Iowa Mass Concrete for Bridge Foundation Study – Phase I

Final Report
December 2011

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

The early-age thermal development of structural mass concrete elements has a large impact on the future durability and longevity of the elements. If the heat of hydration is not controlled, the elements may be susceptible to thermal cracking and damage from delayed ettringite formation.

This study is aimed at developing guidelines for the design and construction of mass concrete placements associated with large bridge foundations. The study consisted of two phases: 1) literature review and 2) preliminary thermal stress analysis and in-depth thermal stress analysis and guideline development. This report describes the research activities conducted and results obtained from the Phase I study.

The published literature and current specifications on mass concrete, as well as the results of construction monitoring from the I-80 bridge at Council Bluffs, Iowa, were reviewed. Two computer programs, ConcreteWorks and 4CTemp&Stress, for thermal analysis of mass concrete, were explored.

Using ConcreteWorks, a sensitivity analysis was performed and various mix proportion, environmental, and construction parameters were examined. The results indicate that, not only concrete materials (such as fly ash and ground granulated blast furnace slag) and mix proportions (such as cement content), but also fresh concrete placement temperature, curing methods, and time of form removal have noticeable effects on thermal cracking.

Further understanding of the effect of each parameter on mass concrete thermal properties would help the Iowa Department of Transportation (DOT) and contractors to identify the most convenient and cost-effective methods to reduce the risk of thermal damage in mass concrete construction.

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IOWA MASS CONCRETE FOR BRIDGE FOUNDATION STUDY – PHASE I

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EXECUTIVE SUMMARY

The early-age thermal development of structural mass concrete elements has a large impact on the future durability and longevity of the elements. If the heat of hydration is not controlled, the elements may be susceptible to thermal cracking and damage from delayed ettringite formation.

The present study is aimed at developing guidelines for the design and construction of mass concrete placements associated with large bridge foundations. The study consists of two phases: (1) literature review and preliminary thermal stress analysis, and (2) in-depth thermal stress analysis and guideline development. This report describes the research activities conducted and results obtained from the Phase I study.

In the Phase I study, published literature and current specifications on mass concrete, as well as the results of construction monitoring from the I-80 bridge at Council Bluffs, Iowa, were reviewed. Two computer programs, ConcreteWorks and 4CTemp&Stress, for thermal analysis of mass concrete were explored.

Using ConcreteWorks, a sensitivity analysis was performed and various mix proportion, environmental, and construction parameters were examined. The results indicate that, not only concrete materials (such as fly ash and ground granulated blast furnace slag) and mix proportions (such as cement content), but also fresh concrete placement temperature, curing methods, and time of form removal have noticeable effects on thermal cracking.

Further understanding of the effect of each parameter on mass concrete thermal properties would help the Iowa Department of Transportation (DOT) and contractors to identify the most convenient and cost-effective methods to reduce the risk of thermal damage in mass concrete construction.

CHAPTER 1. INTRODUCTION

Mass concrete is a structural element of concrete with dimensions large enough to require actions to prevent excessive heat development. Heat development in a concrete element is the result of hydration of the cement. If the heat development is not controlled, the element may experience thermal cracking or delayed ettringite formation.

Thermal cracking is the result of large thermal gradients in a massive placement. Thermal gradients induce stress in the placement, which results from the exterior portion of the placement dissipating heat more rapidly than the interior portion. If the induced stress exceeds the tensile strength of the recently-placed concrete, the placement is likely to experience thermal cracking. Historically, keeping the maximum temperature differential below 35°F was found to reduce the likelihood of thermal cracking.

Delayed ettringite formation, also known as heat-induced delayed expansion (HIDE), results from excessively-high temperatures in a concrete placement. High temperatures in a placement decompose the ettringite that had been previously formed in the concrete and suppressed further ettringite formation.

In the future, if moisture is present in the concrete, ettringite may begin to form in the now solid cement paste, causing expansive pressure in the concrete. If the expansive pressures become too extreme, the placement may experience cracking. It has been established that preventing the maximum temperature in the placement from reaching 160°F will reduce the probability of HIDE.

Objective

The objective of the research is to provide insight on the early-age thermal development of mass concrete and, in addition, provide recommendations for the Iowa Department of Transportation (DOT) mass concrete specification and present best practices for mass concrete construction. The research utilized the software package ConcreteWorks to complete a sensitivity study replicating some typical situations using common mass concrete practices.

Iowa DOT Mass Concrete Specification

The Iowa DOT currently has a developmental specification for mass concrete (Control Heat of Hydration DS-09047, August 17, 2010). The specification was based on national industry practices and experiences on the westbound I-80 bridge over the Missouri River (between Council Bluffs, Iowa and Omaha, Nebraska). The goal of the specification is to provide concrete structures free of thermal damage resulting from heat of hydration during the curing of large concrete cross-sections.

To mitigate the effects of heat of hydration, the Iowa DOT specification has implemented thermal limits for mass concrete placements. To prevent delayed ettringite formation, the specification states that the maximum temperature in a placement may not exceed 160°F during the time of heat dissipation. To prevent thermal cracking, the specification has laid out maximum temperature differentials for placements as shown in Table 1.

Table 1. Maximum temperature differentials

Hours After Placement	Maximum Temperature Differentials (°F)
0–24	20
24–48	30
48–72	40
>72	50

Appendix A contains a matrix of various mass concrete specifications from organizations throughout the US.

ConcreteWorks

ConcreteWorks is an early-age concrete thermal development analysis software. ConcreteWorks was developed by the Concrete Durability Center at the University of Texas. The software is capable of analyzing various environmental, construction, and mix proportion parameters. The available output results for the program include predicting the maximum temperature in the placement, maximum temperature differential, maturity and compressive strength with respect to time, and cracking potential (Folliard, et al. 2005).

Literature Review

Historically, there have been many methods used to control the heat of hydration of mass concrete placements and reduce the thermal damage. Approaches that put limits on mix proportions and material properties include using a low-cement content, reduced heat cements, and/or increased aggregate size; increasing coarse aggregate, fly ash, and/or ground granulated blast furnace slag (GGBFS) content; and requiring water-reducing admixtures. Construction practices used to reduce thermal damage include reducing the fresh placement temperature, post-cooling the concrete with internal cooling pipes, pouring placements during cooler times (nighttime or cooler times of the year), water curing, reducing placement lift height, and using steel forms for rapid heat dissipation or wood forms and insulation for reduced heat dissipation (H.Kosmatka, Kerkhoff and Panarese 2002).

A glossary of terms developed throughout the research is provided in Appendix B

CHAPTER 2. SENSITIVITY STUDY

A sensitivity study was conducted considering various construction, environmental, and mix proportion parameters as follows:

1) Construction and Environmental Parameters
   a) Dimensional Size
   b) Fresh Placement Temperature
   c) Curing Method
   d) Forming Method
   e) Form Removal Time
   f) Ambient Temperature
2) Mix Proportion Parameters
   a) Cement Content
   b) Class C Fly Ash
   c) Class F Fly Ash
   d) Ground Granulated Blast Furnace Slag

ConcreteWorks Verification

The software program ConcreteWorks was verified by comparing the analysis results against the recorded data from the westbound I-80 bridge over the Missouri River. The inputs used for the ConcreteWorks software analysis were developed by investigating the thermal control plans used for the project. Inputs that were unobtainable were estimated by the researchers using knowledge of mass concrete practices.

The analysis results, shown in Figure 1 through Figure 4, identify similarities and differences between the analysis results and the recorded data. The maximum temperature reached in the placement is similar when comparing the analysis and the recorded data, but the recorded data show a more rapid heat dissipation compared to the ConcreteWorks analysis. The minimum temperature results are very similar, except the ConcreteWorks analysis results are more responsive to changes in ambient temperature. There are substantial differences between the recorded data and results from ConcreteWorks with regard to the maximum temperature difference. These differences are the result of the variances in the maximum and minimum temperature. There are also large differences in the ambient temperature between the recorded data and the results of the ConcreteWorks analysis.

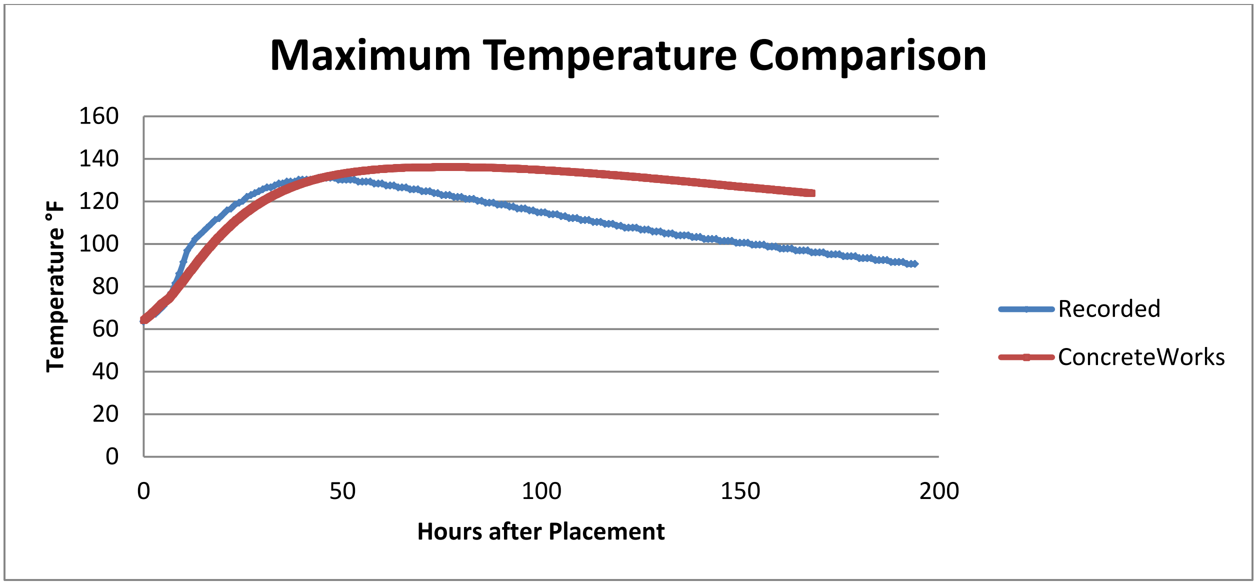

Figure 1. Maximum temperature comparison

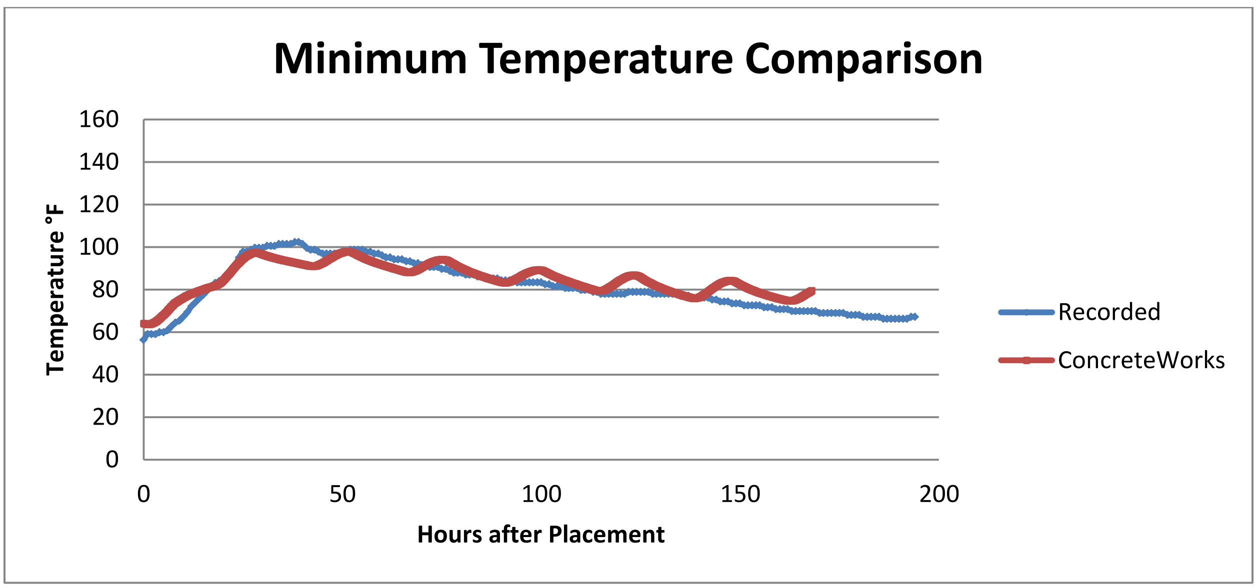

Figure 2. Minimum temperature comparison

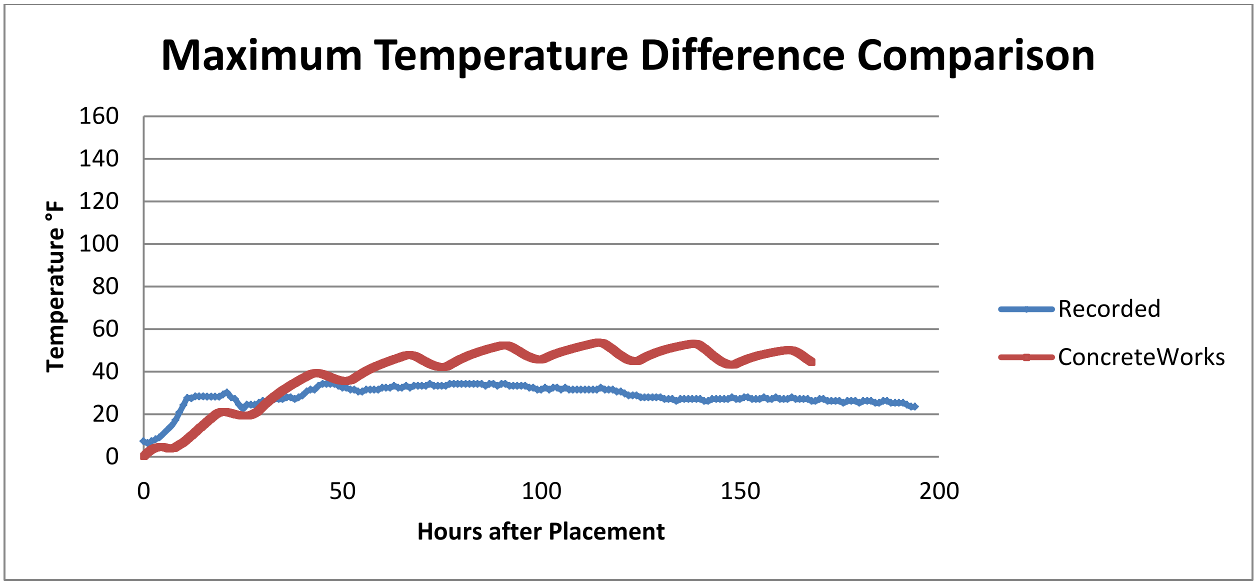

Figure 3. Maximum temperature difference comparison

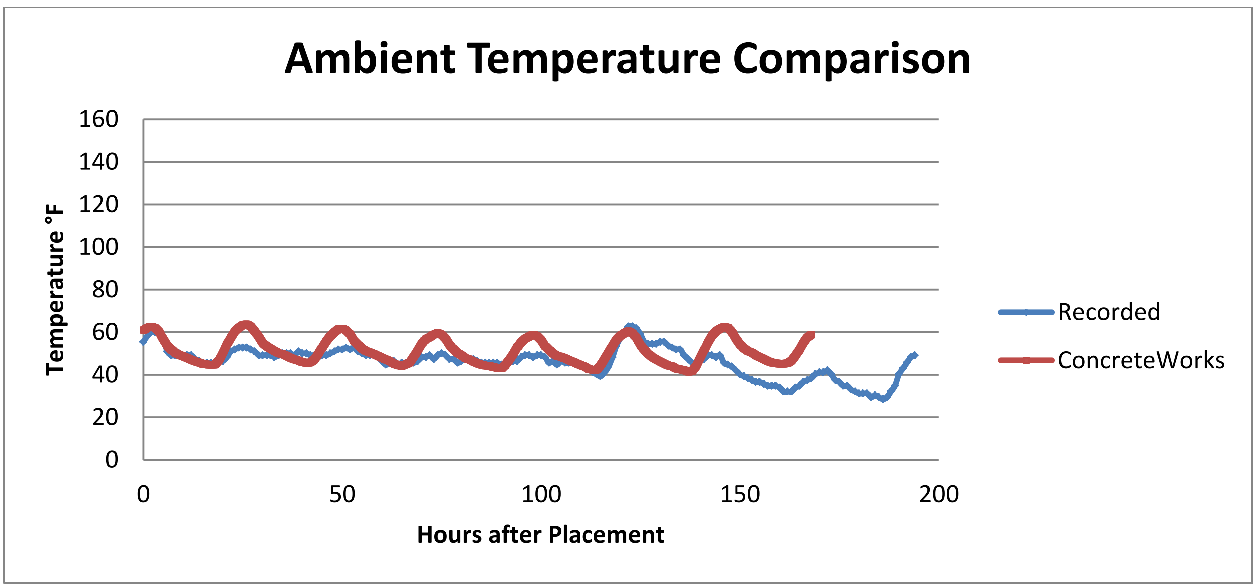

Figure 4. Ambient temperature comparison

Baseline Conditions

Baseline conditions used to complete the sensitivity study analysis were based off the inputs used to model the Pier 1 footing for the westbound I-80 bridge over the Missouri River. Some parameters were changed to better identify changes in thermal development. The form removal time was reduced to three days to be able to identify a cracking potential for the placement; ConcreteWorks only has the capacity to display a cracking potential for the first seven days.

The insulation R value was reduced to one to show the possible benefits of steel formwork. The soil temperature and soil material were also adjusted to produce a more characteristic mass concrete placement.

The parameters that were used to model the actual Pier 1 footing and the sensitivity study are shown in Table 2. The adjusted parameters and ranges used to complete the sensitivity study are shown in Table 3.

The effect of changing some of the inputs caused parts of the sensitivity to generate extreme results. Several parts of the study generated results with extremely high maximum temperatures, maximum temperature differences, and cracking potentials. Some results are unrealistic with regard to real-world practices but are believed to show correct trends and concepts.

