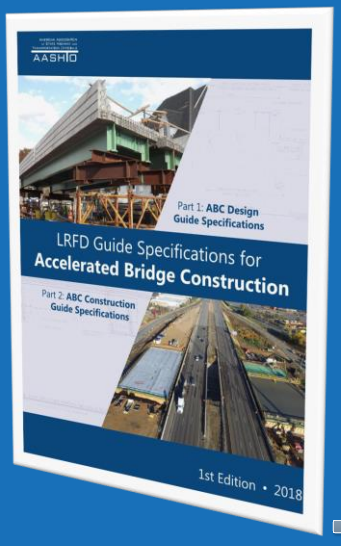
Module 6: ABC Construction Specifications

This module covers:

- Construction specifications
  - Fabrication and assembly planning
  - Quality specifications
  - Repairs
  - Materials specifications
    - High early strength concrete
    - UHPC
    - Non-shrink grout



Module 6 covers construction specifications for ABC.

Construction specifications for ABC can be significantly different than construction specifications for conventional construction. The Guide Specifications for ABC contain significant information on how to specify construction on an ABC project.

This portion of the Guide Specifications for ABC is written similar to the AASHTO LRFD Bridge Construction Specifications. The level of detail is not as significant as a typical project-specific specifications, but the provisions can be used to develop project-specific construction specifications.

Today we will cover:

- fabrication and assembly planning,
- specifications for quality control,
- repair of prefabricated elements,
- and material specifications for high early strength concrete, UHPC, and non-shrink grout.

Section 8 – Fabrication & Assembly Planning

8.2.2—PRECAST CONCRETE ELEMENTS

Shop drawings for precast and prestressed concrete elements shall include, but not be limited to, the following:

- Fully and accurately dimensioned views showing the geometry of the elements including all projections, recesses, notches, openings, blockouts, and other pertinent details
- Details of non-prestressed steel reinforcing clearly shown as to size, spacing, and location, including any special reinforcing required, but not shown on the contract plans, such as post-tensioning anchorage local zone reinforcing or additional reinforcing required for lifting and handling
- Clearly detail size and types of ducts for all post-tensioning tendons and their horizontal and vertical profiles
- Detail size, type and location of duct supports, grout tubes, vents, and drains
- Details and locations of all other items to be embedded in the elements, such as inserts, lifting devices, and post-tensioning hardware including anchorages
- Certified test reports indicating the capacities of post-tensioning anchorage assemblies

C8.2.2

The *AASHTO LRFD Bridge Construction Specifications* contain limited requirements for shop drawings of precast elements. The intent of this article is to specify typical requirements for prefabricated precast concrete elements.

- Estimated camber of non-concentric prestressed elements.
- Dimensional fabrication tolerances of the element.

Prefabricated bridges require a significant amount of fabrication.

The AASHTO LRFD Bridge Construction Specifications do not have significant specifications for prefabrication. Therefore, specifications were developed to ensure quality fabrication practices.

Article 8.2.2 covers the requirements for the fabrication of precast concrete elements. This article specifies the minimum requirements for shop drawings.

Shop Quality Control

8.3—QUALITY CONTROL IN THE SHOP

Quality control during manufacturing shall be in accordance with contract documents and Owner specific quality control requirements for prefabricated steel and precast concrete elements including the provisions of the *AASHTO LRFD Bridge Construction Specifications*.

8.3.1—STEEL ELEMENTS

Quality control for fabrication of steel elements shall be in accordance with Section 11 of the *AASHTO LRFD Bridge Construction Specifications*.

8.3.2—PRECAST CONCRETE ELEMENTS

Quality control for fabrication of precast concrete elements shall be in accordance with Section 8 of the *AASHTO LRFD Bridge Construction Specifications*. The provisions contained herein are intended to supplement this specification.

The requirements of this article are intended to produce precast concrete elements that are built to a prescribed tolerance so that the elements can be successfully connected in the field.

C8.3.2

This document contains information on precast concrete construction. This Article will focus on specifications that are applicable to common prefabricated bridge elements made with precast concrete.

Fabrication of prefabricated bridge elements that need to be connected in the field may require a higher level of fabrication accuracy when compared to precast elements that are not connected (i.e. drainage structure, curbing, etc.). Control of tolerances is a critical aspect of this effort. The provisions contained herein establish a level of quality control that will aid in attaining proper tolerances and quality.

Article 8.3 of the Guide Specifications for ABC covers quality control in the shop.

For steel elements, the AASHTO LRFD Bridge Construction Specifications are referenced. This is because most agencies have longstanding proven specifications for steel fabrication.

More significant provisions are provided for precast elements, as they are not as common in the industry, and there are limited provisions in the AASHTO LRFD Bridge Construction Specifications.

Precast Concrete QC

8.3.2.1—Temporary Precast Fabrication Facilities

Temporary precast fabrication facilities (on-site or near site) may be allowed with permission of the Owner. These facilities shall have fabrication and quality control/management processes that are acceptable to the Owner.

C8.3.2.1

The Owner should specify a prequalification process that ensures a level of quality control management that is consistent with that required for permanent precast fabrication facilities. Most agencies have established processes for prequalifying these facilities.

Some states allow general contractors to fabricate precast concrete elements. Other states require pre-qualified companies or specify industry certifications such as PCI. It is also common in rural areas to prefabricate in a near-site location.

For this case, it is imperative that proper quality control procedures are specified. Article 8.3.2.1 of the Guide Specifications for ABC recommends that project specifications require that temporary precast fabrication facilities develop and use a fabrication and quality control management process. The process should be reviewed and accepted by the owner prior to the start of fabrication.

Precast Concrete QC

8.3.2.2—Pre-Pour Inspection Checklists

The precast fabrication facility shall develop a pre-pour checklist for inspection of items to be checked as part of the pre-pour inspection for each element. The checklist shall be filled out prior to pouring concrete in the forms. The checklist shall focus on items that cannot readily be checked after concrete placement.

All measurements shall be verified against the shop drawings for the element.

The checklist shall include, but not limited to the following:

- Verify all dimensions of the forms. Make specific checks of all formwork that impacts the specified element tolerance criteria
- Verify location, size, and number of blockouts, cast-in items, reinforcing steel, and any other critical tolerance items
- Verify that all items are properly secured and will not move during concrete placement
- Check maintenance and condition of forms and appurtenances. Verify tightness, dimensions, and overall general quality
- For outside casting, verify that the weather condition allows for concrete casting and proper curing

A checklist shall be completed for each element cast. The checklists shall be kept on file or submitted to the Owner if specified.

C8.3.2.2

The Owner should specify whether or not the Owner's representative needs to be present during the pre-pour inspection.

The fabricator may elect to produce formwork that accounts for items that occur during precast manufacturing such as stretching of the forms during concrete placement, shrinkage of the concrete, or elastic shortening of the concrete in prestressed concrete elements. If this is the case, the shop drawings should include this information for verification during the pre-pour inspection.

All measurements should be based on a common datum or working line. Measurements of items based on center-to-center spacing should not be used since it can result in a build-up of tolerance dimensions.

Repeated use, movement, and handling of forms can lead to loss of dimensional quality. Forms may need to be replaced at regular intervals for large production projects.

Article 8.3.2 of the Guide Specifications for ABC include recommended provisions for quality control in the fabrication facility. The process of fabricating a precast element is completed in several stages. Each stage requires a level of quality control. The Guide Specifications for ABC include recommended quality control checklists for each stage of production.

Article 8.3.2.2 of the Guide Specifications for ABC includes a recommended checklist for inspection of the forms and reinforcing prior to the casting of concrete, also known as a pre-pour inspection. This includes dimensional checks, a check on the condition of the forms, and a weather check prior to the pour if the facility is exposed to the elements.

Precast Concrete QC

8.3.2.3—Casting Inspection Checklist

The precast fabrication facility shall develop a checklist for the inspection of the casting process for each element. The checklist shall be filled out during the each concrete pour.

The checklist shall include, but not limited to the following:

- Note weather and other items affecting production
- Verify that the correct concrete mix is being used
- Verify that all specimens for all specified concrete testing have been obtained and prepared properly
- Start and stop time for the pour
- Note the completion of all specimens for specified testing (slump, air content, compressive strength, etc.)
- Verify that concrete is being placed and consolidated properly
- Verify that the correct finishing process is followed
- Verify that the curing process is followed

A checklist shall be completed for each element cast. The checklists shall be kept on file or submitted to the Owner if specified.

C8.3.2.3

Element shop drawings should include notes for concrete type, consolidation methods, finishing methods, and curing methods. These notes should be used for verification against the checklist.

