PCI Plant Quality Talk
Quality Enhancement Committee

National Precast Concrete Association

Precast/Prestressed Concrete Institute

SERIES 1, ISSUE 1 – ACCELERATED CURING

Accelerated curing is advantageous when early strength gain is important or when additional heat is required to sustain the hydration reaction. Accelerated curing may reduce costs and save time to better meet precast concrete production demands and finished product quality. The best way to implement accelerated curing is by adding heat to the precast concrete component while reducing water evaporation through the use of steam, mist, or product tarps.

Common Issues

- If the precast concrete members are not fully covered during accelerated curing, there will be uneven heat distribution and therefore uneven strength gain.
- If the concrete heats up too fast, it may not gain the intended 28-day compressive strength.
- If heated too fast or at a very high temperature, the long-term durability of the concrete will suffer (see information on delayed ettringite formation).

Best Practices

- Fully cover production beds.
- Store compressive strength test cylinders with the pieces.
- Do not exceed 104°F before the concrete has achieved initial set (see QC for initial set time of each mixture).
- After initial set, the internal concrete temperature may ramp up 34°F per hour.
- The maximum internal concrete temperature should be 158°F for straight cement mixtures and 180°F with the proper use of SCMs (Supplementary Cementitious Materials).
- Cool-down should not be more than 50°F per day or 5°F per hour.

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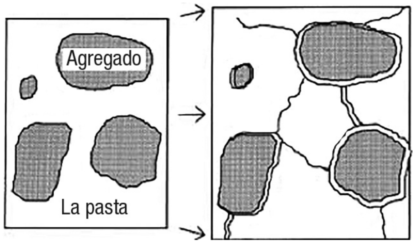
SERIES 1, ISSUE 2 – DELAYED ETTRINGITE FORMATION

Delayed Ettringite Formation (DEF). Sulfate compounds react with calcium aluminate in cement to form ettringite within the first few hours after mixing with water. If concrete is exposed to high temperatures during curing, the ettringite can dissolve and later reform when exposed to moisture, creating expansive forces within the concrete.

Common Issues

- Expansion and cracking can occur in concretes of particular chemical makeup when they have achieved high temperatures soon after placement (about 160 to 210°F).
- This delayed expansion is characterized by expanding paste that becomes detached from various components of the mixture, creating gaps at the paste-aggregate interface. The gap can then be filled with larger ettringite crystals.



Best Practices

- Use sound (proven) aggregate.
- Cure below 158°F for straight cement mixtures and below 170°F for SCM (Supplementary Cementitious Material) mixtures, after initial set (104°F max. during initial set).
- Use SCMs to mitigate the reformation of ettringite.

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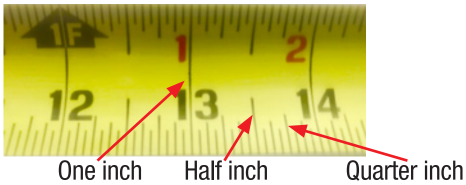
SERIES 1, ISSUE 3 – HOW TO USE A TAPE MEASURE

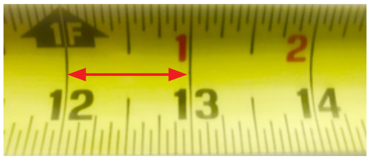
How to Read a Tape Measure

A tape measure is a type of flexible ruler that can be made from a variety of materials including steel, plastic, and cloth. Tape measures come in both imperial units (inches and feet) and metric (centimeters and meters), and have unit breakdowns for further accuracy. The following guides showing how to read a tape measure assume imperial units.

On a standard tape measure, the biggest marking is the inch mark. As the increments get smaller, so does the length of the mark. For example, ½ in. has a bigger mark than ¼ in., which has a bigger mark than ⅛ in., and so on.



The space from the largest mark to the next one is one inch.



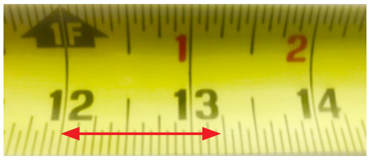
Reading one-half inch is the same as reading one inch, only the space between the second-biggest mark and the biggest mark is read. Think of a half-inch mark as halfway between a full inch.

The remaining markings follow a similar pattern: ¼ in. is half of ½ in.; ⅛ in. is half of ¼ in. Most tape measure markings go as small as 1⁄16 in.

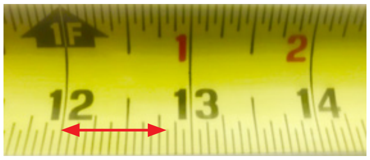
How to Measure Using a Tape Measure

Measure a length by putting the end of the measure at one end of the length you want to measure and keep the tape measure tight, with no sagging. Then take a reading on the tape measure.

To determine the accurate length, read the length in feet and/or inches and add any remaining fractions of an inch. For example, to determine the length shown in the image below, you would add 1 in. + ¼ in. to get 1¼ in., or "one and a quarter inches."



As another example, the image below shows a length that goes from the inch mark to one of the smallest markings, which are sixteenths—there are 16 of these increments per inch. To measure this length, count all the sixteenth markings or larger to get 13⁄16 in.



Note to instructor: Try measuring the following lines with your crew to get a sense of their grasp of the subject.

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SERIES 1, ISSUE 5 – STRAPPING DOWN LOADS

One of the most important jobs during loadout is making sure the proper strapping of products is in place.

Proper strapping of products ensures not only the safe travel of the product but also protects the product from sustaining damage during transit. Spalling at strapping locations is one of the most common complaints of contractors when products arrive at the jobsite.

Best Practices

All employees should be trained in operation procedures for the following:

- Always be aware of your surroundings.
- It is the driver's responsibility to ensure that the load is strapped down correctly.
- Always use chain guards. Refer to the following images of incorrect and correct use of chain guards on a precast concrete member.

Incorrect strapping without chain guards

Correct strapping with chain guards

Incorrect—chain guard is loose

Correct—chain guards are firmly in place

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SERIES 1, ISSUE 6 – CEMENT BALLING IN CONCRETE MIXTURES

When batching concrete mixtures, sometimes some of the constituent materials do not get mixed in homogenously. Often this results in “cement balls”: dry material that forms clumps during batching. These balls will result in a weakened concrete product and should be removed from the concrete if spotted. It is imperative to address the issue immediately.

Potential cause: Improper batching
Actions:

- Ensure proper material discharge timing.
- Ensure proper sequencing of materials:
  - Cement should ribbon in with aggregate.
  - Avoid putting all the water in up front.
  - Do not add high-range water-reducing admixture before the cement is wetted out.
- Increase mixing time.

Potential cause: Mixer condition
Actions:

- Clean any buildup in the mixer and on the mixing blades.
- Ensure all materials are introduced into the mixer at an even rate, not all at once.

Potential cause: Fiber
Actions:

- Make sure the timing of the fiber addition and mixing of fibers is per the manufacturer’s recommendation.
- Consider placing the fibers on the aggregate belt for introduction to the mixer.
- Reduce rate of introduction.

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SERIES 1, ISSUE 7 – MAKING AND TESTING 4 × 8 CYLINDER SPECIMENS

The correct preparation and storage of cylindrical test specimens as per ASTM C31 and PCI requirements is an imperative step in the production of quality precast concrete members. The proper testing of cylinders and recording of compressive strengths as per ASTM C39 and PCI requirements is important as well. Cylinders are needed to determine when concrete has the required compressive strength to strip forms, and safety is of the greatest importance. If required, cylinders are used to determine 7-day strengths. They are also used to determine the 28-day compressive strength as per engineering design requirements.

Best Practices

Making 4 × 8 inch test specimens:

- Equipment needed: cylinder molds, scoop, ⅜ in. diameter steel rod with hemispherical tip, flat level surface.
- Plastic single use molds can be reused a limited number of times; discard plastic molds if they lose their shape.
- Cylinder molds are to be lightly oiled so that the specimen can easily be removed from the mold.
- Take the concrete needed for the cylinders from the middle of the load after all water has been added. The minimum sample size is 1 ft^3.
- Put the concrete in the cylinder mold in two layers of equal volume.
- Each layer must be rodded 25 times, with the rod penetrating about 1 in. into the layer below.
- Each specimen is to be tapped 10 to 15 times with a rubber mallet or an open hand after rodding each layer.
- For self-consolidating concrete, fill the entire mold with concrete at one time with no lifts. Do not rod the concrete or tap the molds.
- Strike off the top of the cylinder.
- Finish the top of the cylinder to smooth the surface with a mag float or a steel trowel.

Storing specimens:

- Move the cylinders to their storage place immediately after finishing, keeping movement to a minimum.
- Once the cylinders have been placed in their curing spot, they are not to be moved until it's time to remove them from the molds.
- Store the cylinders in or on the form where the concrete they represent is being poured.
- Cover the cylinders in the same way that the concrete is covered.
- Handling of hardened cylinders is to be done with care to avoid chipping, breaking, or cracking.
- Remove the cylinder from the mold using air pressure applied to a small hole on the bottom of the mold, or remove the cylinder from the mold using a mold splitter.
- All cylinders must be marked with: job number, product type, mixture design number, cast date, 28-day test date, casting location.