Table 2. Sensitivity study inputs

Group	Input	Actual Inputs	Dimensional Size	Fresh Placement Temperature	Curing Method	Forming Method		Form Removal Time	Placement Date	Cement Content	Class C & F Fly Ash	GGBFS
						3 Day Form Removal	7 Day Form Removal					
Member Type	Member Type	Mass Concrete	Mass Concrete	Mass Concrete	Mass Concrete	Mass Concrete	Mass Concrete	Mass Concrete	Mass Concrete	Mass Concrete	Mass Concrete	Mass Concrete
General	Placement Time	1:00 PM	1:00 PM	1:00 PM	1:00 PM	1:00 PM	1:00 PM	1:00 PM	1:00 PM	1:00 PM	1:00 PM	1:00 PM
	Placement Date	10/20/2008	10/20/2008	10/20/2008	10/20/2008	10/20/2008	10/20/2008	10/20/2008	Varies	10/20/2008	10/20/2008	10/20/2008
	Temperature Analysis	7 days	7 days	7 days	7 days	7 days	7 days	7 days	7 days	7 days	7 days	7 days
	Life Cycle Duration	20 years	20 years	20 years	20 years	20 years	20 years	20 years	20 years	20 years	20 years	20 years
	Location	Omaha, NE	Omaha, NE	Omaha, NE	Omaha, NE	Omaha, NE	Omaha, NE	Omaha, NE	Omaha, NE	Omaha, NE	Omaha, NE	Omaha, NE
Shape	Shape	Rectangular Footing	Rectangular Footing	Rectangular Footing	Rectangular Footing	Rectangular Footing	Rectangular Footing	Rectangular Footing	Rectangular Footing	Rectangular Footing	Rectangular Footing	Rectangular Footing
Dimensions	Dimensional Size: Width	12'	Varies	12'	12'	12'	39.75	12'	12'	12'	12'	12'
	Dimensional Size: Length	43'	Varies	43'	43'	43'	77	43'	43'	43'	43'	43'
	Dimensional Size: Depth	4.5'	Varies	4.5'	4.5'	4.5'	10.5	4.5'	4.5'	4.5'	4.5'	4.5'
	Sides	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Analysis	2D	2D	2D	2D	2D	2D	2D	2D	2D	2D	2D
Mix Proportion	Cement Content	315 lb/cy	315 lb/cy	315 lb/cy	315 lb/cy	315 lb/cy	727 lb/cy	315 lb/cy	315 lb/cy	Varies	Varies	Varies
	Water Content	264 lb/cy	264 lb/cy	264 lb/cy	264 lb/cy	264 lb/cy	264 lb/cy	264 lb/cy	264 lb/cy	264 lb/cy	264 lb/cy	1322 lb/cy
	Coarse Aggregate	1322 lb/cy	1322 lb/cy	1322 lb/cy	1322 lb/cy	1322 lb/cy	1322 lb/cy	1322 lb/cy	1322 lb/cy	1322 lb/cy	1322 lb/cy	1586 lb/cy
	Fine Aggregate	1586 lb/cy	1586 lb/cy	1586 lb/cy	1586 lb/cy	1586 lb/cy	1586 lb/cy	1586 lb/cy	1586 lb/cy	1586 lb/cy	1586 lb/cy	1586 lb/cy
	Air Content	6.50%	6.50%	6.50%	6.50%	6.50%	6.50%	6.50%	6.50%	6.50%	6.50%	6.50%
	Class C Fly Ash	0	0	0	0	0	0	0	0	0	Varies	0
	CaO%	NA	NA	NA	NA	NA	NA	NA	NA	NA	24.3	NA
	Class F Fly Ash	105 lb/cy	105 lb/cy	105 lb/cy	105 lb/cy	105 lb/cy	0	105 lb/cy	105 lb/cy	0	Varies	0
	CaO%	8.7	19	19	19	19	NA	19	19	NA	8.7	NA
	GGBFS	207 lb/cy	207 lb/cy	207 lb/cy	207 lb/cy	207 lb/cy	0	207 lb/cy	207 lb/cy	0	0	Varies
	Admixture	High Range Water Reducer	High Range Water Reducer	High Range Water Reducer	High Range Water Reducer	High Range Water Reducer	NA	High Range Water Reducer	High Range Water Reducer	NA	NA	NA
Material Properties	Cement Type	I/II	I/II	I/II	I/II	I/II	I/II	I/II	I/II	I/II	I/II	I/II
	Blaine	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg	371.5m^2/kg
	Tons CO2	0.9	0.9	0.9	0.9	1.9	0.9	0.9	0.9	0.9	0.9	0.9
	Bogue Values	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II	Ash Grove Type I/II
	Coarse Aggregate	Limestone	Limestone	Limestone	Limestone	Limestone	Limestone	Limestone	Limestone	Limestone	Limestone	Limestone
	Fine Aggregate	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand	Siliceous River Sand
	Hydration Calculation	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default
	CTE	4.1*10^-6	4.1*10^-6	4.1*10^-6	4.1*10^-6	4.1*10^-7	4.1*10^-6	4.1*10^-6	4.1*10^-6	4.1*10^-6	4.1*10^-6	4.1*10^-6
	Concrete k	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F	1.6 BTU/hr/ft/°F
	Aggregate Cp	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F	0.2 BTU/lb/°F
Mechanical	Maturity Method	Nurse-Saul	Nurse-Saul	Nurse-Saul	Nurse-Saul	Nurse-Saul	Nurse-Saul	Nurse-Saul	Nurse-Saul	Nurse-Saul	Nurse-Saul	Nurse-Saul
	Nurse-Saul (a)	-30211	-30211	-30211	-30211	-30211	-30211	-30211	-30211	-30211	-30211	-30211
	Nurse-Saul (b)	10346	10346	10346	10346	10346	10346	10346	10346	10346	10346	10346
	Elastic Modulus	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default
	Splitting Tensile Strength	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default
	Creep	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default
Construction	Fresh Placement Temperature	64 degrees F	64 degrees F	Varies	64 degrees F	64 degrees F	90 degrees F	64 degrees F	Varies	64 degrees F	64 degrees F	64 degrees F
	Form Removal Time	194 hours	96 hours	96 hours	96 hours	96 hours	168 hours	Varies	96 hours	96 hours	96 hours	96 hours
	Forming Method	Wood	Wood	Wood	Wood	Varies	Varies	Wood	Wood	Wood	Wood	Wood
	Form Color	Natural Wood	Natural Wood	Natural Wood	Natural Wood	Varies	Varies	Natural Wood	Natural Wood	Natural Wood	Natural Wood	Natural Wood
	Blanket R Value	2.5	1	1	1	1	1	1	1	1	1	1
	Soil Temperature	46 degrees F	51 degrees F	51 degrees F	51 degrees F	51 degrees F	51 degrees F	51 degrees F	51 degrees F	51 degrees F	51 degrees F	51 degrees F
	Curing Method	None	Wet Curing Blanket	None	Varies	None	None	None	None	None	None	None
	Time between form removal and curing method	NA	1 hr	1 hr	1 hr	1 hr	1 hr	1 hr	1 hr	1 hr	1 hr	1 hr
	Footing Subbase	Sand	Concrete	Concrete	Concrete	Concrete/ Limestone	Concrete	Concrete	Concrete	Concrete	Concrete	Concrete
	Top of Footing	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sides Shaded	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Environment	All	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default
Corrosion Inputs	All	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default

Table 3. Sensitivity study parameter adjustments

Sensitivity Study	Parameter Changed	Range					
Dimensional Size	Dimensions	12' X 43' 4.5'	15' X 43' X 5'	27' X 43' X 7.25'	25.5' X 43' X 9'	38.58' X 77' X 10.5'	
Fresh Placement Temperature	Fresh Placement Temperature	40°F	50°F	60°F	70°F	80°F	90°F
Curing Method	Curing Method	No Curing Method	Curing Compound	Black Plastic	Clear Plastic	Wet Curing Blanket	
Forming Method	Forming Method	Steel Formwork	Wood Formwork	Soil Formwork			
Form Removal Time	Form Removal Time	48 hours	72 hours	96 hours	120 hours	144 hours	168 hours
Placement Date	Placement Date	10/20/2008	7/20/2008				
	Fresh Placement Temperature	40°F	50°F	60°F	70°F	80°F	90°F
Cement Content	Cement Content	560 lb/cy	660 lb/cy	760 lb/cy			
Fly Ash C & F Fly Ash	Class F Fly Ash	cement substitution 0%	cement substitution 10%	cement substitution 20%	cement substitution 30%	cement substitution 40%	cement substitution 50%
	Class C Fly Ash	cement substitution 0%	cement substitution 10%	cement substitution 20%	cement substitution 30%	cement substitution 40%	cement substitution 50%
GGBFS	GGBFS	cement substitution 0%	cement substitution 10%	cement substitution 20%	cement substitution 30%	cement substitution 40%	cement substitution 50%

Dimensional Size

The dimensional size of a unit of structural concrete describes the surface area, least dimension, and volume. Generally, structural elements with larger dimensional size generate higher maximum temperatures, have larger thermal gradients, and are more likely to experience thermal cracking and delayed ettringite formation. The least dimension of a structural element is typically used to describe the dimensional size of a placement because of the strong influence it has on the maximum temperature and thermal gradient of the concrete element.

The Iowa DOT developmental specification DS-09047 defines structural mass concrete as any concrete footing with a least dimension greater than 5 ft, or other concrete placements with a least dimension greater than 4 ft. The specification also requires additional constraints on placements with a least dimension exceeding 6.5 ft.

A sensitivity study was conducted to determine the effect of dimensional size on thermal development of structural elements. The study examined several placements with varying dimensions as shown in Table 4.

Table 4. Dimensional size sensitivity study

Dimensions (ft)					
Width	Length	Depth	Least Dimension (ft)	Surface Area (ft^2)	Volume (yd^3)
12	43	4.5	4.5	1527	86
15	43	5	5	1870	119.5
27	43	7.25	7.25	3337	311.8
25.5	43	9	9	3426	365.5
38.58	77	10.5	10.5	8368.5	1155.3

The sensitivity study results show that as the dimensions of the structural element increase, the maximum temperature, maximum temperature difference, and cracking probability also increase. The results show that the dimensional size of the element greatly impacts the thermal development and the cracking probability as shown in Table 5. A complete set of results for the sensitivity study is contained in Appendix C.

Table 5. Dimensional size sensitivity study results

Dimensions (ft)			Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Probability
Width	Length	Depth			
12	43	4.5	121	45	Low
15	43	5	125	49	Low
27	43	7.25	139	68	Low
25.5	43	9	146	77	High
38.58	77	10.5	151	83	High

Fresh Placement Temperature

Fresh placement temperature is defined as the temperature of the concrete when it is placed. Fresh placement temperature relates directly to the thermal development of the placement. Lowering the placement temperature will lower the eventual maximum temperature of the placement and reduce the thermal gradient.

Lowering the placement temperature slows down the process of hydration in the concrete, reducing the rate at which the heat is generated. Fresh placement temperature is one of the most important factors that influence thermal development of massive structural concrete elements. The Iowa DOT developmental specification limits the fresh placement temperature to the range of 40°F to70°F (A. C. 207 2006).

A sensitivity study was conducted to examine the effect of fresh placement temperature on the thermal development and cracking probability for a structural element. Fresh placement temperatures were analyzed in the range of 40°F to 90°F.

The sensitivity study results show that lower fresh placement temperatures produce structural elements with reduced maximum temperatures, maximum temperature differences, and cracking potentials. The results also show that as the placement temperature increases, the rate of change in the maximum temperature increases due to the assumed accelerated hydration process as shown in Table 6.

Table 6. Fresh placement temperature sensitivity study results

Fresh Placement Temperature (°F)	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Potential
40	98	56	High
50	106	59	High
60	116	64	Very High
70	128	70	Very High
80	141	75	Very High
90	154	80	Very High

Curing Method

Curing practices are essential to prevent moisture loss on the surface of the concrete, allowing the cement to completely hydrate, allowing for proper strength development, and minimizing early drying shrinkage.

A sensitivity study was conducted to evaluate the effects of various curing methods on thermal development. Curing methods that were analyzed included white curing compound, wet curing blanket, clear plastic, and black plastic. The curing methods were compared to analysis results for a concrete structural element where no curing method was used.

The sensitivity study results show that curing compound has no effect on the thermal development of a concrete element when compared to a placement with no curing method. Both clear and black plastic curing methods had no effect on the maximum temperature of the placement or the maximum temperature difference, but slightly reduced the cracking potential in comparison to no curing method as shown in Figure 5 and Figure 6.

The analysis shows that a wet curing blanket has the largest impact on the thermal development of a structural concrete element as shown in Table 7. The analysis results showed that the maximum temperature in the placement remained unchanged, but the maximum temperature difference was greatly reduced. More importantly, the analysis showed a large reduction in the cracking potential when using the wet curing blanket as shown by Figure 7.

Table 7. Curing method sensitivity study results

Curing Method	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Potential
None	121	66	Very High
Curing Compound	121	66	Very High
Black Plastic	121	66	Very High
Clear Plastic	121	66	Very High
Wet Curing Blanket	121	45	Low

