Concrete Technologist Middle East (CTME) Certification

A NRMCA Certification Program

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Goal

- Knowledgeable employees
- Defined scope of responsibilities
- Employee Retention
- Recognition
  - Customers
  - Specifying Authorities

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Needs Assessment

- Product Knowledge
- Mixture Proportioning and Adjustments
- Performance based concrete
- Understanding of Specifications and Project Requirements

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NRMCA Technical Certification

- NRMCA Technical Short Course (1 week)
  - Since 1965
  - Concrete Technologist Level 2
  - Concrete Technologist Level 3
- NRMCA Concrete Durability Course (2 days)
  - Since 2007
  - Concrete Technologist Level 4
  - Online version available – 2 h/day – 3 weeks

NRMCA CTME Certification

- From NRMCA Course Content
  - Both courses
- Unit conversion
- Eliminate information not relevant to Middle East
- Can by updated with info more relevant to ME.

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NRMCA CTME Training

- Self Study
- Develop training program
  - NRMCA will develop/provide annotated slides
- Offer certification exam
  - 2 hours

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Descriptive Notes

Short C

Slag and Silica Fume

Ground Granulated Blast-Furnace Slag (GGBFS)

Slag is a by-product from the manufacture of iron in a blast-furnace. Slags from other metal manufacture (copper, steel, lead, etc.) are not used as cementitious materials in concrete.

Manufacture

In the blast furnace, iron ore, scrap metal, fuel, and limestone or dolomite (fluxing stone) are loaded in layers. Liquid (molten) iron collects at the bottom and slag floats on the top of it. The molten slag, at about 1500 °C, is periodically removed from the blast-furnace and cooled.

- Air cooled slag – is discharged on the ground, cools slowly and used as aggregate for base or in asphalt concrete
- Expanded blast-furnace slag is made porous during cooling and is used as a lightweight aggregate.
- Granulated blast-furnace slag results from rapid cooling of the liquid slag with water. Only granulated slag is useful as a cementitious material.

Quenching (rapid cooling) the slag produces slag granules is done by one of the following:

- Dumping the molten slag in water – older process, does not give a uniform product.
- Pelletizer (air granulator) – molten slag is cooled with water sprays as it falls over a vibrating feed plate. It then passes over a rotating drum, which throws the slag into the air and cools it. Smaller particles are rapidly cooled granules while the larger particles are separated and used as lightweight aggregate.
- Jet process granulator – the molten slag is hit with large amounts water using of high-pressure jets, which is the most efficient method of granulating but uses large quantities of water

Slag granules looks similar to concrete sand. It is de-watered and dried and then ground to a fineness similar to or greater than that of portland cement – 450 to 650 m^2/kg Blaine, depending on the Grade. Slag is harder to grind than portland cement. When interground with cement to make a blended cement, slag particles may be coarser.

The ground product is referred to as Ground Granulated Blast-Furnace Slag, which is a buff colored powder. It is referred to as "slag" in this guide.

Slag is transported similar to portland cement and stored in silos at the ready mixed concrete plant. Care should be taken in identifying the product during storage and batching.

Slag is typically used as a separately batched cementitious ingredient in concrete. It can also used in concrete as a blended cement (Types I(SM) and IS in ASTM C 595).

Composition and Reactivity

Composition of slag results from the fluxing stone (limestone or dolomite) and impurities in iron ore. While composition is reported as oxides, it does not exist as oxides in slag.

Typical chemical composition of slag (from ACI 233R)

Chemical Constituents	Range of composition,

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Problems and Solutions

T7.

A1 Slump 1-2 in.; nominal maximum aggregate size 1 ½ in.
A2.1 Select the basic mixing water from Table A1, 250 lb.
A2.2 Correct for rounded sand shape: (250) - (20) = 230 lb
A2.3 No correction for cement content
A2.4 A/E concrete with total 4.5 percent air.
A2.5 Added air = 4.5 - 1.0 from Table A1 = 3.5%.
A2.6 Cement content is given as 470 lb/cu.yd.
Use Fig 2.1 for 3.5 percent added air and 470 lb of cement
Water reduction of 30 lb is required.
Mixing water = (230) - (30) = 200 lb/cu.yd.
A3 Not applicable since cement factor is specified.
A4 Cement content given = 470 lb/cu.yd.
A5.1 From Table A2 b/b_o = 0.70
(in between 0.71 for 2.80 F.M. and 0.69 for 3.00 F.M.)
A5.2 No modification for b/b_o required
A5.3 druw given as 100 lb/cu.ft.
A5.4 Dry weight of C.A. = (0.70) × (100) × (27) = 1890 lb/cu.yd.
A6.1 Air content = 4.5 percent (Step A2.4)
A7 Absolute volumes in cubic feet
A7.1 Cement = (470) ÷ [(3.15) × (62.4)] = 2.39 cu.ft.
A7.2 Water = (200) ÷ (62.4) = 3.21 cu ft
A7.3 Dry CA = (1890) ÷ [(2.60) × (62.4)] = 11.65 cu.ft.
A7.4 Air = (0.045) × (27) = 1.22 cu ft
A7.5 Sum of cement + water + C.A. + air = 18.47 cu ft

A8.1 Abs. Vol. of F.A. = (27.00) - (18.47) = 8.53 cu ft
A8.2 Dry FA weight = (2.60) × (8.53) × (62.4) = 1384 lb/cu.yd.
(Since dry weight was needed the bulk-dry specific gravity was used.)

A9 Weight, lb Volume, cu ft

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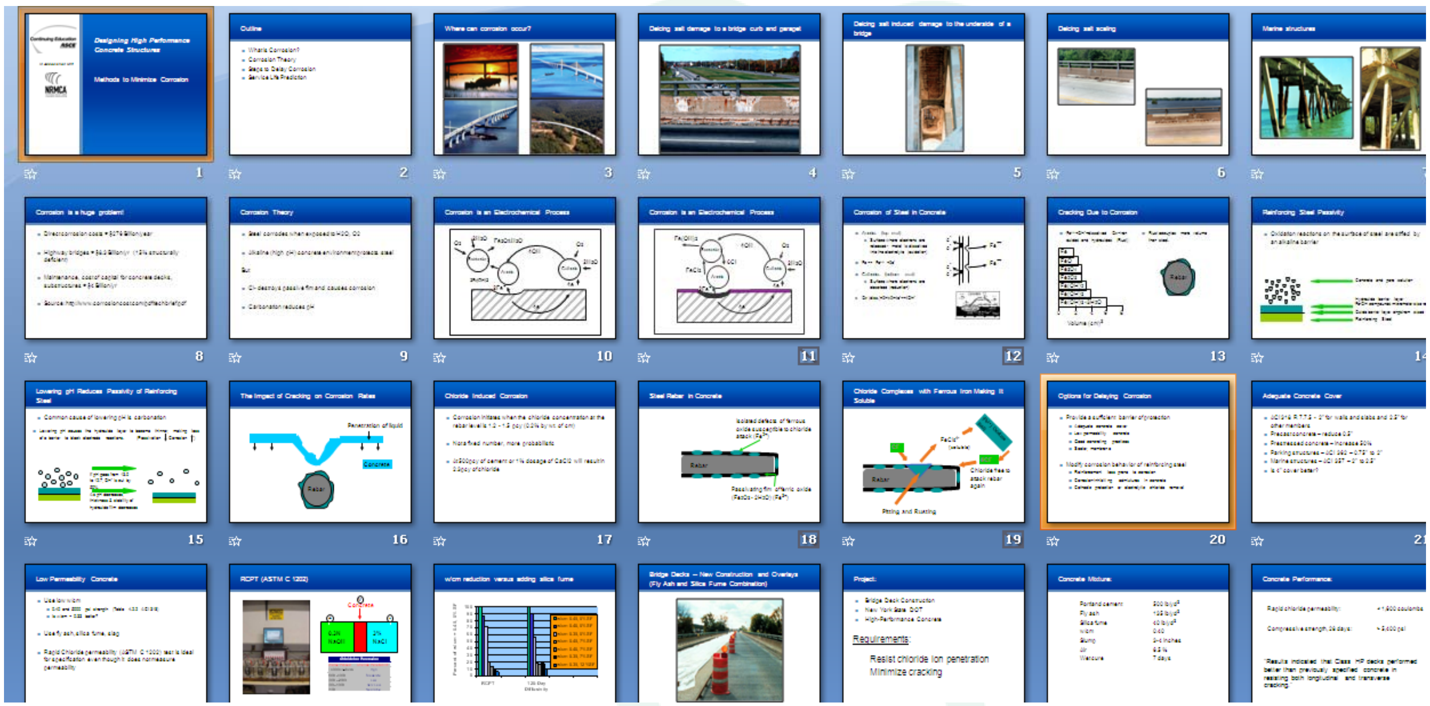
Slides



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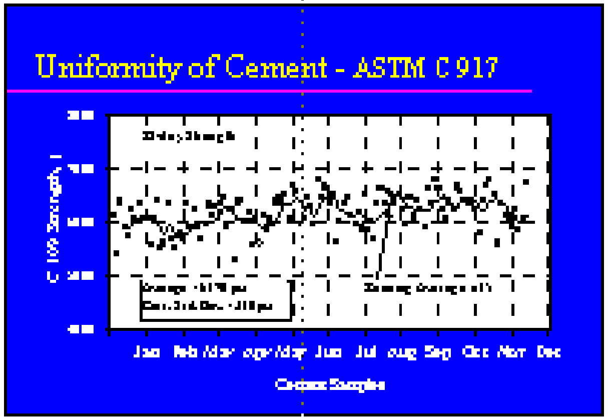
Instructor notes



Uniformity of Cement - ASTM C 917

ASTM C 917 is a standard that provides for the cement manufacturer to test and report the uniformity of cement from one source, based on strength. Typically C 917 evaluation is only conducted for the primary product from a cement plant. For C 917 strength tests, cement is sampled prior to shipping. Mill certificate tests are from production samples obtained from the grinding mill circuit. Samples used for C 917 tests more closely represent the cement the customer gets.

C 917 requires requires sampling frequency of about 10 per month and tests for 7-day and 28-day strength (ASTM C 109) over a period of time.

Reports:

- Individual strength, running average of 5, and overall average during the test period
- Standard deviation (corrected for testing variation) which represents the variability of cement strength over a period from that source

C 917 reports are useful to evaluate the strength level and variability of a cement source, determine periods when strength variations are high, and are useful to evaluate whether concrete strength problems were caused by the cement.

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Fundamentals – an overview

- Brief history
- Terminology
- Ingredient materials
- Basic characteristics of fresh concrete
  - Consistency, setting time…
- Basic characteristics of hardened concrete
  - Curing; Strength and Durability

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Why use concrete?

- Local raw materials
- Relatively economic
- Cast into any shape; texture; color
- Strength and durability can be customized
- Challenges:
  - To make uniform high quality concrete
  - Many people involved such as:
  - Owner, designer, specification writer, material supplier, RM concrete producer, Contractor, Testing lab.

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A typical cubic yard of concrete

	Volume	Weight
Air	6%	--
Cement	10%	500 lb.
Water	18%	300 lb.
Sand	25%	1200 lb.
Coarse Aggregate	40%	1800 lb
	27 cubic feet	~4000 lb.

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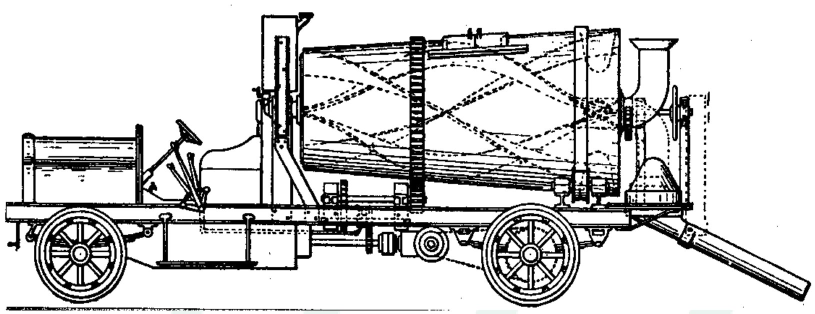
Brief History of Cement & Concrete



- 1916: Patent Application
  - Stephen Stepanian
- 1958: Patent for Front Discharge
  - Jack Willard

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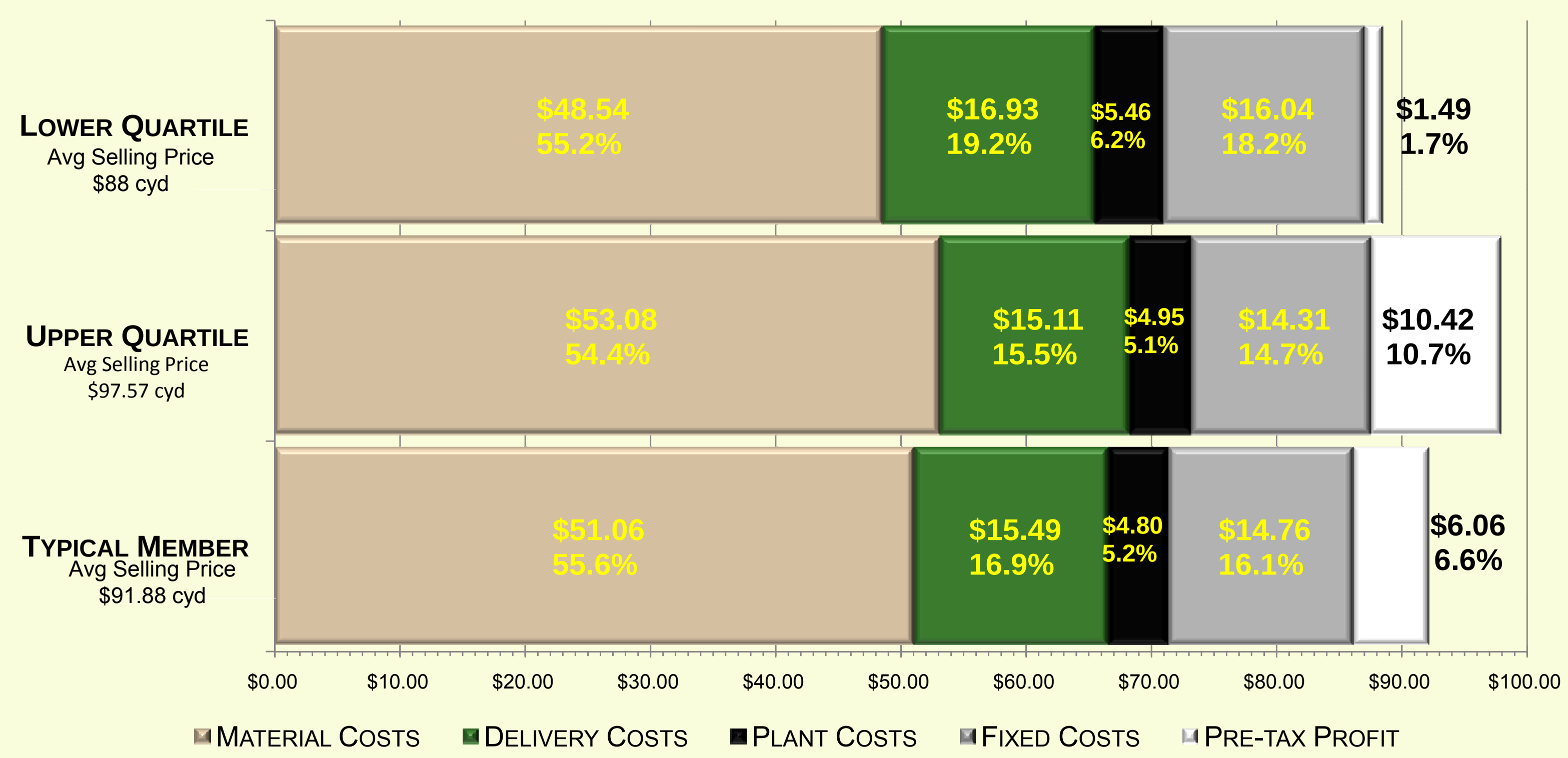
Typical Cubic Yard of Concrete (2008)



Source: NRMCA Industry Data Survey, 2008

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Basic Characteristics of Fresh Concrete

- Workability
  - Slump and slump loss
- Consolidation
- Segregation
- Finishability
- Bleeding
- Setting time
- Air entrainment

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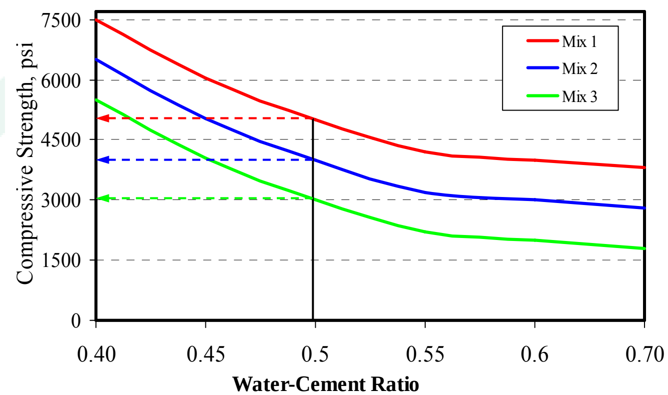
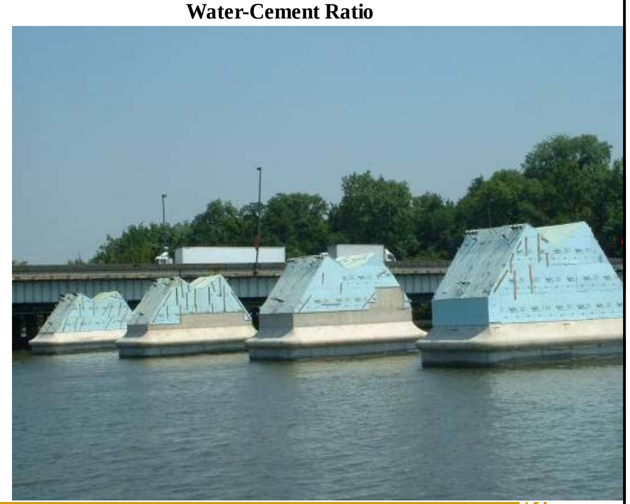
Basic Characteristics of Hardened Concrete

- Strength Development
  - Effect of curing RH, temperature
- Durability
  - Permeability
  - Freeze Thaw
  - Sulfate Attack
  - Shrinkage
  - Alkali Aggregate Reaction
  - Thermal Effects
  - Resistance to Chemicals
  - Carbonation
  - Corrosion
  - Abrasion





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Portland and Blended Cement

- Manufacture of portland cement
- Cement composition phases
- Types of cements their uses.
- ASTM C 150 requirements and related tests
- Quality Control of cement
  - ASTM C 917 reports
- Blended cements in C 595 and C 1157

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Manufacture of Portland Cement

Raw Ingredients

Lime	CaO (C)	60%	Limestone, calcite
Silica	SiO_2 (S)	20%	Clay, shale, fly ash
Alumina	Al_2O_3 (A)	10%	Clay, shale, bauxite
Iron	Fe_2O_3 (F)	10%	Iron ore, clay, mill scale
Sulfate	SO_3 ($\overline{S}$)	3% to clinker	gypsum, anhydrite

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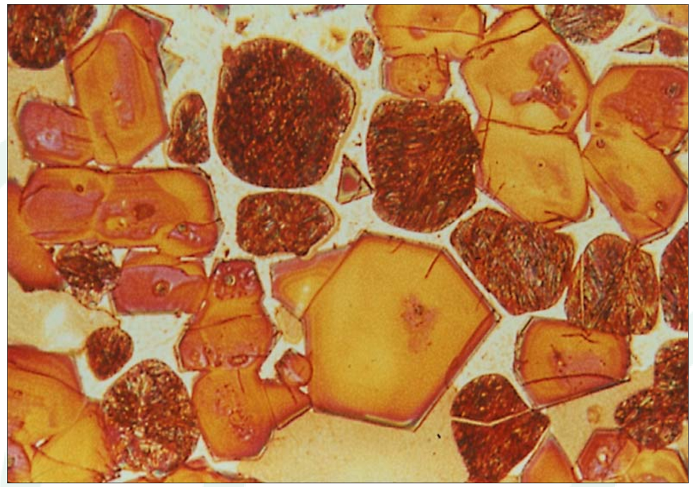
Manufacture of Portland Cement



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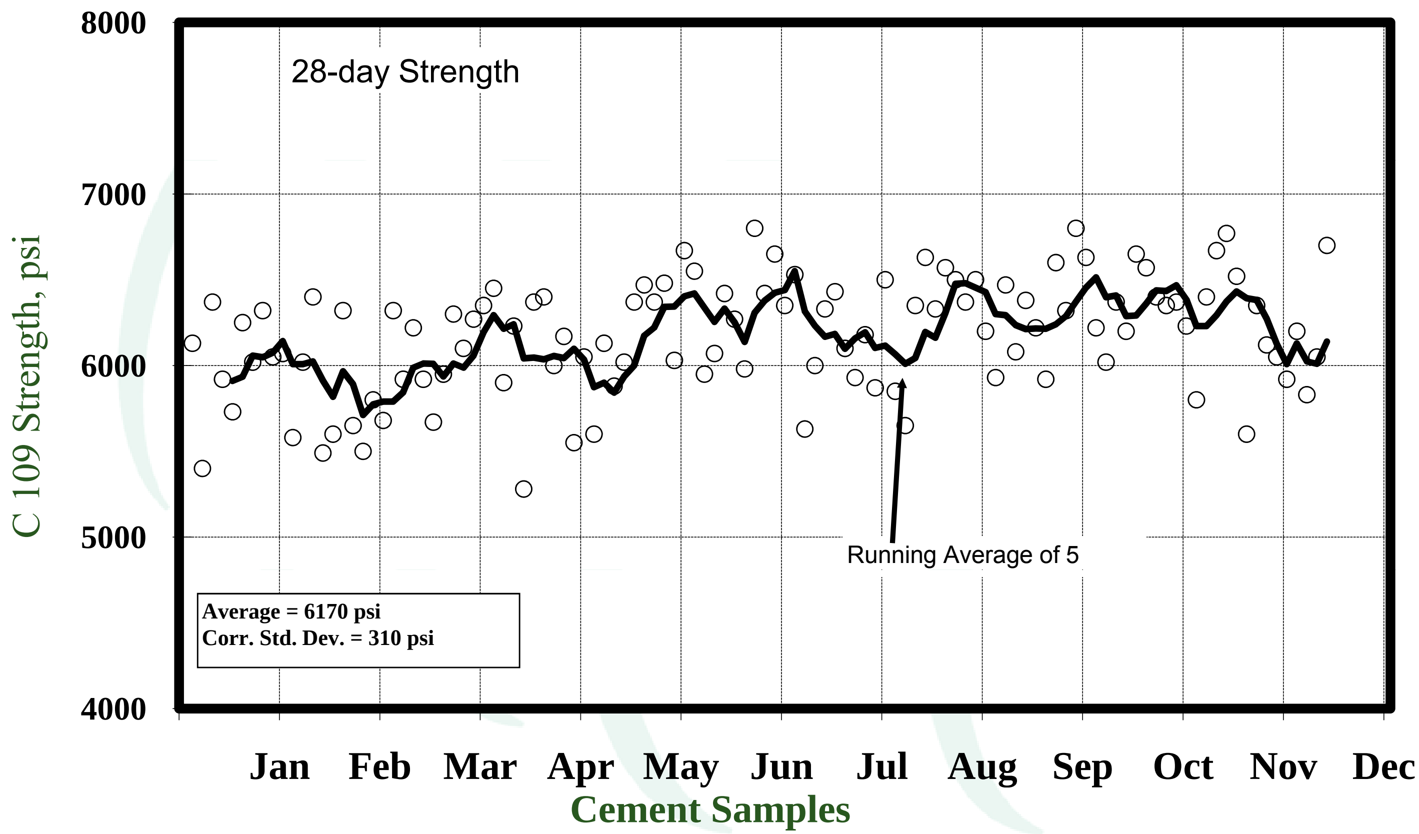
Uniformity of Cement - ASTM C 917