Compression testing of cylinder specimens:

- Turn on the compression machine.
- Check the condition of the neoprene pads. If they are in bad condition, immediately bring this to the attention of the lab technician to obtain new pads. Place the cylinder in the caps.
- Place the cylinder in the compression machine and center the cylinder in the compression machine with the top and bottom platens.
- Ensure the spherically-seated top platen is free to rotate and that the cylinder is perpendicular to the bottom platen.
- Run at full advance until the numbers on the display begin to climb; at this point turn the machine setting to metered advance.
- Continue to load the cylinder at metered advance until failure.
- The load on the cylinder is to be added at a rate of 28 to 42 psi per second.
- Read the number on the display. This number is in pounds of force and needs to be converted to pounds per square inch (psi).
- To convert the display reading to compressive strength in psi, the math is as follows:

$$\frac{\text{load}}{\text{area}} = \text{compressive strength in psi}$$

Example: Load reading $=$ 48,500/area for a 4 $\times$ 8 in. cylinder $=$ 12.57 in.^{2} (Area $= \pi r^2$)

$$\frac{48{,}500}{12.57} = 3858 \text{ psi}$$

- When the conversion is made, record the compressive strength in psi and the age of the concrete.
- For the release strength, break a second cylinder using the same procedure as the first, record the psi, and average the two tests. For the 28-day test, an average of three cylinders is necessary.
- If the compressive strengths are within the required range, the corresponding piece is safe to strip from the form. If the compressive strengths are not within required range, then a Quality Control Inspector is to be contacted and made aware of this critical situation right away.

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SERIES 1, ISSUE 8 – HANDLING EPOXY-COATED REINFORCING BAR

One method of preventing steel reinforcement corrosion in precast/prestressed concrete members is the use of fusion-bonded epoxy-coated reinforcing bar. There are some special considerations to take into account when working with epoxy-coated reinforcing bar.

Common Issues

- Epoxy coating gets scratched or chipped off of the reinforcing bar, creating a place for corrosion to begin.
- Epoxy-coated reinforcing bar is cut and the ends are not recoated, allowing corrosion to begin.
- Steel chains are used to lift epoxy-coated reinforcing bar, damaging the coating.

Best Practices

- When handling epoxy-coated reinforcing bar, take special care not to damage the coating.
- Use nylon strapping to ensure the coating is not damaged by cables or chains.
- Use multiple lift points so that bars are not allowed to sag and rub during handling.
- Epoxy-coated reinforcing bar needs to be stored separately from non-epoxy-coated reinforcing bar.
- Take measures to protect bars, such as storage on wood, plastic, or rubber-coated racks.
- Bars with damaged coatings need to be repaired using an approved repair material before being used.
- If stored outside, epoxy-coated reinforcing bar needs to be protected from direct sunlight. Ultraviolet light degrades the epoxy coating over time.
- When assembling reinforcing bar cages using epoxy-coated reinforcing bar, take care not to damage the epoxy coating.
- When tying cages, use PVC-coated tie wire (4.8.5 of referenced article).

Reference

CRSI product guide, *Specialty & Corrosion-Resistant Steel Reinforcement*.

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SERIES 1, ISSUE 9 – YARDING AND DUNNAGE

The use of dunnage and related storage practices are important to precast concrete. Proper dunnage and yard storage are needed to ensure the quality of precast concrete members. Failure to store products properly can lead to damage or can cause considerable amounts of field repairs. A proper storage plan and dunnage method are necessary to help maintain quality requirements.

Common Issues

- Improperly placed dunnage
- Using the wrong size dunnage
- Precast concrete member stacked incorrectly; dunnage not aligned
- Unlevel or soft ground for storage
- Lack of space
- Dirty dunnage, sap leaking, staining by water runoff from dunnage
- Cracks from poor-quality dunnage

Uneven stacking; dunnage not aligned

Misaligned stacking, tilted stack, and soft ground

Best Practices

- Two dunnage points, unless more are required by design
- Level bearing
- Clean dunnage, non-transfer dunnage materials (i.e. - products that do not leave marks on precast members)
- Adequate storage space
- Flat ground that is paved or graveled
- Grading the yard as required due to traffic or weather conditions
- Quality yard checks for compliance, conducted by Quality Systems Management Team

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SERIES 1, ISSUE 10 – EMBED PLACEMENT

Placing embeds is a vital part of the precast concrete production process. The location of each required embed is significant for the installation/connection of each precast concrete piece. Proper placement will help field crews maintain the erection schedule and contributes to the overall quality of the project. These connections are very important to the success of each project. Embed issues can create significant costs for the field when redesign and/or rework is required, and can cause delays.

Common Issues

- Embeds not in the proper location
- Embeds sunk into the concrete or moved off during casting
- Incorrect shop drawings, causing mislocated embeds
- Lack of consolidation around embeds (voids)
- Embeds missing
- Embed not level
- Lack of training of importance of embed location

Best Practices

- Use standard plates specific to certain product types.
- Shop drawings should provide special embed details with a dimensioned detail.
- Provide a drawing that contains all embeds needed for each piece.
- Have a quality system in place with pre- and post-pour checks for proper embed placement.
- Plant should provide standard work instructions for proper embed placement (refer to PCI MNL 135 for standard imbed tolerances per production type).
- Develop a standard practice to ensure there are no voids beneath the embed as it is being cast.
- Premount embeds whenever possible.
- Avoid placing embeds into concrete that has already begun to set.

Embed not flush with concrete surface

Embed not level

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SERIES 2, ISSUE 1 – MATH FOR PRESTRESSED CONCRETE: PERCENTAGES

The word “percent” (%) means “per 100.” For instance, if 98% of all plant employees wear proper personal protective equipment, then 98 employees out of 100 wear their safety equipment. A lab technician who scored 78% on an ACI exam answered 78 out of each 100 questions correctly.

Percentages and decimal numbers can both be used to express the same mathematical proportions. To convert a decimal number to a percentage, the decimal is moved two places to the right. This is the same as multiplying by 100. To convert a percentage to a decimal, move the decimal point two places to the left, which is the same as dividing by 100.

Percentages and decimal equivalents

0.3% = 0.003
1% = 0.01
5% = 0.05
10% = 0.10
33.3% = 0.333
100% = 1.00
125% = 1.25

The general equation is as follows:

$$\text{Percentage} = \frac{\textit{Part}}{\textit{Whole}} \times 100$$

Example 1:

- A production crew incorrectly located the weld plates in 10 precast concrete pieces out of a total of 65 pieces cast for a project. What percentage of the panels should be reported as nonconformances?
- The total number of panels cast is the *Whole* and the number of panels with weld plate issues is the *Part*.

$$\% = \frac{10 \text{ nonconformances}}{65 \text{ panels cast}} \times 100$$

$$\% = 0.15 \times 100 = 15\%$$

Example 2:

- Fine aggregate was sampled and dried to determine the amount of moisture present. The weight of the wet sample is 1400 g and the weight of the dry sample is 1350 g. What is the moisture content of the sand?
- ASTM C566 states that moisture content of aggregate should be based on its dry weight; therefore, the *Whole* is the dry weight. The *Part* is the amount of water removed during drying, which is the difference between the wet weight and the dry weight.

  1400 g – 1350 g = 50 g of water removed

$$\% = \frac{50 \text{ g}}{1350 \text{ g}} \times 100 = 3.7\% \text{ moisture}$$

Example 3:

- A concrete mixture is designed to achieve 7000 psi. What percentage of the design strength does a cylinder that tests at 7350 psi represent?
- Because we are asking for a percentage of the design strength, the design strength is the *Whole*, even though 7350 is the larger number. In this example the percentage is larger than 100.

$$\% = \frac{7350 \text{ psi}}{7000 \text{ psi}} \times 100 = 105\%$$

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Reference
ASTM C566, *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying.*

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SERIES 2, ISSUE 2 – MATH FOR PRESTRESSED CONCRETE: VOLUME

It is necessary to calculate the volume of precast concrete members to know how much concrete it will take to fill the corresponding formwork.

Rectangular Shapes

The simple equation is:
Length × Width × Height = Volume

Concrete volume is usually discussed in terms of cubic yards.
One cubic yard (yd^3) = 3 × 3 × 3 ft = 27 cubic feet (ft^3)

If you have an 18 in. square beam that's 30 ft long, you will need to convert all the measurements to the same unit to determine the volume. In this case, let's use feet. 18 in. = 1.5 ft, so:

$1.5 \times 1.5 \times 30\ ft = 67.5\ ft^3$
To convert to cubic yards, divide by 27 (the number of cubic feet per cubic yard):
$67.5/27 = 2.5\ yd^3$ of concrete

If you have a panel that's 5 in. thick, 12 ft 6 in. wide, and 26 ft 9 in. long, you will need to convert all the measurements to the same unit before calculating the volume. In this example, let's use feet. (To convert inches to feet, divide by 12.) So:
5 in. = 0.417 ft, 12 ft 6 in. = 12.5 ft, and 26 ft 9 in. = 26.75 ft.
$0.417 \times 12.5 \times 26.75\ ft = 139.4\ ft^3$
To convert to cubic yards, divide by 27: $139.4/27 = 5.16\ yd^3$

If that same panel included a block-out or opening that was 4 × 5 ft, then you would need to calculate that volume and subtract it from the total panel volume to figure out how much concrete it would take to fill the mold, but not the block-out. So:

$0.417 \times 4 \times 5\ ft = 8.34\ ft^3$
$8.34/27 = 0.31\ yd^3$
$5.16 - 0.31\ yd^3 = 4.85\ yd^3$ of concrete

Cylinders

Determining the volume of a cylinder is a little different. The equation is:

$\text{Volume} = \pi \times r^2 \times h$

where

π = pi = 3.14

r = the radius of the cylinder (half the diameter)

h = the height of the cylinder

So, the volume of a cylinder that is 6 in. across and 12 in. high would be:

r = ½ of 6 in. = 3 in.

$r^2 = 3 \times 3 = 9\ in.^2$

h = 12 in.

$3.14 \times 9 \times 12 = 339\ in.^3$

To convert to cubic feet, divide by 1728 (the number of cubic inches per cubic foot: 12 × 12 ×12 in.)