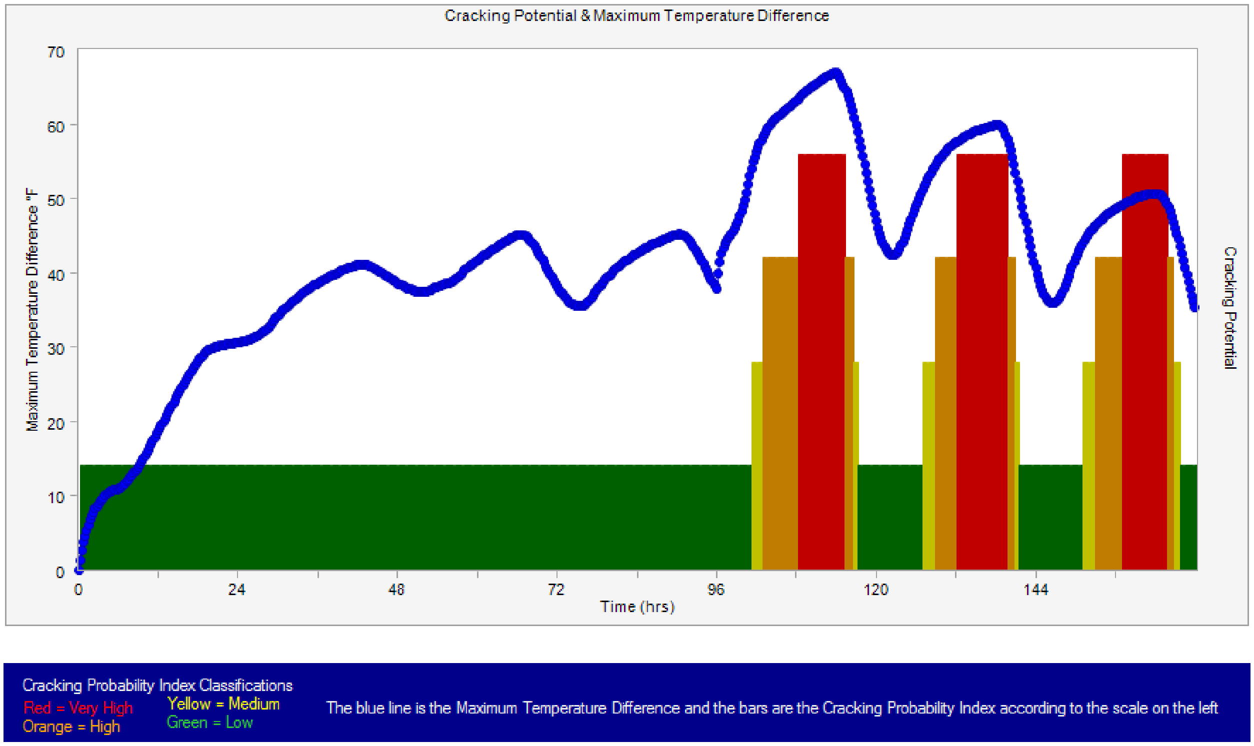

Figure 5. No curing method cracking potential

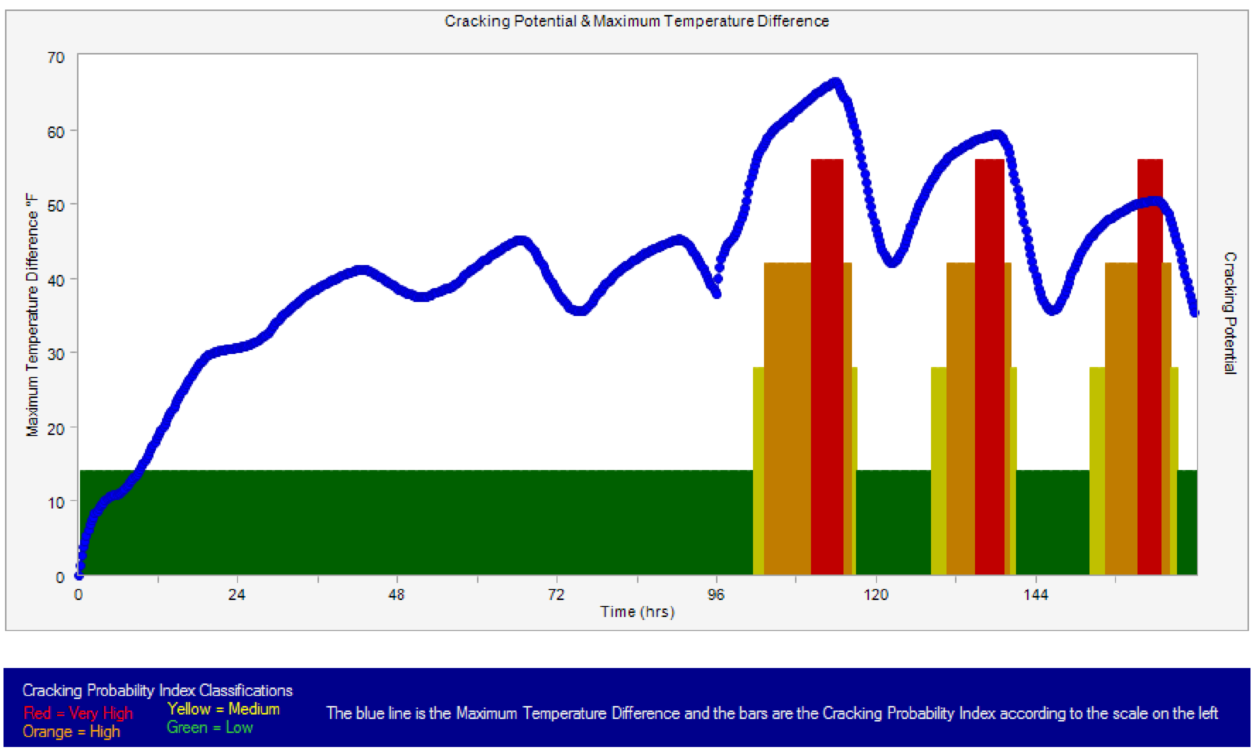

Figure 6. Black/clear plastic cracking potential

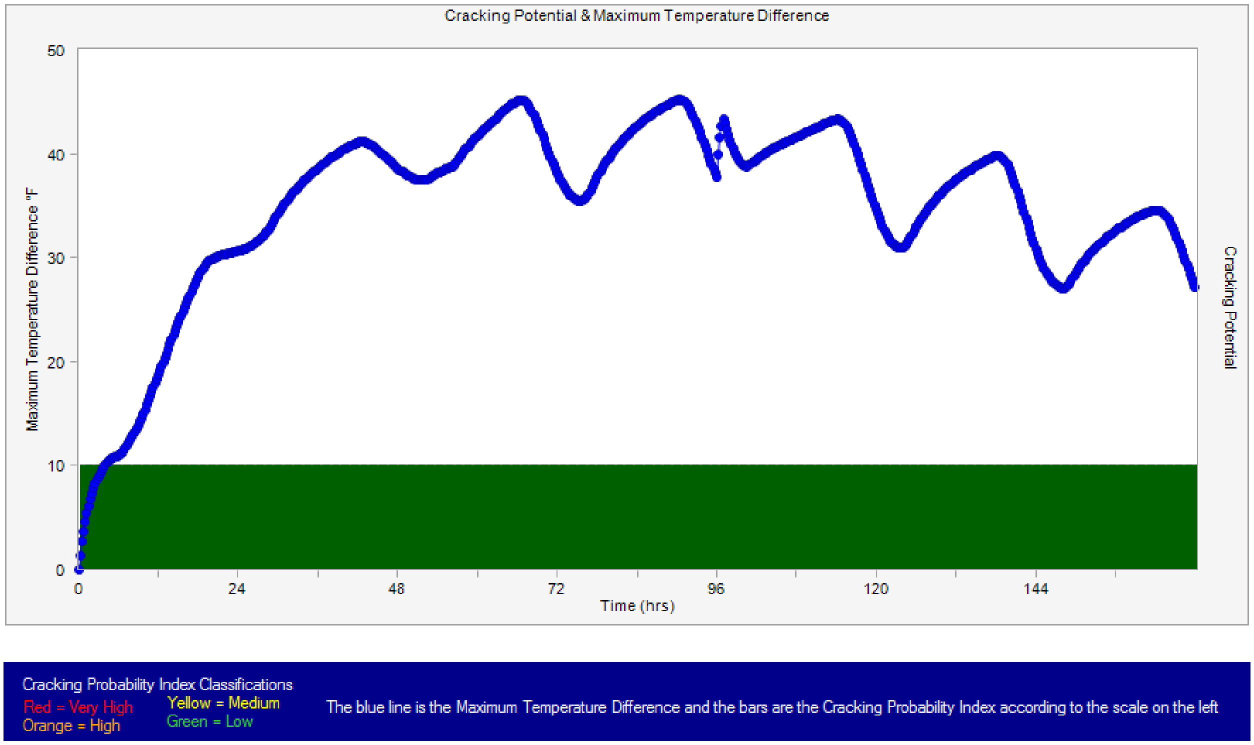

Figure 7. Wet curing blanket cracking potential

Form Removal Time

Form removal time is the length of time after the concrete is placed that the formwork is removed. When the formwork is removed from the structural concrete element, the insulating value of the formwork is removed and the exterior surface of the concrete is cooled to the ambient air temperature. Formwork or another insulating material should be kept in place for a period of time that allows the concrete to gain strength and dissipate enough heat to prevent thermal cracking.

A sensitivity study was conducted to evaluate the effect of form removal time on the thermal development of massive structural concrete elements. Form removal times were evaluated for two to seven days. The starting point of two days was established to be a best-case removal time for mass concrete elements, and the upper limit, seven days, is the maximum allowed by ConcreteWorks to report a cracking potential.

The results show that the formwork removal time has no effect on the maximum temperature in the placement. In addition, the results showed that with an increased form removal time, the cracking potential and maximum temperature difference decreased as shown in Table 8. The increased form removal time allows the concrete to gain more strength and dissipate more heat before being exposed to the cooler ambient temperatures that induce stress in the placement.

Table 8. Form removal time

Form Removal Time	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Potential
48	121	74	Very High
72	121	71	Very High
96	121	66	Very High
120	121	61	Very High
144	121	52	High
168	121	45	Low

Forming Method

Forming method is the means by which the concrete is formed into the desired shape. Common methods of forming concrete include the use of wood formwork, steel formwork, and soil forming. The performance of a formwork is determined by the thermal resistance of the material. Steel has a relatively low thermal resistance, which allows for rapid heat transfer through the material. Wood has a higher thermal resistance than steel, which decreases the rate of heat transfer. Soil, in comparison, has the largest thermal resistance when compared to both steel and wood and greatly reduces the amount of heat transfer.

A sensitivity study was conducted to evaluate how changes in forming methods change the thermal development of structural mass concrete elements. The forming methods that were examined included steel formwork, wood formwork, and soil forming.

The sensitivity study examined two scenarios to identify how formwork affects the thermal development of mass concrete. The first scenario is a smaller placement, which would be associated with little concern of cracking before the formwork is removed, represented by the three-day form removal time. The second scenario is a larger placement, which would be associated with a large concern of cracking before the formwork is removed, represented by the seven-day form removal time.

The three-day form removal time sensitivity study shows that steel formwork performs better than wood formwork by reducing the maximum temperature difference and the cracking potential, as shown by

Table 9. This is assumed to be the result of the fact that steel formwork dissipates heat more rapidly than the wood formwork.

The soil-formed placement generated a higher maximum temperature but a lower maximum temperature difference and cracking potential than either the wood or steel formwork. It is important to note that the soil-formed placement does not require form removal in the same way that the wood and steel formwork does.

Table 9. Forming method—three-day form removal

Forming Method	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Potential
Wood Formwork	121	66	Very High
Steel Formwork	121	63	High
Soil Formed	123	51	Low

The seven-day form removal time sensitivity study shows that wood formwork performs better than steel for placements with concern of cracking before the formwork is removed. As shown in Table 10, wood formwork produced a lower maximum temperature difference and cracking potential compared to steel formwork. This result is attributed to the fact that wood has a larger insulating capacity compared to steel or soil, reducing the thermal gradient while the formwork is in place. Compared to steel, wood formwork requires an extended time before form removal, because it allows heat to dissipate at the reduced rate. In addition, the soil formwork greatly reduced the maximum temperature difference and cracking potential compared to both steel and wood formwork.

Table 10. Forming method—seven-day form removal

Forming Method	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Potential
Steel Formwork	188	129	Very High
Wood Formwork	188	108	Very High
Soil Formwork	188	107	Low

The results show that when cracking after formwork is removed is the largest concern, steel formwork performs better than wood. When cracking before form removal is of concern, wood formwork performs better than steel. In addition, soil performs very well as a forming method for structural mass concrete.

Placement Date and Time

Ambient air temperature in the state of Iowa changes substantially with each season and the time of day. Warmer ambient temperatures cause the exterior portions of the placements to be at a higher temperature, reducing the thermal gradient. In addition, warmer climates generally produce higher fresh placement temperatures, which increase the maximum temperature in the placement. ConcreteWorks has a function that provides average historical ambient temperature versus time relationships for various locations across the US.

A sensitivity study was conducted examining the effects of ambient temperature on the thermal development of mass concrete. The study looked at two separate placement dates—July 20, 2008, and October 20, 2008. These dates were chosen to be two extreme cases to more dramatically show the effect of ambient temperature. October 20th was chosen instead of a winter date to avoid complications with freezing conditions. In addition, the study examined the effects of the fresh placement temperature for each season to explore how the fresh placement temperature contributes to the thermal development.

The maximum and minimum ambient air temperatures for each day used to complete the analysis is shown in Table 11. This large temperature difference needs to be considered when comparing the results, as the fresh placement temperature of the concrete will be greatly affected by the large temperature difference.

Table 11. Daily maximum and minimum temperatures

	October 20, 2008		**July 20, 2008**	
Day	**Maximum Temperature °F**	**Minimum Temperature °F**	**Maximum Temperature °F**	**Minimum Temperature °F**
1	62.6	42.8	86.9	68.5
2	63.7	44.6	85.1	68.2
3	61.7	45.5	85.6	68.2
4	59.5	44.1	86.2	68.7
5	58.8	42.8	87.1	86.5
6	60.4	42.3	85.1	68.7
7	62.4	41.4	85.1	67.5
8	60.1	44.1	84.7	67.8
Average	**61.15**	**43.45**	**85.725**	**70.5125**

The sensitivity study results show that concrete structural elements placed in warmer climates have a reduced maximum temperature difference, even when accounting for the higher fresh placement temperature as shown in Figure 8 and Table 12. The results also show that structural concrete elements placed in a warmer climate produce a higher maximum temperature, especially when considering a warmer fresh placement temperature.

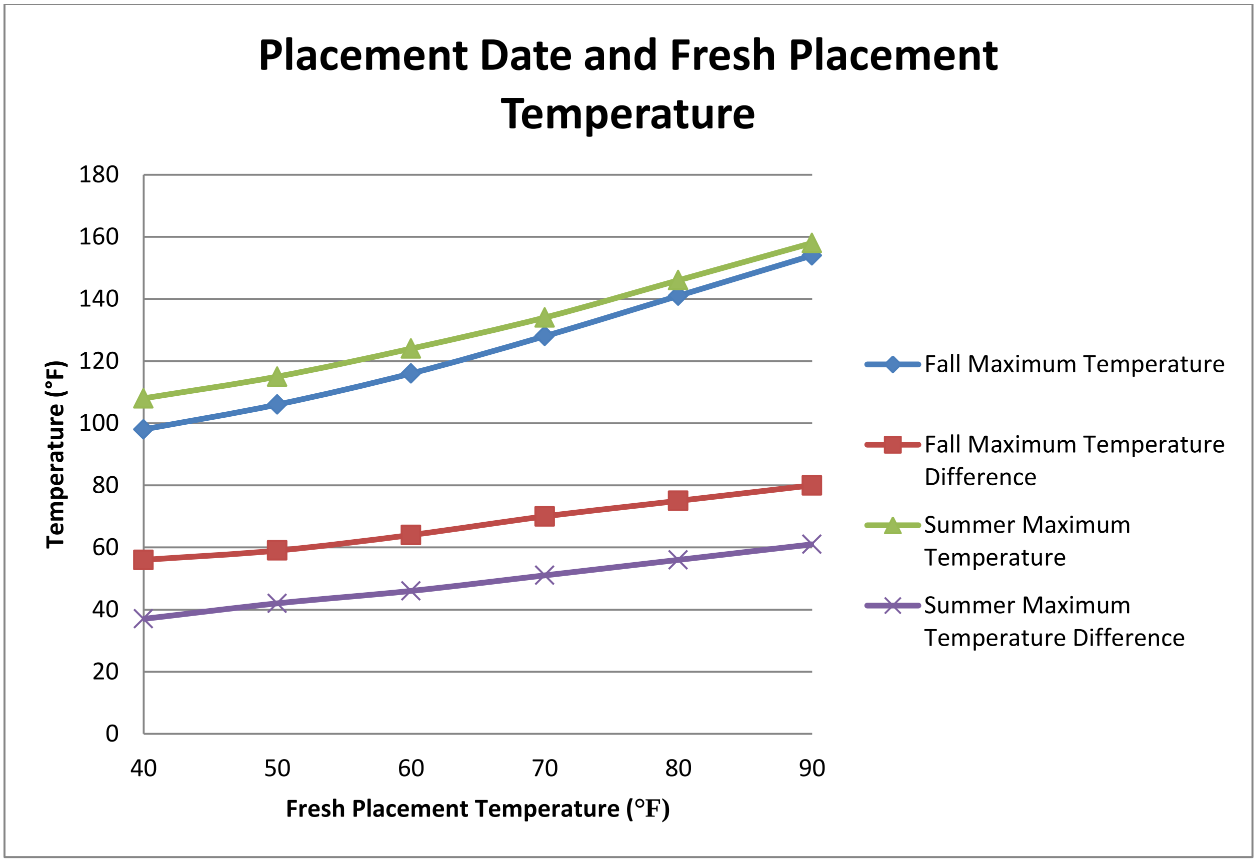

Figure 8. Effect of placement date and fresh placement temperature

Table 12. Placement date and fresh placement temperature

Date	Fresh Placement Temperature (°F)	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Probability
10/20/08	40	98	56	High
10/20/08	50	106	59	High
10/20/08	60	116	64	Very High
10/20/08	70	128	70	Very High
10/20/08	80	141	75	Very High
10/20/08	90	154	80	Very High
7/20/08	40	108	37	Low
7/20/08	50	115	42	Low
7/20/08	60	124	46	Low
7/20/08	70	134	51	Medium
7/20/08	80	146	56	Very High
7/20/08	90	158	61	Very High

Cement Content

Cement content is the number of pounds per cubic yard required for the mix proportion. Cement content, along with the water-to-cement ratio, is a large contributing factor to strength and durability for concrete. In addition, the heat of hydration that is produced is directly proportional to the amount of cement in the concrete; the more cement in a concrete mix, the more heat of hydration that will be generated. The Iowa DOT currently has a developmental specification that limits the minimum cement content to 560 pounds per cubic yard.

A sensitivity study was conducted examining cement content values of 560, 660, and 760 pounds per cubic yard. The results show that the maximum temperature and maximum temperature difference in the placement increased with respect to the cement content as shown in Table 13.

Table 13. Cement content

Cement Content (lbs/yd^3)	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Potential
560	128	63	Very High
660	136	68	Very High
760	144	73	Very High

In addition, the results show that cement content does not have an effect on the cracking potential as defined by ConcreteWorks and shown in Figure 9 and Figure 10. The results are difficult to interpret, because they are always in the range of "very high cracking." However, it is possible and likely that the actual risk of cracking is varying, but always staying within the range of "very high cracking" as defined by ConcreteWorks.

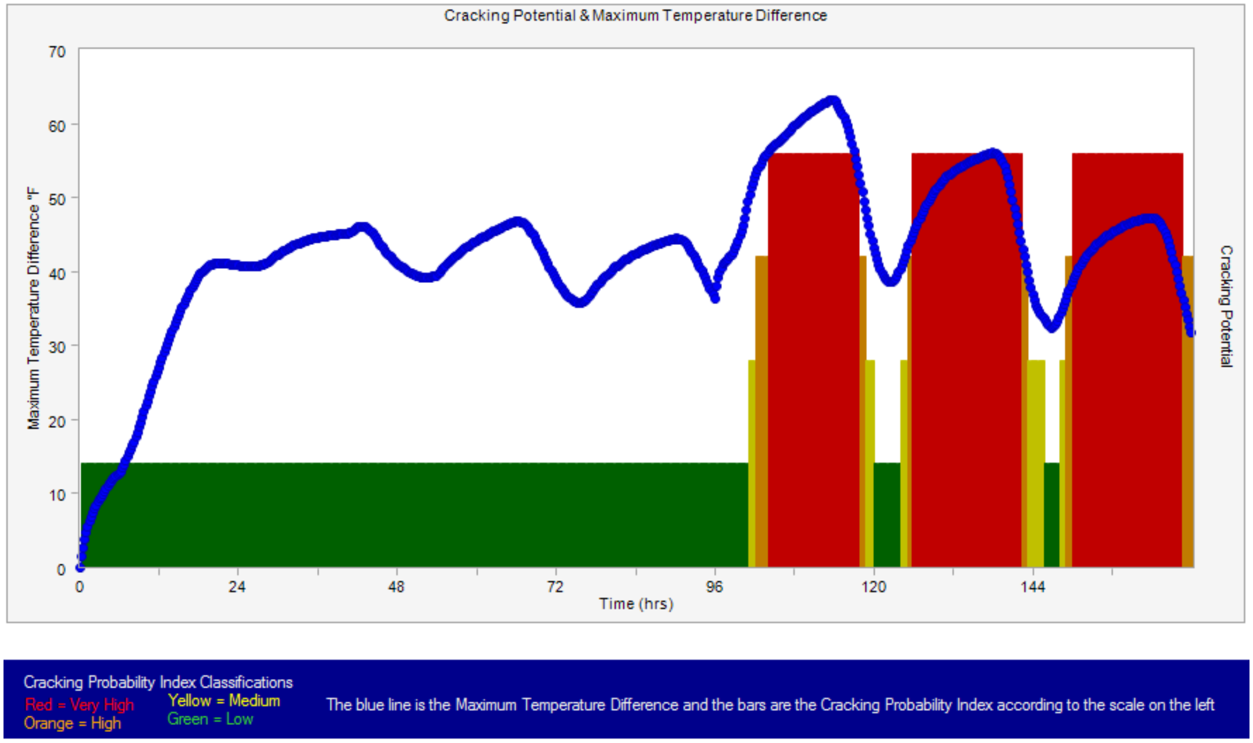

Figure 9. Cement content 560 pounds per cubic yard cracking potential

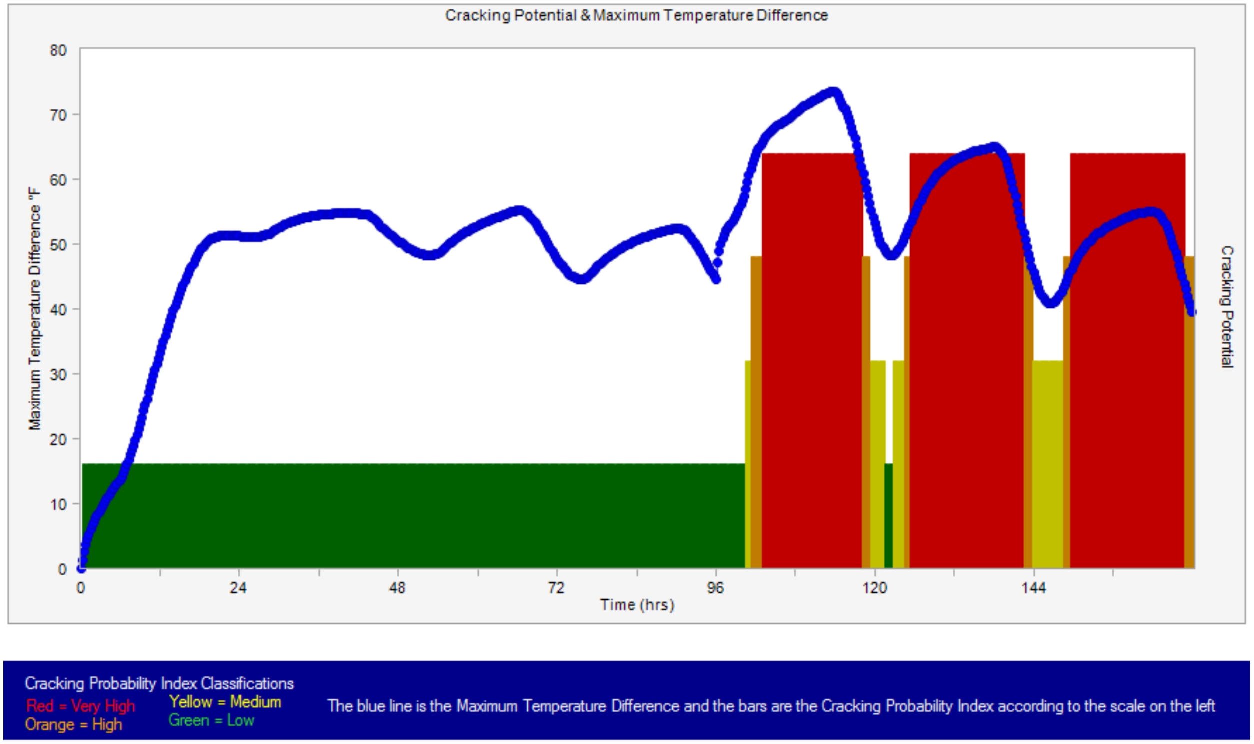

Figure 10. Cement content 760 pounds per cubic yard cracking potential

The lack of change in cracking potential may also be due in part to the fact that, as the cement content increases, the strength of the concrete increases, sufficiently as to not fail, despite the increases in thermal stress.

