PATH 1: Cement Limit Method

Notes for user:

- Consider adding the specification clauses below to PART I – GENERAL.
- Portions bolded and in brackets depend on project conditions.
- Portions underlined and bolded are clauses that are not typically found in standard specifications.
- Some plain text remains for context purposes, bolded when directly beneficial to cement or GWP reduction. All language is at the discretion of the structural engineer of record (SEOR).

1. DEFINITIONS

A. **Cementitious Materials: Portland cement alone or in combination with one or more of the following: blended hydraulic cement, fly ash and other pozzolans, slag cement, and silica fume; subject to compliance with requirements.**

Consider adding specification clauses such as the following for use of CO_2 mineralization technology (e.g. CarbonCure)

B. **[Carbon dioxide mineralization: Active carbonation treatment of concrete during mixing such that the carbon dioxide (CO2) that is injected during mixing is mineralized (i.e. chemically converted into a mineral) within the concrete.]**

C. **[Carbonation treatment: Active introduction of CO2 into the concrete pore fluid which reacts with calcium from calcium hydroxide and calcium silicate hydrate to form calcite (CaCO3).]**

D. **Portland cement clinker - a partially fused product of kiln that is ground to make cement**

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3. SUBMITTALS

E. **<u>Contractor shall supply a *Low Carbon Concrete Compliance Form (Cement)* to the project architect within 6 weeks after completion of concrete work on the project. The mix design number listed on the *Low Carbon Concrete Compliance Form* must match the mix design number shown on the proposed mix design.</u>**

Consider adding specification clauses such as the following regarding shrinkage in lieu of setting water-cement ratio limits to give the supplier more freedom to reduce cement without sacrificing performance the water-cement limits are traditionally specified to control.

F. Provide shrinkage test results for mixtures with shrinkage criteria showing that mixture meets performance criteria. The mix design number shown on the concrete mix design must match with the mix design number shown on the test data.

Consider adding specification clauses such as the following regarding compressive strength to ensure test data is supplied to show reduced cement mixtures will achieve the strengths specified.

G. Submit average compressive strength of proposed concrete mixtures and method used to determine average from either laboratory batches or a past record of field test results. ... Mix design number on the concrete mix design must match the mix design number shown on the test data. Include all test results or history back up data specific to the mix design as part of the submittal. Test results within the past two years shall be used to indicate performance in accordance with history.

Check that test reports and certificates for all ASTM standards listed in Part II are listed in the submittal requirements as well.

H. Product Test Reports and Certificates: For each of the following, signed by manufacturers:

- Cementitious materials, per ASTM C150, **ASTM C595, ASTM C618, ASTM C989, and/or ASTM C1240, as applicable.**

Suggested clause for use of CO_2 mineralization technology (e.g. CarbonCure). An important need in the case of mineralization technologies is to verify the actual amount of "CO2 uptake" and how it leads to OPC use reductions. It is important to keep in mind that the amount of CO2 injected is not the amount of uptake. The uptake is typically only a fraction of the amount of CO2 injected.

- **Carbon dioxide mineralization: Provide concrete producers certificate verifying mineralization of carbon dioxide. Include quantity, location, and supplier of injected CO_2.**

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Consider adding specification clauses such as the following regarding alternate concrete mixtures so that the contractor has the freedom to use multiple strategies for meeting low carbon concrete requirements under the different circumstances that may arise during project construction. Stressing time only pertains to prestressed systems. Stripping time does not apply to concrete filled metal decks.

4. PROJECT GOALS AND BIDDING REQUIREMENTS

A. Alternate Concrete Mixtures: Contractor may propose alternate concrete mixture proportions, and alternates to the use of materials.

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- **Contractor shall supply a revised *Low Carbon Concrete Compliance Form* for each proposed alternate that shows cement use in each alternate concrete mixture is less than the cement limit for the mixture. Multiple alternate mixtures may be provided on one *Low Carbon Concrete Compliance Form*.**

Suggested clause to allow for budget method

- **If contractor chooses to use an absolute project total instead of limits for each mixture, contractor shall supply a revised *Low Carbon Concrete Compliance Form* for each proposed alternate that shows the total project cement use in concrete is less than the maximum allowable cement use in concrete.**

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Consider adding the specification clauses below to PART 2 – PRODUCTS.

