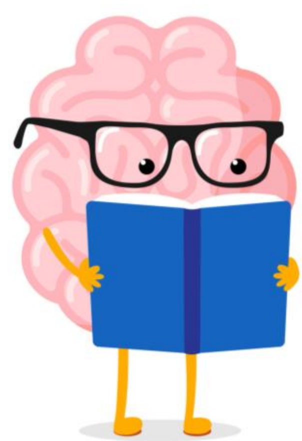
Precast 101

Kayla Hanson, P.E.
Concrete Sealants, Inc. | khanson@conseal.com | (800) 332-7325

1

Learning Objectives

- Explain the difference between precast concrete and ready-mix/cast-in-place concrete.
- Describe benefits of precast concrete over other construction materials.
- Define common precast terms and their significance, including water-to-cement ratio, among others.
- List the raw materials and types of reinforcement used in concrete production.



2

Learning Objectives Continued

- Describe common types of concrete used in precast and their applications.
- Outline the processes and equipment involved in precast concrete manufacturing, including raw material selection, mixing, curing, handling, and beyond.
- Discuss the role of QA and QC in precast operations and list common fresh and hardened concrete tests and their purposes.

THE PRECAST SHOW

3

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

THE PRECAST SHOW

4

History

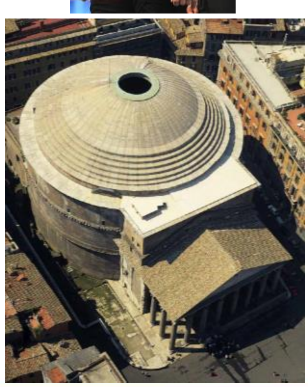
- **Pyramids**
- ~2600 BC onward
- Egypt and Sudan

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

5

History

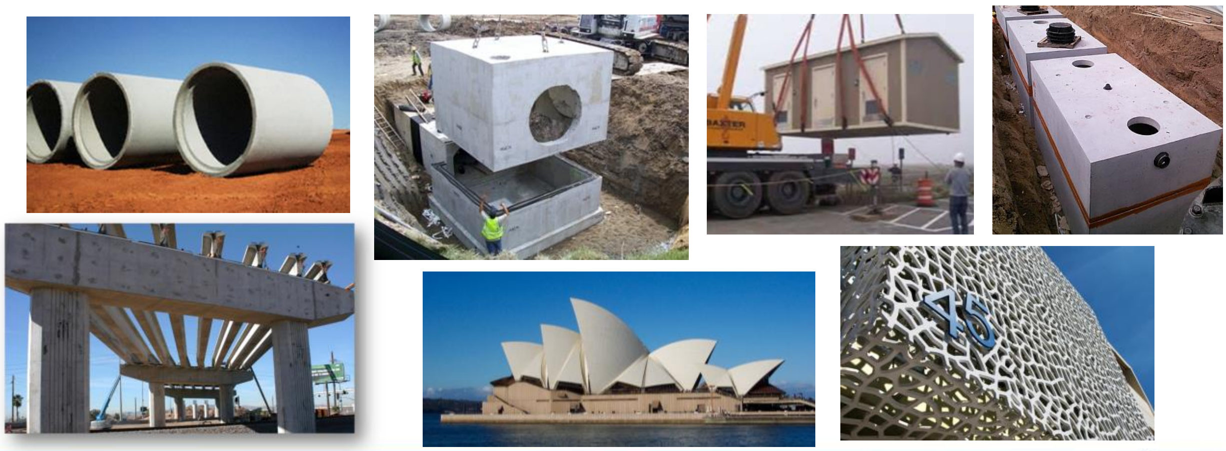
- **Pantheon**
- 125 AD
- Italy



6

What is precast concrete?

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



7

Precast Concrete Production Plant

8

Precast Concrete Jobsites

9

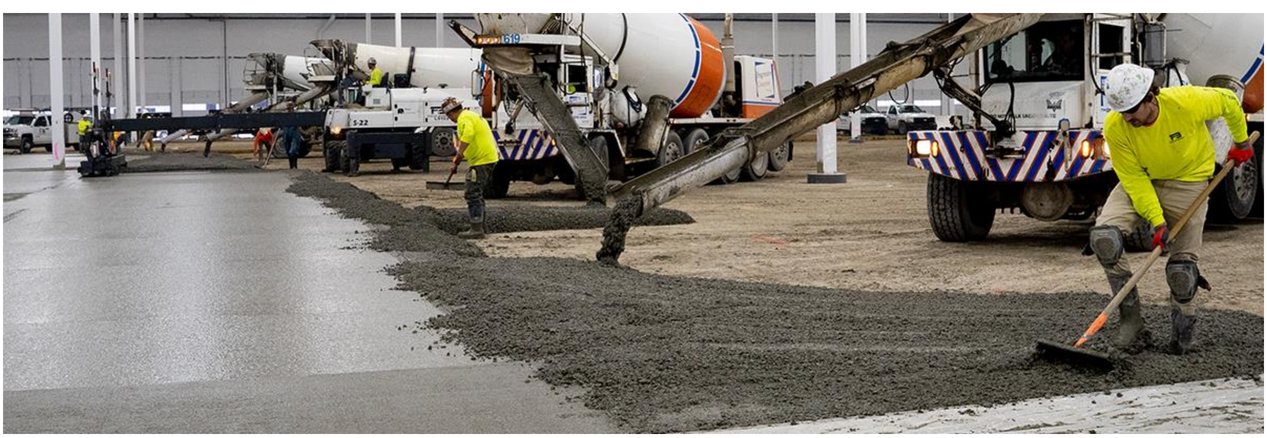
Precast Concrete Jobsites

10

Ready-Mix / Cast-in-Place Concrete Plant

11

Ready-Mix / Cast-in-Place Jobsite

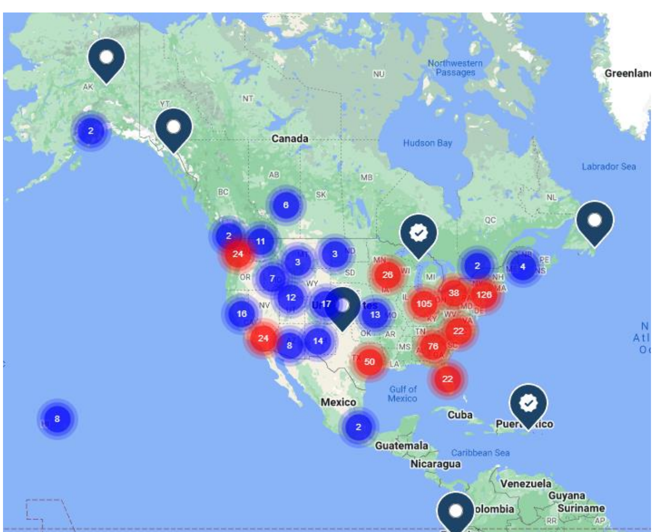


12

Ready-Mix / Cast-in-Place Jobsite

13

Precast Concrete Industry



- 670+ NPCA precast producer members
  - Note: This does NOT account for every precast production plant! Not even close.
- Concrete is the second-most used material in the world
- ~30 billion tons of concrete are used each year

https://www.sciencedirect.com/science/article/abs/pii/S1350630714000387

https://heatmap.news/economy/the-planet-s-jaw-dropping-astonishing-downright-shocking-amount-of-concrete#:~:text=The%20world%20produces%20somewhere%20around,produced%20each%20year%20%5B4%5D.