Article 8.3.2.3 of the Guide Specifications for ABC includes recommended checklists for the pouring of the concrete into the forms.

These checks are primarily concerned with workmanship and quality control of the concrete placement and curing.

Precast Concrete QC

8.3.2.5—Post-Pour Inspection Checklist

The precast fabrication facility shall develop a checklist for the stripping and storing of each element. The checklist shall be filled out during the stripping and storing operation for each element.

The checklist shall include, but not be limited to, the following items:

- Noting the time and weather at the start of the stripping operation
- Verifying all dimensions of the element. Make specific checks of all specified element tolerances
- Noting elements that are out of tolerance, document and forward for disposition by the Owner, Contractor, and the fabricator as based on contract documents
- Inspecting the finish of the element and verify that the finish matches the specified finish
- Noting finish defects, cracking, and other problems
- Documenting significant defects that cannot be addressed with standard finishing techniques and forward for disposition by the Owner, Contractor and the fabricator as based on contract documents

C8.3.2.5

The post-pour inspection should occur immediately after striping and continues until the element is secured in the storage yard.

- Verifying that the correct lifting hardware is used for lifting and transporting the element in the yard
- Verifying the condition of storage area for proper blocking (location and support), methods for prevention of chipping, warping, cracking, contamination, and blocking stains, or any other items that may adversely affect the quality of the element
- Verifying that the element is properly seated on the dunnage and that there are no gaps and that the element is not warped
- Verifying that no damage has occurred during handling of the element
- Documenting damaged elements and forward for disposition by the Owner, Contractor and the fabricator as based on the contract documents
- Verifying release camber of prestressed elements
- Verifying that any required additional curing processes are established in the storage yard

Article 8.3.2.5 of the Guide Specifications for ABC include recommended checklists for inspection of the precast element after removal from the forms.

These checks are primarily concerned with the finish, defect detection, and tolerances.

Dry fitting

8.3.2.6—Dry Fit of Assemblies

If specified in the contract documents, the Contractor or fabricator shall dry fit assemblies or portions of assemblies to demonstrate that the elements will fit together properly in the field.

The dry fit assembly of stacked elements need not include all elements in the portion of the structure. Sub-assemblies (two layers) may be allowed by the Designer if it can be demonstrated that the dry fit of the sub-assembly will provide adequate assurance that the entire structure assembly will be viable.

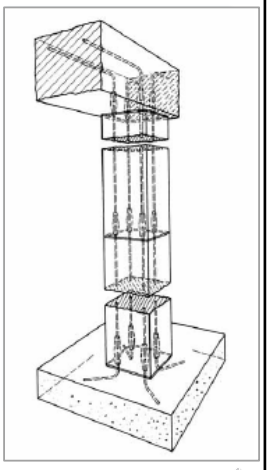
Problems with element fit-up encountered during the dry fit assembly process shall be corrected by the Contractor by repairing the elements according to Article 8.3.2.8. If repairs are not feasible, in the opinion of the Designer, the element will be rejected and a new element will be required to be fabricated.

The Contractor shall develop a dry fit assembly plans for approval by the Designer. The plans shall include details of all assemblies, sub-assemblies, and bracing required to ensure a safe operation during the dry-fit assembly process.

C8.3.2.6

Dry fit of assemblies can be useful for complex structure; however, it will not solve all potential problems since a dry fit only addresses element tolerances. Erection tolerances and field conditions may vary during the actual assembly in the field.

- This can lead to higher costs
- Not necessary for most assemblies



Article 8.3.2.6 of the Guide Specifications for ABC include provisions for dry fitting of prefabricated precast concrete assemblies. This process involves temporarily fitting elements together to ensure proper fit in the field.

Dry fitting entire assemblies is not recommended for most projects as it can lead to higher costs. Another option is to specify dry fitting of adjacent pieces, especially if there is a complex connection.

If dry fitting is specified, the specifications should require that the contractor develop a dry fit assembly plan for approval.

Final Inspection in Shop

8.3.2.7—Final Inspection Prior to Shipping

The precast facility shall develop a checklist for the final inspection of the element. The checklist shall be filled out prior to shipping of each element.

The checklist shall include, but not be limited to, the following items:

- Verifying that the correct lifting hardware is used for lifting and loading the element on the transport equipment
- Verifying that the element is properly seated on the dunnage and that there are no gaps and that the element is not warped
- Verifying that the element is properly secured and stable and that lashing has not damaged the element
- Verifying that no damage has occurred during handling of the element
- Documenting damaged elements and forward for disposition by the Owner, Contractor, and the Fabricator as based on contract documents

C8.3.2.7

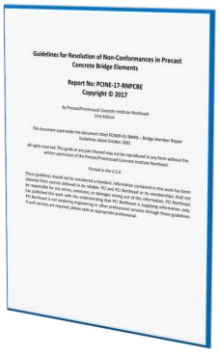
The final inspection should occur just prior to shipping.

Article 8.3.2.7 of the Guide Specifications for ABC includes provisions for the final inspection prior to shipping. This inspection focuses on whether or not the element was properly stored and supported in storage and that it is properly prepared for shipping and assembly.

Repairs

8.3.2.8—Repairs

The repair of non-conformities of precast concrete elements shall be in accordance with the *PCI Manual for the Evaluation and Repair of Precast, Prestressed Concrete Bridge Products (MNL-137-06-E)*.


Guidelines for Resolution of Non-Conformances in Precast Concrete Bridge Elements

Report No: PCINE-17-BNPCBE
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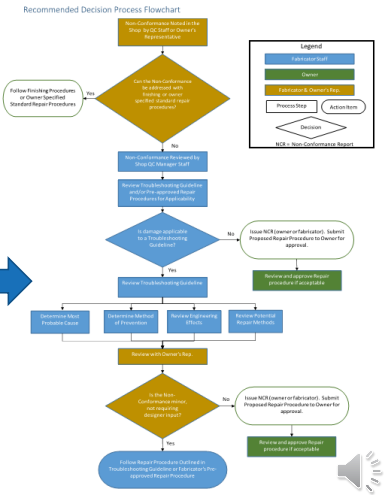
C8.3.2.8

The process of fabrication and handling of large precast concrete elements will inevitably lead to a need to repair elements. The cited manual can be used to manage and address common non-conformities and damage that can occur during fabrication and handling of precast elements. It includes causes of non-conformities, prevention measures, engineering effects, and repair methods. This manual was developed in collaboration between industry and Owners, which represents the best practices for repair of precast concrete elements.

PCI Northeast Guideline

- Expansion of MNL-137
- Includes most common PBEs
- www.pcine.org



Article 8.3.2.8 of the Guide Specifications for ABC include provisions for the management of repairs. It is inevitable that the production of large precast concrete elements will result in minor nonconformances. The Guide Specification Provisions reference the PCI Manual for the Evaluation and Repair of Precast, Prestressed Concrete Bridge Products.

The PCI Northeast Bridge Technical Committee has also published Guidelines for the Resolution of Non-conformances in Precast Concrete Elements. This document contains details for all typical precast concrete bridge elements, including substructure elements and full-depth deck panels. This document contains flowcharts and recommendations for the management of nonconformances. It also includes recommendations for finishing precast elements. It can be downloaded for free at: www.pcine.org.

Assembly Planning

You need instructions for assembly of a toy

Why not for a prefabricated bridge?

8.5—ASSEMBLY OF PREFABRICATED BRIDGE ELEMENTS

The Contractor shall be responsible for the development of an Assembly Plan document. The Assembly Plan shall be considered a working drawing and shall be certified by a registered Professional Engineer with specific knowledge of the Contractor's equipment and "means and methods."

C8.5

An Assembly Plan is a step by step process for the assembly of the prefabricated elements. It is closely linked to the schedule of operations and the interim material strengths necessary for the work to progress.

If you buy a toy or furniture from a store like IKEA, you might need to assemble it. The pieces come with assembly instructions. The construction of a prefabricated bridge is no different. Careful thought must be put into the assembly process and laid out in an assembly plan document.

Article 8.5 of the Guide Specifications for ABC include provisions for the assembly of prefabricated bridge elements. The provisions call for the development of an Assembly Plan Document. This is a step-by-step process for assembly of the prefabricated elements at the bridge site. It is developed by the contractor, since it falls under the realm of contractor means and methods.

Most bridge owners require contractors to develop erection plans for bridge girders. An assembly plan is a more detailed document that covers more than just erection.