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Check that all ASTM standards have been listed to utilize supplementary cementitious materials and other cement-reducing technology deemed acceptable to for project. Note that ACI 318 lists several blended cements appropriate for different exposure classes, particularly for concrete exposed to sulfates. However, Caltrans limits cementitious types to Type II/V due to sulfate content in soils in the Bay Area, so nearly all concrete producers in California supply only Type II/V cements. Thus, Bay Area concrete producers will have difficulty meeting other cements prescriptively specified.

A. **Supplementary Cementitious Materials (SCM):**

- **Fly Ash: ASTM C618, Class F. (Is Class C not available?)**
- **Slag Cement: ASTM C989, Grade 100 or 120.**
- **Silica Fume: ASTM C1240,**
- **High-Reactivity Metakaolin: ASTM C618, Class N.**
- **Natural Pozzolans: ASTM C618, Class N**

Suggested clause for controlling ASR. Use in lieu of prescriptively specifying cement and SCM types and amounts. Edit requirements depending on which ASTM is chosen.

B. Aggregates for alkali silica reactions comply with one of the following options:
   1. Determined to be non-reactive – expansion =< 0.04% at 1 year in accordance with ASTM C1293
   2. Aggregates used with similar composition of cementitious materials shall have at least [X] years in similar exposure conditions with no evidence of deleterious cracking attributable to ASR
   3. Combination of cementitious materials and each aggregate shall be tested by ASTM C1567 to obtain expansion that does not exceed 0.10 at 16 days.
   4. (The concept of alkali loading of concrete – calculated from Portland cement only – can be used – limits include max 3 lb / yd or 4 lb per yd – see ACI 301) This can control increase cement use

C. Cementitious material used shall have at least **[2][X]** years of use with proposed aggregates without detrimental reaction based on testing to ASTM **[C1293 or C1567]**. **[Length change shall not exceed 0.10% at 16 days per ASTM C1567.] or [Length change shall not exceed 0.10% after 2 years per ASTM C1293.]**

Suggested clause for use of CO_2 mineralization technology. Listing specific technology provider assists the contractor in sourcing and approvals. CarbonCure is the only known provider at this time, thus design team should obtain owner approval for sole sourcing until multiple providers are available. Addition restriction to source CO2 from vicinity is only to limit transport emissions and should be removed if too onerous or counterproductive to project aims.

D. **Carbon dioxide mineralization: [ASTM XX] Carbon dioxide in the mixture must be post-industrial CO2 sourced from an emitter within [X] miles from the injection site.**

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2. CONCRETE MIXURES

A. Definition of Mixture Properties:

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Suggested clause to control cracking due to volume change in lieu of prescribing water-cement ratio or maximum cementitious content

- **[Drying shrinkage limit is percentage change in length after 28 days of drying when tested as per ASTM C157 with 3 inches x 3 inches x 11 inches specimen moist cured 7 days prior to drying.]**

B. **Supplementary Cementitious Materials (SCM): Use fly ash, pozzolan, slag cement, and silica fume as needed to reduce the total amount of Portland cement.**

Suggested clause to allow for budget method

C. **If the cement content of a mixture exceeds the allowable cement content per Low Carbon Concrete requirements, demonstrate through the Low Carbon Concrete Compliance Form that the Total Cement used on the project is less than the Total Allowable for the project**

Suggested general structure of text for list of concrete mixtures under Concrete Mixtures section of specifications or General Notes. Note that this is follows the recommendations from National Ready-Mix Concrete Association and the larger local suppliers to move towards more performance-based specifications that do NOT increase strength above the basis of design, nor specify minimum cement, maximum SCMs, maximum water-cement ratio, slump, admixture dosage, etc. It is encouraged to instead specify for performance through exposure class and verification through testing or mock-ups for the characteristics desired such as low permeability, shrinkage limits, workability, temperature control, freeze-thaw resistance, etc.:

X. Type **[X]** – **[Structural Concrete Elements/Applications]**
   - **[Concrete weight type]**

Do not inflate specification of f'c above the compressive strength used in design for purpose of controlling other performance characteristics. See below for recommended means and relevant test standards. Consider extending day to reach f'c beyond traditional 28 days which will allow mixtures using SCMs in place of cement the time needed to reach design strength. Typical later days to strength are 56, 90, and 120, often acceptable for foundations and vertical elements but ultimately for the structural engineer to determine based on construction and occupancy schedule.