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Portland Cement composition

Phases	Amount, %	Property
C_3S	50 – 55	Early strength Heat
C_2S	20 – 25	Later strength
C_3A	5 – 12	Heat Sulfate resistance
C_4AF	~ 8	Color
CSH_2	~ 5	Setting Strength/shrinkage Admixture performance

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Types of Portland Cement ASTM C 150 (AASHTO M 85)

Type	Use	Requirements
I	General Purpose	
II	Moderate Sulfate Resistance Moderate Heat of Hydration	Max C_3A = 8% (C_3S + C_3A), Heat
III	High Early Strength	1 & 3 day strength limits
IV	Low Heat of Hydration	7 & 28 day strength limits
V	High Sulfate Resistance	Max C_3A = 5%

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ASTM C 595 (AASHTO M 240)

Type	Name	% Pozz or Slag
IP (X)	Portland-pozzolan cement	X
IS (X)	Portland blast-furnace slag cement	X
IT (AX)(BY)	Ternary blended cement	X and Y

Options - MS, HS, MH, A

Type IT – A is primary SCM; B is secondary

Example: Type IT(S25)(P15) contains 25% slag and 15% pozzolan

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ASTM C 1157

Type	Name
GU	General purpose (default)
HE	High Early Strength
MS	Moderate Sulfate Resistance
HS	High Sulfate Resistance
MH	Moderate Heat of Hydration
LH	Low Heat of Hydration
Option R	Low Reactivity with Alkali-Reactive Aggregates

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Fly ash and Natural Pozzolans

- Sources, characteristics, and uses
- Specification requirements of ASTM C 618
- Fresh and hardened concrete properties
- Quality control and mixture proportioning

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Fossil Fuel Power Plant

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Physical and Chemical Characteristics

- Loss on Ignition
- Fineness
- Chemical Composition
- Uniformity
- Reactivity - Fineness, glass content, Ca-glass

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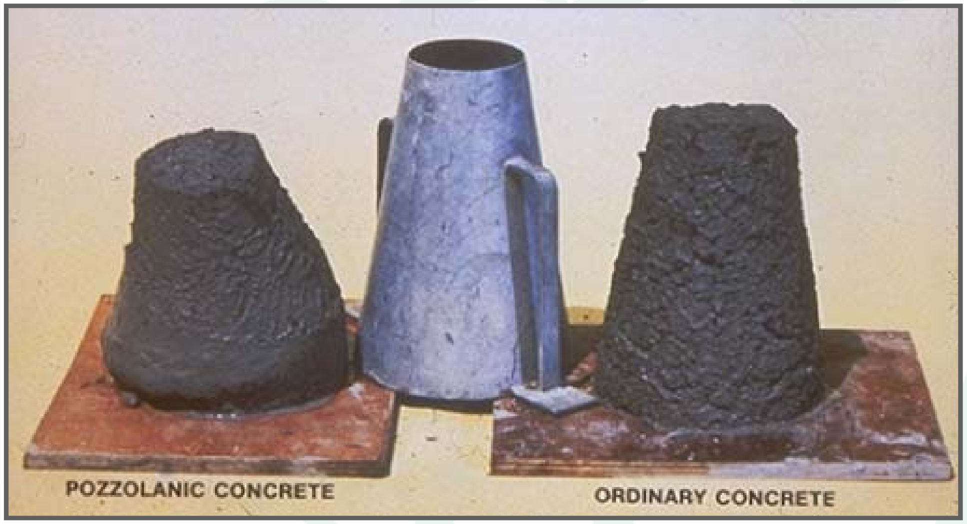
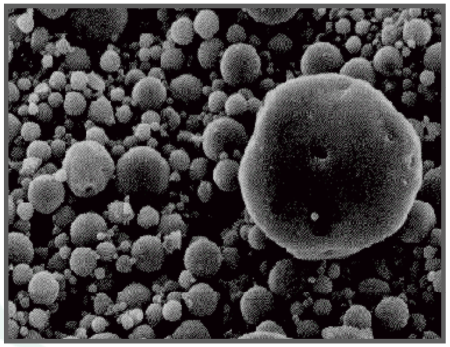
Workability

Workability improves - Size and shape of fly ash.
Spherical shape will act as ball bearing





Improved finishability
Improved pumpability

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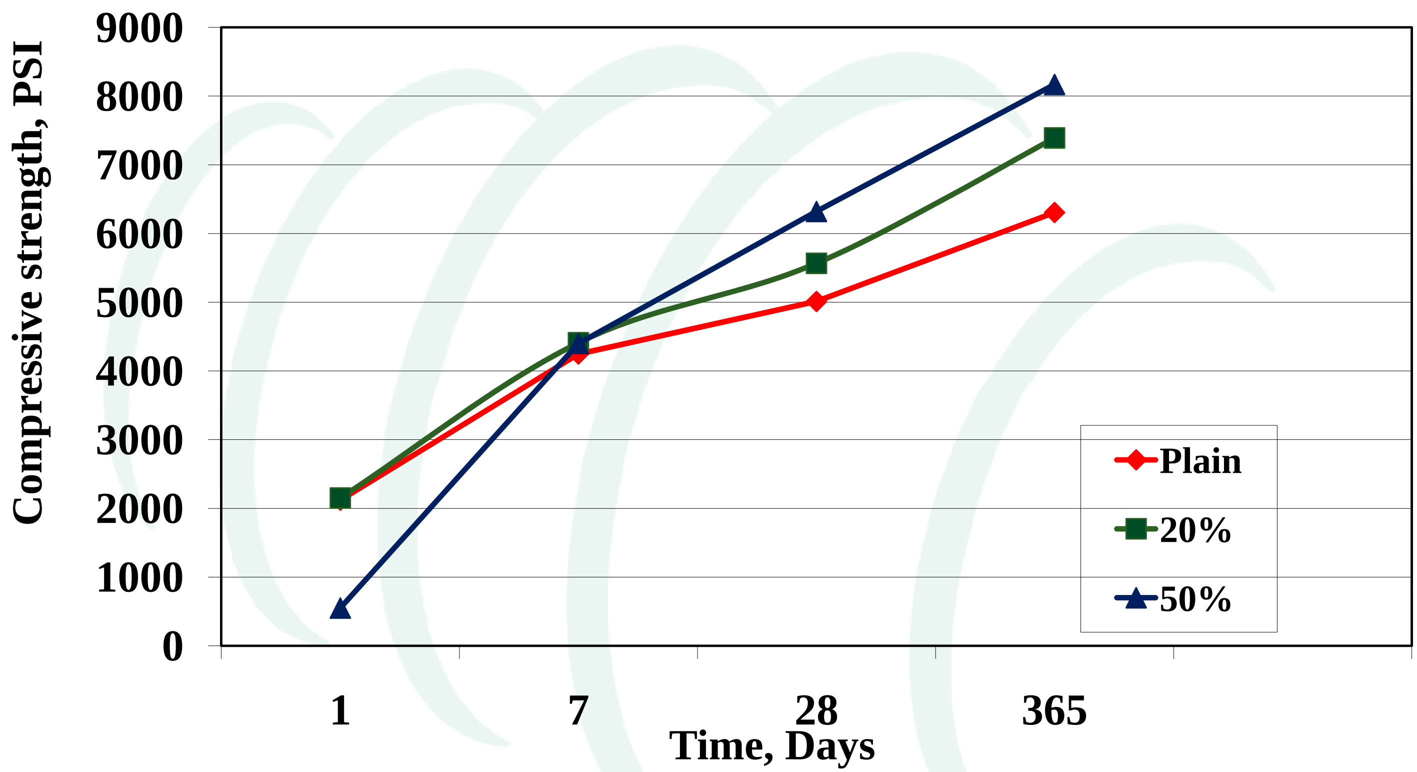
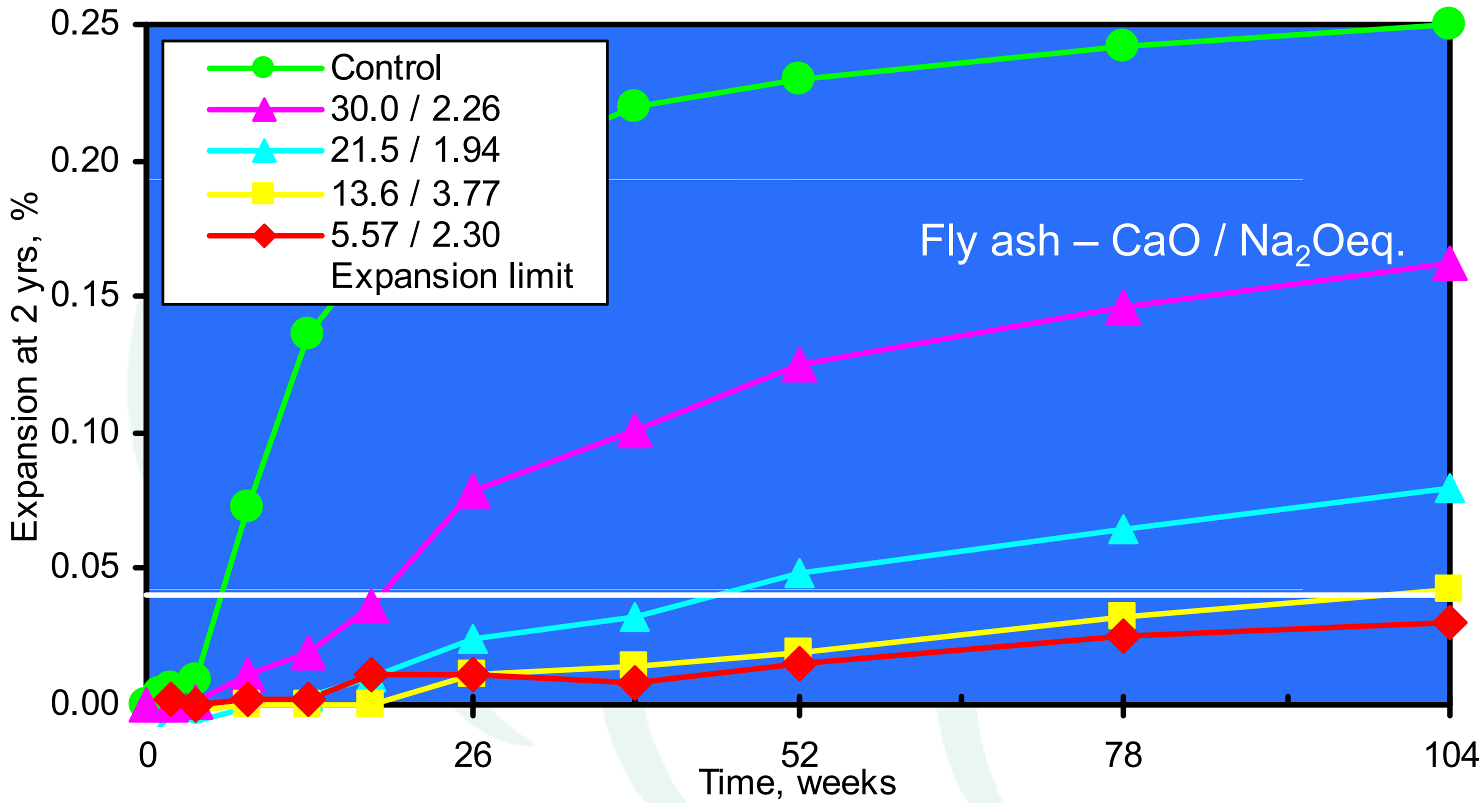
Strength Development



Alkali Aggregate Reactions



Shehata, Thomas, 2000

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Slag Cement

- Sources, manufacture and characteristics
- Requirements of Specification ASTM C 989
- Fresh and hardened concrete properties
- Quality control and mixture proportioning.

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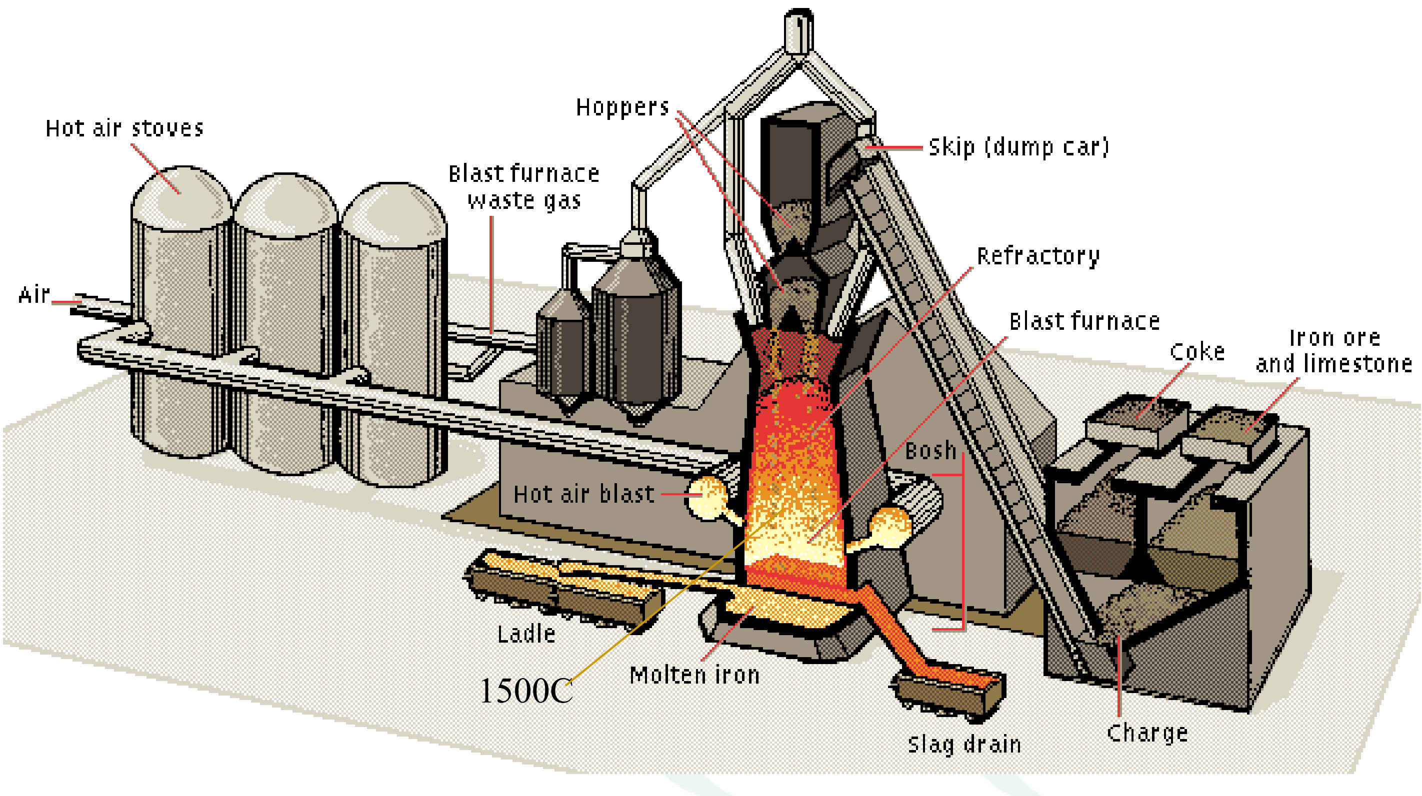
Slag Manufacture - Iron Blast Furnace



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Grades of Slag - ASTM C 989

Slag Activity Index = $\frac{\text{Strength of 1:1 Slag + Cement Mortar}}{\text{Strength of Control Cement Mortar}}$

Grade	7-day Index	28-day Index
80	-	75
100	75	95
120	95	115

Requirements for average of 5 consecutive

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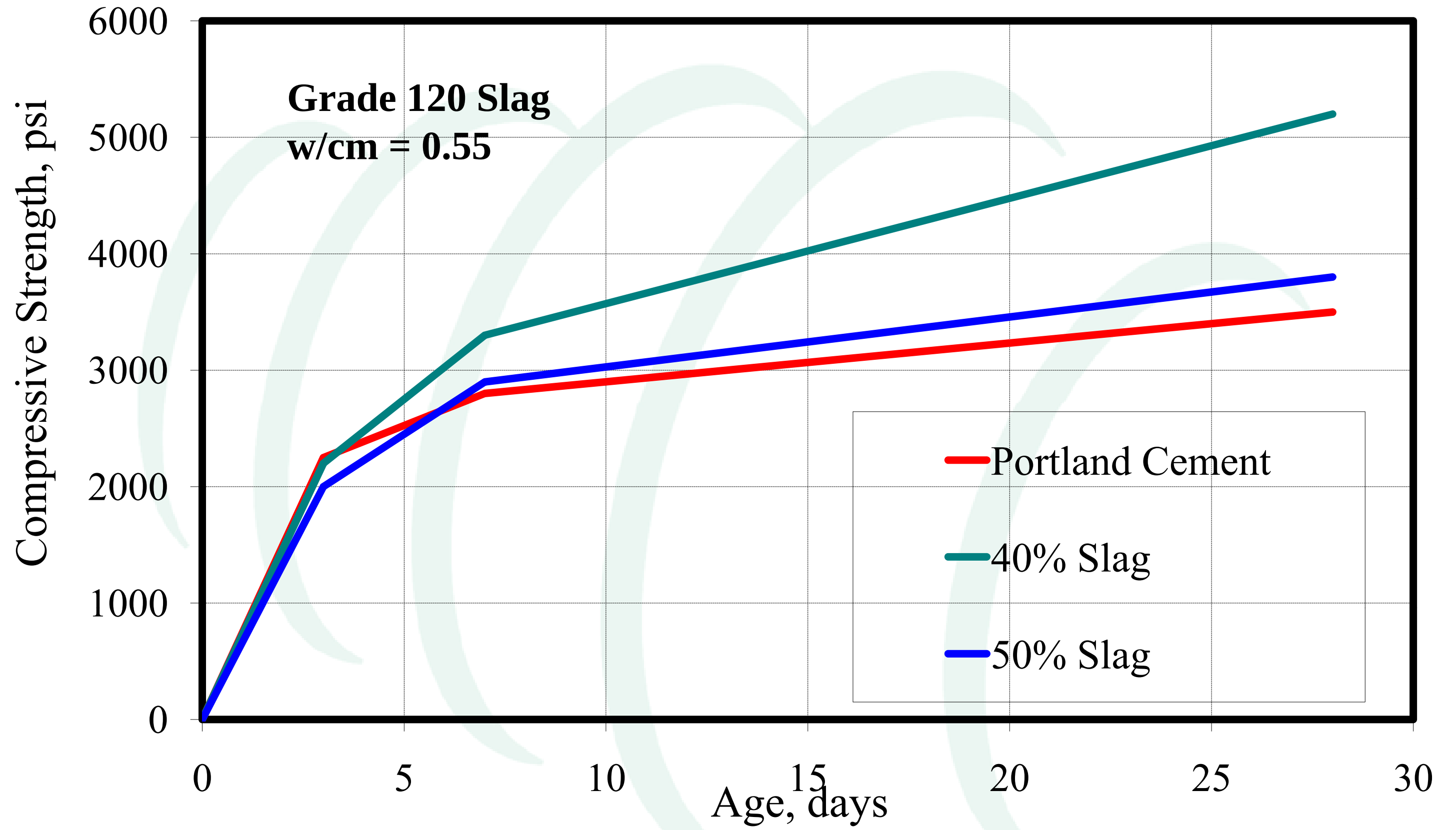
Compressive Strength



Ref: ACI 233R

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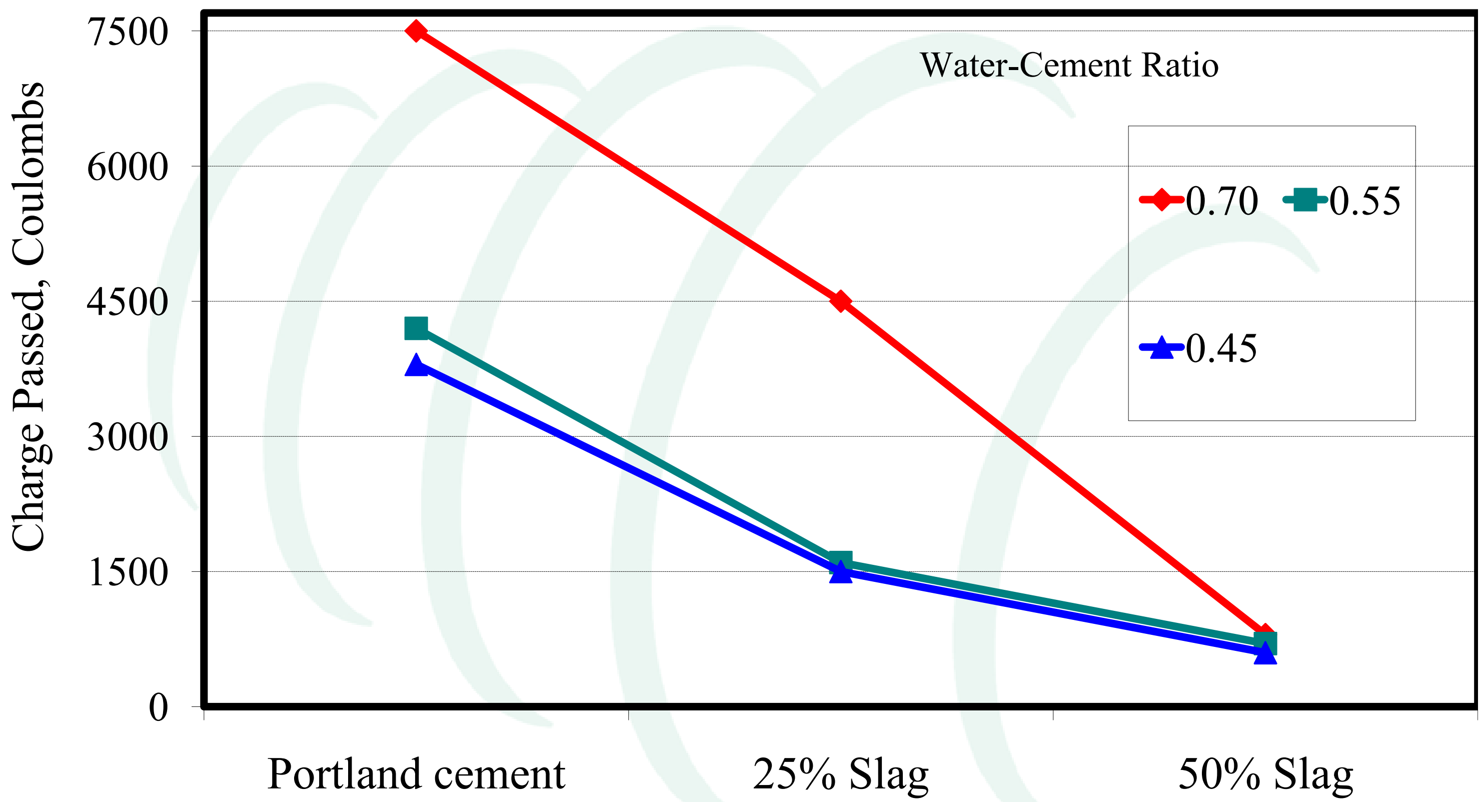
Chloride Permeability



