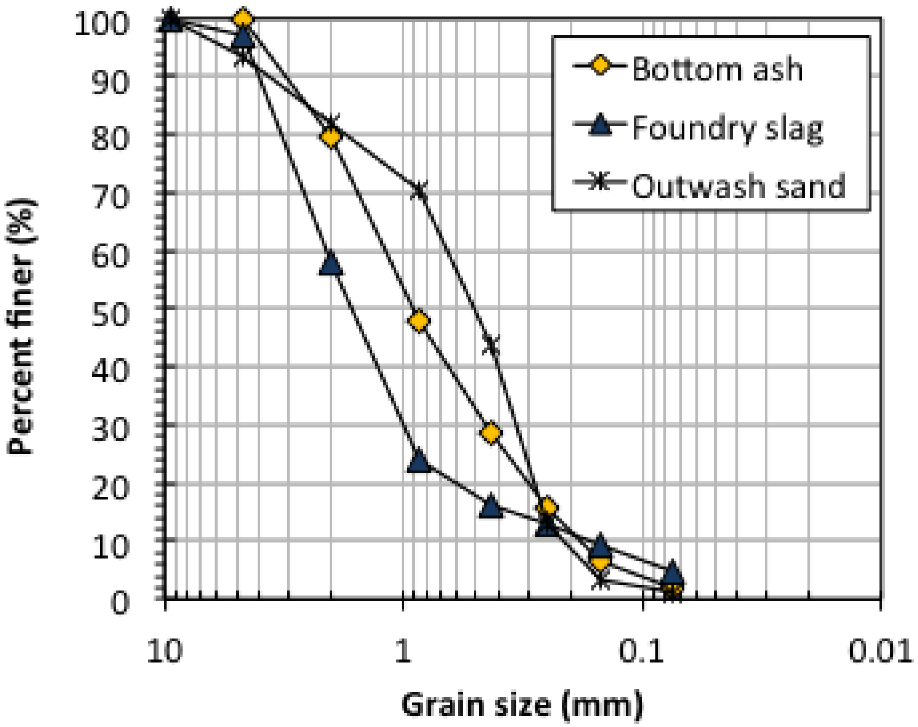
Particle Size Distribution



Index Properties for Foundry Sands

- Fine Sand
- Fines: typically 10 to 12%
- 2 µm Clay: typically 3 to 10%
- Plasticity index (PI): typically NP to 5
- SC, SP, or SP-SM or A-2-4 or A-3
- G_s: 2.52 to 2.73 (Base Sand = 2.66)
- Subrounded to subangular (R = 0.5 to 0.7)

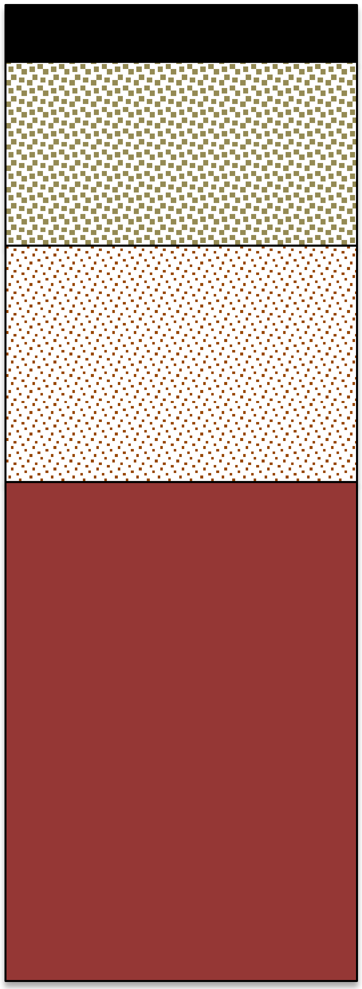
Index Properties for Foundry Slags



Material	G_s
Bottom ash	2.67
Foundry slag	2.36
Glacial outwash sand	2.71

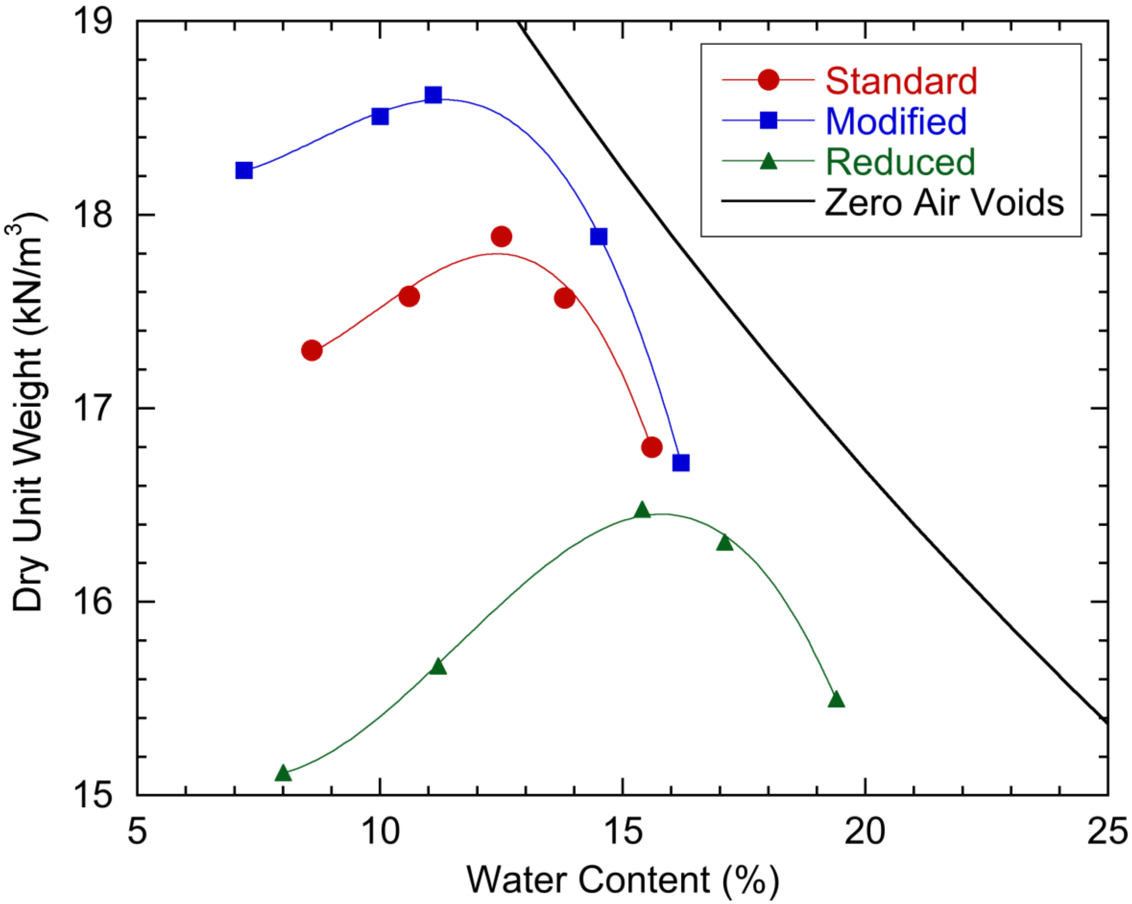
- Pea gravel to sand size (depends on crusher)
- Non-plastic
- SW, SP, GW,
- G_s = 2.2 to 2.4

Subbase Applications



- Compaction
- California bearing ratio (CBR)
- Resilient modulus
- Drainage

Compaction Curves



- Bentonite fraction imparts “bell” shape compaction curve, even with low bentonite content.
- Behaves like a finer textured soil.

With adequate moisture, readily compact to 95% of standard Proctor or 90% of modified Proctor. Relatively dry from foundry (3-5%) – water is needed.

Typical CBRs

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

- Optimum water content and 95% compaction.
- Higher CBR obtained with a more non-plastic fines.
- Plastic fines reduce CBR

Non-Plastic Sands:

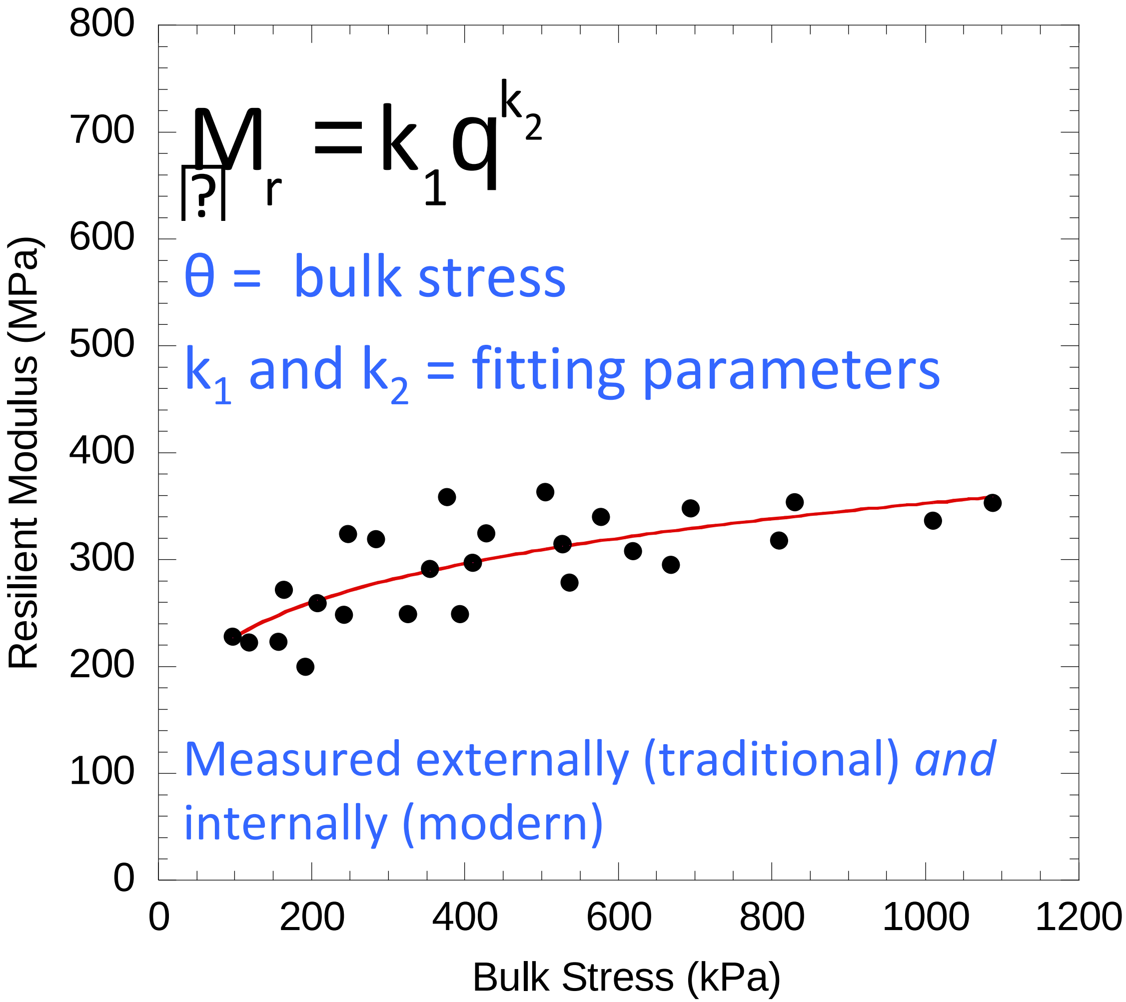
$$CBR = -361 + 32.4\gamma_d - 1.93P_{200} - 264R$$