Assembly Plan Requirements for Prefabricated Elements

8.5.1—ASSEMBLY SEQUENCE AND CONSTRUCTION METHODS

The following minimum information with regard to sequence of assembly shall be included in the Assembly Plan:

- Step-by-step assembly sequence detailing the overall construction process.
- Details of any formwork for closure joints including methods for attachment to the adjacent prefabricated elements.
- Details of all materials to be used for the construction.
- Methods and materials to be used for casting and curing concrete closure joints.
- Estimated timeframe of strength gain for concrete closure joints.
- A statement of compliance with all requirements of applicable environmental permits.
- Any weather limitations for the assembly work.

Article 8.5.1 of the Guide Specifications for ABC includes the recommended minimum information for the assembly sequence that should be included in an Assembly Plan.

Review the bullets on the slide

Assembly Plan Requirements for Prefabricated Elements

8.5.2—LIFTING AND HANDLING PROCEDURES AND DETAILS

The following minimum information with regard to lifting and handling procedures shall be included in the Assembly Plan:

- Details and/or information regarding all equipment that will be employed for the assembly of the bridge.
- Details of all equipment and materials that will be used to lift elements including, but not necessarily limited to cranes, excavators, lifting slings, sling hooks, and jacks.
- A site plan showing crane locations and operation radii. The assembly plan shall also depict all affected utilities, drainage, and protective measures that will be employed throughout the construction activities. If multiple crane set-ups are required, include a separate plan for each crane set-up. The site plan shall show the layout of multi-crane lifts (if required).
- All lifting and handling calculations for each element as specified in Article 8.4.
- Lifting calculations for all crane lifts. The Contractor is responsible for determining the center of gravity for all elements. Special care shall be used for PBEs that are not symmetrical. These elements may require special lifting hardware to allow for installation to the proper grades shown on the plans.
- Methods of adjusting and securing the elements after placement.
- Methods for controlling erection tolerances for both the horizontal and vertical direction including any surveying requirements.

Article 8.5.2 of the Guide Specifications for ABC includes the recommended minimum information for the lifting and handling of elements that should be included in an Assembly Plan.

Review the bullets on the slide

Assembly Plan Requirements for Prefabricated Elements

8.5.3—GEOMETRY CONTROL PLAN

The Contractor shall develop a geometry control plan for the assembly of the prefabricated elements, and it shall be included in the Assembly Plan. The plan shall indicate in detail how the geometric detail of the erection will be controlled and the actions required to assure proper erection of the structure to the dimensions and final grades shown on the plans.

The geometry control plans shall include details of the layout process (lines, marks, survey, etc.) that will be used by the erection personnel for checking the location and elevation of each element prior to releasing the element from the erection equipment.

The plans shall include provisions for regular monitoring of the structure during erection, and methods for adjusting geometry should unacceptable deviations occur.

The plans shall include provisions for monitoring settlement of falsework supported on shallow foundations. The plans shall also address adjustment to the falsework should settlement occur.

C8.5.3

The maintenance of proper structure geometry is critical to the successful erection of prefabricated elements. Most problems with construction of prefabricated elements to date have been related to loss of geometry control due to lack of a well thought out geometry control plan.

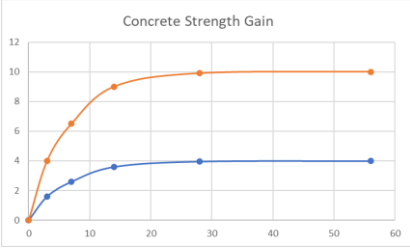
Geometry control and tolerances are an important portion of the assembly plan. Lack of geometry control can lead to significant fit-up problems in the field. The photo shows the assembly of full-depth precast concrete deck panels that did not go very well. The contractor did not pay close attention to geometry during erection, and the result is an uneven edge of the deck which can be seen in the photo. This sort of problem can be avoided with a proper geometry control plan.

Article 8.5.3 of the Guide Specifications for ABC include provisions for the development of a geometry control plan that is part of the assembly plan. The geometry control plan should demonstrate the means of locating and adjusting elements. This includes the use of working lines, layout lines, and control of tolerances.

Assembly Plan Requirements for Prefabricated Elements

8.5.4—INTERIM MATERIAL STRENGTH

The Contractor may take advantage of interim material strength for concrete closure joints and grouted joints. If this approach is to be used, the Assembly Plan shall include calculations for the required strength of the poured materials that can produce connections capable of resisting forces during construction.



C8.5.4

The forces acting on connections during construction are often significantly lower than the forces applied in the completed structure. The initial strength gain for cast materials is often very fast in the early stages of curing, followed by a slower strength gain rate during the remainder of curing. In an ABC process, it is often not feasible to wait for poured materials to gain final strength as the structure is assembled. Allowing construction to proceed prior to final strength gain can save significant time during assembly.

The concept of interim material strength has been used very effectively on a number of ABC projects. The idea is to take advantage of strength gain and partial load during the assembly process. For example, the load on a bridge column is very light until the deck is cast on the bridge. Even then, that load is not full load as there is no live load on the bridge.

Based on this, the element and the connections do not need full strength to proceed with the next steps in the assembly. Using this approach, a contractor can move the assembly forward without needing to wait for connection materials to gain full strength.

The graphic on the lower left shows a typical strength gain chart for two different types of concrete. This demonstrates how some contractors achieve high early strength for poured concrete. The lower chart in blue shows a strength gain curve for a mix that might be a 4000 psi design. The orange curve shows the strength gain for a mix that might be a 10,000 psi design. As you can see, the 10,000 psi mix attains a strength of 4000 psi much faster. This sort of concrete mix design is common in the precast industry and becoming more common in the ABC world. We present this information as this sort of approach may be used in an assembly plan process.

Assembly Plan Requirements for Prefabricated Elements

8.5.5—POST-TENSIONING

The following minimum information with regard to assembly of post-tensioned structures shall be included in the Assembly Plan:

- Prestressing details including sizes and properties of tendons, anchorages, plates, and assemblies
- Additional reinforcement necessary to resist the anchor block stresses
- Details and locations of all duct couplers including methods for sealing ducts to prevent poured materials from entering the duct and to prevent pumped grout from leaking from the duct (if a grouted post-tensioning system is specified)
- Details for accommodation of misaligned ducts
- Details of stressing equipment
- Details and locations of all grout ports and vent ports
- Details of grouting equipment, grout mix design and method of mixing and placing grout

The Assembly Plan shall also include a detailed stressing procedure for the post-tensioning. The procedure shall include stressing procedures containing the following minimum information:

- Stressing plan showing the sequence of stressing of tendons
- Calculations for losses during stressing based on the actual materials provided
- Details of the jacking sequence, jacking forces, and initial elongation of each tendon at each stage of installation based on the actual material properties of the tendons used (actual area and actual modulus of elasticity, etc.)

The Assembly Plan shall also include a detailed grouting procedure for the post-tensioning. The procedure shall include:

- Methods for mixing grout
- Sequence of grouting
- Locations for grout injection
- Venting procedures
- Grouting procedures including materials sampling and testing

Article 8.5.5 of the Guide Specifications for ABC includes the recommended minimum information for the assembly of post-tensioned structures. Post-tensioning systems can be quite complex. There are very specific procedures and steps that need to be followed in order to have a successful assembly.

Assembly Plan Requirements for Prefabricated Elements

8.5.6—ASSEMBLY SEQUENCE FOR POST-TENSIONED FULL DEPTH DECK PANELS

The assembly of full depth deck panels that are connected with post-tensioning shall be such that the post-tensioning force does not impart unintended forces in the supporting beams or girders during the post-tensioning process. The following is a general sequence of assembly that shall be followed. Deviations from this sequence will only be allowed with approval by the Owner.

1. Install all permanent bracing for the supporting beams as shown on the contract plans.
2. Clean and remove all debris from the top flanges of beams.
3. Erect the precast deck panels within the specified erection tolerances, according to the Assembly Plan and geometry control plan.
4. Prevent shifting of panels during assembly and post-tensioning.
5. Once all panels are erected, adjust the vertical elevations of panels using adjustment hardware or shims to match the specified vertical geometry of the deck.

C8.5.6

These provisions are for use in bridge decks that are to be made composite with the supporting beams or girders and include post-tensioning for the connection between adjacent deck panels.

The sequence described may be adjusted by the Designer provided that the sequence is consistent with the design assumptions. The critical aspect of this sequence is the application of the post-tensioning jacking forces prior to the establishment of composite action. This is typically achieved after the installation of grout in the shear connector pockets.

