Appendix E
Supplementary Concrete Specification Example

This appendix provides an example of project-specific supplementary specification for structural concrete. The example herein builds from Example 2 - Service Life Design Report for a Bridge Substructure presented in Appendix D and conveys the durability-related requirements to the construction site. That example Service Life Design report provided a durability assessment for the reinforced concrete substructure of a cable-stayed bridge located Mideast of the United States. The objective of the Service Life Design report was to determine the required binder combinations, concrete quality and concrete cover to meet the required service life of 100 years.

The durability-related requirements concluded in the Service Life Design report must still be effectively conveyed to the construction site through project drawings and project-specific specifications. The follow provides one means of accomplishing this. In the following example project-specific specification provisions are provided as amendments to the AASHTO 'LRFD Bridge Construction Specifications', 4th Edition, 2017.

It is noted that only durability-related requirements derived from the conclusions of the example Service Life Design report are included and additional project-specific details would need to be included in a complete and implementable supplementary concrete specification. Further, the test methods and associated frequencies included below are only indicative for the example project discussed in the Example 2 Service Life Design report in Appendix D. Test methods and frequencies must always be adjusted on a project-specific basis with due consideration of durability-related issues (e.g., exposure conditions and applicable deterioration mechanisms) and with considerations of other project specific details (e.g., construction methods, structural details, etc.).

E1.0 Introduction

This supplementary specification for structural concrete of the substructure of two-span cable-stayed bridge design example shall comprise the AASHTO 'LRFD Bridge Construction Specifications', 4th Edition, 2017 together with the following project-specific supplementary provisions. The following supplementary provisions utilize the article numbering system from the AASHTO 'LRFD Bridge Construction Specifications'. To facilitate their implementation, the supplementary provisions include instructions to amended articles in underlined text, with the underlined text stating how the specific article is amended.

Articles of the AASHTO 'LRFD Bridge Construction Specifications', 4th Edition, 2017 not mentioned below shall apply unaltered. Cross references herein and in AASHTO 'LRFD Bridge Construction Specifications', 4th Edition, 2017 are by default referring to the equivalent article in AASHTO 'LRFD Bridge Construction Specifications', 4th Edition, 2017 as modified herein.

8.2 Classes of Concrete

8.2.1 General

Add the following:

Use Class A(HPC) concrete, as modified by Table 8.2.2-2, for all bridge components. Compressive strength of concrete shall be as specified in project drawings.

Concrete mix designs shall consist of the following binder compositions:

- Portland Cement with 20 percent to 25 percent Class F fly ash by mass of total cementitious materials shall be used for all structural elements and exposure conditions except drilled shafts.
- As an alternative solution, Portland Cement with 30 percent to 45 percent GGBS by mass of total cementitious materials may be used for pile caps, piers, tower pedestals.
- Portland Cement with 45 percent Class F fly ash by mass of total cementitious materials shall be used for the drilled shafts

Required properties for structural concrete mix designs are provided in Table 8.2.2-2. Additionally, Table 8.2.2-2 indicates for which concrete alkali-aggregate reactivity (AAR) tests and freeze-thaw tests are required. Details on AAR tests are provided in Articles 8.3.3 and 8.3.4.

The utilized mix designs shall simultaneously comply with requirements from Table 8.2.2-2 and compressive strength requirements as specified in project drawings. Concrete exposed to the river water and soil shall have minimum concrete compressive resistance of 4 ksi, while concrete exposed to freeze-thaw cycles with or without exposure to de-icing salt shall have a minimum compressive strength of 4.5 ksi.

Fulfilment of the required maximum averaged chloride migration coefficients at 28 days of maturity based on 3 individual samples. Samples shall be either 3 cylindrical specimens sliced from 3 different cast cylinders or 3 different cores (e.g., from 3 individual cast cubes) in accordance with dimensions provided in Section 5 of NT Build 492.

Article 8.4.1.2 describes test methods and frequencies during trial batch testing, while Article 8.5.6 describes test methods and frequencies during production testing.