Fly Ash

Fly ash is a commonly-used supplementary cementitious material in concrete as a partial substitute for Portland cement. Fly ash provides increased ultimate strength and workability, as well as a reduction in the heat of hydration. In addition, mix proportions incorporating fly ash have a reduced rate of strength development. There are two different types of fly ash, Class C and Class F. The largest differences are that Class F is sulfate resistant, while Class C is not; in addition, Class F has reduced heat of hydration compared to Class C. More information on the differences between Class C and Class F fly ash is provided in Appendix D.

The Iowa DOT specification limits the amount of cement substitution for Class F and ground granulated blast furnace slab to 50 percent, with a maximum substitution of Class C fly ash to 20 percent. The percentages encompass the quantity included in the blended cement.

A sensitivity study was completed to examine the effects of fly ash substation in concrete mix proportion on the thermal development of structural concrete elements. The study examined the maximum substation for both Class C and Class F fly ash with ranges of 0 to 20 percent and 0 to 50 percent, respectively. For the purposes of this sensitivity analysis, the chemical composition of the fly ash was assumed to match the analysis provided by Headwaters Co., as shown in Table 14.

Table 14. Headwaters Co. chemical compound breakdown (Chemical Comparison of Fly Ash and Portland Cement 2005)

CHEMICAL COMPOUND	POZZOLAN TYPE			CEMENT
	CLASS F	CLASS C	CLASS N	
SiO	54.90	39.90	58.20	22.60
$A1_2O_3$	25.80	16.70	18.40	4.30
Fe_2O_3	6.90	5.80	9.30	2.40
CaO	8.70	24.30	3.30	64.40
MgO	1.80	4.60	3.90	2.10
SO_3	0.60	3.30	1.10	2.30
Na_2O & K_2O	0.60	1.30	1.10	0.60

The maximum substitution of Class C and Class F fly ash produced a large reduction in the heat of hydration, as well as the cracking potential, as shown in Table 15. The results show that the maximum substation of Class F fly ash has a larger effect on the thermal development of the placement compared to Class C, as shown by Figure 11, Figure 12, and Figure 13.

Table 15. Fly ash sensitivity study

Substitution	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Potential
No Substitution	134	67	Very High
Class F 10%	127	64	Very High
Class F 20%	121	61	Very High
Class F 30%	115	58	Very High
Class F 40%	109	55	Very High
Class F 50%	104	52	High
No Substitution	134	67	Very High
Class C 10%	130	66	Very High
Class C 20%	127	65	Very High

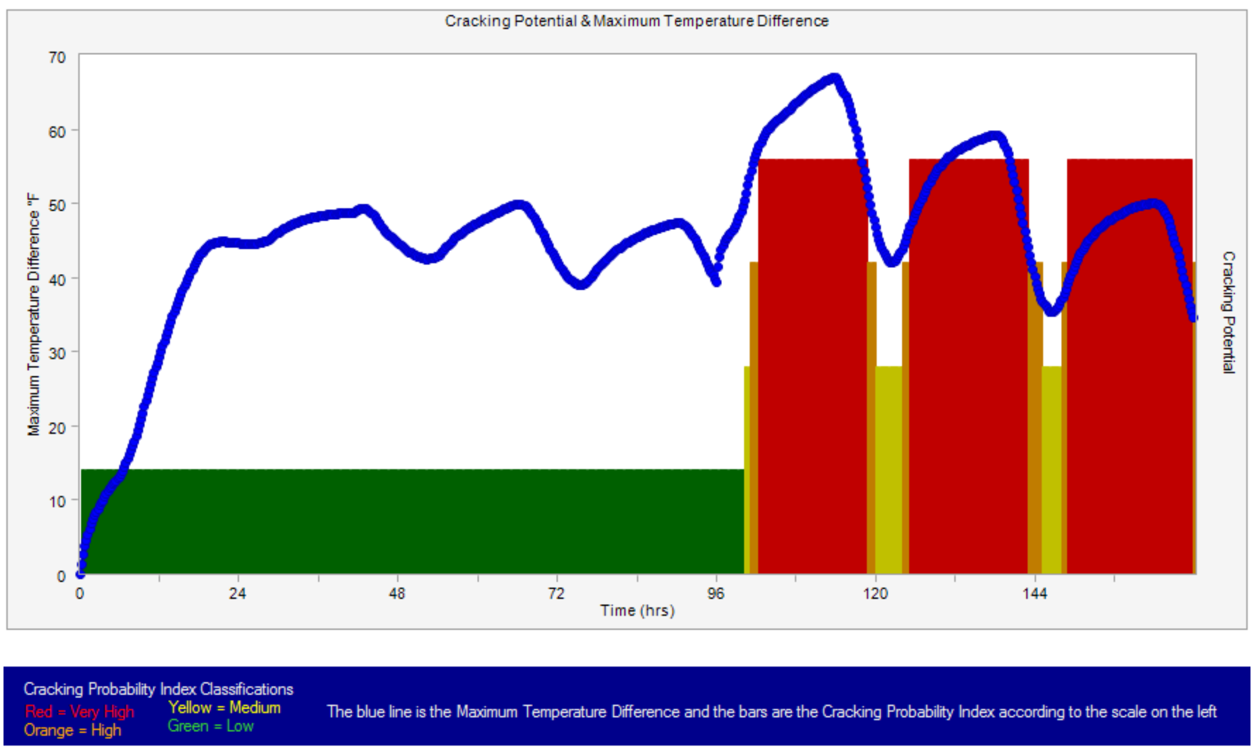

Figure 11. No fly ash substitution cracking potential

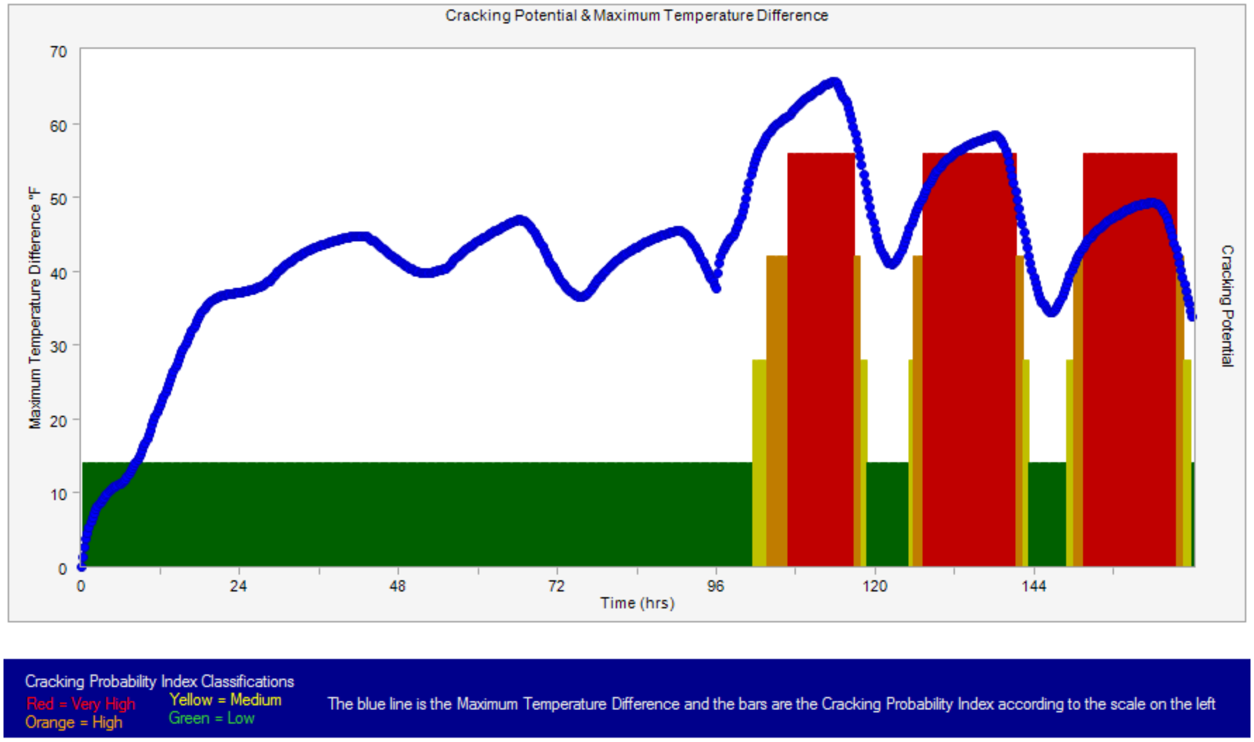

Figure 12. 20 percent Class C fly ash substitution cracking potential

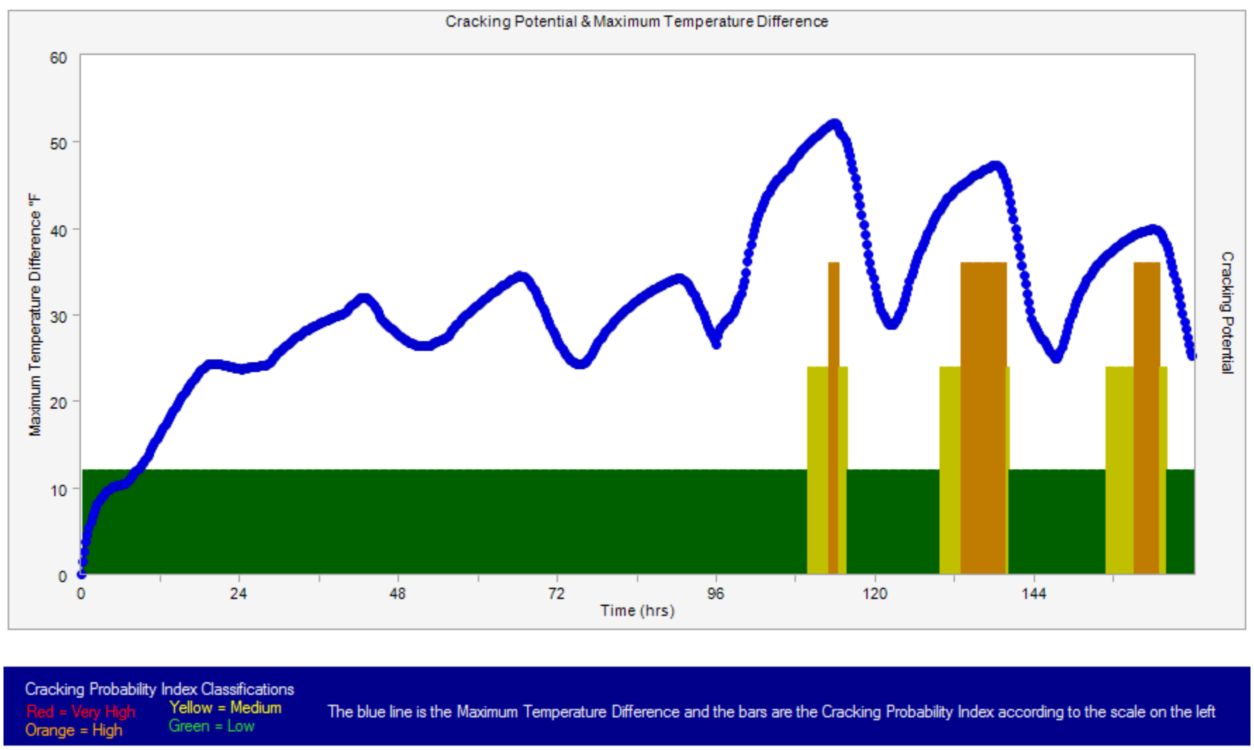

Figure 13. 50 percent Class F fly ash substitution cracking potential

Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag (GGBFS), also referred to as cement slag, is commonly used as a supplementary cementitious material to increase the ultimate strength of the concrete and reduce the heat of hydration. Like a concrete mix that includes fly ash, mixes that include GGBFS have a reduced rate of strength development.

The sensitivity study examined GGBFS substitutions from 0 to 50 percent, with 50 percent being the maximum allowed by the Iowa DOT specification. The results show that substituting GGBFS reduces the maximum temperature and cracking potential but does not affect the maximum temperature difference as shown in Table 16, Figure 14, and Figure 15.

Table 16. GGBFS sensitivity study results

Substitution	Maximum Temperature (°F)	Maximum Temperature Difference (°F)	Cracking Potential
0%	134	67	Very High
20%	131	67	Very High
30%	128	67	Very High
40%	126	68	Very High
50%	125	68	Very High

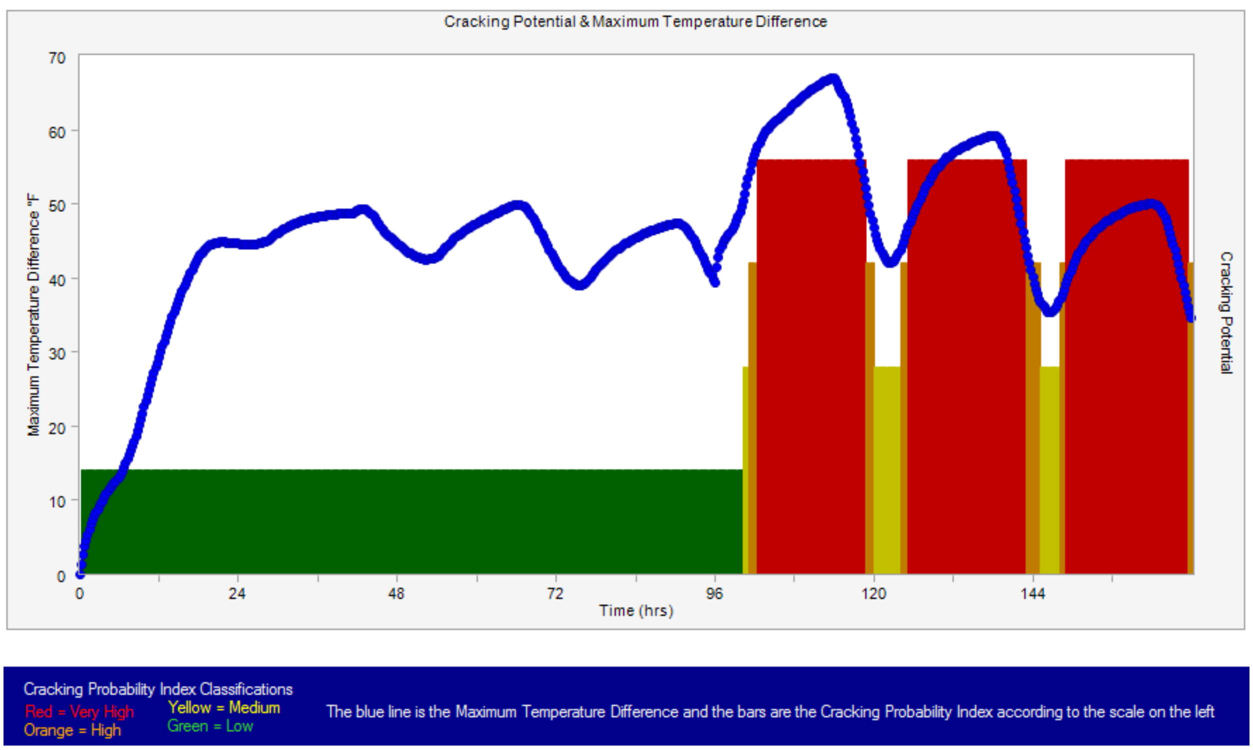

Figure 14. 0 percent GGBFS substitution cracking potential

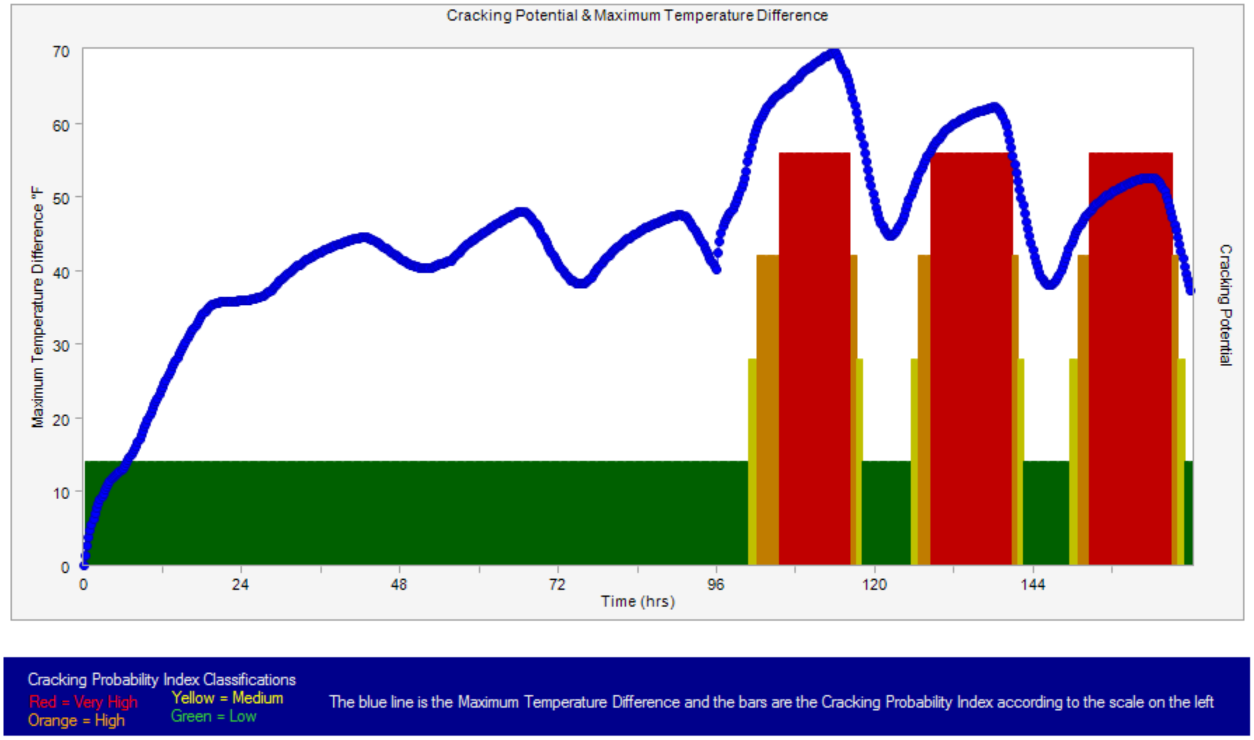

Figure 15. 50 percent GGBFS substitution cracking potential

CHAPTER 3. CONCLUSIONS AND RECOMMENDATIONS

Various mix proportion, construction, and environmental parameters can have a large effect on the thermal development of structural mass concrete elements, as illustrated by the sensitivity study. The results of the sensitivity study have been compiled in Table 17.

