
Kiewit
Mass Concrete Constructability
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Kiewit Engineering Group, Inc.

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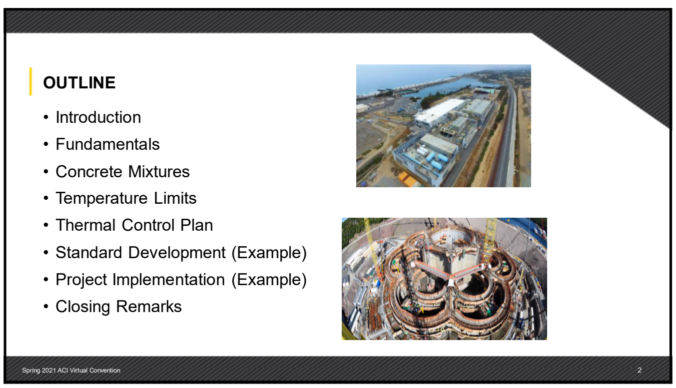
OUTLINE
• Introduction
• Fundamentals
• Concrete Mixtures
• Temperature Limits
• Thermal Control Plan
• Standard Development (Example)
• Project Implementation (Example)
• Closing Remarks
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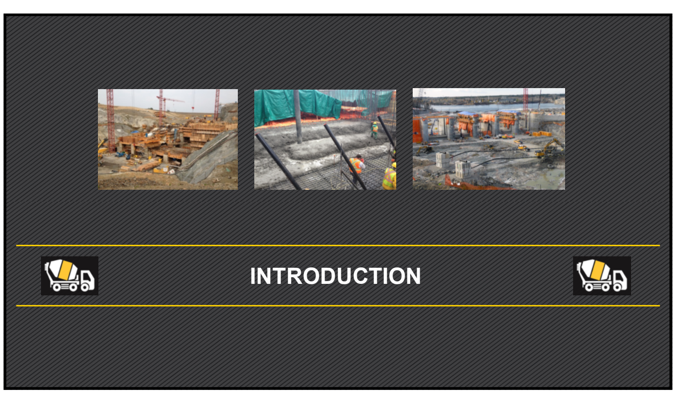
INTRODUCTION

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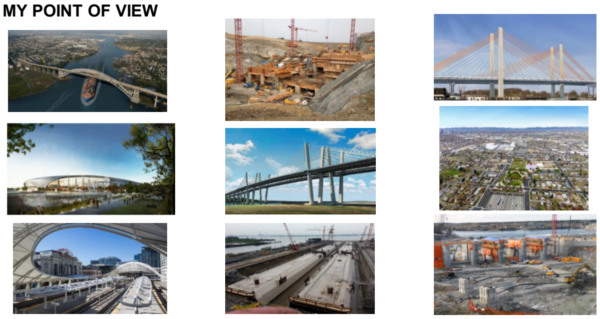
MY POINT OF VIEW



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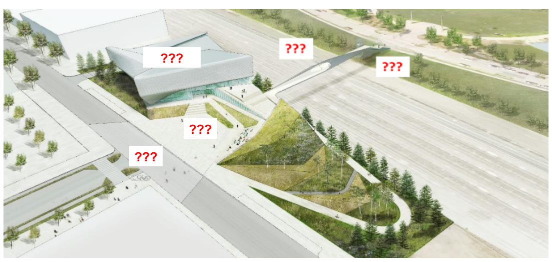
WHY CONSTRUCTABILITY IS IMPORTANT?



What would be the conditions and applicable Standards, Specs and Codes for concrete at each area identified above? Same, or not? Why?

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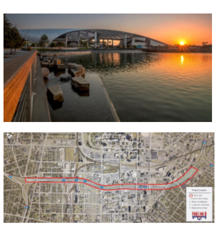
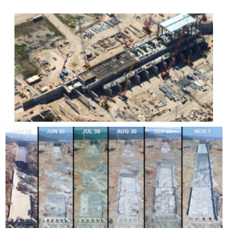
IMPROVE CONSTRUCTABILITY = IMPROVED PRODUCTIVITY



Accelerated Schedule / Fast-Track



Emergencies

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SPECIFICATIONS' CONSTRUCTABILITY CHALLENGES

Clear Goals, Undefined Requirements

"The contractor shall submit the combination of materials that will produce concrete to meet the requirements of the structure with respect to workability, dimensional stability and freedom from cracking, low temperature rise, adequate strength, durability and low permeability to the..."