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Slag - Proportioning

- Typical - 35 to 50%
- Lower early age strengths, delayed initial set
- w/c ratio = w/(cement + slag) ratio
- Water demand - 1 to 5% lower
- Adjust sand content
- Admixture dosage
  - Similar for air entraining admixtures

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Silica Fume

- Sources and available forms;
- Requirements of Specification ASTM C1240
- Fresh and hardened concrete properties
- Quality control and mixture proportioning

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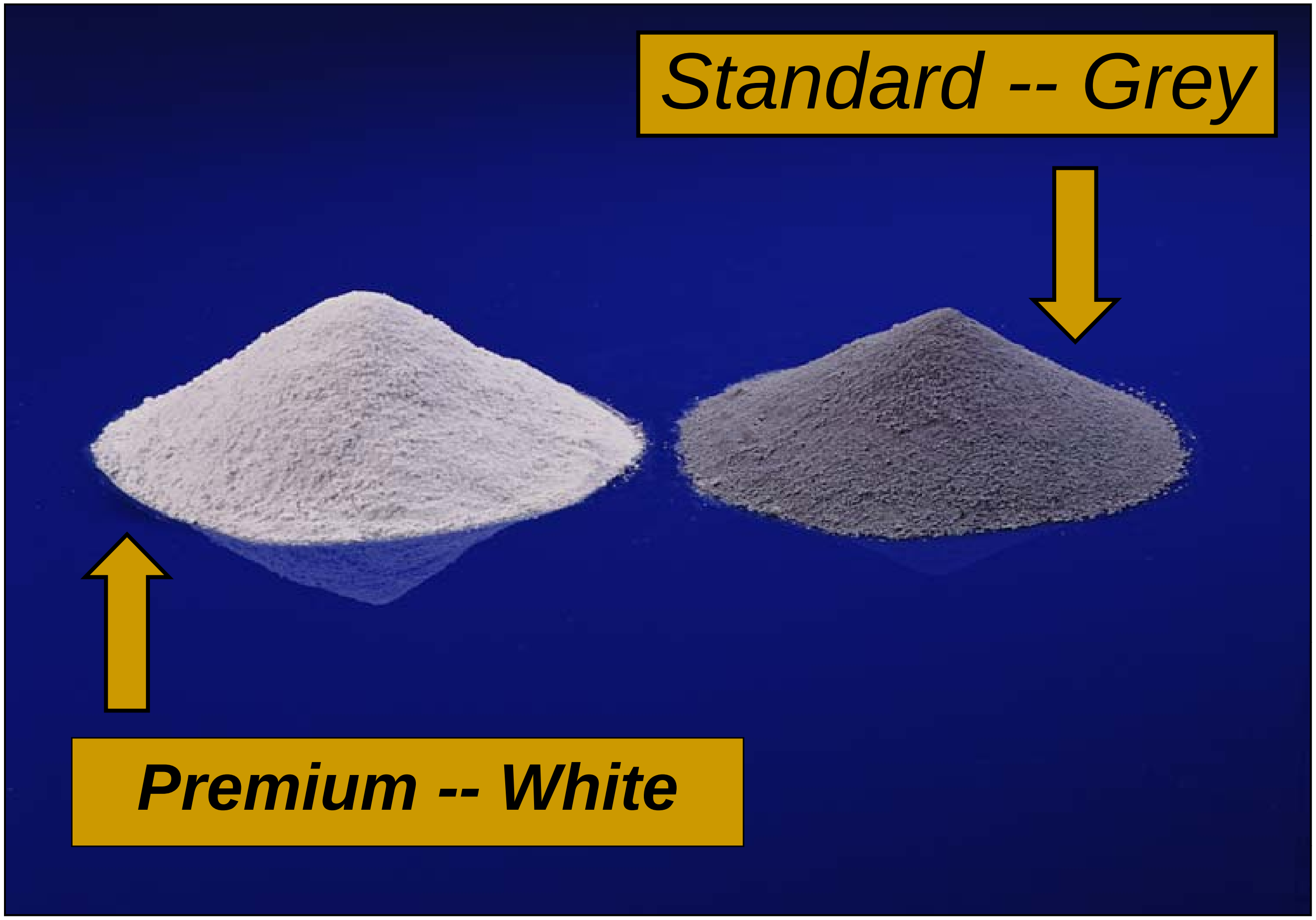
Silica Fume



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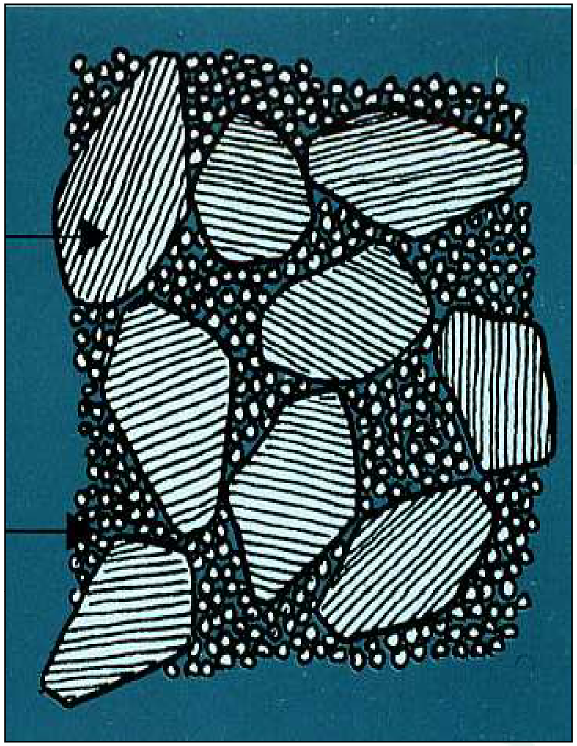
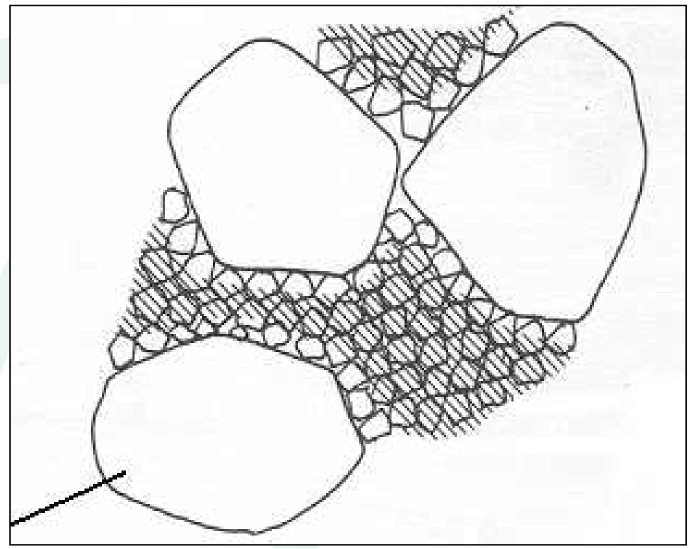
Silica Fume - Mechanism





Chemical - Pozzolanic

Physical – Particle packing

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Silica Fume - High Strength

311 South Wacker, Chicago

Key Bank Tower, Cleveland

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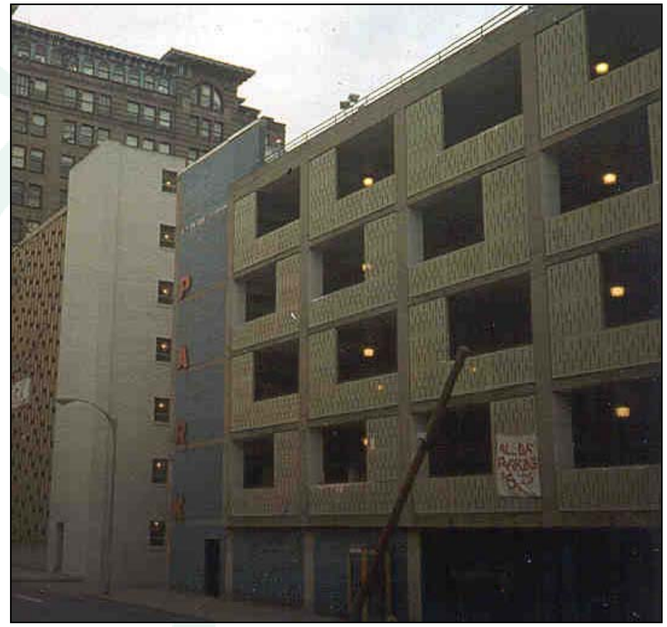
Silica Fume - Low Permeability

Bridge Deck Overlay



Parking Garages

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Silica Fume – Placing and Finishing

One-Pass Finishing

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Mixing Water – ASTM C 1602

- Potable water
- Non-potable sources – needs to be qualified for use
- Water from ready mixed concrete operations
  - Needs to be qualified for use and quality monitored
- Combined – mixtures of the above

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Hydration, Microstructure and Permeability

- Fundamentals of cement hydration
- Impact of supplementary cementitious materials
- Role of SCMs and w/cm on pore structure and permeability

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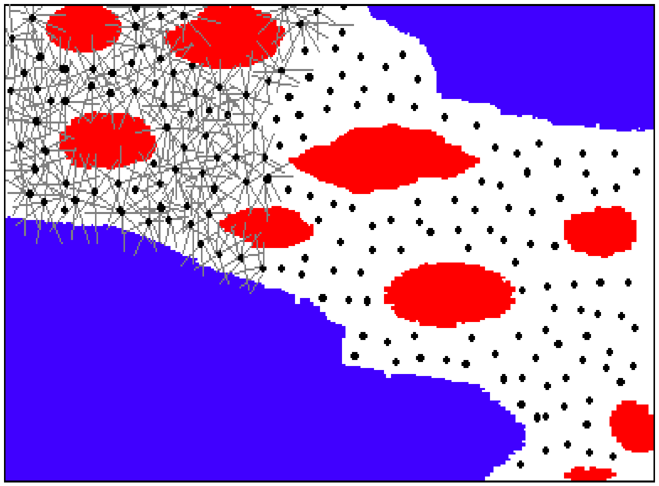
Hydration

- Cement reacts with water to form cementitious compounds



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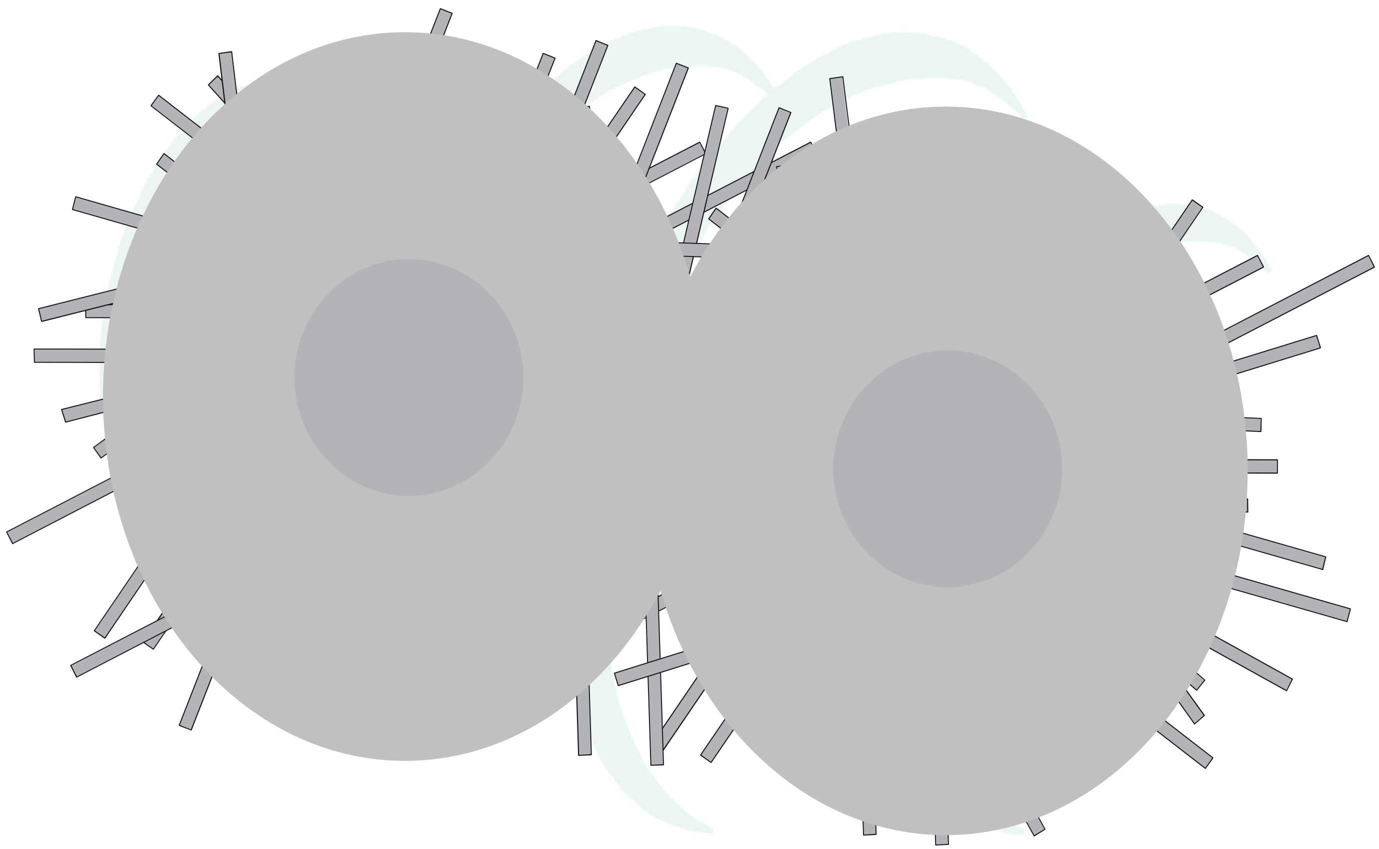
Hydration



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Hydration

Cement + Water	→	C-S-H + CH	Hydraulic
Pozzolan + CH	→	C-S-H	Pozzolanic
Slag + Water	Alkali/lime activator →	C-S-H (no CH)	Hydraulic
Slag + CH	→	C-S-H	Pozzolanic

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General principle

Low Permeability

↓

Good Durability

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Aggregates

- Types of aggregates
- Requirements for aggregates-ASTM C 33
- Stockpiling and sampling
- Effects of Aggregates on Concrete properties
- Quality control for aggregates
- Lightweight aggregates
- Heavyweight aggregates

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Types of Aggregates used in Concrete

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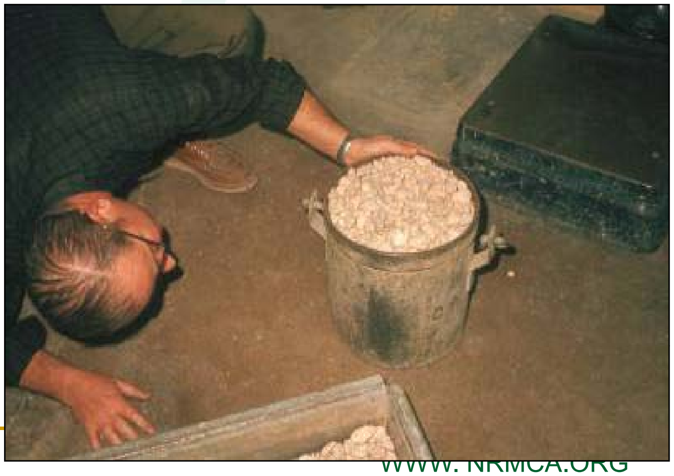
ASTM C 33
Standard Specification for Concrete Aggregates

- Ordering Information
- Fine and Coarse Aggregate Characteristics
- Grading
- Soundness
- Abrasion resistance
- Deleterious materials



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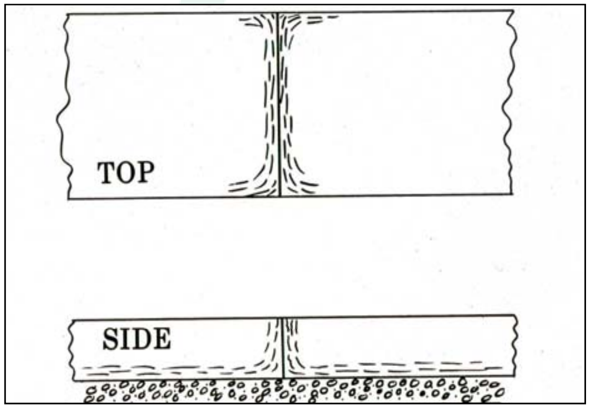
Aggregate Properties for use in Concrete

- Freeze-thaw durability



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Harmful Materials in Aggregate

Substance	Effect on Concrete
Organic Impurities	May cause deterioration, effects setting & hardening
Material Finer than 75 µm	Increases water requirement, may affect bonding
Coal, lignite & other lightweight materials	Affects durability, may cause popouts, color change
Soft particles, chert	Affects durability, may cause popouts
Clay lumps, friable particles	Affects workability and durability, may cause popouts
Alkali reactive aggregates	Abnormal expansion, map cracking and popouts

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Lightweight Aggregate (ASTM C 330)

- Expanded
  - Shale
  - Clay
  - Slate
  - Slag

Produce structural lightweight concrete 1350 to 1850 kg/m^3 (90 to 120 lb/ft^3)

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Heavyweight Aggregate
ASTM C 637, C 638 (Radiation Shielding)

- Barite
- Limonite
- Magnetite
- Ilmenite
- Hematite
- Iron
- Steel punchings or shot

Produce high-density concrete up to 6400 kg/m^3 (400 lb/ft^3)

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Aggregate tests and calculations

- Sampling - field and lab
- Moisture
- Grading and fineness modulus
- Specific gravity and absolute volume
- Bulk density
- Other tests

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Sampling Aggregates ASTM D 75
Fine Aggregate

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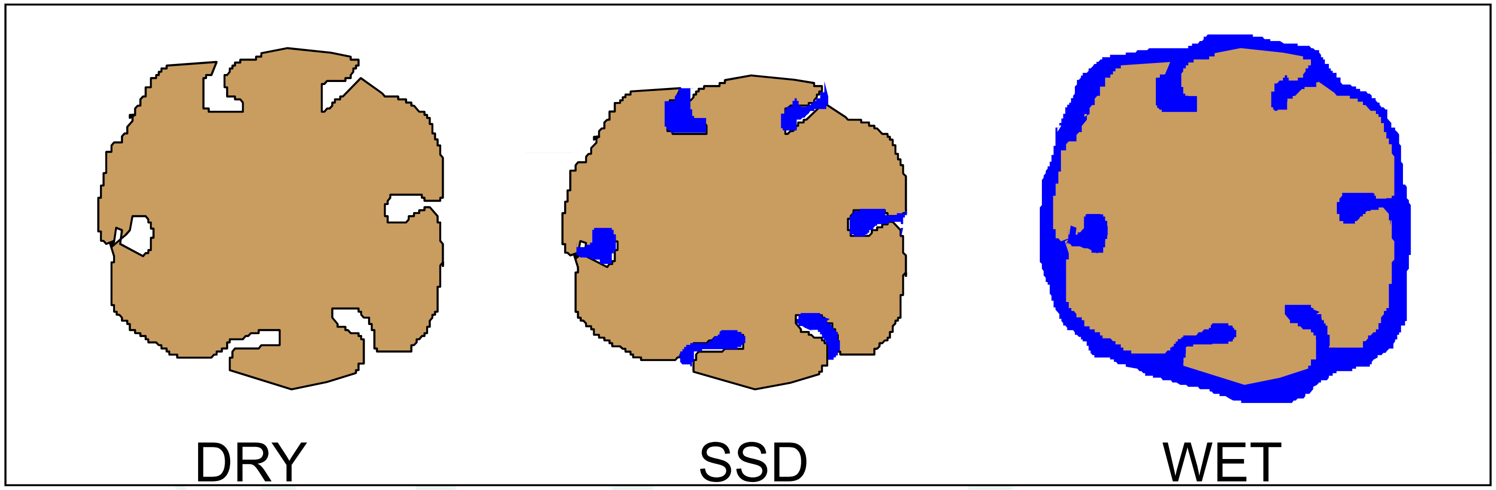
Aggregate Moisture Content



Total moisture = Free + Absorbed

Free Moisture = Total - Absorbed

Free Moisture is included in Mixing Water

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Particle Distribution of Aggregates
ASTM C 136 Sieve Analysis

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Particle Distribution of Aggregates ASTM C 136 Sieve Analysis

Sieve	Wt. retained, g	Ind. % retained	% Retained	% Passing
3/8 in.	0.0	0.0	0.0	100.0
No. 4	40.5	8.1	8.1	91.9
No. 8	65.5	13.0	21.1	78.9
No. 16	82.7	16.4	37.5	62.5
No. 30	96.3	19.2	56.7	43.3
No. 50	111.7	22.2	78.9	21.1
No. 100	87.2	17.3	96.2	3.8
No. 200	15.2	3.0	99.2	0.8 (W&D
Pan	0.6	0.1		
200 W	3.3	0.7		

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Bulk Density of Aggregates - ASTM C 29 Unit Weight

- Weigh the empty bucket
- Fill in three equal layers
- Rod each layer 25 times
- Level the final layer with rod & fingers

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Organic Impurities - ASTM C 40

Specific Gravity & Absorption - C 127

Coarse

Aggregate

- Soak sample for 24 hours
- Towel dry to SSD condition

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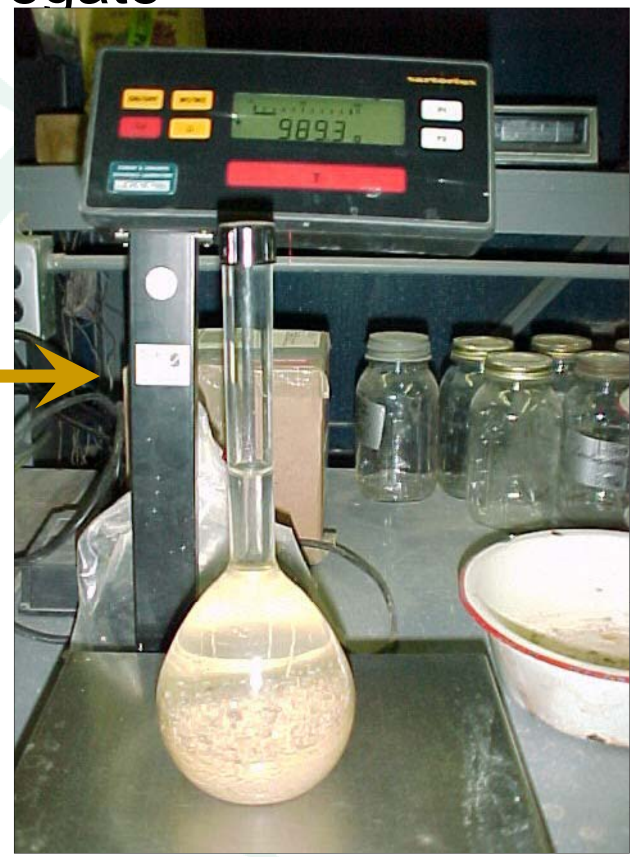
Specific Gravity & Absorption - C 127