Article 8.5.6 of the Guide Specifications for ABC includes the recommended sequence for the construction of post-tensioned bridge decks. This is especially important for bridge decks that are composite with the underlying girders. An important aspect of the sequence is that the post-tensioning should be completed prior to making the deck composite with the girders. If the post-tensioning is applied after composite action is achieved, the post-tensioning force would create a positive bending moment in the girders, which could potentially lead to overstressing and reduced structural capacity.

Assembly Plan Requirements for Prefabricated Elements

6. Clean and remove all debris from the grout joints and post-tensioning connection hand holes. Pre-wet the joints as specified on the plans or specifications.
7. Connect all post-tensioning ducts. Seal ducts with materials that will prevent the intrusion of joint grout and extrusion of duct grout.
8. Install grout in joints between panels according to the specifications. Care shall be taken to prevent joint grout from penetrating the post-tensioning ducts or falling to areas below the bridge.
9. Cure joint grout until it reaches the minimum required compressive strength for the application of post-tensioning as specified in the Assembly Plan.
10. Demonstrate that the ducts are free of water and debris immediately before installing tendons.
11. Install tendons in post-tensioning ducts if pressure test is successful. This work may be completed prior to step 8.

An air pressure test can be specified to ensure that the duct is properly sealed.

This strength is typically less than the specified grout strength. Significant time can be saved by allowing stressing at an interim strength.

This is a continuation of the previous provision.

Assembly Plan Requirements for Prefabricated Elements

12. Stress post-tensioning tendons according to the Assembly Plan.
13. Install grout in post-tensioning ducts according to the Assembly Plan. This work may be completed after step 14.
14. Form and cast haunches and shear connector blockouts according to the specifications or the Assembly Plan. Care shall be taken to prevent grout from falling to areas below the bridge.
15. Cure all grout areas.
16. Keep live load off the deck until the grout in the shear connector blockouts reaches the compressive strength specified in the specifications or the Assembly Plan.

Owner specifications may require the use of corrosion inhibitor for tendons that left un-grouted in ducts for significant periods of time.

This is also a continuation of the previous provision.

This demonstrates that the assembly of a post-tensioned bridge deck is a complex construction operation. As we discussed earlier, the final product is a very durable system that will last many years. Therefore, it is still desirable for certain bridges.

This complexity has led to the development of alternate connections in precast decks including the use of reinforced concrete closure joints and UHPC.

Assembly Plan Requirements for Prefabricated Elements

8.5.7—ASSEMBLY SCHEDULE

The Contractor shall develop a detailed estimated schedule for all assembly steps. The schedule shall be submitted with the Assembly Plan. The following minimum information shall be included in the assembly schedule:

- Provide a detailed critical path method schedule with the timeline for all operations
- Indicate operations that will occur concurrently and operations that are dependent on completion of other operations
- Account for setting and cure times for concrete closure joints
- Show all interim strength gain estimates
- Show additional time intervals to account for potential field problems and weather delays
- Provide a contingency plan for schedule adjustment in the event of a major equipment breakdown or other major delays

C8.5.7

The assembly schedule noted herein is an estimated schedule that is intended to identify the anticipated workflow for the completion of the assembly. It should be a "best estimate" of the workflow that demonstrates that the assembly can be executed within the time constraints in the contract documents. It should be understood by all parties that the schedule may need to be altered during the execution of the work based on actual production rates and actual delays. Multiple schedules may be required for complex, multi-phase projects.

Article 8.5.7 of the Guide Specifications for ABC includes provisions for the assembly schedule. This is one of the most important parts of an assembly plan. The contractor should develop a detailed critical path timeline for all operations involved in the assembly. This schedule should account for construction processes, and importantly, the expected strength gain of cementitious materials.

The assembly schedule should include additional time intervals to account for potential field problems. It should also address contingency plans for schedule adjustment in the event of equipment breakdown or other significant delays.

Assembly Plan Requirements for Bridge Systems

8.6.1—ASSEMBLY SEQUENCE AND CONSTRUCTION METHODS

The Assembly Plan shall conform to the requirements noted in Article 3.5, supplemented as follows:

Temporary Support System (Falsework): Submit detailed plans for items such as temporary support structures, falsework, cofferdams, shoring, and temporary bridges. The falsework plans shall include, but not limited to, the following:

- Details of bents, ground beams, foundations, and temporary drilled shafts or piling
- Type and grade for all materials
- Elevations and dimensions of temporary bearings, as necessary, to match the relative positions of the final permanent bearings at the bridge site
- Geotechnical report and calculations for the support of the falsework
- Design calculations and supporting data
- Design calculations and supporting data for all temporary works
- Notes or details regarding the removal of the temporary works

Bridge systems require careful planning. Article 8.6.1 of the Guide Specifications for ABC contains recommended requirements for Assembly Plans to assist designers with the development of construction specifications for bridge systems.

This portion of the article notes assembly plan requirements for temporary supports for bridge systems.

Assembly Plan Requirements for Bridge Systems

Lateral Slide Plan: The lateral slide plan shall be submitted as a working drawing. The lateral slide plan shall include, but not be limited to the following:

- Any applicable cut sheets of equipment and materials to be used to move the bridge (in any direction)
- Details of the move system, components, mechanical devices, jacks, temporary blocking, and operational techniques
- Details of the horizontal slide components and proposed jacking or pulling system (jacks, tracks, pumps, PLC equipment, schematic hydraulic layout, etc.)
- Revisions to the concepts, materials, components, erection methods, and sequencing indicated on the contract plans
- Changes to locations of permanent support conditions, cross section component sizes and connectivity, construction joints in any plane, and splice location, sizes, and types
- Calculated superstructure weight for the move based on actual, known dimensions of components and known densities of materials
- Quality control procedures to be followed during the structure move including system test prior to move
- Contingency plans for jacking system failure, misalignments during move, binding of slide track (if used) and excessive wind loads
- Estimated coefficient of friction of sliding systems or resistance of rolling systems, and the anticipated maximum force to be used in the jacking system
- Weight capacities of the move system during all jacking/pulling, raising or lowering, and moving operations
- Operational details for the control of the movement (forward and reverse), braking, lifting and lowering

This Portion of the article includes specific recommendations for assembly plans for lateral slide bridge systems.

Assembly Plan Requirements for Bridge Systems

SPMT Installation Plan: Submit detailed working drawings, and/or cut sheets of all equipment and material used for the movement of the bridge using SPMTs. The SPMT installation plan shall include, but not necessarily be limited to, the following:

- Details of the bridge staging area including general layout and surface grading, surfacing material, drainage, environmental protection, material storage area, concrete delivery methods, shelters, heavy lift travel paths, accesses, fences, gates, barriers, offices, and workshops if specified
- Details of the move system, components, mechanical devices, jacks, temporary blocking, and operational techniques
- Details of the SPMT equipment including layout and hydraulic controls and zoning
- Revisions to the concepts, materials, components, erection methods, and sequencing indicated on the contract plans
- Changes to locations of permanent support conditions, cross section component sizes and connectivity, construction joints in any plane, and splice locations, sizes, and types
- Calculated superstructure weight and center of gravity for the move based on actual, known dimensions of components and known densities of materials
- Detailed calculations for all temporary support structures in the staging areas
- Detailed calculations for the SPMT configuration including:
  - Falsework located between the SPMTs and the bridge
  - Dynamic forces acting on the system during the move
  - System stability during all phases of the move including stability while traveling over grades and when the system is subjected to outside forces (dynamics, wind, etc.)
  - Stability of the SPMT hydraulic system including zone pressures during all phases of the move
  - Calculations for the allowable twist in the bridge structure during the move (if not specified in the contract documents)
- Detailed calculations and plans for the proposed attachment to the bridge if attachment of the falsework to the bridge substructure is required
- Clearances for all utilities and other structures along the travel path
- Details of construction, and intended access under the completed superstructure
- Geotechnical report and calculations for the bridge staging area and bridge travel path
- Means of mitigating high or concentrated loads over susceptible soils or underground utilities
- Quality control procedures to be followed during the structure move
- Weight capacities of the SPMTs
- Operational details for the control of the movement (forward and reverse), braking, lifting, and lowering

This Portion of the article includes specific recommendations for assembly plans for SPMT bridge systems.

As you can see there is a long list of requirements, which reinforces the need for significant planning for bridge system installations.

Section 10 – Non-shrink Grout

10.4.3—NON-SHRINK GROUTS

Materials for non-shrink grout shall be specifically formulated to meet the requirements of the intended purpose. Typical requirements include:

- high early strength gain (commensurate with the project schedule),
- minimal shrinkage or slight expansion,
- good bond to adjacent concrete,
- durability equal to or better than the connected elements,
- easily placed (flowable for confined joints), and
- ability to extend grout to fill large volumes.