- Strength - f'c **= [design strength]** psi (at **[XX]** days)

Suggested clauses in lieu of prescribing water-cement ratio or maximum cementitious content to control cracking due to volume change

- Shrinkage limit = **[0.0XX%]**

Suggested clause in lieu of prescribing water-cement ratio for durability under special exposure conditions. F=Freeze-thaw, S=Sulfates, W=Contact with water, C=Corrosion protection. See ACI 318 for which exposure class numbers to use under each category. Exposure class with X=0 indicates that the specific exposure does not apply to the member.

- Exposure class: **[FX, SX, WX, CX]**

Suggested clause in lieu of prescribing minimum cement, maximum water-cement ratio, or higher strength for lower permeability under potentially corrosive environments. ASTM C1202 using the rapid chloride penetrability test (RCP) is the most common test method, though several other ASTM and AASHTO standards exist and may be more appropriate for the project concrete application. Note that AASHTO TP 119 Bulk Resistivity and AASHTO T358 Surface Resistivity by Wenner probe are more precise and easier to perform than RCP but sensitive to geometry, saturation, cement hydration, leaching, and temperature.

NRMCA recommends using 2500 coulombs for exposure classes requiring w/cm of 0.50 or 1500 coulombs for exposure classes requiring w/cm of 0.40.

- Resistance to chloride penetration: Max **[XXXX]** Coulombs per ASTM C1202 – using accelerated curing for 28 days as defined in ASTM C1202 when the mixture contains SCMs

Suggested clauses in lieu of setting limits on SCMs for freeze-thaw (not typically needed in the Bay Area). Air content as required in ACI 301 based on aggregate size and assigned F exposure class.

- Freeze-thaw: Air content **[X]%**

Clause for Low Carbon Concrete Code requirement, prescriptive method. Insert value from limits table according to concrete strength in Low Carbon Concrete section of green building code or values agreed by project team (ideally including the structural engineer, architect, contractor, and local concrete supplier(s). Any exceedances over the limit for one mixture should be balanced with reductions below the limits for other mixtures.

- Maximum cement = **[Insert agreed value here]** lb/cyd

Examples of text for list of concrete mixtures under Concrete Mixtures section of specifications or General Notes:

FOR EXAMPLE ONLY:

A. *Type A – Foundation: Footings, Grade Beams, Pile Caps*
   - *Normal weight concrete*
   - *Strength - f'c = 4000 psi (at 90 days)*
   - *Exposure class: F0, S1, C0, W0*
   - *Maximum cement = **[Insert agreed value here]** lb/cyd*

B. *Type B – Walls, Columns, Beams, Topping Slabs*
   - *Normal weight concrete*
   - *Strength - f'c = 6000 psi (at 56 days)*
   - *Exposure class: F0, S0, C0, W1*
   - *Shrinkage limit = 0.05%*
   - *Maximum cement = **[Insert agreed value here]** lb/cyd*

C. *Type C – Suspended Slabs*
   - *Normal weight concrete*
   - *Strength - f'c = 5000 psi (at 28 days)*
   - *Exposure class: F0, S0 C1, W0*
   - *Shrinkage limit = 0.040%*
   - *Maximum cement = **[Insert agreed value here]** lb/cyd*

D. *Type D – Prestressed Slabs (parking)*
   - *Normal weight concrete*
   - *Strength - f'c = 6000 psi (at 56 days)*
   - *Strength at prestressing = 3000 psi (at 3days)*
   - *Exposure class: F0, S0, C2, W1*
   - *Resistance to chloride penetration: Max **1500** Coulombs per ASTM C1202*
   - *Maximum cement = **[Insert agreed value here]** lb/cyd*