Table 8.2.2-2: Summary of Exposure Zone, Concrete Mix Requirements and Test Requirements

Exposure Zone	Structural Element	Cover (inch)(1)	Binder composition	Max w/cm (2)	Air Content ASTM C231 or ASTM C173	Max. Average Chloride Migration NT Build 492 at 28 days(3)	Max. Chloride Content ASTM C1152	AAR Tests	Freeze-Thaw Tests
Submerged/Buried(4)	Drilled Shafts	6/3	Portland Cement + 45% Fly Ash Class F	0.4	-	-	-	-	-
Splash Zone/ Atmospheric with moderate de-icing salts(4),(5)	Pile Caps Tower Pedestals Piers	2	Portland Cement + 20-25% Fly Ash Class F	0.4	6 ±2%	15.5×10^{-9} in^2/s (10.0×10^{-12} m^2/s)	0.1%	x	x
		3	Portland Cement + 30-45% GGBS	0.4	6 ±2%	11.3×10^{-9} in^2/s (7.3×10^{-12} m^2/s)	0.1%		
Atmospheric with severe de-icing salts(5)	Towers (exterior) at deck level	3	Portland Cement + 20-25% Fly Ash Class F	0.4	6 ±2%	11.8×10^{-9} in^2/s (7.6×10^{-12} m^2/s)	0.1%	x	x
Atmospheric without de-icing salts(5)	Towers (interior)	1.5	Portland Cement with 20-25% Fly Ash Class F	0.4	6 ±2%	15.5×10^{-9} in^2/s (10.0×10^{-12} m^2/s)	0.1%	x	x
	Towers (exterior) below deck level	2							
	Towers (exterior) > 35 ft above deck level	2							

(1) Greater concrete covers may be specified if needed for ease of construction.
(2) Max w/cm = Maximum water/cementitious material ratio.
(3) Chloride migration coefficients are applicable only to the corresponding concrete mix design, cover and exposure conditions.
(4) Concrete exposed to the river water and soil shall have minimum concrete compressive resistance of 4 ksi.
(5) Concrete exposed to freeze-thaw cycles with or without exposure to de-icing salt shall have a minimum compressive strength of 4.5 ksi.

8.2.4 Air-entrainment Requirements

Concrete for elements with required freeze-thaw testing per Table 8.2.2-2 shall be air-entrained and freeze-thaw testing shall include evaluation of fresh and hardened air content. Fresh air content shall comply with limits provided in Table 8.2.2-2, while the hardened air content shall comply with the following:

- The air-void system of the concrete mix will be considered satisfactory when the average of tests shows a spacing factor not exceeding 0.008 inches, with no single test greater than 0.010 inches, and air content greater than or equal to 3.0 percent in the hardened concrete. For concrete with a water-to-cementitious materials ratio of 0.36 or less, the average spacing factor will not exceed 0.0098 inches, with no single value greater than 0.0118 inches.

8.3 Materials

8.3.1 Cements

This following paragraph is added:

Cementitious materials shall be from Agency approved material sources[1].

Portland Cement shall contain <0.6% equivalent Na_2O as defined in ASTM C150. Portland Cement with a higher alkali content may be acceptable if other measures to mitigate AAR are provided. Alternative measures will be subject to review and approval by the Engineer. The limit on the alkali content does not apply to the drilled shafts concrete mix.

8.3.3 Fine Aggregate

The following is added:

Fine aggregates shall be from Agency approved material sources[1].

Potential reactive aggregates will be addressed through the provisions of AASHTO R80-17. Risk of AAR is minimized by selecting a nonreactive aggregate as defined in AASHTO R80-17 or selection of adequate preventative measures in accordance with AASHTO R80-17. The full procedure in AASHTO R80-17 shall be carried out as part of pre-testing and at change in the source of supply of fine aggregate.

---

[1] Agency approved materials and material sources are often referred to as Qualified Products List or QPL.

8.3.4 Coarse Aggregates

The following is added:

Coarse aggregates shall be from Agency approved material sources[1]. Coarse aggregate for concrete with required freeze/thaw testing (See Table 8.2.2-2) shall comply with requirements for freeze-thaw of aggregate set out in the local Standard Specifications[2].

