PCI Plant Quality Talk Series 3
Quality Enhancement Committee

Series 3, Issue 1 – Prestressing Strand Traceability

Series 3, Issue 2 – Concrete Cover Over Reinforcement

Series 3, Issue 3 – Form Surface Defect Assessment

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SERIES 3, ISSUE 1 – PRESTRESSING STRAND TRACEABILITY

MNL-116 and MNL-117 require that prestressing strand used in pretensioned applications meet ASTM A416/A416M, *Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete* for uncoated strand and ASTM A882/A882M, *Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand* for coated strand.

Requirements

- Each coil must have tags indicating the heat number that ties to a mill certificate. Each mill certificate must indicate the strand meets ASTM specifications.
- Plant testing of strand is not required if heat numbers and mill certificate indicate the strand meets ASTM specifications.
- Certificates must be kept on file for at least five years after usage date.
- Incoming strand shall be inspected for damage, excessive scaling, and pitting.
- Light rusting that can be removed with finger pressure or light rubbing is allowable. A good test is to try to remove the rust with a pencil eraser. Rust that can be removed in this way is acceptable. Do not use the strand if there is pitting.
- At least annually, the plant should verify that it has evidence on file that the strand being used has been tested in accordance with ASTM A1081/A1081M, *Standard Test Method for Evaluating Bond of Seven-Wire Steel Prestressing Strand*. The strand manufacturer should be able to provide ASTM A1081/A1081M test data upon request.
- Tensioning records are required to identify date of use, bed location, pack number, jack equipment, and other information. (Refer to MNL-116 Section 6.3.3 for full requirements.)

Best Practices

- Have a comprehensive mill certificate cataloging program within the Quality Department of your company.
- Upon receipt of prestressing steel, review the mill certificates from the supplier for conformance with the purchase requirements (e.g., size, area, modulus of elasticity, steel grade).
- Store unopened packs in a safe, secure area, off the ground.
- Ensure accurate daily record keeping of strand usage.
- Educate plant personnel about the importance of strand pack identification tags.

Other Resources

For additional information on the acceptability of rust on steel prestressing strand, reference Sason, A. S. 1992. “Evaluation of Degree of Rusting on Prestressed Concrete Strand.” *PCI Journal* 37(3): 25-30. https://doi.org/10.15554/pcij.05011992.25.30.

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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; W3l 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 D3l 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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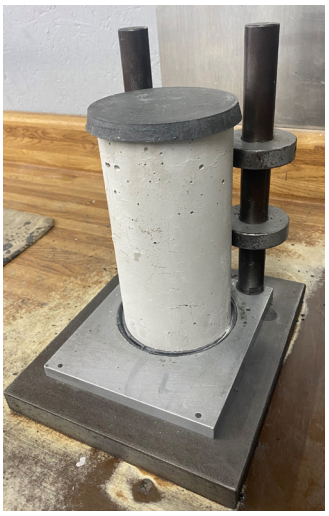
SERIES 3, ISSUE 5 – CAPPING OF CYLINDERS

To help ensure that the results of compressive strength tests accurately reflect the strength of the specimens, of the specimen, the ends of the cylinders must be plane, level, and perpendicular to the cylinder side. Unless the specimen ends are cast or ground to within 0.002 in. (0.05 mm) of a plane surface, the specimen ends will need to be capped.

There are two approved methods to cap a cylinder provided in ASTM C39/C39M, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. In the first method, neoprene pads that sit inside a steel retainer are placed on both ends of the cylinder before testing. This neoprene pad system is referred to as an unbonded system and must conform to ASTM C1231/C1231M, *Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders*.

The second method covers the ends of the cylinder with a capping material that conforms to ASTM C617/C617M, *Standard Practice for Capping Cylindrical Concrete Specimens*. This capping method is referred to as a bonded capping system because the capping materials adhere to the ends of the cylinder and result in smooth and parallel cylinder ends. The most common material used in precast concrete operations is sulfur mortar due to its rate of strength gain.





	NEOPRENE PADS	SULFUR MORTAR CAPPING
Pros	• Relatively inexpensive • Quick and easy to test cylinders • Cylinders need minimal preparation to be tested	• Covers a large range of compressive strengths • Fracture patterns from cylinders are typically consistent • Compression results are typically more consistent
Cons	• Requires different pad durometers (50, 60, and/or 70) for different compressive strengths • Only covers concrete compressive strength between 1500 and 7000 psi without qualification testing, or up to 12,000 psi with qualification testing • Usage of pads must be tracked • Requires greater attention to finishing specimen ends and placing fresh cylinders on a level surface for initial curing	• Handling of molten sulfur mortar requires special safety precautions • Hydrogen sulfide gas may be produced while capping; proper ventilation is required • A cap-curing period before compressive strength testing (2-16 hours) is recommended • Initial investment in equipment can be expensive • Periodic cube strength tests are required

Best Practices

- The individual performing compressive strength tests should be a qualified technician.
- Ensuring cylinder molds are clean and watertight helps ensure compression tests have an accurate representation of the sampled batch.
- Proper preparation is needed to ensure the ends of the concrete cylinders/cores are smooth and the load bearing surfaces are parallel, as specified in ASTM C39/C39M, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*.