Plastic Sands:

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

γ_d in kN/m^3, P_{200} in %, R is Krumbein roundness (use 0.6), BC = bentonite content (%)

Resilient Modulus

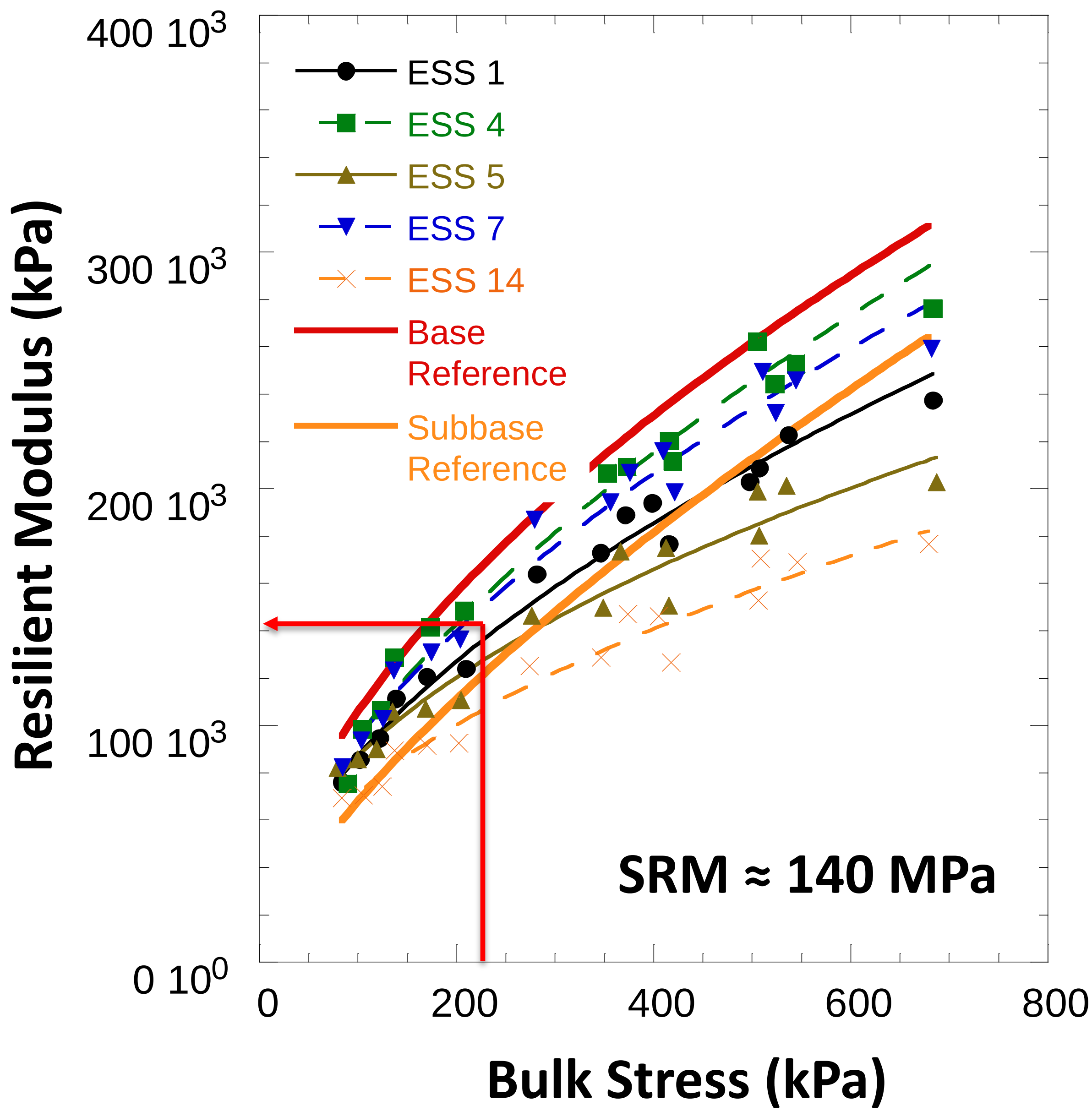


Summary resilient modulus (SRM) at bulk stress = 208 kPa.

Resilient Modulus: BC < 6%

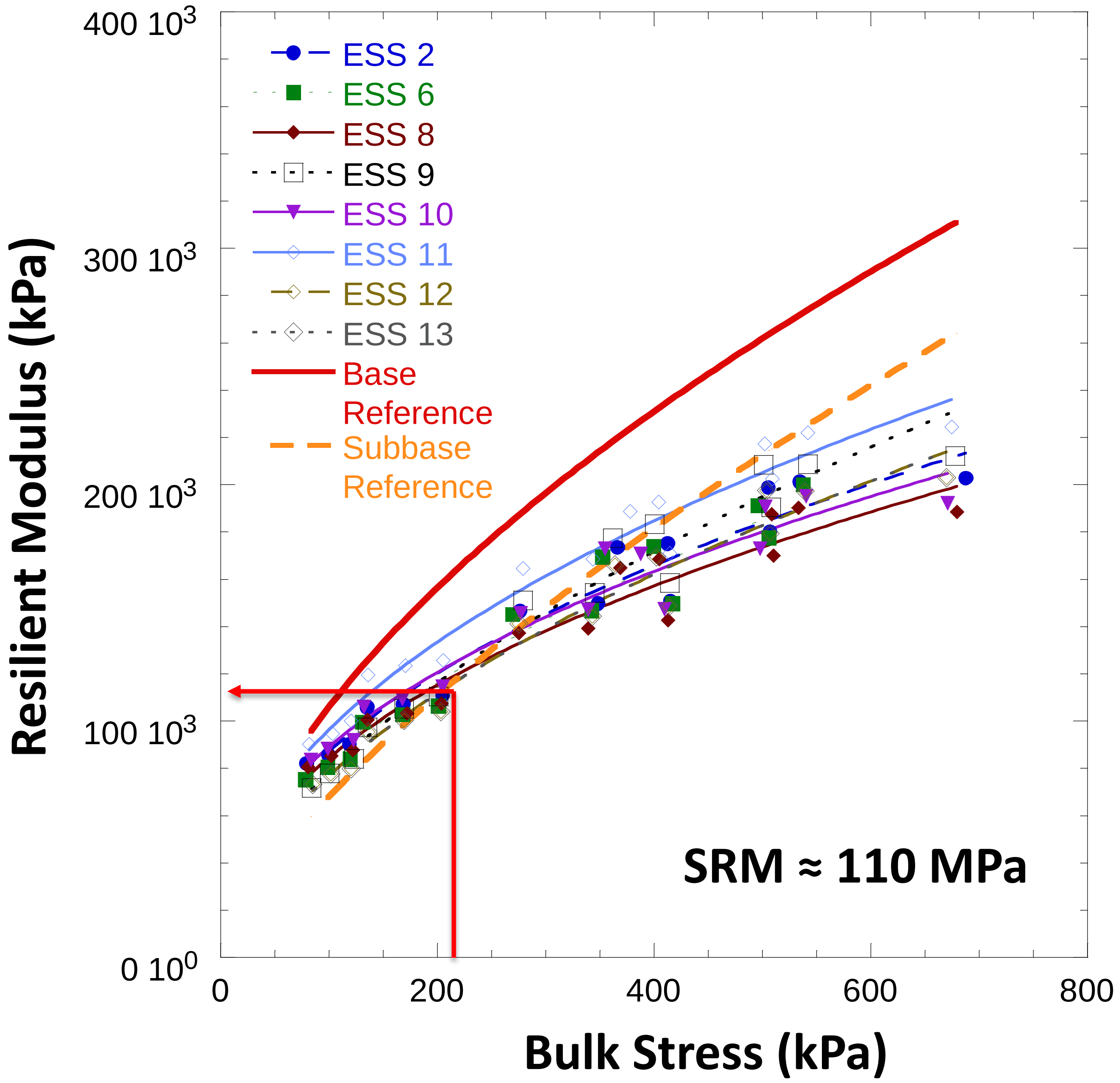
Many foundry sands have modulus falling between conventional subbase & base.