The Contractor shall use pre-bagged non-shrink grout that is approved by the Owner. The following testing shall be used for qualification of non-shrink grouts. In lieu of contract specific acceptance limits, the acceptance levels listed shall be met.

1. Compressive strength in accordance with AASHTO T 22 (ASTM C39) (Cylinders) or AASHTO T 106 (ASTM C109) (Cubes). The minimum compressive strength shall be 5 ksi measured at 24 hours after initial set.
2. Restrained shrinkage in accordance with AASHTO T 334 (ASTM C1581) (Ring Test). The specimen shall exhibit no cracking in 4 days.
3. Bond strength according to ASTM C1583. The minimum acceptable bond stress shall be 200 psi.
4. Durability Factor in accordance with AASHTO T 161 (ASTM C666). The specimen shall have a minimum durability factor of 80 percent.
5. Permeability in accordance with AASHTO T 277 (ASTM C1202) (Rapid Chloride Permeability). The maximum permeability value shall be 1,500 coulombs measured at 56 days.

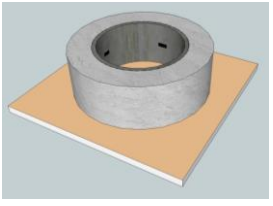
C10.4.3

Non-shrink grouts are highly engineered materials. Pre-mixed package grouts are preferred over site mixed grouts due to the high demand placed on these materials.

In most cases, it is not feasible (cost and time) to perform pre-qualification testing for an individual project. It is recommended that Owners require pre-qualification testing of non-shrink grouts for the establishment of a pre-qualified list of approved non-shrink grouts to be used in ABC connections.

There are a number of potential tests for the prequalification process. The document *Material Characterization of Field-Cast Connection Grouts* (Swenty, Graybeal, 2013) includes a listing of potential tests and the results of testing on a number of commercially available grouts. There is no standard for the levels of performance for some of these tests. The Owner should review these parameters and adjust the testing regime accordingly.

- There is no standard for non-shrink grouts
- Not all grouts are alike
- Many shrink quite a bit
- Some expand



In the following slides, we will cover construction specifications for commonly used materials in ABC. These are included in Section 10 of the Guide Specifications for ABC.

Article 10.4.3 of the Guide Specifications for ABC include provisions for specifying non-shrink grouts. There are literally dozens of non-shrink grouts in the market, however, there are no AASHTO construction specifications for this material. Many states maintain approved product lists for proprietary non-shrink grouts, but there is no standard in the industry.

Research by FHWA has shown that not all grouts performed the same. In fact, many grouts shrink during curing. FHWA has developed a list of performance tests that can be run on non-shrink grout that will improve the performance. Performance measures include strength gain, minimal shrinkage, durability better than the connected concrete, ease of placement, and the ability to fill large voids.

Shrinkage of grouts has proven to be an issue with durability, since water can migrate through cracks. Typical shrinkage tests on grout only measure free shrinkage of a mortar bar. Without restraint the specimen will not crack. To check the true performance of a grout, a confined shrinkage test is in order. A test has been developed by AASHTO and ASTM that is called the ring test. The graphic on the right shows what a test might look like. The concept is that a ring of grout or concrete is cast around a steel ring equipped with strain gauges on the inner surface. As the concrete shrinks, the steel ring will be put into compression. When the concrete cracks, the strain goes to 0.

The performance recommended by FHWA is that the specimen in this test exhibit no cracking in

four days. The other performance measures and tests are listed in this article. These tests should be considered as part of a pre-qualification testing program. Once a grout is approved for use, these tests would not be required during construction.

Section 10 – Concrete Materials

10.4.4—HIGH EARLY STRENGTH CONCRETE

In lieu of Owner-specified concrete mixes, the Contractor shall design and be responsible for the performance of a concrete mix used for closure joints and other rapid construction processes according to Section 8 of the *AASHTO LRFD Bridge Construction Specifications*, as amended herein.

The concrete shall be designed to meet the following goals:

- Meet the required compressive strength (both interim and final) in an accelerated manner;
- Reduce the cure time for the concrete;
- Provide durable (low permeability) concrete; and
- Provide low shrinkage properties to reduce cracking in the field

C10.4.4

This specification is based on performance specifications that have been successfully used in several states. This type of concrete is often used in closure joints. This specification has been used to produce concretes with strength of 4 ksi attained within 12 hours after initial set. The required strength of the concrete should be based on the design strength of the connection.

This specification does not have a specific strength or strength gain timeframe, since both will vary from project to project. The timeframe for strength development will greatly affect the concrete mix design and cost. Designers should consult with concrete producers for mixes that are required to develop strength in less than 12 hours to determine the feasibility of developing this type of mix using local materials.

High early strength concrete is becoming a common material in ABC. It can be used to connect concrete elements in reinforced concrete closure joints. When combined with hooked bars, the width of the joints can be kept quite small. This can be a cost-effective means of connecting precast elements when compared to other options such as post-tensioning or UHPC. This is because it can be produced in large quantities and delivered with ready-mix trucks.

The photo on the right shows the construction of a large bridge in Boston MA. High early strength concrete was used in the closure joints to connect the deck panels.

Article 10.4.4 of the Guide Specifications for ABC include provisions for the development of a performance specification for high early strength concrete. As with non-shrink grouts, shrinkage of the confined concrete is a significant concern. As we discussed earlier today, cracking in these joints due to restrained shrinkage can be problematic for durability.

Reasons for cracking in joints

Concrete closure Joints

- Concrete in closure joints is highly restrained during curing
  - Autogenous shrinkage leads to tensile stress and cracking
  - To minimize cracking, the concrete tensile resistance gain needs to outpace the shrinkage tensile strength gain during curing

If: Internal shrinkage tensile stress ≥ Mod. Of Rupture = Crack

This varies over time

The question that can be asked is: What causes cracking in closure joints?

The concrete placed in closure joints is highly restrained by the adjacent elements. Autogenous shrinkage will result in the development of tensile stress in the concrete during curing. The key to minimizing shrinkage cracks is to have the concrete tensile resistance gain outpace the shrinkage tensile strength gain during curing. Adding moisture to concrete during curing delays the development of autogenous shrinkage, allowing the concrete to gain strength before shrinkage occurs.

Section 10 – High Early Strength Concrete

The high early strength concrete shall conform to the requirements of Section 8 of the *AASHTO LRFD Bridge Construction Specifications* amended as follows:

1. Portland cement shall be Type II, IIA or III conforming to AASHTO M 85 or M 240, as appropriate.
2. Portland cement shall conform to AASHTO M 85 with compatible admixtures and air entraining agent.
3. Water-cementitious material ratio shall not exceed 0.4 by weight, including water in the admixture solution and based on saturated surface dry condition of aggregates.
4. The amount of entrained air shall be 6.0 +/– 1.5 percent when tested according to AASHTO T 152.
5. The early strength characteristics of the concrete shall be commensurate with the intended construction procedure that is developed by the Contractor in the Assembly Plan.

The most significant concern with this use of concrete is restrained shrinkage leading to cracking. Therefore, special admixtures and testing is required to develop a mix that will cure with minimal cracking.

Some of the provisions contained herein are applicable to concretes used in northern environments where the concrete is exposed to freeze thaw cycles and de-icing salts. The Designer may waive the applicable portions of these specifications for bridges in more temperate climates.

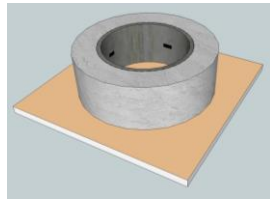
The Designer may allow loads to be applied to high early strength concrete prior to the achievement of the specified final strength. See Article 8.5.4.

The provisions in the Guide Specifications for ABC includes performance testing for the pre-qualification of a high early strength concrete. There are several keys to reducing shrinkage in concrete. Research has shown that a water to cementitious material ratio that is less than 0.4 is beneficial. Other recommended material properties are listed in the provision as well.

Section 10 – High Early Strength Concrete

6. A shrinkage reducing admixture shall be tested by an approved testing lab and meet the requirements of ASTM C494 Type S, except that in Table 1 length change shall be measured as: Length Change (percent of control) shall be a minimum of 35 percent less than that of the control. Table 1 Length Change (increase over control) shall not apply. Shrinkage reducing admixtures shall not contain expansive metallic materials.
7. It is recommended that the mix be tested for restrained shrinkage according to AASHTO T 334. The test is considered successful if there is no cracking in the sample at 14 days maturity.
8. The maximum allowable total chloride content in concrete shall not exceed 0.1 percent by weight of cement.
9. The concrete mix design shall have a maximum rapid chloride ion permeability of 1,500 coulombs at not more than 56 days when tested according to AASHTO T 277. Multiple samples shall be tested using the intended curing methods in order to establish the required cure times for the mix.