14

What is precast concrete?

- Concrete cast **elsewhere** than its final location and cured in a **controlled** environment
- **Composite material** made of natural ingredients, manufactured materials, and industrial byproducts
- Displays highest strength in **compression**
- Service life can be **100+ years**
- Infrastructure, residential, commercial, industrial, architectural applications, and **beyond**

15

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

16

17

Concrete Raw Materials

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

18

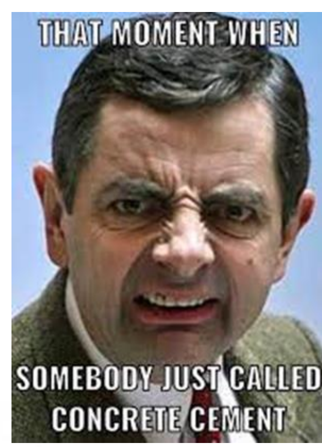
Concrete Raw Materials

- **Paste (binder):**
  - Cement
  - Water
  - Supplementary cementitious materials (SCMs)
  - Admixtures
- **Aggregates ("filler"):**
  - Coarse aggregates
  - Fine aggregates

19

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 or hydraulic cement
  - "Hydraulic" means it reacts readily with water



20

Portland Cement Origins

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

21

Portland Cement Primary Ingredients

Limestone

Clay

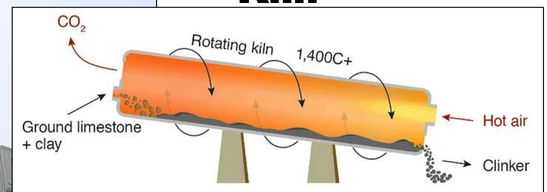
Silica

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

22

Portland Cement Production

Kiln



Clinker

23

Portland Cement Production

Clinker

Gypsum

24

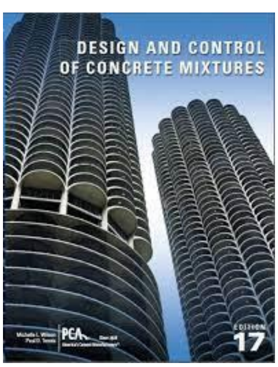
Cement Types

- The proportions of each of the raw materials in the cement, and how the cement is ground, determines how the cement will perform
- Type I: For <u>general use</u>
- Type II: For general use or when <u>moderate sulfate resistance</u> is desired
- Type III: For use when <u>high early-age strength</u> is desired
- *Type IV: For use when a <u>low heat of hydration</u> is desired (not readily available today)*
- Type V: For use when <u>high sulfate resistance</u> is desired
- Type IL: Can be used as Type I or Type II in most applications
- Blended cements

THE PRECAST SHOW

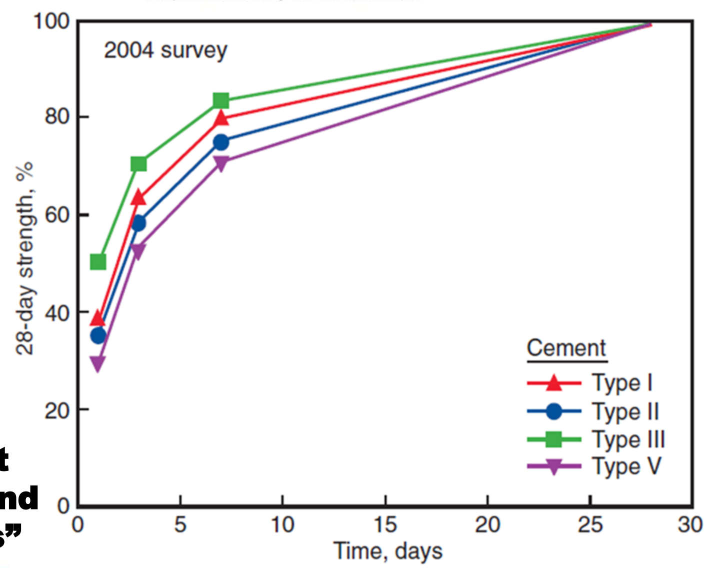
25

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).



THE PRECAST SHOW

26

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?

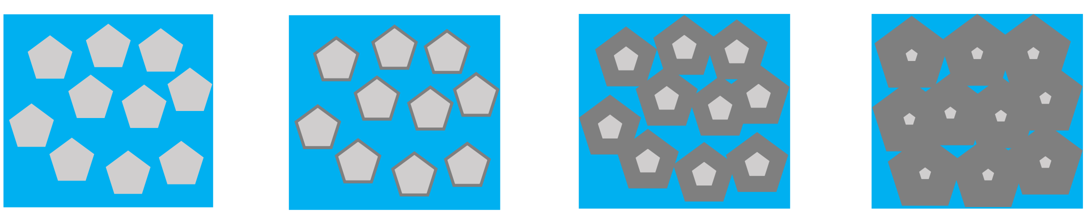
27

28

Cement and Water

29

Cement Hydration



- Water
- Cement
- Hydration Products

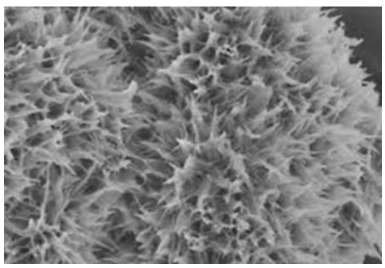
30

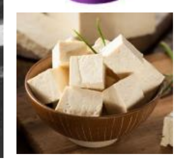
2 Main Products of Cement Hydration

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.