E. *Type E – Lightweight Fill in Metal Deck*

- *Lightweight concrete: Max 110 pcf*
- *Strength - f'c = 4000 psi (at 28 days)*
- *Maximum cement = **[Insert agreed value here]** lb/cyd*

F. *Type F – Lean Concrete Fill (beneath footings and conduit encasement)*
   - *Normal weight concrete*
   - *Strength - f'c = 500 psi (at 28 days)*
   - *Cast Against Earth – 3"*
   - *Maximum cement = **[Insert agreed value here]** lb/cyd*

Low Carbon Concrete Compliance Form (Cement)

This form shall be completed by the party indicated under each section for compliance with project Low-Carbon Concrete requirements

Project name _____ Date _____

DESIGN TEAM TO COMPLETE FOR PLAN CHECK APPROVAL						**CONCTRACTOR TO COMPLETE**				
Structural engineer shall complete and include within concrete specification of the Project Manual submitted to the building department for plan check.						*General Contractor shall complete and submit to the Architect within 6 weeks of completion of the concrete work.*				
Date:						Date:				
Structural Engineer Company Name:						General Contractor Company Name:				
Signature:						Signature:				
Print Name:						Print Name:				
Concrete mixture name	Design strength, f'c **per spec** (psi)	Used for (indicate if needs early strength)	Volume Estimated (cyd)	Max Cement Content **per spec** (lb/cyd)	Cement Limit **per code** (lb/cyd)	Volume Supplied (cyd)	Concrete Supplier Name	Concrete Batch Code	Actual Cement Content (lb/cyd)	Cement Limit **per code** (lb/cyd)
Type A	*5000*	*Foundation*	*1000*	*250*	*See code*	*1100*	*ABC Concrete*	*ABC123XYZ*	*245*	*See code*
These rows only for use if contractor is pursuing budget method		Total cement of all concrete used on Project (lbs)				Total cement of all concrete used on Project (lbs)				
		Total cement allowed for all concrete on Project (lbs)				Total cement allowed for all concrete on Project (lbs)				
Signature of Approval at Plan Check:						Signature of Approval for TCO Permit:				
Print Name:						Print Name:				
Date:						Date:				

PATH 2: Embodied Carbon Limit Method

Note for user: In addition to the clauses recommended for Path 1 (Cement Limit Method) above, add the specification clauses below to PART I – GENERAL

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3. SUBMITTALS

A. **Environmental Product Declaration, in compliance with ISO 14025 Type III, third-party verified eco-label, for each concrete mixture type or each concrete mixture to be used.**

If following Path 2, use these clauses instead of clauses referencing Low Carbon Concrete Compliance Form (Cement) of Path 1.

B. **Contractor shall supply a *Low Carbon Concrete Compliance Form (Global Warming Potential)* to the project architect within 6 weeks after completion of concrete work on the project. The mix design number listed on the Low Carbon Concrete Compliance Form must match the mix design number shown on the proposed mix design.**

Suggested clause to allow for budget method

C. **If Contractor chooses to use concrete mixtures that exceed GWP limits specified herein, the Contractor must show on the completed** *Error! Reference source not found.* ***(Global Warming Potential)*** **that the total concrete GWP remains below the total GWP allowance for the project. Total project GWP allowance is calculated by multiplying the volume of each concrete mixture type with the specified GWP limit for the mixture.**

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Use the specification clauses below in PART 2 – PRODUCTS in place of the Concrete Mixtures section of Path 1 above.

