INTRODUCTION TO SELF-CONSOLIDATING CONCRETE

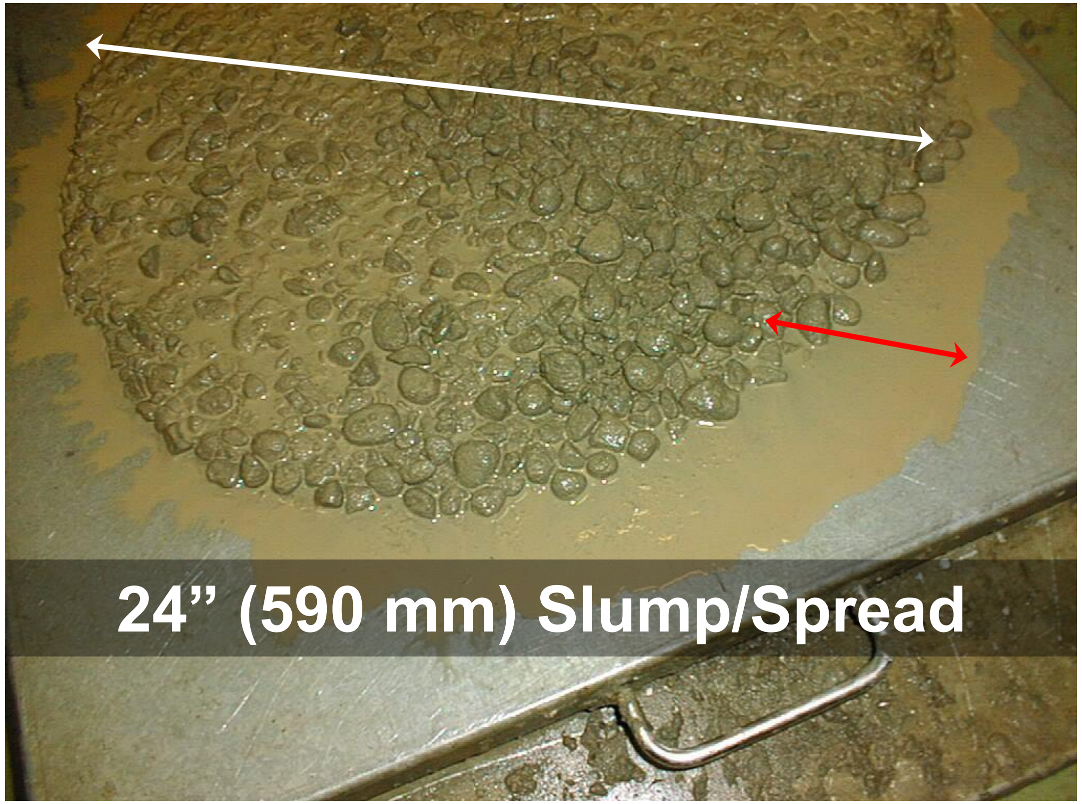
American Concrete Pipe Association

Agenda

- What is SCC
- Terminology
- Applications for SCC
- How are SCC mixes developed
- Testing methods

What is SCC?

- SCC is more than flowable concrete
  - it is a highly engineered fluid with unique Rheological properties



This is not SCC. You cannot just add water or admix and get SCC!

What is it?

Self Consolidating Concrete is a highly flowable, non-segregating concrete that can flow into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation.

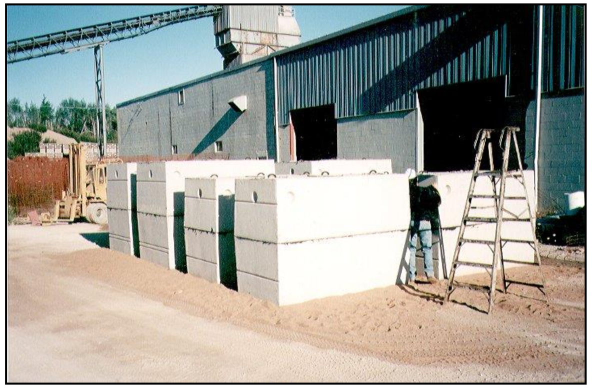
ACI 237

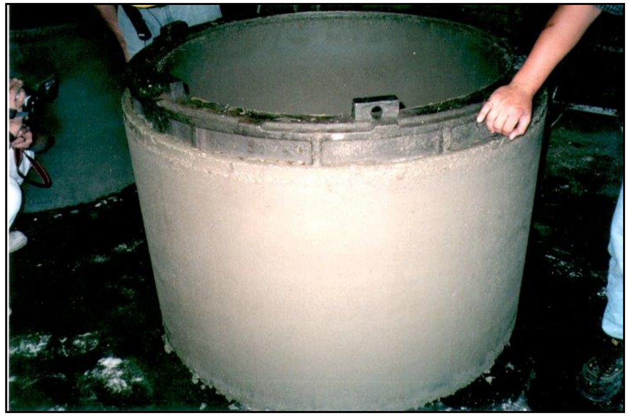
What this means is that SCC is *much* more than flowable concrete

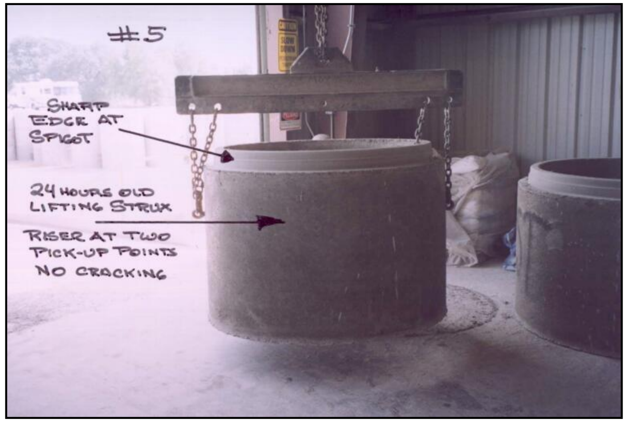
SCC fills the formwork without vibration and with a significant reduction in labor.

Where Can SCC be used?

Where Can SCC be used?







SCC Terminology

Rheology, Viscosity, Thixotropy and more…

Rheology

The science dealing with flow of materials, including studies of deformation of hardened concrete, the handling and placing of freshly mixed concrete, and the behavior of slurries and pastes.

Cement and Concrete Terminology, ACI Publication SP-19

Viscosity

The property of a material which resists change in the shape or arrangement of its elements during flow, and the measure thereof.