Hidden Goals, Defined Requirements

Minimum Volume of Coarse Aggregate: The minimum requirements detailed herein apply to all methods of placement, including pump mixes. All mixes shall contain a minimum of 39% coarse aggregate by volume...

1) ...,
2) ...,
3) Bridge decks; bridge deck concrete mixes shall contain a minimum of 41% coarse aggregate and total minimum aggregate volume of 67%,

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PROJECT EXPECTATIONS

- **In most cases, concrete is not only expected to meet slump and strength, but…**
  - ✓ *Design vs. construction demands*
  - ✓ *Consistent workability*
  - ✓ *Economics*
  - ✓ *Improved durability*
  - ✓ *Visual appearance*
  - ✓ *Optimized mixes*
  - ✓ *Better consistency*
  - ✓ *Less rework*
  - ✓ *Better quality*
  - ✓ *Trust*

Concrete shall be constructable while meeting the design intent and quality expectations for the intended performance in service.

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DIFFERENT VIEWS AND INTERESTS

What the Owner wants?

What the Architect / Designer wants?

What the Contractor needs to build the Project?

What the Concrete Producer needs to do?

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FUNDAMENTALS

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TYPES OF MASS CONCRETE

- ***Traditional mass concrete:*** Use for structures such as dams, typically lightly reinforced, where the majority of the structure is mostly mass concrete and is constructed of sequential placements.

- ***Thermally-controlled concrete:*** Use for structures such as high-rise building foundations or bridges, typically heavily reinforced, where the majority of the structures are individual placements

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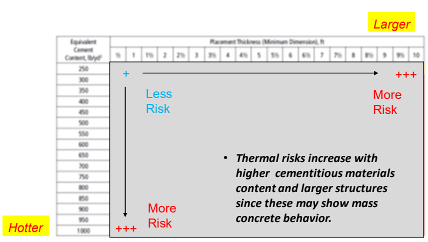
MASS CONCRETE – IN SIMPLE TERMS…



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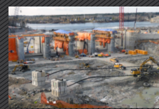

CONCRETE MIXTURES

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CONCRETE MIXTURE *DEVELOPMENT*

BOOK-CRETE (30 TO 60 days)	LAB-CRETE (90 TO 120 days)	CON-CRETE (15 TO 60 days)
• Technical requirements • Materials availability • Procurement • Pre-qualification • Transportation	• Lab resources • Trial testing • Materials properties • Fresh/Hardened • Validations	• Batch plant systems • Mockups • Workability/Pumping • Thermal • Optimizations

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CONCRETE MIXTURE *PROPORTIONING*

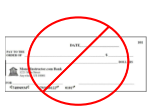
STRENGTH
- w/cm ratio

DURABILITY
- Freeze/Thaw
- Sulfate Resistance
- Permeability
- Service Life

WORKABILITY
- Slump Retention
- Consolidation
- Finishing

THERMAL
- Tmax / Tdiff
- Thermal Control

ECONOMICS
- Mix Costs
- Field Operations
- Quality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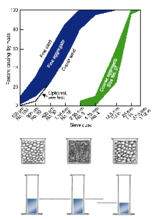
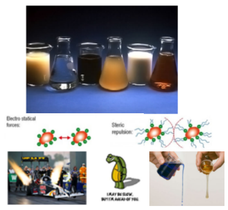
CONCRETE MIXTURE *OPTIMIZATION*