Potential reactive aggregates will be addressed through the provisions of AASHTO R80-17. Risk of AAR is minimized by selecting a nonreactive aggregate as defined in AASHTO R80-17 or selection of adequate preventative measures in accordance with AASHTO R80-17. The full procedure in AASHTO R80-17 shall be carried out as part of pre-testing and at change in the source of supply of coarse aggregate.

8.3.8 Mineral Admixture

The first bullet point is deleted and replaced by following:

- Class F fly ash-AASHTO M 295 (ASTM C618)

The following sentence is added:

Mineral admixtures shall be from Agency approved material sources[1].

8.4 Proportioning of Concrete

8.4.1 Mix Design

8.4.1.2 Trial Batch Tests

The following is added:

Satisfactory performance of the proposed mix design shall be verified by trial batch tests. The requirements in this section shall be verified during trial batch tests. Frequency of testing during

---

[2] Local Standard Specifications (e.g., State Department of Transportation Standard Specifications or similar) typically include the local practice for freeze/thaw testing of coarse aggregate including test methods, acceptance limits and testing frequency. It is typically recommendable to rely on local Standard Specifications (i.e., local practice) for evaluation of freeze/thaw resistance of aggregate. Subjecting previously approved aggregate to an alternative test methods introduces a risk for a rejection of a suitable aggregate source. Test methods commonly include direct evaluation by exposing the aggregate to freeze-thaw cycles (e.g., AASHTO T 103) or indirect evaluation of aggregate soundness (e.g., AASHTO T 104, ASTM C 88) or freeze-thaw testing of concrete containing the aggregate (e.g., ASTM C 666), and some Departments of Transportation have developed internal protocols (e.g., New York State Department of Transportation Test Method No. NY 703-08 P,G).

trial batch testing shall be 100% (i.e., each and every load produced). In this context, the term load means one agitating truck load.

The mix design shall comply with the following:

- All requirements to constituent materials from Article 8.3
- Requirements to binder composition and water/cement ratio from Table 8.2.2-2
- Compressive strength requirements as specified in project drawings and minimum values from Table 8.2.2-2
- The maximum average chloride migration coefficient measured at 28 maturity days in accordance with NT Build 492 shall not exceed the required value in Table 8.2.2-2 and the coefficient of variation of results shall not exceed 20% (i.e., 0.20)
- The initial acid-soluble chloride content of concrete shall be tested in accordance with ASTM C1152
- Concrete for use in elements subject to freezing and thawing (see Table 8.2.2-2) shall additionally be tested as follows:
    - The hardened air-void system shall be tested in accordance with ASTM C457 Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete using a magnification factor between 100 and 125.
    - The fresh air content shall be tested in accordance with ASTM C231 or ASTM C173

8.4.4 Mineral Admixtures

<u>This article is deleted and replaced by the following:</u>

Mineral admixtures shall be used in the amounts specified in Article 8.2.2 and Table 8.2.2-2.

In calculating the water-to-cementitious materials ratio of the mix, the weight (mass) of the cementitious materials shall be the sum of the weight (mass) of the Portland cement and the mineral admixtures.

8.4.5 Air-Entraining and Chemical Admixtures

<u>This article is deleted and replaced by the following:</u>

Air-entraining and chemical admixtures shall be used as specified in mix design data provided for approval per Article 8.4.1.3.

8.5 Manufacture of Concrete

8.5.6 Sampling and Testing

The following text is added:

- Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method, ASTM C173
- Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method, ASTM C231
- Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete, ASTM C457
- Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete, ASTM C1152
- Standard Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction, AASHTO R80

For concrete with a chloride migration coefficient requirement (See Table 8.2.2-2), testing shall be at least once per 2,000 cubic yard of concrete produced. A test shall consist of 3 samples. The chloride migration coefficient of the concrete shall be determined in accordance with:

- NT BUILD 492 (1999). Concrete, mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration experiments. NORDTEST method 492. NORDTEST, Espoo, Finland.

The fresh air content shall be tested for concrete mix design including air entrainment for compliance with the specified fresh air content in Table 8.2.2-2 in accordance with ASTM C231 or ASTM C173. Testing shall be the greater (i.e., more often) of one test per 130 cubic yard of concrete placed or one test per placement.