$339/1728 = 0.20\ ft^3$

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SERIES 2, ISSUE 3 – HOT WEATHER CONCRETING

Hot weather problems are mostly encountered in the summer months, but need to be considered whenever fresh concrete is exposed to any of the following: high temperatures, high winds, low humidity, and direct sunshine.

The Effects of Hot Weather on Concrete

High concrete temperature causes a higher water demand, which can prompt the addition of water, resulting in lower strength and reduced durability. Higher temperatures accelerate the rate of slump loss and can cause loss of entrained air. Generally, concrete that is cured at high temperatures at an early age will not be as strong at later ages (28 days) as the same concrete cured at lower temperatures.

High temperatures, high wind velocity, and low relative humidity can each cause a high rate of evaporation, which can promote plastic shrinkage cracking before the concrete sets, and encourage early-age drying shrinkage. Thermal cracking may result from rapid variations in temperature, such as when concrete members are cast on a hot day followed by a cool night. High temperatures also accelerate cement hydration and contribute to the likelihood of thermal cracking in thicker concrete segments.

Hot weather conditions can result in a rapid rate of evaporation of moisture from the surface of the fresh concrete that makes a “spongy, rubber-like” surface that’s difficult to finish. It will also accelerate the set time of concrete, and therefore the finishing processes will need to occur at a faster rate. Typically, high relative humidity lessens the effects of high temperature with regard to rapid moisture loss.

Best Practice Options

- Follow supplier recommendations for adjusting concrete with the use of water-reducing and set-retarding admixtures.
- Use hydration control admixtures to extend workability times in high temperatures.
- Change the concrete mixture constituents or proportions to reduce the heat generated by cement hydration, such as by using a Type II moderate heat cement. Also, the use of fly ash, slag cement, or calcium carbonate can reduce potential problems with high concrete temperatures.
- Schedule concrete placement to avoid interruptions and delays in placing and finishing. Concrete should be placed immediately, and sufficient personnel should be available to place and handle the concrete.
- When possible, avoid the hottest part of the day when placing concrete.
- Do not sprinkle water on the surface of concrete members to facilitate finishing; this can result in a higher water-cement ratio at the surface, resulting in surface scaling.
- Lower concrete temperature by using chilled water or ice as part of the mixing water. Chilled water can reduce concrete temperature by up to 10°F; ice can reduce temperature by up to 20°F. The overall water content will need to be reduced based on the volume of the ice added to the mixture.
- Concrete temperature at the mixer shall be maintained below a maximum of 95° F, unless otherwise specified and managed.
- Sprinkling and shading the aggregate helps lower the temperature of the concrete.
- Use windbreaks, sunscreens, mist fogging, or evaporation retardants to slow evaporation and reduce the risk of plastic shrinkage cracking.
- Micro fiber may be used to reduce the risk of plastic shrinkage cracking.
- Do not exceed the maximum allowable mixing water content established for the concrete mixture proportions.
- During dry and hot days, when the temperature of the steel forms exceed 120°F, wet the formwork before placing concrete. Do not allow excessive water to pond, and make sure the casting surface is free of excess water before placing concrete.
- Start curing as soon as possible after finishing is completed. Cover to retain moisture in the enclosure, thus increasing humidity at the concrete surface.
- Ensure that test cylinders maintain their temperature and moisture for the initial curing, matching the members in the casting bed.
- Accelerators may be used in hot weather to expedite finishing operations and to avoid plastic shrinkage cracking.

References

ACI 305R-10 Guide to Hot Weather Concreting

PCI TM-103, *Quality Control Technician/Inspector Level III Training Manual*, provides a method for determining the potential for plastic shrinkage cracking based on weather conditions and concrete temperature.

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SERIES 2, ISSUE 4 – COLD WEATHER CONCRETING

Cold Weather Considerations

Cold weather is when air temperature has fallen to, or is expected to fall below, 40 degrees F during the protection period. These conditions require special safeguards when placing, finishing, and curing concrete.

In its plastic state, concrete will freeze if its temperature falls below about 25°F. If fresh concrete freezes, its potential strength can be reduced by more than half, and its durability will be negatively affected as well. Concrete should be protected from from rapid cooling to maintain favorable curing.

As concrete cures, cement hydration generates heat. Newly placed concrete should be protected to retain this heat and thereby maintain favorable curing temperatures. Large temperature differences between the surface and the interior of the concrete mass should be prevented, as thermal cracking may result when this difference exceeds about 35°F.

Best Practice Options

- Concrete temperature can be controlled by heating the mixing water and/or the aggregates. The aggregates should not be heated to above 180°F.
- Chemical admixtures can accelerate the rate of setting and strength gain. Accelerating chemical admixtures are commonly used in the winter. Nonchloride accelerators should be used for prestressed concrete or when corrosion of steel reinforcement or metal in contact with concrete is a concern. Accelerating admixtures do not prevent concrete from freezing.
- Accelerating the rate of set and strength gain can also be accomplished by increasing the amount of portland cement or by using a Type III cement (high early strength).
- Preparations should be made before concrete placement in cold weather conditions. Snow, ice, and frost should be removed and the temperature of surfaces and metallic embedments in contact with concrete should be above freezing. This might require heating the formwork before concrete placement.
- Insulated blankets and/or tarps should be ready before casting starts. Enclosures and insulated forms may be needed for additional protection, depending on ambient conditions. Corners and edges are most susceptible to heat loss and need particular attention.
- If heat is applied to accelerate curing, the concrete surface should not be allowed to dry out while it is in a plastic state as this can cause plastic shrinkage cracks. Subsequently, concrete should be cured.
- Concrete temperature at the mixer shall be maintained above 50°F. Under best practices, MNL 116 requires that the combined concrete and forms temperature maintain a minimum of 50 degrees after placement and during curing. Materials shall be free of ice, snow, and frozen lumps before entering the mixer.

References

ACI 306R-16 *Guide to Cold Weather Concreting*

PCI MNL-116, *Manual for Quality Control for Plants and Production of Structural Precast Concrete Products*

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SERIES 2, ISSUE 5 – PROPER STEEL FORM CARE

Purchasing metal forms and/or rails to create formwork for concrete is expensive. However, when forms are cared for properly they can provide years, and even decades, of useful service.

The use of release agents at fresh concrete contact surfaces is recommended in every case. The use of a release agent helps to prevent concrete from sticking to the forms, which can result in buildup and possibly damage the integrity of the concrete members. Concrete buildup can cause damage to the forms when trying to remove hardened concrete from them. Forms with permanently attached hardened concrete will produce a surface of reduced quality.

Form Setup

- Apply the release agent with a sprayer and wipe the forms down with a rag or mop to distribute the form oil evenly if there is excessive release agent on them.

During Form Use

- Ensure formwork is securely fastened to prevent blowouts or form buckling from the concrete pressure applied when placing and vibrating.
- Ensure the forms fit tightly together to prevent movement and potential form damage during concrete placement, and to prevent paste leakage, which causes honeycombing.

Cleanup and Maintenance

- Inspect forms after each use for surface damage or attached concrete.
- Remove concrete residue from the forms with a scraper.
- Closely examine the backs of the forms or the insides of the form rails and remove any concrete buildup. Removing buildup reduces the weight of the forms and the energy required of employees during setup.
- After cleanup, coat the face of the forms lightly with a form release agent to prevent corrosion, using either a spray or brush-on application.

Storage

- Store the forms under a roofed area, or in the worst case, place the forms under a securely fastened waterproof tarp.
- Spray or brush the form surfaces liberally with release agent if the form storage is expected to be longer than one month, then recoat them every two to six months while idle, depending on exposure.

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SERIES 2, ISSUE 6 – PLACEMENT OF CONVENTIONAL CONCRETE

- Fresh concrete should be placed in the form as near as possible to its final position for conventional concrete.
- A primary aim of proper placement is to have as little segregation or separation of the mixture components as possible. Placing concrete on top of previously placed concrete and allowing a natural self-leveling action helps prevent segregation and pour lines.
- Square-nose shovels, concrete hoes, come-a-longs, or other concrete tools should be used. Garden rakes, round-nose shovels, or garden hoes should not be used because they tend to cause segregation.
- If a chute is used to place the concrete, control of the chutes has a considerable effect on segregation. The chute should be located to minimize the vertical fall of the concrete and sloped so that the flow is steady, but not too fast.

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SERIES 2, ISSUE 7 – VIBRATION OF CONVENTIONAL CONCRETE

Why Vibrate Concrete?

- Vibrating concrete allows trapped air to rise to the surface and escape, and aggregates to align.
  - Applying vibration causes the aggregate particles to oscillate and move.
  - Coarse aggregate particles become more closely aligned with each other.
  - Fine aggregate particles fill all the small cavities between the coarse aggregate particles.
- Concrete becomes stronger and more durable.
- Reinforcement gets encapsulated. Reinforcing bar is an integral part of the concrete; it is vital that the steel is completely encased in concrete.

Best Practices

- Never vibrate the reinforcing bar. This practice leaves air voids and leads to rust forming and eventual failure of the concrete surface. It may also push large aggregates away, weakening the interface between the reinforcing bar and concrete.
- The correct application of vibration is vital for a homogeneous product. Employees operating vibrators should be properly trained.
- Using internal vibrators to move concrete horizontally tends to cause segregation and should be avoided. An exception is made where concrete must flow beneath a horizontal blockout, in which case the concrete should be deposited on one side of the blockout and vibrated until it flows beneath the blockout to a level slightly higher than the bottom of the blockout.
- Internal vibrators should not be forced into the concrete but allowed to sink in under their own weight.
- Avoid inserting or withdrawing the internal vibrator too fast. Withdraw internal vibrators at 1 to 2 in. per second.
- Lifts or layers of concrete to be vibrated should not exceed 24 in.
- The internal vibrator should penetrate the previous layer of concrete a minimum of 6 in., when depth allows, to integrate the concrete between the two layers.
- Avoid touching the form or mold skin with the internal vibrator.
- Avoid touching the reinforcing steel with the internal vibrator.
- Avoid running the internal vibrator outside the concrete, but do not turn vibrator off before removing it from the concrete.
- To ensure a properly functioning tool, vibrators should be cleaned and inspected for damage daily.