Fine Aggregate



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L.A. Abrasion – ASTM C 131

Steel Charge:

11 spheres = 4584 g

500 revolutions

Sieve over No. 12

Weigh material retained

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Chemical Admixtures

- Requirements in Specification ASTM C 494
- Air-entraining admixtures-ASTM C 260
- Effective use of admixtures
- Cement-admixture compatibility
- Special Admixtures and uses
- Fibers

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Purpose of Admixtures

- Improve characteristics of Fresh Concrete
  - Increase workability
  - Reduce water requirement
  - Setting time control
  - Bleed and / or segregation control
  - Hydration control
  - Pumpability
  - Finishability

- Improve characteristics of Hardened concrete
  - Increased Strength
  - Increased Durability (Corrosion, ASR, Permeability, Freeze-thaw)
  - Economy

Types of Chemical Admixtures

- Air Entraining Admixtures (ASTM C 260)
- Water Reducing/Plasticizing
  - ASTM C 494 – Type A, Type D (retarding), Type E (accelerating)
  - ASTM C 1017 – Type I, Type II (retarding)
- High Range Water Reducing
  - ASTM C 494 – Type F, Type G (retarding)
- Set Controlling
  - ASTM C 494 – Type B for retarding
  - ASTM C 494 – Type C for accelerating

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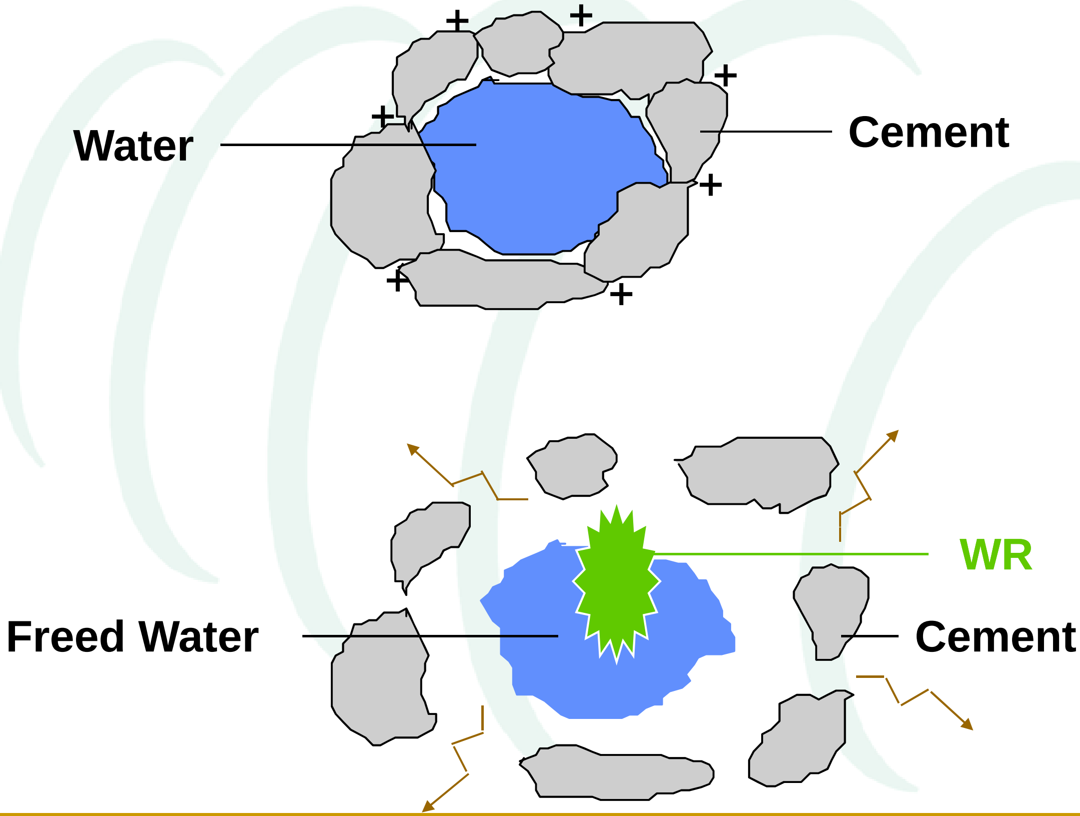
Mechanism of Water Reducers



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Specialty Chemical Admixtures

- Hydration Control
- Corrosion Inhibitors (ASTM C 1582)
- Shrinkage Reducing Admixtures
- Alkali-Silica Reactions
- Anti-Washout
- Viscosity Modifying Admixtures
- Color
- Fibers

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Proportioning Concrete Mixtures

- Selecting mixture characteristics
- Required information on material properties
- Proportioning by absolute volume method
- Adjustments to trial batches
- Proportioning with pozzolans and slag
- Yield, calculated batch quantities

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Proportioning Concrete Mixtures

Before we proportion concrete mixtures, we need to know:

- Application (pavement, slab)
- Strength requirement
- Durability requirements - w/cm, other
- Characteristics of the materials
  - Cementitious materials – types and relative density
  - Sand – fineness modulus, relative density, absorption, moisture
  - Stone – nominal max size, relative density, bulk density, absorption, moisture
  - Water
  - Admixtures

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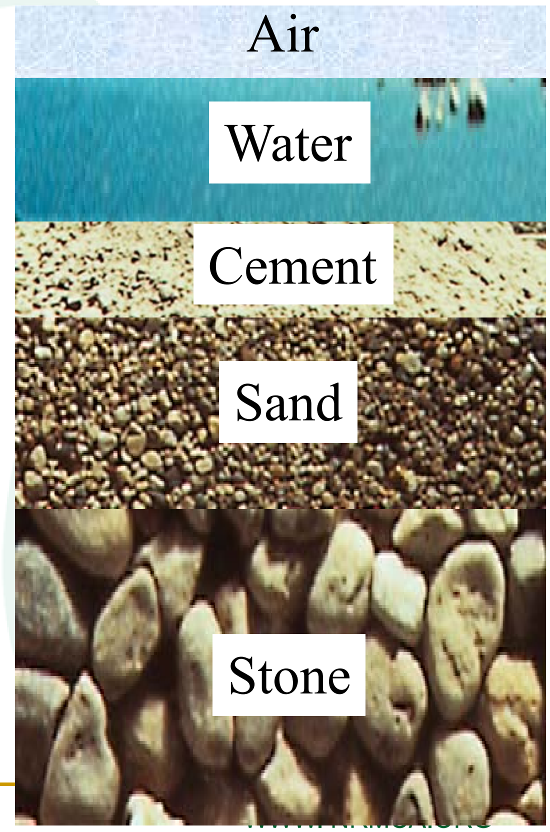
Sequence in Mixture Proportioning

- Water requirement
- Air content
- Cementitious materials
- Coarse aggregate
- Sand



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Required Average Strength

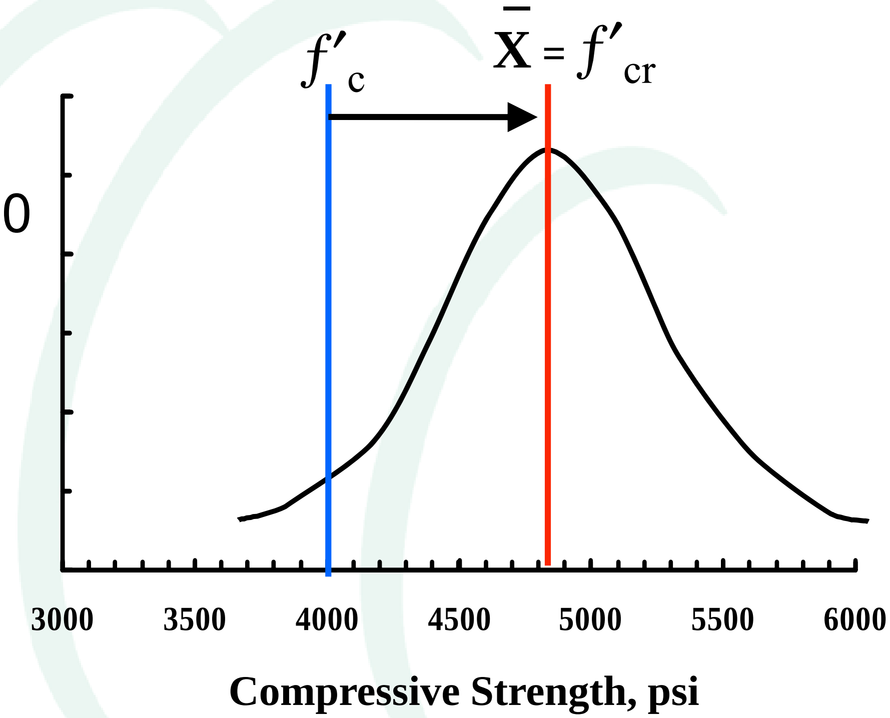
With past test record

$$f'_{cr} = f'_c + 1.34\ S$$

$$f'_{cr} = f'_c + 2.33\ S - 500$$

Without past test record

f'_c, psi	f'_{cr}, psi
less than 3000	$f'_c + 1000$
3000 to 5000	$f'_c + 1200$
over 5000	$1.10f'_c + 700$



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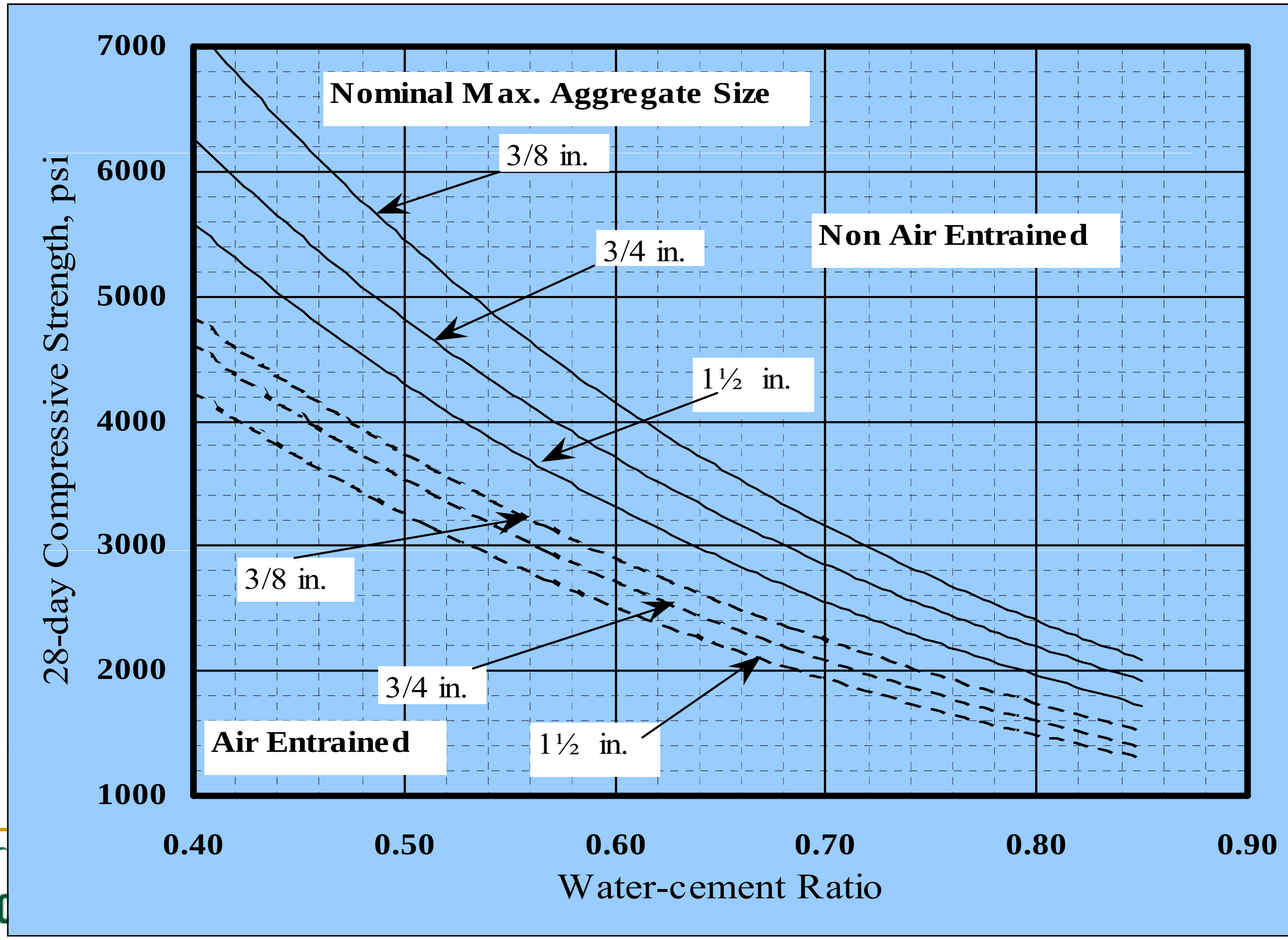
w/cm to strength



Select mixing water

Slump, inches.	Mixing Water, lb./cu. yd.					
	No. 4 (Mortar)	3/8 in.	1/2 in.	3/4 in.	1 in.	1½ in.
Non-Air Entrained Concrete						
1 - 2		310	295	280	265	250
3 - 4	420	335	325	310	295	280
6 - 7		375	355	335	320	305
Air-Entrained Concrete						
1 - 2		280	270	260	245	235
3 - 4	380	305	300	290	275	265
6 - 7		345	330	315	300	290

Make adjustments for cementitious materials and admixtures

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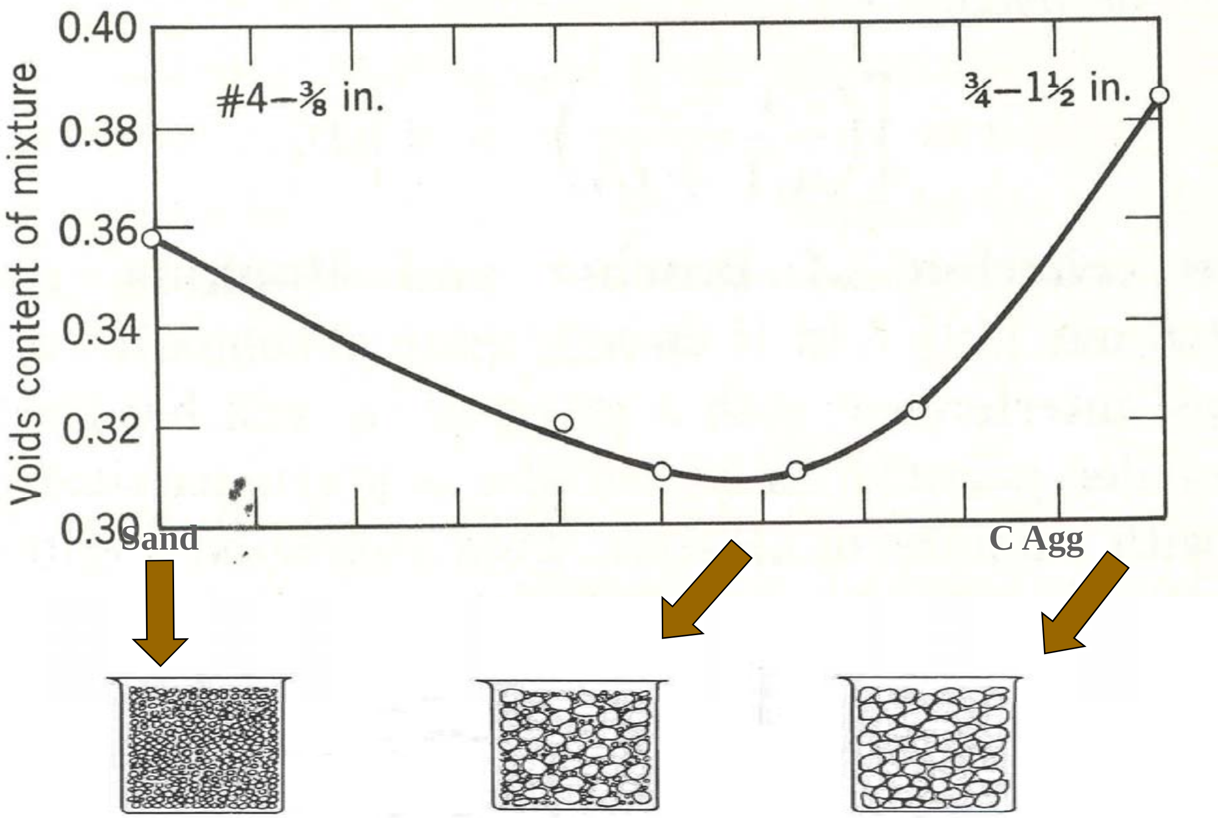
Paste Content
Effect of Aggregate Grading



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Trial Batches

- Verify and make adjustments

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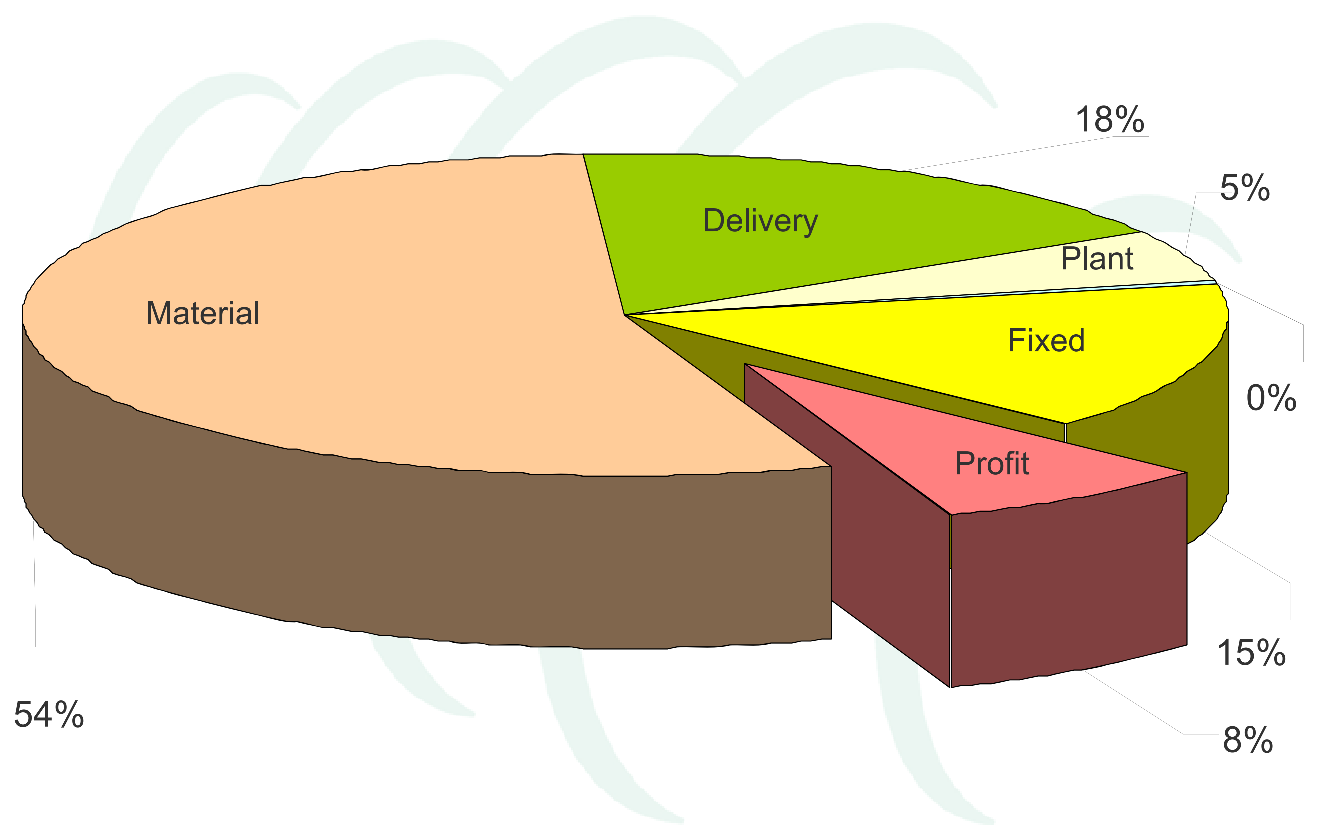
Typical Cost of Concrete



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Production, Delivery & ASTM C 94

- Overview of concrete production
- Requirements of Specification ASTM C 94
- Requirements for mixing water
- Weighing and batching equipment and tolerances
- Mixing Concrete - Batching Sequences; Mixing Concrete; Evaluating mixing Uniformity
- Plant recorders, records and delivery tickets
- Delivery requirements - Jobsite adjustments