Cement and Concrete Terminology, ACI Publication SP-19

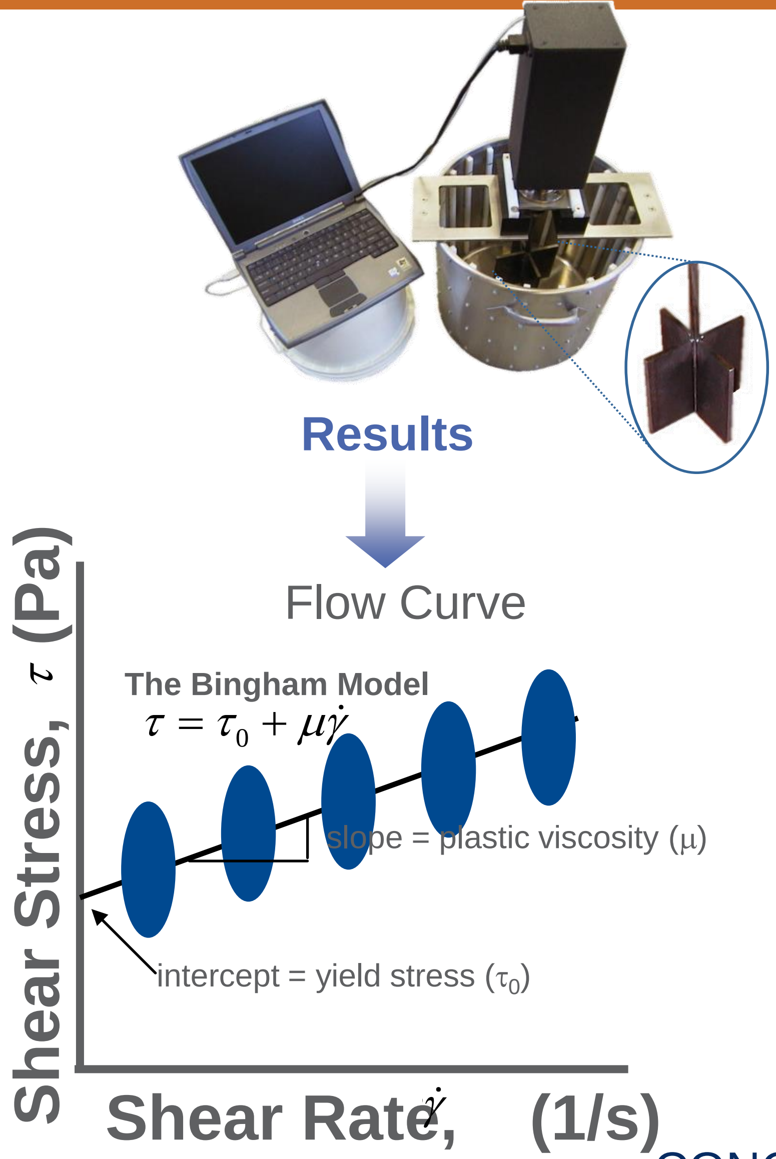
Thixotropy

- The tendency of a material to act as a semi-solid (gel) at rest and a fluid while in motion.

- A material is said to have thixotropic properties when it exhibits a decrease in viscosity with time when the material is subjected to a constant shearing stress

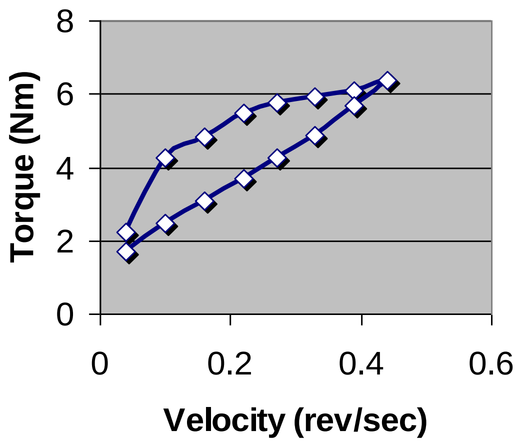
Concrete Rheology

- The rheology of concrete is measured with a concrete rheometer, which determines the resistance of concrete to shear flow at various shear rates.
- Concrete rheology measurements are typically expressed in terms of the Bingham model, which is a function of:
  - **Yield stress:** the minimum stress to initiate or maintain flow (related to slump)
  - **Plastic viscosity:** the resistance to flow once yield stress is exceeded (related to stickiness)
- Concrete rheology provides many insights into concrete workability.
  - Slump and slump flow are a function of concrete rheology.