References

ACI 309R, *Guide for Consolidation of Concrete*

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Concrete Institute

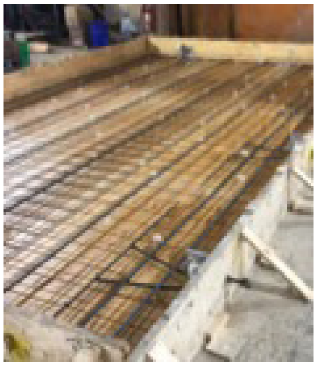
SERIES 2, ISSUE 8 – HOUSEKEEPING AND PRODUCT QUALITY

Precast concrete quality starts in the initial steps of the production process. One important step is to clean around the production mold. This helps to ensure that debris doesn't get tracked or carried into the mold. It also makes for a safer work environment during the production process.

Best Practices

- Keep the area around the mold clean. After strip-out, remove debris from around the working area.
- Inspect the mold surface for debris while applying the release agent and remove any foreign material.
- Inspect the mold after the steel reinforcement is installed and before concrete placement. An industrial vacuum works well to remove the debris from between the reinforcing and form faces.
- Mechanic-style magnets on an extension rod work well for removing metal particles or tie wires before casting.

These steps should help eliminate any additional work to remove and patch debris after stripping the product.



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SERIES 2, ISSUE 9 – AGGREGATE MOISTURE

Why is understanding aggregate moisture important?

Consider this scenario for a 3 yd batch of concrete: A change in the moisture content of the sand from 2% to 6%, because of an overnight rain storm, has the same effect as adding about 18 gal. (150 lb) of water to your mixer! Sand, and even rock, can hold a lot of water that will affect concrete consistency if adjustments are not made.

The moisture content of the rock and sand used in making concrete has a large effect on the slump or spread of concrete, typically adding 10% to 40% of the total water to the mixture. The aggregate moisture can change the effectiveness of the water-reducing admixture, how much air can be entrained in a mixture, the slump life, and even the color of an architectural concrete. Allowing your batch computer to adjust for the proper moisture content of the rock and sand if using an in-line sensor on the aggregates allows a producer to consistently deliver the needed workability and strength. Proper adjustments allow optimization of concrete and save money. Below is one of many ways to determine aggregate moisture.

What you'll need

- Scale: typically one that is readable to 0.01 g
- Source of heat: electric burner or hot plate works well
- Frying pans: built-in handles help reduce the risk of burns
- Container to obtain aggregate from pile or bin
- Small scoop

Procedures

- Obtain a representative sample of the aggregate. This is a very important step in the process, as moisture content can vary widely within a bin or a pile. If taking from a pile, a quick stir with the loader before sampling helps. Taking a few scoops from different areas and recombining them in a container will also increase accuracy.
- Reduce your sample to a minimum of 500 g of rock or sand. This amount is usually adequate for determining moisture content for batching concrete.
- Weigh the sample of wet aggregate.
- Heat the sample until all of the water evaporates.
- Pro tip: To easily determine when the aggregate is completely dry, place a strip of printer paper directly on top of the heated aggregate. If the paper curls, there is still moisture evaporating from the sample.
- Allow aggregate to cool sufficiently to not damage the scale.
- Calculate the aggregate moisture to 0.1%, as shown below.

Example Calculation of Total Moisture

Container weight:	300 g
Container + wet sand:	1510 g
Container + dry sand:	1472 g

$$\text{Aggregate moisture} = \frac{(\text{Container + wet sand}) - (\text{container + dry sand})}{(\text{Container + dry sand}) - (\text{container weight})} = \frac{1510-1472}{1472-300} = \frac{38}{1172} = 0.032 = 3.2\%$$

Remember to account for the aggregate absorption, as this amount of water doesn't contribute to the mixture or affect the slump, because it is inside the aggregate pores. The aggregate supplier can provide you with the absorption value.

Total moisture – Absorption = Free moisture

Use the free moisture in correcting batch weights of the aggregate and water for moisture content.

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SERIES 2, ISSUE 10 – BATCH PLANT AGGREGATE LOADER

One of most important jobs at a batch plant is the operation of the front end loader. The operator has the ability to feed the plant consistent materials, resulting in a consistent batching operation.

Common Issues

- Loading off the bottom of the pile
- Loading from different locations
- Stacking material too high
- Inconsistent moisture content

Best Practices

- Inspect aggregate stockpiles for debris and cross contamination before starting the loading operation.
- Keep the loader bucket at least 18 in. off the ground while loading the plant.
- Stack aggregates only as high as the loader will reach.
- Keep different size and color aggregates separated to prevent contamination.
- Contaminated aggregate can result in rejected fresh concrete or precast concrete members.
- Stir the aggregate within the storage before charging the batch plant.

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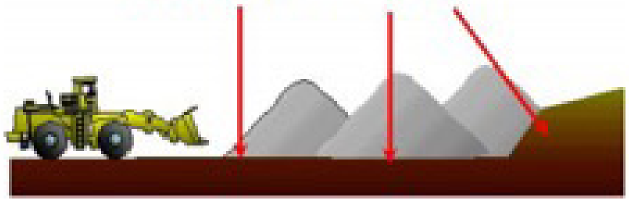
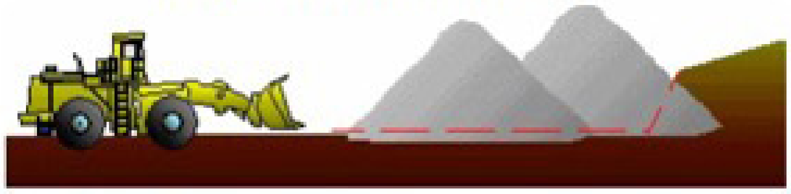
STOCKPILING TECHNIQUES FOR CLEAN STONE

DON'T DIG UP THE MAT



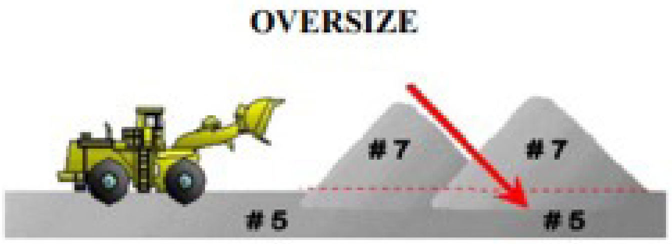
DO KEEP THE BUCKET UP



DON'T STOCKPILE
NEAR CONTAMINANTS

DO REMOVE CONTAMINANTS

DON'T STOCKPILE OVER
LARGER SIZES



DO STOCKPILE OVER
SAME SIZE OR SMALLER

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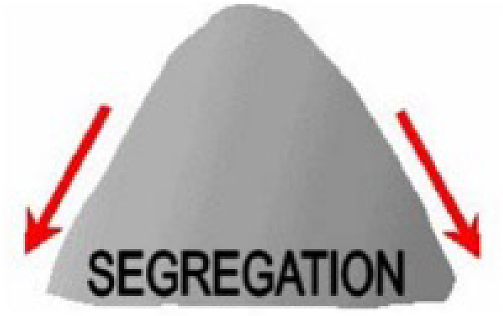
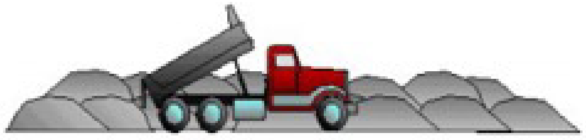
STOCKPILING TECHNIQUES FOR CLEAN STONE

DON'T CONE UP

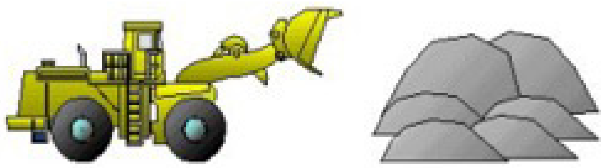


DO DUMP TIGHTLY IN SINGLE PILES



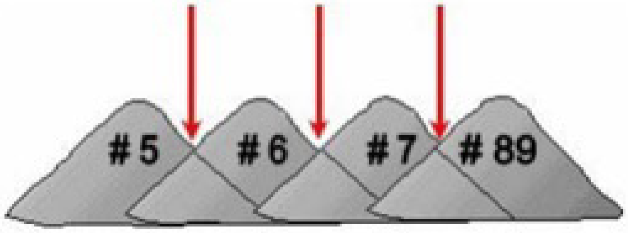
DON'T DUMP OVER THE END

DO STACK AS HIGH AS LOADER WILL REACH



DON'T OVERLAP SIZES

CONTAMINATION



DO SEPARATE DIFFERENT SIZES

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SERIES 2, ISSUE 11 – CEMENT MILL CERTIFICATES

What is a Mill Certificate?

A mill certificate is a quality assurance document used to verify/certify the material's chemical and physical attributes for the customer. The data represented on the mill certificate are typically averages of the tests performed by the manufacturer in the month reported. A mill certificate should be retained for each stockpile from which your plant receives deliveries (usually a lot, silo, or production number, as shown on the bill of lading).