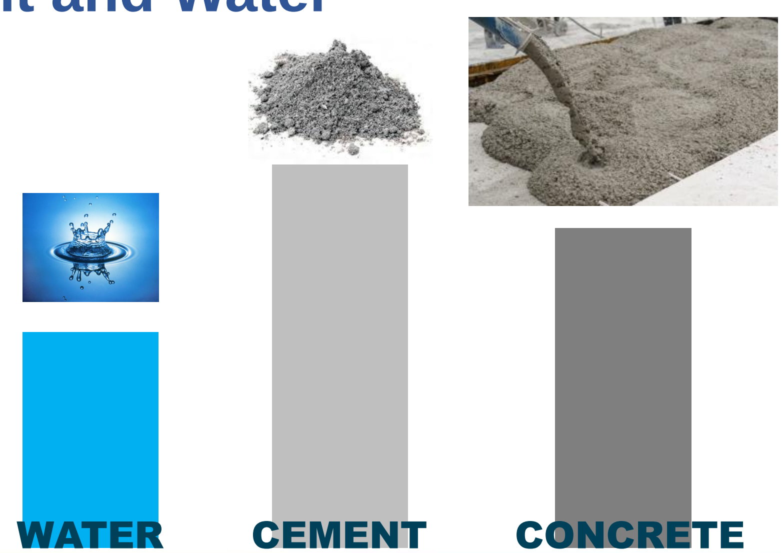




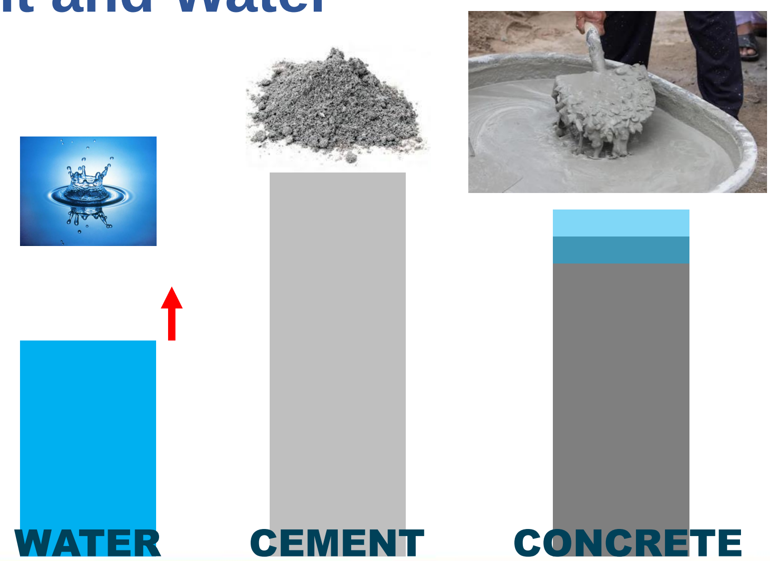
31

Cement and Water



32

Cement and Water



33

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
- 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

34

Water-to-Cement Ratio Examples

- 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
- Water-to-cementitious materials ratio (w/c_m) = weight of water / weight of all cementitious materials in a batch of concrete
  - 336 lbs water / (60 lbs fly ash + 640 lbs cement) = 0.48

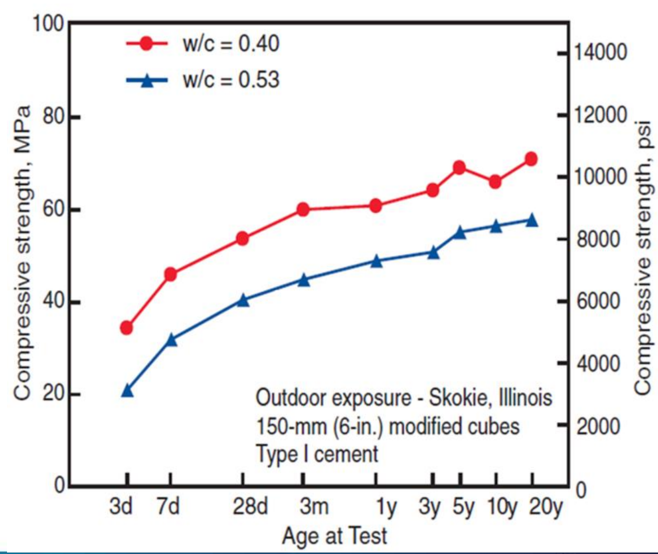
Cement

Fly Ash

35

Water-to-Cement Ratios

- Concrete's water-to-cement ratio (w/c) has a <u>significant</u> 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"

36

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**

37

Supplementary Cementitious Materials (SCMs)

- Supplementary cementitious materials (SCMs) are used in conjunction with – and as a partial replacement for – portland cement
  - Pozzolanic vs. hydraulic
  - Can be pre-blended with hydraulic cement
- Common types:
  - Fly ash
  - Slag cement
  - Silica fume
  - Metakaolin

38

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

THE PRECAST SHOW

39

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

THE PRECAST SHOW

40

Chemical Admixtures

- Main reasons for using admixtures:
  - Achieve certain properties in concrete more effectively than by other means
  - Maintain the quality of concrete during the stages of mixing, transporting, placing, finishing, and curing (especially in adverse weather conditions or intricate placements)
  - Overcome certain emergencies during concreting operations
  - Economy
- 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

41

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.

42

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

THE PRECAST SHOW

43

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

THE PRECAST SHOW

44

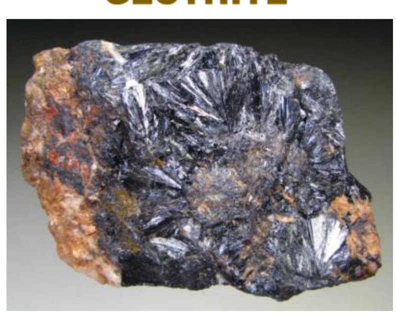
Light Weight Aggregate Concrete

45

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

46

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

47

Aggregate Gradation

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

48

Aggregate Size and Gradation

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

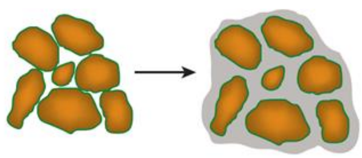
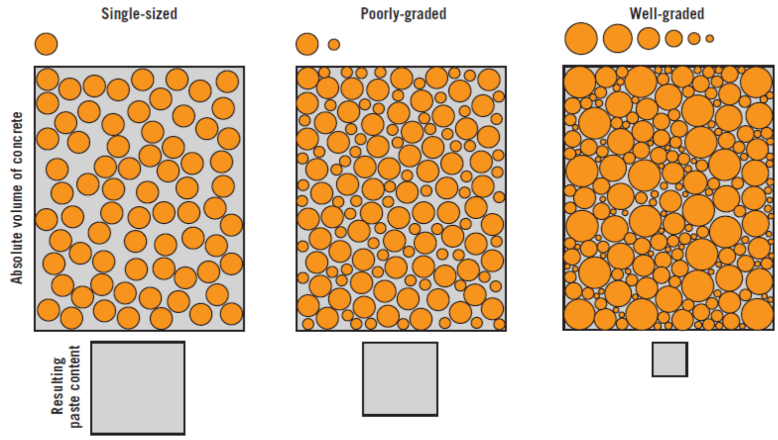


Figure 6-14. Illustration of the dispersion of aggregates in cohesive concrete mixtures.