The cited restrained shrinkage test is a test that can be used to compare one mix against another during mix development. The cited recommended age to cracking is approximate based on typical test results of successful High Early Strength concretes. Cracking of a sample before 14 days does not necessarily mean that the mix is inadequate. Likewise, cracking of a sample after 14 days does not guarantee that the material will not crack in the field. The field test specified in Article 10.4.4.2 is a more accurate test of intended field performance. The AASHTO T 334 test can be used to compare the High Early Strength mix to normal deck concrete. If the two mixes perform in a similar manner, the Owner and Contractor may elect to move forward with the field test noted in Article 5.4.4.2.



A restrained shrinkage test is also recommended. The ring test can be used during the development of the mix design for the concrete. This test will not guarantee that the actual joint will not crack, but it can be used to compare one mix against another.

The recommended performance measure for this test is no cracking after 14 days of cure.

Section 10 – High Early Strength Concrete

10.4.4.1—Mix Design

The Contractor shall design and submit for approval the proportions and test results for a concrete mix which shall attain the minimum final design compressive strength and the early compressive strength as defined by the Assembly Plan.

Should a change in sources of material be made, a new mix design shall be established and approved prior to incorporating the new material. When unsatisfactory results or other conditions make it necessary, the Owner will require a new mix design.

All tests necessary to demonstrate the adequacy of the concrete mix shall be performed by the Contractor, including, but not limited to: strength, slump, air content, temperature, initial set, and final set (AASHTO T 197). Additionally, a confined shrinkage test should be performed in accordance with AASHTO T 334.

Compressive strength tests shall be determined on field cured cylinders (6×12-inch cylinders) at intervals that are commensurate with the intended construction schedule.

The Contractor may make use of specialized concrete strength gain measurement equipment such as maturity testing in order to gain a better understanding of the concrete strength gain characteristics. The development of this system shall be made part of the mix design development process.

C10.4.4.1

Owners may elect to develop prescriptive specifications for high early strength concrete. In this case, these specifications would be superseded.

Article 10.4.4.1 of the Guide Specifications for ABC includes provisions for a performance-based mix design. The contractor is responsible for developing a mix, testing the mix, and submitting it for approval as part of the assembly plan.

Section 10 – High Early Strength Concrete

10.4.4.2—Field Trial Placement

A trial placement should be undertaken before the intended date of the initial closure pour placement. Sufficient time shall be allotted to allow for modifications of the mix and re-testing if the trial placement does not meet the specified requirements. The Contractor shall demonstrate proper mix design, batching, placement, finishing and curing of the high early strength concrete. The trial placement shall simulate the actual job conditions in all respects including plant conditions, transit equipment, travel conditions, admixtures, forming, use of bonding compounds, restraint of adjacent concrete, placement equipment, and personnel.

The trial placement shall be a full size mock-up of the actual conditions that are to be encountered in the completed structure. Restraint of the closure joint by

C10.4.4.2

The purpose of the trial placement is to demonstrate the effectiveness of the high early strength concrete in the actual structure. A timeframe of 90 days before the actual placement is recommended to allow sufficient time to adjust the mix and re-test. Restrained shrinkage is a common cause of cracking in closure joints. The trial placement is intended to establish the potential for cracking in the joint. The goal is to have minimal cracking with acceptable crack widths. The restrained shrinkage testing may be waived by the Owner for closure joints that are not exposed to the environment in the final structure (i.e., footing closure joints).

An example of a trial placement test is shown in Figure C10.4.4.2-1. This trial pour was for a closure joint between full-depth precast concrete panels. The reinforcement and joint configuration depicted represents the same conditions in the completed

As previously stated, the ring test may not guarantee that a closure joint will not crack.

If an owner desires a higher level of pre-construction testing, a full scale test can be run. Article 10.4.4.2 of the Guide Specification Includes recommended provisions for this test.

The key is to have a test specimen that is similar to the proposed closure joint.

Section 10 – High Early Strength Concrete

adjacent concrete or steel elements shall be included in the mock-up.

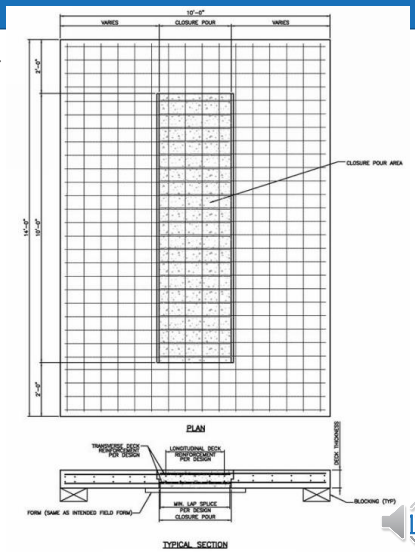
Acceptance requirements for the trial placement shall be as follows:

- The trial placement concrete shall not exhibit cracking or separation from the adjacent element in excess of 0.010 inches wide.
- There shall be no more than one visible transverse crack per 10 feet of joint length. A visible crack is defined as a crack between 0.010 and 0.016 inches wide.
- The evaluation of the trial placement shall take place 14 days after placement.

If the trial placement fails these requirements, the Contractor will be required to submit a corrective action plan on how to prevent the cracks and/or how to repair the cracks. If significant cracking occurs, the Owner may require the Contractor to conduct more trial batches and trial placements using corrective measures.

structure. Other types of closure joints may require different details that more closely match the details of the actual joint.

Example of a field trial placement



The detail on the right is included in the Guide Specifications for ABC. It is an example of a full-scale test specimen that was used on several projects in the northeast.

This precast panel is approximately 10 feet wide and 14 feet long. The center of the panel is a large block out that is approximately 10 feet long with reinforcing projecting from the precast portions. The width of the closure joint should be approximately the width of the joint in the proposed project. The reinforcement should also be similar to the proposed design. The surrounding precast concrete completely confines the concrete in the closure joint area.

The Guide Specifications for ABC include recommendations for the criteria for this test.

- The closure joint concrete shall not exhibit cracking or separation from the adjacent element in excess of 0.010 inches
- There shall be no more than one visible transverse crack per 10 feet of joint length. A visible crack is defined as a crack between 0.010 inches and 0.016 inches.
- The evaluation of the performance is completed 14 days after placement.

This can be an expensive test to run. An owner may elect to allow the use of a previously approved high early strength concrete on subsequent projects with similar joint details.

Section 10 – Ultra High Performance Concrete Specifications

10.4.5—ULTRA HIGH PERFORMANCE CONCRETE FOR CLOSURE JOINTS

The Contractor shall supply a pre-mixed manufactured Ultra High Performance Concrete (UHPC) that meets the performance requirements specified below.

The general mix requirements shall conform to the following:

- Water-to-cementitious materials ratio < 0.25
- Portland cement content ≥ 1,000 lb/yd^3
- Maximum aggregate size ≤ 0.25 times the fiber length.
- Maximum aggregate size ≤ 0.125 inches (3.2 mm)
- Contains fiber reinforcement ≥ 2 percent (by volume)

UHPC shall be capable of resisting a sustained post-cracking tensile stress of greater than 720 psi.

C10.4.5

The provisions contained in this Article are based on the FHWA Publication *Design and Construction of Field-Cast UHPC Connections* (Graybeal 2014), which is a synthesis of research completed at FHWA and other organizations.

The availability of UHPC products that meet this specification may be limited. If only one company can produce UHPC to these specifications, the Owner should treat the item as a proprietary product and obtain the required approvals for use of such items.

Materials for fiber reinforcement can vary. The most common UHPC in use contains steel fiber reinforcement that is approximately 0.008 inches in diameter and 0.5 inches in length. The fibers are straight fibers with a minimum tensile strength of 290 ksi. Other fiber materials can be used if the required material performance requirements of Article 10.4.4.1 are met.

A specific AASHTO or ASTM specification is not available for tensile testing of UHPC. The manufacturer should provide testing results that demonstrate the behavior of the material in sustained tension after cracking.

Performance Specification developed by FHWA

The specification of ultra-high-performance concrete has been problematic in the industry. At first, the only available material was a proprietary mix. A number of states have been working with local universities to develop non-proprietary mixes. FHWA has developed a performance specification for UHPC that can be used for the procurement of proprietary and non-proprietary mixes.

Article 10.4.5 of the Guide Specifications for ABC includes provisions for a performance specification for UHPC. There are several key provisions that must be met in order for a mix to be considered UHPC.

