Concrete Pumping: Applied Fluid Dynamics

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Who Cares about Pumping?

- Contractor
- Pumping Contractor
- Ready Mix Provider
- Inspector

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ACI 304.2R – Placing Concrete by Pumping Methods

Getting what you want

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ACI 304.2R – Placing Concrete by Pumping Methods

- Understand pumping equipment.
- Understand pumping safety.
- Understand pipeline and accessories.
- Understand couplings, gaskets, assembly, disassembly, and clean out.

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Special Inspector Requirements

- Understand proportioning pumpable concrete.
- Know how to apply sand fineness modulus (FM), coarse aggregate size, and required pipeline
- diameter.
- Know the importance of moisture condition of lightweight aggregate on pumping.
- Understand the effect that pumping has on slump control.
- Understand that pumping pressures are affected by length of pipe, diameter of pipe, and
- cu yd/hr.
- Understand field practices.
- Know hand signals.
- Know proper practices for field control of pumped concrete.

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Mixtures for Concrete Pumping

- Review of the important aspects of mixtures
- Some guidance on the why behind our "rules" of thumb
- How to predict pumpability from first principles
- How to "fix" mixtures when pumpimg is a problem

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Mixture Proportioning

- Was once easy – sand cement water rocks
- Slump was a good measure of water content (interparticle spacing, but lets not get ahead of ourselves)
- Today slump does not always indicate water content or viscosity

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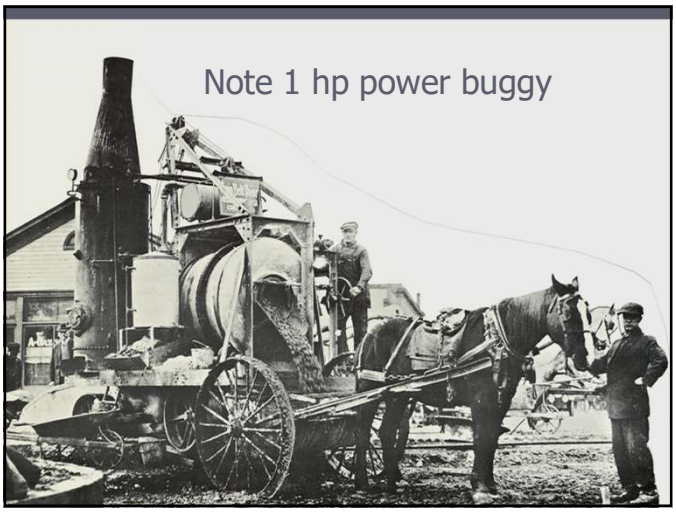

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Mixture Proportioning – The Process

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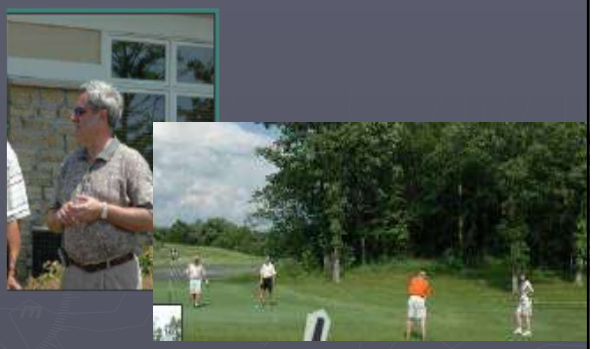

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Relevant Factors

- Cement
- Aggregate
- Water
- Admixtures
- Pozzolans
- Proportions
- Batching and Delivery

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ACI 211 process

- Set water content to get workability
- Set cement to meet durability or strength
- Set Coarse Aggregate content so it is close to full
- Set Air volume
- Fill the yard with sand

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Rocket Science

- Concrete is as sophisticated as rocketery
- Applied Fluid Mechanics – forces acting on the fluids and on the systems can be predicted.
- Understanding how mixtures affect the above makes pumpability a predictable property

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Rheology

- The study of deformation and flow of matter.
- Involves relations between shear stress and shear rate.

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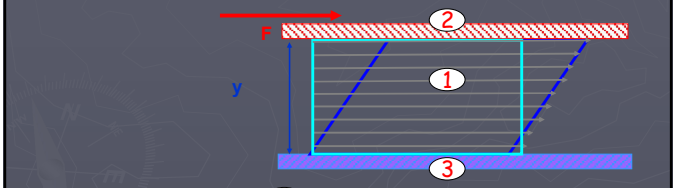
Rheology

Rheology studies the relations between force, deformation and time in fluids.