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

THE PRECAST SHOW

49

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: $\mathbf{D_{max} = 1/5*B}$
  - 3/4 of the clear spacing between reinforcing bars and 3/4 of the clear spacing between reinforcing bars and the forms/molds: $\mathbf{D_{max} = 3/4*S}$ **and** $\mathbf{D_{max} = 3/4*C}$
  - 1/3 of the depth of slabs: $\mathbf{D_{max} = 1/3*T}$

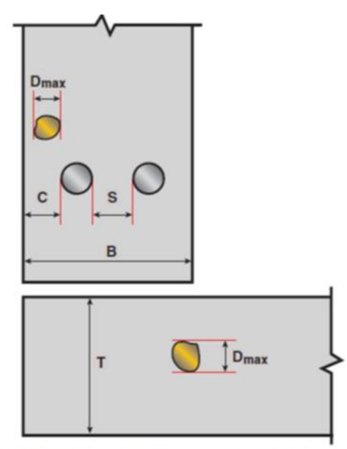


Figure 6-12. ACI 318 requirements for nominal maximum size of aggregates, D_{max}, based on concrete dimensions, B, T, and reinforcement spacing, S.

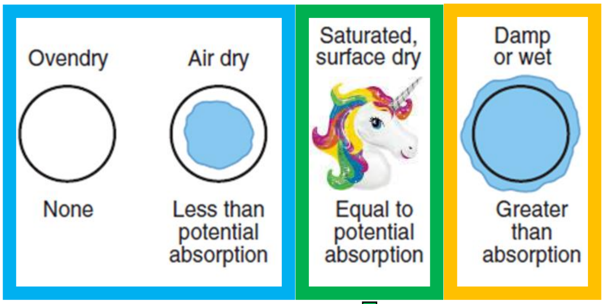
Figure from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

THE PRECAST SHOW

50

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.

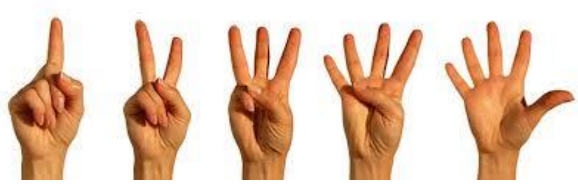
Figures from Portland Cement Association's (PCA) "Design and Control of Concrete Mixtures"

THE PRECAST SHOW

51

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)



THE PRECAST SHOW

52

Wet-Cast Concrete ("Conventional")

53

Wet-Cast Concrete ("Conventional")

54

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




55

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

56

Self-Consolidating Concrete (SCC)

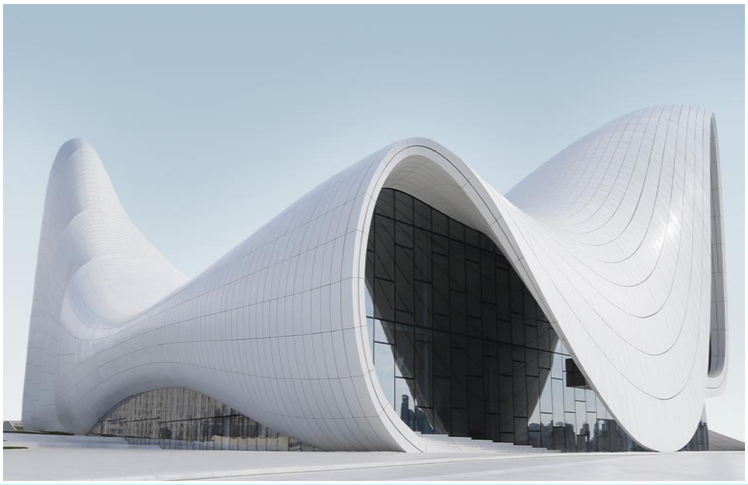
Uses LESS water than conventional wet cast concrete!

57

Self-Consolidating Concrete (SCC)