Table 17. Sensitivity study results

Sensitivity Study	Input	Maximum Temperature	Maximum Temperature Difference	Cracking Potential
Dimensional Size	Reducing Dimensional Size	*	*	*
Fresh Placement Temperature	Reducing Fresh Placement Temperature	*	*	*
Curing Method	Curing Compound			
	Black Plastic			*
	Clear Plastic			*
	Wet Curing Blanket		*	*
Form Removal Time	Increasing Form Removal Time		*	*
Forming Method: Cracking After Form Removal	Steel Formwork		*	*
	Soil Formwork		*	*
Forming Method: Cracking Before Form Removal	Wood Formwork		*	*
	Soil Formwork		*	*
Placement Date	Cooler Seasons	*		
	Warmer Seasons		*	*
Cement Content	Reduce Cement Content	*	*	
Fly Ash	Substitute Class F Fly Ash	*	*	*
	Substitute Class C Fly Ash	*	*	*
GGBFS	Substitute GGBFS	*		*

* indicates a reduction in the category

Following is a list of the most-beneficial practices to reduce the likelihood of thermal damage to structural mass concrete elements. The list is in order of most beneficial to least beneficial.

1. Keep fresh placement temperatures as low as reasonably possible.
2. Use wet curing methods when possible; if wet curing is not possible, use plastic wrap curing methods.
3. If possible, use extended form removal times.
4. Use soil form placements when possible. Use wood formwork with possibly additional insulation when there is considerable concern about cracking before the formwork is removed. Use steel formwork for placements when there is less concern about cracking when formwork is in place.
5. Include supplemental fly ash and GGBFS in the concrete mix design, preferably Class F fly ash over both Class C and GGBFS.
6. If there is relatively less concern for excessive maximum temperatures in the concrete, place elements in warmer ambient temperatures when possible.
7. Use mix designs with lowered cement contents.

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APPENDIX A. MASS CONCRETE SPECIFICATIONS ACROSS THE US

	Definition of Mass	Material	Chemical Admixtures	Temperature Monitoring Equipment	Temperature Restrictions	Developer Restrictions	Monitoring	Cooling system requirements	Plan
Iowa DOT (2010)	Structural mass (concrete footing) least dimension 5ft, Other concrete 4ft	Minimum cement content of 560 lb/yd^3, Max water to cementitious ratio 0.45, Class C fly ash maximum 20% substitution, Total substitution of cement limited to 50% Type I/II, IP, or IS	Air Entrainment required, water reducing and retarding may be used	sensor locations, backups, 2 systems, accuracy +/-2deg, 10 sensors	Maximum temperature differential restriction by hours after placement, Max pour 70deg Min 40deg at pour, Max during heat dissipation 160deg, max temperature differential overall 50deg(at 72 hours)	For 6.5 or greater deep must be developed by PE	Continuous monitoring by engineer or qualified person, every 4 hours, stop once interior temperature is within 50deg of average outside temperature	recommendations	Contractor developed DOT approved
California DOT (2008)	Structural mass least dimension 7ft	Minimum cement content of 505 lb/yd^3, allowable GGBFS 50-75percent by weight of cementitious material, other supplementary cementitious material 25-35percent by weight of cementitious material		sensor locations, backups, how to wire and place sensors	max allowable temp. 160deg max temperature, max differential 35deg		Monitored by licensed engineer, every hour, stop once maximum interior temperature is falling	detailed list	Contractor developed DOT approved
South Carolina DOT (1997)	Any concrete least dimension 5ft				max pour temp 80deg, max temperature differential 35 deg		monitored until interior is within 35deg of air temperature		Contractor developed DOT approved
Kentucky DOT (2004)	Any concrete least dimension 5ft	Grade F fly ash, Grade 100 and 120 GGBF, Type I(SM) and IS		range +/- 1deg, backups, 8 sensors with their locations	Max pour 70deg, over max for concrete 160deg, max temperature differential of 35deg		monitored every 4 hours, monitor until interior is within 35 deg of average outdoor temperature	recommendations	Contractor developed DOT approved
West Virginia DOT (2006)	Any concrete least dimension 4ft	maximum percentages for cementitious materials (very detailed)		redundant set required, how to wire and where to place sensors, 10 sensors	Overall max for concrete 160deg, max temperature differential of 35deg		hourly, stop monitoring once interior temperature reaches it's maximum		Contractor developed DOT approved
Florida DOT (2010)				must be inspected and approved	Overall max for concrete 180deg, max temperature differential of 35deg	developer qualifications must be approved	every 6 hrs. monitor until concrete is with 35def of air temperature		Contractor developed DOT approved
Arkansas DOT (2003) Type B Concrete		Substitute up to 120pounds of cement for fly ash			Temperature at placement 50-75deg, 36deg max temperature differential		monitor at least 7 days	recommendations, cannot cool fine aggregate by watering	
Idaho DOT (2004)	Footing thicker than 4ft				35deg max temperature differential		Monitor for full 7 day curing time		
Texas DOT (2004)	Any concrete least dimension 5ft			2 systems, temperature recording devices, or maturity meters	Placement temp between 50-75deg, max temperature differential of 35deg, max allowable temp of 160deg		Monitor for 4 days	recommendations, formwork must be kept in place for 4 days	Base plan on equations for Portland Cement Association's Design and Control of Concrete Mixtures
New York DOT (2010)				sensor locations, backups	35 deg max temp differntial				

APPENDIX B. GLOSSARY

Activation Energy—Total energy required per unit quantity of molecules for a reaction to take place. Units [J/mol].

Activation Energy Factor 1 *(4C Temp&Stress)*—Energy required per unit quantity of molecules for a reaction to take place when temperature is above 20 degrees C. Units [J/mol].

Activation Energy Factor 2 *(4C Temp&Stress)*—Additional average energy required per mole per degree C below 20 degrees C for a reaction to take place. Units [J/ (mol*^{o}C)].

Creep—Deformation of concrete due to a constant sustained load (with stress below the yield strength) dependent upon time.

Equivalent Age/Maturity *(4C Temp&Stress)*—M=∑e^(E/R*(1/293-1/(273+θ)))Δt, where E is the activation energy, R is the gas constant (8.314), θ is the concrete temperature in degrees C, and Δt is the time interval in hours. Units [hr].

Flux—Flow of energy. Function describing the energy transfer from heat or radiation.

Heat Transfer Coefficient—The amount of heat that is transferred through an area of a system for a given unit of time with a temperature difference between the boundaries of 1 degree. Units [KJ/(m^2*hr*^{o}C)].

Initial Strain—Strain due to change in temperature, moisture transportation, and/or chemical changes within the concrete.

Maturity—A concept based off the idea that strength gain in concrete is a function of curing time and temperature.

Shield Definition *(4C Temp&Stress)*—Material properties covering the concrete, and the time period in which it is in place. Described as a constant piecewise function, and can be used in accordance with wind velocity to develop the heat transfer coefficient function.

Specific Heat—Heat required per unit mass to raise the temperature 1 degree. Units [KJ/(kg*^{o}C)].

Strain—Deformation of a body in reference to an unstressed position due to applied forces. Units [unit less] or [m/m].

Thermal Coefficient/Coefficient of Thermal Expansion—The expansion or contraction of a material in comparison to its length per 1 degree temperature change. Units [1/^{o}C] or [strain/ ^{o}C].

Thermal Conductivity—The amount of heat transferred through a given thickness per unit area and unit time for a 1-degree temperature difference between the boundaries. Units [$KJ*m/(m^2*hr*^oC)$] or [$KJ/(m*hr*^oC)$].

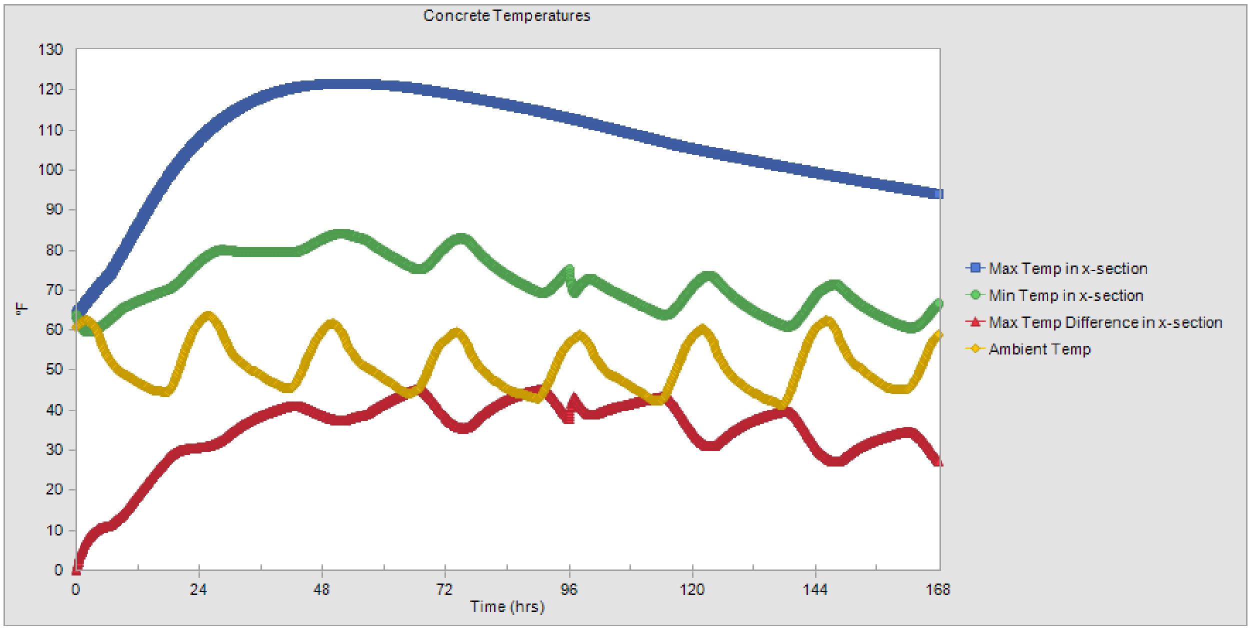
Thermal Expansion—Change in volume due to a temperature change, based off coefficient of thermal expansion.

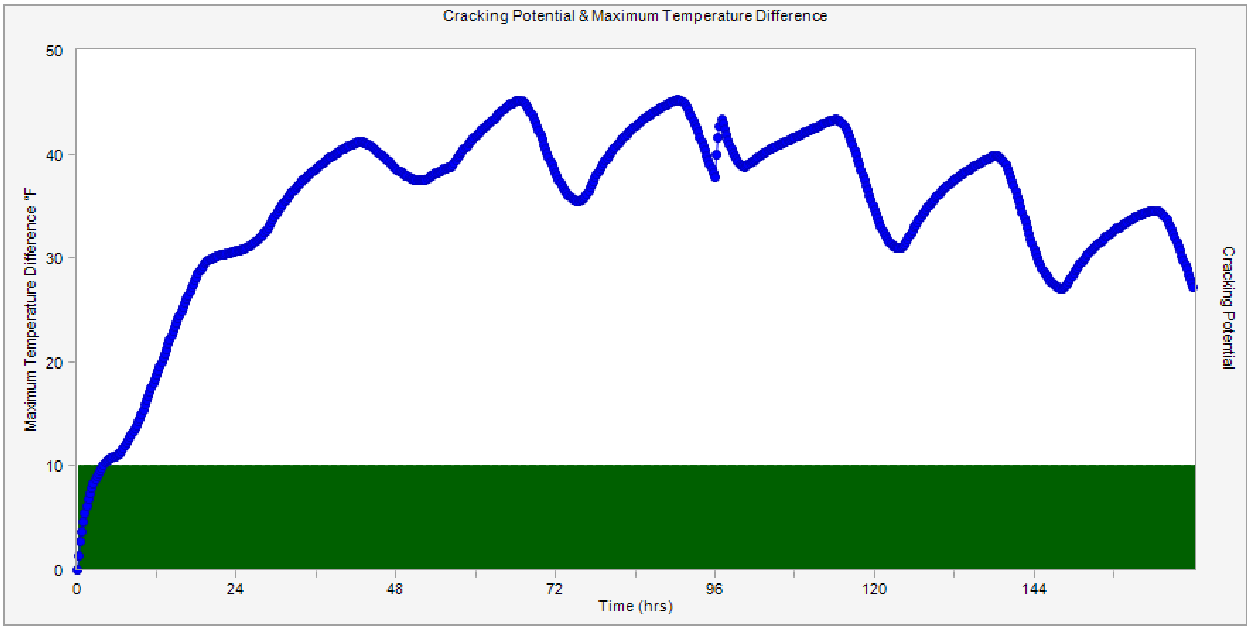
Time Temperature Factor/Maturity *(ConcreteWorks)*—$M(t) = \sum(t_a - t_o)\Delta t$, where t_a is the average concrete temperature during curing time Δt. T_o is the datum temperature, which is the temperature when the concrete strength gain stops. Units [^oC-hr].

APPENDIX C. DIMENSIONAL SIZE

Pier 1 Footing: 43x12x4.5 ft

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	45	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	



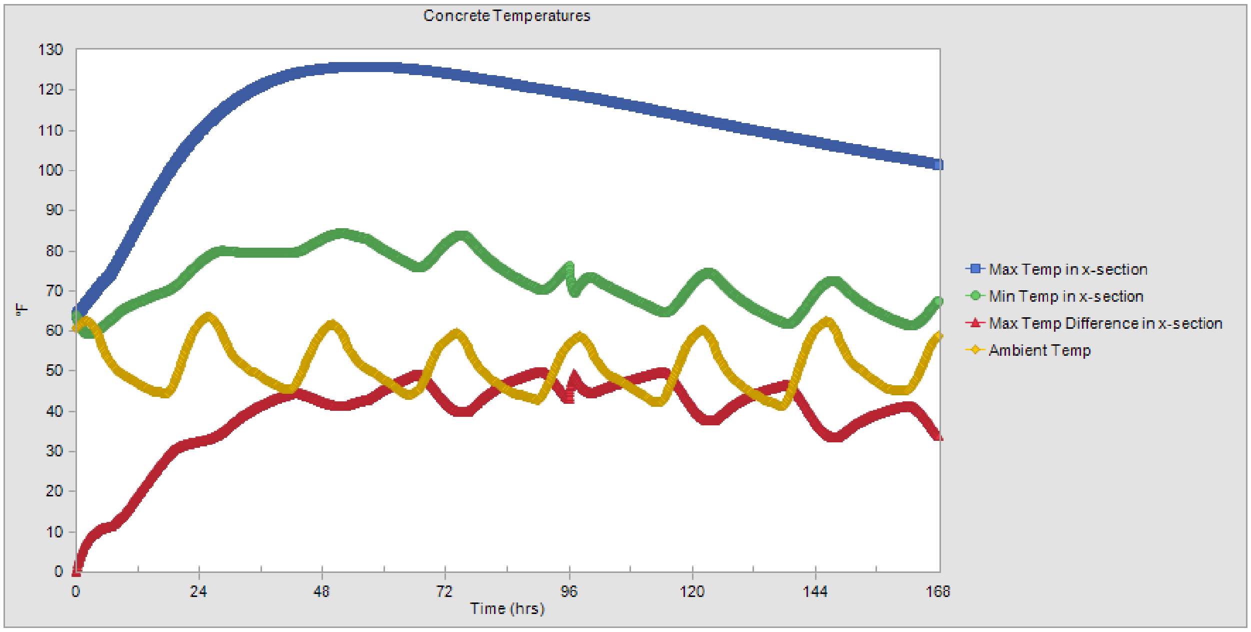


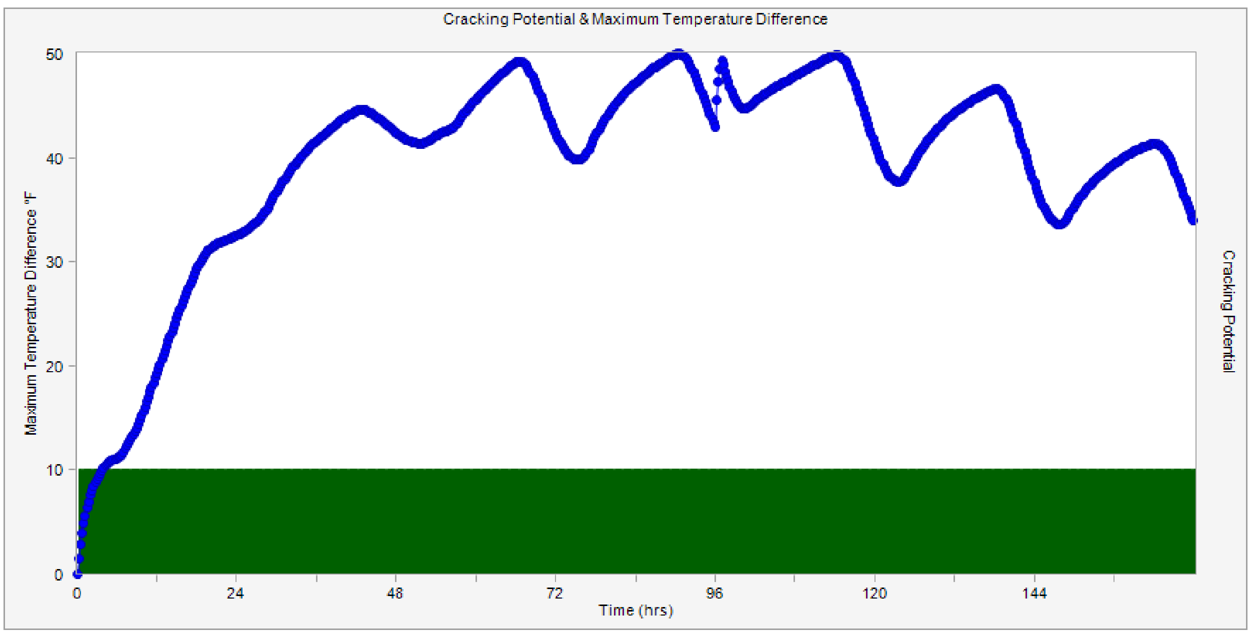
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Pier 2 Footing: 43x15x5 ft