Tested at optimum water content & 95% compaction.

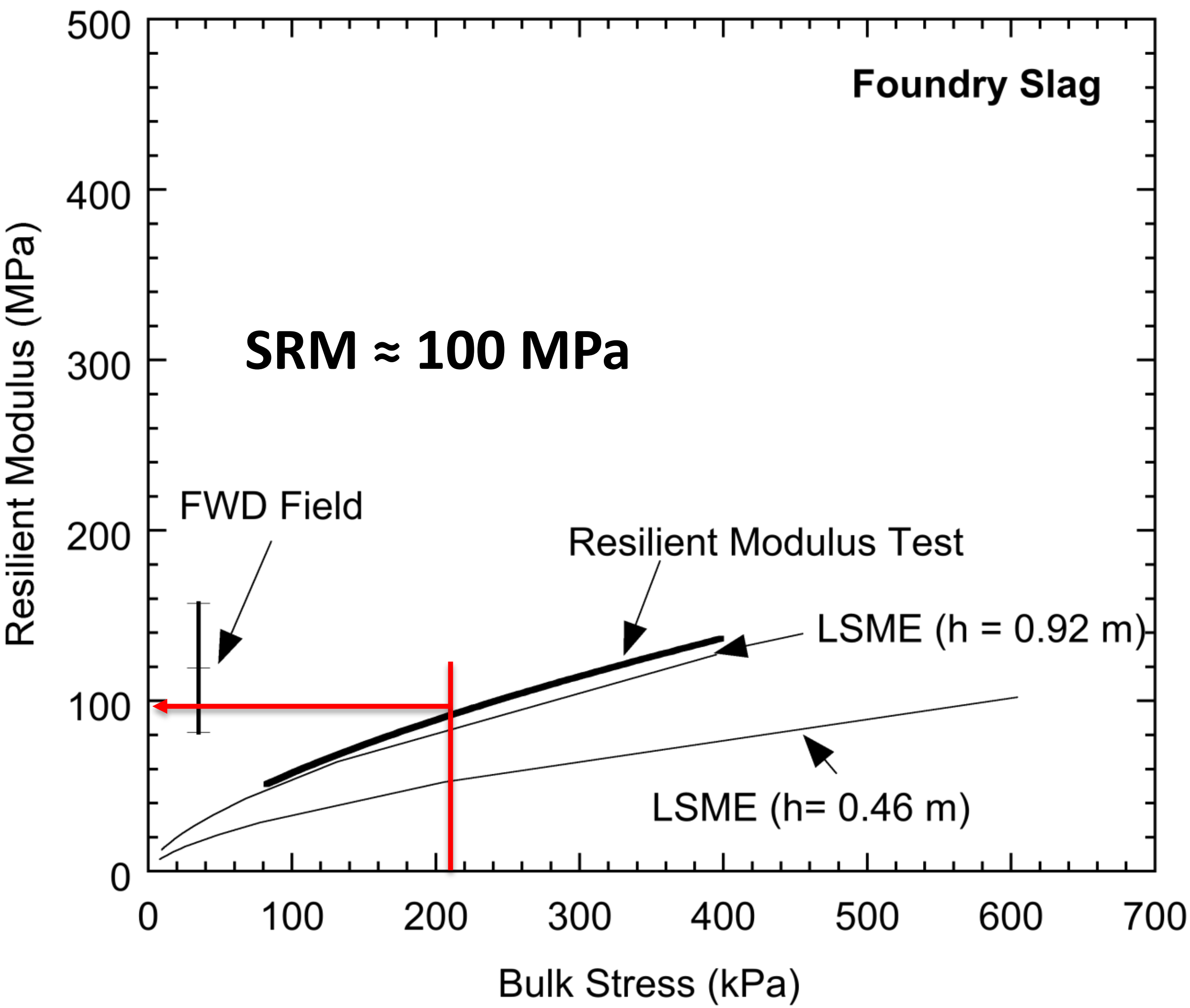


Resilient Modulus: BC > 6%

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

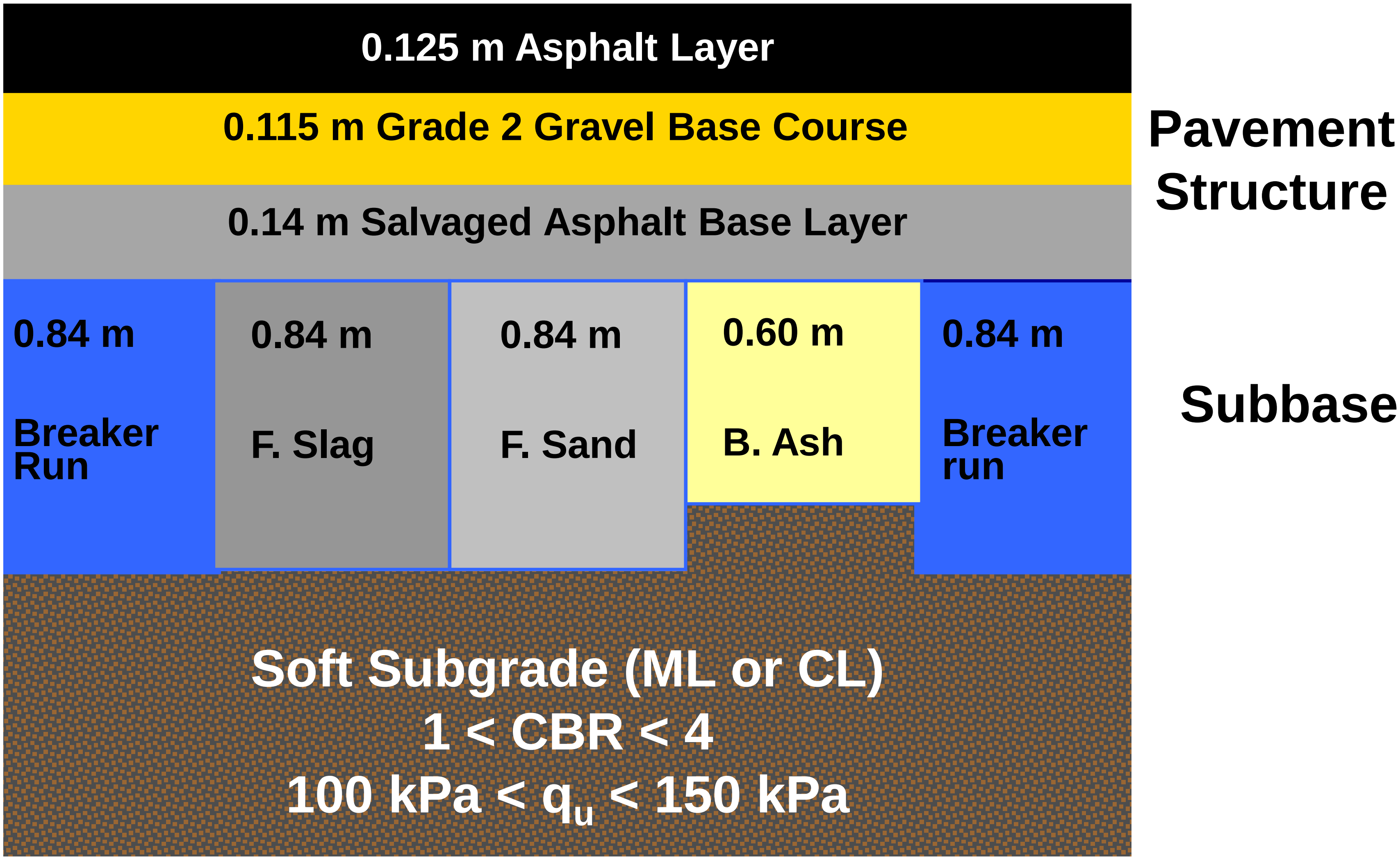


Resilient Modulus of Foundry Slag

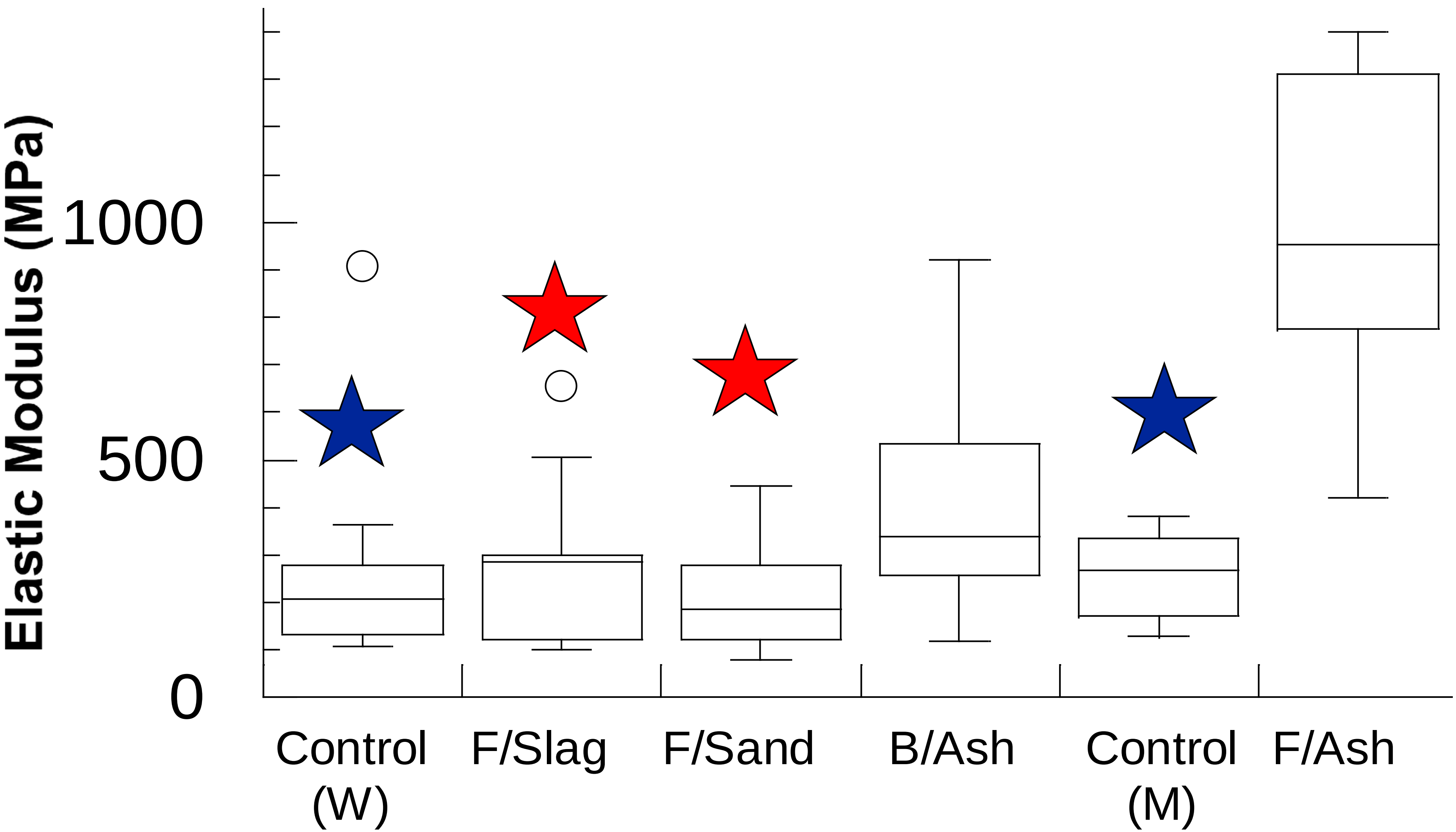


- Recommend SRM = 100-120 MPa. Similar to foundry sand, but drains readily.
- Use as base or subbase.

Full-Scale Field Test: Wisconsin State Highway 60



Field Performance: Five Years After Construction



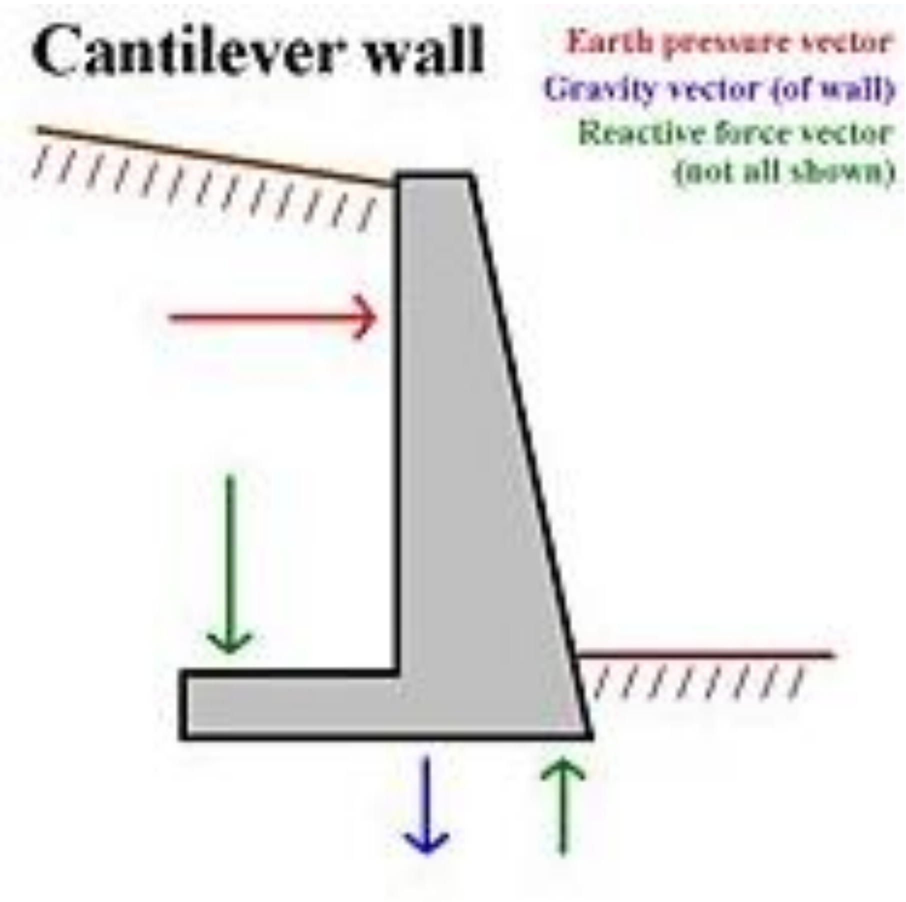
Recap Poll # 2 – True or False

- Foundry sands compact like fine textured soils with a bell-shape compaction curve. True or False?