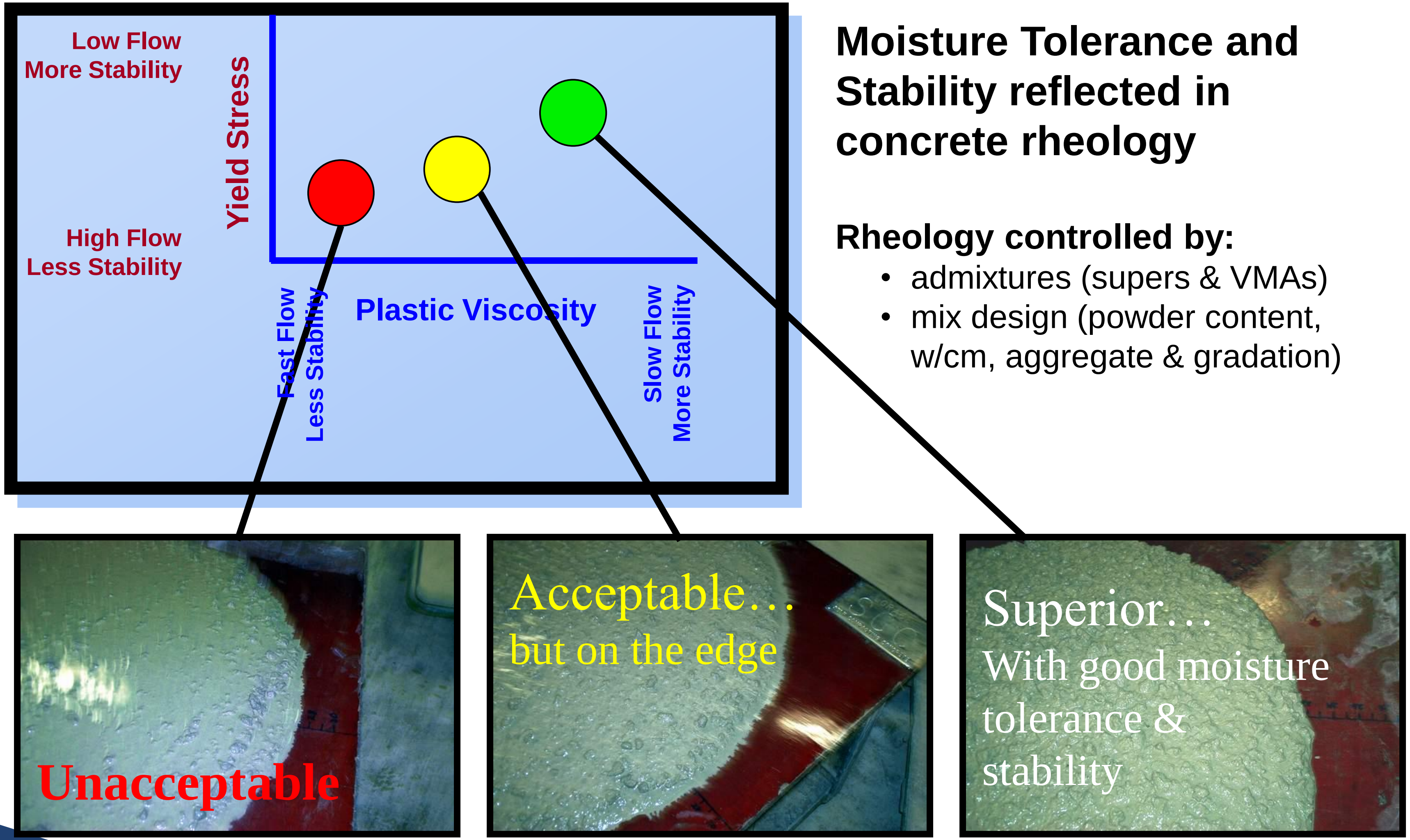


Rheology – Targets for SCC Mixes

- Static YIELD STRESS (t_0)
  - Low enough such that concrete will flow under own weight
- VISCOSITY (m)
  - Low enough to allow flow,
  - High enough to prevent segregation



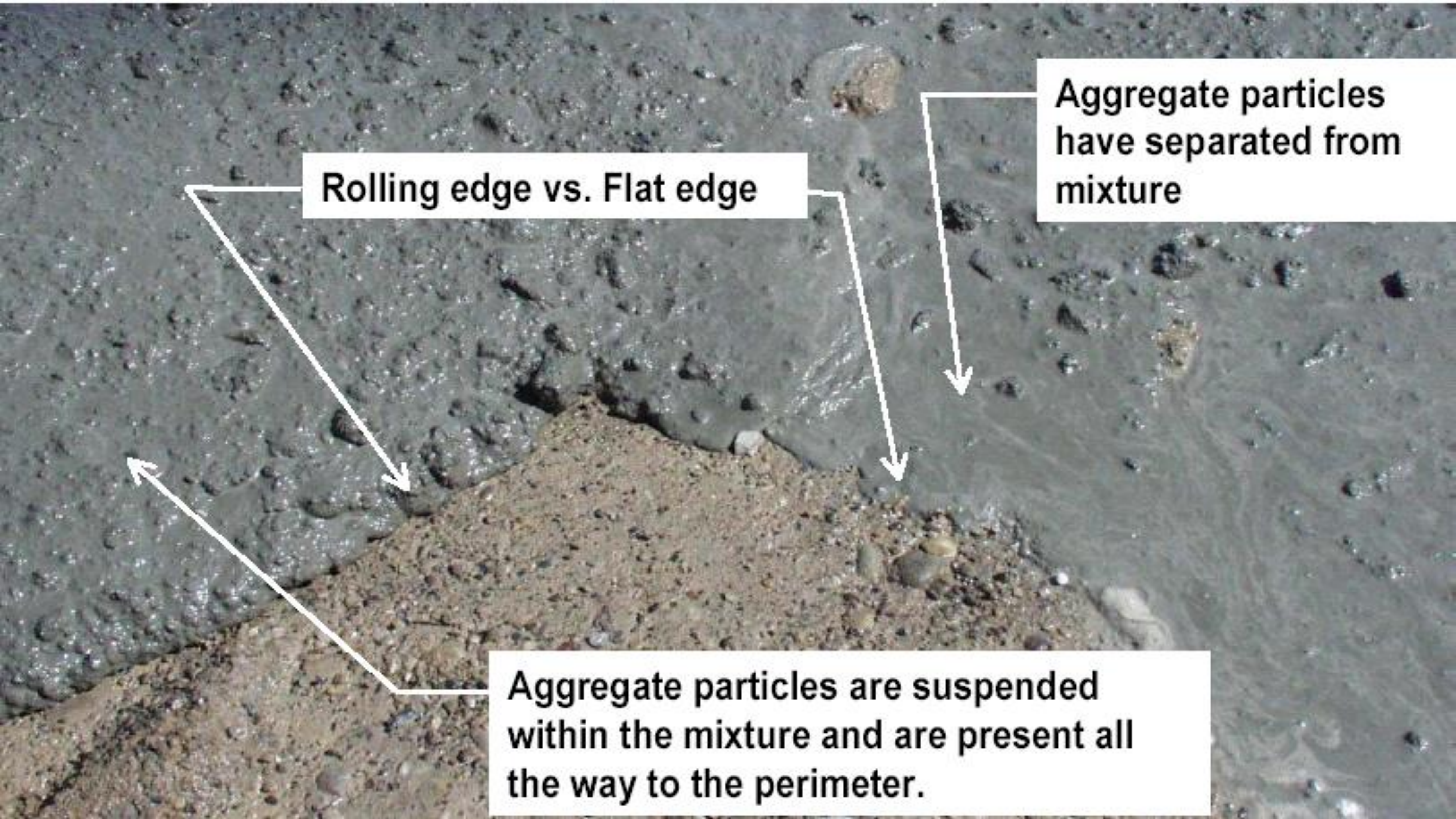
SCC: Rheology and Stability



Moisture Tolerance and Stability reflected in concrete rheology

Rheology controlled by:

- admixtures (supers & VMAs)
- mix design (powder content, w/cm, aggregate & gradation)


Rolling edge vs. Flat edge
Aggregate particles have separated from mixture
Aggregate particles are suspended within the mixture and are present all the way to the perimeter.