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	49	°F
Max Temperature	125	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	



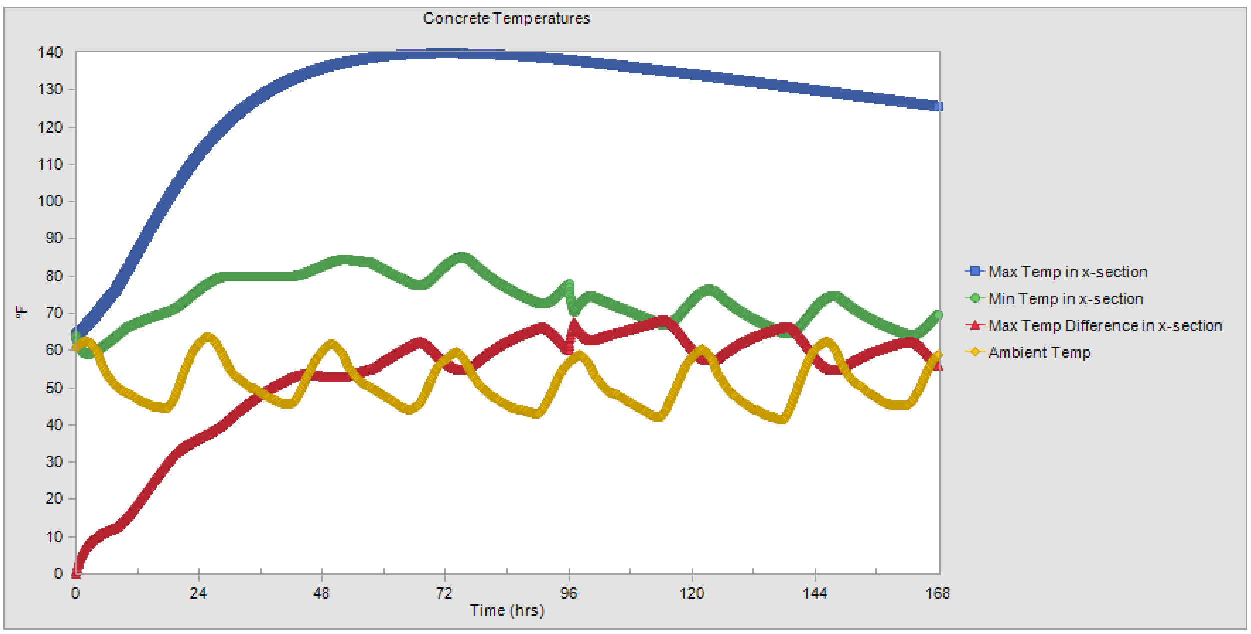


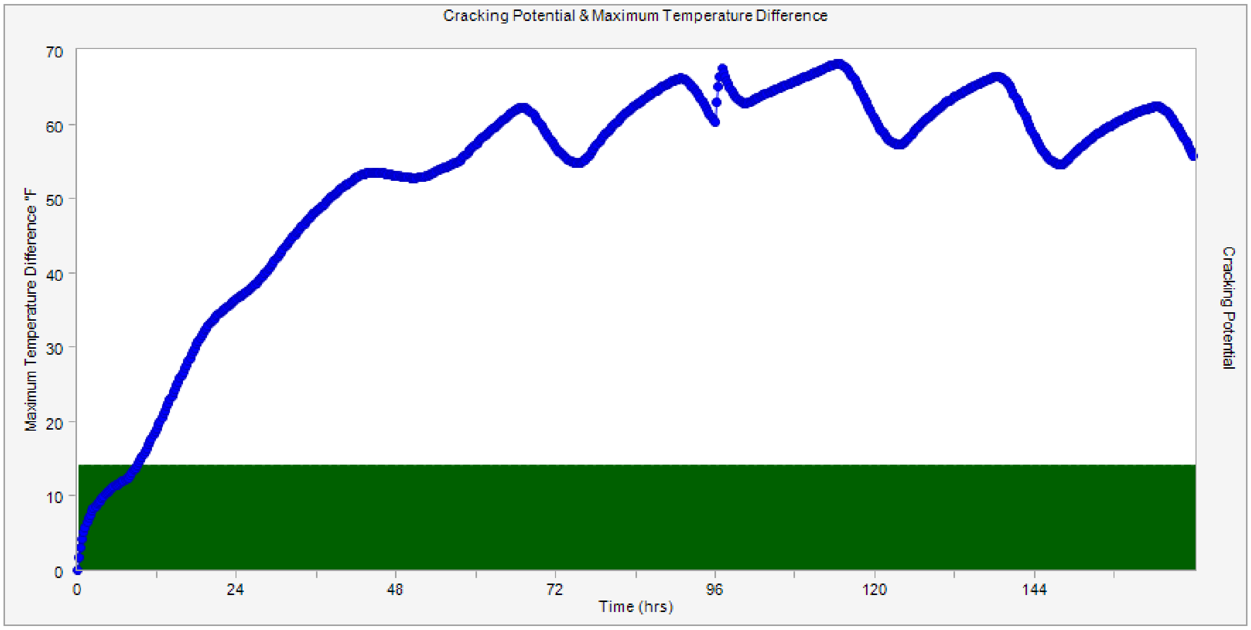
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Pier 3 Footing: 43x27x7.25 ft

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	68	°F
Max Temperature	139	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	



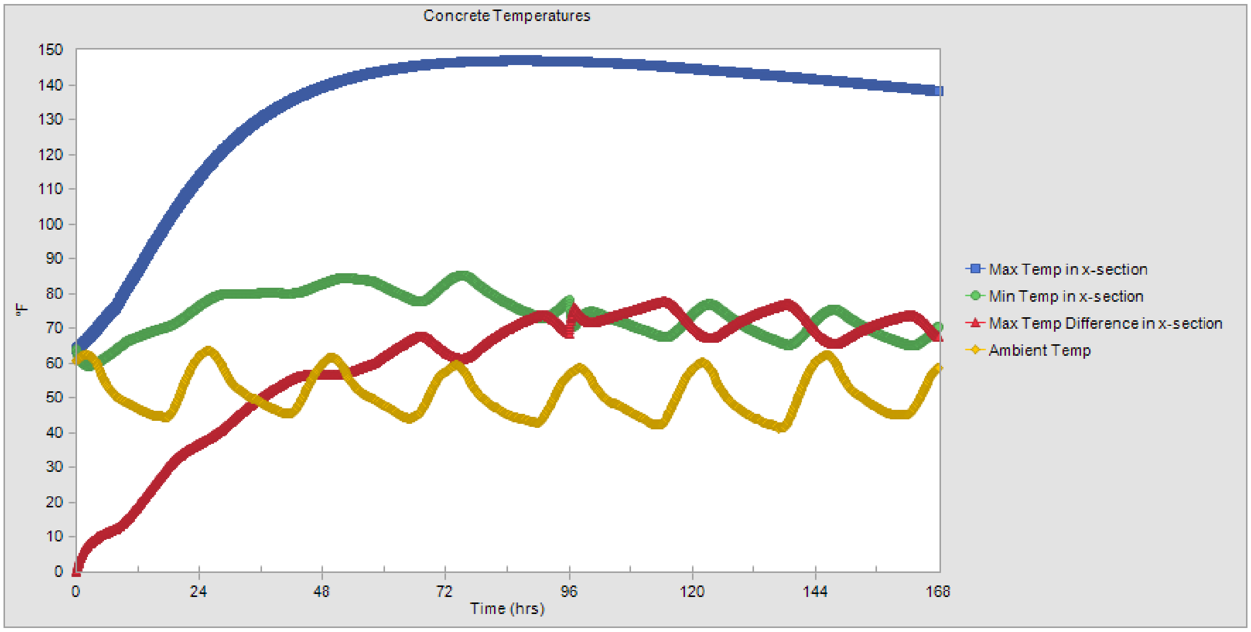


Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

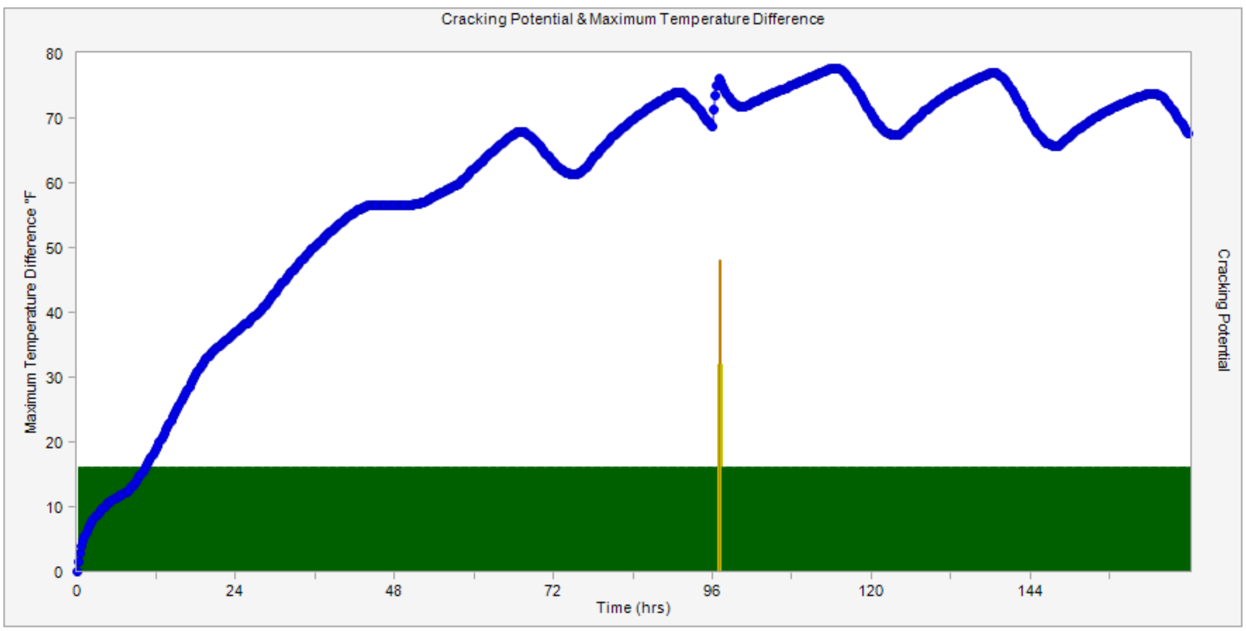
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Pier 7 Footing: 43x25.5x9 ft

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	77	°F
Max Temperature	146	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	



Concrete Temperatures
°F
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp

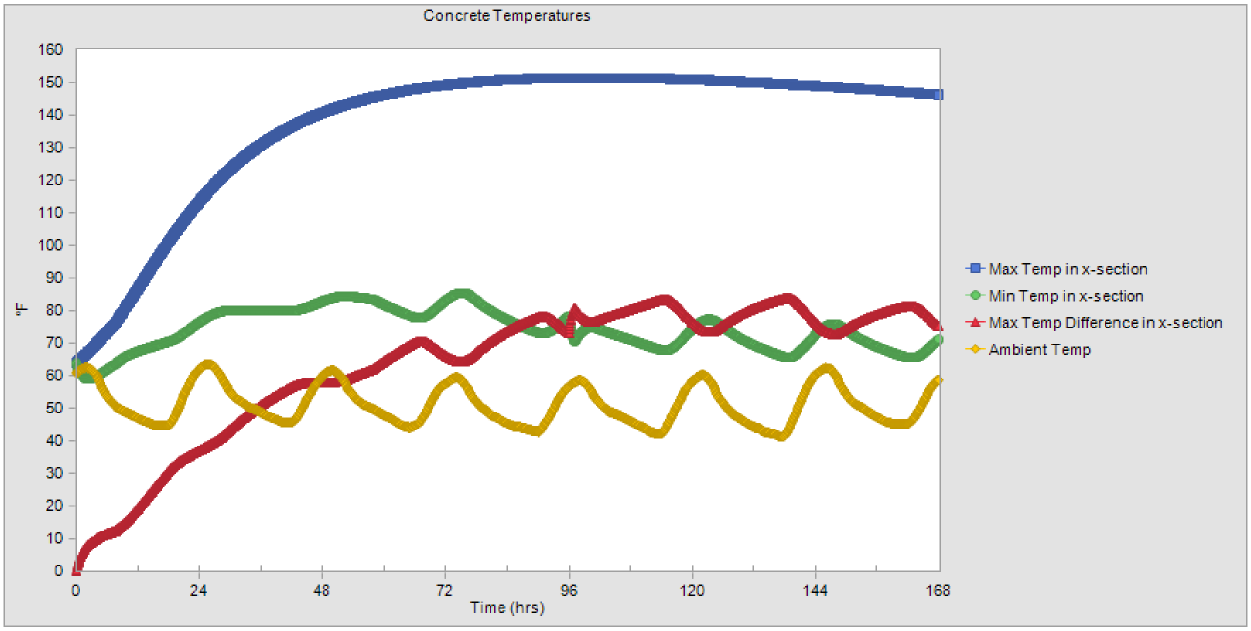


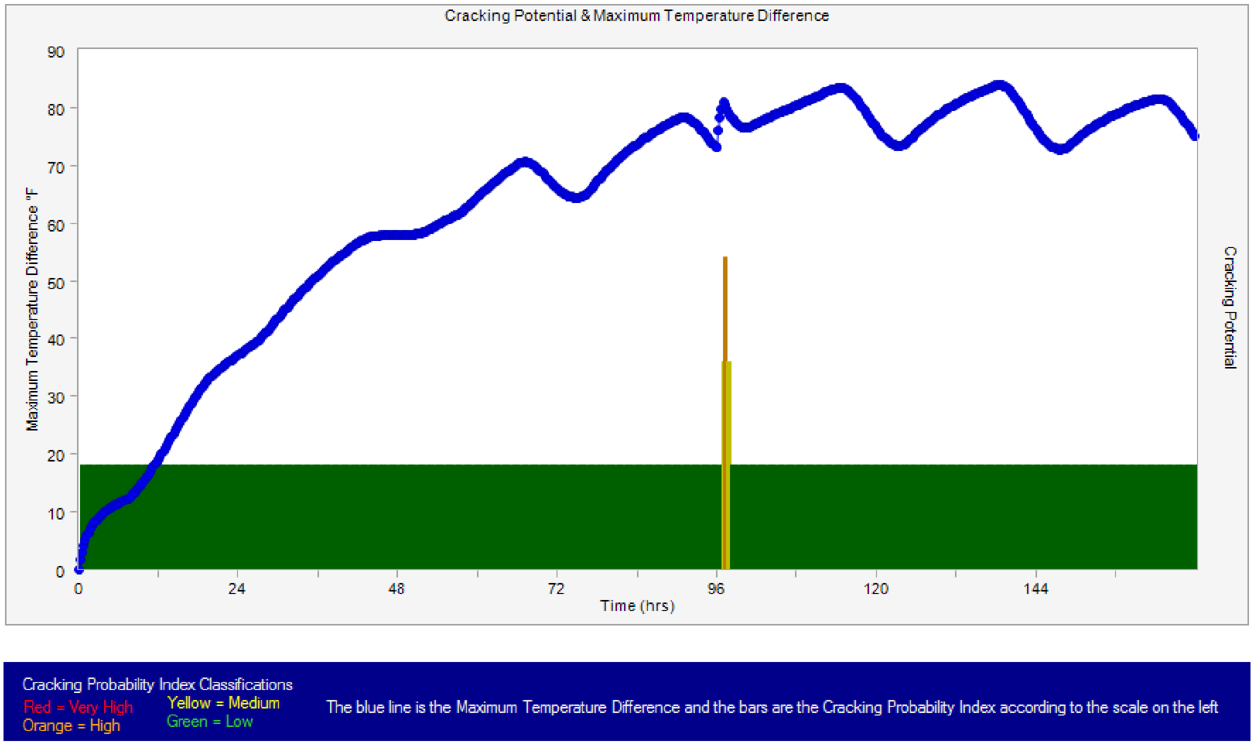
Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
Time (hrs)
Cracking Potential

Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Pier 8 Footing: 77 ft x 39 ft 7 in. x 10.5 ft

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	83	°F
Max Temperature	151	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	