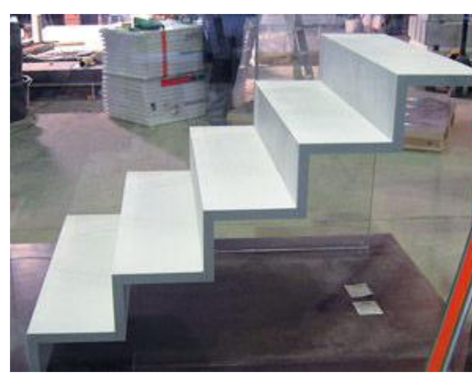
58

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



59

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



60

Precast Production Process & Types of Plants

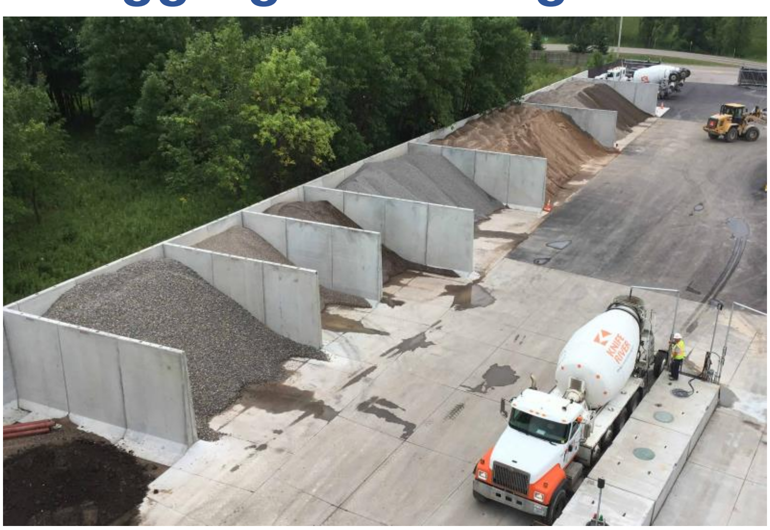
61

62

The Yard

63

Aggregate Storage



64

Avoiding Aggregate Cross-Contamination

65

Aggregate Hoppers & Cementitious Material Silos

66

Aggregate and Cementitious Material Conveyance

67

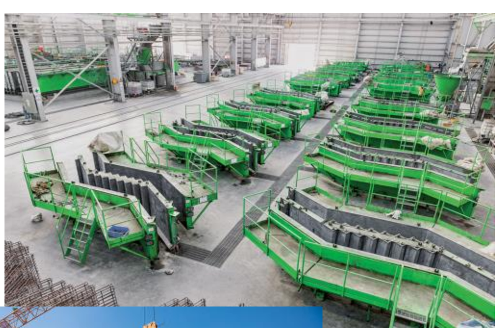
Reinforcement Storage

68

Production Facility Interior

69

Production Facility Interior



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

70

Mixers, Forms, and Concrete Buckets

71

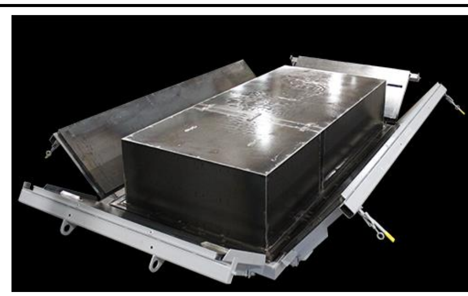
Concrete Mixers

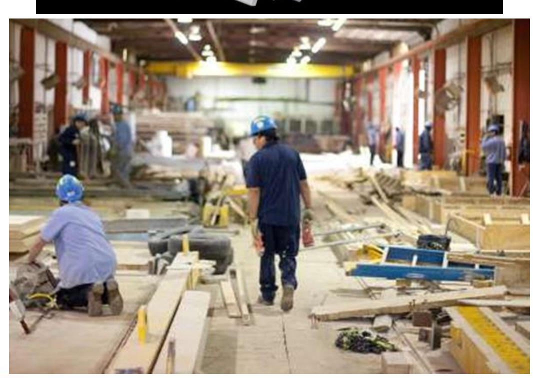
72

Forms / Molds

73

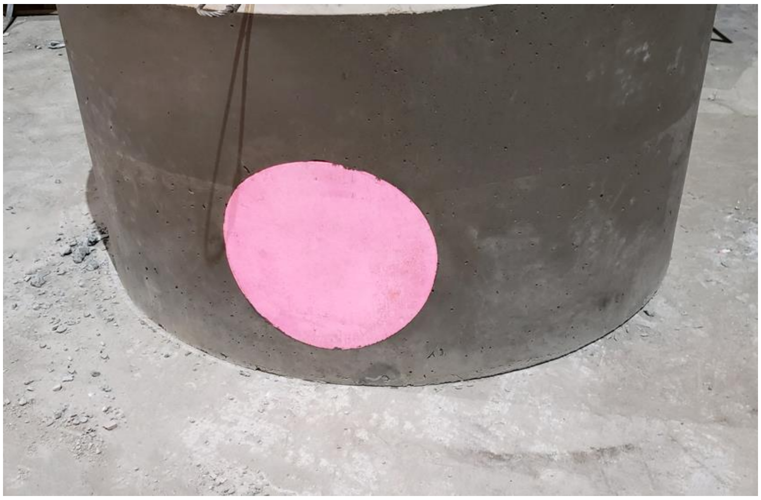
Forms / Molds





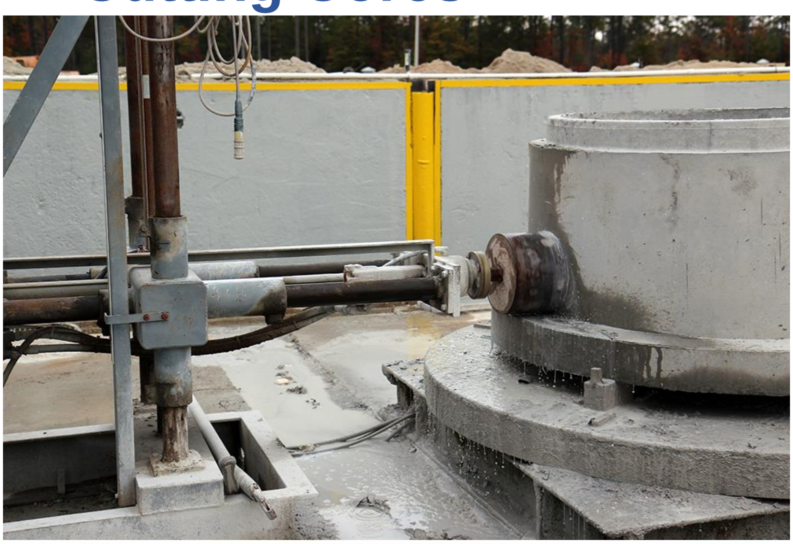
74

Knockouts and Blockouts



75

Cutting Cores

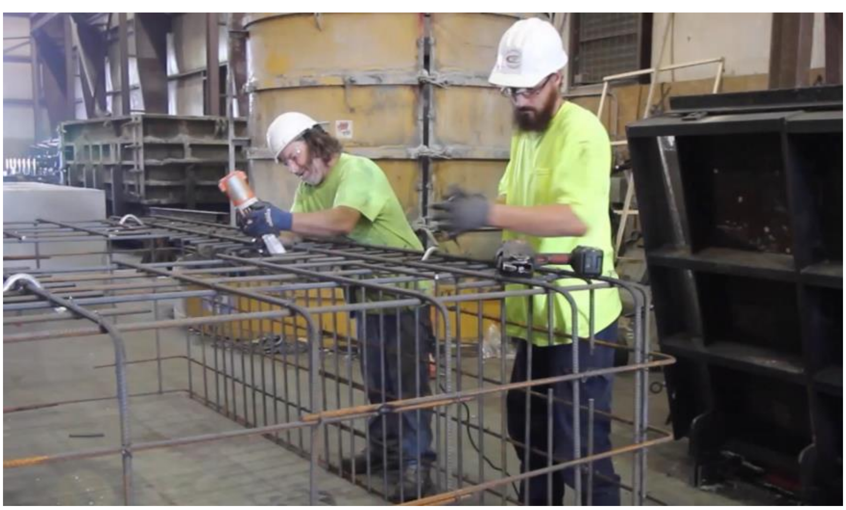


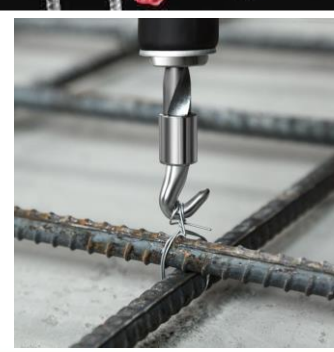
76

Bench / Invert

77

Reinforcement Fabrication





78

Chemical Admixture Equipment