QUALITY SCHOOL

SCC Mix Development

Understanding Key Properties

Key Plastic Properties of SCC: Filling Ability

- The ability of the concrete to flow freely under its own weight, and to completely fill formwork of any dimension and shape without leaving voids
- Filling ability is impacted by:
  - Slump Flow
  - Viscosity (T20/T500)
  - Aggregate Shape
  - Aggregate Ratio
  - Placing Methods
  - Size and configuration of the Forms

Key Plastic Properties of SCC: Passing Ability

- The ability of concrete to flow freely in and around dense reinforcement without blocking

Key Plastic Properties of SCC: Passing Ability

- Passing Ability is impacted by:
  - Slump Flow
  - Viscosity (T20/T500)
  - Aggregate
    - Shape
    - Ratio
    - Size
  - Placing Methods
  - Form or Rebar Spacing

Key Properties of SCC

- **Resistance to Segregation**
  - During placement and while flowing, the concrete should retain its stability.
  - There should be no separation of aggregate from paste or water from solids and no tendency for coarse aggregate to sink downwards through the fresh concrete mass under gravity
  - Resistance to segregation is the most difficult to achieve

Key SCC Plastic Properties

- ***Dynamic Stability*** - The characteristic of fresh concrete that ensures uniform distribution of solid particles and air voids as the concrete is being transported and placed.

- ***Static Stability*** - The characteristic of fresh concrete that ensures uniform distribution of solid particles and air voids once all the placement operations are complete and until the onset of setting.

Plastic Properties

- Stability is Impacted by:
  - Slump Flow
  - Viscosity (T20/T500)
  - Aggregate Size
  - Aggregate Ratio
  - Aggregate Specific Gravity
  - Powder Content
  - Air Content
  - Paste Content
  - Mortar Content
  - Transportation and Placing Methods
  - Admixture Content
  - Water Content

SCC Mixture Proportioning

- Developing SCC consists of material combinations and relationships of:
  - Cementitious Materials
  - Sand / Aggregates
  - Admixtures
  - Water

SCC mix design approaches

- **High Powder Content** and high-range water-reducing (HRWR) Admixture
- **Lower Powder Content**, HRWR Admixture, and Viscosity Modifying Admixture (VMA)
- **Moderate Powder Content**, HRWR Admixture, w/wo Moderate VMA addition

SCC Aggregate Selection

Aggregate Variability

Size and distribution

Angularity and aspect ratio

Water demand

SCC mixture success:

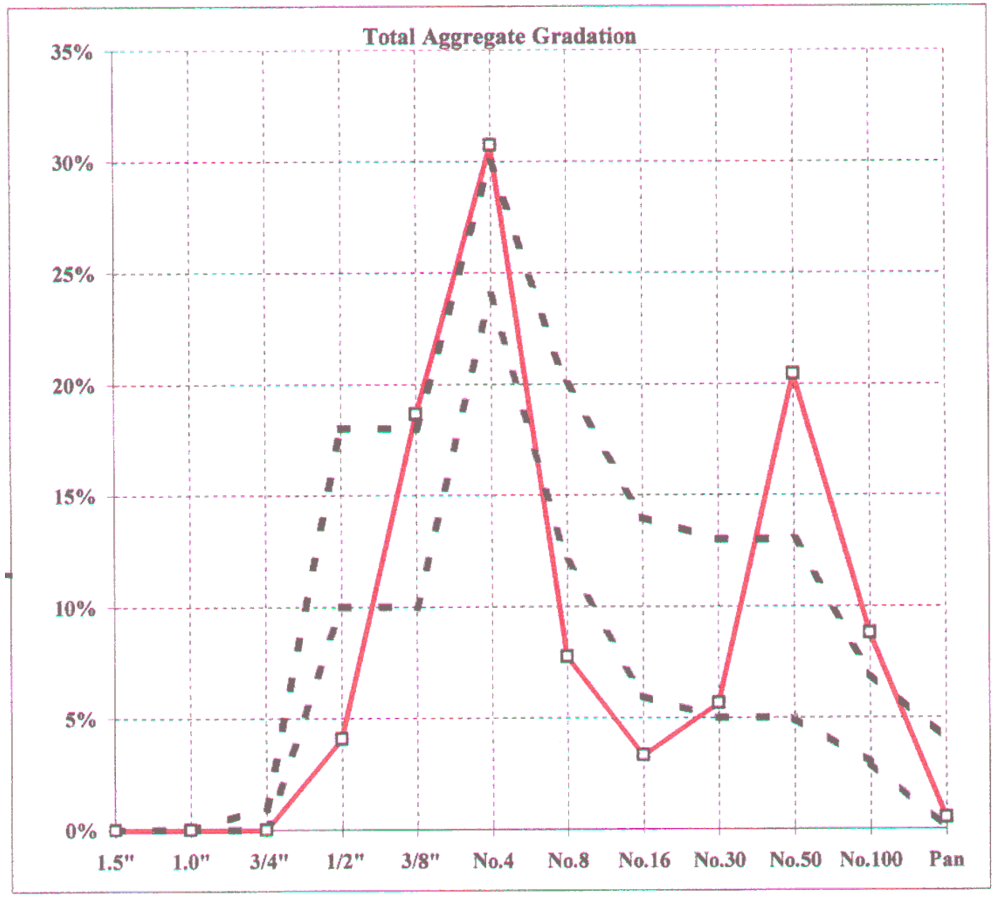
- **Must use locally available materials**
- **Quality of the ingredients can vary dramatically**
- **One mix design *does not* fit all**

SCC Proportioning Steps

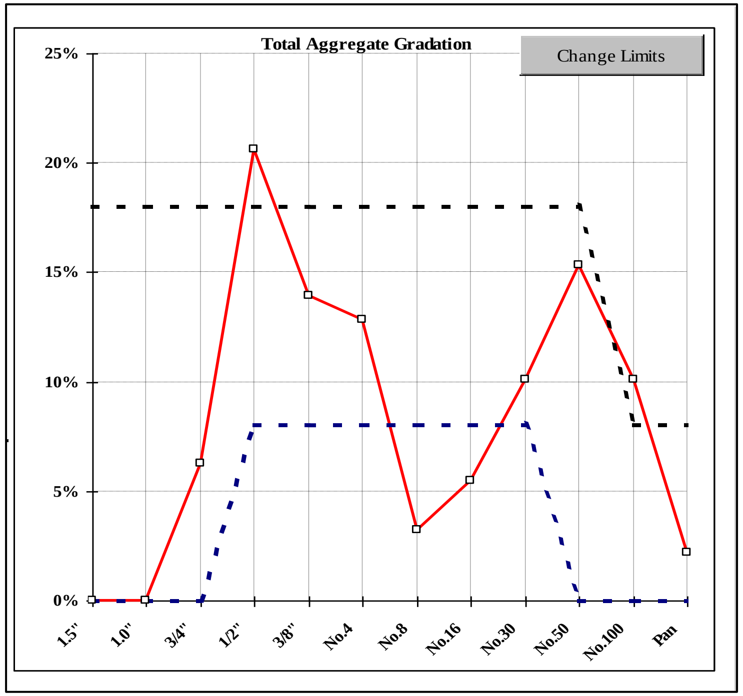
- Determine required slump flow
- Select coarse aggregate size
- Determine the required air content
- Estimate the required powder content
- Estimate the required water content
- Calculate coarse and fine aggregate amounts after Powder, Water and Air contents are determined
- Calculate paste and mortar volume
- Adjust coarse and fine aggregate weights based on paste and mortar volumes
- Select admixture types and dosage
- Batch Trial Mixture – Make adjustments and batch again