- Foundry sands have comparable CBR and modulus as conventional base course materials. True or False?
- Field data have shown that foundry sands and slags can perform comparable to conventional construction materials in the field. True or False?
- Foundry sands with higher bentonite content have higher CBR and modulus. True or False?

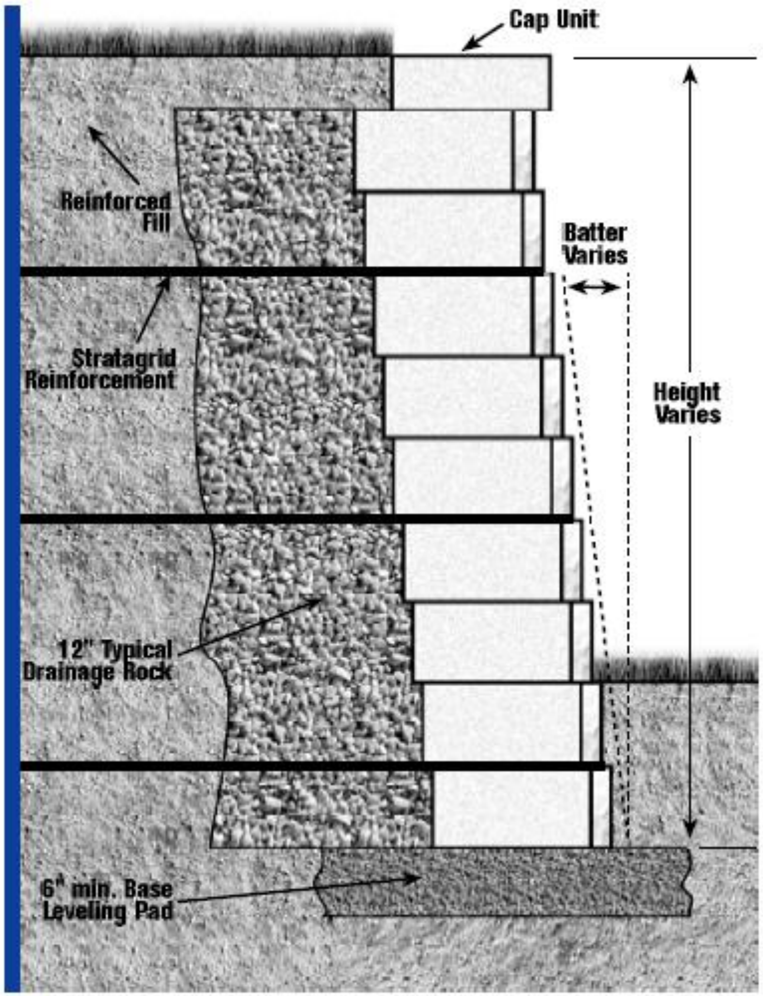
Retaining Structure Backfill/Structural Fill

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

Conventional Retaining Wall



Mechanically Stabilized Wall



Direct Shear Strength of Foundry Sands

Unsoaked:

