Precast 101

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National Precast Concrete Association

History

- **Pyramids**
- ~2600 BC onward
- Egypt and Sudan

- **Aqueducts**
- 312 BC onward
- Italy

History

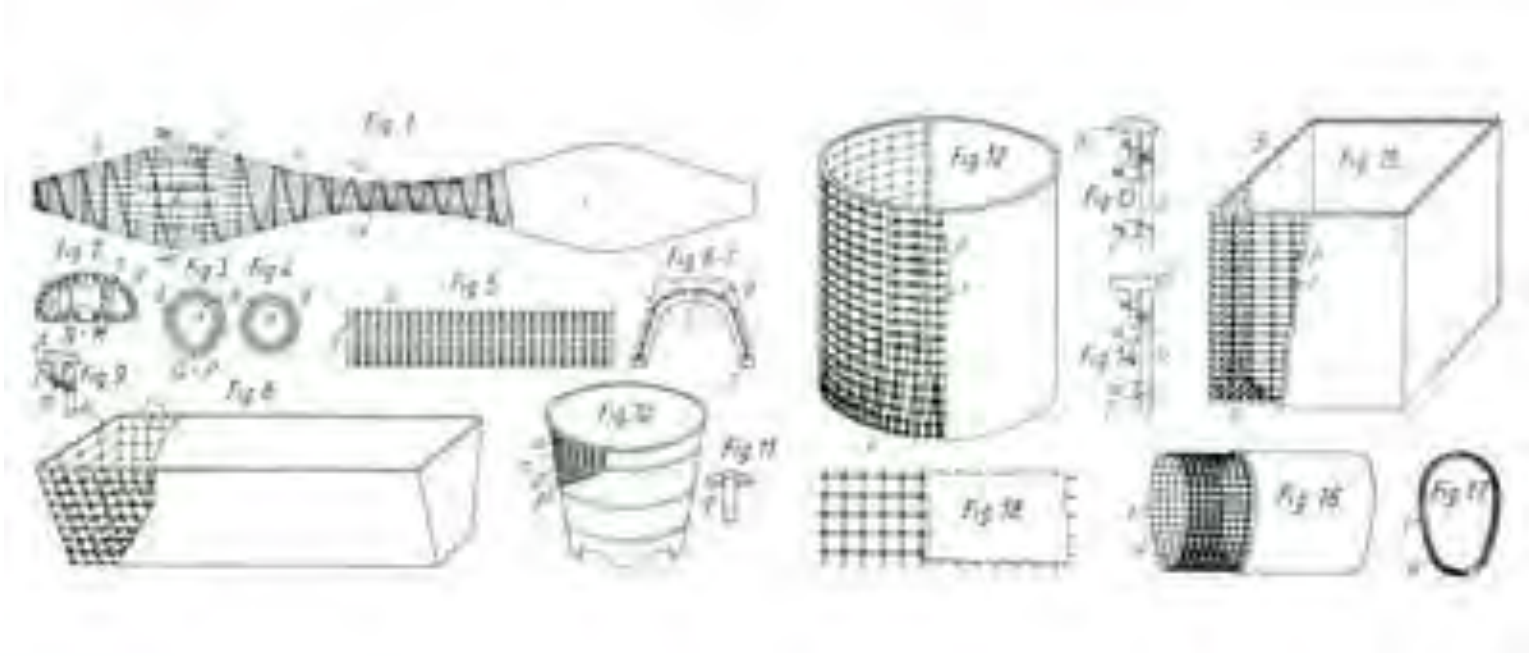
- **Pantheon**
- 125 AD
- Italy

History

French gardener Joseph Monier

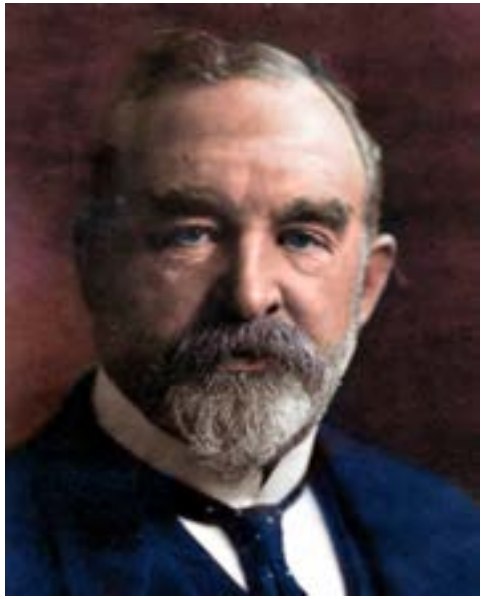
Incorporating reinforcing

in his concrete pots,



Precast Concrete

John Brodie



Session Overview

1. What is precast concrete?
2. Concrete raw materials
3. Types of concrete used in precast
4. Precast production process and plant equipment
5. Curing concrete
6. Concrete design, strength, and reinforcement
7. Prestressing
8. QA/QC and concrete testing
9. Plant safety

What is Concrete?

What is Concrete?

A hard building material made by mixing:

cement

water

gravel

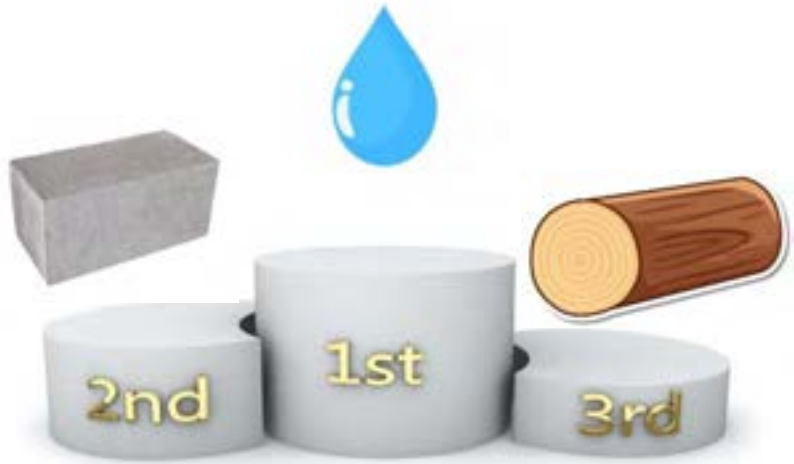
sand

What is Concrete?

Composite material made of natural ingredients, manufactured materials, and industrial byproducts

How Much Concrete Do We Use?

Rank	Material	Estimated yearly amount in US tons
#1:	Water	9,000,000,000,000
#2:	Concrete	30,000,000,000
#3:	Wood	6,600,000,000
#4:	Steel	2,090,000,000
#5:	Plastics	380,000,000



What is Precast Concrete?

CAST-IN-PLACE CONCRETE MANUFACTURING

PRECAST CONCRETE MANUFACTURING

PRECAST SHOW

What is Precast Concrete?

CAST-IN-PLACE (CIP) CONCRETE DELIVERY

PRECAST CONCRETE DELIVERY

What is Precast Concrete?

CAST-IN-PLACE CONCRETE INSTALLATION

PRECAST CONCRETE INSTALLATION

Ready-Mix / Cast-in-Place Jobsite

Precast Concrete Production Plant

What is Precast Concrete?

FRESH CAST-IN-PLACE CONCRETE

FRESH PRECAST CONCRETE

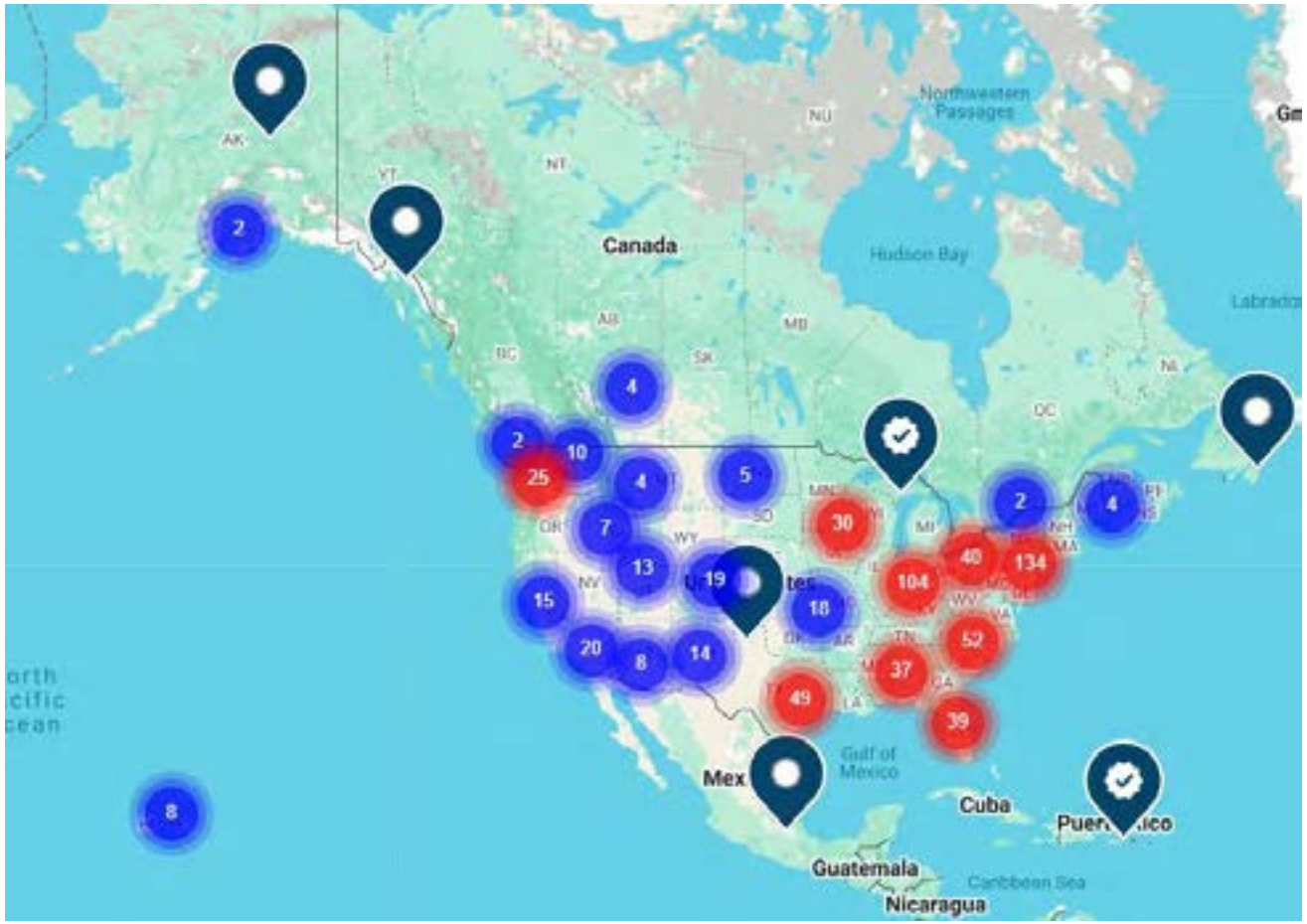
What is precast concrete?

- Precast concrete: concrete cast elsewhere than its final location and cured in a controlled environment

Precast Concrete Jobsites

Precast Concrete Jobsites

Precast Concrete Industry



- 670+ NPCA precast producer members
  - Note: This does NOT account for every precast production plant! Not even close.

Why precast concrete?

- Strength
- Durability
- Optimization
- Long service life
- Economy
- Ease of installation
- Modularity
- Accelerated schedules
- Safety
- Versatility, flexibility, and innovation
- Precise manufacturing
- Local availability
- Reliable supply chain
- Resilience
- Sustainability
- Resilience

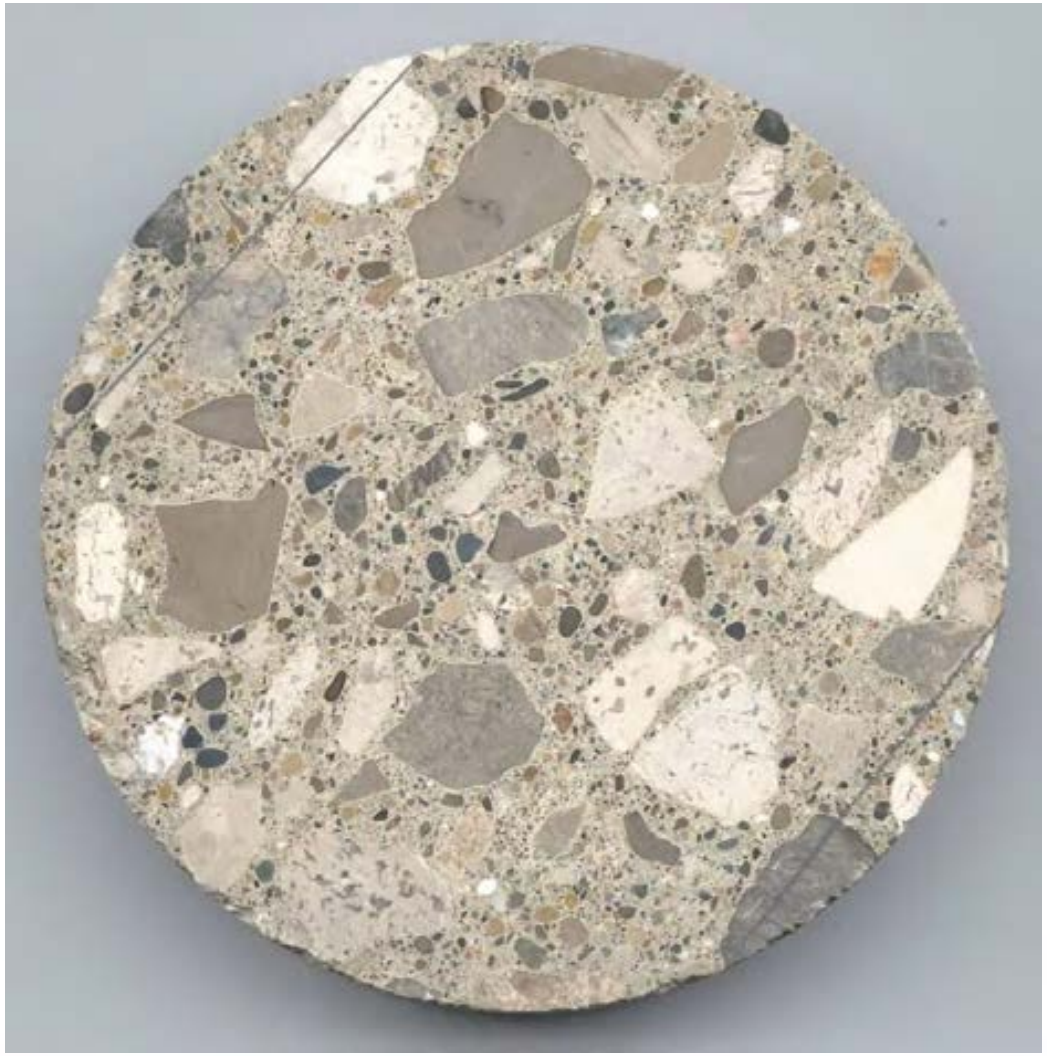
Concrete Raw Materials

- Cement
- Water
- Supplementary cementitious materials (SCMs)
- Admixtures
- Coarse aggregate
- Fine aggregate