8.11 Curing Concrete

8.11.5 Mass Placements

Article 8.11.5 with provisions for mass placements is added:

Concrete elements, with and without reinforcement, with minimum dimension of 7 ft or greater shall be considered as mass placements. Elements that comply with the definition of a mass placement shall be designated as such on project drawings.

Project-specific Thermal Control Plans are required for all mass concrete and these plans shall include provisions to limit the maximum temperature of curing concrete to 160°F and temperature differential between the central core of the placement and the exposed concrete surface to a maximum of 35°F.

Use the guidelines in ACI 207, "Mass Concrete," to develop the Thermal Control Plan. Develop the Thermal Control Plan using historical temperature ranges for the anticipated time of the mass placement. Re-create the plan if the work schedule shifts by more than one month. Thermal Control Plans shall be developed for each mass placement using thermal modeling and methods acceptable to the Designer. Individual mass placements shall not begin until the Designer has approved the associated Thermal Control Plan.

The plans shall be based on the concrete mix design to be used and shall consider the adiabatic temperature rise of the concrete, concrete placement temperature, element geometry, time between consecutive pours, formwork insulation and curing methods, ambient conditions, and cooling systems (if used). The plan shall include details of the temperature monitoring, including sensor locations, plans for cases of sensor failure and protection of the sensors during concrete placement and consolidation.

Thermal control measures may include a combination of the following elements:

- Selection of concrete ingredients including aggregates, gradation, and cement types, to minimize heat of hydration;
- Use of ice, precooling of aggregate, or other concrete cooling ingredients including liquid nitrogen dosing systems;
- Controlling rate or time of concrete placement and consideration of individual lift heights and time delay between lifts;
- Use of insulation or supplemental external heat to control heat loss;
- Use of supplementary cementing materials;
- Use of a cooling system to control the core temperature; or
- Vary the duration formwork and insulation remains in place.

For each mass placement temperature monitoring data shall be submitted as confirmation that the above-mentioned temperature limits were achieved. Temperature measurements shall include measurements from 2 sets of temperature sensors. Install devices to measure the surface temperature no more than 2 in. from the surface. Install devices to measure the core temperature at the center of concrete mass or as informed by the Thermal Control Plan and subject to approval of the Designer. Use these devices to simultaneously measure the temperature of the concrete at the core and the surface. Maintain temperature control methods until conditions for termination of thermal control measures in the thermal control plan are met.

If the core temperature exceeds 160°F, the mass concrete element will be subject to review and acceptance by the Engineer using forensic analyses to determine its potential reduction in service life or performance. Proceed with subsequent construction on the affected element only when notified regarding acceptance. Repair any resulting cracking if the temperature differential between the central core of the placement and the nearest concrete surface exceeds 35°F at no expense to the Department and revise the Thermal Control Plan as necessary to prevent further occurrences.

___________________ *(Additional project-specific input for a complete provision on mass placement/Thermal Control Plans)*[3].

8.19 Evaluation of Cover in Hardened Concrete

Article 8.19 is added as follows:

For elements cast in formwork and accessible for inspection upon formwork removal, measure the achieved concrete cover thickness on all accessible surfaces of the hardened concrete in accordance with the following standard:

- The German Concrete and Construction Association, Technical Report, Concrete Cover and Reinforcement per Eurocode 2. Deutscher Beton- und Bautechnik-Verein, DBV-Merkblatt, Betondeckung und Bewehrung nach Eurocode 2 (in German).

Perform a minimum of 40 measurements per concrete surface and evaluate for conformance with cover thickness requirement per Table A.1 of the above reference. Elements in the Splash zone and Atmospheric with moderate de-icing salts exposure zones shall be shown to comply with the 5% quantile test evaluation, while elements in the Atmospheric with severe de-icing salts exposure zone shall comply with the 10% quantile test evaluation.

[3] Additional detail on mass placements, thermal control plans, and thermal control measures is available in the literature (see e.g. ACI 207.1R-05 Guide to Mass Concrete, ACI 207.2R-07 Report on Thermal and Volume Change Effects on Cracking of Mass Concrete, etc.) which may be considered for additional project-specific provisions for mass placements.