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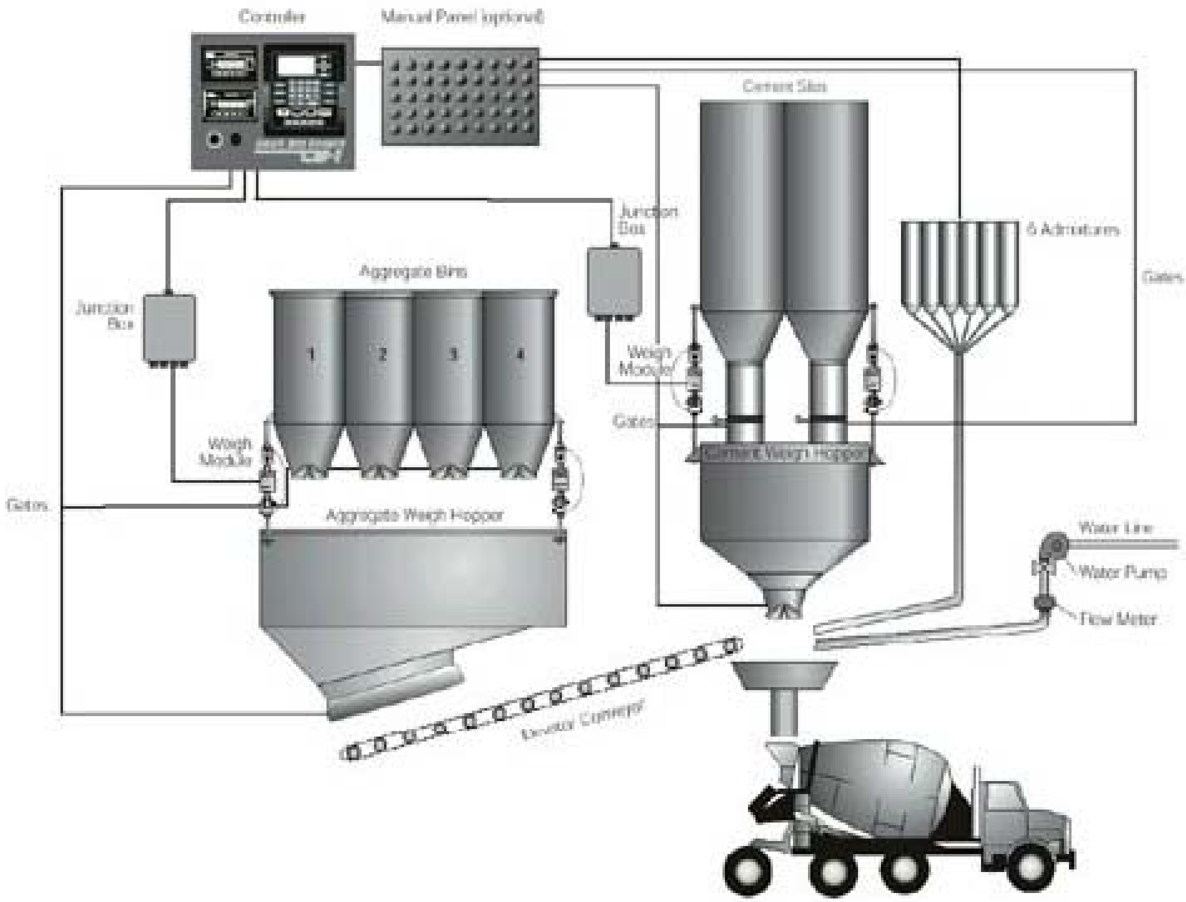
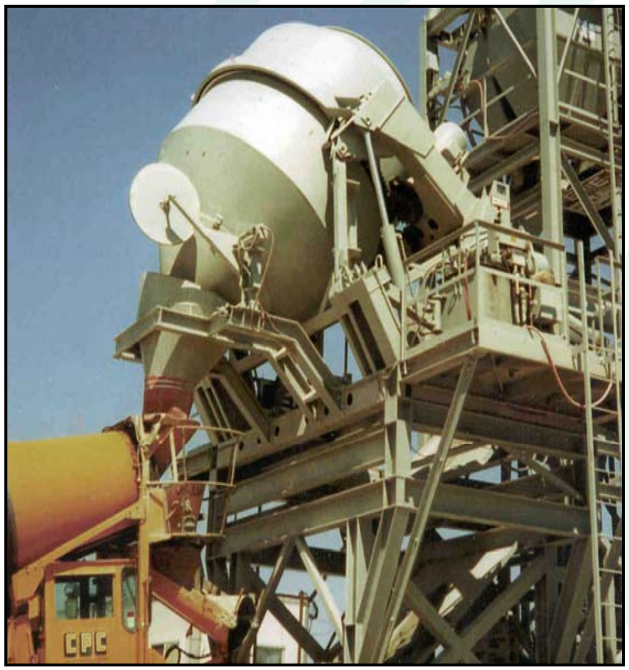
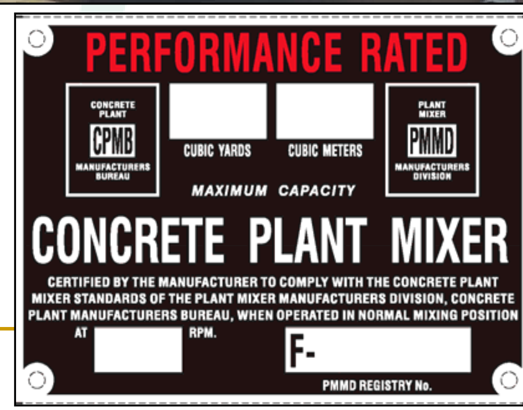
Flow of Materials

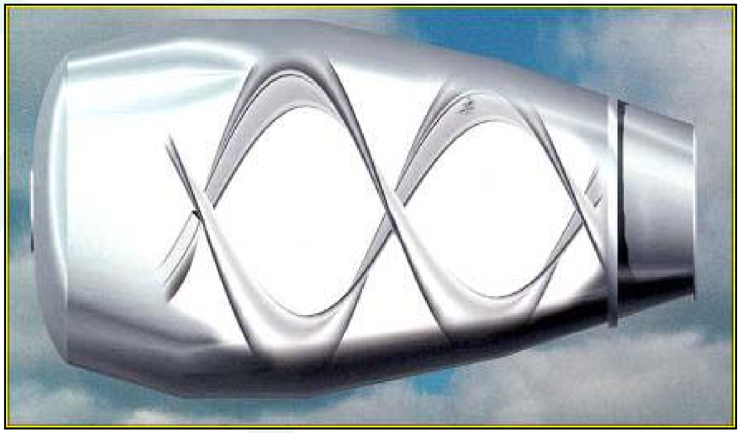


Revolving Tilt-Drum Mixer



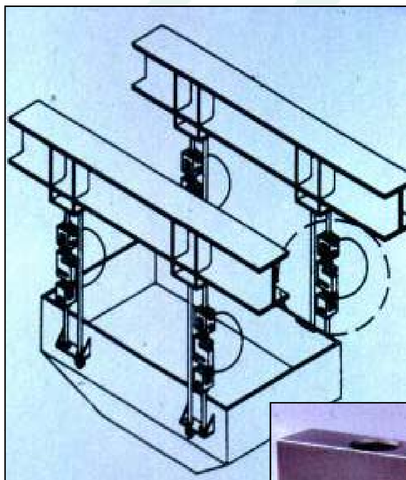


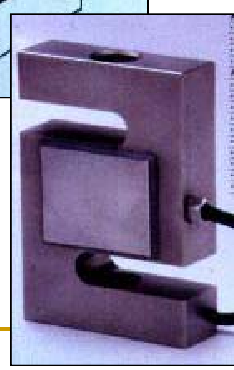
Truck Mixers



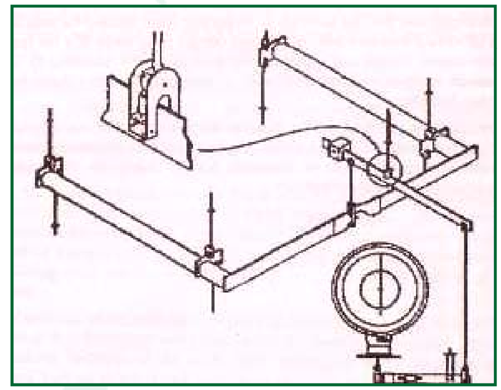
Types of Scales

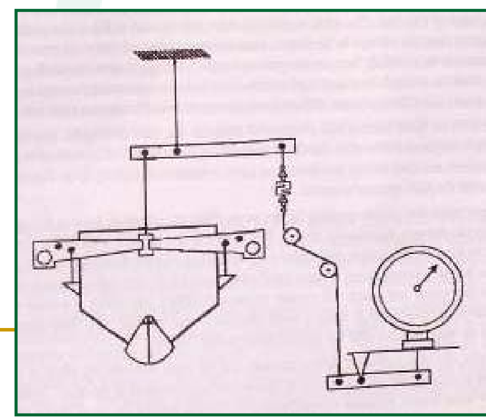
Load cell





Lever-





Volumetric Measurement

- Water meters
- Admixture dispensers
- Accuracy
  - Verified every 90 days
  - Calibrated every 6 months

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Accuracy of Batching

- Aggregates
- Storage should maintain distinct types / sizes
- Handling procedures to minimize segregation
- Batching accuracy
  - Individual Batchers ± 2% of required weight
  - Cumulative Batchers ± 1% of intermediate and final cumulative wt.

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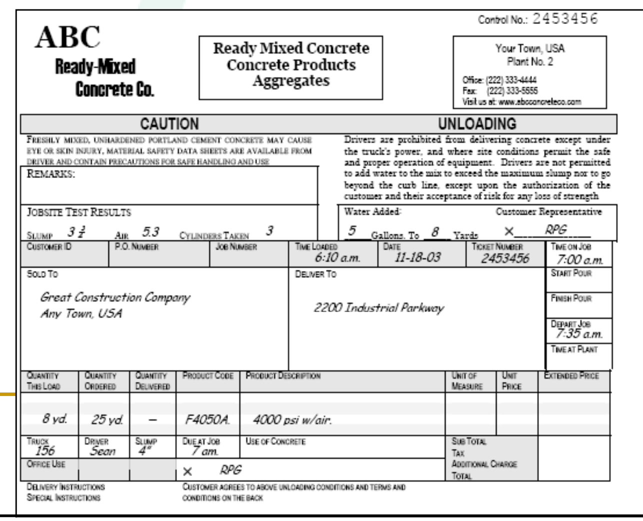
Batch Records

- Batch Recorders
  - Non-tamper able record of actual batch quantities
  - Identified to delivery tickets
- Delivery Tickets
  - Record of mix furnished
  - Jobsite notes / purchaser acceptance



Control No.: 2453456

ABC Ready-Mixed Concrete Co.

Ready Mixed Concrete
Concrete Products
Aggregates

Your Town, USA
Plant No. 2
Office: (222) 333-4444
Fax: (222) 333-5555
Visit us at: www.abcconcreteco.com

CAUTION

FRESHLY MIXED, UNHARDENED PORTLAND CEMENT CONCRETE MAY CAUSE EYE OR SKIN INJURY, MATERIAL SAFETY DATA SHEETS ARE AVAILABLE FROM DRIVER AND CONTAIN PRECAUTIONS FOR SAFE HANDLING AND USE

UNLOADING

Drivers are prohibited from delivering concrete except under the truck's power, and where site conditions permit the safe and proper operation of equipment. Drivers are not permitted to add water to the mix to exceed the maximum slump nor to go beyond the curb line, except upon the authorization of the customer and their acceptance of risk for any loss of strength

REMARKS:

JOBSITE TEST RESULTS
SLUMP 3 1/2 AIR 5.3 CYLINDERS TAKEN 3

Water Added: 5 Gallons. To 8 Yards
Customer Representative × RPG

CUSTOMER ID	P.O. NUMBER	JOB NUMBER	TIME LOADED	DATE	TICKET NUMBER	TIME ON JOB
			6:10 a.m.	11-18-03	2453456	7:00 a.m.

SOLD TO: Great Construction Company, Any Town, USA

DELIVER TO: 2200 Industrial Parkway

START POUR:
FINISH POUR:
DEPART JOB: 7:35 a.m.
TIME AT PLANT:

QUANTITY THIS LOAD	QUANTITY ORDERED	QUANTITY DELIVERED	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT OF MEASURE	UNIT PRICE	EXTENDED PRICE
8 yd.	25 yd.	–	F4050A.	4000 psi w/air.			

TRUCK	DRIVER	SLUMP	DUE AT JOB	USE OF CONCRETE
156	Sean	4"	7 am.	

OFFICE USE — × RPG

SUB TOTAL
TAX
ADDITIONAL CHARGE
TOTAL

DELIVERY INSTRUCTIONS
SPECIAL INSTRUCTIONS

CUSTOMER AGREES TO ABOVE UNLOADING CONDITIONS AND TERMS AND CONDITIONS ON THE BACK

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Specifications

ASTM C 94 Specification for Ready Mixed Concrete

- Address joint and separate responsibilities of:
  - Owner, purchaser, or specifier
  - Producer and contractor
  - Testing agency
- Project specification requirements govern

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Basis of Purchase

Sold by Volume -- cubic yard or cubic meter

$$\text{Yield} = \frac{\text{Total weight of batch}}{\text{Unit weight of concrete}}$$

When ordering account for:

- Waste
- Spillage
- Over excavation
- Form Deflection
- Loss of air
- Settlement

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Ordering Information

Purchaser Specifies:

- Coarse aggregate size
- Slump
- Air content

Option A - Performance

- Strength

Option B - Prescriptive

- Cement Content
- Maximum water
- Admixtures

Option C - Mixed

- Strength
- Minimum Cement
- Admixtures

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Delivery Requirements

- Max 100 revs initial mixing
- Max 300 revs. - mixing and agitation
- 90 minute time limit - batching to end of discharge
- Slump tolerances
  - ± Tolerance depending on slump
  - Producer responsible for slump later of:
    - 30 minutes from time ordered
    - 30 minutes after arrival at jobsite
- Air content requirements
  - ± 1.5%
  - Permitted to adjust air a the jobsite
- Job-site Water Addition
  - 1 addition - after arrival at the job-site + 30 revs
  - Do not exceed maximum water

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Shrinkage and Cracking

- Types of physical volume change in concrete
  - Shrinkage in plastic and hardened states
- Controlling and minimizing cracking
- Testing and identifying conditions that result in cracking

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Concrete ~~Never~~ *Always* Cracks!

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Why does concrete contract?

- Chemical shrinkage - Hydration
- Moisture loss (drying shrinkage)
- Temperature

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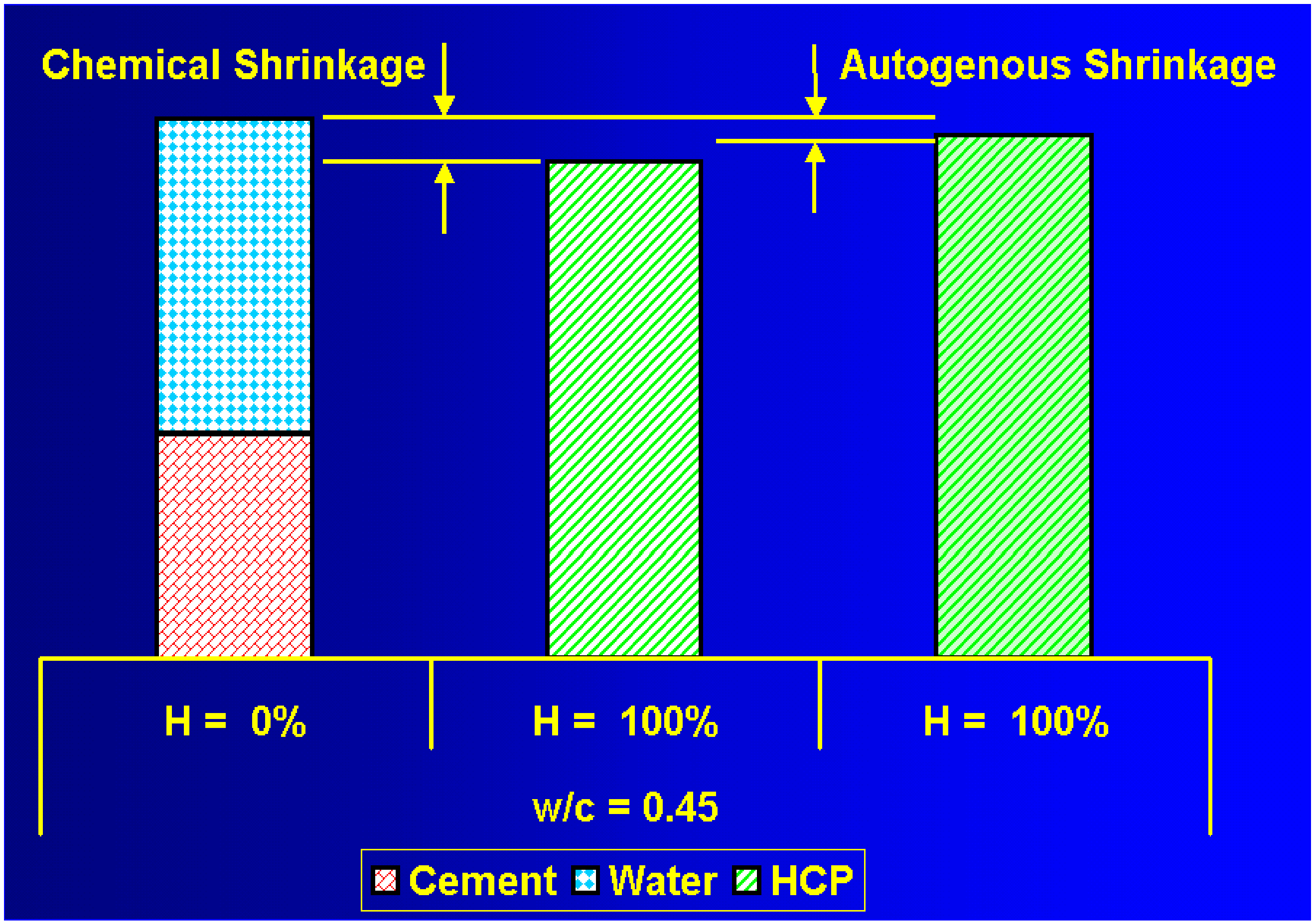
Chemical vs. Autogenous Shrinkage



Minimizing Drying Shrinkage

- Minimize paste (water) content
- Minimize moisture loss to the system (evaporation retarders, curing compounds)
- Supply extra water (burlap)
- Adjust timing of drying

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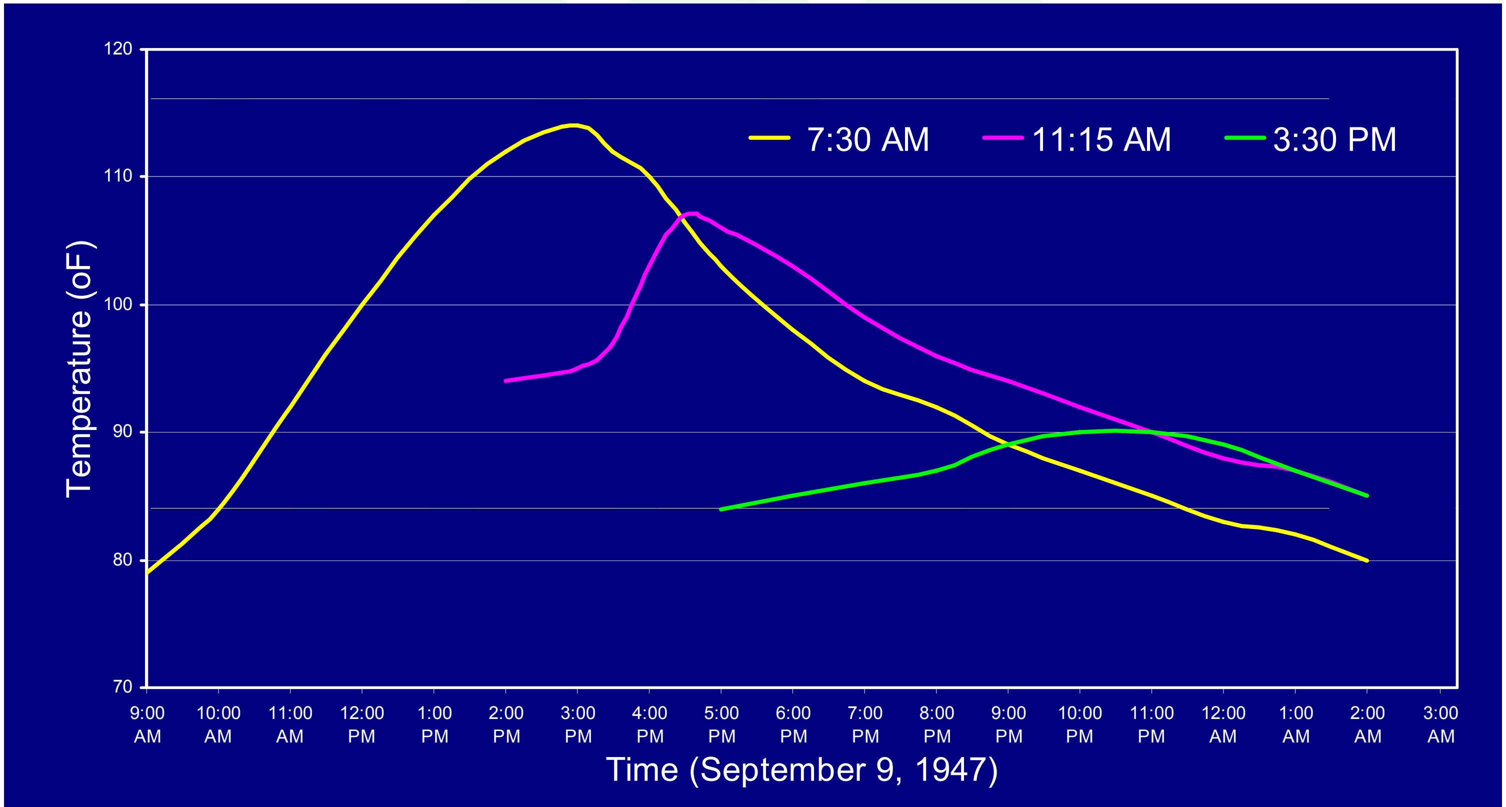
Concrete Temperature – Placement time



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Measuring Shrinkage & Cracking

- C157 – prism length change
  - Initial is at 24 hours
  - Drying only starts at 28 days (or other)
- C1581 – ring shrinkage test
  - Readings start immediately
  - Drying starts at selected age

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Cracking

The real trick with cracks is to get them where we want them

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Fundamentals of Durability

- Corrosion
  - Mechanisms, tests and measurements, and strategies for minimizing
- Sulfate attack (chemical, physical, DEF, thaumasite)
  - Mechanisms, tests and criteria and strategies for minimizing
- Alkali Aggregate Reactions
  - Mechanisms, tests and criteria and strategies for minimizing

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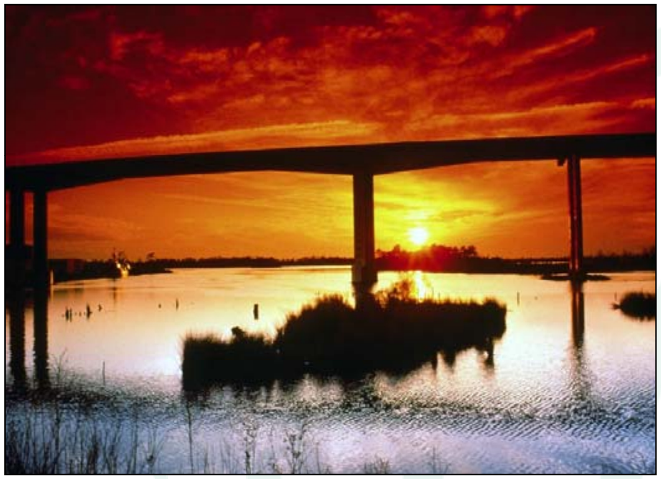
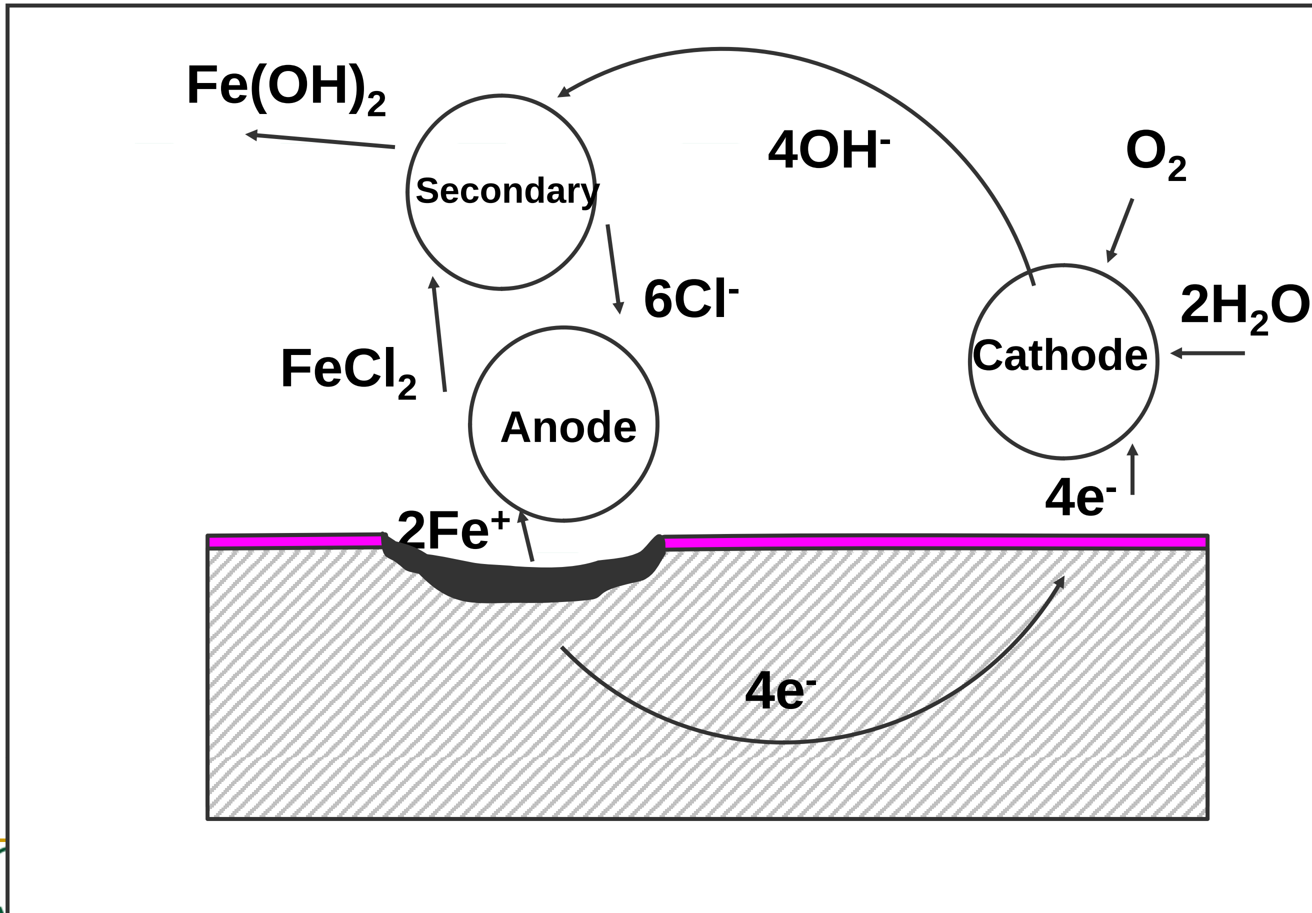
Where can corrosion occur?