- Aggregate grading makes a difference



- Admixtures enhance performance



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TEMPERATURE LIMITS

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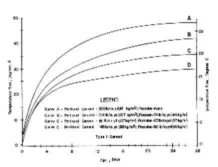
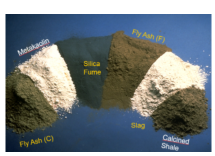
ADIABATIC TEMPERATURE RISE (ATR)

- ATR is mainly affected by type and quantity of cementitious materials
- Reducing ATR
  - ✓ Reduce total cementitious materials
  - ✓ Use less Portland Cement
  - ✓ Use more low heat SCMs (Class F fly ash and slag)

Description		
Very low	Traditional Mass Concrete	ATR < 80 °F
Low		
Moderate	Thermally Controlled Concrete	ATR > 80°F
High		
Very high		





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ADIABATIC TEMPERATURE RISE (ATR)

Methods	Description
Simplified approach	Use a mathematical expression such as Gajda et al, 2014: Rise = 0.16* (1.0*Cem + 0.5*FAsh + 0.8*CAsh + 1.2*SFMK + Factor*Slag), °F
Computer modeling	Use a simplified analytical/modeling software such as ConcreteWorks®; an advanced finite element analytical/modeling software; or a combination thereof.
Semi-adiabatic testing	Use a commercially available semi-adiabatic test chamber; a field fabricated super-insulated test block; a lab fabricated insulated box; or a combination thereof.
Adiabatic testing	Use adiabatic test method such as CRD-C 38, Method of Test for Temperature Rise in Concrete
Field placement	Use a field mass placement having large dimensions, such as a crane footing, with insulation and monitoring temperature at locations intended to be monitored during construction
Other methods	Use a method described in ACI 207.2R, such as Schmidt's method; or other method approved by the owner

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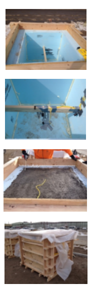
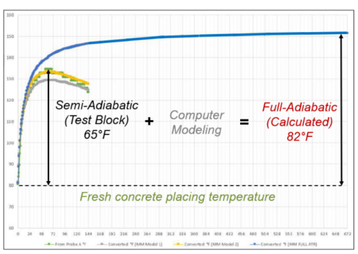
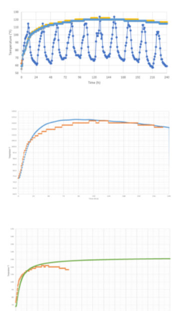
ADIABATIC TEMPERATURE RISE (ATR)







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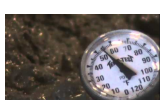
FRESH CONCRETE PLACING TEMPERATURE

- **Main concerns**
  - ✓ Effect on fresh properties
  - ✓ Effect on thermal and shrinkage
  - ✓ Effect on ultimate strength and long-term durability
- **Industry limits**
  - ✓ Typical limit (ACI 301/305/306)
    - 95 °F max., maximum
    - 40 to 50 °F, minimum (depending on placement attributes)



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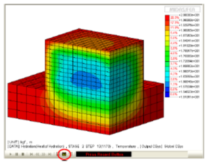
MAXIMUM CONCRETE TEMPERATURE

- **Main concerns**
  - ✓ Long term effect on strength and durability
- **Industry limits**
  - ✓ Typical "safe" limit (ACI 301)
    - 158/160 °F – with / without mitigation
  - ✓ Alternative "safe" limit (ACI 308 / 201 / CSA A23.1)
    - 158/160 °F – without mitigation
    - Up to 185 °F – with mitigation (add SCMs)
    - Greater than 185 °F – not permitted (may be justified with testing)
  - ✓ Increased acceptance of alternative limits but not yet a global consensus



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ALTERNATIVE MAXIMUM CONCRETE TEMPERATURE

Table 6.2.2.2—Recommended measures for reducing potential for DEF in concrete exposed to elevated temperatures at early ages*