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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. The bond between reinforcement and the surrounding concrete is critical to a precast concrete component's performance.

Storage

- 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

- Proper bending and handling of reinforcement during fabrication is needed to ensure that the reinforcement placed in the precast component will provide the necessary strength, constructability, and durability during its use. Bend diameters and hook lengths are carefully considered in the design and detailing of the precast component.
- All reinforcement must be fabricated in accordance with detailed production and fabrication drawings. ACI 117, *Specification for Tolerances for Concrete Construction and Materials*, outlines reinforcement fabrication 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.

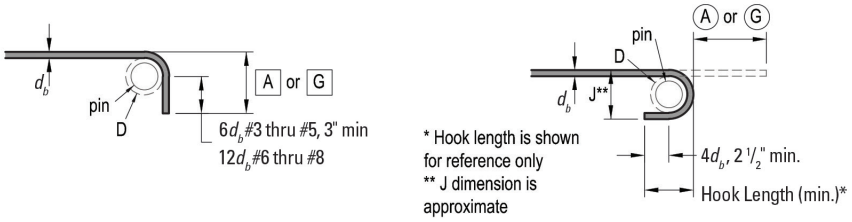


Figure 1. Concrete Reinforcing Steel Institute's standard hook and bend details in accordance with ACI 318.

- 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 unless the project specifications require compliance with different requirements, such as AASHTO. 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 should only be welded where shown on the fabrication and production drawings in accordance with approved plant welding procedures and AWS D1.4, *Structural Welding Code-Reinforcing Steel*.
  - 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 generally 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), AWS D1.4 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 or AASHTO and depend on the concrete strength, steel grade, and reinforcement bar size and spacing.

Additional Resources from CRSI

- CRSI RB4.1, *Supports for Reinforcement Used in Concrete* (2016)
- CTN-M-2-11 *Field Guide for Rust on Reinforcing Bars*
- ETN-M-5-14: *Rust, Mill Scale, and Other Surface Contaminants on Steel Reinforcing Bars*
- *Placing Reinforcing Bars*, 10th ed. (2019)

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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 9 – STEEL FORMS AND FORM PANELS

Steel forms for manufacturing precast concrete products are one of the most significant investments in any precast concrete manufacturing operation. Poorly maintained forms make poor quality products while forms that are properly maintained and repaired can provide years, and even decades, of useful service.

Forms should be checked regularly for deformed and damaged parts, such as bent or warped sections, cracks, broken welds, rust, loose bolts or fasteners, and broken or inoperable hardware. Deformed formwork can lead to concrete products not meeting quality standards and specifications. Damaged parts can potentially lead to safety issues.

Check for Dimensional Accuracy

- Always measure all forms and forming equipment, including pallets, headers, truing rings, and removeable parts, prior to their initial use and after repairs. Forms and forming equipment should also be routinely measured quarterly or in accordance with an established maintenance policy.
- To ensure all products made by a form stay within allowable tolerances, measurements should not vary from the nominal dimensions of products cast by that form by more than half of the allowable manufacturing tolerances.
- Forms should be leveled and secured on the production floor according to the recommendations of the form manufacturer. It should not be possible to lift forms off the production floor during product removal.
- Forms with gaps in seams greater than ⅛ in. in width should be tagged for maintenance. If a form has gaps greater than ⅜ in., it should be taken out of service until it can be repaired.

Check for Form Operability

- All parts of the form, including hinges, latches, wheels, tracks, fittings, pins, hydraulic arms, and other moving parts, should operate without excessive force. Parts that do not operate correctly should be repaired or replaced before excessive force can cause breakage, or worse, cause personal injury.

Track Progress of Maintenance and Repair of Formwork

- Forms or equipment with major defects or that pose a safety hazard should be marked or tagged as being inoperable until repairs are completed.

Form Maintenance Policy

- Follow the procedures within the plant Quality Systems Manual for ongoing maintenance, cleaning, inspection, lubrication, and repair to ensure that all steel forms in use meet required dimensional tolerances. Such procedures should be followed monthly or quarterly at a minimum.
- Report form maintenance issues to the Quality Control Manager.
- **Under no circumstances should unsafe or nonconforming forms be used.**

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SERIES 3, ISSUE 10 – CAMBER IN PRESTRESSED PRECAST CONCRETE COMPONENTS

Camber is the upward deflection created by an eccentric stressed strand pattern located below the precast component's center of gravity. Estimated camber is calculated typically at two time periods: initially (after stripping) and at 28 days. The design loads, length of span, and component cross section factor into the amount of prestressing force required, which affects the amount of camber.