Aggregates

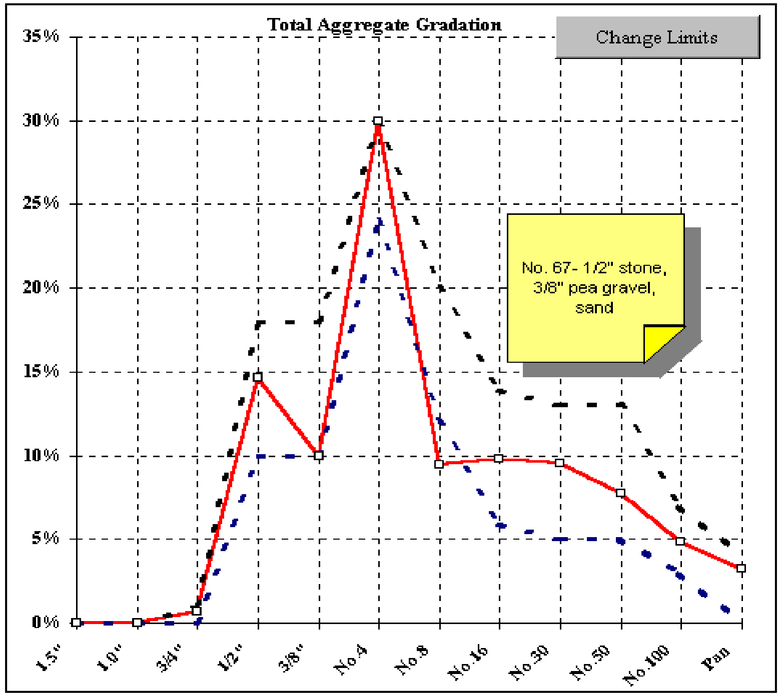
- Many coarse aggregates available in North America are Gap Graded, and thus have low volumes of No. 8 and No. 16 sieve size particles
- The optimized grading curve for SCC is much tighter than for conventional concrete
- Optimizing mix packing density is critical for many SCC mixes, so it is may be necessary to blend aggregate sources



Aggregate Grading



An example of a typical # 57 blend, indicating a Gap Graded Aggregate



An optimized SCC aggregate gradation with blended aggregates

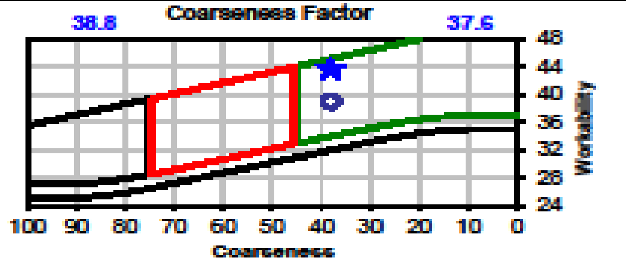
Pipers Pipes
SCC-Proposed1
Pipe O Rama
Great Pipe

Design PSI (f'_c): 5000
Design Slump: 24" to 30"
Location: Pipevile, YX
Placement:

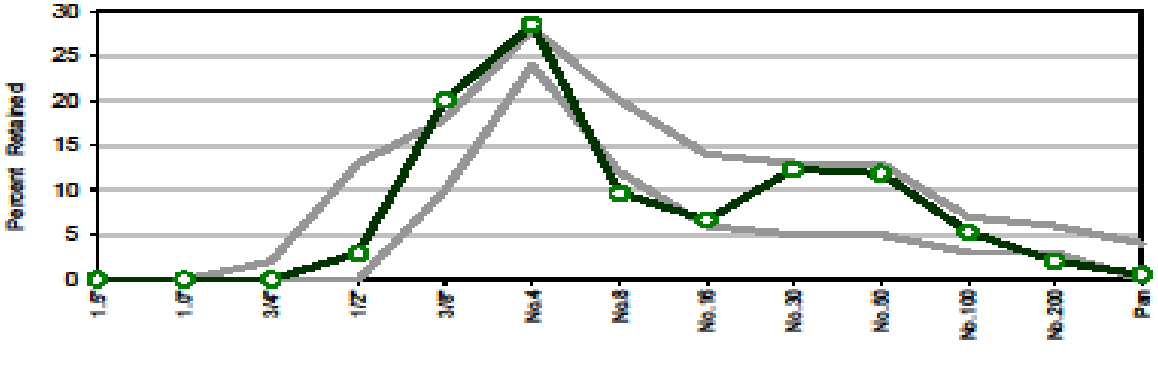
Agg. Gradation Limits: 4.2 SCC.1 Concrete

	Weight Lbs	Abs. Vol. Cu.Ft.	% Vol.		Cost
Cementitious Materials					
Calportland P4X	600	3.05	80.0		–
Jensen Class F	150	1.10	20.0		–
					–
					–
Total Cementitious	750	4.16			–
Jensen A7	1200	7.26	42.5%		–
Jensen A3	300	1.81	10.6%		–
Jensen Concrete Sand	1320	8.01	46.9%	1.00	–
					–
					–
Design Air Content	4.0	1.08			–
Water: 35.1 Gal	292	4.68			–
					–
Total:	3862	27.00			–

Admixture	Oz/yard	oz / cwt
HRWR	127.50	17.00
Admix C3	15.00	2.00
AEA	1.99	0.27
		-
		-
		-



Plastic Density - Cu.Ft.	143.05
Paste Fraction	32.7%
Paste Fraction + Air	36.7%
Mortar Fraction	61.3%
Air Vol / (Cementitious + water)	12.2%
Sand / Agg ratio (Vol)	0.47
Workability Factor (fines)	38.8
Coarseness Factor:	37.6
W-Adj (Workability-Adjustment)	43.7
O.I.F	1233
Vol Water / Vol Cemt	1.126
Water/Cementitious Ratio	0.389



Combined Agg. Blend FM= 4.73 FM of Sand 2.890

Possible Powder Content

	Slump Flow (in) <22	Slump 22-26 (in) 22-26	Slump Flow (in) >26
Powder Content (pcy)	< 650	650 - 750	750 +