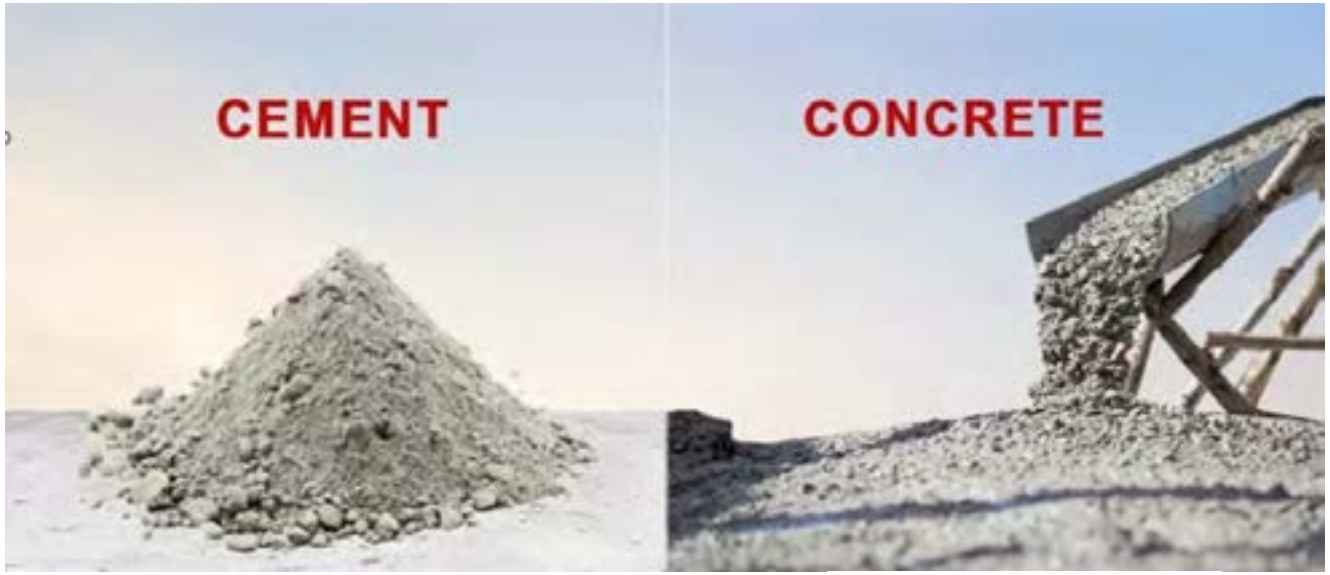
Concrete Raw Materials

- **Paste (binder):**
  - Cement
  - Water
  - Supplementary cementitious materials (SCMs)
  - Admixtures

- **Aggregates (“filler”):**
  - Coarse aggregates
  - Fine aggregates



Cement vs Concrete



Cement

- Cement is a dry powder that chemically reacts with water, hardens, and adheres to other materials to bind them together
  - Also called **portland cement**


PARAGON
BUILDING PRODUCTS
PORTLAND CEMENT
TYPE I-II-V
LOW ALKALI SULFATE RESISTANT
NET WT. 94 LBS. (42.64 kg)
ONE CU FT.
LAFARGE
TYPE I & II
REGULAR
PORTLAND
CEMENT
94 LBS./42.6 KG.
MOISTURE RESISTANT BAG
PORTLAND CEMENT
Cemento Portland Tipo I
COMMERCIAL GRADE
QUIKRETE
TYPE I
LEHIGH
HEIDELBERGCEMENT Group
PORTLAND
CEMENT
TYPE I-II

Portland Cement Origins

- **Joseph Aspdin**
- 1778-1855
- 1824 patent: “an improvement in the mode of producing an artificial stone”

Portland Cement Primary Ingredients

Limestone

Clay

Silica

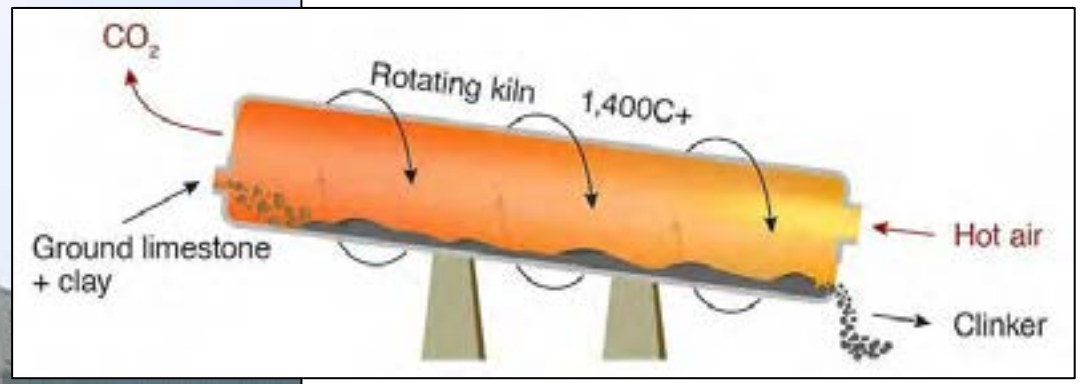
- The proportions of each of these materials in the cement determines how the cement will perform

Portland Cement - Hydraulic

It reacts with water to form a paste.

Portland Cement Production

Kiln



Clinker

Portland Cement Production

Clinker

Gypsum

Traditional Cement Types

Type I: For general use

Type II: For general use or when moderate sulfate resistance is desired

Type III: For use when high early-age strength is desired

Type IV: For use when a low heat of hydration is desired (not readily available today)

Type V: For use when high sulfate resistance is desired

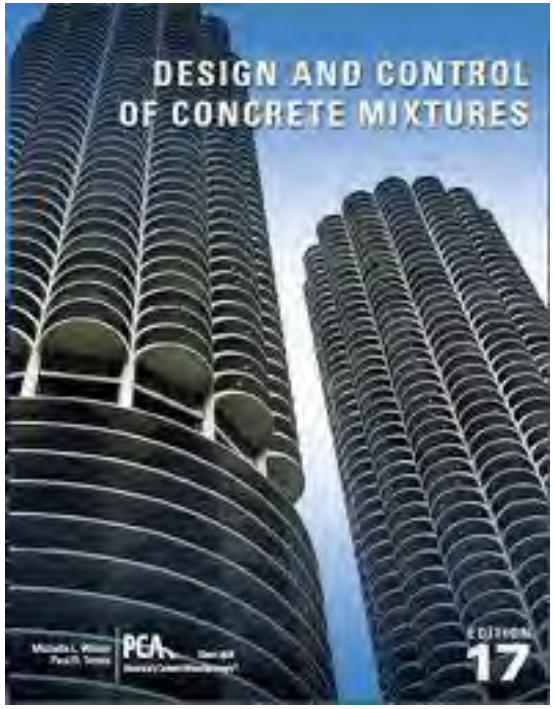
These cements conform to specification ASTM C150

Cement Types

- Type IL: Limestone cement or PLC. Can be used as Type I or Type II in most applications
- Type IP, IS, IT: Blended cements

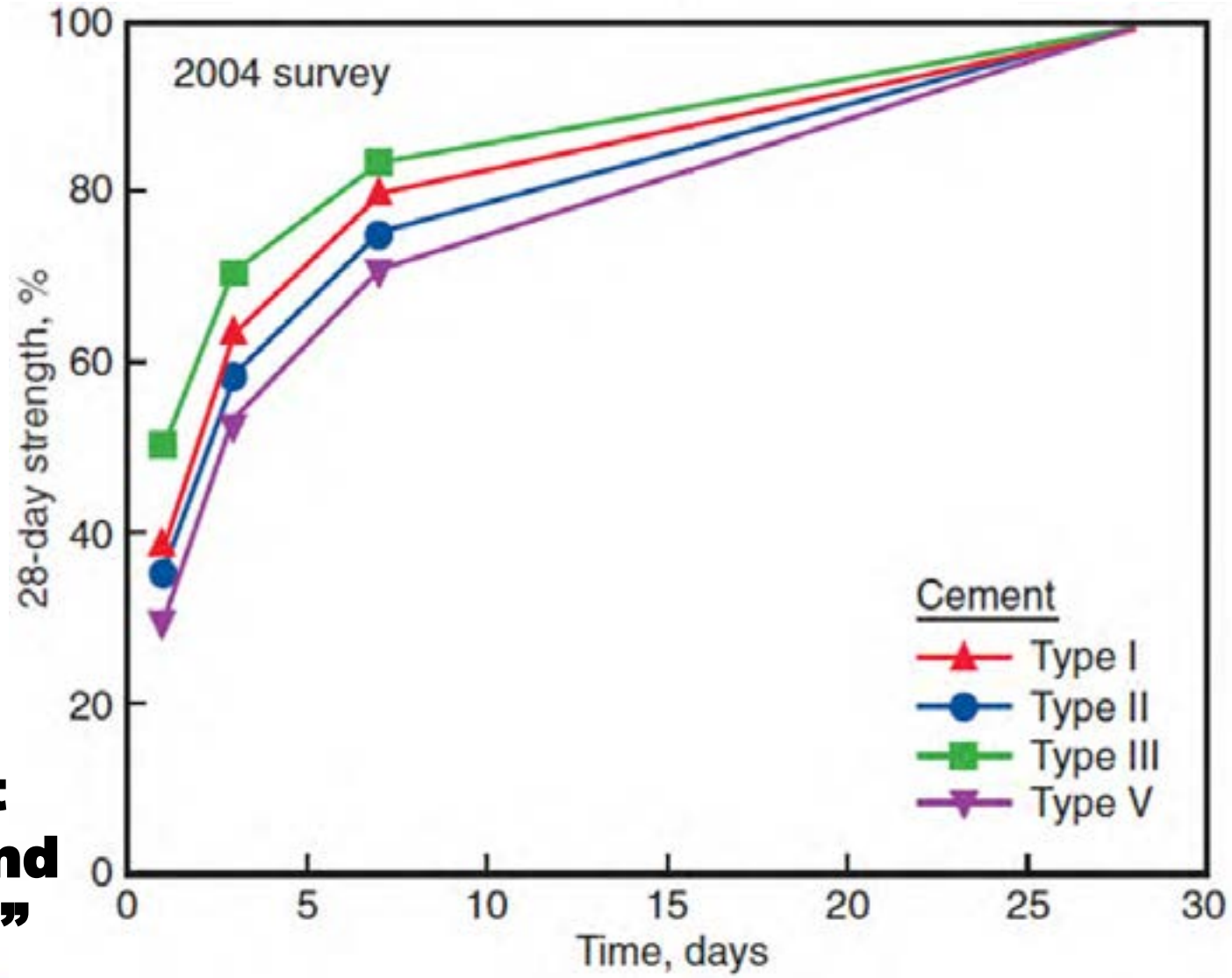
These cements conform to specification ASTM C595

Cement Types



Graph from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

Figure 3-33. Relative strength development of portland cement mortar cubes as a percentage of 28-day strength. Mean values adapted from Bhatty and Tennis (2008).



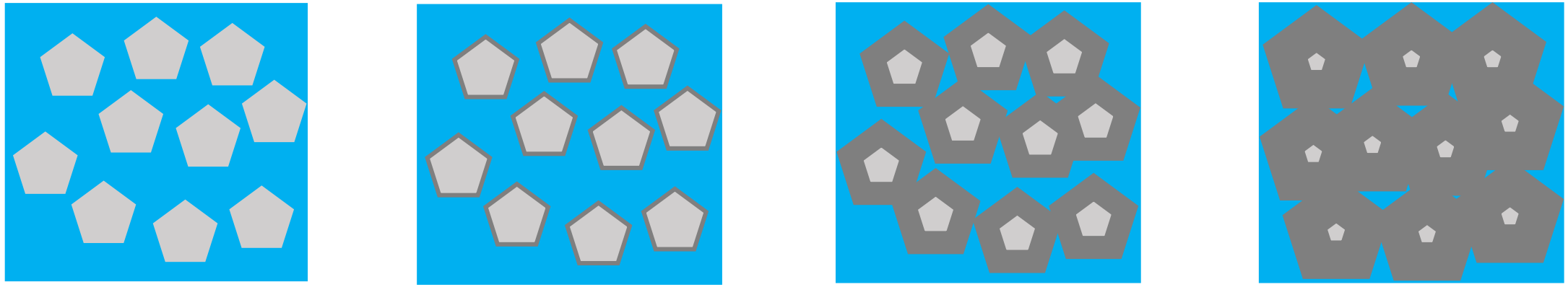
Mixing Water

- Water must be potable/drinkable
- Well water or city water is acceptable
- Well water must conform to ASTM C1602

What about washout water?

When cement meets water

Cement Hydration

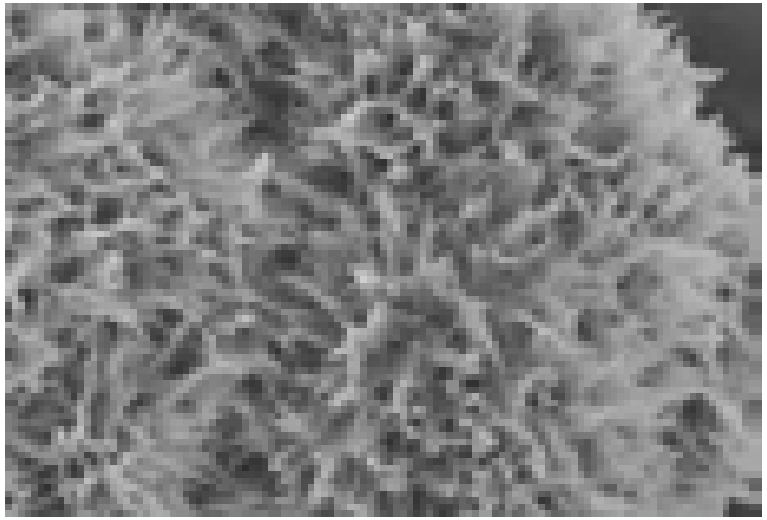


- Water
- Cement
- Hydration Products

2 Main Products of Cement Hydration

Calcium Silicate Hydrate (CSH)

- Primary cementitious binder.
- Greatest contributor to strength.
- The main “glue” in concrete.



Calcium Hydroxide (CH)

- Little to no cementitious properties.
- Contributes little to strength.
- Helps maintain high pH of concrete.