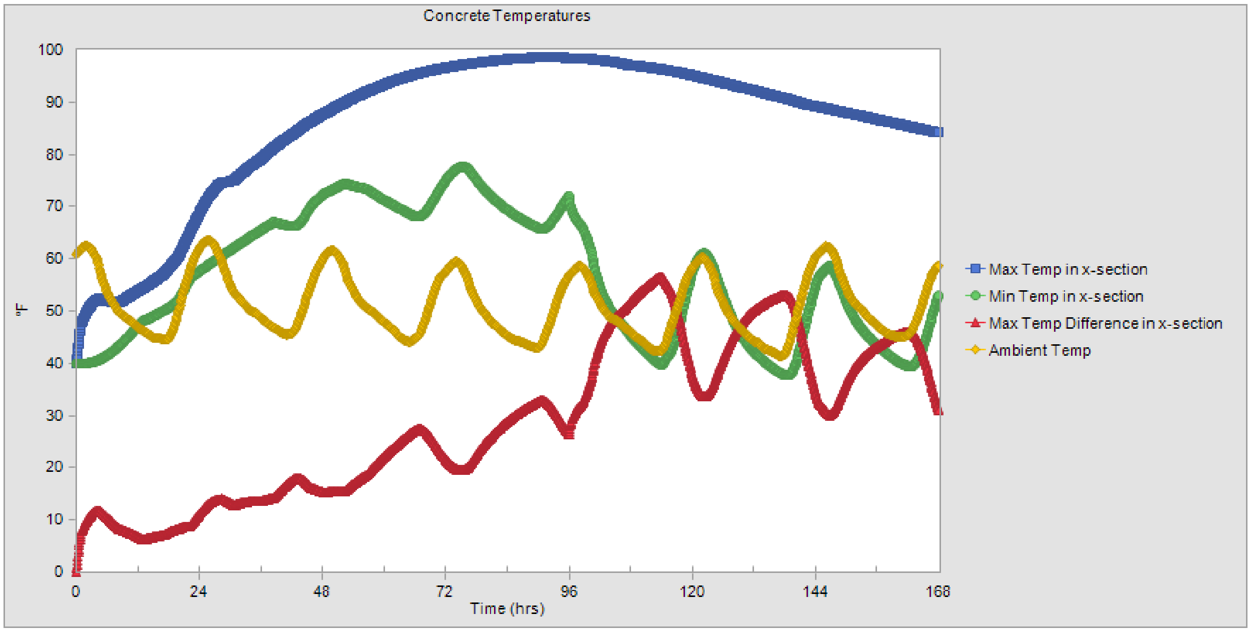


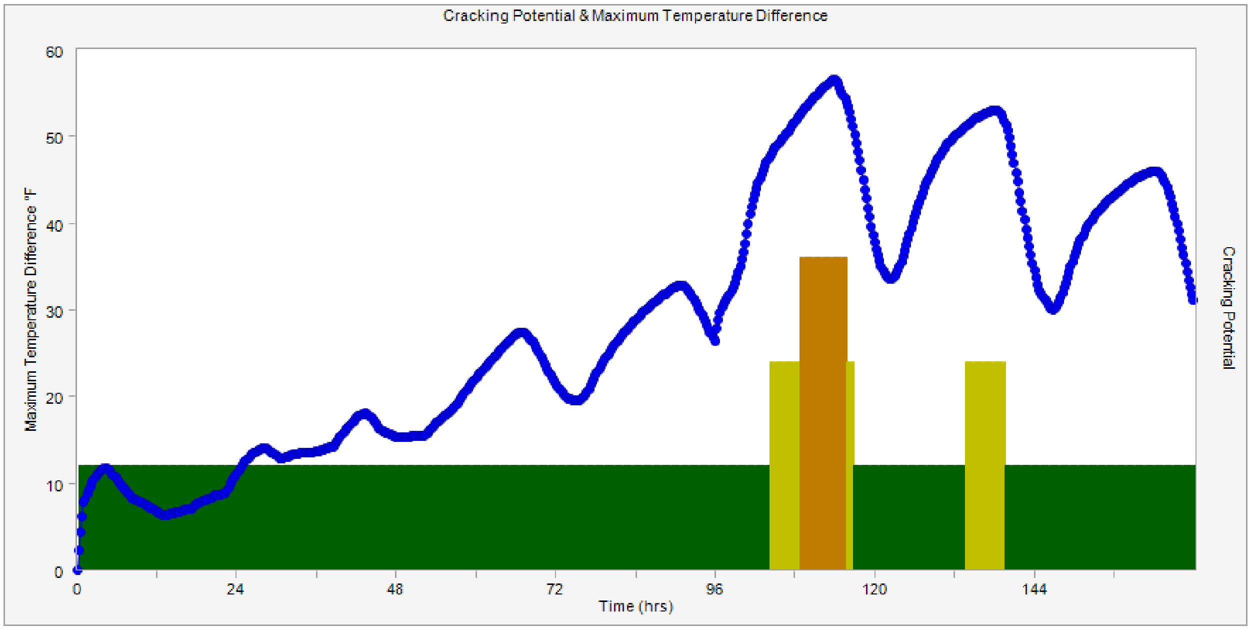

Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
Cracking Potential
Time (hrs)
0
24
48
72
96
120
144
0
10
20
30
40
50
60
70
80
90
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Fresh Placement Temperature

40°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	56	°F
Max Temperature	98	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	



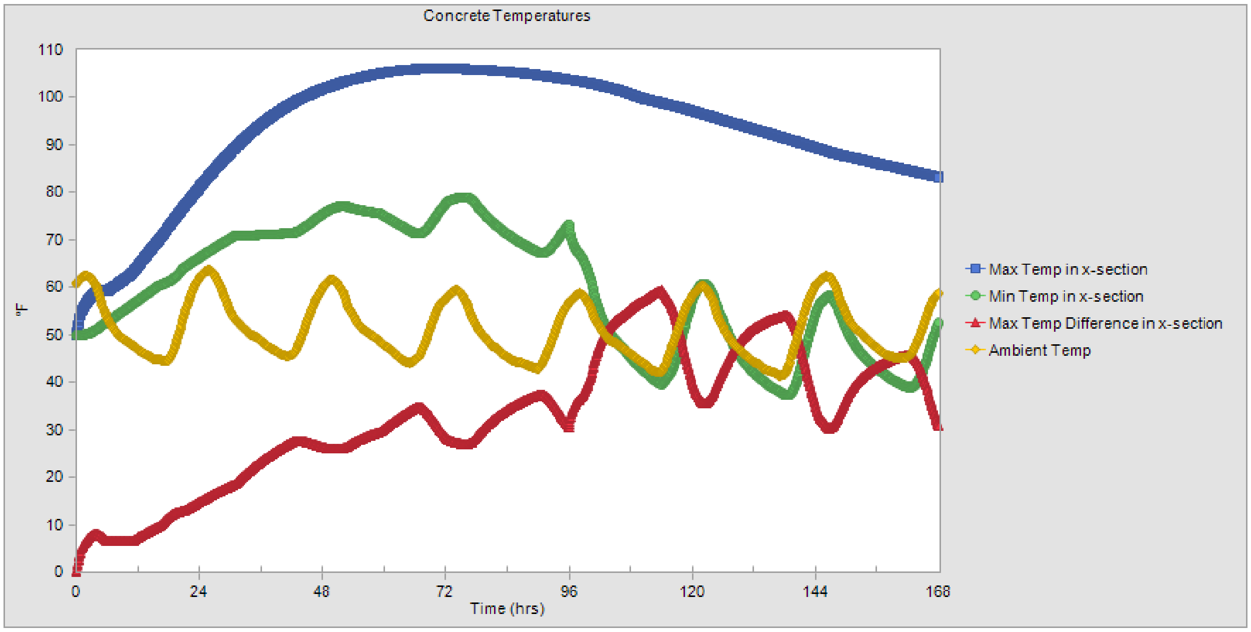


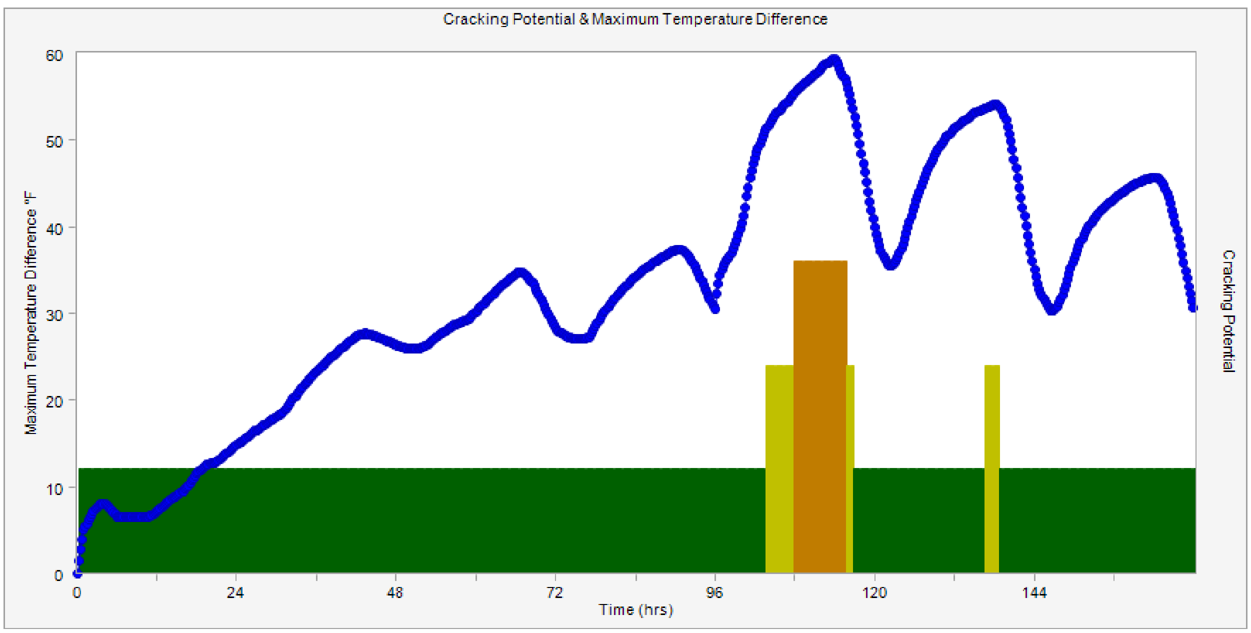
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

50°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	59	°F
Max Temperature	106	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	



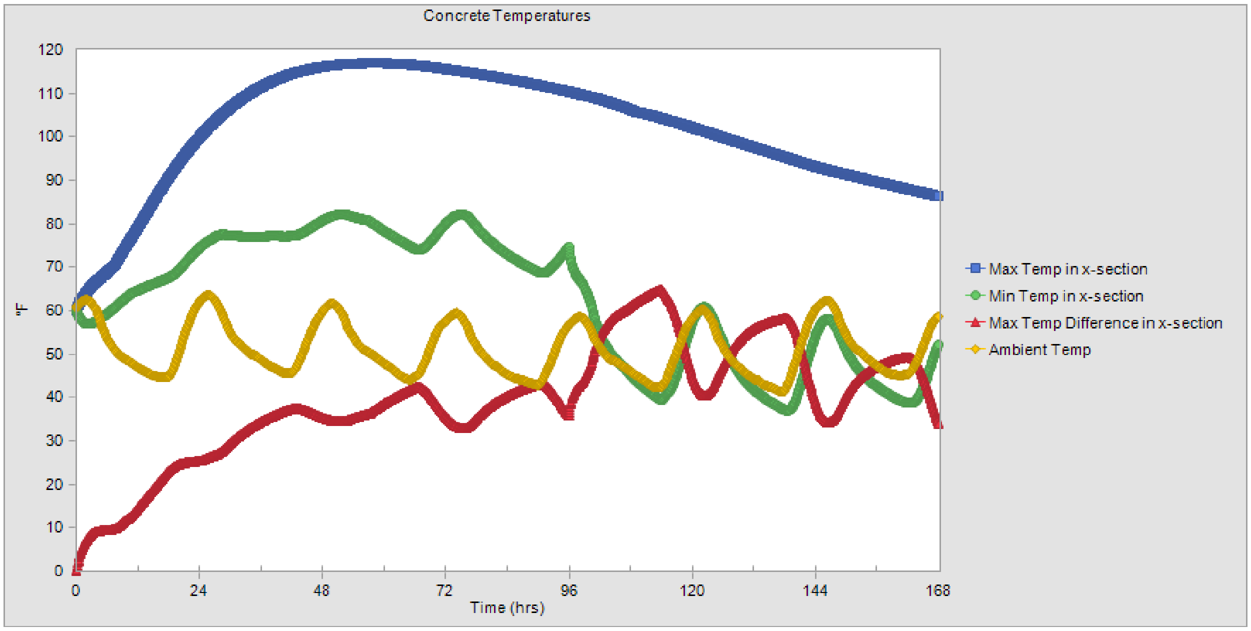


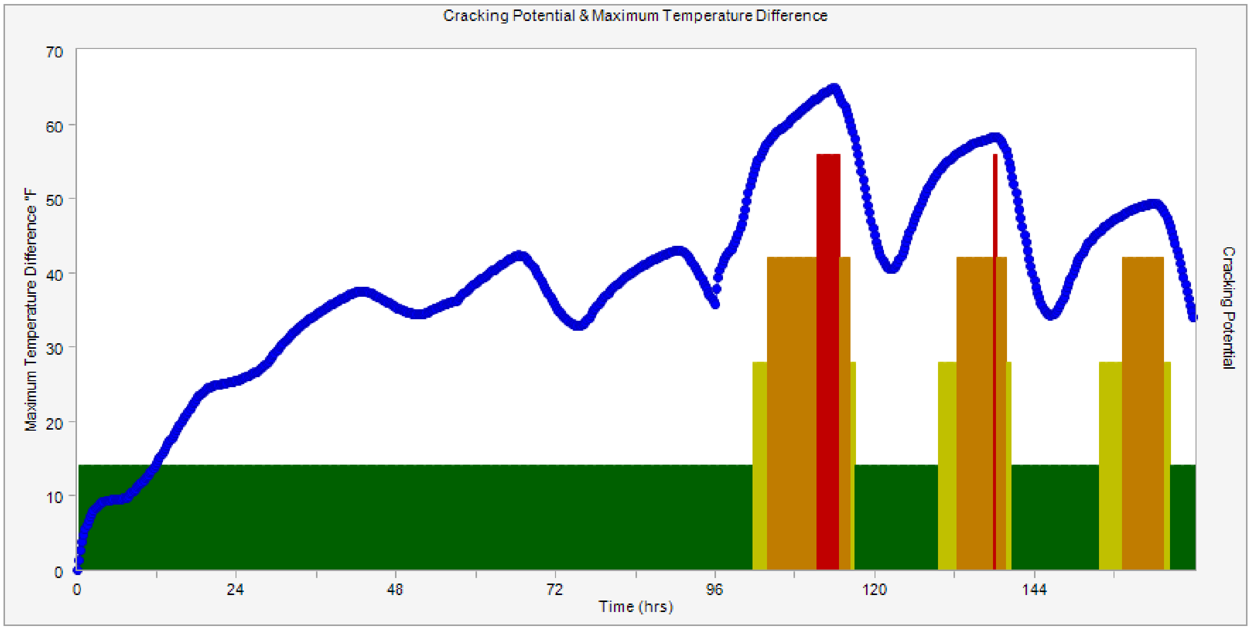
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

60°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	64	°F
Max Temperature	116	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



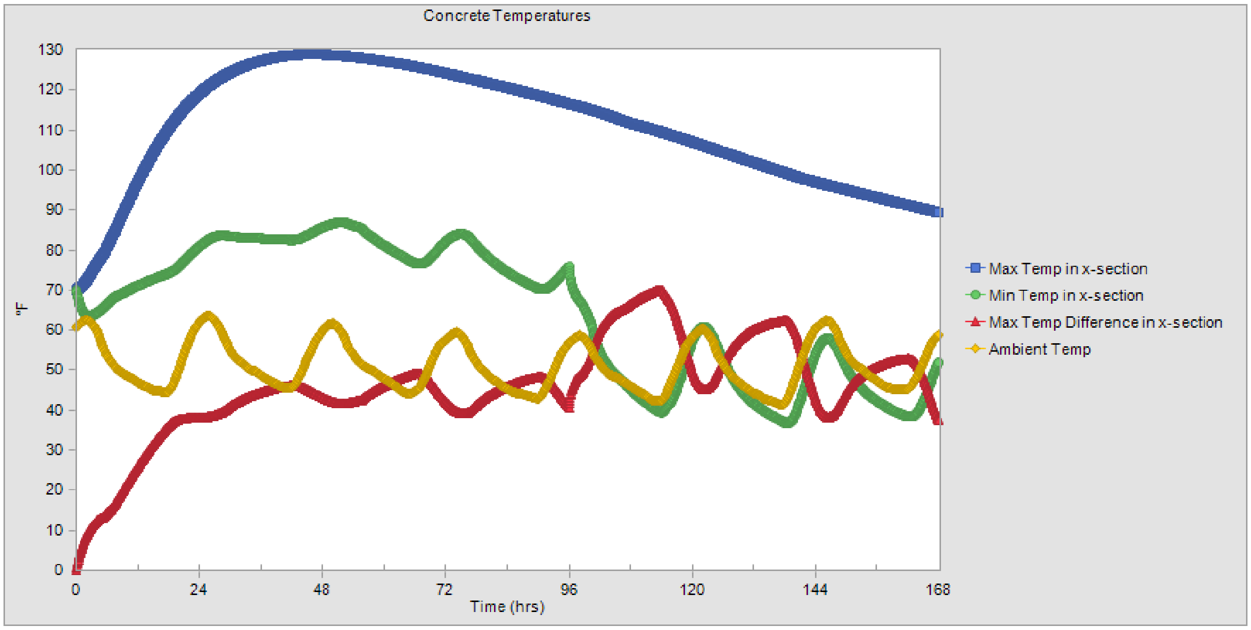


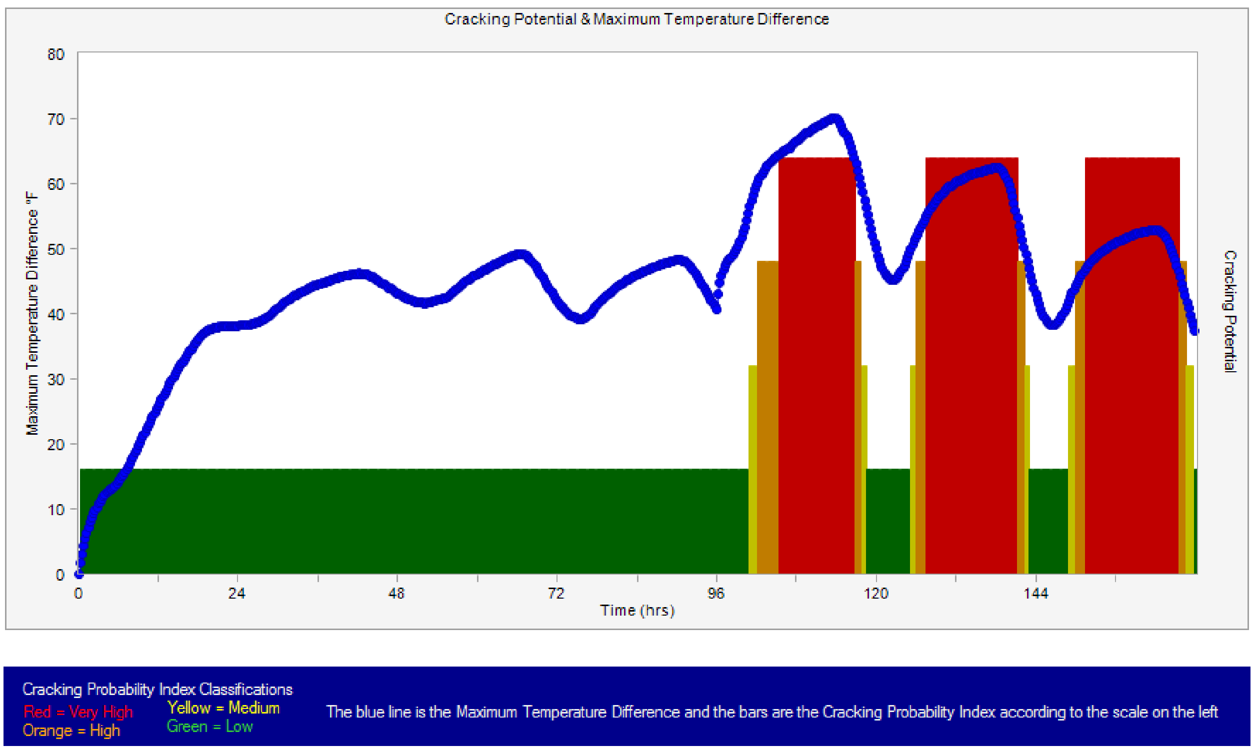
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