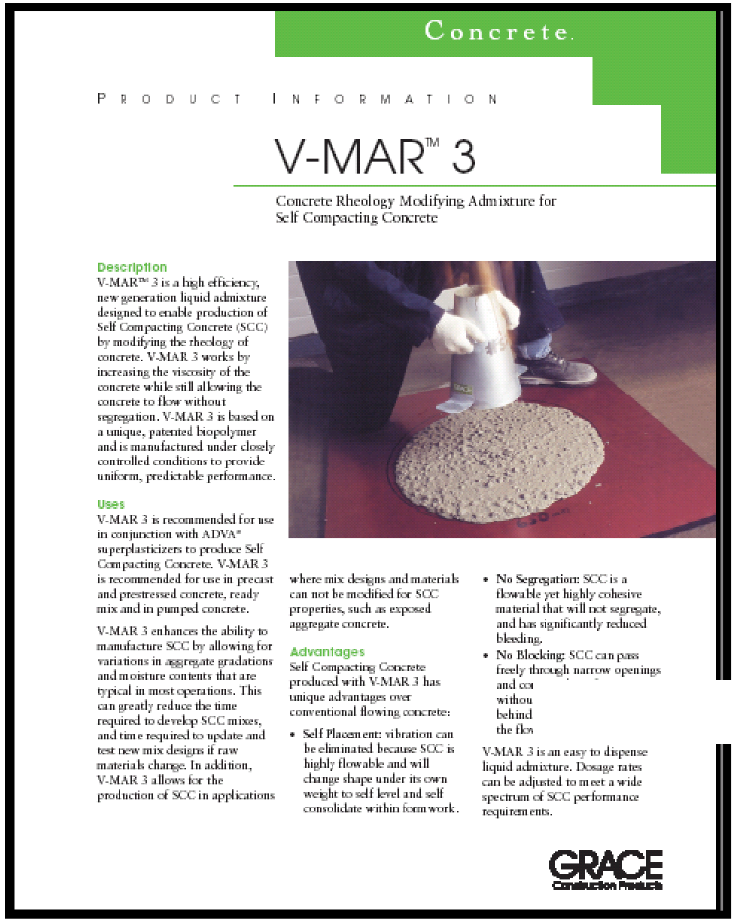
Absolute volume of coarse aggregate	28-32% (total mix volume)
Paste Fraction (calculated on volume)	34-40% (total mix volume)
Mortar Fraction (calculated on volume)	60-70% (total mix volume)
Typical w/cm	0.32 – 0.45
Typical cement (powder content)	650-800 pounds

SCC Admixture Usage

- SCC Polycarboxylate Superplasticizers
  - Excellent flowability with improved stability compared to superplasticizers for conventional concrete. Increased mix forgiveness.
- Viscosity Modifying Agents
  - For difficult aggregates and production conditions such as low cementitious and paste volumes. Increases mix forgiveness / water tolerance.
- Extended Slump Life Polycarboxylate Superplasticizers
  - Excellent flowability with improved stability; formulated for the concrete market for added workability retention
- Common admixtures such as AEA, retarders/HS and accelerators also work with SCC

Viscosity Modifiers

- Acts as a ‘thickening’ agent
- Protects against segregation
- Dispense direct into mix
- No effect on set times or air content
- Provides flexibility of water contents



Concrete.

PRODUCT INFORMATION

V-MAR™ 3

Concrete Rheology Modifying Admixture for Self Compacting Concrete

Description

V-MAR™ 3 is a high efficiency, new generation liquid admixture designed to enable production of Self Compacting Concrete (SCC) by modifying the rheology of concrete. V-MAR 3 works by increasing the viscosity of the concrete while still allowing the concrete to flow without segregation. V-MAR 3 is based on a unique, patented biopolymer and is manufactured under closely controlled conditions to provide uniform, predictable performance.

Uses

V-MAR 3 is recommended for use in conjunction with ADVA® superplasticizers to produce Self Compacting Concrete. V-MAR 3 is recommended for use in precast and prestressed concrete, ready mix and in pumped concrete.

V-MAR 3 enhances the ability to manufacture SCC by allowing for variations in aggregate gradations and moisture contents that are typical in most operations. This can greatly reduce the time required to develop SCC mixes, and time required to update and test new mix designs if raw materials change. In addition, V-MAR 3 allows for the production of SCC in applications where mix designs and materials can not be modified for SCC properties, such as exposed aggregate concrete.

Advantages

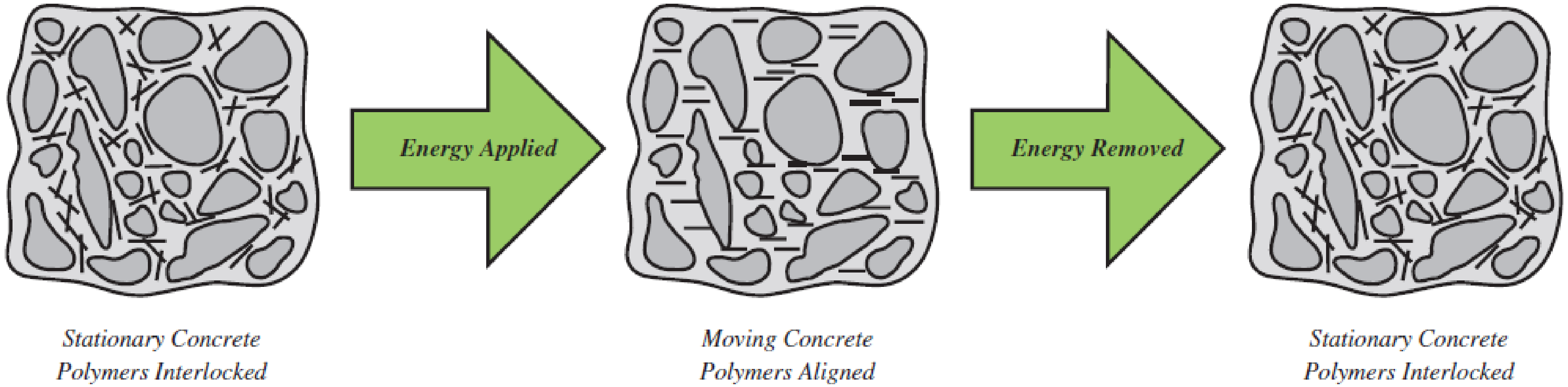
Self Compacting Concrete produced with V-MAR 3 has unique advantages over conventional flowing concrete:

- Self Placement: vibration can be eliminated because SCC is highly flowable and will change shape under its own weight to self level and self consolidate within formwork.
- No Segregation: SCC is a flowable yet highly cohesive material that will not segregate, and has significantly reduced bleeding.
- No Blocking: SCC can pass freely through narrow openings and co[illegible] withou[illegible] behind the flo[illegible]

V-MAR 3 is an easy to dispense liquid admixture. Dosage rates can be adjusted to meet a wide spectrum of SCC performance requirements.