- It must contain fiber reinforcement in excess of 2% by volume
- It must exhibit post-cracking tensile stress resistance in excess of 720psi.

The specification doesn't explicitly require steel fibers, however, research has shown that only steel fibers can develop the post-cracking tensile stress resistance. The specification was written in this fashion to allow for the development of alternate fibers for future UHPC mixes.

Section 10 – Ultra High Performance Concrete Specifications

10.4.5.1—Material Performance Testing

The Contractor shall perform material performance testing for the UHPC. Table 10.4.5.1-1 includes the required material tests, test frequency, acceptance requirements, and the stage of project delivery when they shall be conducted.

C10.4.5.1

Identification of material performance tests and acceptance requirements is highly recommended. They provide a means to assess the properties of a particular UHPC mix design and can validate the appropriateness of material characteristics to the intended needs of a project.

Some material performance tests are appropriate for completion in the laboratory before construction, and other tests are performed during construction.

Many of the UHPC tests conducted are well established tests used for conventional concrete. For some tests, the procedures may need to be modified to capture the true behavior of UHPC and to expedite testing. The use of 3 in. diameter cylinders for compressive strength tests should be considered due to the high forces required to complete the tests.

Performance Specification developed by FHWA

Article 10.4.5.1 of the Guide Specifications for ABC notes that acceptance testing and performance testing is required for UHPC.

Section 10 – Ultra High Performance Concrete Specifications

Table 10.4.5.1-1— Recommended Performance Testing for UHPC Mixes

Test Method	ASTM	Pre-Const. Testing	Constr. Testing	Testing Frequency	Acceptance Requirements
Flow	C1437	Yes	Yes	Once per mix	• Flow range from 7 to 10 inches
Compressive strength	C39 C109	Yes	Yes	At least once per 25 yd^3 (19 m^3) or once per 12-h shift	• > 14 ksi after 4 days • > 21 ksi after 28 days • > 14 ksi before application of construction or live loads
Chloride ion penetrability	C1202	Yes	Not Required	N/A	• ≤ 500 coulombs by 28 days
Freeze-thaw resistance	C666A	Yes	Not Required	N/A	• RDM ≥ 95 percent after 300 cycles
Shrinkage	C157	Yes	Not Required	N/A	• ≤ 800 microstrain at 28 days • Consider curing scenarios

Note: RDM = Relative dynamic modulus of elasticity

Performance Specification developed by FHWA

Table 10.4.5.1-1 of the Guide Specifications for ABC lists the required pre-construction testing and construction testing. Highlights include:

- Compressive strength in excess of 14 ksi after four days
- Compressive strength in excess of 21 ksi after 28 days
- Chloride permeability less than 500 coulombs at 28 days.

Section 10 – Ultra High Performance Concrete Specifications

10.4.5.2—Surface Preparation

The Contractor shall prepare the surface of the adjacent concrete according to Article 10.6.1.

The surfaces of the adjacent elements that are to be connected with a UHPC joint shall be pre-wet to a surface saturated dry (SSD) condition prior to placement of the UHPC.

C10.4.5.2

The preparation of surfaces where the precast component bonds with the field-cast UHPC is critical to ensure durability and long-term performance of the system. Lack of bond allows water infiltration and potentially accelerates the degradation of the concrete and embedded rebar. UHPC can bond exceptionally well to conventional concrete at connection interfaces; however, the bond strength is highly dependent on the surface preparation of the precast concrete. Similar to other cementitious materials, UHPC is not likely to form a strong bond with smooth, dry, precast concrete.

A better bond is achieved with a surface exhibiting micro- and macrotexture. Good bonding has been demonstrated when UHPC is cast against a precast concrete element with an exposed aggregate finish. There are several methods that can be used to create this finish including the use of retarders in the precast form during fabrication combined with moderate water blasting, sand blasting of the joint surfaces after casting, and high pressure water blasting after casting. Sand blasting and high pressure water blasting can cause damage to protruding coated reinforcing steel, therefore these options may not be feasible in all situations.

Pre-wetting the precast concrete interface to an SSD condition immediately before the UHPC is placed also improves bonding. Pre-wetting eliminates the dehydrating effect that occurs when dry concrete extracts water from the newly placed UHPC.

Performance Specification developed by FHWA

Early UHPC projects used on bare concrete decks exhibited minor water leakage at the interface between the precast panel and the UHPC material. This was studied by FHWA. The conclusion was that the adjacent dry concrete surface had absorbed moisture from the UHPC at the interface, resulting in a loss of bond.

Article 10.5.4.2 of the Guide Specifications for ABC include provisions to address this problem. The first provision is to use an exposed aggregate finish at the interface. The second provision is to pre-wet the interface to achieve a surface saturated dry condition prior to the UHPC pour. These measures have proven to help eliminate issues at the interface region of the UHPC joint.

Section 10 – Ultra High Performance Concrete Specifications

10.4.5.3—Formwork for UHPC

Formwork that will be in contact with the UHPC shall have a non-absorbing finish. Formwork shall be properly sealed in order to contain the fluidity of UHPC mixes.

Pours that are not flat shall be retained through the use of top forms.

Forms shall be constructed to allow a slight overfilling of the connection and may include features to provide a slight pressure head on the pour after it is placed.

C10.4.5.3

Fresh UHPC is a fluid, self-consolidating material that contains little or no coarse aggregate. Because of these features, the formwork used to contain the material requires tighter control than the formwork used for conventional concrete. UHPC also places higher pressures against the formwork compared with conventional concretes.

Success or failure of UHPC placement is directly related to Contractor and construction inspector attentiveness to ensuring that the formwork is properly sealed and capable of resisting the hydrostatic pressures from the UHPC in the unhardened state. The formwork should be nearly leak proof under the application of water.

UHPC is a self-leveling material that will not normally set on a grade before initial set. Even roadway cross slopes have proven to be problematic when placing UHPC in deck joints. Top forms combined with placement "chimneys" have proven to be successful methods for properly placing UHPC.

As is common with fluid materials cast into enclosed spaces, trapped air must be provided an exit so that the space can be filled by the UHPC. Small amounts of air trapped in the UHPC and in the connection spaces during placement can result in the UHPC initially appearing to fill the void space, and then later subsiding slightly as the air escapes. The use of a form "chimney" combined with a top form can be used to sustain a slight pressure head on the unhardened UHPC and address any subsidence effects from the release of air.

One of the issues with UHPC is that it is very fluid when placed. This causes two problems:

First, the forms need to be carefully sealed to prevent leakage of UHPC during the pour. Experience has shown that UHPC will leak through even the smallest hole in a form.

Second, the mix is essentially self-leveling and can run easily downhill. If the pour is not perfectly flat, it will not stay in place without forming. For pours on slopes such as cross slopes on bridge decks, top forms will most likely be required to maintain the cross slope on the top of the poor.

Article 10.4.5.3 of the Guide Specifications for ABC include provisions to address these two issues. Other recommendations are also included.

Section 10 – Ultra High Performance Concrete Specifications

Other UHPC Provisions

10.4.5.4—Mixing UHPC

10.4.5.5—Placing UHPC

10.4.5.6—Finishing UHPC

10.4.5.7—Curing UHPC

The Guide Specifications for ABC also include UHPC provisions for:

- mixing,
- placing,
- finishing,
- and curing

Section 10 – Surface prep for Concrete Connections

10.6.1—SURFACE PREPARATION FOR CONCRETE CONNECTIONS

The Contractor shall prepare the interface surfaces of elements that are to be in contact with cementitious closure joint materials.

The interface surface of connections requiring resistance against water infiltration should be cast with an exposed aggregate finish. The method of achieving this finish shall not damage any coatings on any reinforcing steel that is projecting from the elements.

In lieu of exposed aggregates, the surfaces shall be cleaned of all laitance and other deleterious materials prior to placement of closure joint materials.

The interface of the concrete elements shall be prepared to a saturated surface dry condition (SSD) prior to placement of cementitious joint materials. The surface shall be moist, but free of standing water.

C10.6.1

Research completed on UHPC materials has shown that an exposed aggregate finish greatly improves the bond of the materials (Graybeal 2014 & 2017) and resistance to water infiltration. This approach is recommended for all bridge deck applications, especially if the final deck surface is exposed. This same approach can improve the bond of all cementitious materials as it removes laitance and provides a mechanical interlock with the joint material.

Saturated surface dry is defined as the condition of a surface where the surface is "dry" (i.e., surface adsorption would no longer take place), but the inter-particle voids are saturated with water. The process of preparing a surface to a SSD condition normally requires pre-wetting for at least several hours prior to placement of joint materials.