τ(shear strength)=

F (force) / A (area)

1 Liquid that flows

3 Still area

2 Area in motion

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Ability of Plates to Slip Across Surface

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Fluid Properties the Basics

- Newtonian Fluids have a viscosity that relates shear rate in the fluid and shear stress in the fluid

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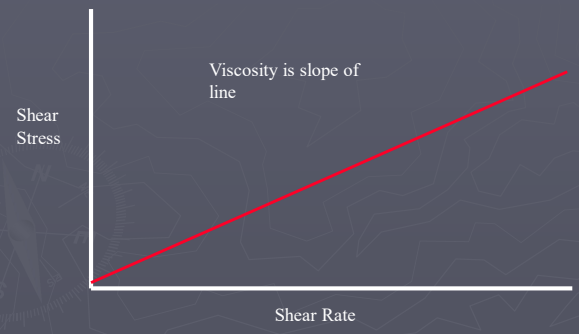
Viscosity



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Viscosity Models

Newtonian

$$\tau = \mu \dot{\gamma}$$

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Affecting the Forces

attraction between cement particles

Flocculation

Low Fluidity

⇩water increase of the W/C ratio

repulsion between cement particles

Dispersion

High Fluidity

⇧water decrease of the W/C ratio

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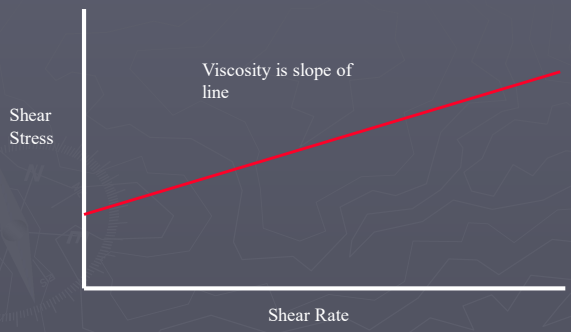
Bingham Model



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Workability

The slump cone really measures τ_0

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Workability Ease of Finishing

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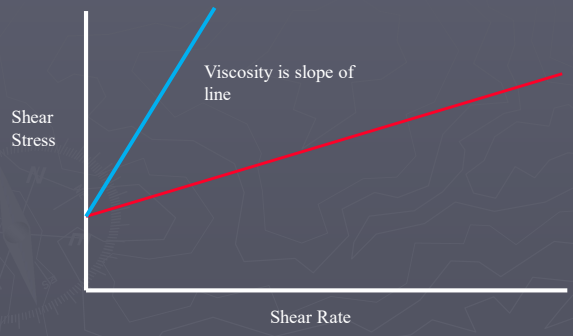
Slump and Viscosity



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Viscosity Models

Bingham Plastic

$$\tau = \tau_0 + \mu \dot{\gamma}$$

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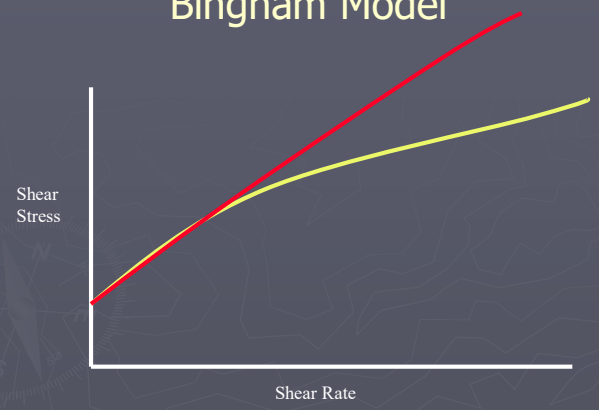
Bingham Model



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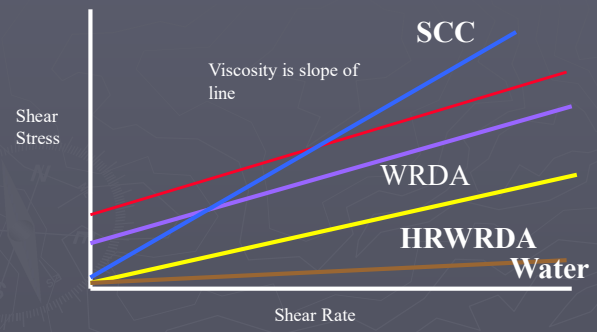
Viscosity Behavior



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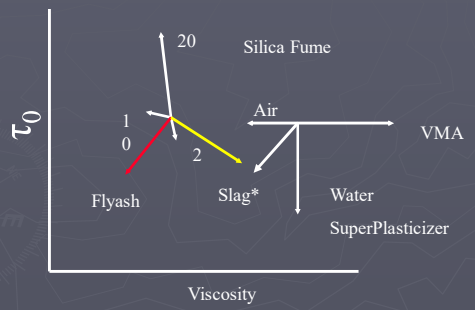
Mixture Design - Rheology



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How to Change Viscosity

- Alter the properties of the particles, the fluid or their interaction
- Admixtures
- Geometry (particle packing)

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Static and Dynamic Stability

- Static -the mixture at rest
- Dynamic – the mixture in motion

- Stable mixes do not segregate

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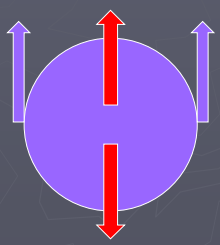
A particle in the fluid