Corrosion is an Electrochemical Process



Options for Delaying Corrosion

- Provide a sufficient barrier of protection
  - Adequate concrete cover
  - Low permeability concrete
  - Good concreting practices
  - Sealer, membrane

- Modify corrosion behavior of reinforcing steel
  - Reinforcement less prone to corrosion
  - Corrosion-inhibiting admixtures in concrete
  - Cathodic protection or electrolytic chloride removal

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Low Permeability Concrete

- Use low w/cm
  - 0.40 and 5000 psi strength (Table 4.2.2 ACI 318)
  - Is w/cm = 0.33 better?
- Use fly ash, silica fume, slag
- Rapid Chloride permeability (ASTM C 1202) test is ideal for specification even though it does not measure permeability

Chemistry of Sulfate Attack

- $C_3A + C\overline{S} + 12H \rightarrow C_4A\overline{S}H_{12}$ (monosulfate)
- $C_4A\overline{S}H_{12} + 2C\overline{S} + 20H \rightarrow C_6A\overline{S}_3H_{32}$ (ettringite)
- $Na_2SO_4 + Ca(OH)_2 + 2H_2O \rightarrow 2NaOH + CaSO_4.2H_2O$ (gypsum)

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Ettringite crystals

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Sulfate Resistance

Bridge columns in North Dakota in sulfate soils

Sulfate Attack Preventive Measures

- Use of appropriate cements
- Utilize low w/cm
- Utilize an appropriate mineral admixture (essential for very severe sulfate environment)

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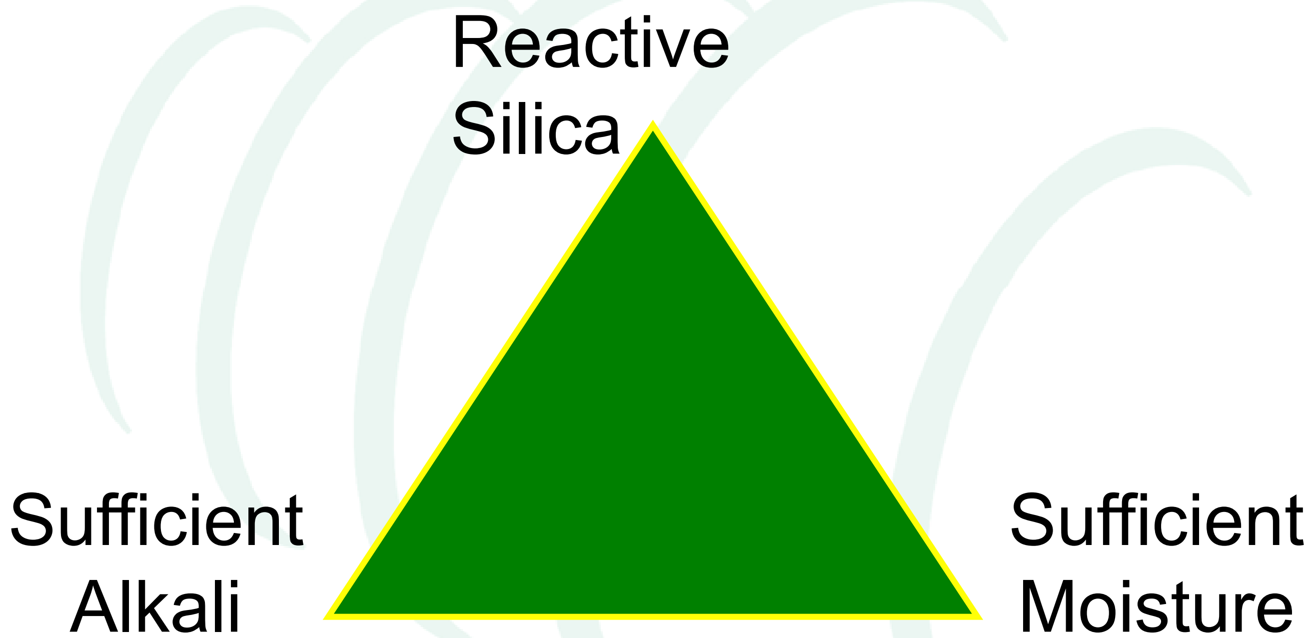
Alkali Aggregate Reactions



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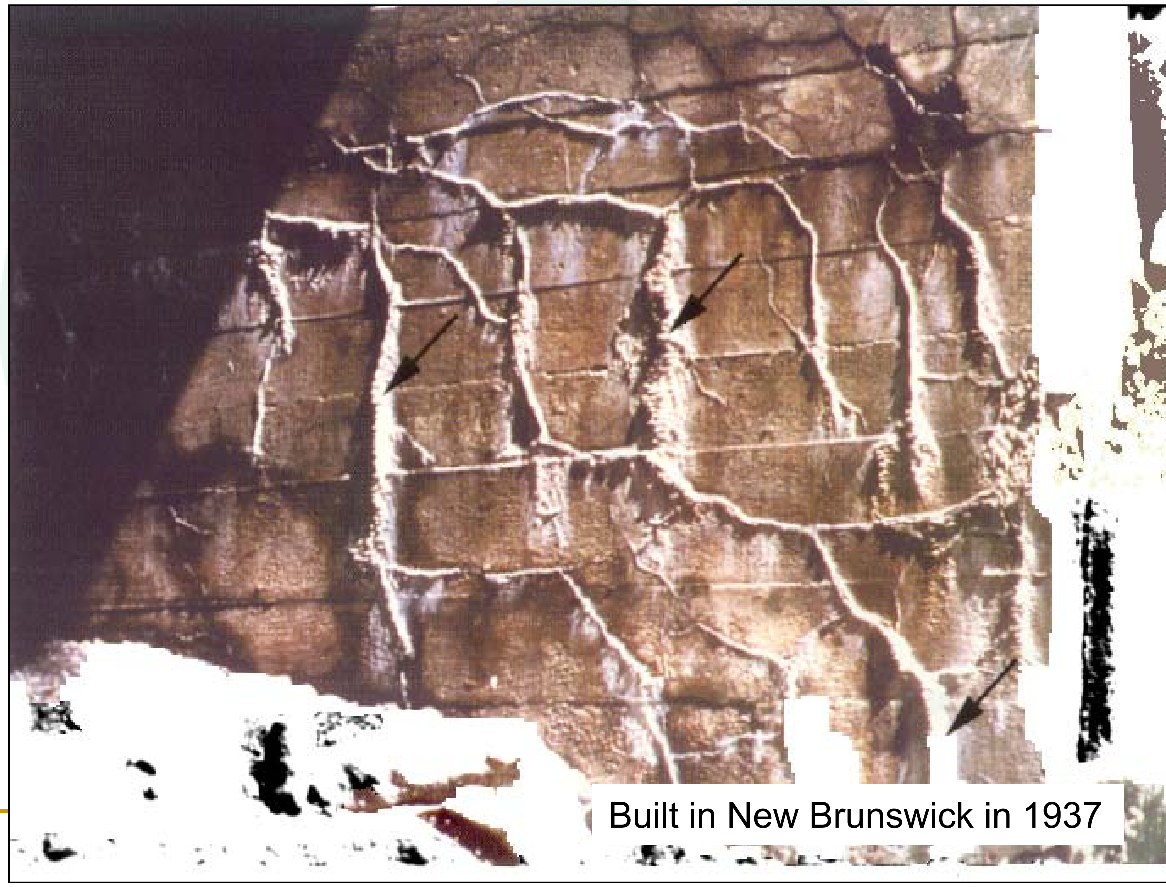
ASR map cracking / leaching on a bridge abutment



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ASTM tests for ASR

- C 295 (petrographic analysis of aggregate)
  - indicates presence of potentially expansive minerals
- C 289 (quick chemical test for aggregate)
  - not reliable
- **C 1260 - (rapid mortar bar for aggregate)**
  - **Fast – very severe, might fail non-reactive aggregate**
- **C 1293 (concrete prism)**
  - **slow, may be the most reliable test**
- C 227 (mortar bar)
  - may pass potentially reactive aggregate
- C 441 (mortar bar-pyrex to qualify effectiveness of SCM)
  - no standardized limits
- **C 1567 - (rapid mortar bar for SCM)**
  - **Fast, qualifies a cementitious material-aggregate combination**

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ASR Preventative Measures

- Use non-reactive aggregate
- Limit alkali (<0.6% alkali cement) – must not be only solution (migration, deicer appln.)
- Use supplemental cementing materials
- Use suitable chemical admixtures

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Alkali Carbonate Reaction

- Certain carbonate rock (dolomitic)
- Uncommon (IL, IN, IA, MI, MO, NY, SD, VA, TN, WI)
- Mechanism not well understood

- Avoid aggregate or dilute it or use smaller size
- Use very low alkali cement
- Pozzolans not effective

Basic statistical computations

- Average
- Standard Deviation and Coefficient of Variation
- Normal Distributions and properties
- Statistical concepts for mixture overdesign and strength test results
- Applications to quality control

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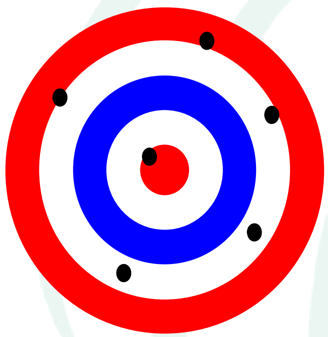
Statistical Concepts



Inaccurate
Variable

Inaccurate
Precise

Accurate
Precise

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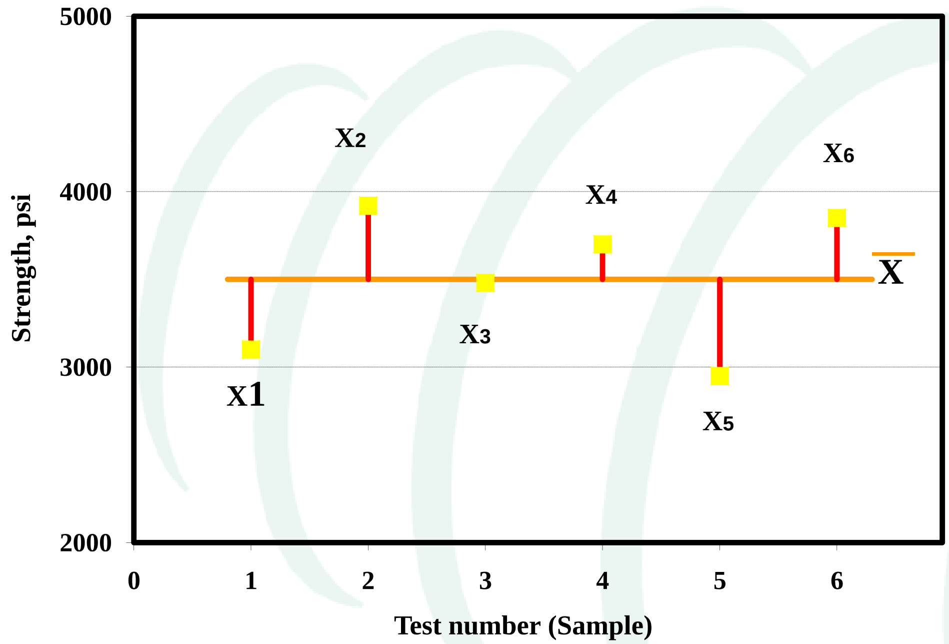
Measure of Variability - Standard Deviation



$$S = \sqrt{\frac{\Sigma (X_i - \overline{X})^2}{(n-1)}}$$

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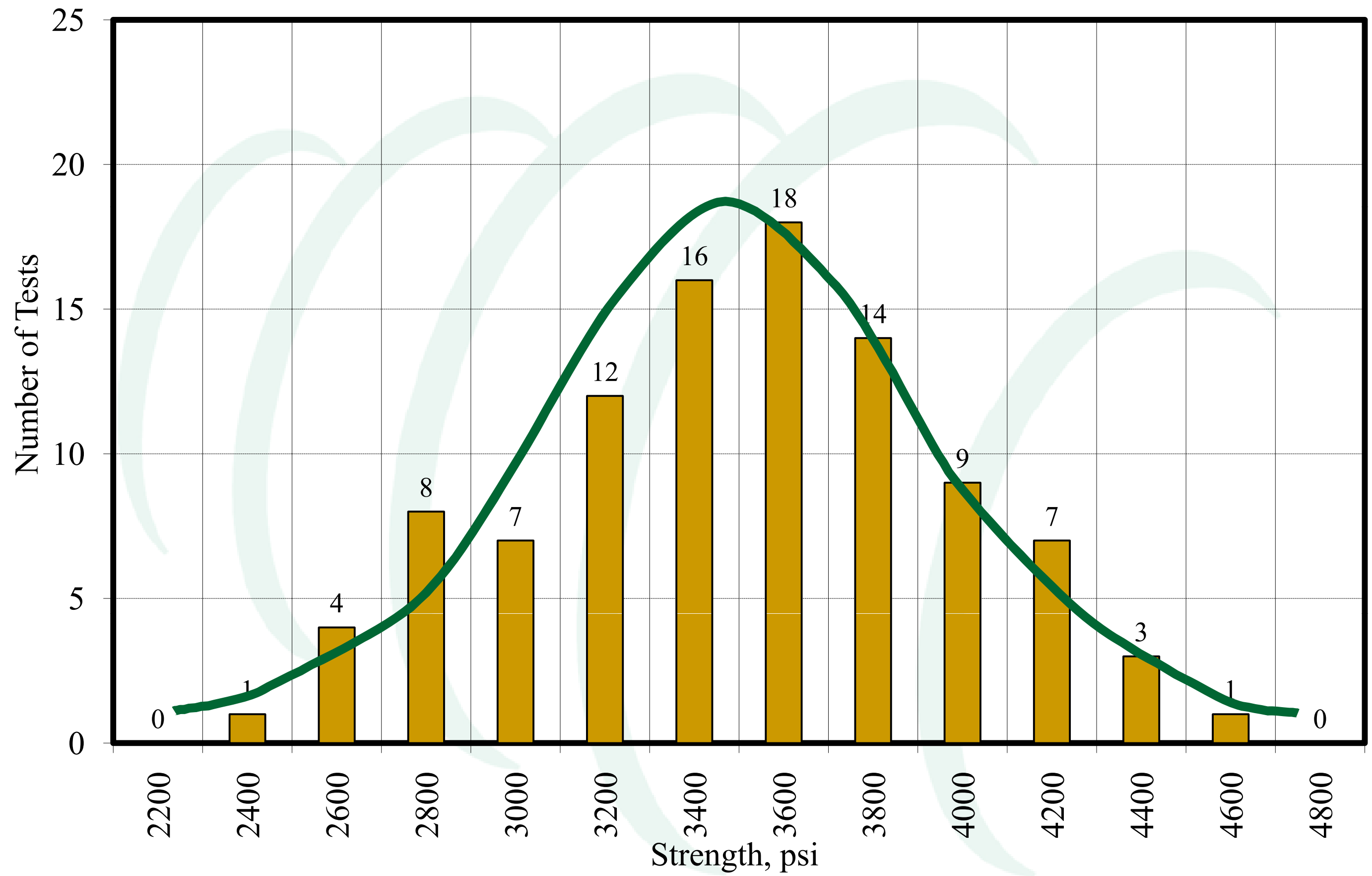
Frequency Distribution



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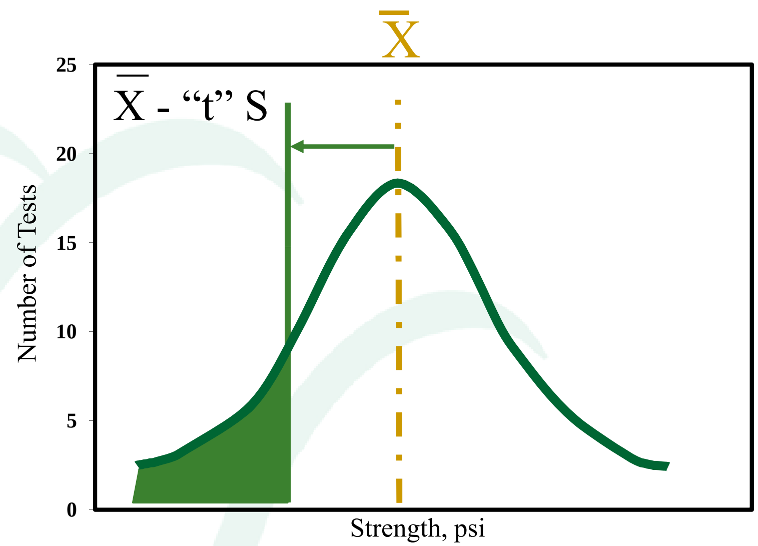
Percentage of Tests Less Than

Table 2

Strength Level	Percent Less than
$\bar{X} - 0.43\ S$	33
$\bar{X} - 0.84\ S$	20
$\bar{X} - 1.00\ S$	16
$\bar{X} - 1.28\ S$	10
$\bar{X} - 1.64\ S$	5
$\bar{X} - 1.96\ S$	2.5
$\bar{X} - 2.00\ S$	2.25
$\bar{X} - 2.33\ S$	1.0
$\bar{X} - 3.00\ S$	0.10



Example

$\bar{X}$ = 4000 psi; S = 350 ps

10% of tests less than? Or

90% of tests greater than?

$\bar{X}$ - 1.28 S

3552

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Strength over-design

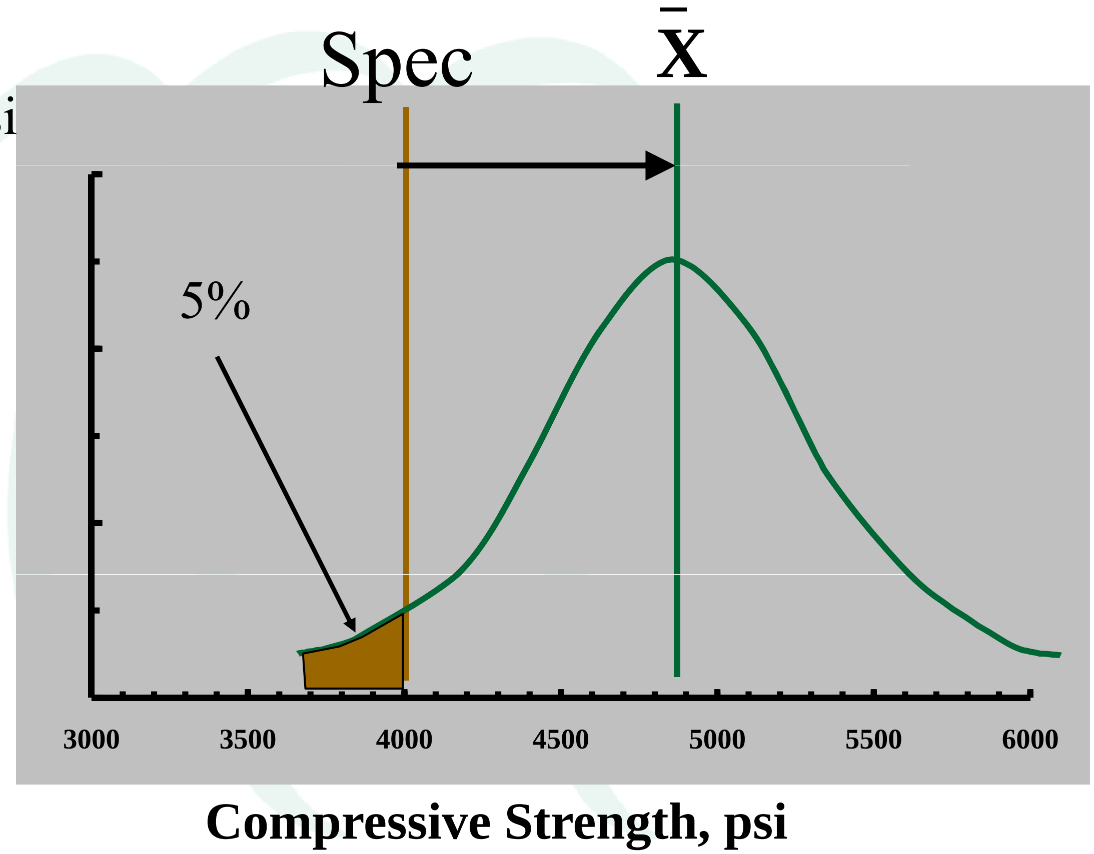
Example

Specified = 4000 psi
Acceptable:
5% less than spec.