Cement is manufactured by combining raw materials such as limestone, clay, sand, and iron, which are mixed and heated in a kiln at temperatures around 2700°F. Fluctuations in the amounts and chemistries of these raw materials can cause varying degrees of fluctuations in the physical and chemical properties of the cement. Because of these variables, it's important to understand that all cements are not the same. One cement isn't necessarily better or worse than the other, but different cements will perform differently, so they shouldn't be used interchangeably.

It is the job of the cement manufacturer to monitor the materials and processes and make changes in their processes to limit these fluctuations. Just like your plant wants to produce consistent concrete, a cement supplier wants to produce consistently performing cement.

What to Do With It

Mill certificate information is important for monitoring the physical and chemical trends over time. Below are examples of a few things to watch for and their potential effects on your concrete's performance:

- **Blaine fineness:** This is an indication of how finely ground the cement is. The higher the number, the finer the particle size. Finer cements exhibit higher early strengths, higher water demand, faster set times, and higher required air-entraining admixture dosages.
- **Minus(–) 325 mesh:** This is another indication of the fineness of cement. It's a measurement of how much of the cement will be retained on a #325 sieve. In conjunction with the Blaine, this value can give you a better indication of the particle size distribution. If the Blaine is very high (such as 4800) and 325 mesh is low (such as 82), it's an indication that there is a large amount of "super-fines," which have a tendency to easily hydrate with atmospheric humidity. Because they have already reacted, their presence is detrimental to concrete.
- **Vicat set time:** This is a measure of how quickly the cement will reach initial set (500 psi). It's reported on the mill certificate in minutes. The result reported on the mill certificate will not directly correlate to the concrete set time, but a change in cement set time will predict a change in concrete set time. A faster set time will likely result in a need to start finishing the concrete faster.
- **C_3A and C_3S contents:** Changes in these two compounds can affect early strength development, as higher contents will result in higher early strength. Higher C_3A-content cements will require a higher dosage of high-range water-reducing admixture than an equal amount of a lower C_3A-content cement.
- **Total alkalis:** The total alkalis impact the effectiveness of chemical admixtures and any supplementary cementitious materials (SCMs) such as fly ash or slag. Alkalis are typically reported as Na_2O equivalent. Changes in Na_2O equivalent on the mill certificate may indicate a change in how the admixtures and SCMs perform. Also, higher alkali content increases the potential for alkali-aggregate reactivity if reactive aggregates are in use.
- **One-day and 28-day strength:** Cement strength gives no indication of potential concrete strength, but can be used to troubleshoot concrete strength fluctuations. If the one-day strength drops on the mill certificate, you may see a drop in the concrete strength.

If the processes in your batch plant are optimized and monitored closely and you're still having issues, contact your cement supplier for guidance.

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SERIES 2, ISSUE 12 – BUGHOLES

Bughole Assessment/Troubleshooting

Providing customers with the desired quality of finish is very important, and the manner in which this expectation is satisfied can have significant cost impacts to the company. Final finishing processes to repair surface imperfections can bottleneck the production cycle, diminish aesthetic features, and reduce customer confidence in the product quality. Minimizing the potential for bugholes is an efficient way to achieve high-quality surface finishes at relatively low cost. Employees should be familiar with how the following production aspects affect surface quality, and be able to identify potential sources and evaluate solution options.

Form Conditions

- Dents, holes, build-up, and general roughness can potentially cause bugholes.
- The form material type can affect bugholes; wood forms are typically more forgiving than steel.
- Excess moisture should be removed from forms; trapped water can cause surface defects.
- A reactive release agent should be used, not a barrier type.
- Excess release agent/form oil should be removed from the form surface; too much form oil will cause very small bugholes and dark staining.

Concrete Handling

- The drop height of the concrete should be minimized to avoid trapping air.
- Place concrete slowly; this gives air in the form time to get out as it is displaced by concrete as the mold is filled.
- Allow enough mixing time to homogeneously blend the materials without adding too much extra time to any one batch.

Consolidation Method

- Use self-consolidating concrete or a highly fluid concrete, when possible.
- If vibrating conventional concrete, use the proper frequency and amplitude vibrator. Low-slump concrete responds better to low-frequency/high-amplitude vibration, whereas higher-slump concrete responds better to high-frequency/low-amplitude vibration.

Concrete Properties

- Select well-graded and clean aggregate.
- Use a coarse aggregate size that will pass between the reinforcing bar spacing.
- Have sufficient paste volume to fill the voids in the combined aggregate.
- Have sufficient viscosity to avoid excessive bleeding (higher T-20 test results).
- Ensure sufficient slump life to place all of the concrete batched.

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SERIES 3, ISSUE 2 – CONCRETE COVER OVER REINFORCEMENT

Concrete cover is the minimum required distance between the outer edge of embedded reinforcement and the surface of the concrete. The engineered production drawings (piece drawings or piece tickets) should specify the required concrete cover over the reinforcement for the component based on the component exposure within the structure.

Proper concrete cover serves to protect the precast concrete component in the following ways:

- It protects steel reinforcing bars and strand from corrosion due to infiltration of moisture into the concrete.
- It provides thermal insulation in the event of a fire.
- It provides proper embedment of the reinforcement in concrete to allow full development of the reinforcement for resistance against the various stresses imparted to the member.
- It reduces the potential for reinforcement shadowing on the concrete face.

Concrete cover problems can occur during fabrication of precast concrete components due to a variety of causes, including:

- Congestion of reinforcement and embeds
- Incorrect dimensioning of reinforcement and associated conflict with other reinforcement or embeds
- Improper fabrication of reinforcement or placement, such as incorrect radius on stirrups, reinforcement being placed incorrectly, or improper chairing of reinforcement
- Formwork built to incorrect dimensions and/or formwork movement
- Insufficient support or anchoring of the reinforcement to withstand the concrete placement and vibration process
- Walking on the reinforcing cage while placing concrete

Best Practices

- Correctly fabricate and check the reinforcement and other embedded items.
- If a conflict between reinforcement and embeds is observed, contact Engineering.
- Adequately support and restrain the reinforcement and embeds from shifting during the concrete placement and vibration process.
- Perform a comprehensive QC inspection using the approved drawings.

ACI Concrete Cover Requirements

The following is Table 20.5.1.3.3, Specified concrete cover for precast-nonprestressed or prestressed concrete members manufactured under plant conditions, from the American Concrete Institute's *Building Code Requirements for Structural Concrete* (ACI-318-19).

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CONCRETE EXPOSURE	MEMBER	REINFORCEMENT	SPECIFIED COVER, IN.
Exposed to weather or in contact with ground	Walls	No. 14 and No. 18 bars; tendons larger than 1-1/2 in. diameter	1-1/2
		No. 11 bars and smaller; W3I and D31 wire and smaller; tendons and strands 1-1/2 in. diameter and smaller	3/4
	All other	No. 14 and No. 18 bars; tendons larger than 1-1/2 in. diameter	2
		No. 6 through No. 11 bars; tendons and strands larger than 5/8 in. diameter through 1-1/2 in. diameter	1-1/2
		No. 5 bar; W31 or D31 wire and smaller; tendons and strands 5/8 in. diameter and smaller	1-1/4
Not exposed to weather or in contact with ground	Slabs, joists, and walls	No. 14 and No. 18 bars; tendons larger than 1-1/2 in. diameter	1-1/4
		Tendons and strands 1-1/2 in. diameter and smaller	3/4
		No. 11 bar, W31 or D3I wire and smaller	5/8
	Beams, columns, pedestals, and tension ties	Primary reinforcement	Greater of d_b and 5/8 and need not exceed 1-1/2
		Stirrups, ties, spirals, and hoops	3/8

Aggregate Size Considerations

- The clear distance between reinforcement and formwork shall be equal to the specified concrete cover or 1.5 times the maximum aggregate size, whichever is larger.
- The concrete cover and the concrete mixture design used must comply with the production drawings.
- These restrictions may be waived if the design professional verifies that the concrete can be properly consolidated.
- More information can be found in ACI 211.1, *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*, and ACI 302.1R, *Guide to Concrete Floor and Slab Construction*.

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SERIES 3, ISSUE 3 – FORM SURFACE DEFECT ASSESSMENT

A form surface defect rating index can be used during the quality control process to determine the severity of surface defects on concrete-formed surfaces resulting from the performance of the concrete mixture and evaluate whether the appearance of the forming surface on precast concrete is maintained over time. The rating index provides a method to monitor the consistency of the surface aesthetics of concrete members, and it can be used to determine the suitability of a concrete mixture for a given application. Precast concrete manufacturing plants can also use this rating index to document and track progress of mixture development, consolidation technique, and efforts to troubleshoot defects.

An example of a form surface defect rating index is provided here for reference. This index is subjective and is intended for internal quality control purposes only.

When using the form surface defect rating index, visually inspect the formed surface of the concrete member to identify the presence and distribution of defects and blemishes. Assign an index value to the concrete member using the criteria shown in Table 1. One or more of the worst items in a category can be used to establish the defect rating. Record the presence of surface defects along with the corresponding values from the index table.

TABLE 1. FORM SURFACE DEFECT RATING INDEX

0	Formed surface is smooth and defect free. Minor pinholes, not exceeding 1/16 in., cover no more than 5% of the surface area. Bugholes or voids greater than 1/4 in. are found in generalized areas but not throughout the member. Minor rust or markings are isolated to one area of the member.
1	Minor pinholes, not exceeding 1/16 in., cover more than 5% of the surface area. Bugholes or voids greater than 1/4 in. do not exceed two per square foot. Rust or markings appear four or more times on one member. Scaling, rust, or markings are predominantly in an isolated area of the piece.
2	Small bugholes or voids greater than 1/8 in. cover more than 50% of the formed surface. Bugholes or voids greater than 1/4 in. cover more than 20% of the surface. Voids larger than 1/2 in. do not exceed three per square foot. Scaling, rust, or markings appear on up to 50% of product length.
3	Many large bugholes or voids are observed. Small bugholes or voids cover more than 90% of the formed surface. Large amounts of scaling, covering more than 50% of formed surface, are observed. Consistent or patterned rust or markings cover more than 50% of the formed surface.