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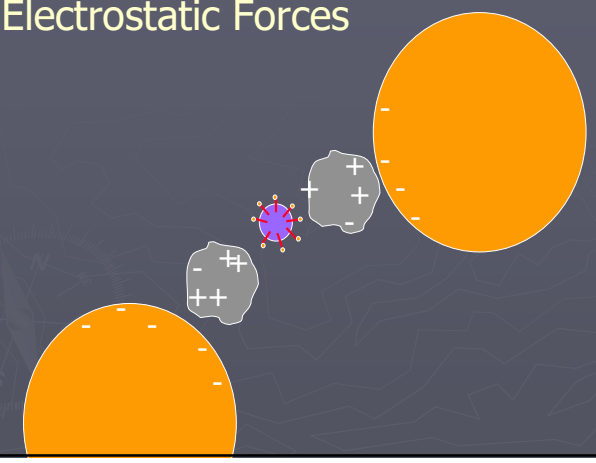
Electrostatic Forces



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Self Compacting(Levelling) Concrete Mk I

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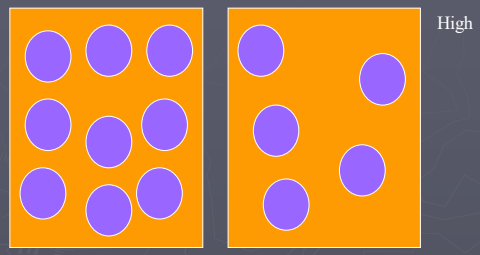
Water Cement Ratio



The fluidity of a water-cement system is a function of attractive and repulsive forces between cement particles

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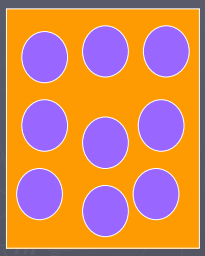
Particle Interaction



Particles have a preferred location and they can quickly achieve it, and 'gel'

A spring and dashpot model lets the particles slip by one-another, but not snap back into statis immediately

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Aggregates

- For decorative concrete the ideal gradation depends on what you are trying to accomplish

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Gradation is important

- 8/18
- Fuller's curve(s)

$$y = \left(\frac{d}{D}\right)^{0.5}$$

- Try to reduce the voids

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Gradation is important

- FHWA maximum density line

$$y = \left(\frac{d}{D}\right)^{0.45}$$

- Reduce specific surface

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Statistics Gone Mad

- My Preference : Palotas Equation

$$y = \frac{100}{\log_{10}^{\frac{1+0.3m_o}{\log(D)-0.3m_o+1}}(100D)} \log_{10}^{\frac{1+0.3m_o}{\log(D)-0.3m_o+1}}(100D)$$

M_o = Optimum Fineness modulus

Applies for D 5 to 80 mm, Agg/Cement Ratio 4 to 10 by mass

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Aggregate Shape

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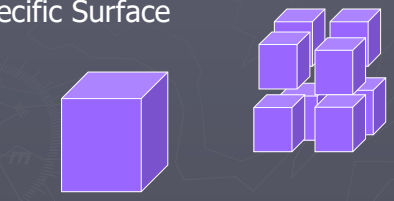
Concrete Mixtures

- Aggregate
- Gradation
- Specific Surface



Cube 2a – ss = 3/a

Cube ss= 6/a

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Reynolds Number

- Ratio of inertial and viscous forces

$$\mathrm{Re} = \frac{\rho v L}{\mu}$$

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Bernoulli Equation

$$\left(P + \frac{1}{2}\rho v^2 + pgh \right)_1 = CONSTANT$$

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Bernoulli's Equation in Real Life

$$\left(P+\frac{1}{2}\rho v^2+pgh\right)_1=\left(P+\frac{1}{2}\rho v^2+pgh\right)_2+f_{1-2}$$

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Friction

- Head loss

$$h_f = f_f \frac{L}{R_h}\frac{v^2}{2g}$$

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So what?

- All of these items have impact
- Need to know and predict for successful pumping

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Predicting Pumpability

- Two kinds of pumping –will it pump and will it pump well
- Mixtures with a water content below 230 lb per cubic yard are suspect.
- Sand is the enemy – low sand contents
- Mixtures with molecular entanglement admixtures (some VMAs) will dampen the electrostatic forces

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Predicting Pumpability

- Static stability –mixes that segregate in the hopper are problems
- Gap grading is desirable – particularly gaps at the 16 sieve
- Air is compressible – for long systems the air can absorb the pump energy

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Fixing Problems

- Guidance for immediate actions
  - Remove sand and replace with coarse aggregate
  - Increase coarser fraction of coarse aggregate
  - Add water not superplasticizer – as a general rule – segregation becomes the risk quickly

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Questions?

- **Thanks for the time and attention**

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