Article 10.6.1 of the Guide Specifications for ABC includes provisions for the preparation of surfaces for concrete connections. This provision includes a recommendation to use an exposed aggregate finish to prevent leakage of water. This provision also recommends the use of surface saturated dry conditions prior to the placement of cementitious materials.

There is no standard specification that defines surface saturated dry. The commentary for this article includes a definition that states:

"The condition of a surface where the surface is "dry" (i.e. surface absorption would no longer take place), but the interparticle voids are saturated with water." Another way of defining this is a surface that is visibly damp, but with no standing water or water droplets on the surface.

The commentary indicates that in order to achieve a surface saturated dry condition, prewetting would be required for at least several hours prior to the placement of joint materials.

Section 10 – Grouted Coupler Connections

10.6.3—GROUTED COUPLER CONNECTIONS

Grouted reinforcing bar couplers shall conform to the requirements for Mechanical Splices in Section 9 of the *AASHTO LRFD Bridge Construction Specifications*, as amended herein.

C10.6.3

The basis for these provisions is the *Building Code Requirements for Structural Concrete* (ACI-318-14). The Type 1 couplers specified herein are currently included in the *AASHTO LRFD Bridge Construction Specifications*. The Type 2 couplers are a stronger connector that is included in the *Building Code Requirements for Structural Concrete* (ACI-318-14), where they are used for seismic applications.

10.6.3.1—Materials

Grouted reinforcing bar couplers shall be specifically designed to join reinforcing bars from within a precast concrete element to projecting bars from an adjacent precast concrete element. The couplers shall use cementitious grout placed inside a steel casting to develop the strength of the connection. Threaded connections may be used for the portions of the coupler that are placed within the precast element if the strength of the coupler meets or exceeds the requirements of this specification.

When requested by the Designer, the Contractor shall furnish certified test reports, verifying the ability of the coupler to meet this specification.

C10.6.3.1

Some agencies maintain a pre-qualified list of approved mechanical connectors. The Owner may waive the need for certified test reports for pre-qualified connectors.

The grout used for couplers is specifically formulated to produce the desired results.

Article 10.6.3 of the Guide Specifications for ABC include recommended specification language for grouted couplers. These devices are proprietary and make use of proprietary materials.

Prequalification of couplers is typically achieved through mechanical testing of the devices. This is to ensure that the couplers will meet the strength and ductility requirements specified.

As previously discussed in this training, the Guide Specifications for ABC contain two types of couplers. Type 1 couplers are the same as mechanical bar splicers in the AASHTO LRFD Bridge Design Specifications, which need to develop 1.25 times the specified bar yield stress. Type 2 couplers need to develop 100% of the specified tensile strength of the connected bar.

The specifications should require that certified test reports be supplied to verify the strength of the couplers.

Section 10 – Grouted Coupler Connections

The grout used for the inside of the couplers shall be supplied by the manufacturer of the coupler. The grout shall be matched with the coupler and be the same grout as the certified test report for the coupler. No other grout shall be substituted in the couplers unless additional certified test reports are submitted for the grout/coupler system.

Two types of grouted reinforcing bar couplers are allowed (Type 1 and Type 2). The Contractor shall furnish and install the type specified in the contract documents. Type 2 connectors shall be used for all connections if the contract documents do not specify the coupler type.

The material requirements and testing of Type 1 grouted couplers shall be in accordance with the provisions for mechanical splices in the *AASHTO LRFD Bridge Construction Specifications*.

The material requirements and testing of Type 2 grouted couplers shall be in accordance with the provisions for mechanical splices in the *AASHTO LRFD Bridge Construction Specifications*, except that the coupler shall be capable of developing 100 percent of the specified tensile strength of the bars being spliced.

This requirement equates to a strength equal to or exceeding 125 percent of the specified yield strength of the connected bar.

This requirement is based on the tensile (ultimate) strength of the connected bar. For grade 60 reinforcing bars, this equates to approximately 150 percent of the specified yield strength of the connected bar.

This article also requires that the grout inside the coupler be supplied by the manufacturer of the coupler. These devices use specialized grout materials to achieve high strength and consistent results.

The commentary notes that for Grade 60 reinforcing bars, the Type 2 coupler needs to develop 150% of the specified yield stress of the connected bar.

Section 10 – Grouted Coupler Connections

10.6.3.2—Installation of Grouted Couplers

Grouted couplers shall be installed in strict accordance with the coupler manufacturer's specifications. The following is a general sequence of construction that is applicable to coupler installation. Minor modifications to this sequence may be required for each installation based on the manufacturer's specifications.

1. Maintain a minimum temperature of 50°F and a maximum temperature of 90°F during installation, grouting, and curing of grout.
2. Determine the width of the joint between the elements based on the layout and tolerance requirements specified in the Assembly Plan.
3. Recommend that the projecting reinforcing bars from the adjacent element be cast longer than required and cut to length in the field after the joint width is determined. Check the length of the projecting dowel to ensure that the embedment within the coupler will meet the manufacturer's specified minimum embedment. Account for the actual width of the joint between the two elements for the dowel length.

C10.6.3.2

The performance of grouted splice couplers is primarily related to the embedment length of the bars within the couplers and the compressive strength of the grout. The provisions contained herein focus on achieving adequate embedment and quality grouting. In most cases, grouted coupler connections consists of a coupler cast into one precast element combined with a dowel bar projecting from the adjacent element that is inserted into the coupler. The connection is completed by injecting and curing grout in the coupler. For these provisions, the term "dowel" will refer to the projecting bar from one element, and the term "coupler" will refer to the device that is cast into the second element.

See Section 8 for more information on Assembly Plans.

The length of the dowel should be based on the actual width of the joint, not the specified width. The actual width will vary depending on the fabrication and erection tolerances of the elements. It is common to cast dowels with extra length and cut them to the exact length in the field after erection of the first element. This approach will ensure that the dowel embedment length will be adequate.

Article 10.6.3.2 of the Guide Specifications for ABC include recommended specification language for the installation of grouted couplers. These provisions are based on common practice used in the industry.

An important aspect of this provision is a recommendation to cut the projecting reinforcing bars to the required length just prior to erecting the connected element. This allows for adjustment of joint widths without sacrificing embedment length into the coupler.

These provisions also note that minor modifications to the sequence may be required based on the manufacturer's specifications for their product.

Section 10 – Grouted Coupler Connections

4. Cut the dowels if necessary to achieve the proper embedment. Repair of coatings at the ends of cut bars is not required.
5. If required, place bedding grout in the joint prior to placing the second element (horizontal joints). Crown the thickness of the grout toward the center of the joint so that the grout can be displaced outward as the upper element is lowered onto the joint. Take precautions to prevent the non-shrink grout from entering the coupler above (e.g., seal washers around dowels).
6. Erect, shim, plumb, and stabilize the second elements in accordance with the Assembly Plan. Engage all couplers in the joint. Allow excess joint grout to seep out of the joint.
7. Trowel off excess joint grout to form a neat joint once the element is set, plumbed, and aligned. Pack grout into any voids around the joint perimeter.
8. Flush out the couplers with clean potable water.
9. Mix the special coupler grout according to the manufacturer's recommendations for methods and proportions of mix and water.

Repairs for coatings are not required since the coupler will provide ample protection.

10. Make four sets of three 2-inch cube specimens for testing. Cure the specimens according to AASHTO T 106. Test one set of cubes for compressive strength at a minimum of 24 hours (or to determine when to release bracing) and 28 days. Store extra sets for longer term testing, if necessary.
11. Pump the coupler grout into the coupler. Start from the lower port. Pump until the grout is flowing freely from the upper port.
12. Cap the upper port first and then remove the nozzle to cap the lower port. Proceed to the remaining couplers until all couplers are grouted.
13. Cure the joint according to the non-shrink grout manufacturer's recommendations. Maintain a temperature of 50°F during curing.

The Contractor shall be responsible for sampling and testing grout specimens. The Owner reserves the right to test the extra sets of grout specimens at their discretion.

This provision also recommends testing requirements for the grout. It notes that the contractor is responsible for sampling and testing of the grout specimens.

End of Module 6

Available Modules

Non-seismic

1. General Provisions and Common Connections
2. Substructure Design
3. Superstructure Design
4. Bridge Systems
5. Durability of ABC Designs
6. ABC Construction Specifications

Seismic

7. Introduction to ABC Seismic
8. Seismic Connection Design and Detailing
9. Seismic Pocket and Socket Connections
10. Seismic Integral Connections