Quarter-point increments may be used to adjust form surface defect ratings if the appearance does not fit clearly into one rating category.

For possible causes of surface effects and suggested remedies, see ACI 309.2R-15, *Guide to Identification and Control of Visible Surface Effects of Consolidation on Formed Concrete Surfaces.*

Definitions from ACI CT-18, ACI Concrete Terminology

- **Bugholes:** see **surface air voids** (preferred term).
- **Honeycomb:** voids left in concrete between coarse aggregates due to inadequate consolidation.
- **Scaling:** Local flaking or peeling away of the near-surface portion of hardened concrete or mortar.
- **Surface air voids:** small regular or irregular cavities, usually not exceeding 5/8 in. (15 mm) in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation.

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SERIES 3, ISSUE 6 – REINFORCEMENT

Concrete is strong in compression but less so in tension. Steel exhibits strength in tension. When these materials are used together strategically, they complement each other, resulting in a very strong construction material: reinforced concrete. During the manufacturing process care must be taken throughout material procurement, storage, and fabrication to optimize the benefits of concrete and steel together.

Storage

- The bond between reinforcement and the surrounding concrete is critical to a precast concrete member's performance.
- Regardless of the type of reinforcement, the time of year, or the storage location, all reinforcement should be stored elevated from the ground. When reinforcement contacts the ground, contaminants such as dust, dirt, and oil can cling to the reinforcement's surface and reduce its ability to bond with concrete.
- Limiting the exposure of reinforcement to moisture will reduce the amount of rust that will develop on the reinforcement prior to its use.
- Some reinforcement may be shipped from the supplier with minor spots of rust. Rough steel surfaces can enhance the bond with concrete, so minor amounts of rust can improve bond strength. However, reinforcement must not be used if it shows signs that rusting has reduced the reinforcement's cross-sectional area.
- All reinforcement materials—whether bundles, mats or coils—must always be easily identifiable for as long as you have the material. The mill identification tag affixed to the shipment, which shows the supplier name, steel grade, dimensions and/or bar size, heat number, and other information, must remain attached to the supply until the supply is completely used.
- Stored reinforcement should be protected when in proximity to welding operations. Welding sparks can cause damage and create weak spots that may lead to failure.
- For information about the handling of epoxy-coated reinforcement, see Q*uality Talk Series 1, Issue 8: Handling Epoxy-Coated Reinforcing Bars*.

Fabrication

- All reinforcement must be fabricated in accordance with a detailed steel plan document. ACI 318, *Building Code Requirements for Structural Concrete*, outlines product-specific tolerances. However, some projects or jurisdictions will specify different tolerances, so it is imperative that the project documents clearly indicate the governing tolerance requirements.
- Use care when measuring, cutting, and bending reinforcement to ensure accuracy.
- Bending reinforcement in extremely cold weather without preheating of the bars may cause cracking or brittle breakage.
- Using reinforcement templates or jigs for frequently used or standard designs can help expedite the reinforcement cutting, layout, and assembly process while also reducing possibilities for human error.

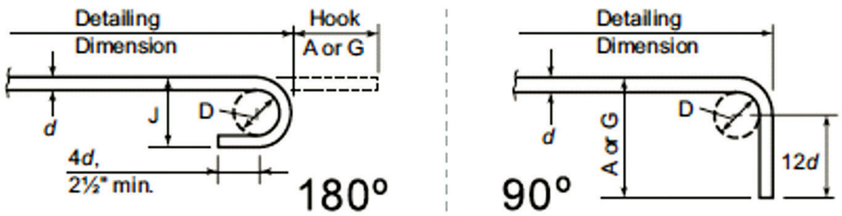

Figure 1. Concrete Reinforcing Steel Institute's standard hook and bend details in accordance with ACI 318.

- When bending reinforcing bars, benders in the field or fabricators in the shop must exercise caution to ensure that the bends are not too sharp (with the proper radius for the reinforcing bar size). Reinforcing bars may crack or weaken if bent too sharply.
- All reinforcement should be bent in accordance with standard Concrete Reinforcing Steel Institute (CRSI) fabrication practices. Give special attention to the minimum bend diameters and hook dimensions associated with different bar sizes, lengths, and steel types, which are set forth by CRSI and reference ACI 318.
- If the design, project specifications, or detailed reinforcing plans require a bend in reinforcing around a corner, it is not acceptable to substitute straight sections tied or welded together.
- Reinforcement cages, bar mats, and other configurations must be fabricated into rigid assemblies so they will retain their shape, dimensions, spacing, and integrity during handling, transport, positioning in the form, and concrete placement.
- Reinforcement that complies with ASTM A615, Standard *Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*, is usually not weldable direct from the supplier. Prior to welding, carbon equivalence calculations must be performed to determine any preheating requirements. If the carbon equivalent falls outside of the target range, the bars must be preheated before welding as determined by the carbon equivalence calculation.
- Reinforcement that complies with ASTM A706, *Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement*, is a low-carbon reinforcement. It is considered weldable without performing carbon equivalent calculations as long as the material temperature is above freezing.
- When the reinforcement is below 32°F (0°C), ACI-318 requires low-carbon reinforcement to be preheated to at least 70°F (20°C), with that minimum temperature maintained during the welding process.
- When welding any type of reinforcement, be careful not to burn through the reinforcement or cause undercutting; these actions compromise the reinforcement and weld integrity.
- Lap splices allow two lengths of reinforcement or two ends of welded wire reinforcement to be joined to act as one continuous section of reinforcement. Minimum lap splice lengths are dictated by ACI 318 and depend on the concrete strength, steel grade, and reinforcement bar size and spacing.

Additional Resources from CRSI

- *Placing Reinforcing Bars*, 10th ed. (2019)
- CRSI RB4.1, *Supports for Reinforcement Used in Concrete* (2016)

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SERIES 3, ISSUE 8– HANDLING, TRANSPORTING, AND CURING TEST SPECIMENS

During fresh concrete production, concrete samples are taken to make test specimens (typically cylinders or cubes) in accordance with ASTM C31/C31M, and per PCI MNL 116 and PCI MNL 117 requirements. Quality control teams use test specimens to evaluate hardened properties of concrete products such as the compressive strength of the concrete. Care must be taken while handling, transporting, and curing test specimens because the strength of a test specimen can be greatly affected by jostling, changes in temperature, and exposure to drying conditions, particularly within the first 24 hours after casting.

Handling Test Specimens

- Make test specimens as near as possible to the location where they will be cured.
- When moving freshly made test specimens, use your hands, a large trowel, or a similar device to lift and support them from the bottom of the molds.
- If the top surface of the test specimen is marred during movement, immediately refinish the top surface as instructed by ASTM C31/C31M.
- If a test specimen is cast from concrete with slump less than approximately 1 in. (25 mm), do not disturb it even in the first 15 to 30 minutes after casting. These test specimens are especially susceptible to damage such as cracks or weakened planes when handled.
- Store test specimens on a level, stable surface until they are to be tested for product stripping or transported for final curing. Test specimens made with self-consolidating concrete (SCC) may be more greatly affected by uneven surfaces. Do not place completed test specimens in an area of residual vibration from the formwork, and shield all test specimens from direct sunlight.
- Protect all specimens from rough handling at all ages.
- Once the test specimens have been placed in their initial curing spot, do not disturb them in any way until they are either ready to be stripped or tested.

Transporting Test Specimens

- Upon completion of initial curing, transport test specimens to the laboratory for final curing. Transport should occur within 48 hours after specimens were cast, but at least 8 hours after final set (as determined by ASTM C403/C403M). Note that test specimens are typically 12 to 14 hours old when they are transported and are very susceptible to damage if mishandled.
- Move test specimens carefully, and only remove the test specimen mold after they reach the laboratory.
- Ensure that plastic caps or bags remain on test specimens to avoid moisture loss during transit. Use insulation material to retain heat during cold-weather exposure.
- Ensure that test specimens are cushioned and well secured during transit to prevent damage from vibration and jarring.
- Do not exceed 4 hours of transportation time.
- Record any mishaps that occur during transportation, such as test specimens being chipped, cracked, or dropped.
- Retain test specimen identification throughout the entire life cycle of each test specimen.
- When a third-party testing laboratory is involved, record when the test specimens are transported and when final curing begins.

Initial Curing of Test Specimens

- All test specimens are subject to a period of initial curing:
    - Cure test specimens by applying the same methods as those used for the units they represent, up to the time of detensioning or stripping from the form/mold.
    - Store the specimens in or on the form where the concrete they represent is being poured.
    - To the fullest extent possible, protect all surfaces of the test specimens from the elements in the same way (temperature and moisture environment) that the formed unit is protected.
    - In lieu of actual curing with the component, test specimens may be cured in curing chambers correlated in temperature with the product they represent. In such a case, constantly verify the correlation by use of recording thermometers in the curing chambers and comparison with the temperature records of the product, and by use of the same methods of moisture retention for curing chambers and casting beds.