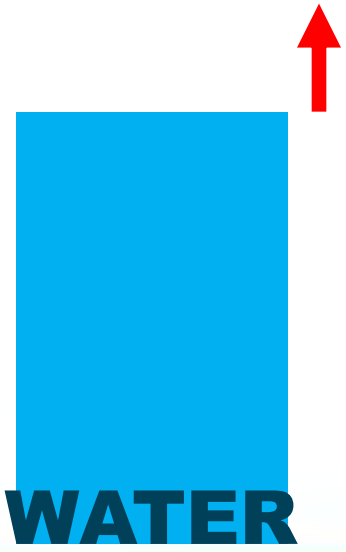
Cement and Water

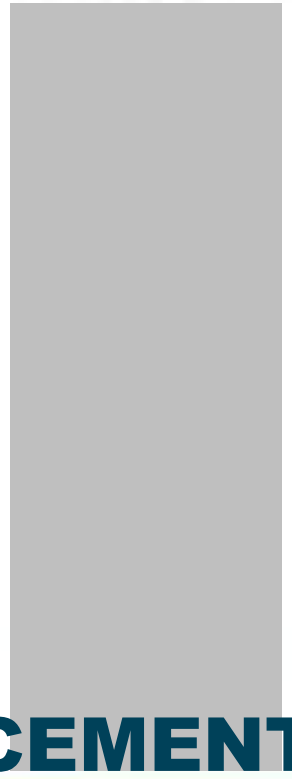
WATER

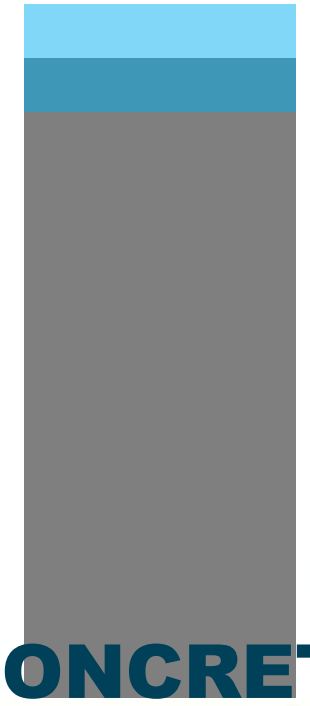
CEMENT

CONCRETE

Cement and Water







WATER CEMENT CONCRETE

Water-to-Cement Ratio

- Water-to-cement ratio (w/c) = weight of water / weight of cement in a batch of concrete
- Water-to-cementitious materials ratio (w/c_m) = weight of water / weight of all cementitious materials in a batch of concrete

$$w/c_m = \frac{\text{Weight Water}}{\text{Weight Cementitious Materials}}$$

- $w/c_m = \frac{250 \text{ lbs}}{600 \text{ lbs}} = 0.42$

Water-to-Cement Ratio

- Varies depending on the type of concrete and the application

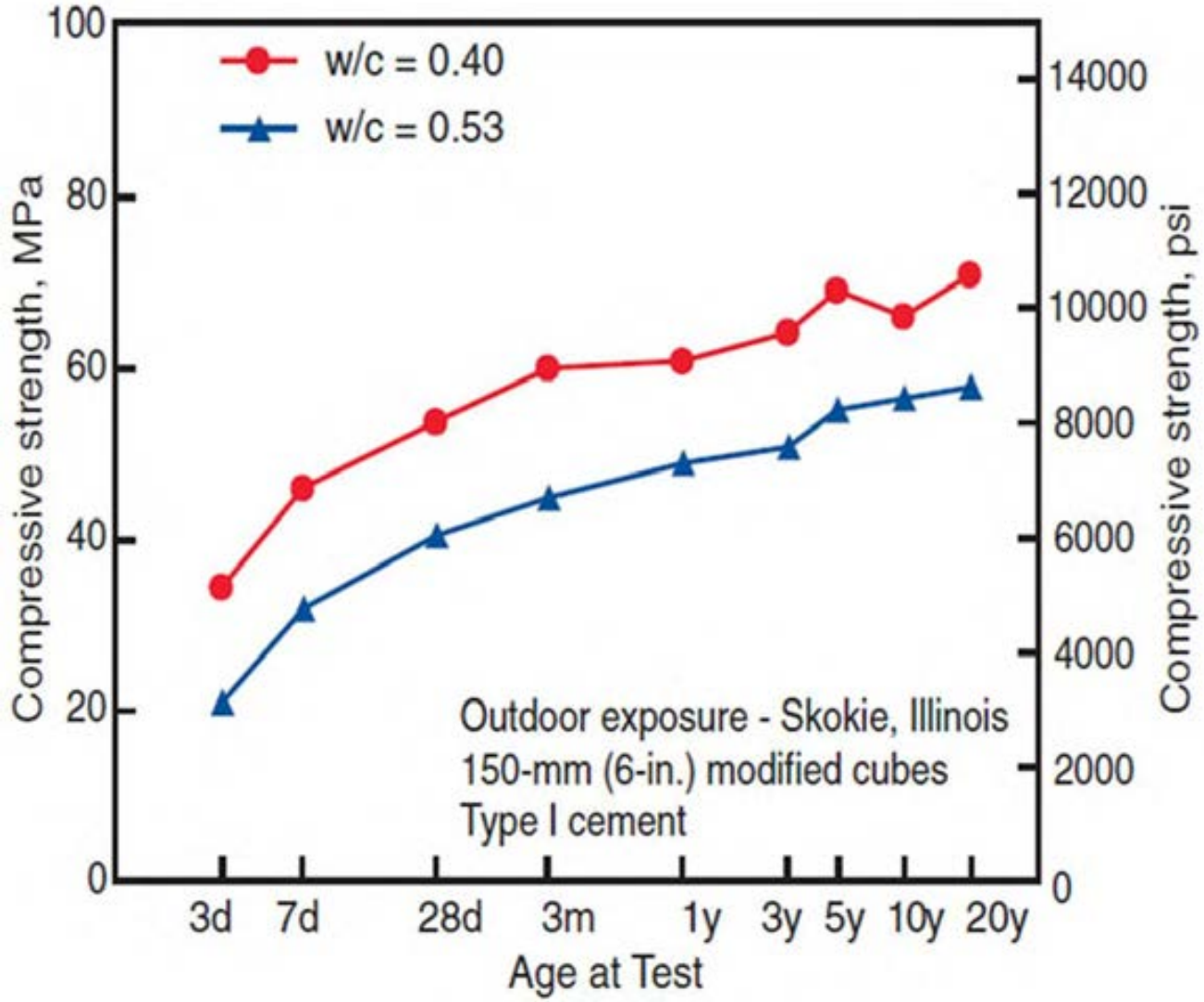
- In the right quantities, water and cement will create a very strong, durable, and impermeable paste

- Water demand varies day-to-day

w/c or w/c_m should be 0.50 or lower

Water-to-Cement Ratios

- Concrete's water-to-cement ratio (w/c) has a significant impact on concrete's strength and durability.
- Generally:
  - A higher w/c -> lower strength and reduced durability
  - A lower w/c -> higher strength and increased durability



Graph from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

What Happens When *More* Water is Added

- Water-to-cement ratio (w/c) = weight of water / weight of cement in a batch of concrete
  - 336 lbs water / 700 lbs cement = 0.48
- Add two extra gallons of water (8.43 lbs of water per gallon = 16.86 lbs water)
  - **353 lbs water / 700 lbs cement = 0.504**

Supplementary Cementitious Materials (SCMs)

- Supplementary cementitious materials (SCMs) are used in conjunction with – and as a partial replacement for – portland cement

- Common types:
  - Fly ash
  - Slag cement
  - Silica fume
  - Metakaolin

Supplementary Cementitious Materials (SCMs)

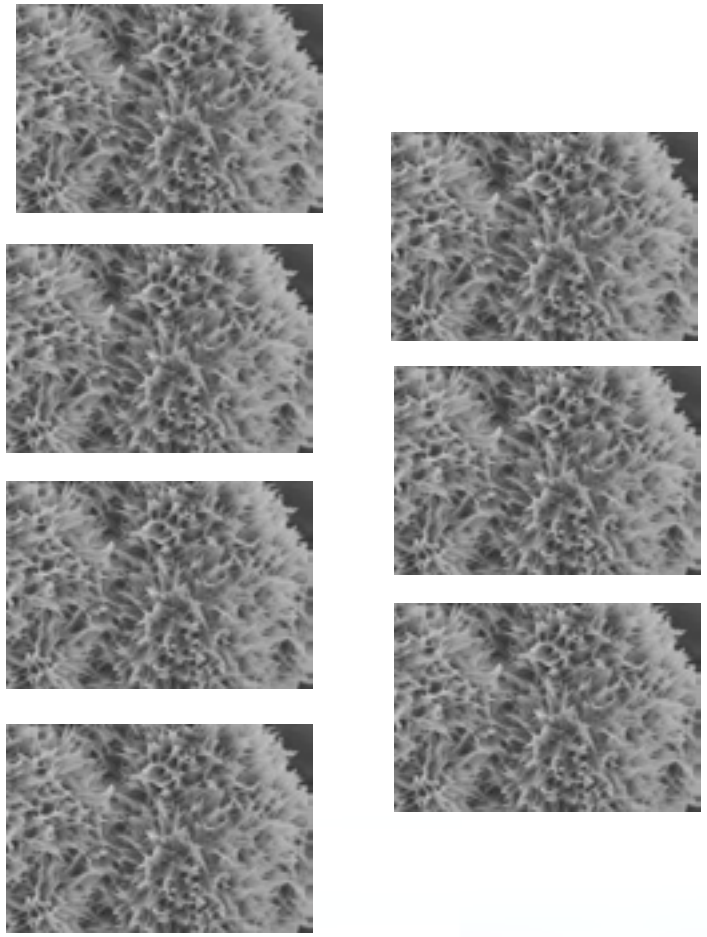
Hydraulic vs Pozzolanic

Hydraulic cement needs only water to react

Pozzolanic cement needs calcium hydroxide (CH) and water to react

2 Main Products of Cement Hydration

CSH



CH

2 Main Products of Cement Hydration

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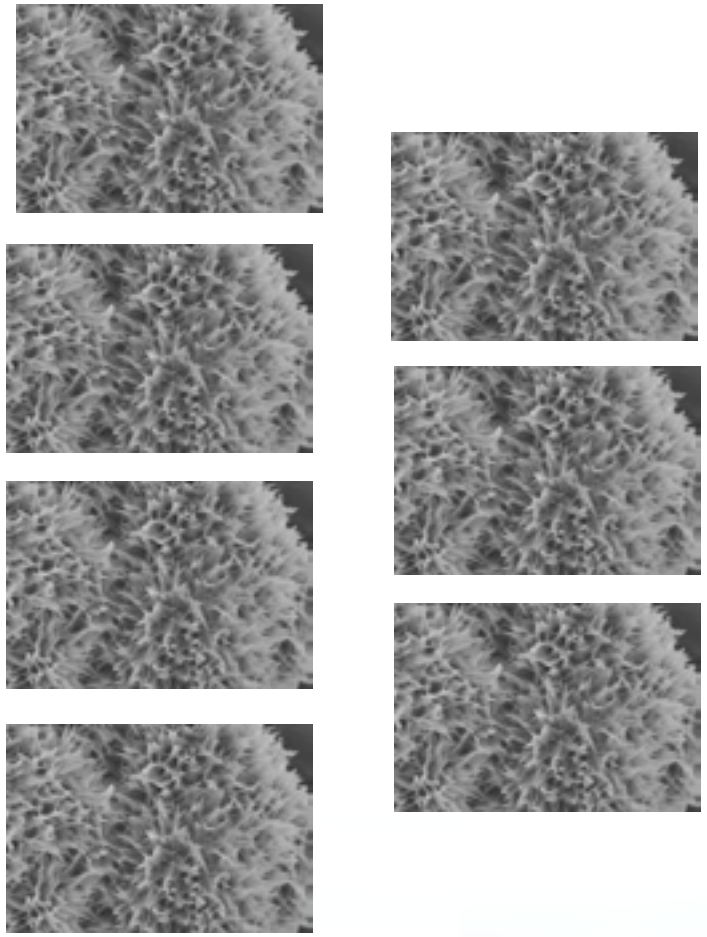

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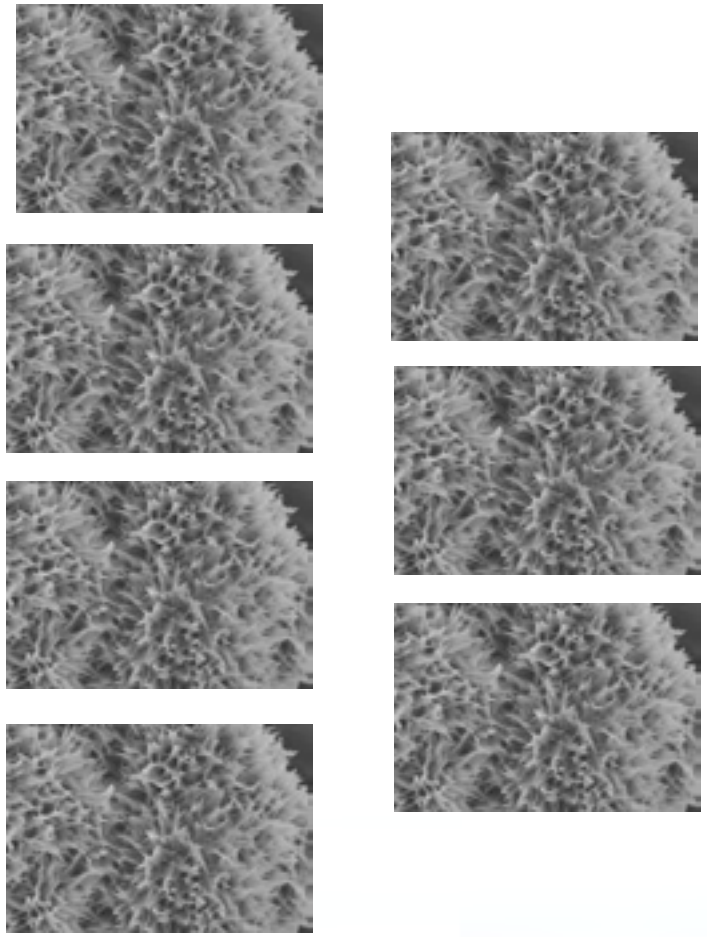

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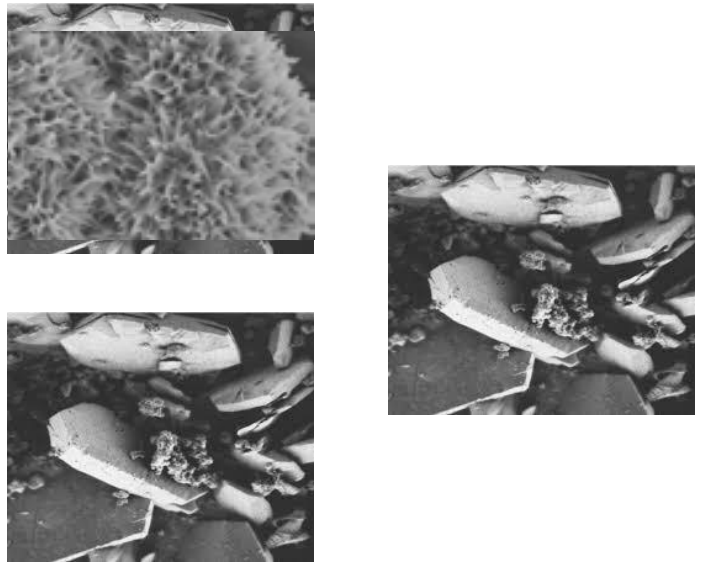


Supplementary Cementitious Materials

Pros (+)	Cons (-)
Increased long-term strength	Slower early-age strength gain (this can be beneficial in some cases, though!)
Increased density	Increased water demand
Decreased permeability	Tougher finishing/stickier
Improved durability	Material properties can vary more than cement
Many are industrial byproducts (“green” material)	Availability can be inconsistent

Chemical Admixtures

- Most every concrete mix today uses some type of admixture
- Liquid or powder
- Dosed in ounces or pounds

- Common types/uses:
  - Air-entrainers
  - Water-reducers
  - Plasticizers
  - Accelerators
  - Retarders
  - Permeability reducers
  - Corrosion inhibitors
  - Coloring
  - Permeability-reducers
  - Antimicrobials

Chemical Admixtures

- Main reasons for using admixtures:
  - To assist in production
    - Set retarders or accelerators
    - Viscosity modifiers
  - To achieve certain hardened concrete properties
    - Strength Enhancers
    - Permeability Reducing
  - Some can do both
    - Air Entraining
    - Water Reducers

Chemical Admixtures

An admixture's effectiveness depends upon:

- Admixture composition, addition rate, time of addition
- Type, brand, and amount of cementitious materials
- Water content
- Aggregate shape, gradation, and proportions
- Mixing time
- Slump
- Temperature of the concrete

Chemical Admixtures

- No admixture is a substitute for good concreting practices
- No admixture will completely fix or recover poor concreting practices
- Always consult with the admixture supplier regarding use, dosage, admixture compatibility with other ingredients in the concrete, etc.