Maximum concrete temperature T	Prevention required
$T \leq 158°F$ (70°C)	No prevention required
$158°F < T \leq 185°F$ ($70°C < T \leq 85°C$)	Use one of the following approaches to minimize the risk of expansion: 1. Portland cement meeting requirements of ASTM C150/C150M moderate or high sulfate-resisting and low-alkali cement with a fineness value less than or equal to 430 m^2/kg 2. Portland cement with a 1-day mortar strength (ASTM C109/C109M) less than or equal to 2850 psi (20 MPa) 3. Any ASTM C150/C150M portland cement in combination with the following proportions of pozzolan or slag cement: a) Greater than or equal to 25 percent fly ash meeting the requirements of ASTM C618 for Class F fly ash b) Greater than or equal to 35 percent fly ash meeting the requirements of ASTM C618 for Class C fly ash c) Greater than or equal to 35percent slag cement meeting the requirements of ASTM C989/C989M d) Greater than or equal to 5 percent silica fume (meeting ASTM C1240) in combination with at least 25 percent slag cement e) Greater than or equal to 5 percent silica fume (meeting ASTM C1240) in combination with at least 20 percent Class F fly ash f) Greater than or equal to 10 percent metakaolin meeting ASTM C618 4. An ASTM C595/C595M or ASTM C1157/C1157M blended hydraulic cement with the same pozzolan or slag cement content as listed in Item 3
$T > 185°F$ (85°C)	The internal concrete temperature should not exceed 185°F (85°C) under any circumstances.

*Assembled from Ghorab et al. (1980), Ramlochan et al. (2003), Thomas (2001), Thomas et al. (2008b).

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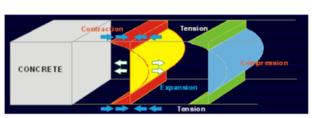
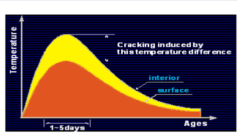
MAXIMUM CONCRETE TEMPERATURE DIFFERENCE

- **Main concerns**
  - ✓ Thermal cracking
- **Industry limits**
  - ✓ Typical "safe" limit (ACI 301)
    - 35 °F fixed limit
  - ✓ Alternative "safe" limit (CSA A23.1)
    - Higher fixed limit (low CoTE concrete)
    - Incremental limit
    - Performance based with testing
  - ✓ Increased acceptance of alternative limits but not yet a global consensus





Ref. InTrans Project 10-384 (2014)

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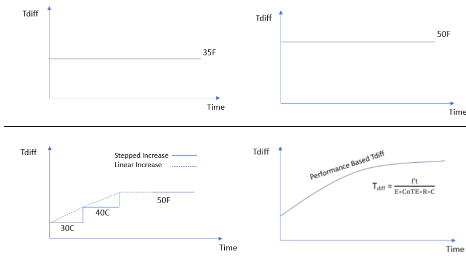
MAXIMUM CONCRETE TEMPERATURE DIFFERENCE



Fixed Limits

Incremental and Performance Limits

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THERMAL CONTROL PLANS

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WHAT IS A THERMAL CONTROL PLAN?

- TOOL for the Contractor to plan, manage and execute mass placements:
  - ✓ Control & monitor temperature
  - ✓ Reduce thermal shrinkage
  - ✓ Minimize thermal cracks
- Know the behavior, challenges and effects:
  - ✓ Mixture proportions
  - ✓ Placing cycles, heat sinks, formwork or insulation removal
  - ✓ Maximum temp and temp difference
  - ✓ Duration of thermal control and monitoring
  - ✓ Corrective measures (e.g. pre-cooling or post-cooling)

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IMPLEMENTING A THERMAL CONTROL PLAN

1. Analytical Modeling
2. Thermal Control Plan
3. Field Implementation
4. Verification and Validation
5. Revise and Update

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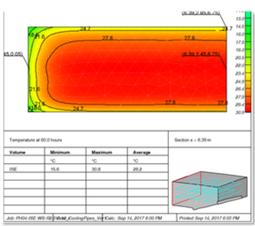
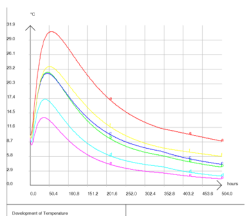
ANALYTICAL MODELING