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Final Curing of Test Specimens

- Cure test specimens by one of the two methods described in ASTM C31/C31M:
  - Standard curing—used for acceptance testing and quality control (typical production plant curing)
  - Field curing—used to estimate the in-place strength of product for stripping purposes or to determine whether a structure is capable of being put in service (typical field-placed concrete curing, or special contract document requirement)
- Standard curing:
  - Control and record the initial curing temperature.
  - Upon completion of initial curing and within 30 minutes after removing the test specimens from their molds, cure test specimens with free water maintained on their surfaces at all times at a temperature of 73.5°F ± 3.5°F (23°C ± 2°C).
  - During the curing period, use lime-saturated water storage tanks or moist rooms maintained at 100% relative humidity until time of testing, except when capping with sulfur mortar capping compound.
- Field curing:
  - After stripping of the unit, remove the remaining test specimens from their molds and field-cure them in the same ambient conditions as required by project specifications for the product they represent until the time of testing.

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SERIES 3, ISSUE 11– POUR LINES

A pour line is a blemish that appears on a formed concrete surface as a color difference between successive concrete lifts within a pour. Pour lines may be relatively transverse or angled and are typically associated with the placement method and consistency of the concrete. Pour lines are often mistakenly identified as cold joints; the latter may have more serious structural consequences than pour lines.


Double tee exhibiting significant pour lines.

Causes of pour lines

Pour lines are often an indication of a change in concrete properties between batches of concrete during placement, or they may show a merge line between different areas of initial concrete placement. Typical causes include the following:

- **Delays.** If there is a delay between loads of concrete, the concrete in one layer in the forms may have already settled by the time the next layer is placed. Layering may also occur if excessive time passes between starting and finishing discharge for one layer and placing of the next layer. When delays occur, the result may be a variation of color, or possibly texture, typically caused by a slight change in the water-cementitious material ratio between each pour, batch, or layer. Darker fine material may also be brought to the surface with the paste in the first layer before the subsequent layer is placed.
- **Placement methods.**
  - The first discharged concrete into a form will roll at the form face, creating a head of paste along the edges. When two of these leading edges meet, the paste on the form face may be excessive, resulting in a pour line/sand streak or minor discoloration. When distributing concrete within a panel at the form face after the initial concrete discharge, always place additional concrete on the already discharged concrete, moving the concrete mass into areas needed by dragging with a rake.
  - Vibration near the leading edge of a concrete placement can cause the appearance of pour lines. To minimize the formation of discoloration pour lines when placing concrete in the flat face of a panel such as a wall panel, cover the entire panel face with concrete before applying any vibration.
- **Variations between batches.** Pour lines may also be due to natural color variation between concrete batches, a different rate of consolidation or vibration, or a difference in the curing stage of the fresh concrete.
- **Differences in viscosity.** With self-consolidating concrete (SCC), pour lines may occur because viscosity varies between layers or batches. The relative viscosity of SCC can be monitored with regular testing with the T-50 test method (ASTM C1611/C1611M).

If a visible line is found on an exposed concrete surface, it does not necessarily indicate a cold joint. This may be just a color variation between layers or batch placement that may fade with time. A pour line of this type can be a noncritical blemish and does not indicate a significant structural defect. However, pour lines do affect the aesthetics of a component and can be a meaningful concern in architectural products.

Avoiding pour lines

- Always keep the discharge behind the leading edge of the concrete flow as concrete moves across the panel during placement. If the discharge moves ahead of the flow, the newer discharged concrete may overcome the leading-edge paste, resulting in discoloration from trapped air and form oil that creates a pour line.
- Carefully monitor concrete consistency from batch to batch to ensure consistent concrete color and appearance. Pour lines can form when segregation and changes in concrete quality or water content occur between loads.
- After the initial load is placed, start placing subsequent loads on top of previously placed concrete, staying behind the flow edge and therefore pushing the leading edge across the form. Avoid starting at a new discharge point where two flow edges can come together.
- Avoid delays between loads. The flow edge may begin to stiffen before the next load can continue to move the edge during a pour.
- Form oil should be applied as directed by the manufacturer. If too much form oil is used during setup, the flow edge of the concrete will screed excess oil off the form face at the leading edge, resulting in a pour line or other discoloration.

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NPCA
National Precast Concrete Association

PCI
Precast/Prestressed Concrete Institute

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SERIES 3, ISSUE 12 – REINFORCEMENT SHADOW LINES

Reinforcement shadow lines typically look like faint shadowy lines on the surface of the concrete directly adjacent to the reinforcing steel. The shadowing may reflect the presence of steel reinforcement bars (rebar), strand, mesh, or other embedded items within the component. The severity or contrast of the shadow largely depends on the concrete mixture design, the amount of concrete cover of reinforcement, vibration of reinforcement, placing methods, and other factors.

Similar to pour lines, reinforcement shadow lines can be considered a noncritical blemish, rather than a significant structural defect. However, the accepting authority—the contractor, architect, owner, or jobsite inspector—may deem this defect to be an unacceptable finish defect.

To avoid reinforcement shadow lines:

- Take care to ensure an adequate amount of concrete cover of reinforcement (clear distance) is available for the coarse aggregate to flow around the reinforcement and panel face.
- Ensure as-specified reinforcement spacing, and take care to not disturb the cover during concrete placement. Limit concrete fall to 2 to 3 ft or less by means of a proper drop chute or device.
- For conventional concrete, ensure that vibration equipment (i.e., internal vibrators) is not in direct contact with reinforcement. Direct contact with reinforcement may amplify vibrations possibly resulting in increased consolidation of the concrete adjacent to the affected reinforcement. Concrete with increased consolidation may change appearance near the local reinforcement, thus resulting in shadowing of the reinforcement.
- Use aggregates that match the color of the paste as closely as possible. A high contrast in color between the cement paste (including pigments) and aggregates will increase the tendency for shadowing effect.
- If a combination of heavy reinforcement and a particular concrete mixture design are cause for concern, consider constructing a mock-up using the designed reinforcement and mixture design, with anticipated production practices to evaluate the acceptability of appearance.

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SERIES 4, ISSUE 1 - EFFLORESCENCE BASICS

What Is Efflorescence?

Efflorescence is a whitish, powdery residue on the surface of concrete. It occurs due to the presence of soluble salts, such as calcium hydroxide, in the materials used to make concrete.

In concrete at early ages, the hydrated cement contains a substantial amount of calcium hydroxide as a normal product of the hydration reaction between cement and water. Some of the calcium hydroxide that has dissolved in the mixing water migrates to the surface of the fresh concrete, where it reacts with carbon dioxide in the air to form the whitish deposit.

After stripping, efflorescence may appear within a few days. It sometimes does not appear until weeks, months, or (in rare cases) years have passed. Although efflorescence is generally harmless from a structural viewpoint, its initial appearance can be extremely detrimental to the appearance of a finished structure.

What Causes Efflorescence?

A combination of circumstances causes efflorescence.

- First, soluble substances must be in one or more of the materials. An abundance of calcium hydroxide is always present in concrete, but the quantity of soluble alkalis that contribute to efflorescence will vary depending on the cement source.
- Second, moisture must be present to dissolve the substances.
- Third, evaporation or hydrostatic or capillary pressure must cause the solution containing the dissolved substances to move toward the surface of the concrete. There must be a pathway through the pores or cracks in the concrete for the solution to move. Frequent wetting of the concrete surface helps facilitate this path.
- Fourth, the solution must evaporate once it reaches the surface of the concrete, leaving these soluble substances behind as efflorescence.

If any one of these conditions is eliminated, efflorescence will not occur. In most good-quality concrete, the efflorescence tendency will decrease with increasing age, and this decrease is assisted by rapid drying and carbonation of the surfaces. However, concrete that is constantly or frequently saturated with water can continue to develop efflorescence for years.

Minimizing Efflorescence

- Use a low-alkali cement, or a cementitious materials combination low in alkalis.
- Use sand that meets the requirements of ASTM C33/C33M, ASTM C144, or CSA A23.1. Never use unwashed sand containing soluble alkali sulfates or sand contaminated from soil runoff, plant life, or decomposed organic compounds.
- Use clean mixing water that is free from harmful amounts of acids, alkalis, organic material, minerals, and salts.
- Consider using additives and/or surface sealers.
- Use ingredients and methods to reduce concrete permeability and produce a concrete with a low water absorption (5% to 6% by weight or 12% to 14% by volume). Concrete permeability and water absorption are the key factors that the producer can influence to minimize efflorescence. It is therefore important to ensure the following:
  - Properly graded aggregates
  - A minimum cement content for stripping and service strength requirements
  - A low water-cementitious material ratio
  - Good consolidation techniques
  - Thorough curing

Pigment Considerations

- Coloring pigments usually have no positive or negative effect on efflorescence. Synthetic pigments are water insoluble and do not contain noticeable amounts of water-soluble salts.
- Pigments may appear to aggravate an efflorescence problem by making efflorescence more visible.
- Efflorescence deposited on the surface may mask the true color of the concrete, so that the pigment seems to be fading, even though the pigment itself has not changed.

Other Resources
Additional information on efflorescence can be found in PCI Technical Note TN-3, *Efflorescence on Precast Concrete*.

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SERIES 4, ISSUE 2 – REMOVING EFFLORESCENCE

Efflorescence is a whitish, powdery residue on the surface of concrete. It occurs due to the presence of soluble salts, such as calcium hydroxide, which can be in the materials used to make concrete. When efflorescence occurs during or immediately following construction, your first impulse may be to immediately wash it off with water or an acid cleaning solution. This is *not* advisable, particularly in cool or damp weather, because such action can introduce more water into the concrete. The water or cleaning solution will wash some of the alkali salts from the surface, but it will also dissolve and carry the salts back into the concrete, thus causing a reoccurrence of the efflorescence. In almost all cases, if you can wait a year or two before acting, most of the salts will migrate to the surface—thus, the problem may solve itself by normal weathering. The water-soluble alkali salts will gradually weather away.

Heavy calcium carbonate efflorescence, although less common, is extremely difficult to remove because it forms a hard white crust. After weathering to calcium hydrogen carbonate, it may be easily removed; otherwise, acidic cleaners may be necessary.