79

QC Area

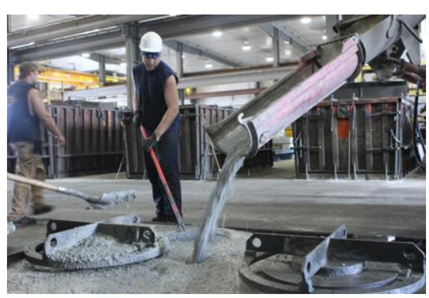
80

Batching Controls

81

Concrete Placing

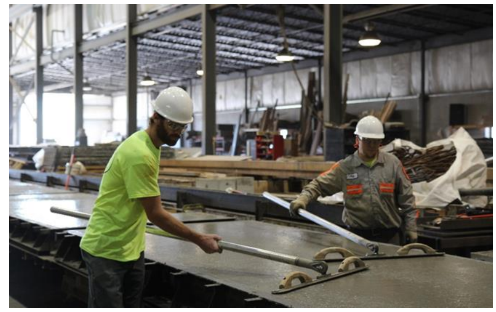
- Depositing and distributing freshly mixed concrete in the location where it will cure and harden
  - Deposit concrete as close to final location as possible
  - Minimize free-fall heights to less than 6 ft
  - Handle fresh concrete as little as possible

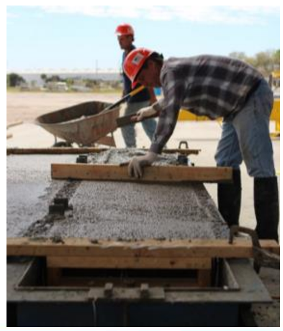


82

Concrete Finishing

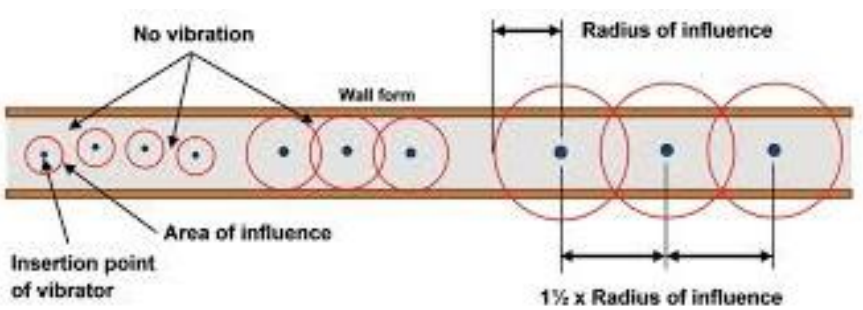
- Leveling, smoothing, consolidating, and otherwise treating fresh concrete surfaces to produce a desired appearance and surface service
- Order of operations:
  - Place the concrete
  - Consolidate
  - Screed/strike off
  - Float
  - Final finish (trowel, broom, etc.)





83

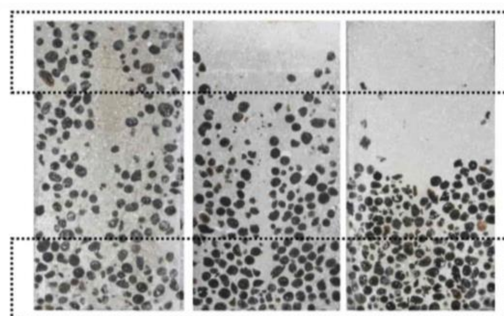
Concrete Consolidation



84

Importance of Concrete Consolidation

- Helps draw entrapped air to the unformed surface and out of the concrete, reducing pores and voids while increasing density
  - Bugholes are a sign of too little consolidation
  - Segregation is a sign of much consolidation