$\bar{X}$ = Spec + 1.64 S

S = 550 psi
$\bar{X}$ = 4902 psi

S = 350 psi
$\bar{X}$ = 4574 psi



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Requirements of ACI 318, 301

- Durability Requirements – Exposure Classes
- Strength Overdesign
- Mixture submittals
- Evaluation and acceptance of concrete
- Investigation of low strength results

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Code vs. Specification

- Building Code
  - Minimum requirements for design and construction to protect the public
  - Legally adopted (police power)
- Specification
  - Owner-established requirements for materials and construction
  - Project contract documents

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ACI 301 Specification for Structural Concrete

Core

- Section 1 — General Requirements
- Section 2 — Formwork and Formwork Accessories
- Section 3 — Reinforcement and Reinforcement Supports
- Section 4 — Concrete Mixtures
- Section 5 — Handling, Placing, and Constructing

Additional by option

- Section 6 — Architectural Concrete
- Section 7 — Lightweight Concrete
- Section 8 — Mass Concrete
- Section 9 — Prestressed Concrete
- Section 10 — Shrinkage Compensating Concrete

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Step 2 (a) Calculate Average Strength, f'_{cr}

Example
$f'_c = 4000$ psi
$S = 400$ psi

Equation 5-1

$$f'_{cr} = f'_c + 1.34\ S$$

$$f'_{cr} = 4000 + 1.34 \times 400 = 4536 \text{ psi}$$

Equation 5-2

$$f'_{cr} = f'_c + 2.33\ S - 500$$

$$f'_{cr} = 4000 + 2.33 \times 400 - 500 = 4432 \text{ psi}$$

Use the higher value

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Step 3 Mix Design and Submittal

Furnish data showing mix design will obtain required average strength, f'_{cr}

- Field Tests between 10 and 30 tests
- Can use same data used for calculating S

- Laboratory Trial Batches
- Three point curve
- Water-cement ratio
- Cement content

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ACI 318-08 Acceptance

During the Job - Should meet both criteria

$f'_{cr} = f'_c + 1.34\ S$

1. Average of 3 consecutive $\geq f'_c$

$2.33/\sqrt{3} = 1.34$

2. Single test $\geq (f'_c - 500)$

For f'_c > 5000 psi – Single test $\geq 0.9f'_c$

$f'_{cr} = f'_c + 2.33\ S - 500$
1% chance of failure

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ACI 318-08 Exposure Classes

- Category F
  - Exposure to freezing and thawing cycles
- Category S
  - Exposure to water-soluble sulfates
- Category P
  - Conditions that require low permeability concrete
- Category C
  - Conditions that require additional corrosion protection of reinforcement

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Exposed to water-soluble sulfates

Exposure Category S – Exposure to water-soluble sulfates			
Class	**Description**	**Water-soluble sulfate (SO_4) in Soil, percent by weight**	**Sulfate (SO_4) in Water, ppm**
S0	Negligible	$SO_4 < 0.10$	$SO_4 < 150$
S1	Moderate	$0.10 \leq SO_4 < 0.20$	$150 \leq SO_4 < 1500$ Seawater
S2	Severe	$0.20 \leq SO_4 < 2.00$	$1500 \leq SO_4 < 10{,}000$
S3	Very severe	$SO_4 > 2.00$	$SO_4 > 10{,}000$

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Requirements for Concrete - Exposure Class S

Exposure Class	Max w/cm	Min f'_c psi	Cementitious Materials - Types			Additional Requirement
			C 150	C 595	C 1157	
S0	-	2500	-	-	-	
S1	0.50	4000	II	IP(MS), IS(<70)(MS)	MS	
S2	0.45	4500	V	IP (HS) IS(<70)(HS)	HS	No calcium chloride admixtures
S3	0.45	4500	V + pozz or slag	IP (HS) IS(<70)(HS) + pozz or slag	HS + pozz or slag	No calcium chloride admixtures

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Overview of Fresh Concrete Tests

- Sampling;
- Slump;
- Unit Weight (density),
- Air Content;
- Temperature;
- Making and Curing Cylinders

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Testing Hardened Concrete

- Compressive and flexural strength tests
- Factors affecting strength
- Precision of strength tests
- Core testing
- Nondestructive testing

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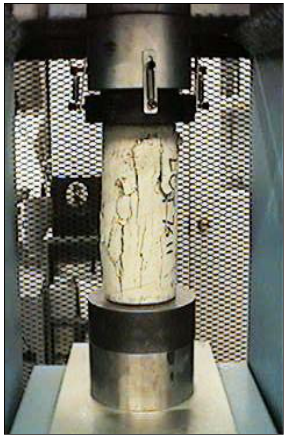
Analysis of Test Report

- Tabulate the test reports in the order of date made
- Date of pour
- Ambient temperature
- 7 & 28 day strengths
- Slump, air content and temperature
- Duration of initial curing



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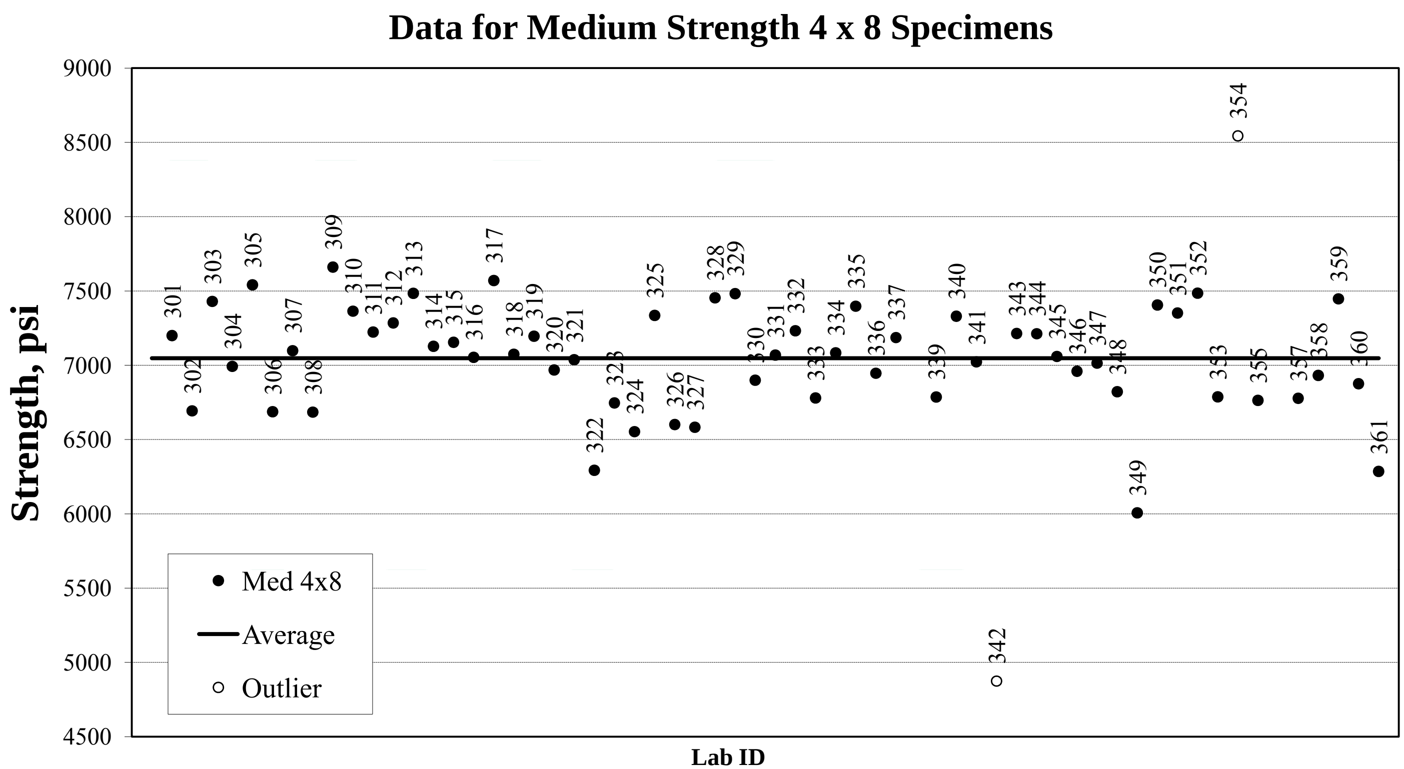
Strength Round Robin Testing



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Sampling Concrete ASTM C 172

Pay Attention to:

- How the sample was taken
- Sample Container
- Segregation / Re-mixing
- Delays in Sampling
- Loss of air / Sampling from a Pump

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ASTM C 31 Compressive Strength

- Specimens made in accordance with C31 or C192
- Made in 3 layer when rodded, 2 layers when vibrated
- Standard size, 6” x 12” or 4”x8”
- Curing depends on how the compressive strength data is used
- Standard Curing
- Field Curing

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Effects of Initial Curing

Variables:

- Ambient Temperature 60-80°F
- Prevent Moisture Loss
- Immersed in Limewater

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Grinding Cylinders – High Strength

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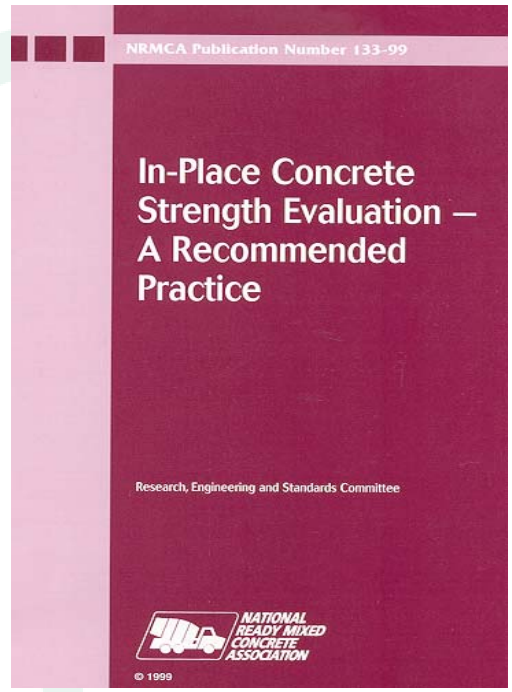
What if you have Low Test Results?

NRMCA Pub 133:

- Was cylinder tested properly
- Is f'_c needed for the structure
- Try non-destructive testing
- Try core tests
- Try load testing
- Corrective Measures



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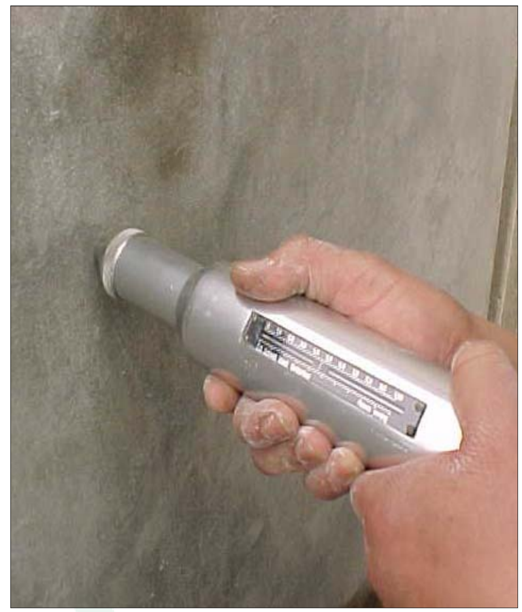
Rebound Hammer ASTM C 805

- It is not a substitute for compressive strength !!!!
- Variables
  - Moisture
  - Hardness of Surface
  - Smoothness of the surface
  - Corrective Measures
  - Aggregate Type



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Windsor Probe ASTM C 803

- It is not a substitute for compressive strength !!!!
- Variables
  - Different Probes for Lightweight
  - Moisture
  - Hardness of Surface
  - Smoothness of the surface
  - Mohs Hardness of Aggregate

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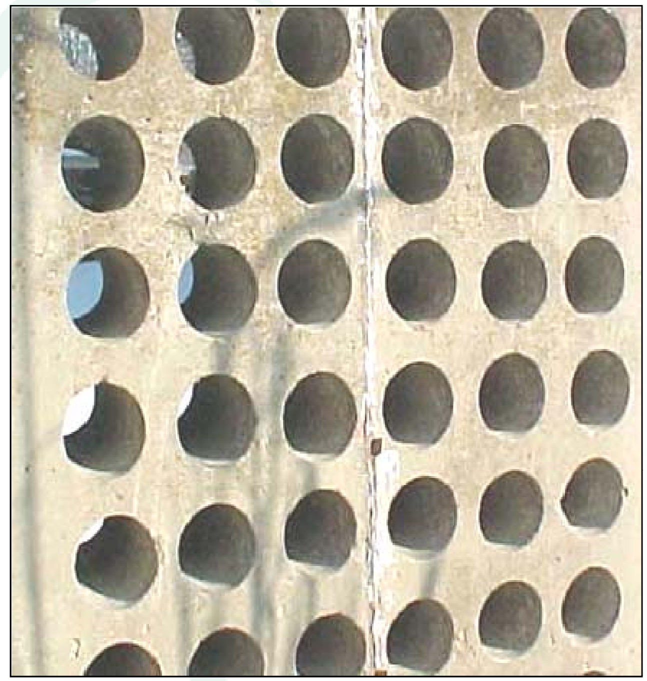
Concrete Core Testing

ASTM C 42 Obtaining and Testing Drilled Cores

- Do you really need to
- core the structure ?
  - When ?
  - Where ?
  - How Many ?



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Quality Control Procedures

- Review of quality control program
- Material Handling and Storage
- Quality control monitoring - charts

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Definitions

- Quality control. Actions taken by a producer or contractor to provide control over what is being done and what is being provided so that the applicable standards of good practice for the work are followed.

- Quality assurance. Actions taken by an owner or his representative to provide assurance that what is being done and what is being provided are in accordance with the applicable standards of good practice for the work.

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Scope of QC activities

- Sampling and testing
  - Concrete materials
  - Concrete
- Plant and field control of concrete production
- Evaluation and procurement of new equipment and tools to improve quality
- Specification review
- Concrete mixture optimization
- Research and development
  - Optimization
  - Innovation
- Evaluation of concrete performance
- Failure analysis and prevention

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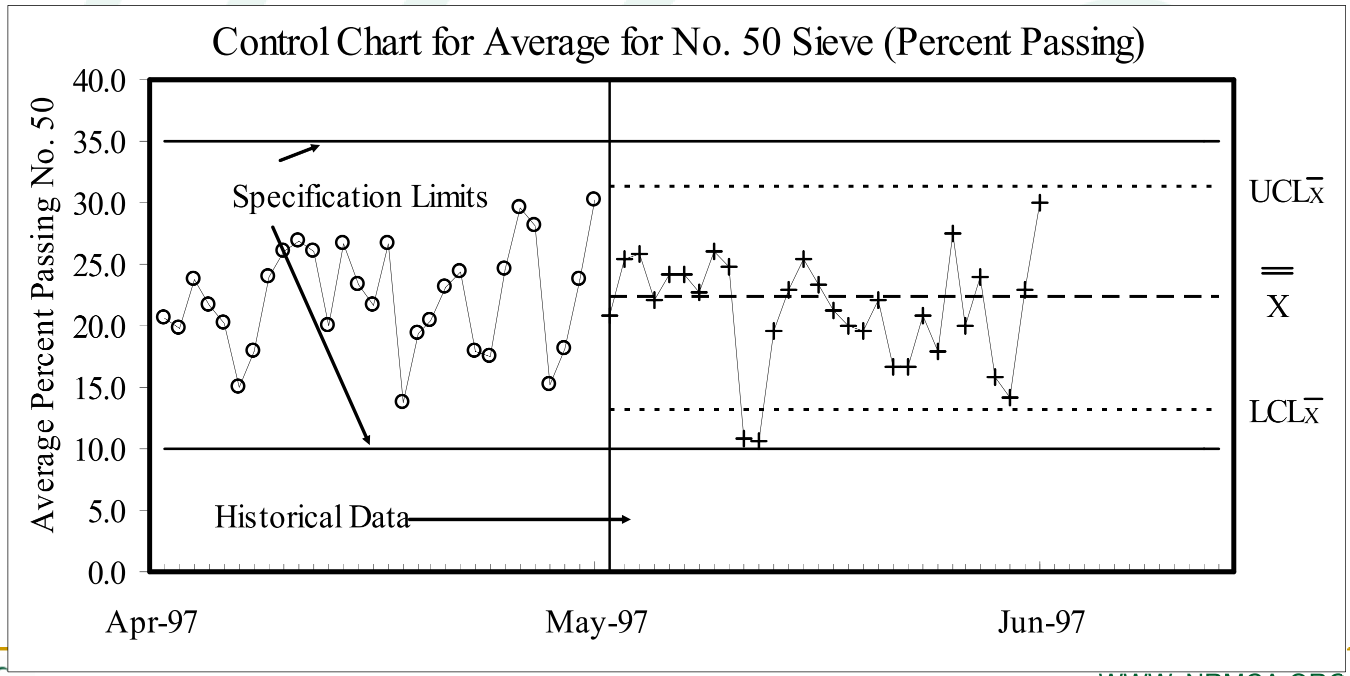
Control Charts

- Visual Check
- Establish points for corrective action



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Material Storage and Handling

- Aggregates

Unloading, stockpiling, and moving without segregation

Sizes stored in separate bins

Sizes separated to avoid contamination

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Plant control of concrete production

- Maintenance
  - Batch plant equipment
  - Truck mixers
- Replacement schedule
- Calibration of scales and volumetric devices
  - Frequency
  - Evaluation of batching accuracy
- Plant and truck mixer certification
- Selection and investment in new equipment

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Concrete mixture optimization

- Specification criteria and on-going historical data
- Periodic review of mix performance - statistical
- Broad range water/cement ratio relationship for basic mixes, with and without fly ash
- Quantifying the efficiency (strength or otherwise) of supplementary cementitious materials
- Evaluate new mixes - trial lab or field batches to confirm performance
- Mixtures for high performance
  - Self consolidating concrete
  - Low permeability
  - Shrinkage

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Quality Assurance

- Submittals
- Mixtures and construction procedures will comply with contract documents
- Test records
  - Past records
  - Trial batches
- Prequalification tests of materials and concrete
  - Performance based
- Request variance from specification requirements

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Handling, Placing; Finishing and Curing concrete

- Site Preparation
- Placement Methods
- Finishing Procedures
- Curing

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Dampen Subgrade

- Dampen when there is danger of plastic shrinkage cracking
- No ponding or standing water

ACI 302 now recommends that the sub-grade normally be dry

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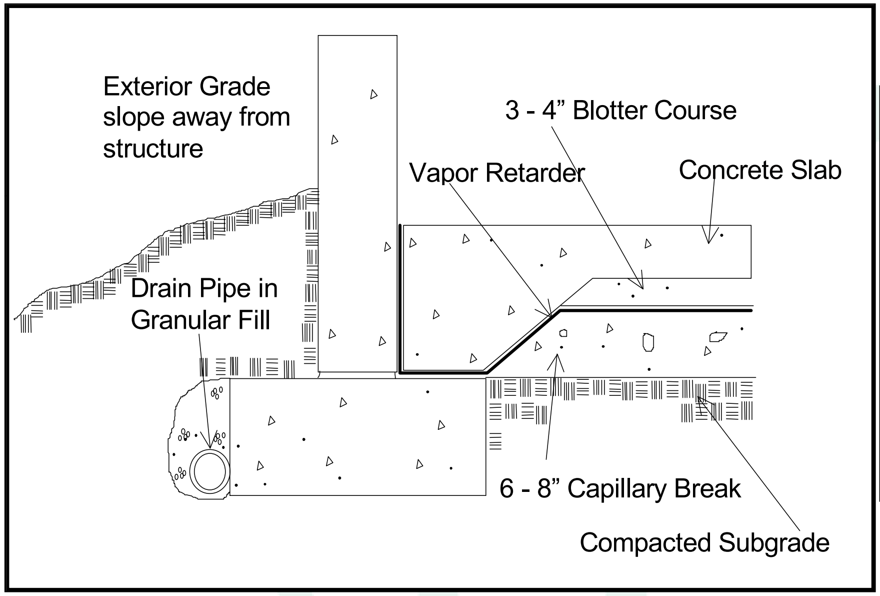
Vapor Retarders/Barriers



- Vapor retarders when floor covering installation is anticipated – directly under slab

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Placing Concrete

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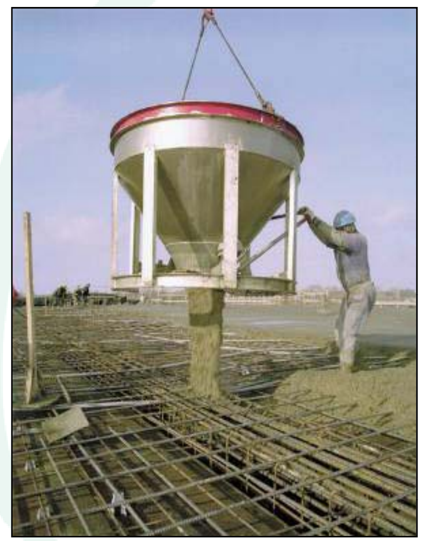
Cranes and Buckets

- Above ground placements
- Clean discharge.
- Bucket capacity - compatible with delivered load and placement capacity



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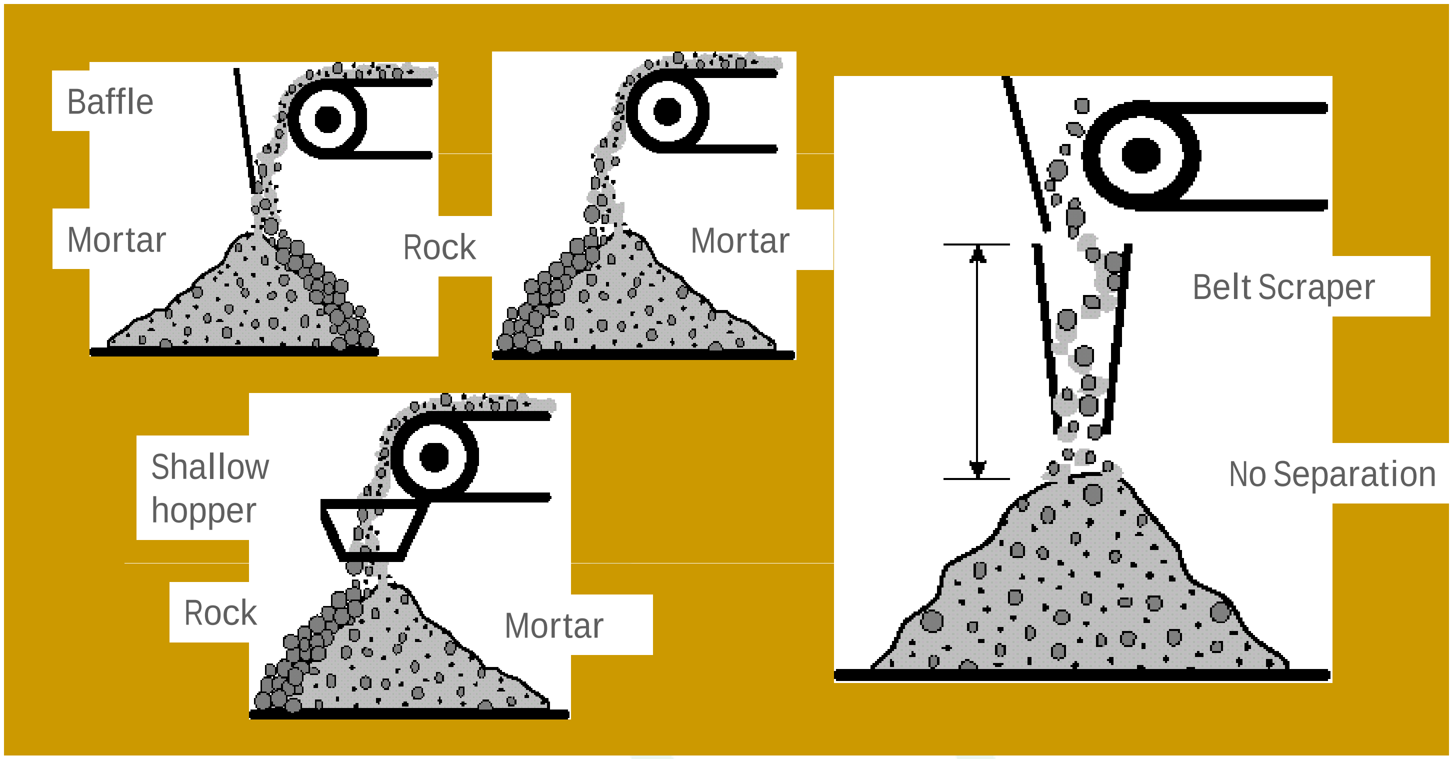
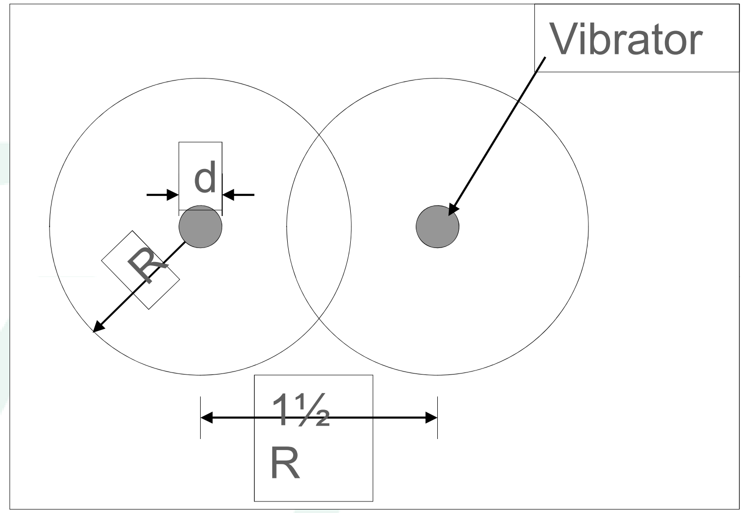
Avoid Segregation