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THERMAL CONTROL PLAN

Thermal Control Table
Block Pedestal
4500 PSI | 65% Grade 100 Slag

		No Insulation			Light Insulation[3]			Moderate Insulation[3]			Heavy Insulation[3]		
Ambient Temp[1] F°	Concrete Temp[2] F°	Max Core Temp F°	Max Temp Diff F°	End Thermal Control[4] Days	Max Core Temp F°	Max Temp Diff F°	End Thermal Control[4] Days	Max Core Temp F°	Max Temp Diff F°	End Thermal Control[4] Days	Max Core Temp F°	Max Temp Diff F°	End Thermal Control[4] Days
90	90	159	50	N/A	166	37	5.5	171	25	7.5	175	16	10.5
	80	149	43	N/A	155	32	5.0	160	22	7.0	164	14	9.5
	70	139	37	N/A	145	27	4.5	149	19	6.5	153	12	8.5
70	90	153	60	N/A	161	44	6.0	168	31	9.0	173	20	12.5
	80	142	53	N/A	150	39	5.5	157	28	8.0	161	18	12.0
	70	132	46	N/A	139	35	5.0	145	24	7.5	150	16	11.0
	60	121	39	N/A	128	30	4.5	134	21	7.0	138	14	10.0
	50	111	31	N/A	117	25	4.0	123	18	6.5	[illegible]	12	9.0
50	90	147	71	N/A	157	52	7.0	165	36	10.0	[illegible]	23	15.0
	80	133	62	N/A	144	46	6.5	152	32	9.5	158	21	14.0
	70	120	52	N/A	130	40	6.0	139	29	9.0	145	19	13.0
	60	107	42	N/A	117	34	5.5	125	25	8.5	132	16	12.0
	50	93	33	N/A	103	28	5.0	112	21	8.0	119	14	11.5
30[5]	70	107	59	N/A	121	47	6.5	132	34	9.5	141	22	13.5
	60	91	47	N/A	105	40	6.0	117	29	9.0	127	19	12.5
	50	76	36	N/A	90	32	5.5	102	25	8.5	112	17	12.0

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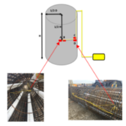
FIELD IMPLEMENTATION

1. Temperature Monitoring
2. Pre-Cooling
3. Insulation
4. Post-Cooling



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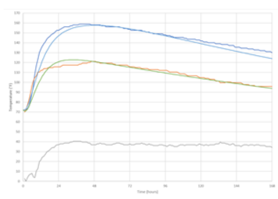
VERIFICATION / VALIDATION

S/N:	9560692	9563135	9560259	8443100	8458430
Job:	PEDBRG	PEDBRG	PEDBRG TOP1	PEDBRG	PEDBRG
Location:	MID1	MID2	TOP 1	TOP2	AMBNT TEMP
Logger Su	9	9	9	9	9
Run State	Run	Run	Run	Run	Run
Start Date	2/6/2020 11:28	2/6/2020 11:29	2/6/2020 11:25	2/6/2020 11:27	2/6/2020 11:49
Last Dowr	2/14/2020 16:56	2/14/2020 16:56	2/14/2020 16:55	2/14/2020 16:56	2/14/2020 16:54
Elapsed Ti	197.47	197.45	197.5	197.48	197.08
Data Inter	60	60	60	60	60
Number c	198	198	198	198	198
Current Reading:					
Time (hrs	Temperature (°F)	Temperature (°F)	Temperature (°F)	Temperature (°F)	Temperature (°F
197.47	123.8	123.8	95	95	73.4
Maximum	159.8	158	120.2	122	
Logged Readings (198):					
Time(hrs)	Temperature (°F)	Temperature (°F)	Temperature (°F)	Temperature (°F)	Temperature (°F
0	35.6	35.6	41	39.2	51.8
1	41	41	51.8	50	44.6
2	48.2	46.4	53.6	51.8	42.8
3	71.6	68	48.2	48.2	42.8
4	73.4	71.6	46.4	44.6	39.2
5	73.4	71.6	46.4	46.4	39.2
6	73.4	73.4	69.8	68	39.2
7	77	75.2	68	68	39.2
8	82.4	80.6	68	68	37.4
9	89.6	87.8	68	68	33.8
10	96.8	96.8	69.8	69.8	33.8
11	109.4	107.6	71.6	73.4	33.8
12	118.4	116.6	77	77	35.6
13	123.8	122	82.4	82.4	39.2
14	131	129.2	87.8	89.6	39.2
15	134.6	132.8	96.8	96.8	37.4
16	138.2	134.6	100.4	102.2	41
17	140	138.2	104	105.8	42.8
18	141.8	140	105.8	107.6	35.6