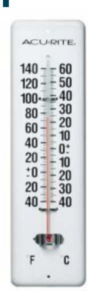


85

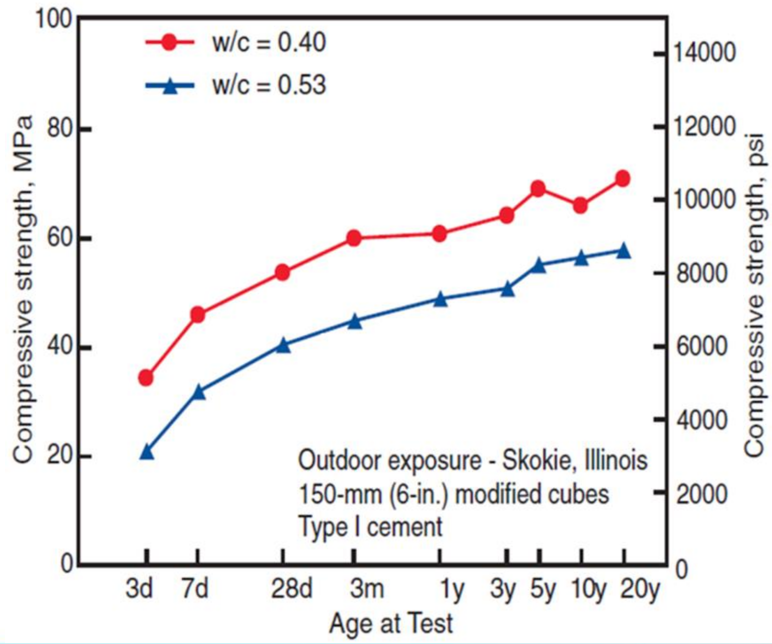
Curing Concrete

- 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**



86



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

87

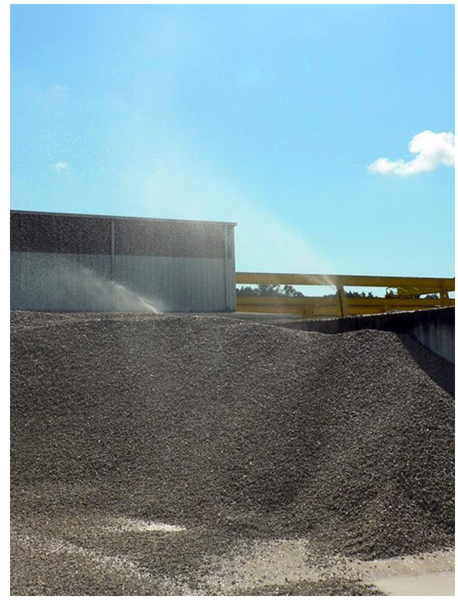
Cold Weather Curing

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

88

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



THE PRECAST SHOW

89

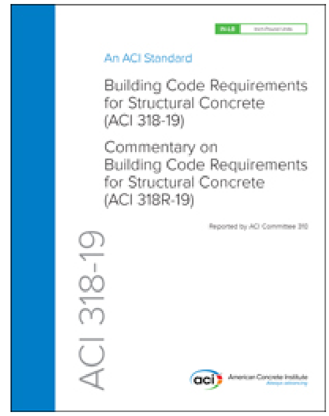
Accelerated Curing

THE PRECAST SHOW

90

Standards, Codes, & Specifications

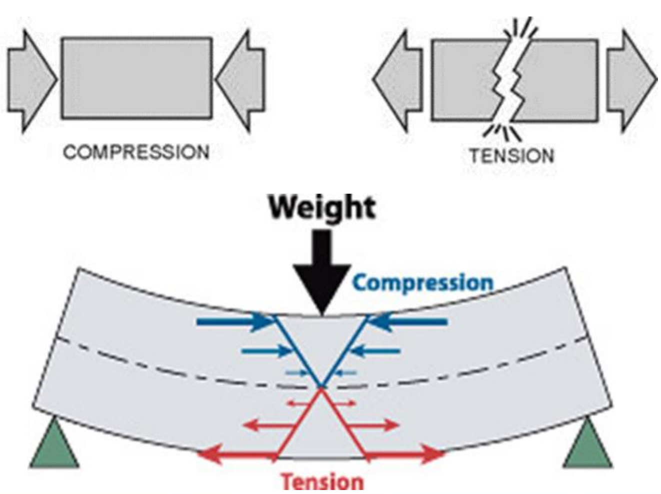
- Standard: Requirements for manufacturing, testing, or installing a particular product
  - ASTM C478, "Standard Specification for Circular Precast Reinforced Concrete Manhole Sections"
- Code: Detailed rules outlining what to do
  - ACI 318, "Building Code Requirements for Structural Concrete"
- Specification: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



THE PRECAST SHOW

91

Concrete Strength

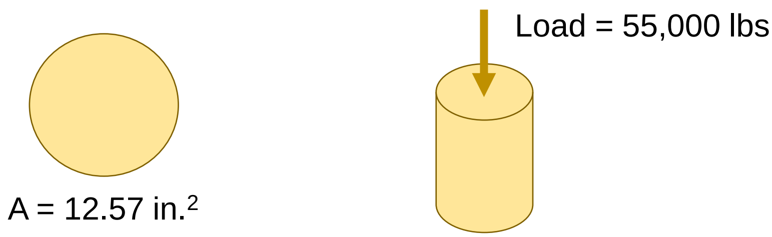


THE PRECAST SHOW

92

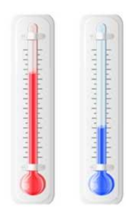
Concrete Strength

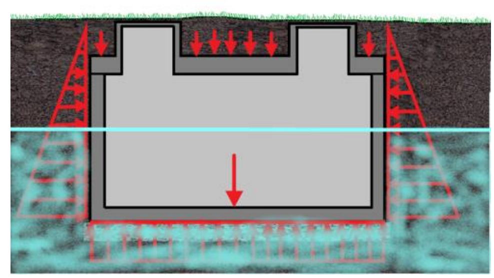
- Example: A 4-inch by 8-inch concrete cylinder
- Stress = load per unit area
  - Load applied to the cylinder = 55,000 lbs
  - Cross-sectional area of the cylinder = 12.57 in.^{2}
- Stress = 55,000 lbs/12.57 in.^{2} = 4,375 lbs/in.^{2} = **4,375 psi**



93

Loads and Forces



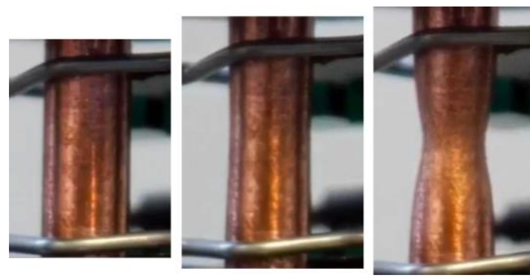


- Structure's self-weight
- Thermal stresses
- Shrinkage
- Buoyant forces
- Hydrostatic loads
- Soil loads
- Wheel loads
- Wind, snow, rain, seismic
- Handling loads

94

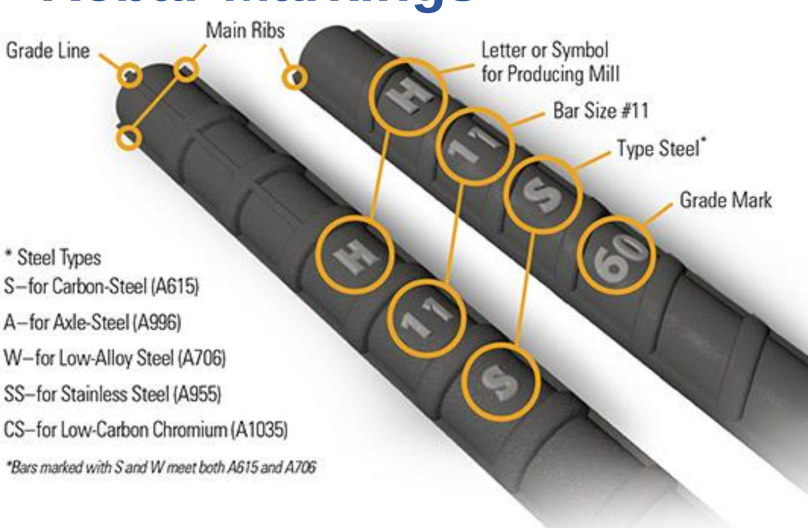
Reinforcement

- 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



95

Rebar Markings



* Steel Types
S–for Carbon-Steel (A615)
A–for Axle-Steel (A996)
W–for Low-Alloy Steel (A706)
SS–for Stainless Steel (A955)
CS–for Low-Carbon Chromium (A1035)
Bars marked with S and W meet both A615 and A706

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

96

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

97

Traditional Steel Reinforcement (Rebar)