2. CONCRETE MIXTURES

Suggested clause to allow for budget method

D. **If Contractor chooses to use concrete mixtures that exceed GWP limits specified below, the Contractor must calculate the total project GWP from the submitted EPDs to show that the total concrete GWP remains below the total GWP allowance for the project. Total project GWP allowance is calculated by multiplying the volume of each concrete mixture type with the specified GWP limit for the mixture. The total actual project GWP is calculated by multiplying the volume of each concrete mixture type with the GWP reported on the EPD for the mixture.**

Suggested general structure of text for list of concrete mixtures under Concrete Mixtures section of specifications or General Notes:

X. Type **[X]** – **[Structural Concrete Elements/Applications]**

Use similar performance requirements as in Path 1: Max Cement Content section above. In lieu of maximum cement content, use:

- Maximum GWP = **[Insert limit here]** kgCO2e/m3

Examples of text for list of concrete mixtures under Concrete Mixtures section of specifications or General Notes:

Y. Type A – Foundation: Footings, Grade Beams, Pile Caps
- Normal weight concrete
- Strength - f'c = 4000 psi (at 90 days)
- Exposure class: F0, S1, C0, W0
- Maximum Embodied Carbon = **[Insert limit here]** kg-CO2e/m3

Z. Type B – Walls, Columns, Beams, Topping Slabs
- Normal weight concrete
- Strength - f'c = 6000 psi (at 56 days)
- Exposure class: F0, S0, C0, W1
- Shrinkage limit = 0.040%
- Maximum Embodied Carbon= [**Insert limit here]** kg-CO2e/m3

AA. Type C – Suspended Slabs
- Normal weight concrete
- Strength - f'c = 5000 psi (at 28 days)
- Exposure class: F0, S0 C1, W0
- Shrinkage limit = 0.050%
- Maximum Embodied Carbon= **[Insert limit here]** kg-CO2e/m3

BB. Type D – Prestressed Slabs (parking)
- Normal weight concrete
- Strength - f'c = 6000 psi (at 56 days)
- Strength at prestressing = 3000 psi (at 3days)
- Exposure class: F0, S0, C2, W1
- Resistance to chloride penetration: Max **1000** Coulombs per ASTM C1202
- Maximum Embodied Carbon= **[Insert limit here]** kg-CO2e/m3

CC. Type E – Lightweight Fill in Metal Deck
- Lightweight concrete: Max 110 pcf
- Strength - f'c = 4000 psi (at 28 days)
- Maximum Embodied Carbon= **[Insert limit here]** kg-CO2e/m3

DD. Type F – Lean Concrete Fill (beneath footings and conduit encasement)
- Normal weight concrete
- Strength - f'c = 500 psi (at 28 days)
- Cast Against Earth – 3"
- Maximum Embodied Carbon= **[Insert limit here]** kg-CO2e/m3

Low Carbon Concrete Compliance Form (Embodied Carbon)

This form shall be completed by the party indicated under each section for compliance with project Low-Carbon Concrete requirements

Project name _____ Date _____

DESIGN TEAM TO COMPLETE FOR PLAN CHECK APPROVAL						**CONCTRACTOR TO COMPLETE**				
Structural engineer shall complete and include within concrete specification of the Project Manual submitted to the building department for plan check.						*General Contractor shall complete and submit to the Architect within 6 weeks of completion of the concrete work.*				
Date:						Date:				
Structural Engineer Company Name:						General Contractor Company Name:				
Signature:						Signature:				
Print Name:						Print Name:				
Concrete mixture name	Design strength, f'c **per spec** (psi)	Used for (indicate if needs early strength)	Volume Estimated (cyd)	Max EC **per spec** (kg/m^3)	EC Limit **per code** (kg/m^3)	Volume Supplied (cyd)	Concrete Supplier Name	Concrete Batch Code	Actual EC (kg/m^3)	EC Limit **per code** (kg/m^3)
Type A	*5000*	*Foundation*	*1000*	*250*	*See code*	*1100*	*ABC Concrete*	*ABC123XYZ*	*245*	*See code*
These rows only for use if contractor is pursuing budget method		Total EC of all concrete used on Project (kgCO2e)				Total EC of all concrete used on Project (kgCO2e)				
		Total EC allowed for all concrete on Project (kgCO2e)				Total EC allowed for all concrete on Project (kgCO2e)				
Signature of Approval at Plan Check:						Signature of Approval for TCO Permit:				
Print Name:						Print Name:				
Date:						Date:				