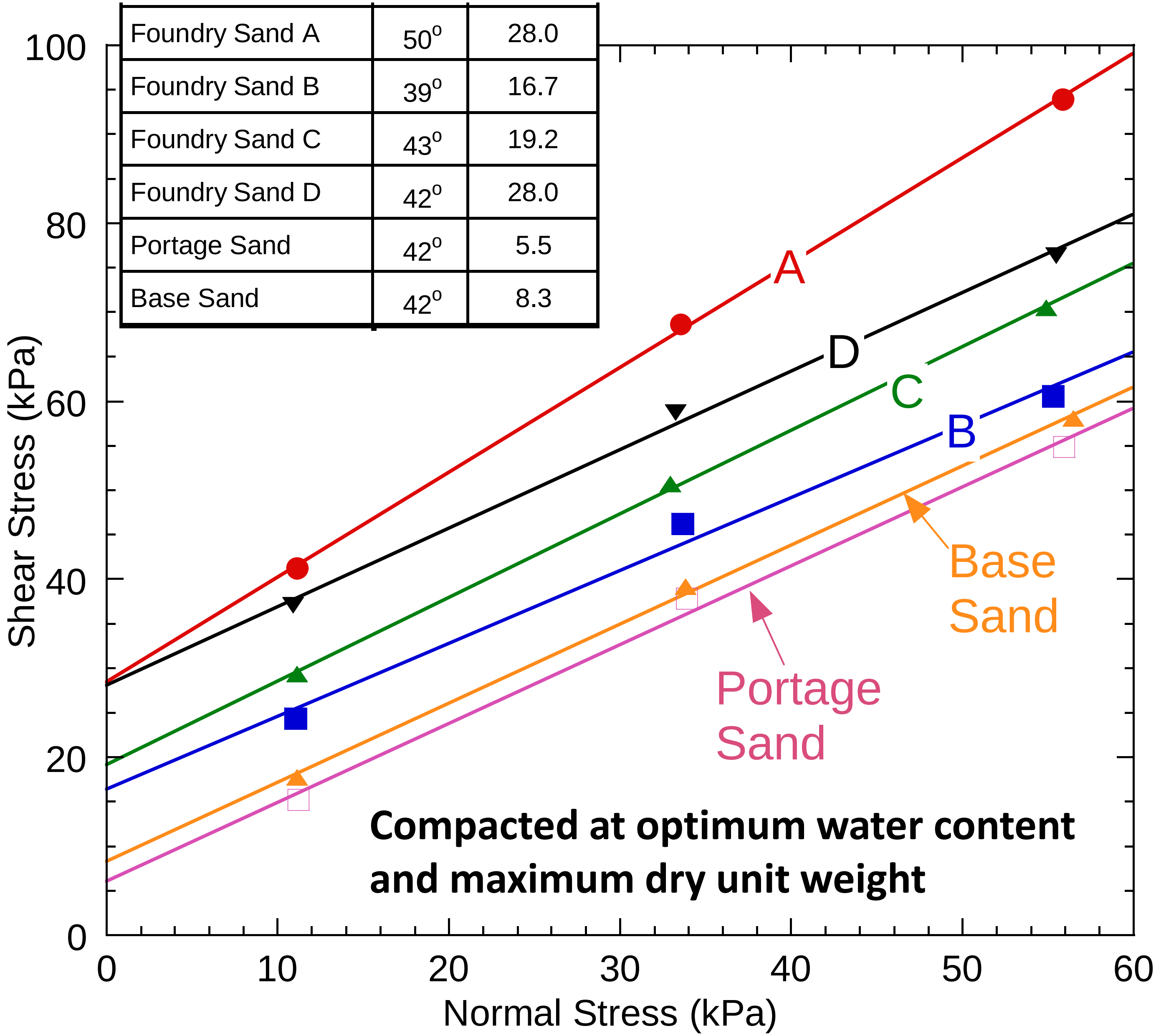
$\phi \sim 40^o$

c' varies

Soaked

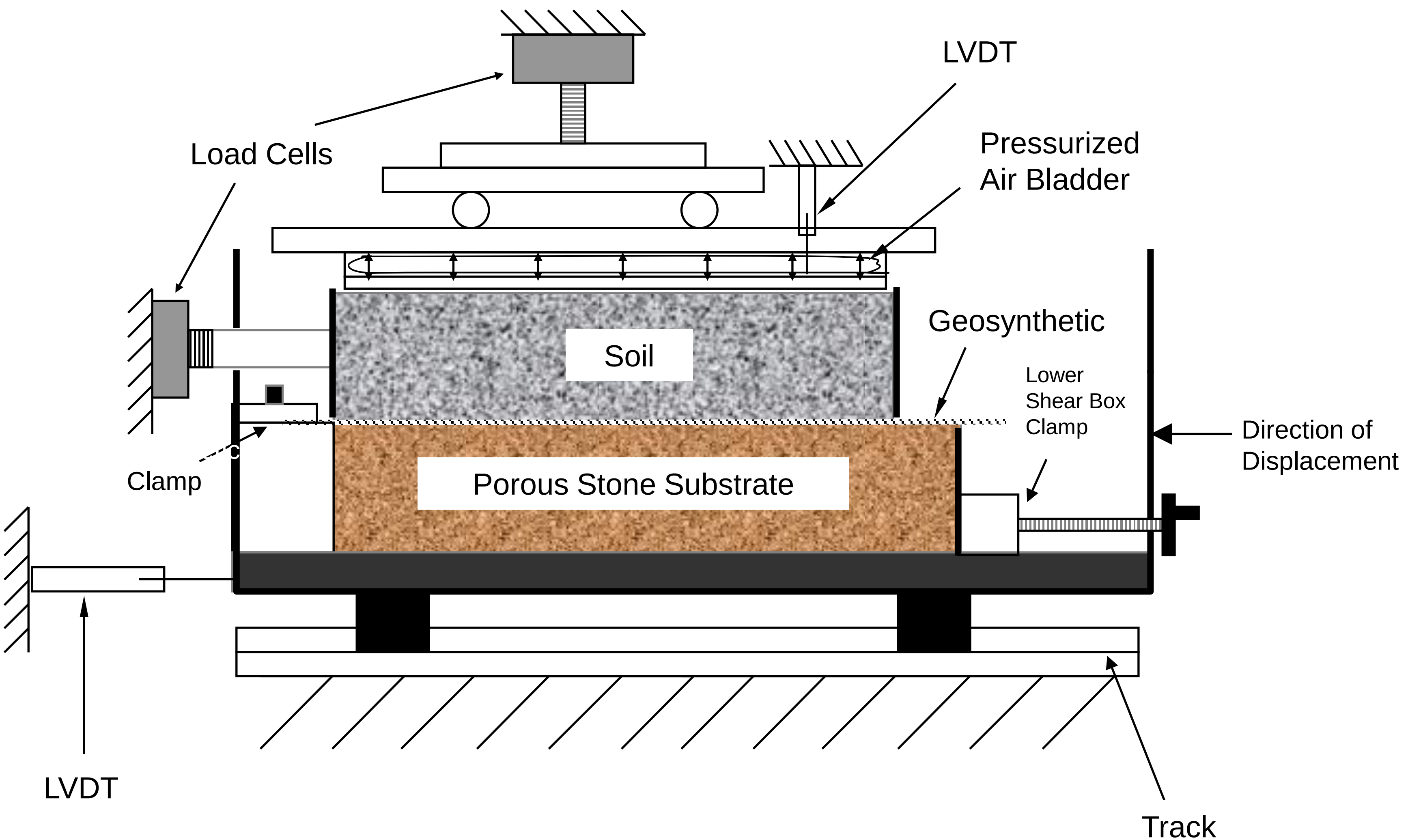
$\phi \sim 40^o$

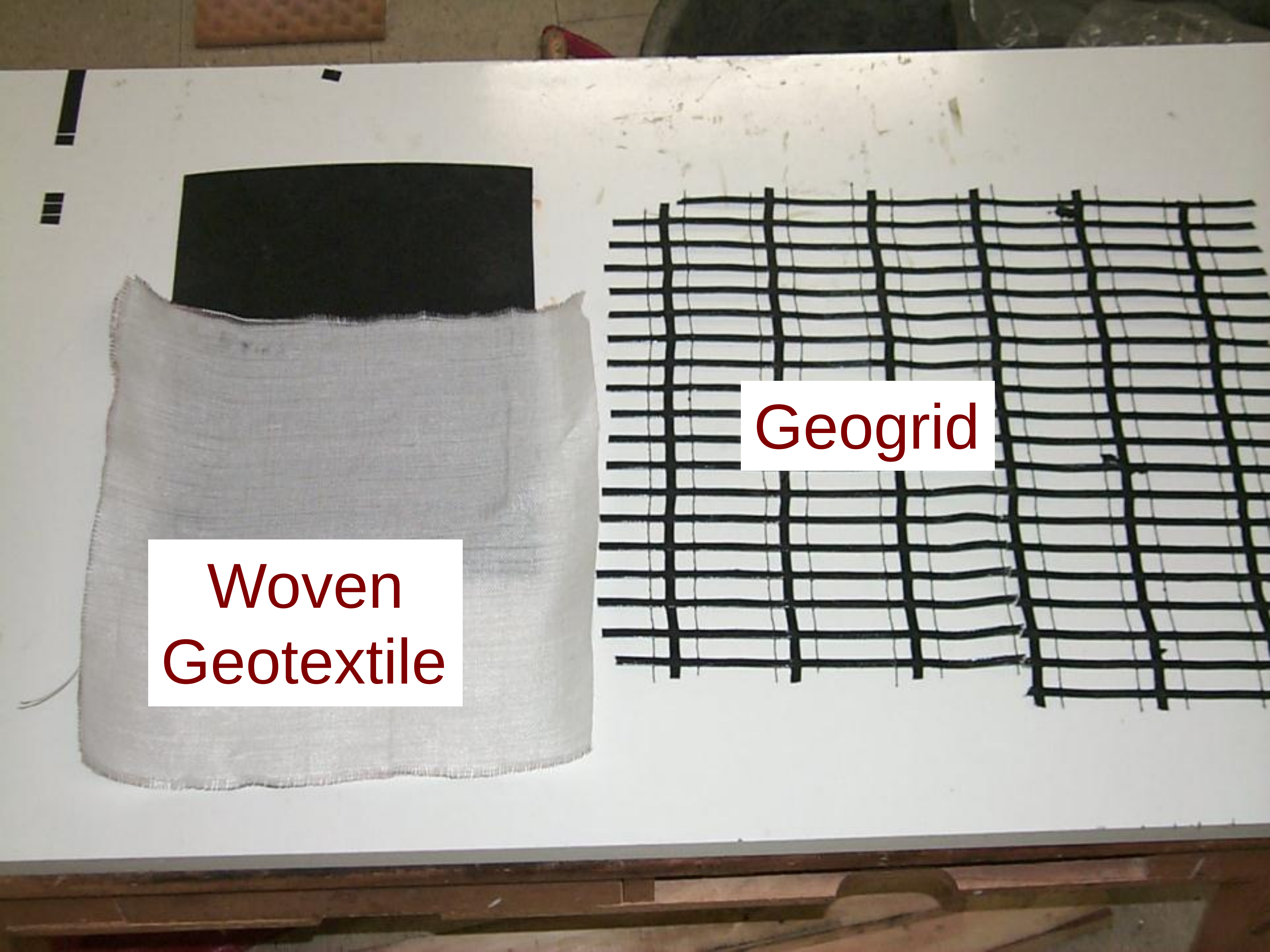
c' ~ 0



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

Large-Scale (D 5321) Direct Shear Machine




Woven
Geotextile
Geogrid

Frictional Efficiencies

$E(\%) = \tan\delta'/\tan\phi' \times 100$

δ' = interface friction angle

ϕ' =internal friction angle

Geotextile:

Base Sand - 83%

Foundry Sands - 61 to 74%

Geogrid:

Base Sand - 96%

Foundry Sands - 51 to 71%

Retaining Wall and Structural Fill Design Recommendations for Foundry Sands

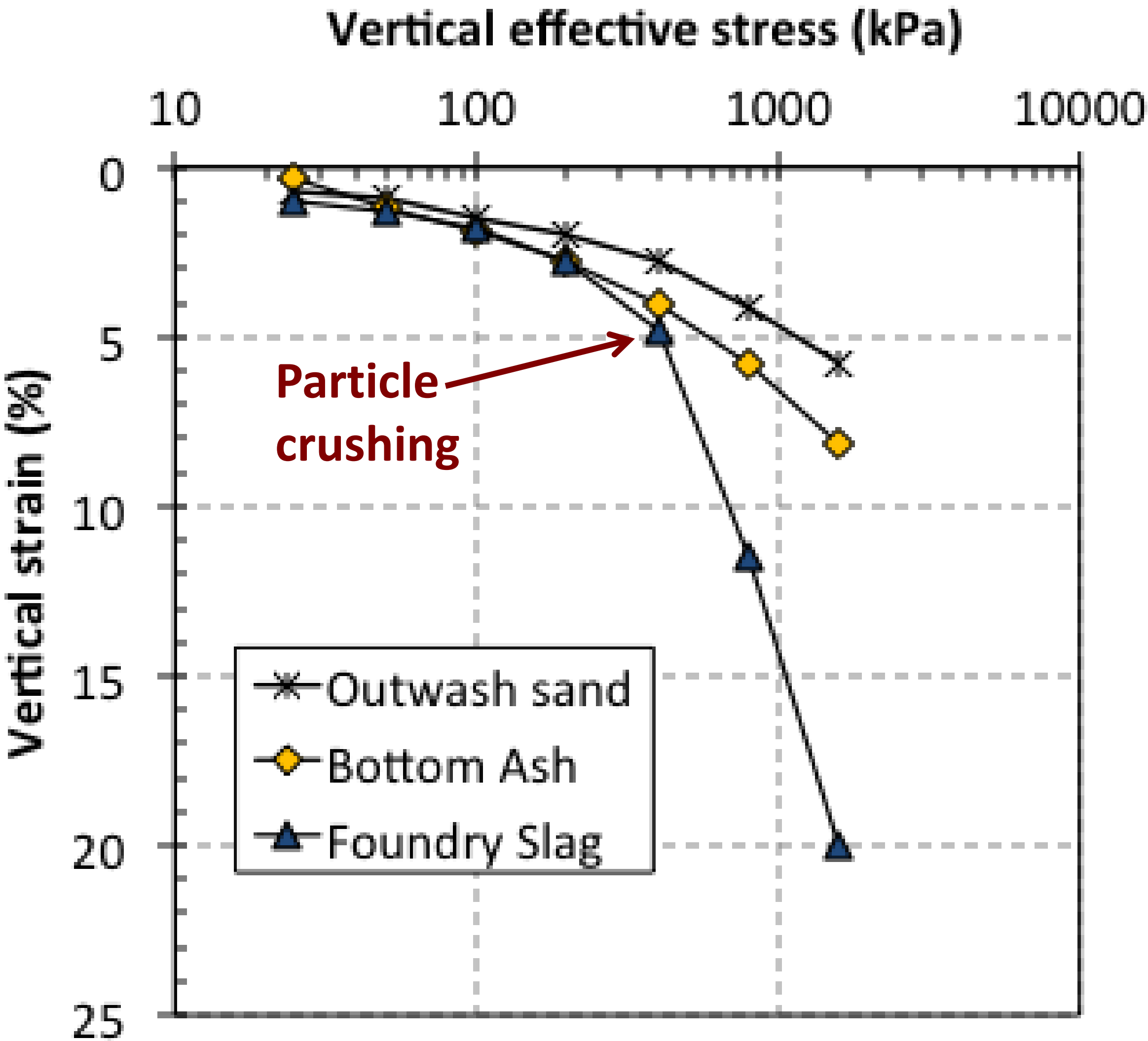
- $\phi' = 40^o$, $c' = 0$
- E = 55% for geogrids
- E = 65% for geotextiles
- Compact dry of optimum water content

Recommendations for Foundry Slags

Material	Friction Angle
Outwash sand	37°
Bottom ash	44°
Foundry slag	38°

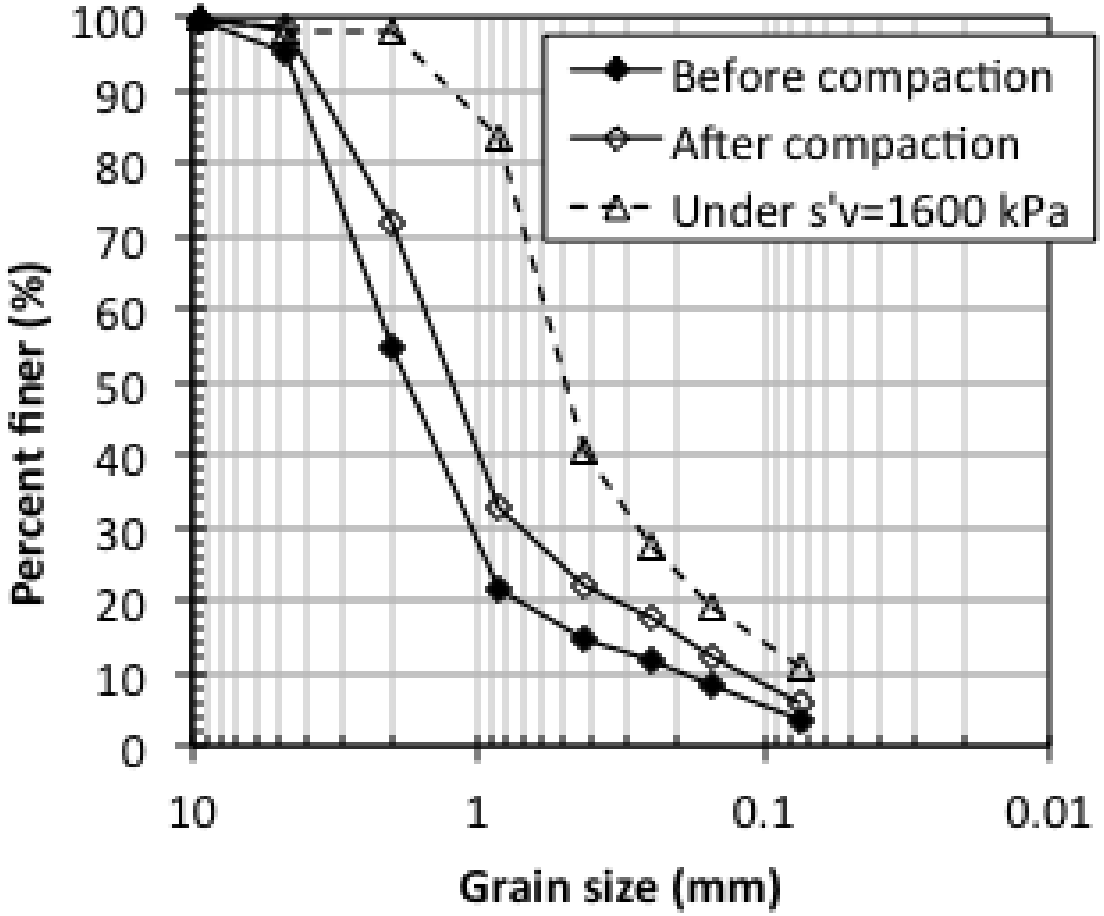
- $\phi' = 38^{o}$, $c' = 0$
- E = 90% (geogrid)
- E = 80% (geotextile)

Using Foundry Slag in Deep Fills



Particle crushing can occur at higher stresses (> 400 kPa, ~ 30 m deep)