Aggregates

- Together, coarse aggregate and fine aggregate make up about:
  - 60% - 75% of the concrete volume
  - 70% - 85% of the concrete mass

- ☑ Clean
- ☑ Hard
- ☑ Strong
- ☑ Durable
- ☑ Free of impurities

Normal Weight Aggregates

FINE AGGREGATE (SAND)

COARSE AGGREGATE (CRUSHED STONE)

COARSE AGGREGATE (GRAVEL)

- Normal weight aggregate densities range from 75 lb/ft^3 to 110 lb/ft^3
- Used for most concrete applications

Light Weight Aggregates

EXPANDED CLAY

EXPANDED SHALE

- Light weight aggregate densities range from 35 lb/ft^3 to 70 lb/ft^3, but can be as low as 15 lbs/ft^3
- Used for wall panels, architectural components, and other concrete where reduced weight is important, as well as for internal curing

Light Weight Aggregate Concrete

Heavy Weight Aggregates

- Heavy weight aggregate densities are typically greater than 130 lbs/ft^3
- Used for bollards and other security applications, counterweights, etc.

GEOTHITE

MAGNETITE

Aggregate Gradation

- Fine aggregates: less than 5 mm (0.2 in.)
- Coarse aggregates: greater than 5 mm (0.2 in.)

Aggregate Size and Gradation

- Use the largest maximum size aggregate possible AND use well-graded aggregate

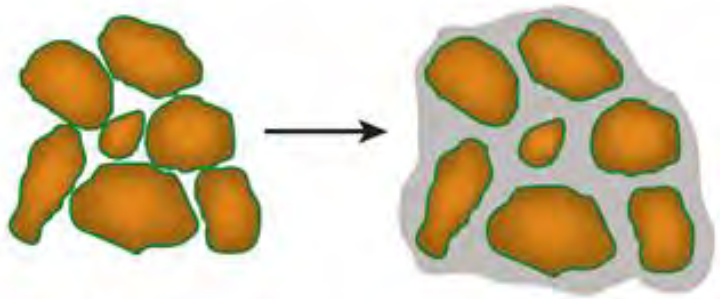
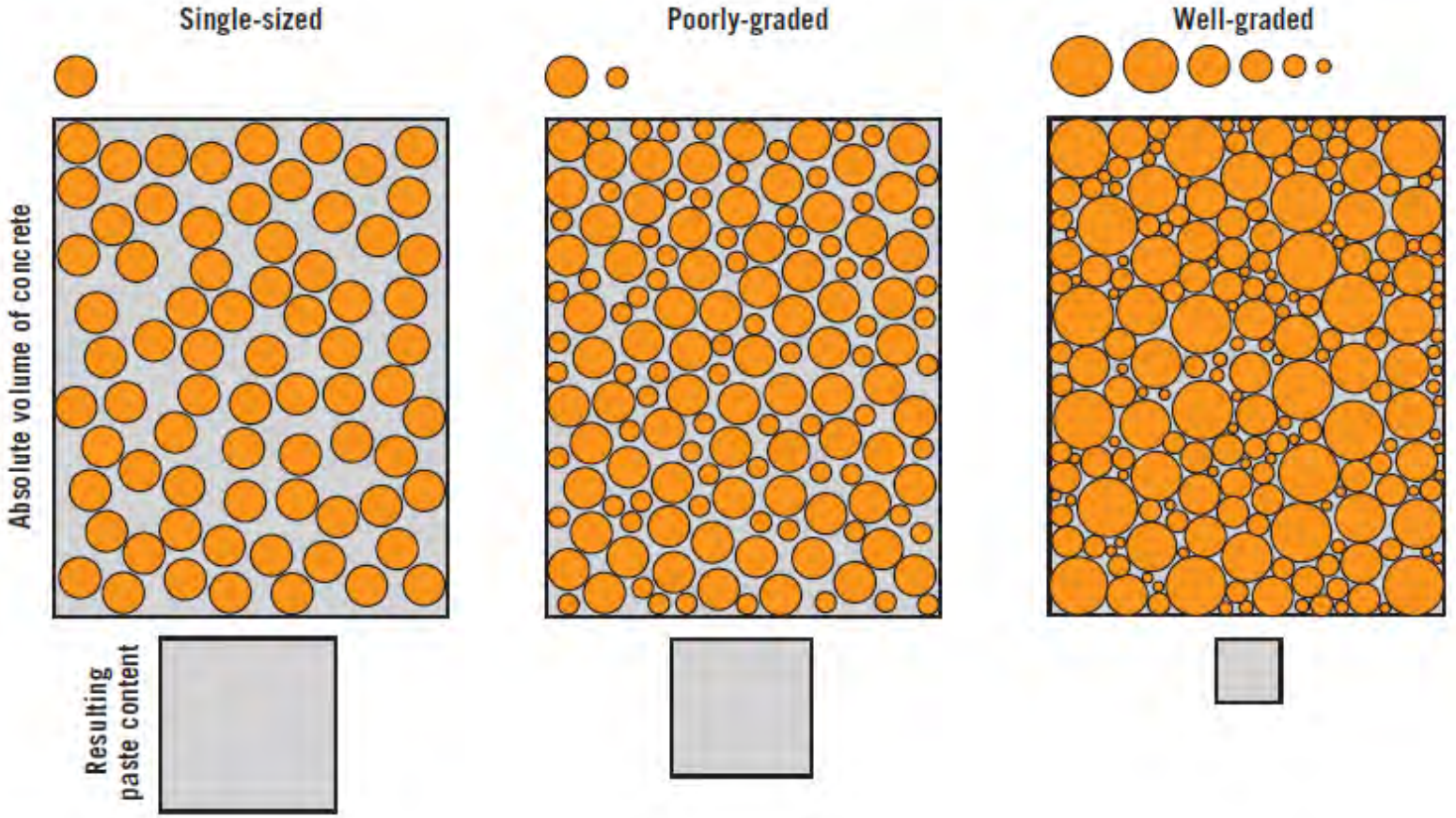


Figure 6-14. Illustration of the dispersion of aggregates in cohesive concrete mixtures.



Figures from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

Maximum Aggregate Size

- Maximum aggregate size depends on the size and shape of the concrete element and the reinforcing steel:
  - 1/5 of the narrowest dimension of a vertical concrete member: **D_{max} = 1/5*B**

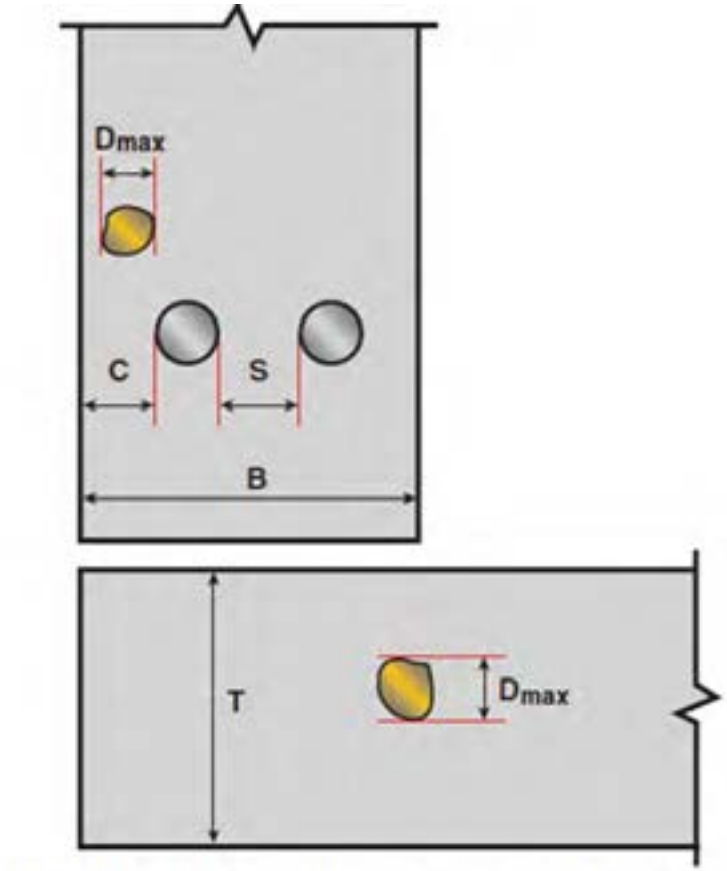


Figure 6-12. ACI 318 requirements for nominal maximum size of aggregates, D_{max}, based on concrete dimensions, B, T, and reinforcement spacing, S.

Figure from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

Maximum Aggregate Size

- Maximum aggregate size depends on the size and shape of the concrete element and the reinforcing steel:
  - 1/3 of the depth of slabs: **D_{max} = 1/3*T**

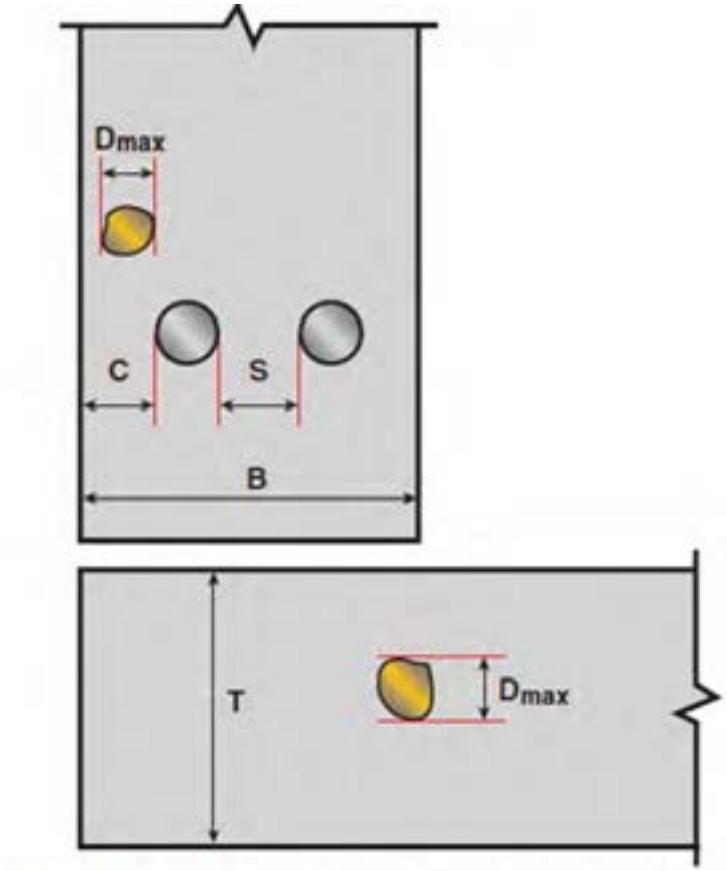


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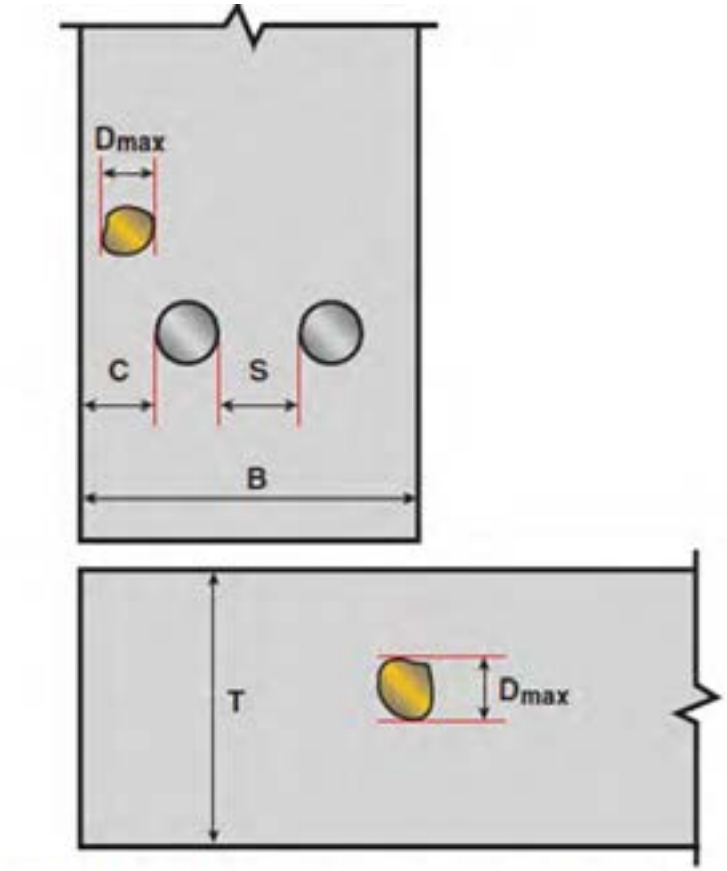
Figure from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

Maximum Aggregate Size

- Maximum aggregate size depends on the size and shape of the concrete element and the reinforcing steel:
  - 3/4 of the clear spacing between
    - reinforcing bars
    - reinforcing bars and the forms/molds:

D_{max} = 3/4*S and D_{max} = 3/4*C



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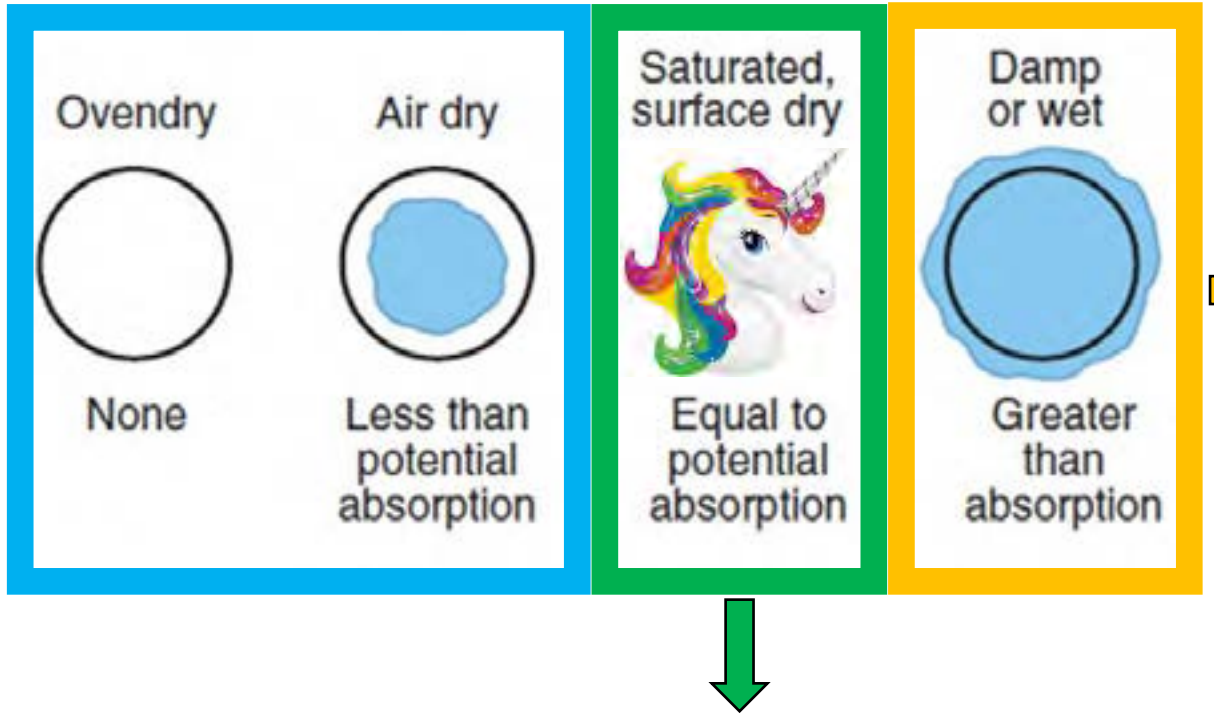
Aggregate Moisture Conditions

Oven Dry and Air Dry:
Aggregates are dryer than SSD, so they will absorb water from the concrete mix. Increase the mix design's water weight by the calculated amount.