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REVISE / UPDATE

- When a revision or update may be necessary:
  - ✓ Field conditions are known, but the model is inaccurate and not conservative
  - ✓ Field conditions are known, but the model is inaccurate and highly conservative
  - ✓ Proposed change to construction sequence, materials, means/methods, etc.
- Other things to consider when evaluating a revision or update:
  - ✓ Inadequate field implementation
  - ✓ Different field conditions
  - ✓ Concrete mix changes
  - ✓ Formwork or insulation changes
  - ✓ Unknown field operations change

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CSA A23.1-19 STANDARD - EXAMPLE

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CSA A23.1-19, CLAUSE 7.6.3 – MASS CONCRETE

7.6.3.2 Temperature requirements for mass concrete

7.6.3.2.1 General
The temperature requirements for mass concrete placements shall comply with Clauses 7.6.3.2.2 to 7.6.3.2.5 unless otherwise specified or approved by the owner.

- 7.6.3.2.2 Adiabatic Temperature Rise
- 7.6.3.2.3 Maximum Placing Concrete Temperature
- 7.6.3.2.4 Maximum Concrete Temperature
- 7.6.3.2.5 Maximum Concrete Temperature Difference

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CSA A23.1-19, CLAUSE 7.6.3 – MASS CONCRETE

7.6.3.2.2 Adiabatic temperature rise
The predicted adiabatic temperature rise of concrete mixes for mass placements shall be reported in the concrete mix design submittal. The method to calculate adiabatic temperature rise shall be identified and reviewed by the concrete producer and contractor.

Notes:
1) *Adiabatic temperature rise of mass concrete can be determined by using tests and analytical methods. Refer to information in Annex T for guidance.*
2) *Refer to Clause 6 of CSA A23.2-24C for further information regarding mix design submittals.*

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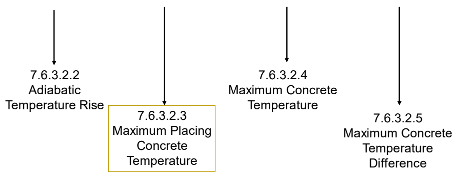
CSA A23.1-19, CLAUSE 7.6.3 – MASS CONCRETE

7.6.3.2 Temperature requirements for mass concrete

7.6.3.2.1 General

The temperature requirements for mass concrete placements shall comply with Clauses 7.6.3.2.2 to 7.6.3.2.5 unless otherwise specified or approved by the owner.



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CSA A23.1-19, CLAUSE 7.6.3 – MASS CONCRETE

7.6.3.2.3 Maximum placing concrete temperature

In the absence of a thermal control plan, the maximum placing concrete temperature for mass concrete placements shall comply with Table 14 for permissible concrete temperatures at placing.

Note: *Lowering the placing concrete temperature is beneficial to reduce temperature rise of mass concrete that can lead to high concrete temperatures and large temperature differentials.*

Table 14
Permissible concrete temperatures at placing
(See Clauses 5.2.5.4.1, 7.2.2.1, 7.5.1.3, 7.6.3.2.3, and 8.5.5.)