Efflorescence Test Area

Before beginning efflorescence cleaning operations on a large scale, a small area (at least 1 square yard) of the concrete surface should be cleaned and checked to be certain there is no undesirable effect on the concrete surface finish or adjacent corrodible materials such as glass, metal, or wood. A strip-off plastic can be sprayed onto glass and aluminum frames to protect them. The effectiveness of the method on the sample area should not be judged until the surface has dried for at least one week. If possible, concrete should be cleaned when the weather conditions, including temperature and relative humidity, allow for rapid drying. Slow drying increases the possibility of recurring efflorescence and discoloration.

Suggested Testing Process

When choosing a cleaning method to remove efflorescence from precast concrete, the least-damaging option should be tested first. The following is a suggested order for testing efflorescence removal procedures (beginning with the least damaging technique):

1) Dry scrubbing with a stiff fiber brush (particularly if the surface is brushed shortly after appearance of efflorescence).
2) Abrasive blasting with industrial baking soda. This abrasive will minimally affect the concrete surface. Residues should be blown, vacuumed, or brushed from the surface. Do *not* use water to remove residue on the surface—the water could dissolve salts and carry them into concrete, causing additional efflorescence.
3) Vigorous dry scrubbing of the finish with a stiff fiber brush followed by low-pressure washing of the surface.
4) Chemical cleaning compounds such as detergents, hydrochloric (muriatic) or phosphoric acid, or other commercial cleaners used in accordance with the manufacturer's recommendation. To prevent the chemicals from being absorbed deeply into the surface of the concrete, areas to be cleaned chemically should be thoroughly saturated with clean water before the cleaning material is applied. Surfaces should also be thoroughly rinsed with clean water after application so that no traces of detergents or acid remain on the surface of the concrete. Cleaning solutions should not be allowed to dry on the concrete surface. Residual salts can flake or spall the surface, or they may leave difficult-to-remove stains. Misapplication of hydrochloric (muriatic) acid can lead to corrosion of adjacent or embedded metals with shallow cover. Care should be taken to use diluted solutions of acid to prevent surface etching, which may reveal the aggregate and slightly change surface color and texture. Apply the solution to just one small area (less than 4 ft^2) at a time, and then wait about 5 minutes before scouring off the salt deposit with a stiff bristle brush and moving on to the next small area.

Any of the following diluted solutions of acids will effectively remove efflorescence:

- 1 part hydrochloric (muriatic) acid in 9 to 19 parts water
- 1 part phosphoric acid in 9 parts water
- 1 part phosphoric acid plus 1 part acetic acid (vinegar) in 19 parts water
- 1 part acetic acid in 5 parts water

Hydrochloric (muriatic) acid may leave a yellow stain on white concrete. Therefore, if an acid solution is needed to clean white concrete, a solution with phosphoric or acetic acid should be used.

Safety Precautions

- Materials used in chemical cleaning can be highly corrosive and are frequently toxic. Therefore, rubber gloves, safety eyewear, a respirator, and other protective clothing should be worn, in accordance with the manufacturer's recommendations, when using acid solutions or strong detergents.
- All precautions on a product label should be followed as these cleaning agents can affect eyes, skin, and breathing.
- Materials that can produce noxious or flammable fumes should not be used in confined spaces unless adequate ventilation can be provided.

Other Resources

Additional information on efflorescence can be found in PCI Technical Note TN-3, *Efflorescence on Precast Concrete*.

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SERIES 4, ISSUE 3 – WATER-CEMENTITIOUS MATERIAL RATIO

The water-cementitious material ratio (*w*/*cm*) is the ratio of the mass of water to the mass of the cementitious material in a concrete mixture, expressed as a decimal. It is a key factor affecting the properties of concrete, such as strength, workability, durability, and consistency.

The water-cementitious material ratio is calculated as follows:

w/cm = Mass of water / Total Mass of cementitious materials

The mass of the water used in the calculation includes the mass of the water directly added to the mixture as well as that added indirectly, such as in the aggregates. The total mass of the cementitious materials includes the mass of the cement as well as the mass of any supplementary cementitious materials such as fly ash, silica fume, and slag.

Instructions for a concrete mix design will specify the *w*/*cm*. The *w*/*cm* is used to determine the maximum amount of water to add to the mix including free water in excess of the saturated surface dry (SSD) condition of aggregates. If too much water is added to the concrete, the actual *w*/*cm* will be higher than the specified *w*/*cm*. That is a problem because adding too much water can weaken concrete: The excess water creates a diluted paste that separates cement particles. Then, when the cement and water chemically react to form crystals, the crystals are too far apart to form a strong bond. Concrete with a higher *w*/*cm* ratio is more susceptible to dry shrinkage cracking.

The water content requirements for a concrete mixture can be influenced by any or all of the following:

- Cementitious material types and content
- Aggregate size and shape
- Air content
- Admixtures
- Environmental conditions

Water demand can be lowered by the following:

- Increased air content
- Increased aggregate size
- Use of a rounded or cubical aggregate
- Use of a high-range water-reducing admixture

On the other hand, water demand is increased by the following:

- Increased concrete temperatures
- Increased cementitious material content
- Increased aggregate angularity
- An increase in the ratio of fine aggregate to coarse aggregate
- Use of lightweight aggregates

Per MNL 116 and MNL 117, the maximum allowable *w*/*cm* ratio for normal weight concrete is 0.45. During production, the *w*/*cm* is not allowed to vary from the ratio specified in the mixture design by more than 0.02.

Example:

Assume a batch with 30 gallons of water, 550 lb of cement, and 150 lb of fly ash. Each gallon of water weighs 8.33 lb. Aggregates are at SSD condition.

30 gallons × 8.33 lb/gallon = 250 lb of water

w/cm = 250 lb water / (550 lb cement + 150 lb fly ash) = 0.36

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SERIES 4, ISSUE 5 – MATH FOR PRESTRESSED CONCRETE: CONCRETE YIELD

Concrete is ordered by volume (per cubic yard) and batched by weight. If concrete ingredients are not accurately batched and combined, the materials may produce either more or less than the desired volume.

Yield refers to the actual volume of concrete produced from the batched materials.

- *Over yield* occurs when the weight of the materials batched provides a volume of concrete that is more than what was originally calculated and ordered. An over yield of concrete can increase the risk that the concrete may be rejected because it fails the project acceptance criteria for fresh concrete, strength, or durability requirements. If over yields are due to batching inaccuracy, that can also cause problems with inventory control of ingredients.
- *Under yield* occurs when the weight of the materials batched provides a volume of concrete that is less than what was originally calculated and ordered. An under yield of concrete can negatively affect the resulting properties of the mixture. For example, 2% under yield may result in 2% more cementitious material content per cubic yard than what was ordered. Under yield can also increase the standard deviation of strength, thereby reducing the quality of the concrete and increasing the cost of all concrete produced. An under yield can also lead to the need to order an additional, partial load because there is insufficient concrete to complete the casting operation.

Calculating Density (ASTM C138/C138M) (see Note 1)

- Select a container whose volume is known.
- Weigh the dampened, empty container.
- Fill the container with concrete, as described in ASTM C138/C138M.
- Weigh the full container; record the value to nearest tenth (0.1) of a pound
- Subtract the empty container weight from the full container weight to get the weight of the concrete.
- Divide the weight of the concrete by the known container volume to get the density (unit weight) of the fresh concrete.

Calculating Yields

Calculate the following using the total weight of all materials batched (aggregate, water, cement, etc.):

- Yield per batch in cubic feet = Total weight of all materials (lb) / Fresh density (lb/ft^3)
- Yield per batch in cubic yards = Total weight of all ingredients batched (lb) / [Fresh density (lb/ft^3) × 27]
- Yield per cubic yard in ft^3/yd^3 = Yield per batch in ft^3/Number of cubic yards delivered
- Yield as a percentage = (Actual volume of concrete/Reported volume) × 100

Example Problem

Assume a concrete batch with the following properties:

Volume of concrete targeted = 4 yd^3
Weight of materials batched = 15,930 lb
  Cementitious materials = 2800 lb
  Sand = 5520 lb
  Stone = 6627 lb
  Water = 118 gal x 8.33 lb/gal = (983 lb)

Density (unit weight) of the concrete = 147.52 lb/ft^3

Yield = 15,930 / (147.52 × 27) = 3.99 yd^3 in the actual batch

Yield per batch = 15,930 lb/147.52 lb/ft^3 = 107.98 ft^3

Cubic yards delivered = 4

Yield per cubic yard = 107.98 ft^3/4 yd^3 = 26.99 ft^3/yd^3

Yield (%) = (3.99 yd^3 4 yd^3) × 100 = 99.8%

Gravimetric Air Content Calculation

ASTM C138/C138M provides a method for calculating the air content of freshly mixed concrete using the gravimetric method.

The formula for calculating gravimetric air content is as follows:

$A = (B - C) \times 100/B$

where

A = air content as a percentage by volume

B = theoretical air-free density of the concrete in pounds per cubic foot

C = density (unit weight) of the fresh concrete in pounds per cubic foot

For example, if the theoretical air-free unit weight is 151.7 lb/ft^3 and the measured density (unit weight) is 141.4 lb/ft^3, the air content would be 6.8%:

A = (151.7 lb/ft^3 – 141.4 lb/ft^3) × 100/151.7 lb/ft^3 = 6.8%

Notes

1. This is a summary of the steps involved. Be sure to review ASTM C138/C138M for a full description of the process and requirements.
2. The suggested tolerance for yield is ±1% for non-air-entrained concrete and ±2% for air-entrained concrete. (NRMCA TIP-8, Concrete Yield)

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