Particle Size Curves Showing Crushing of Slag Under High Stress

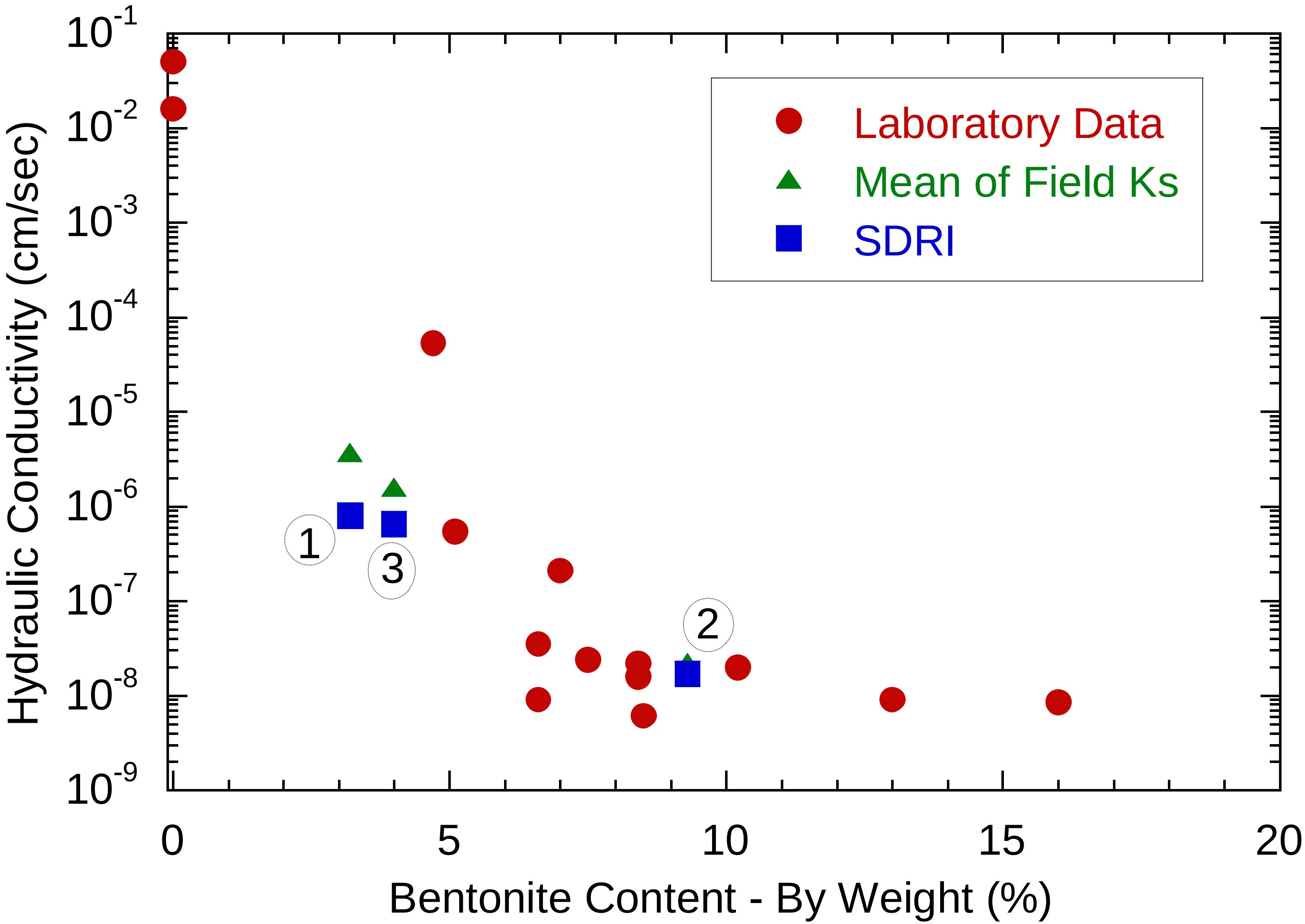


Slight reduction in particle size due to compaction.

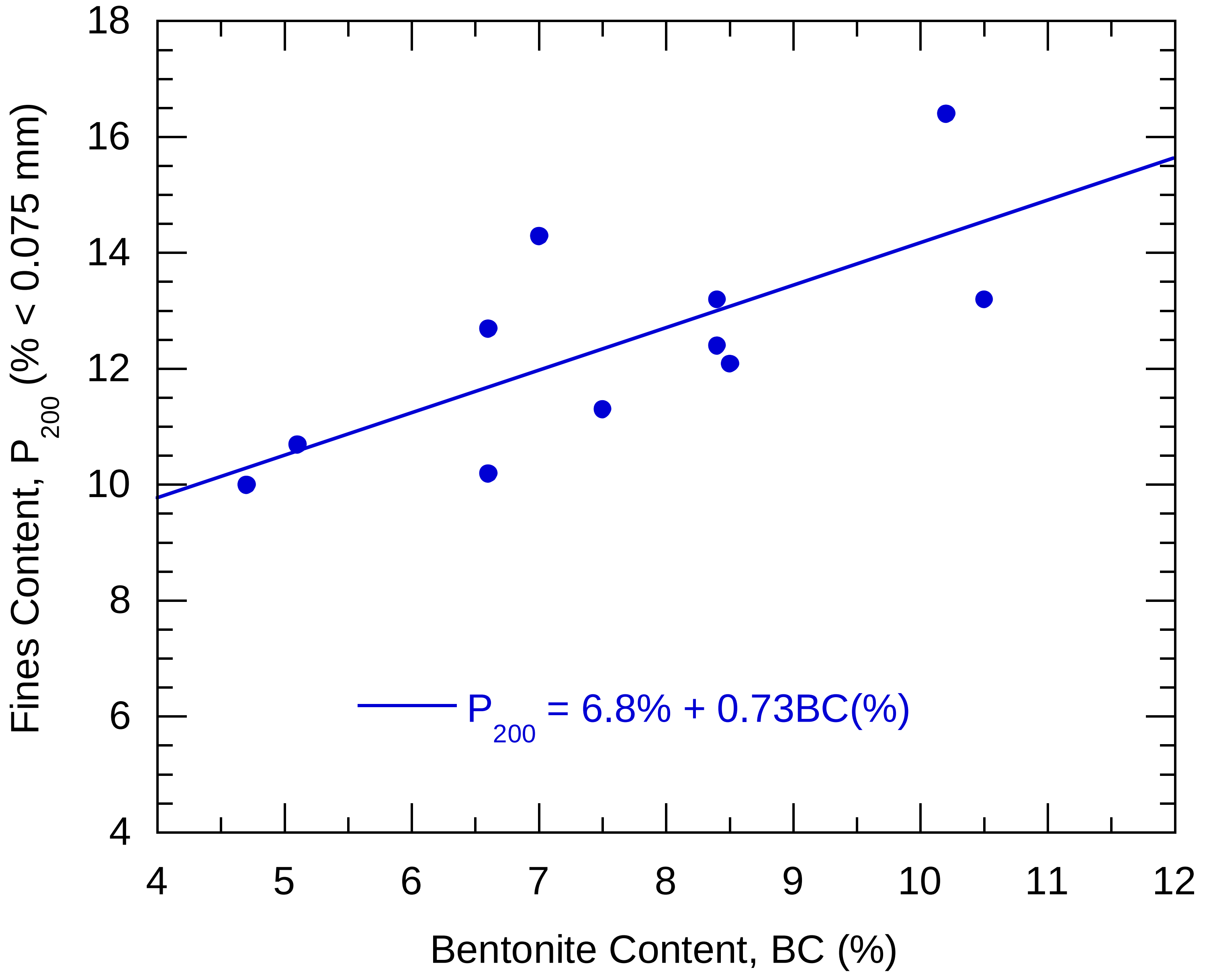
Substantial reduction in particle size due to crushing at high stress.

For deep fills, measure shear strength and compressibility for site-specific conditions.