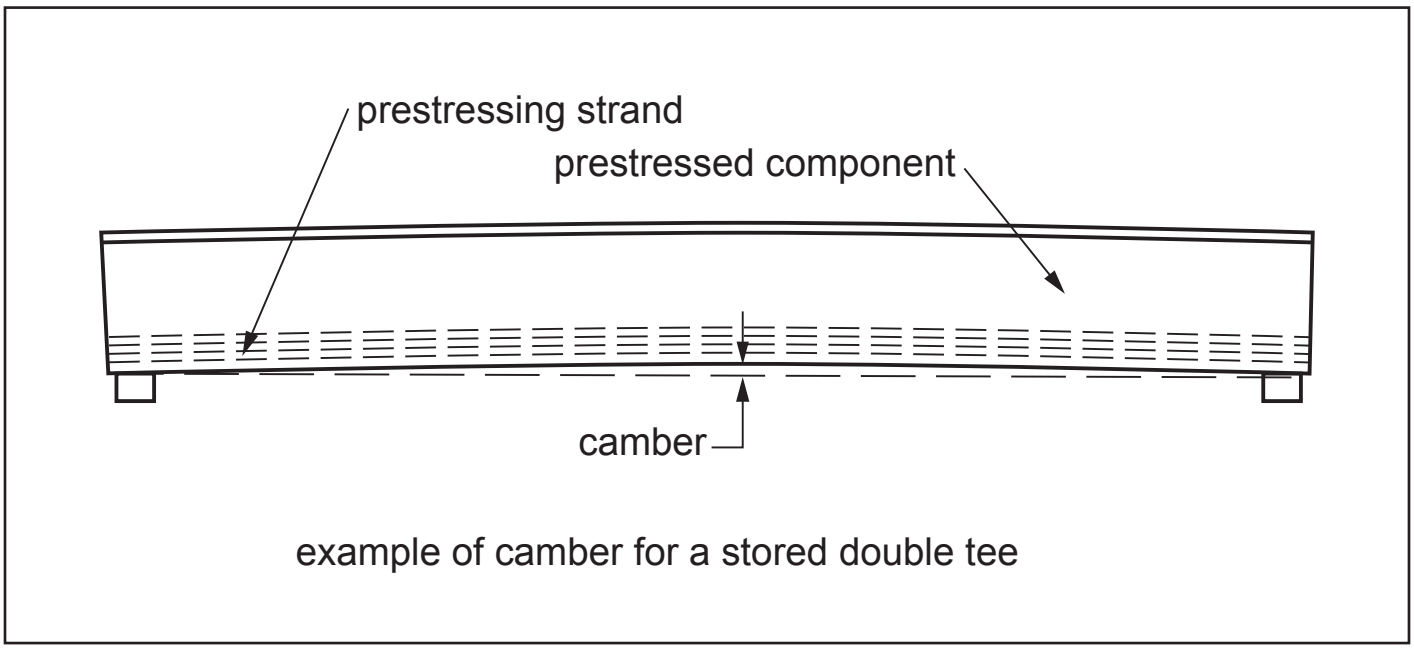
Measuring and recording camber is important because it can alert precast concrete plants to variations in production and storage procedures. Confirming cambers to the initial and 28-day design values helps verify product quality and consistency between pours.

Initial camber can vary between components of the same design due to:

- Varying release strengths
- Varying dunnage locations
- Varying time of obtaining camber measurement
- Inconsistent concrete unit weight
- Component temperature (effects of differential cooling after stripping)
- Varying durations before strand release

28-day cambers can vary between components of the same design due to:

- Varying 28-day strengths
- Varying dunnage locations
- Location in stack due to sunshine exposure
- Location in stack due to moisture exposure



example of camber for a stored double tee

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What should QC look for in the yard?

- QC should ensure that components are stored at dunnage locations shown on the drawings for each component. Dunnage should be level and not twist components.
- Component storage should be reviewed periodically after initial placement to ensure settlement has not occurred and dunnage is sound.

Best practices for camber measurement:

- The component drawings should indicate the designed initial stripping camber and 28-day camber.
- Measure and record the camber after the product is stripped and stored at proper dunnage locations. The same length of time after stripping should be used when comparing stripping cambers from pour to pour. Time and temperature can affect initial camber measurements.
- Cambers should be measured at the same time of day
- Measure and record the 28-day camber (a different age may be specified in the contract documents). When components are stacked, the top component camber can vary from those below due to absorbed moisture on the top surface or the expansion effect of sunshine.

Camber is inherent in most unsymmetrical prestressed components.

- Camber is the vertical deflection due to prestress forces in the strand being concentrated lower in the component height or thickness.

Additional items that can affect camber:

- Methods used to measure camber as well as differences in how individuals approach measurement can contribute to variances.
- Components stored for long periods of time (in excess of 28 days) can continue to gain camber.
- Product weight variation from component elements that cause change in product weight and/or concrete volume (e.g., blockouts, shortened flanges, recesses, pour stops, etc.)

Confidence of alignment of components when installed can be confirmed in the plant by performing proper camber checks. Contact the responsible engineer when cambers are out of accepted tolerance from the design values or between components of same design and length.

When camber control procedures must be utilized for plant-stored product, they should be determined by the responsible engineer. Adjusting dunnage locations or adding weight to components to control high cambers can mitigate out of tolerance cambers.

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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.

PCI Plant Quality Talk
Quality Enhancement Committee

Note: Please complete this form and return to the Quality Control Manager. All crew members should be observant and report to their foreman anything out of the ordinary on a project. See something, say something.

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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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