Damp/Wet:
Aggregates are wetter than SSD, so they will contribute water to the concrete mix. Reduce the mix design's water weight by the calculated amount.

Saturated Surface Dry:
Aggregates that are SSD do not contribute water to the concrete mix, nor do they absorb water from the concrete mix. No moisture adjustment needed.

Figures from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

Reinforcing

Concrete

Strong in **Compression**

Reinforcing

Concrete

Weak in **Tension**

Reinforcing

Steel

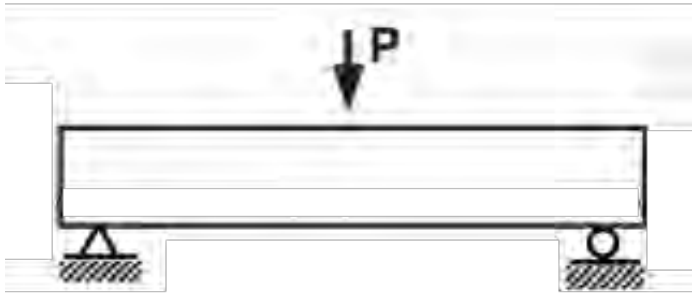
Very strong in **Tension**

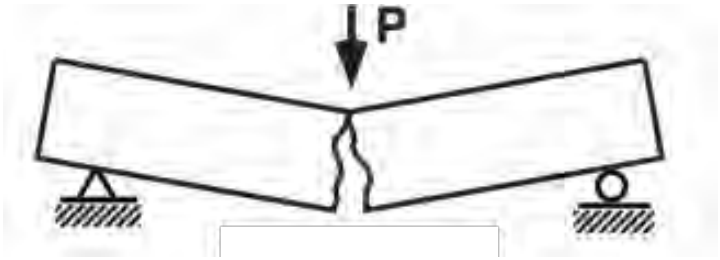
Reinforcing

Concrete and steel work great together

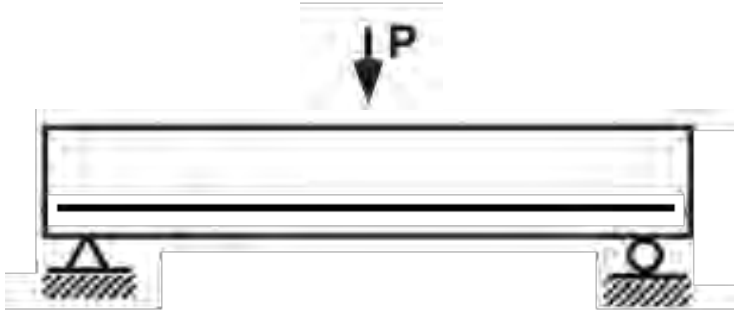
Reinforcing

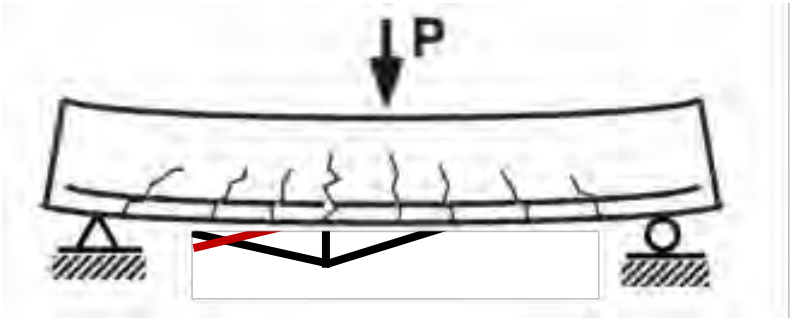
Concrete:





Reinforced Concrete:





Types of Reinforcing Used in Precast Concrete

Carbon steel rebar or wire

Types of Reinforcing Used in Precast Concrete

Epoxy coated reinforcing

Types of Reinforcing Used in Precast Concrete

Galvanized / Zinc coated

Types of Reinforcing Used in Precast Concrete

Stainless steel

Types of Reinforcing Used in Precast Concrete

Glass fiber

Types of Reinforcing Used in Precast Concrete

Fibers

Types of Concrete Used in Precast

1. Wet-cast concrete (conventional concrete)
2. Dry-cast concrete (also called zero-slump or no-slump concrete)
3. Self-consolidating concrete (SCC)
4. High-performance concrete (HPC)
5. Ultra high-performance concrete (UHPC)

Wet-Cast Concrete (“Conventional”)

Wet-Cast Concrete (“Conventional”)

Dry-Cast Concrete (Zero-Slump, No-Slump)

Dry-Cast Concrete (Zero-Slump, No-Slump)

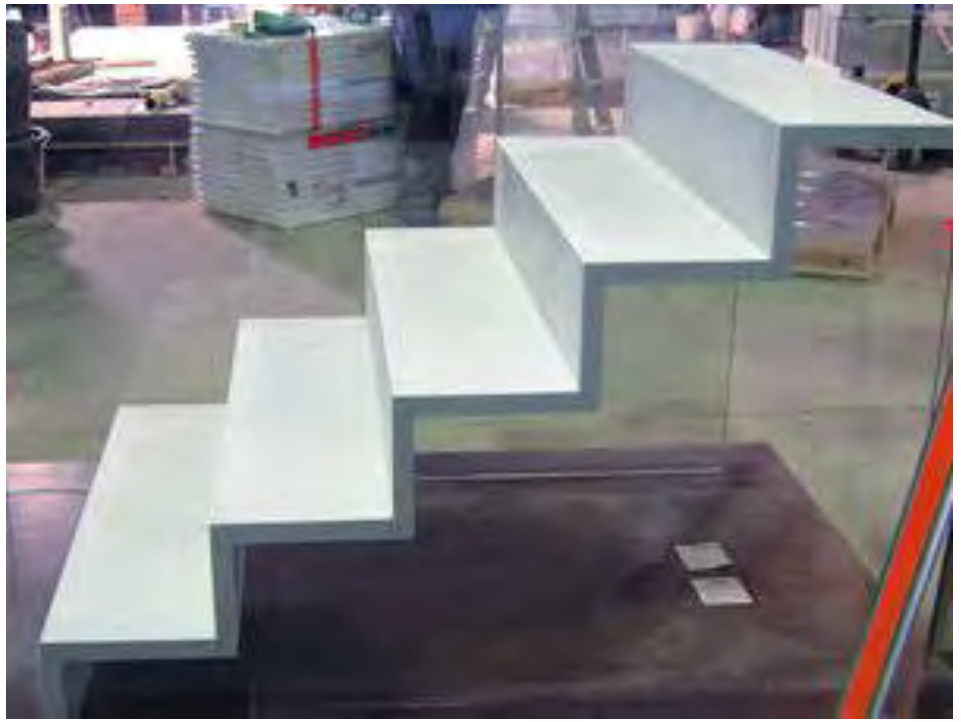
Self-Consolidating Concrete (SCC)

Uses LESS water than conventional wet cast concrete!

Self-Consolidating Concrete (SCC)

High-Performance Concrete (HPC) and Ultra High-Performance Concrete (UHPC)

High-Performance Concrete (HPC) and Ultra High-Performance Concrete (UHPC)



Precast Production Process & Types of Plants

The Yard

Aggregate Storage

Avoiding Aggregate Cross-Contamination

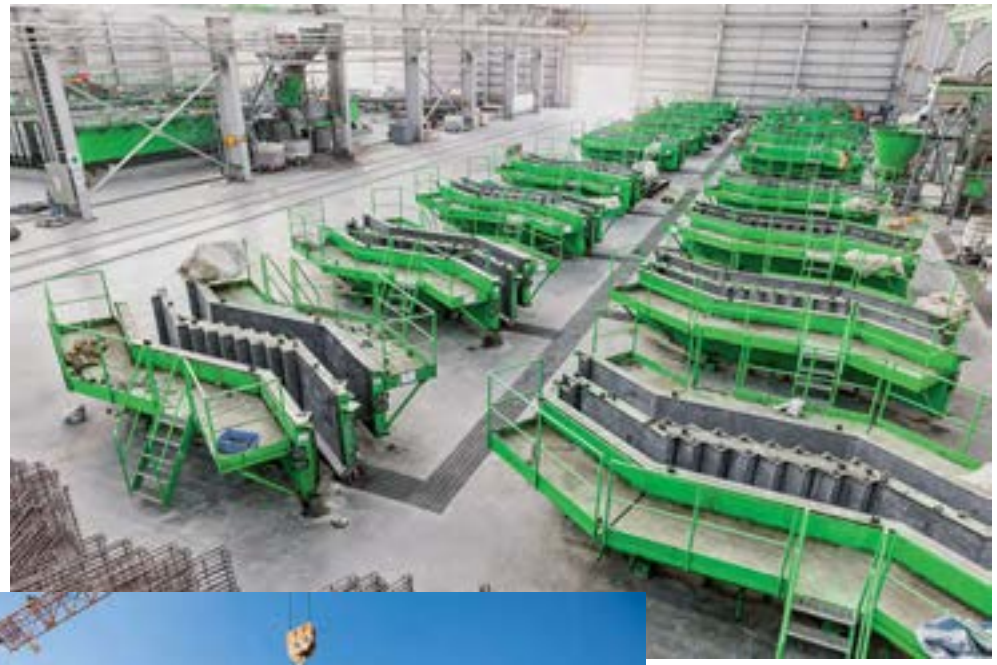
Aggregate Hoppers & Cementitious Material Silos

Aggregate and Cementitious Material Conveyance

Reinforcement Storage

Production Facility Interior

Production Facility Interior



Some plants specialize in making one type of product, while others may have a hundred unique forms