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

98

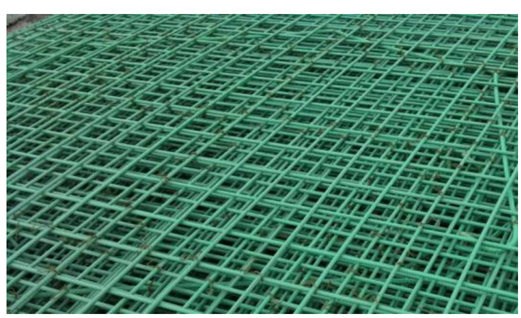
Welded Wire Reinforcement

- ASTM A1064 and ASTM A185: welded-wire reinforcement

99

Epoxy-Coated Reinforcement

- ASTM A775: epoxy-coated steel reinforcement



100

Zinc-Coated Reinforcement

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

101

Other Types of Reinforcement

Glass Fiber Reinforcement

Basalt Reinforcement

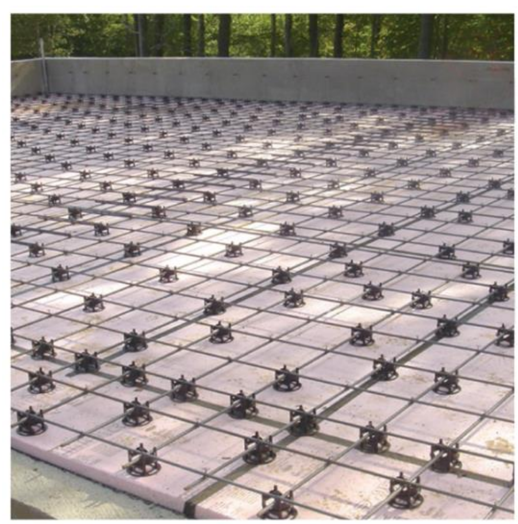
102

Concrete Cover Over Reinforcement

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

103

Chairs and Spacers



104

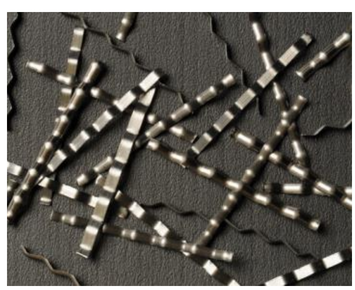
Fiber Reinforcement

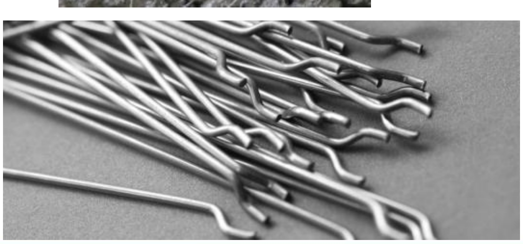
- Macrofibers and microfibers
- Steel fibers and synthetic fibers

THE PRECAST SHOW

105

Steel Fiber Reinforcement





THE PRECAST SHOW

106

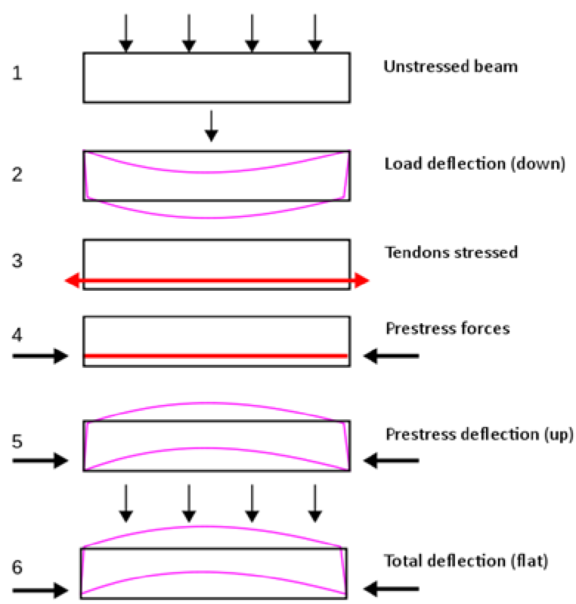
Synthetic Fiber Reinforcement




107

Prestressing

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



108

109

Prestressing

110

Prestressing

111

112

QA/QC and Concrete Testing

113

Quality Assurance & Quality Control

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

114

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

115

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.)

116

Fresh Concrete Testing

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

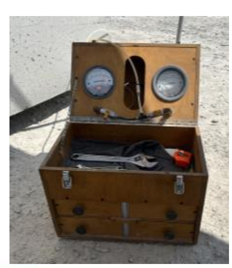



117

Hardened Concrete Testing

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





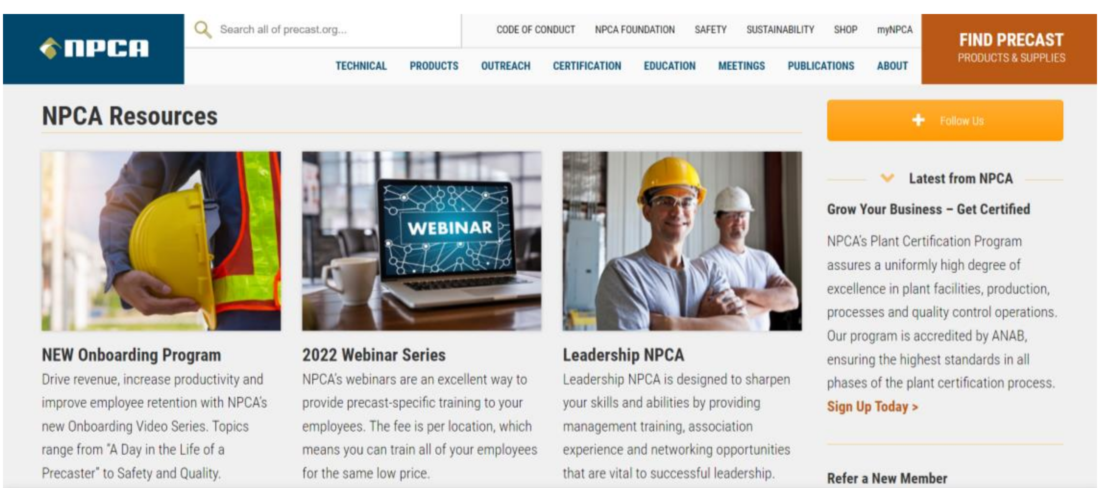
118

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

119

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



120

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.

121

Most Common Injuries in Manufacturing

- Slips
- Trips
- Falls
- Caught in/between

122

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

123

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

124

Precast 101

Kayla Hanson, P.E.

Concrete Sealants, Inc. | khanson@conseal.com | (800) 332-7325

125