	Temperatures, °C	
Thickness of section, m	**Minimum**	**Maximum**
< 0.3	10	32
≥ 0.3 – < 1	10	30
≥ 1 – < 2	5	25
≥ 2	5	20

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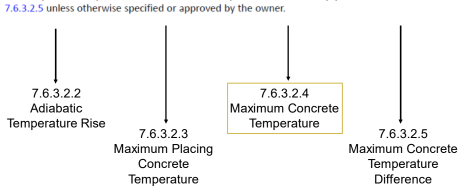
CSA A23.1-19, CLAUSE 7.6.3 – MASS CONCRETE

7.6.3.2 Temperature requirements for mass concrete

7.6.3.2.1 General

The temperature requirements for mass concrete placements shall comply with Clauses 7.6.3.2.2 to 7.6.3.2.5 unless otherwise specified or approved by the owner.



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CSA A23.1-19, CLAUSE 7.6.3 – MASS CONCRETE

7.6.3.2.4 Maximum concrete temperature

The maximum concrete temperature in mass placements shall not be greater than

a) 70 °C for non-HVSCM concrete;
b) 75 °C for HVSCM-2 concrete; and
c) 85 °C for HVSCM-1 concrete.

Note: *The maximum concrete temperature is mainly influenced by the temperature rise of concrete and fresh concrete placing temperature at time of placement. Information and references in Annex T are provided for guidance into the considerations to the applicable maximum concrete temperature for different conditions and concrete properties.*

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CSA A23.1-19, CLAUSE 7.6.3 – MASS CONCRETE

7.6.3.2 Temperature requirements for mass concrete

7.6.3.2.1 General

The temperature requirements for mass concrete placements shall comply with Clauses 7.6.3.2.2 to 7.6.3.2.5 unless otherwise specified or approved by the owner.

- 7.6.3.2.2 Adiabatic Temperature Rise
- 7.6.3.2.3 Maximum Placing Concrete Temperature
- 7.6.3.2.4 Maximum Concrete Temperature
- 7.6.3.2.5 Maximum Concrete Temperature Difference

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7.6.3.2.5 Maximum concrete temperature difference

7.6.3.2.5.1

The maximum concrete temperature difference in mass placement shall not be greater than 20 °C, specified as a fixed limit, except where higher temperature difference limits are permitted as provided for in Clauses 7.6.3.2.5.2 to 7.6.3.2.5.4.

Note: *The maximum temperature difference in mass concrete can be specified in different ways based on the concrete properties and placement attributes. Refer to Annex T for further information and guidance.*

7.6.3.2.5.2

A maximum concrete temperature difference fixed limit shall be specified not to exceed 25 °C when the coefficient of thermal expansion of the concrete is less than 10 millionths/°C, except as provided for in Clause 7.6.3.2.5.4.

7.6.3.2.5.3

An incremental maximum temperature difference limit shall be specified not to exceed 25 °C, except as provided for in Clause 7.6.3.2.5.4.

Note: *Refer to Clause T.4.3.3 for information on incremental temperature difference limits.*

7.6.3.2.5.4

A performance based approach based on numerical analysis and modeling with a project specific testing program shall be specified when a maximum concrete temperature difference limit higher than 25 °C is permitted.

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7.6.3.3 Temperature monitoring

The concrete and ambient temperatures shall be monitored during the thermal control period to determine compliance with temperature requirements in Clause 7.6.3.2. The specific locations for temperature monitoring shall be identified in the thermal control plan. The maximum concrete temperature shall be measured at the interior core of the mass placement where the highest concrete temperature is expected. The temperature differentials between the core and concrete near the surface shall be monitored. The concrete temperature near the surface shall be monitored at a minimum of one representative location between 25 and 75 mm of the concrete surface. Any additional monitoring locations shall be identified in the thermal control plan.