Vibration

Radius of Action



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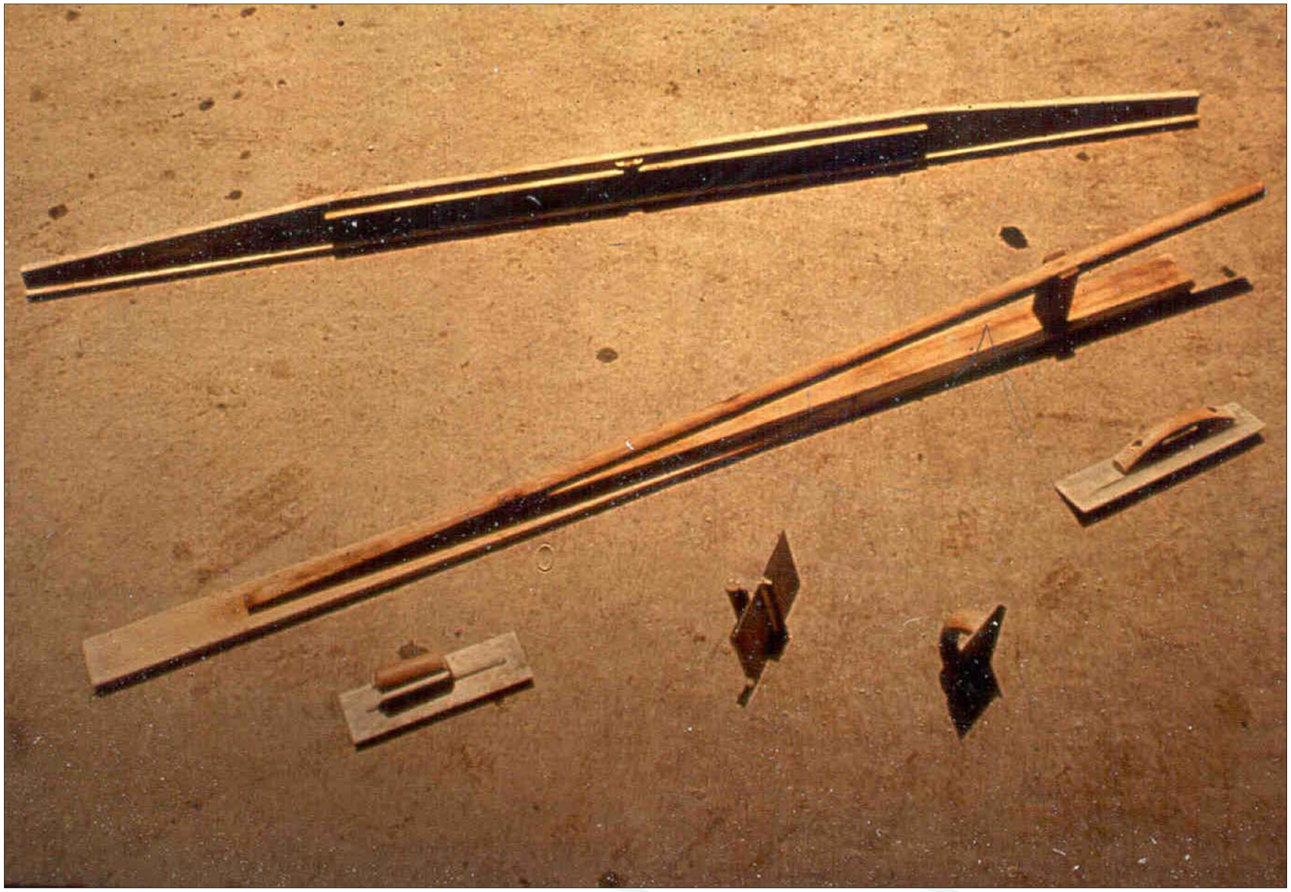
Concrete Finishing Tools



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Bullfloating

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Machine Troweling

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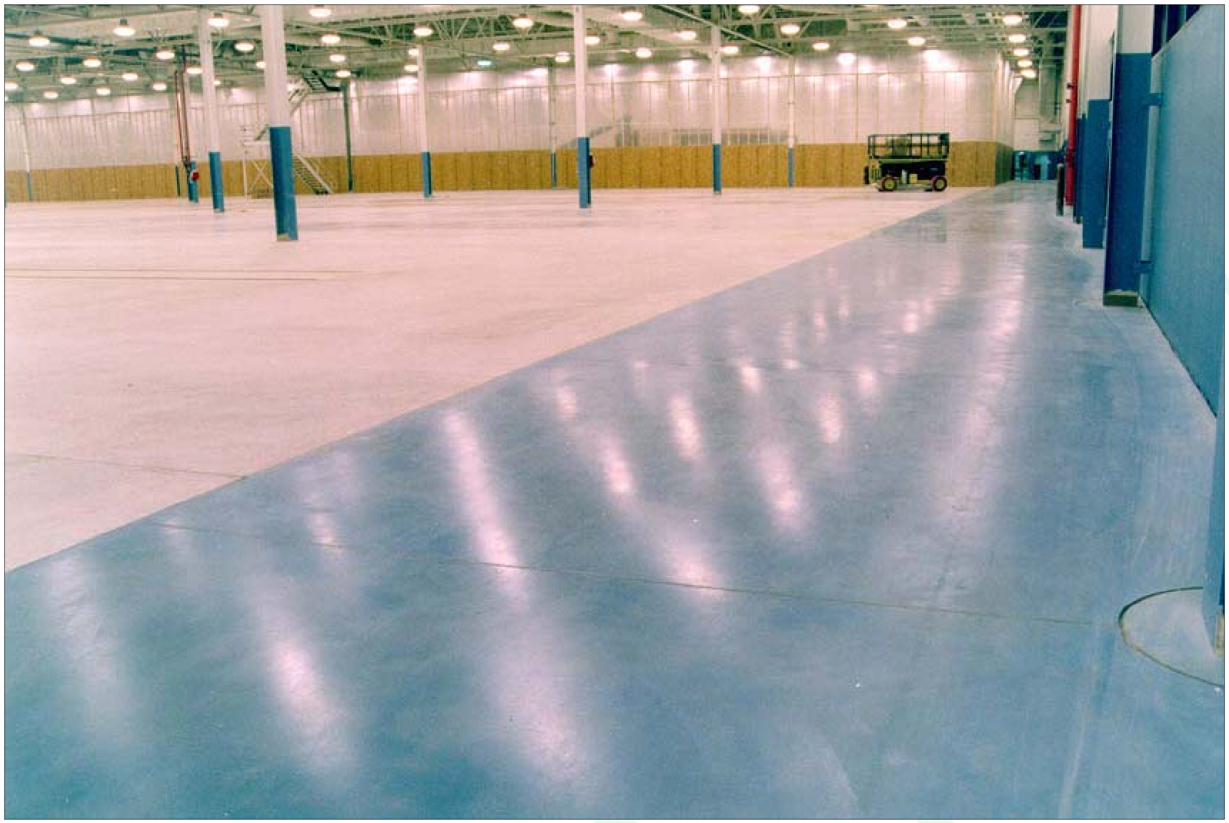
Super-flat Industrial Floor



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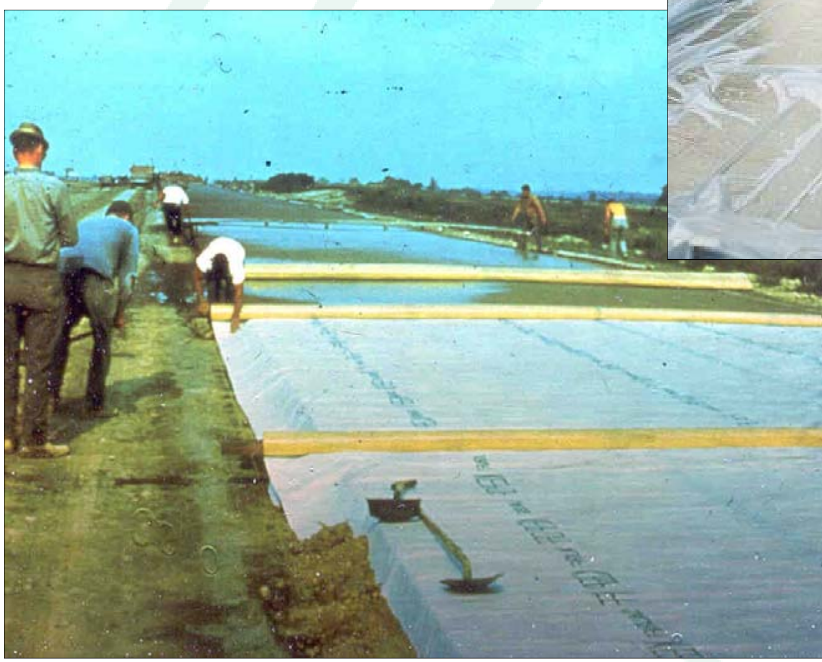
Curing Paper / Plastic Sheets



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Concrete in Extreme Weather

- Conditions and affects on concrete
- Estimating concrete temperature
- Plastic shrinkage cracking
- Delivery and jobsite precautions

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Hot weather concreting problems….

- Increased plastic shrinkage
- Handling, compacting and finishing difficulties
- Controlling air content
- Cement-admixture interactions like very delayed setting times, poor strengths
  - SO_3 – C_3A imbalance slows C_3S hydration

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Control of Temperature

- Is there a temperature limit?
- For reducing 1^0 F concrete temperature reduce:
  - Cement by 9^0 F
  - Aggregates by 1.6^0 F
  - Water by 4^0 F

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Control of temperature ….

- Cool the water
  - Chiller – 10^0 F; Ice – 20^0 F; Liquid nitrogen – 20^0 F+

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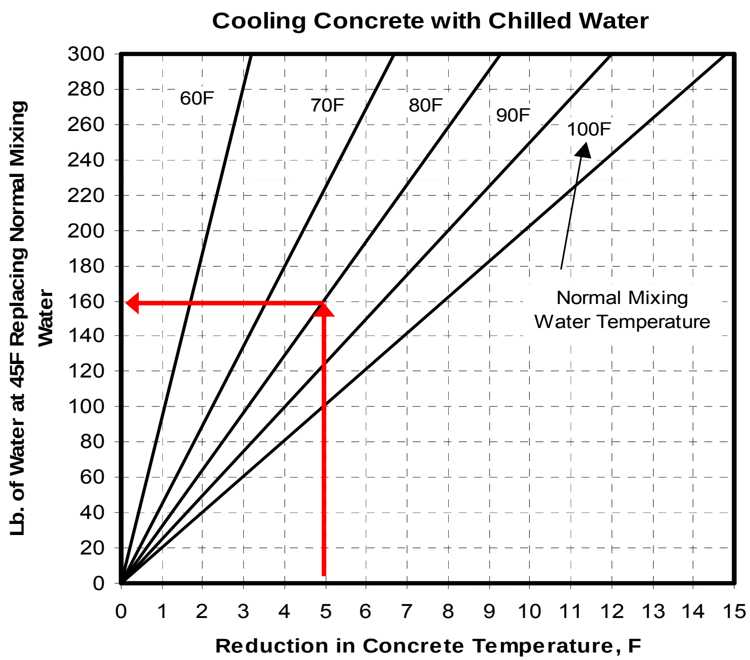
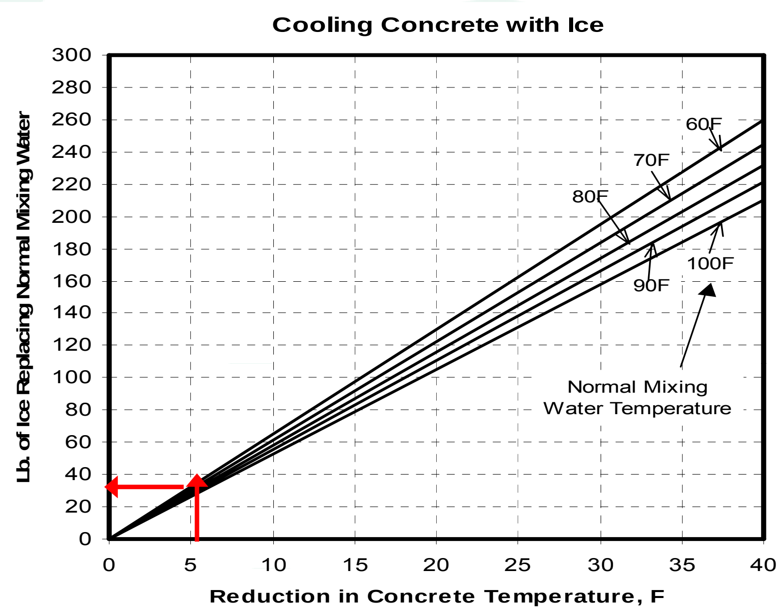
Effect of chilled water (45 F) and ice





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Control of temperature ….Liquid Nitrogen

Hoover Dam By-pass

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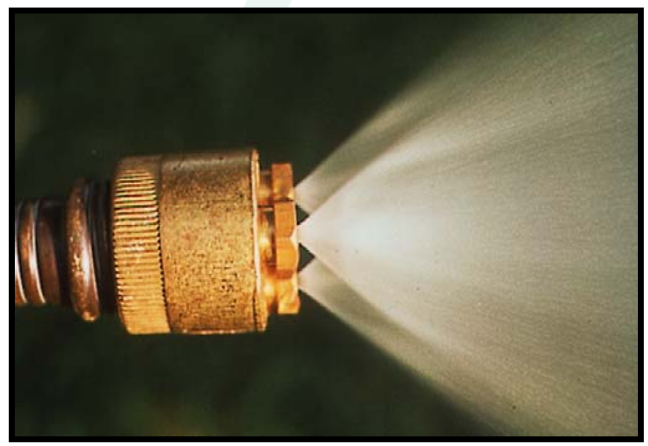
Minimize Plastic Shrinkage Cracking

- Provide proper equipment and man power
- Fogging and Misting or evaporation retardants
- Use vapor barriers under slabs, dampen sub-grade
- Set up wind barriers
- Use synthetic fibers
- Accelerate set time



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Troubleshooting Concrete

- Causes and Prevention
  - Surface defects
  - Cracking
  - Strength
  - Discoloration

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Can we correct a problem?

Depends when we see it

- Concrete in the truck – return it
- Fresh concrete - maybe
  - Correct the next batch
  - Dig it out
- Hardened concrete – probably not
  - Fill cracks
  - Repair surfaces
  - Retrofit
  - Remove

First find the cause!!!!!!!

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Reasons for troubleshooting problems

- Fresh properties
  - Too stiff / wet / variable between loads
  - Placement method – loss of air, etc.
  - Setting time
- Workmanship
  - Construction tolerances
  - Surface finish
- Tensile stresses exceed strength
  - Cracking
- Deterioration
  - Chemical attack
  - Physical distress

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Strength Problems

- Ensure proper testing
  - Certified technicians
  - Proper initial curing
  - Specimen Care

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Cracking

Joint pattern

Timing the cut
Joint depth

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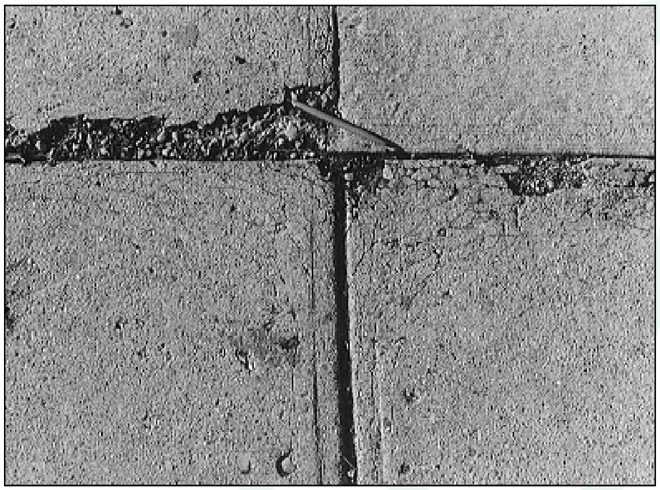
Cracking – Later Age



Freeze-Thaw

Internal Expansion
Chemical or Physical

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Surface Defects – bug holes

Results from Improper Consolidation
Concrete mixture too stiff during placement

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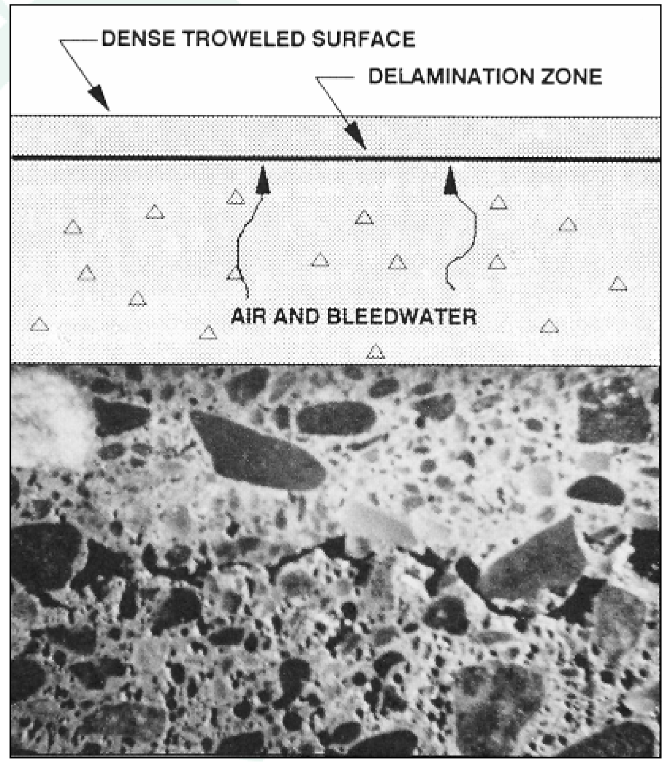
Delamination



- Improper Finishing - timing
- Hard Troweled Finishes

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Dusting

- Unvented heaters
- Water on surface during finishing
- Weak surface

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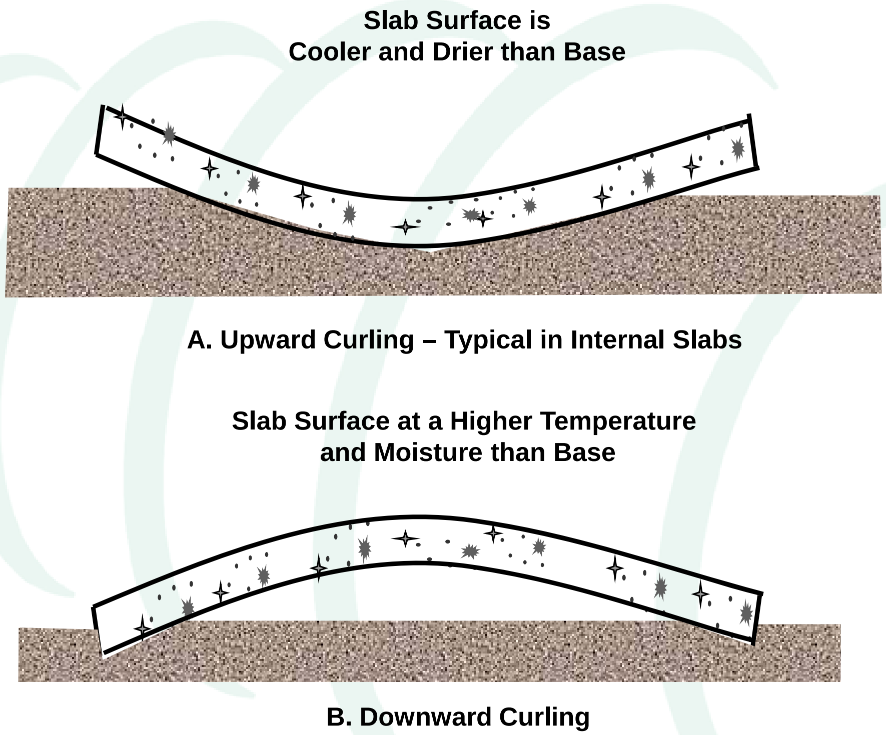
CIP 1

Curling



Differential drying shrinkage or temperature

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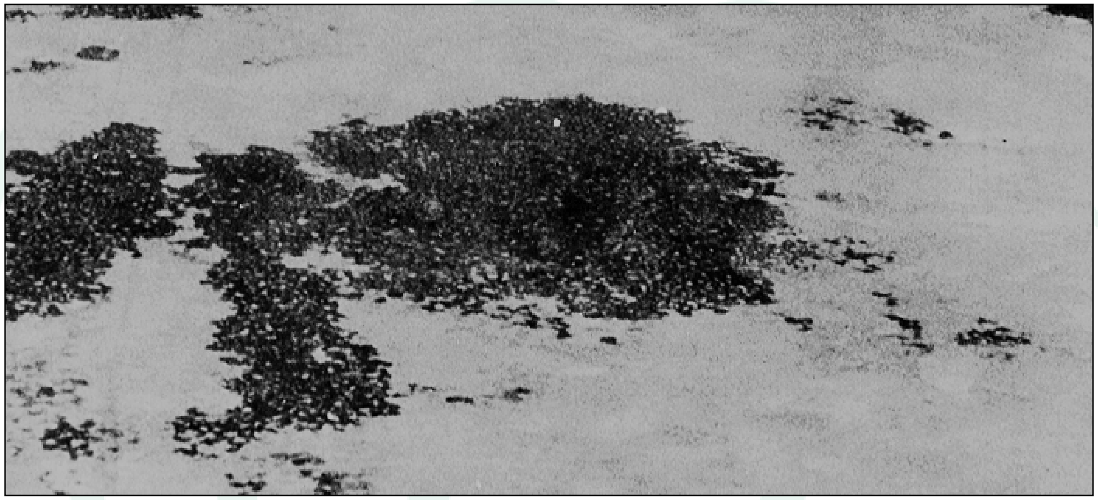
Discoloration



- Improper timing and finishing
- Calcium Chloride
- Hard Trowelled finishes
- Slag Concrete
- Polyethylene burns

CIP 23

Concrete Technologist Middle East (CTME) Certification

A NRMCA Certification Program

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