GRACE Construction Products

Viscosity Modifiers…what they do



Large polymer structure of VMA align in the direct of the applied energy (flow) and allow paste to lubricate coarse, angular sand particles reducing internal friction.

Viscosity Modifying Admixture Benefits

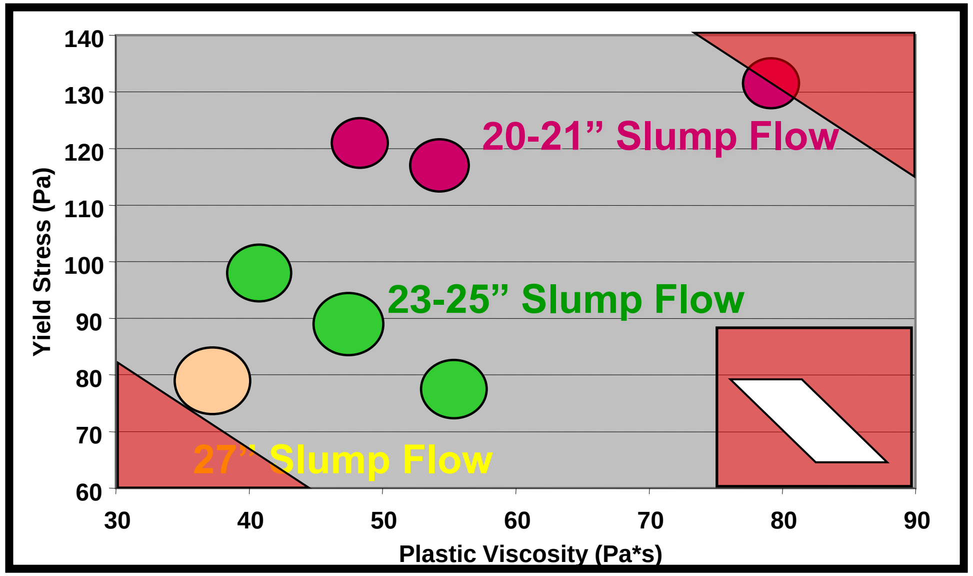
- Drycast products – Pipe, Manholes, etc
- Hollowcore
- SCC mixtures to reduce bug holes
- High cementitious content mixes; making it easier to discharge without sticking to the drum

VMA Benefits

Performance Attributes	Plastic Concrete Benefits	Hardened Concrete Benefits
Rheology modifier acting as a *lubricant*: • Concrete flows more readily at low shear rates, without vibration (SCC, paving, truck discharge, poorly shaped aggregates) • Improve extrusion and surface texture (creamier with more body than V-MAR3)	• Mix 'lubricity' • Cohesive without being 'sticky' • Less clumping and lumps • Improved surface finishes • Even flows from the mixer – up the belts – out of the hopper and into the machinery • Less sticking in the chutes • Wide window of water flexibility • No effect on water contents • Generates more paste – potentially reduce cement content • Able to use less than optimum sand and stone – especially if added cement is used to enable	• Moisture retention aids curing • Higher strengths through better curing, lower air contents • Less cracking due to moisture retention • Better surface finish, swipe/webbing • More paste on surface, generally less bugholes • Crisper edges • Pallets and headers remove easier • Fewer defects

Effects of HRWR and VMAs on Rheology

- **Same Mix Design**
- **Different dosages of Superplasticizers and VMAs**



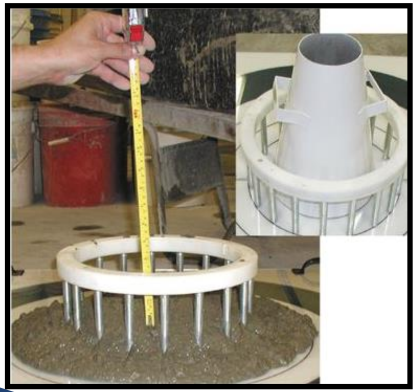
- Mixes made with different admixtures can have similar slump flow yet different rheology
- In general, for mixes with the same slump flow, those with higher viscosity are more stable
- *The edges of the Workability Box are dangerous*
  - mixes with very low yield and viscosity may segregate
  - mixes with very high yield and viscosity may not “self consolidate”

Adjustments to mix

Property	Powder Content	Water Content	Maximum Coarse Aggregate Size	Sand-to-Aggregate Ratio	VMA Dosage	HRWR Dosage
Fluidity						
Too Low		↑			↓	↑
Too High		↓			↑	↓
Viscosity						
Too Low	↑	↓			↑	
Too High		↑			↓	
Insufficient Passing Ability	↑	↓	↓	↑	↑	
Stability						
Excessive Segregation	↑				↑	
Aggregate Pile			↓	↑		
Mortar Halo	↑	↓			↑	↓