Notes:

1) *The maximum temperature at the interior core of the concrete might not be located in the geometrical centre of the mass placement. The concrete temperature near the surface would be typically measured by installing a temperature measuring device tied to a reinforcing bar near the surface.*
2) *Monitoring temperature of concrete at or near the surface of a corner or an edge of a mass placement might be necessary for cold weather protection, but it is not a requirement to meet thermal control of mass concrete.*

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7.6.3.4 Thermal control plan

The contractor shall submit to the owner for approval a thermal control plan to demonstrate that the requirements for controlling and monitoring temperature will be achieved during the thermal control period, including the following information unless otherwise specified or approved by the owner:

a) dimensions of mass placements;
b) specified temperature limits;
c) concrete mix design submittal;
d) methodology used for thermal analysis and/or modelling;
e) properties of the concrete;
f) predicted adiabatic temperature rise of the concrete;
g) concrete placing temperature considerations;
h) calculated maximum concrete temperature;
i) calculated maximum concrete temperature difference;
j) ambient temperature and weather considerations;
k) insulation and curing recommendations;
l) temperature monitoring devices and locations;
m) requirements to avoid thermal shock (24 h concrete surface temperature drop);
n) criteria to terminate thermal control;
o) recommendations to meet temperature limits;
p) results from thermal analysis and/or modelling;
q) possible corrective measures;
r) relevant technical guidelines or references; and
s) any other information or details such as pre-cooling or active cooling with embedded pipes that might be required to ensure proper implementation of thermal control measures to meet specifications, construction demands, placement attributes, and technical requirements.

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PROJECT IMPLEMENTATION - EXAMPLE

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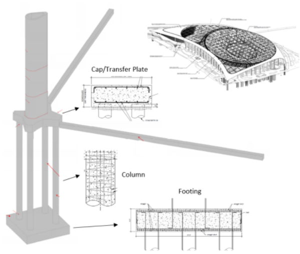
FOUNDATION STRUCTURE OVERVIEW



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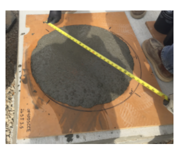
OPTIMIZED CONCRETE MIXTURE PROPORTIONS

- ***Low Heat***
  - ✓ Lower total cm
  - ✓ Higher fly ash
  - ✓ Better aggregates
  - ✓ Later age strength
- ***High Strength***
  - ✓ Lower w/cm ratio
  - ✓ Avoid too high fly ash
- ***Less Shrinkage***
  - ✓ Reduced water
  - ✓ Enhance with admixtures
- ***SCC***
  - ✓ Improved aggregate grading
  - ✓ Balanced paste and mortar
  - ✓ Enhance with admixtures
- ***High MOE***
  - ✓ Good "stiff" coarse aggregate
  - ✓ Qualify with testing



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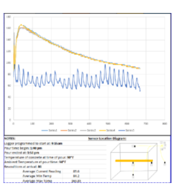
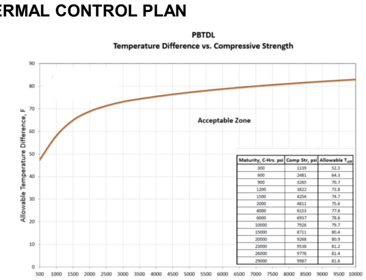
PERFORMANCE BASED THERMAL CONTROL PLAN





Maturity, C-Hrs. psi	Comp Str, psi	Allowable T_{diff}
300	1139	52.3
600	2481	64.3
900	3265	70.7
1200	3822	73.8
1500	4254	74.7
2000	4811	75.6
4000	6153	77.6
6000	6937	78.6
10000	7926	79.7
15000	8711	80.4
20000	9268	80.9
23000	9538	81.2
26000	9776	81.4
29000	9987	81.6

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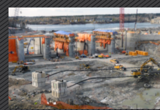

CLOSING REMARKS

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CLOSING REMARKS

- ✓ **Specifications:**
  - Outdated and need to adapt knowledge to practice
- ✓ **Concrete Mixes:**
  - Optimize concrete mixes to reduce heat of hydration
- ✓ **Temperature Limits:**
  - Know and reduce adiabatic temperature rise
  - Target lower placing concrete temperatures
  - Mitigate maximum "peak" temperature
  - Control maximum temperature difference by testing and developing performance-based limit
- ✓ **Thermal Control:**
  - Follow basic principles to implement thermal control measures to reduce temperature and control temperature changes that could lead to thermal cracking

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