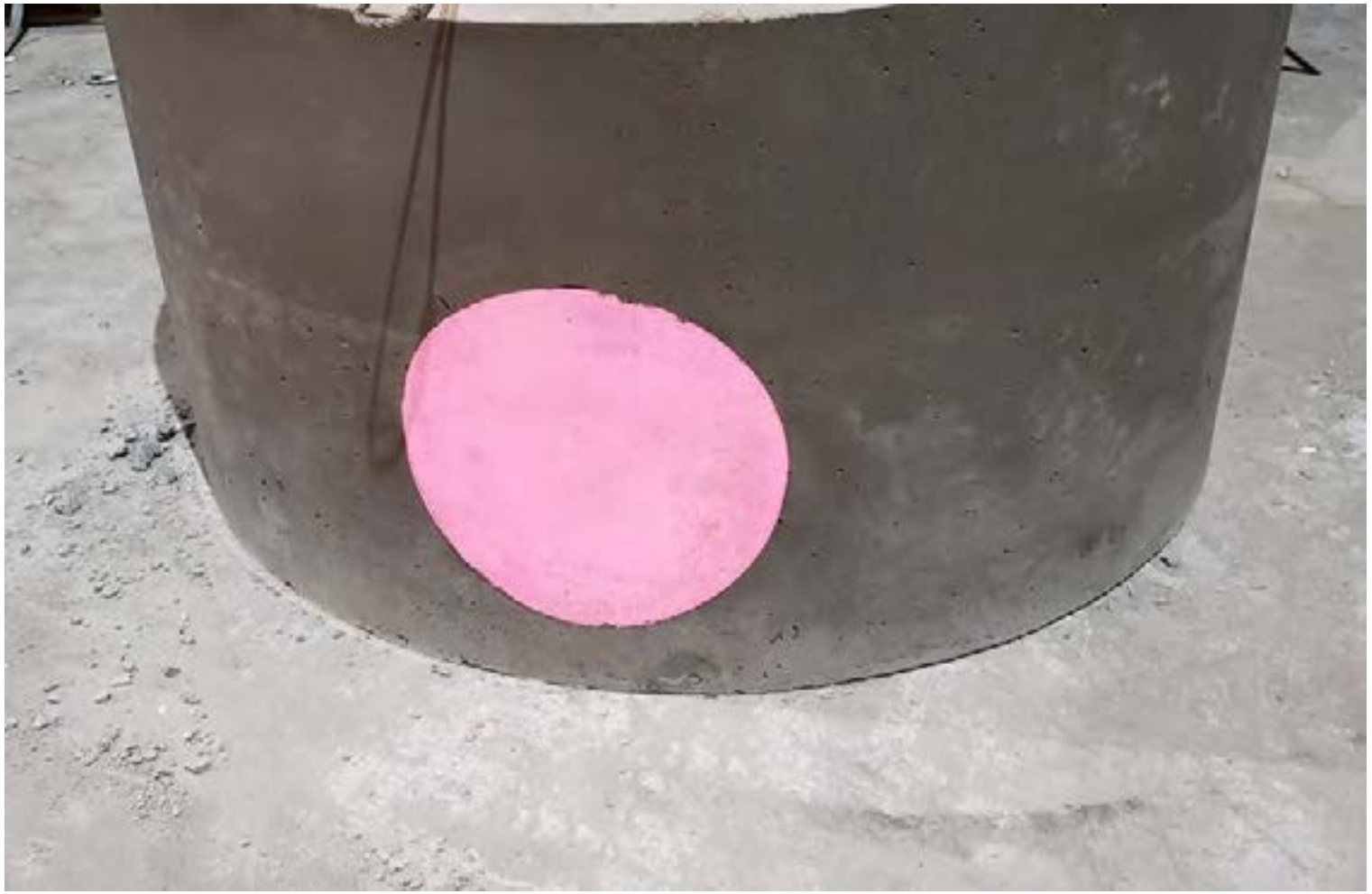
Mixers, Forms, and Concrete Buckets

Concrete Mixers

Forms / Molds

Forms / Molds

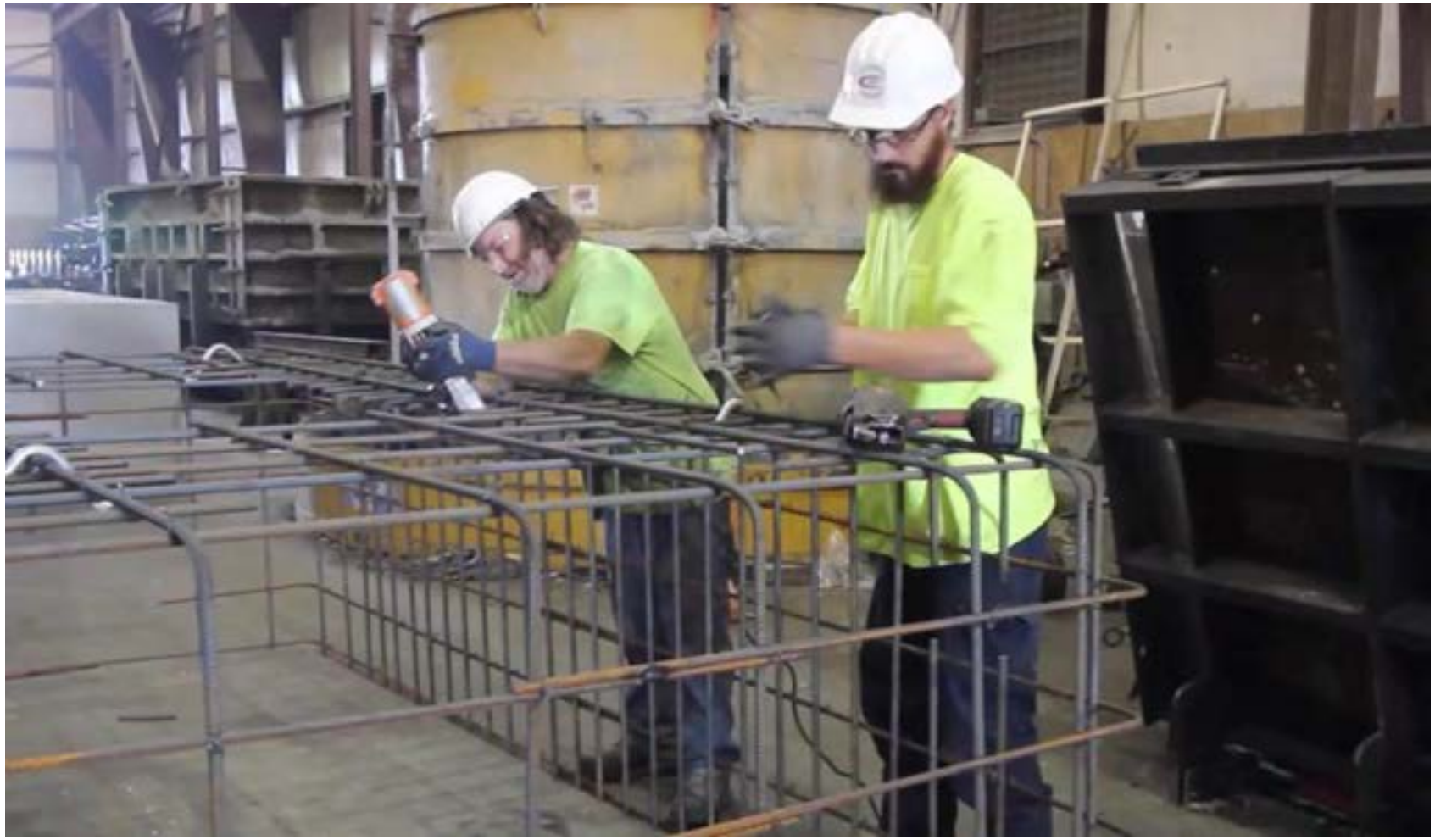
Knockouts and Blockouts



Cutting Cores

Bench / Invert

Reinforcement Fabrication



Chemical Admixture Equipment

QC Area

Batching Controls

Concrete Placing

- Depositing and distributing freshly mixed concrete in the location where it will cure and harden
  - Deposit concrete as close to final location as possible
  - Minimize free-fall heights to less than 6 ft
  - Handle fresh concrete as little as possible

Concrete Consolidation

- Helps draw entrapped air to the unformed surface and out of the concrete, reducing pores and voids while increasing density

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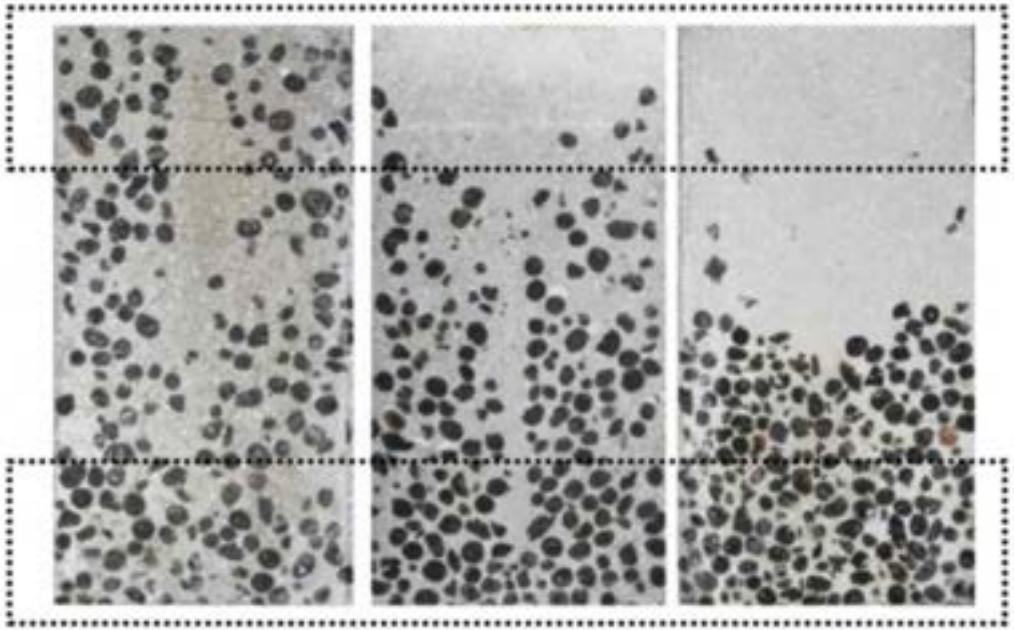
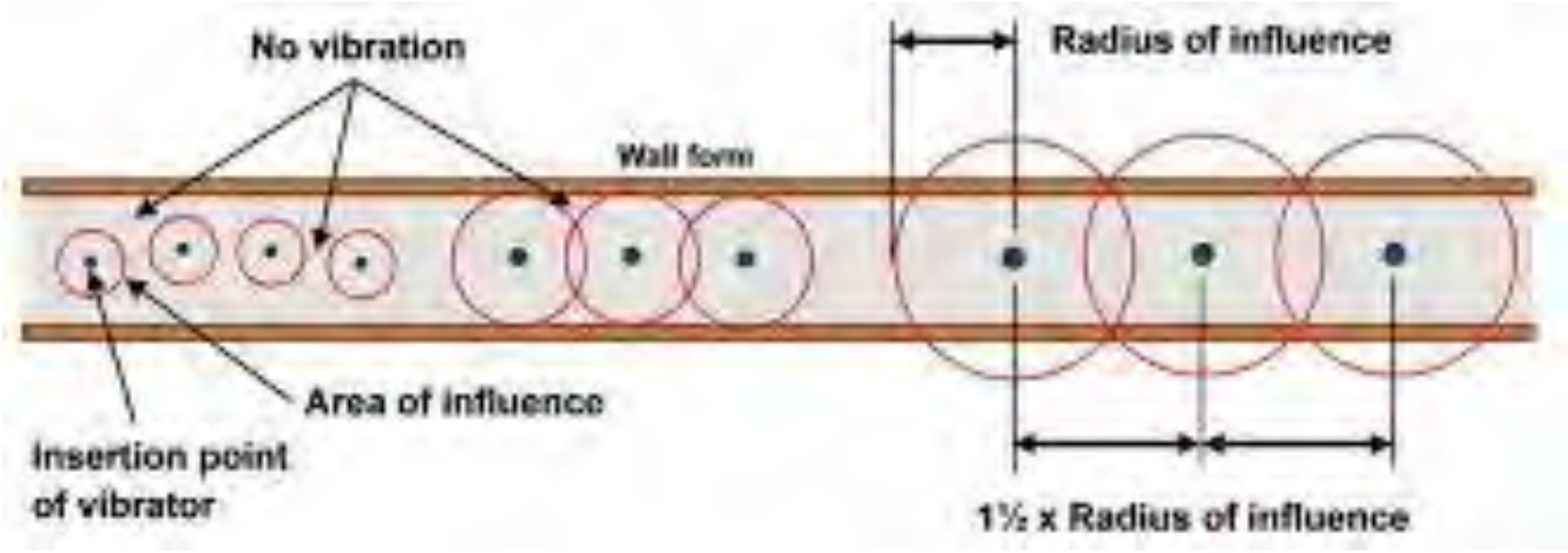
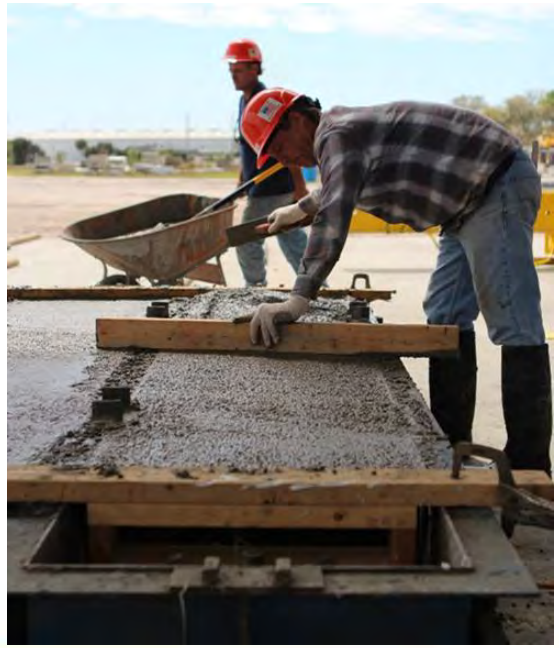


Concrete Consolidation



Concrete Finishing

- Leveling, smoothing, consolidating, and otherwise treating fresh concrete surfaces to produce a desired appearance and surface service
- Order of operations:
  - Place the concrete
  - Consolidate
  - Screed/strike off
  - Float
  - Final finish (trowel, broom, etc.)



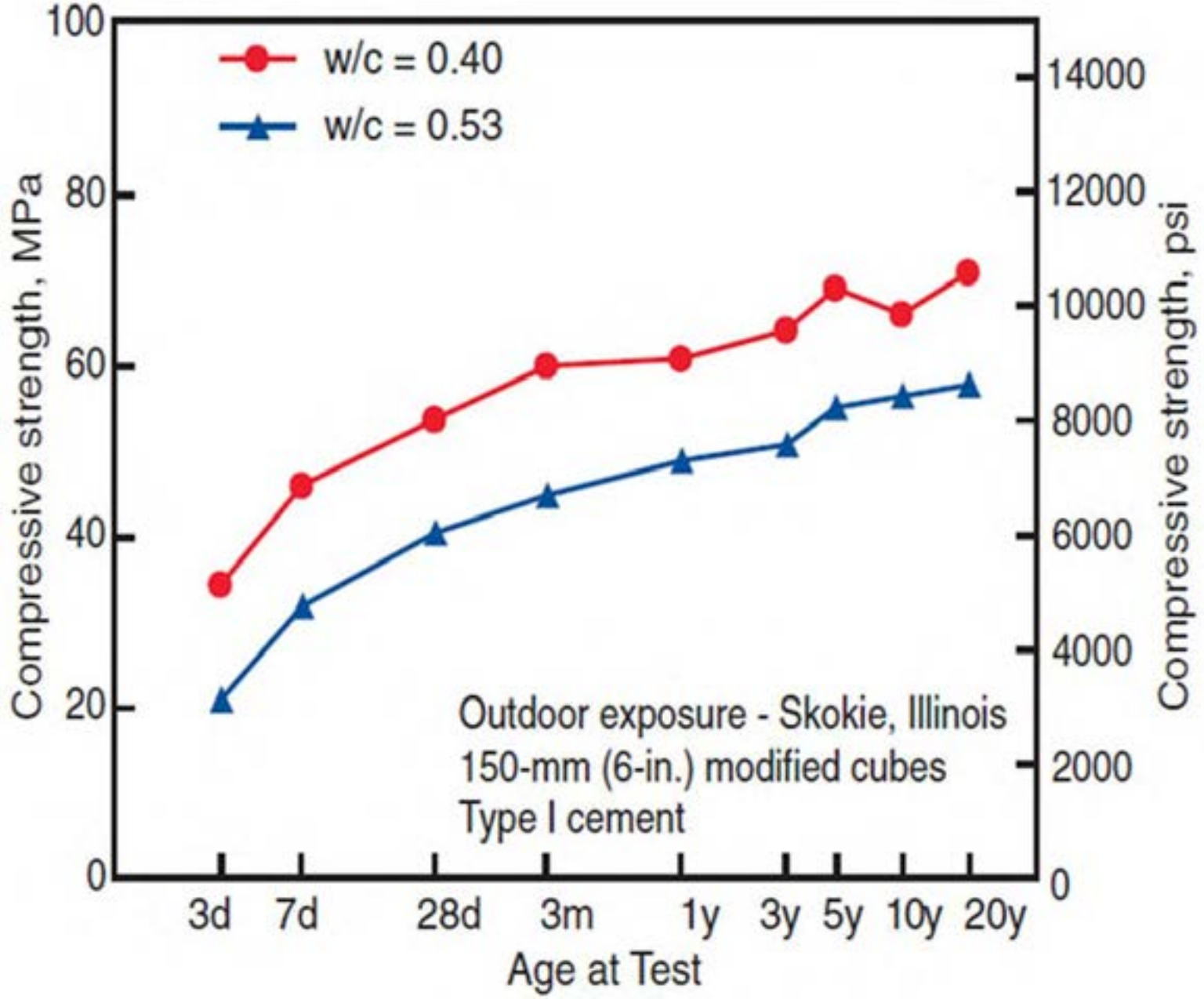
Curing Concrete

- Providing adequate ambient conditions to allow the concrete to achieve the desired properties for its intended use
- Everything up to this point could be lost if curing is not done properly.