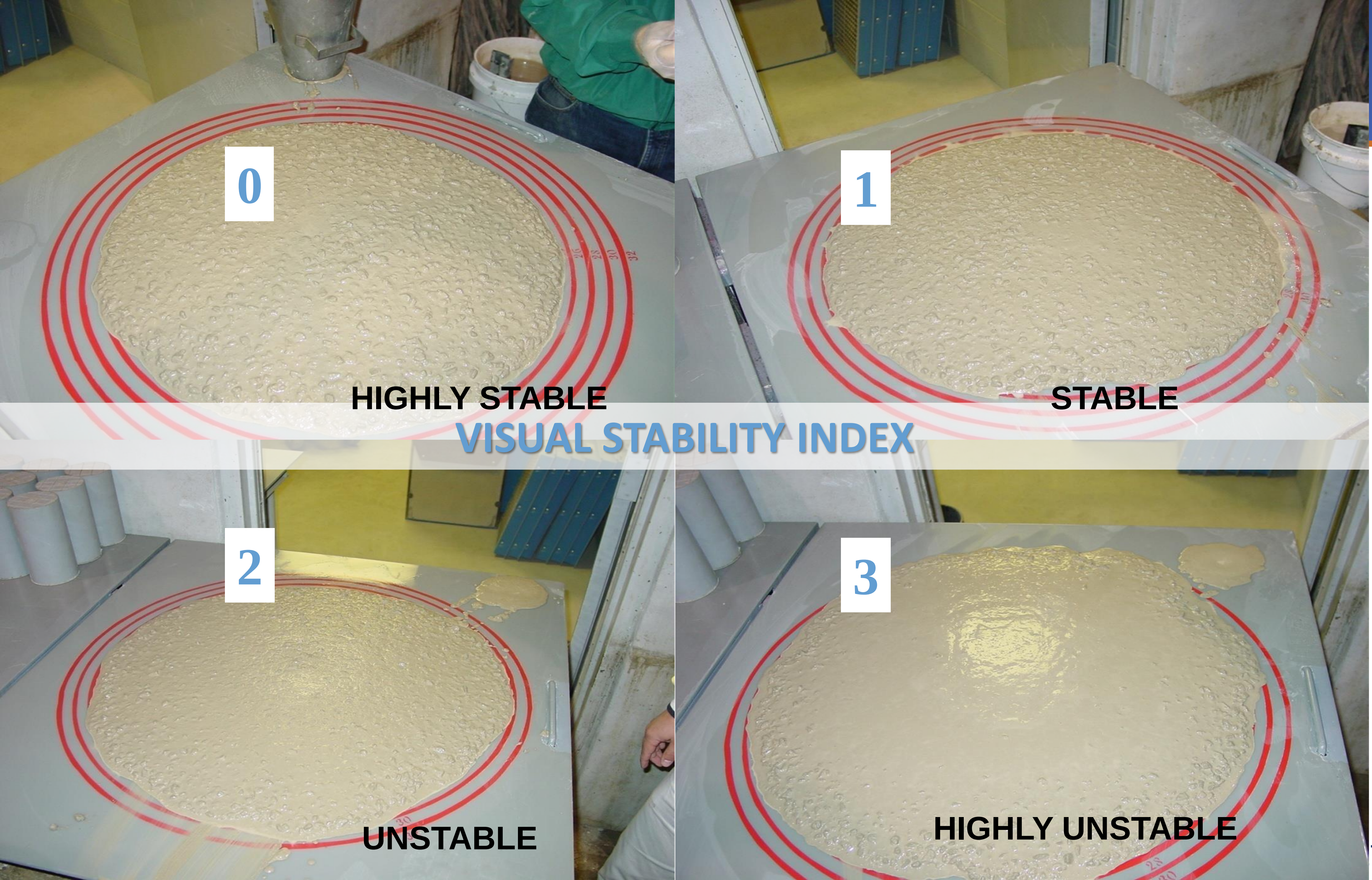
Test Methods to Evaluate SCC in Fresh State

- Workability:
  - ASTM C11611 - Standard Test Method for Slump Flow of Self-Consolidating Concrete
- Stability:
  - ASTM C1610 Column Segregation Test
  - ASTM C1712 Rapid Assessment Test for SCC Segregation
- Passing Ability:
  - ASTM C1621 J-Ring



ASTM C1611 – Slump Flow

VISUAL STABILITY INDEX



SCC Flow Characteristics ASTM C1621

- J-Ring test (passing ability)
- Comparison of J-Ring flow and Slump flow tests

Column Segregation Test – ASTM C1610

ASTM C1712 Rapid Assessment Method for SCC Segregation

Penetration Depth (PD) and Different Stability Levels

Highly Stable (PD ≤10 mm) | Stable (10 mm < PD ≤ 25 mm) | Unstable (Pd > 25 mm)

'Unofficial' Finger test

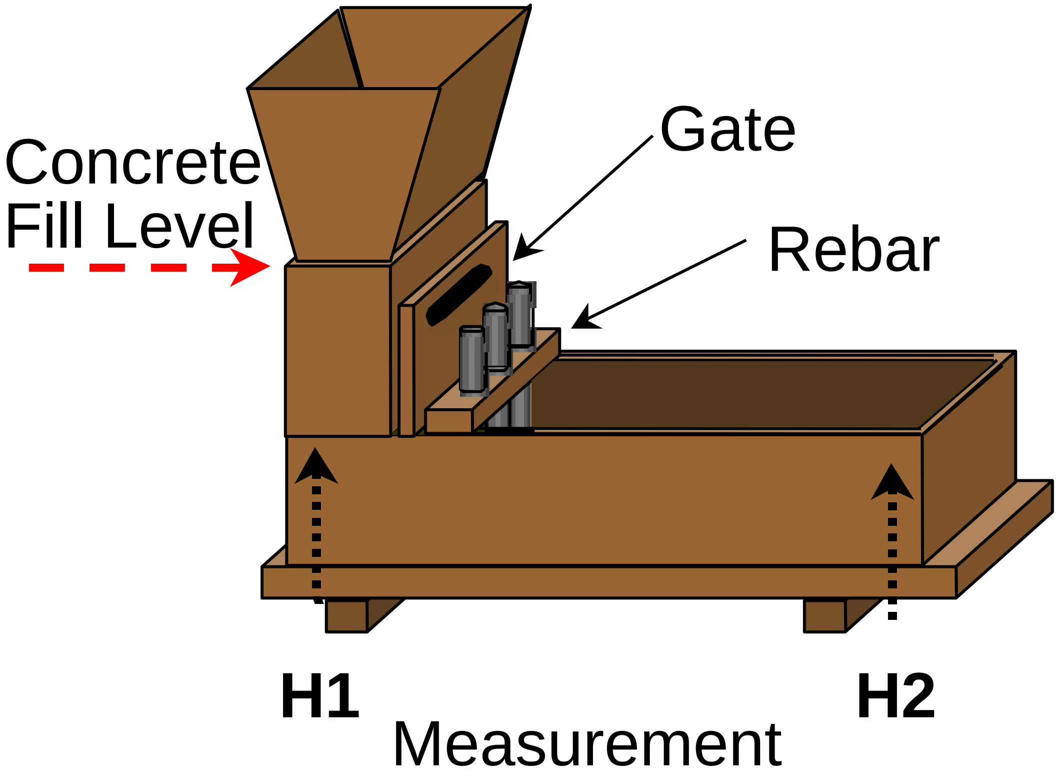
L Box Test

Test for passing ability indicated by the difference in concrete height between H1 and H2

Blocking ratio = H2/H1

BR = 1.0 is Excellent

BR = 0.9 Acceptable



U Box Test

Concrete must reach at least 30 cm height after passing through rebar

V Funnel Test

Modified Standard Tests for SCC

SCC Sources of Information

- ACI
  - Committee 237 – Self Consolidating Concrete
  - Committee 211H; Proportioning
- PCI
  - Guidelines for SCC
- ASTM
  - Test methods
- Other Resources
  - European, French, Japanese Guidelines
  - PCA Bibliography for SCC
  - NRMCA
  - RILEM Proceedings (International SCC conferences)
  - ACBM Proceedings (1st North American SCC Conference)
- Your friendly, local Admixture Field Sales Rep


Thank You