Drainage & Foundry Sands



Fines Content & Bentonite Content

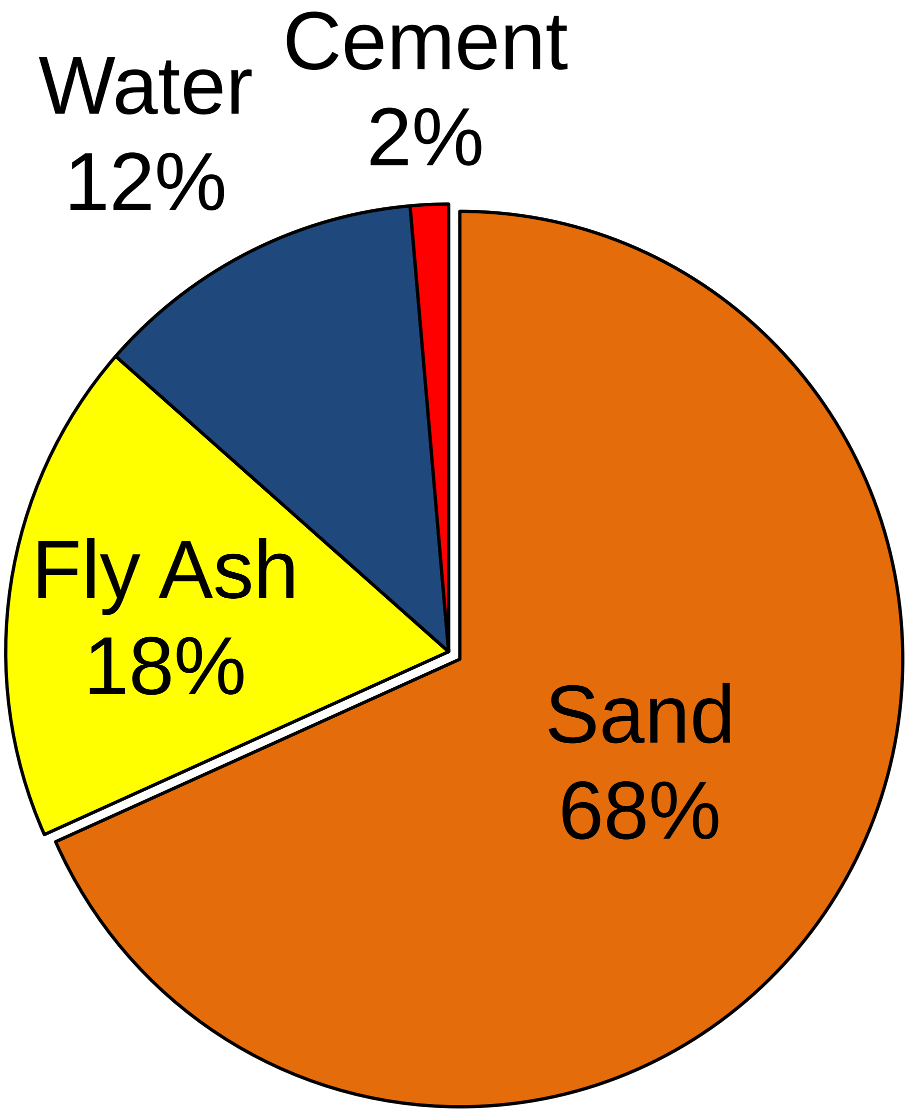


Recap Poll # 3 – True or False

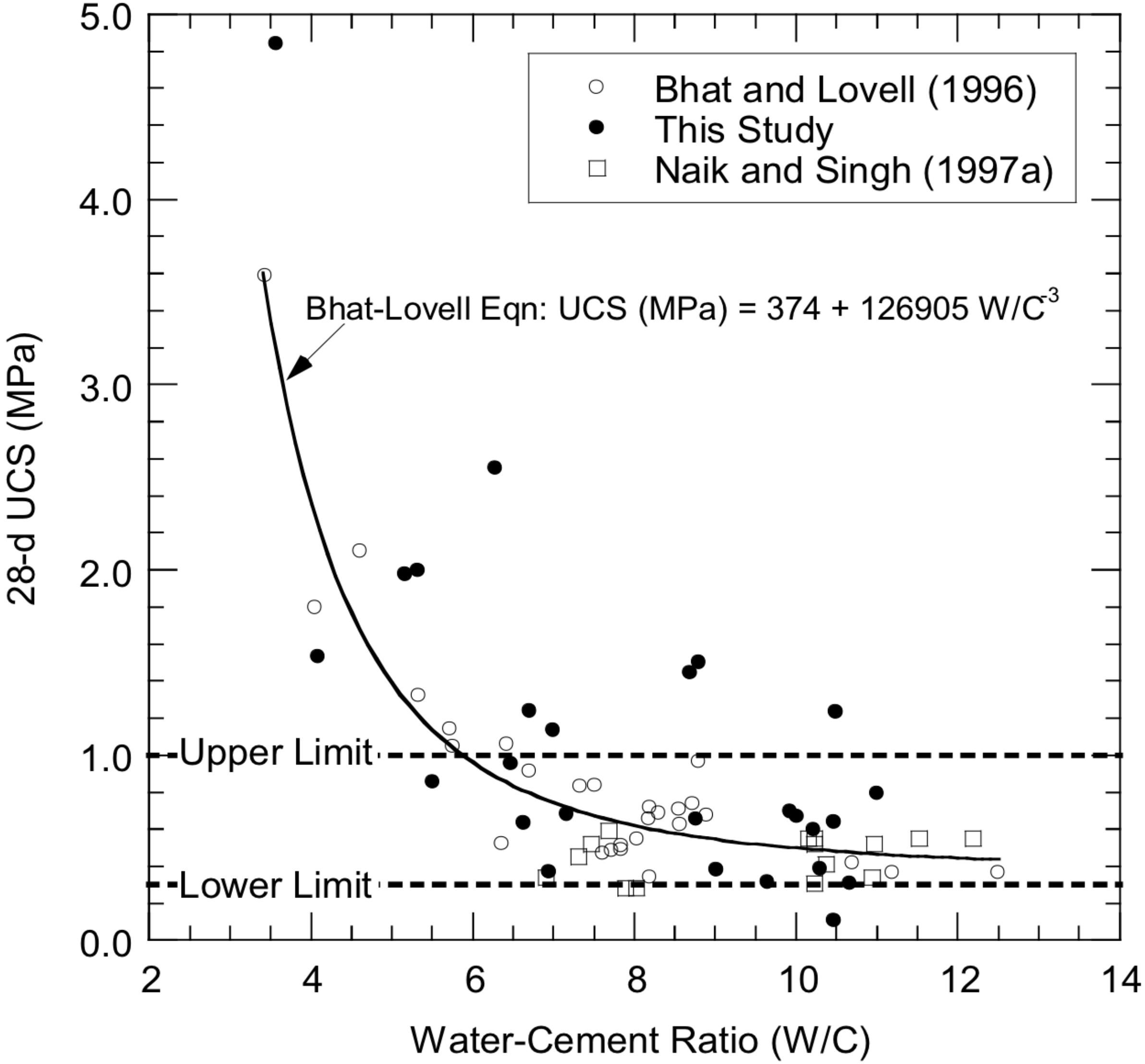
- Foundry sands have much higher friction angle than their base sand. True or False?
- Geogrids have higher efficiency than geotextiles when used as reinforcement with foundry sand or slags. True or False?
- Foundry slags are more compressible under high stress than natural quartz sands. True or False?
- Except for the highest bentonite contents, foundry sands drain well. True or False?

Foundry Sands in Flowable Fill

- Flowable slurry mixed & delivered like concrete.
- Modest strength, but excavatable
- Trench backfill, underground void backfill, pipeline grouting.

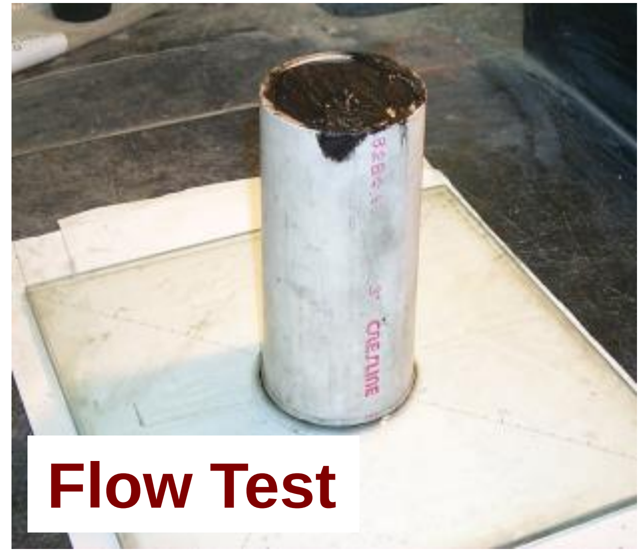


Strength and Mix Design



Use water-cement ratio of 9 to 12 to ensure strength in correct range (0.3 – 1.0 MPa).

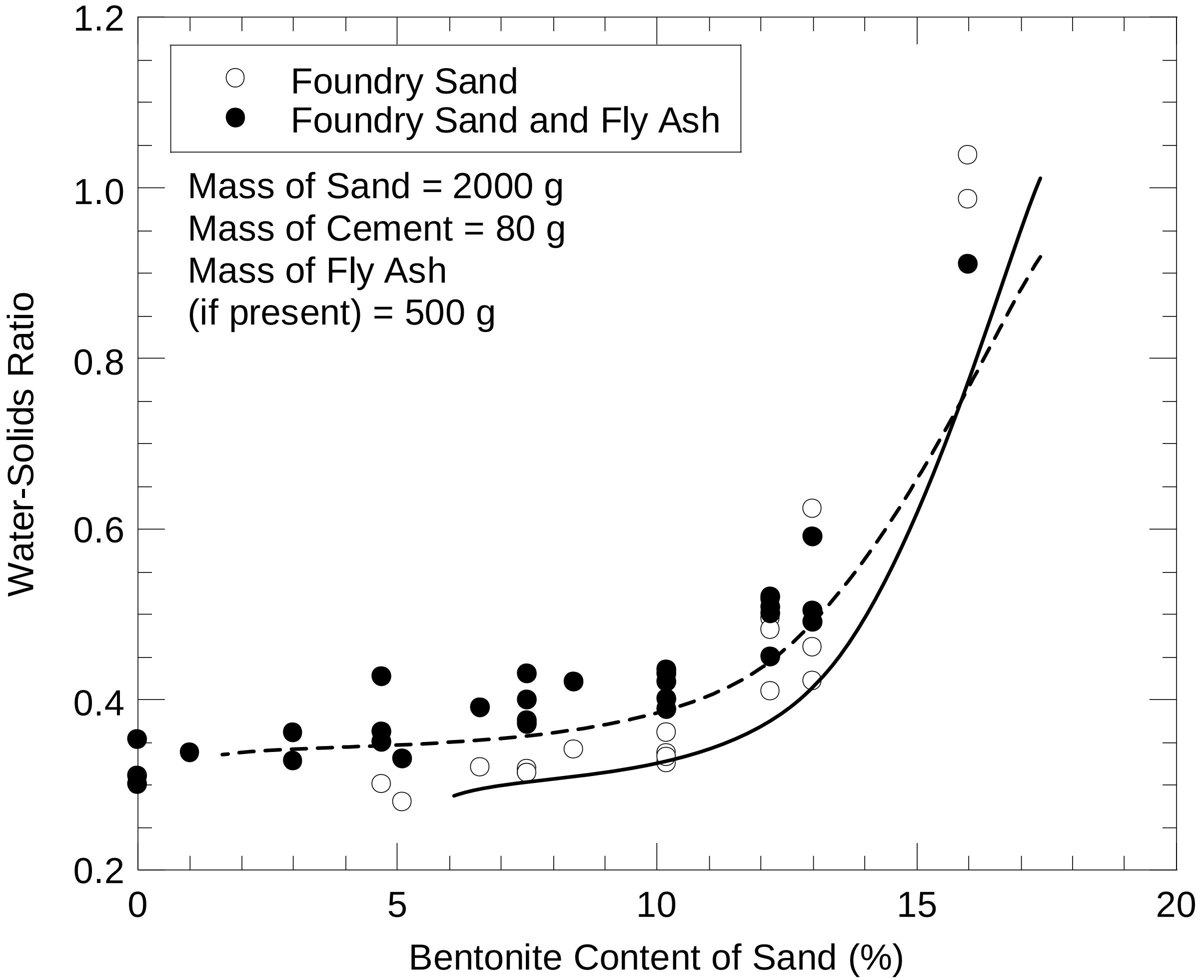
Ensuring Adequate Flow



Good Flow

Too Low

Water-Solids Ratio to Achieve Target Flow



Sands with more bentonite require more water to achieve target flow of 200 mm.

Bentonite binds with water, increasing viscosity of mix.

Recap Poll # 4 – True or False

- Flowable fill is designed to be adequately strong, but not so strong that it cannot be excavated. True or False?

- The water required in a flowable fill increases with bentonite content. True or False?

- A water-cement ratio within 9 – 12 will achieve appropriate strength. True or False?