Time

Temperature

Moisture



Graph from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

Cold Weather Curing

- Use heated mix water (180° F or lower)
- Cover curing products and apply a heater under the tarp
- Keep aggregates indoors
- Mix design adjustments

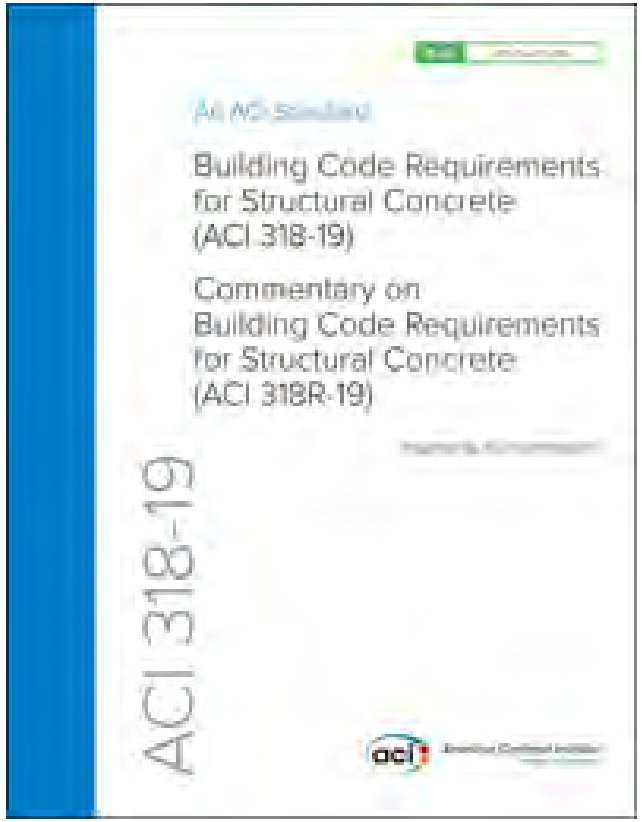
Hot Weather Curing

- Add ice to mix water
- Cover curing products with light colored sheeting
- Mist aggregate stockpiles
- Keep aggregates indoors or out of direct sunlight
- Mix design adjustments
- Keep forms and rebar indoors prior to use

Accelerated Curing

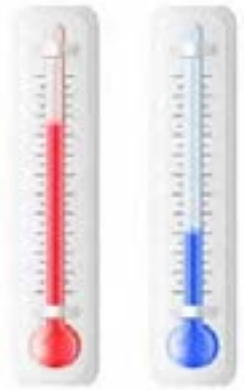
Standards, Codes, & Specifications

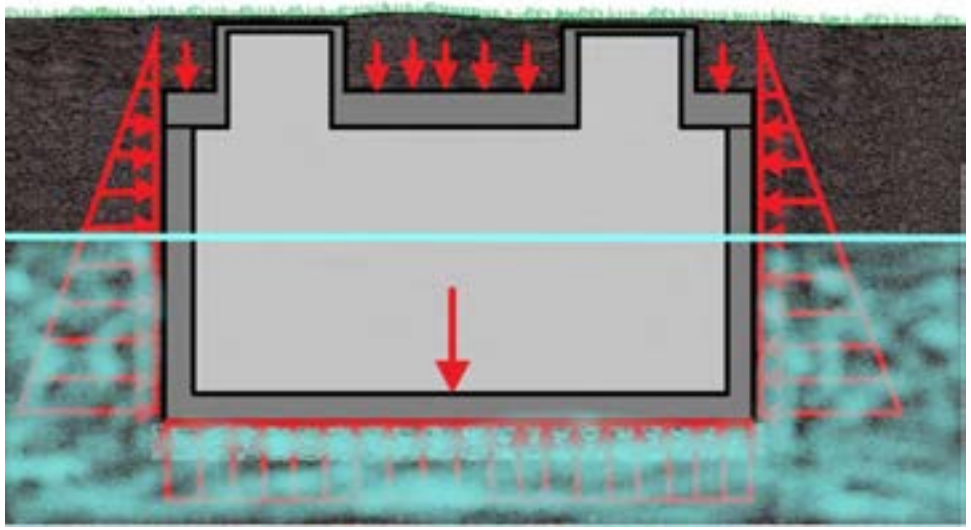
- Standard: Requirements for manufacturing, testing, or installing a particular product
  - ASTM C478, “Standard Specification for Circular Precast Reinforced Concrete Manhole Sections”
- Code: Detailed rules outlining what to do
  - ACI 318, “Building Code Requirements for Structural Concrete”
- Specification: Outlines the requirements, codes, and standards for a particular job
  - Indiana DOT Specification for Pavement



Loads and Forces

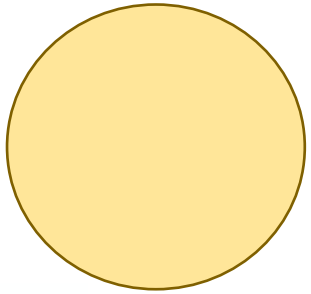
- Structure’s self-weight
- Thermal stresses
- Shrinkage
- Buoyant forces
- Hydrostatic loads
- Soil loads
- Wheel loads
- Wind, snow, rain, seismic
- Handling loads



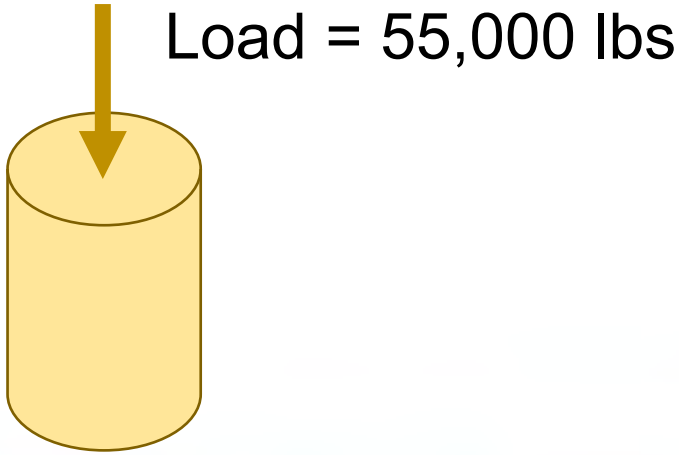


Concrete Strength

- Example: A 4-inch by 8-inch concrete cylinder
- Stress = load per unit area
  - Load applied to the cylinder = 55,000 lbs
  - Cross-sectional area of the cylinder = 12.57 in.^{2}
- Stress = 55,000 lbs/12.57 in.^{2} = 4,375 lbs/in.^{2} = **4,375 psi**

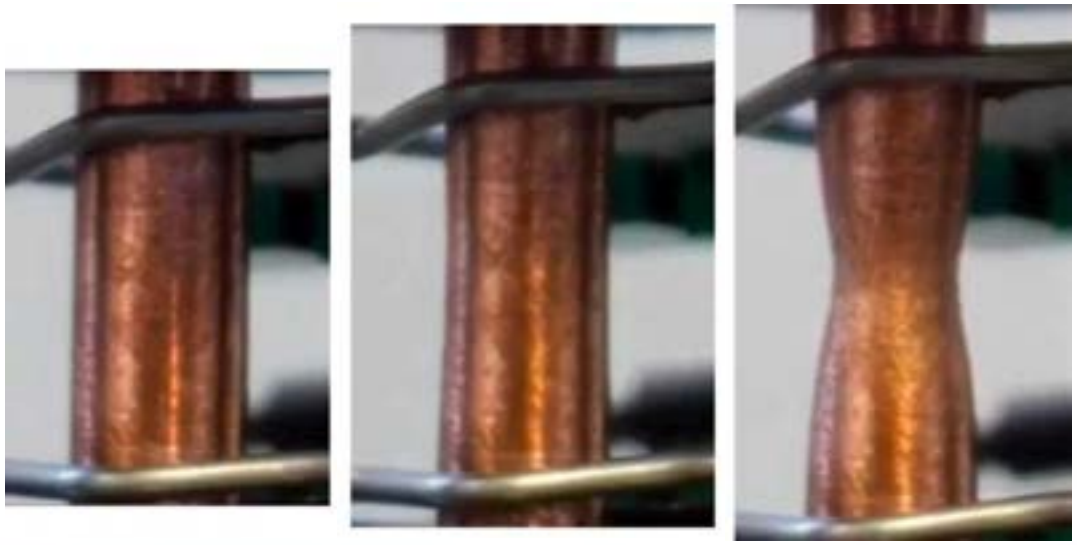


A = 12.57 in.^{2}



Reinforcement

- Concrete is strong in compression but weak in tension
- Concrete is brittle; steel is ductile
- Reinforcement supplies strength to withstand tensile, shear, and flexural forces



Rebar Markings

Grade 60 shown

Grade 40 – No grade markings
Grade 60 – 60
Grade 75 – 75
Grade 80 – 80
Grade 100 – 100
Grade 120 – 120

Rebar Size Chart

U.S. Standard Reinforcing Steel Bars				
Bar Size Designation	Area Square Inches	Weight lb Per Foot	Diameter	
			inches	mm
#3	.11	.376	.375	9.53
#4	.20	.668	.500	12.7
#5	.31	1.043	.625	15.88
#6	.44	1.502	.750	19.05
#7	.60	2.044	.875	22.23
#8	.79	2.670	1.000	25.40
#9	1.00	3.400	1.128	28.58
#10	1.27	4.303	1.270	31.75
#11	1.56	5.313	1.410	34.93
#14	2.25	7.650	1.693	43.00
#18	4.00	13.600	2.257	57.33

Traditional Steel Reinforcement (Rebar)

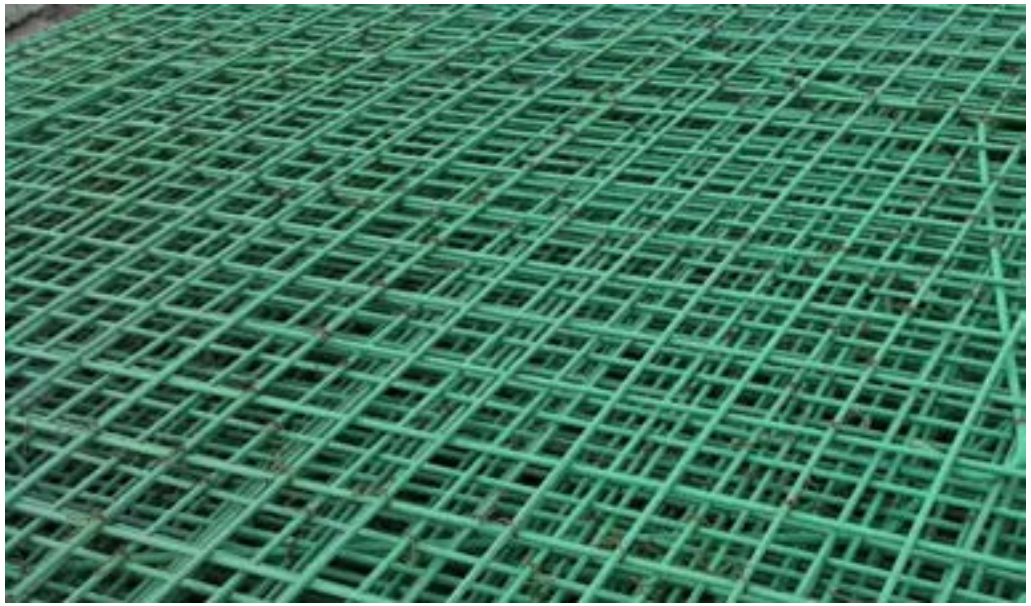
- ASTM A615: deformed and plain carbon-steel bars (“non-weldable”)
- ASTM A706: deformed and plain low-alloy steel bars (weldable)

Welded Wire Reinforcement

- ASTM A1064 and ASTM A185: welded-wire reinforcement

Epoxy-Coated Reinforcement

- ASTM A775: epoxy-coated steel reinforcement



Zinc-Coated Reinforcement

- ASTM A767: zinc-coated (galvanized) steel bars

Other Types of Reinforcement

Glass Fiber Reinforcement

Basalt Reinforcement

Splicing Reinforcement

Lap Splicing

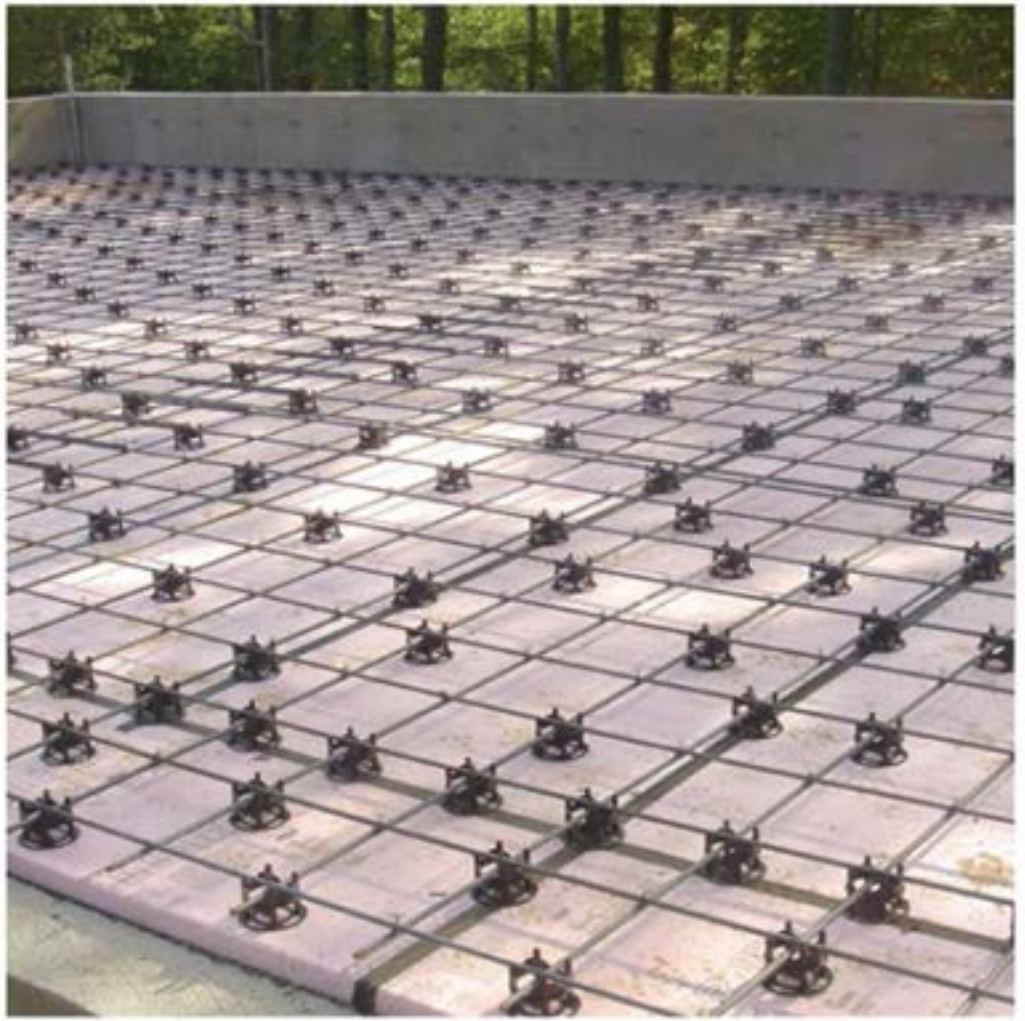
Mechanical Splicing

Splicing Reinforcement

Concrete Cover Over Reinforcement

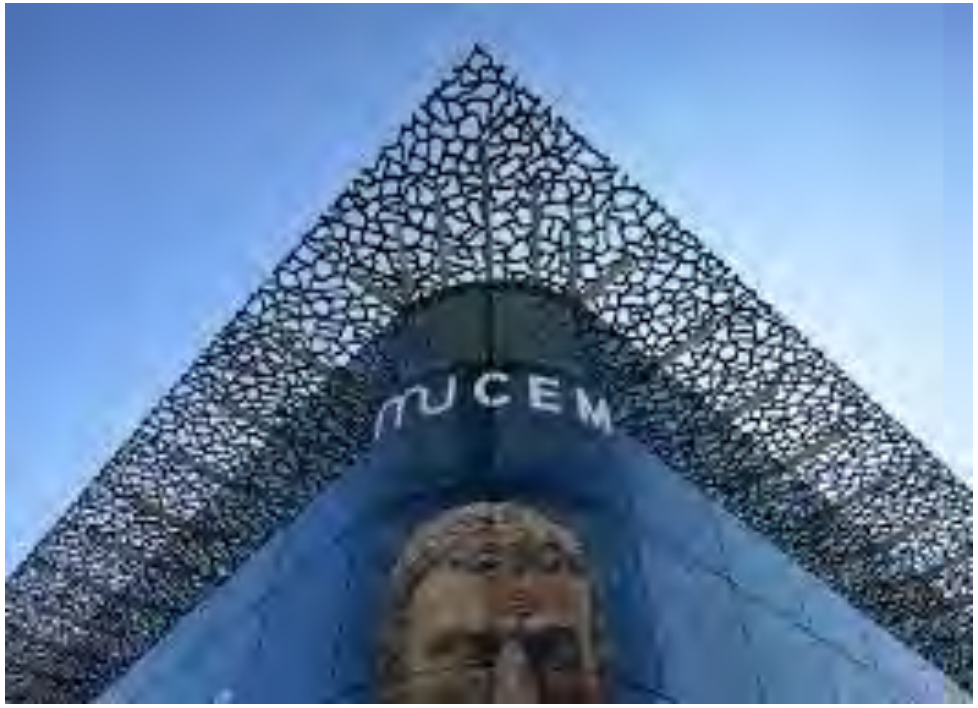
- Concrete cover over reinforcement must always be ½” or greater

Chairs and Spacers



Fiber Reinforcement

- Macrofibers and microfibers
- Steel fibers and synthetic fibers

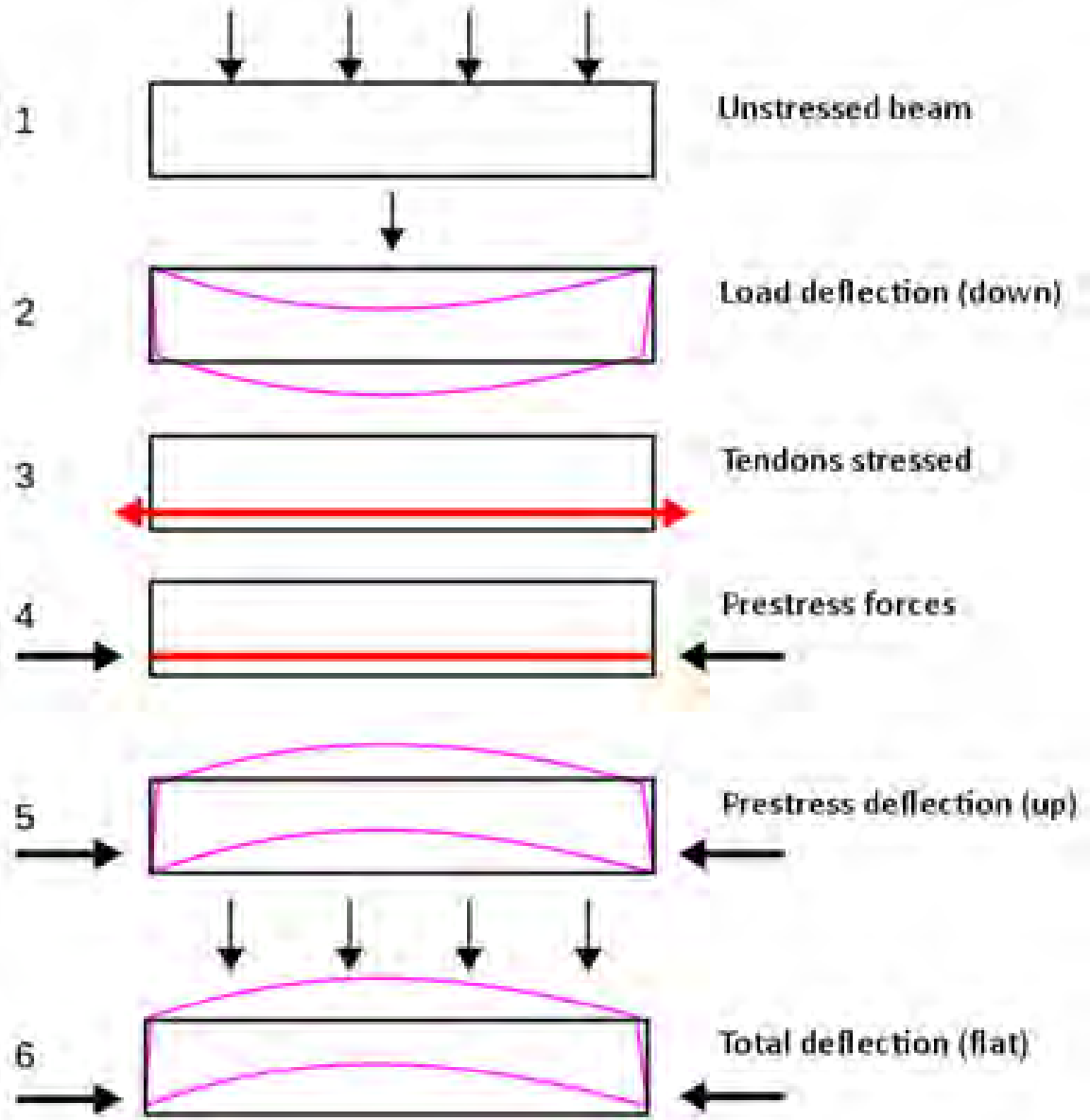


Steel Fiber Reinforcement

Synthetic Fiber Reinforcement

Prestressing

- Concrete placed in compression prior to supporting applied loads
  - Pre-tension
  - Post-tension



Prestressing

Other embeds

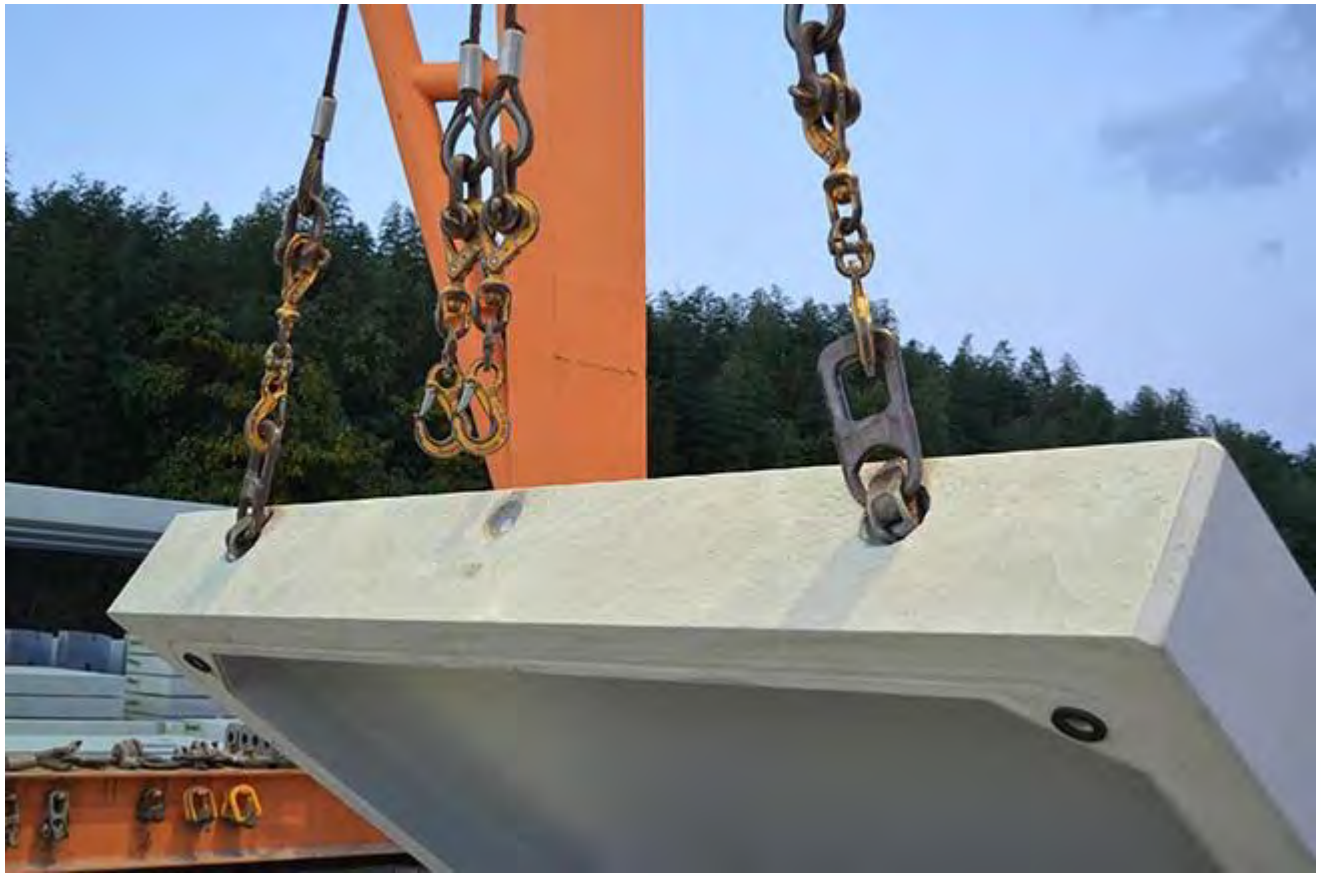
Duct Terminators

Hatches

Steps

Pipe Connectors

Lifting Devices



QA/QC and Concrete Testing

Quality Assurance & Quality Control

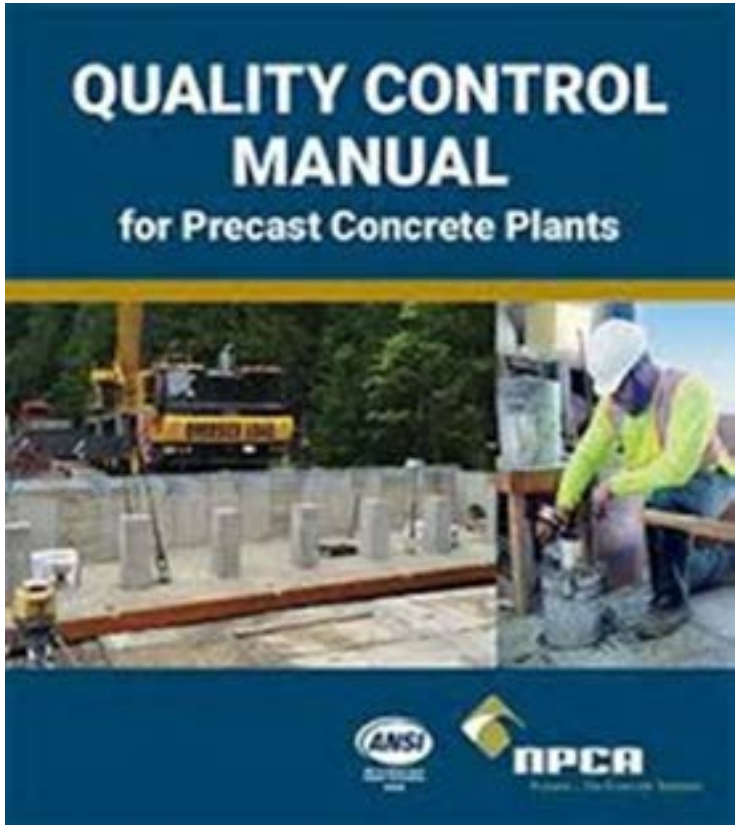
QA	QC
Process-oriented	Product-oriented
Defect prevention	Defect identification
Proactive strategy	Reactive strategy

How QA/QC Ensures Consistently High Quality

1. Qualified and educated personnel
2. Completeness of work orders and product drawings
3. Quality of raw materials
4. Quality of forms
5. Fabrication and positioning of reinforcing steel
6. Positioning of embedding items
7. Concrete quality
8. Placement and consolidation of concrete
9. Curing of concrete
10. Product dimensions
11. Handling, storing and transporting product
12. Recordkeeping
13. Testing
14. Continuous improvement

Concrete Properties

- Unit weight
- Air content
- Slump
- Slump flow, spread, VSI
- Temperature
- Consistency
- Homogeneity
- Strength
- Volume stability
- Density
- Watertightness
- Thermal and acoustic insulation
- Durability (resistance to abrasion, freeze/thaw, impact, fire, harsh environments, etc.)



Fresh Concrete Testing

- Air content
- Slump
- Unit weight/density
- Temperature
- SCC only:
  - Slump flow or spread
  - Visual stability index
  - J-ring

Hardened Concrete Testing

- Compressive strength
- Three-edge bearing
- Watertightness
  - Vacuum testing
  - Hydrostatic testing

Other Tests

- Concrete durability tests:
  - Absorption
  - Absorption under pressure
  - Freeze-thaw durability
  - Electrical conductivity
  - Length change
  - Potential for alkali-silica reactivity
  - Scaling resistance
  - Abrasion resistance
  - Chloride ion ingress

Plant Safety, Technical, and Best Practices Resources at www.precast.org

Proactive Safety Measures

- Safety training throughout onboarding
- Fostering a safety culture
- Ongoing training:
  - Monthly safety meetings
  - Morning huddles, Weekly Toolbox Talks
  - Regular safety training for all employees
- Plant practices:
  - Proper personal protective equipment (PPE)
  - Regular equipment inspections, plus daily spot-checks
  - Use the right tool for the job, each time
  - Use equipment designed for ergonomics
  - Instill a sense of ownership

Be aware of your surroundings at all times.

Most Common Injuries in Manufacturing

- Slips
- Trips
- Falls
- Caught in/between

NPCA Plant Safety Resources

- NPCA safety resources: www.precast.org/safety
  - 6-Module Safety Video (English and Spanish)
  - Occupational Health Program & Written Exposure Control Plan for Respirable Crystalline Silica
  - Bi-Monthly Toolbox Talks
  - Employee Safety Handbook

Summary

1. What is precast concrete?
2. Concrete raw materials
3. Types of concrete used in precast
4. Precast production process and plant equipment
5. Curing concrete
6. Concrete design, strength, and reinforcement
7. Prestressing
8. QA/QC and concrete testing
9. Plant safety

Questions

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Precast 101

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