70°F Fresh Placement Temperature

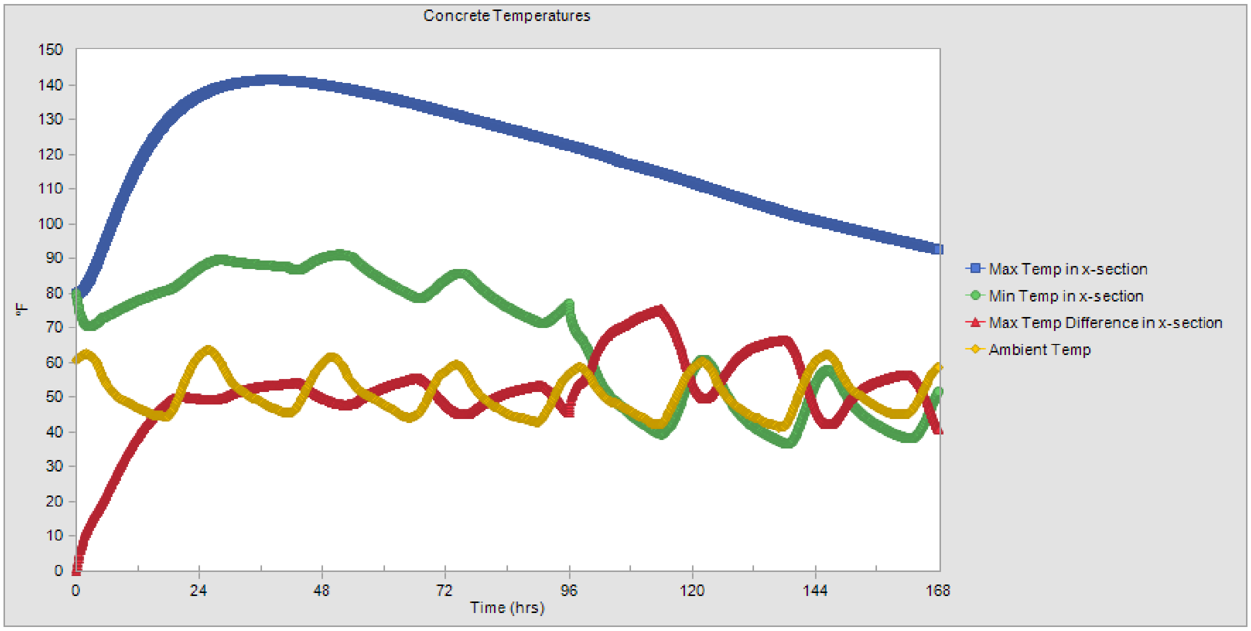
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	70	°F
Max Temperature	128	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

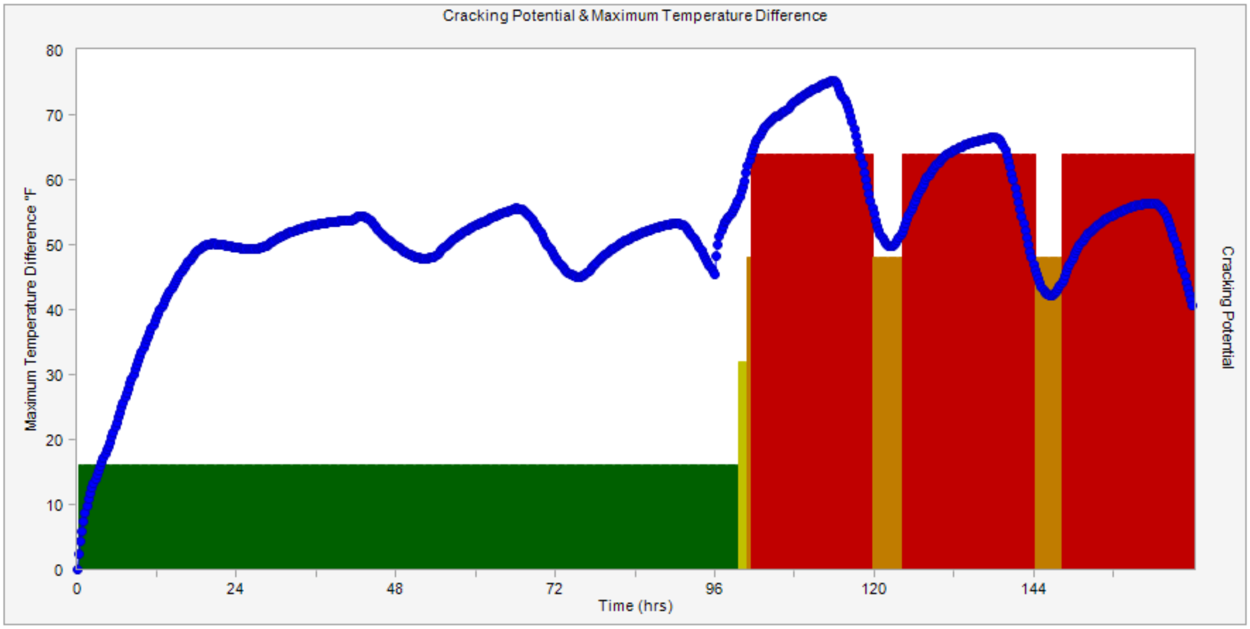

Concrete Temperatures
130
120
110
100
90
80
70
60
50
40
30
20
10
0
°F
0
24
48
72
96
120
144
168
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp


Cracking Potential & Maximum Temperature Difference
80
70
60
50
40
30
20
10
0
Maximum Temperature Difference °F
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

80°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	75	°F
Max Temperature	141	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



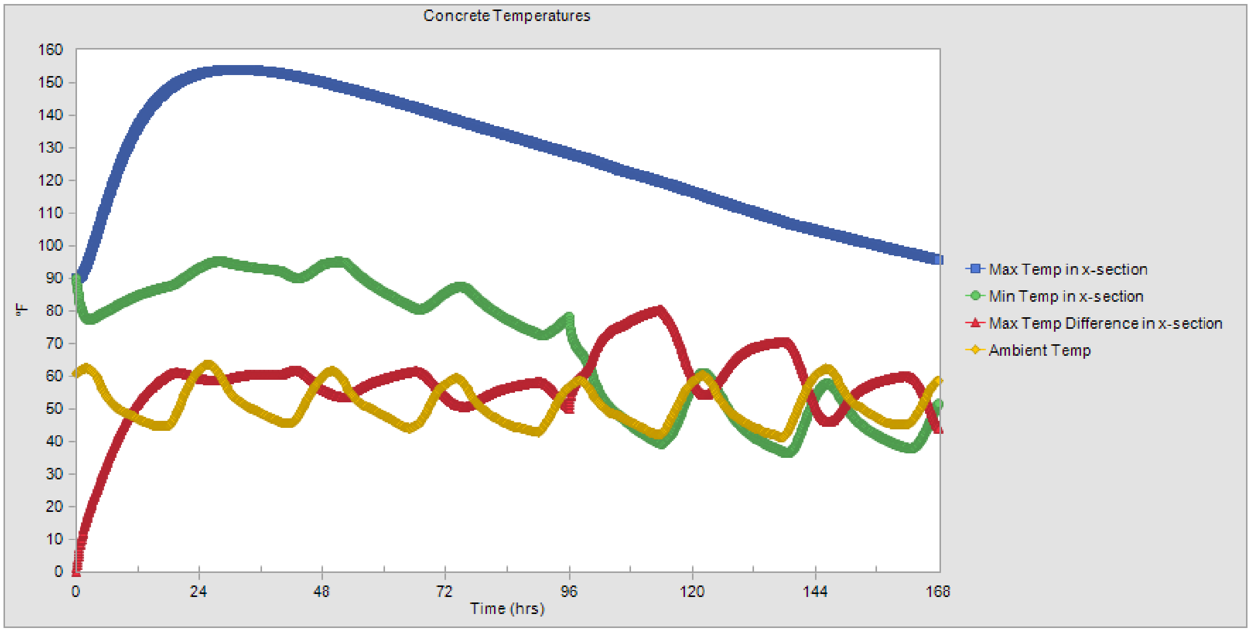


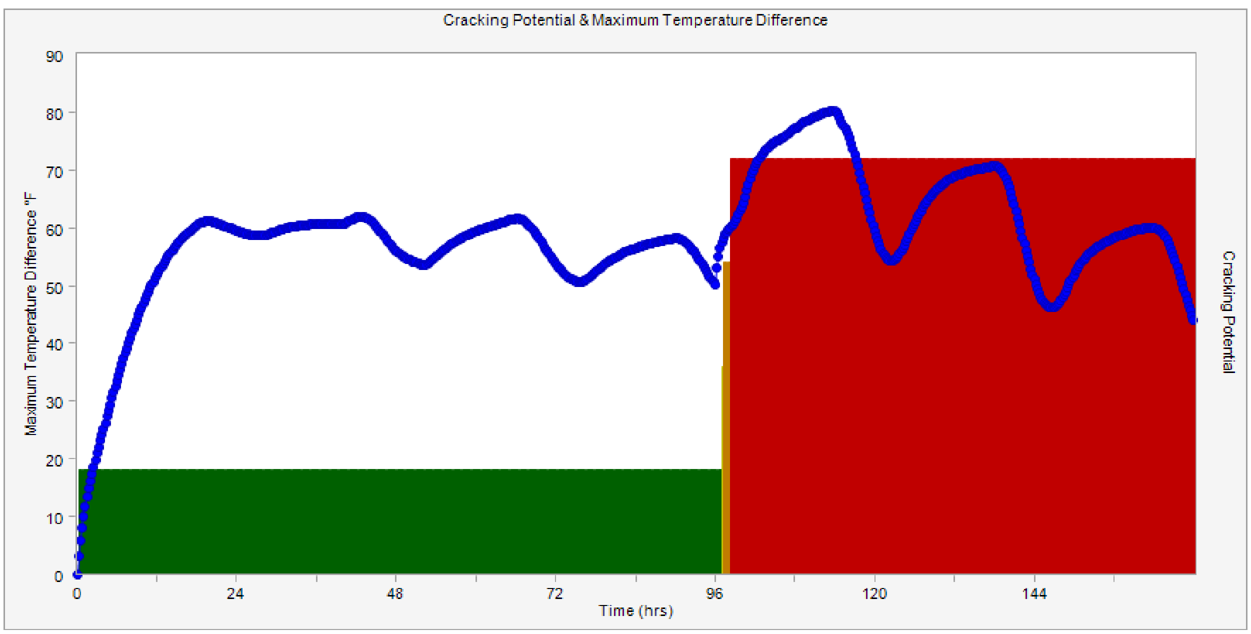
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

90°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	80	°F
Max Temperature	154	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	





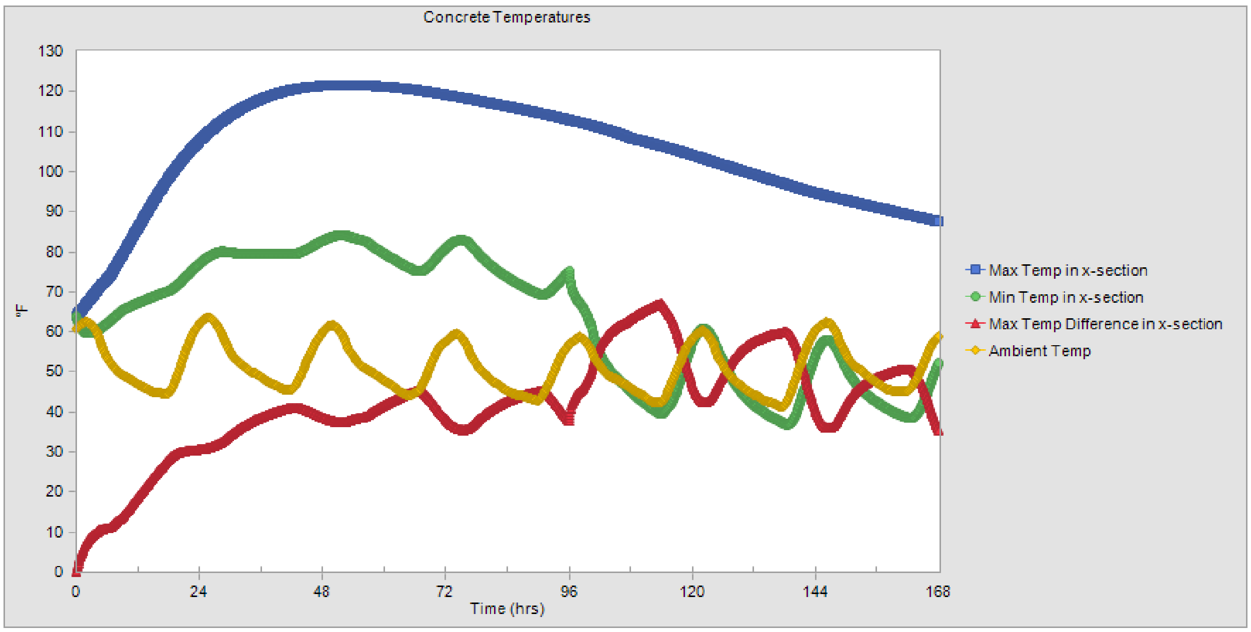
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

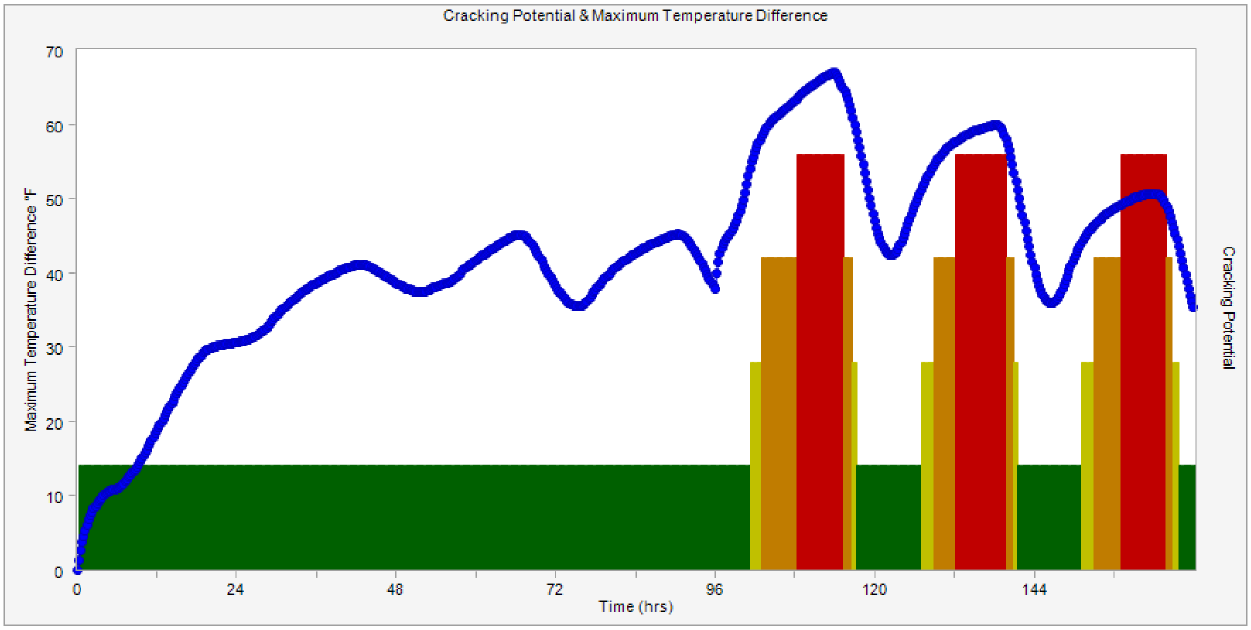
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Curing Method

No Curing Method

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	66	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



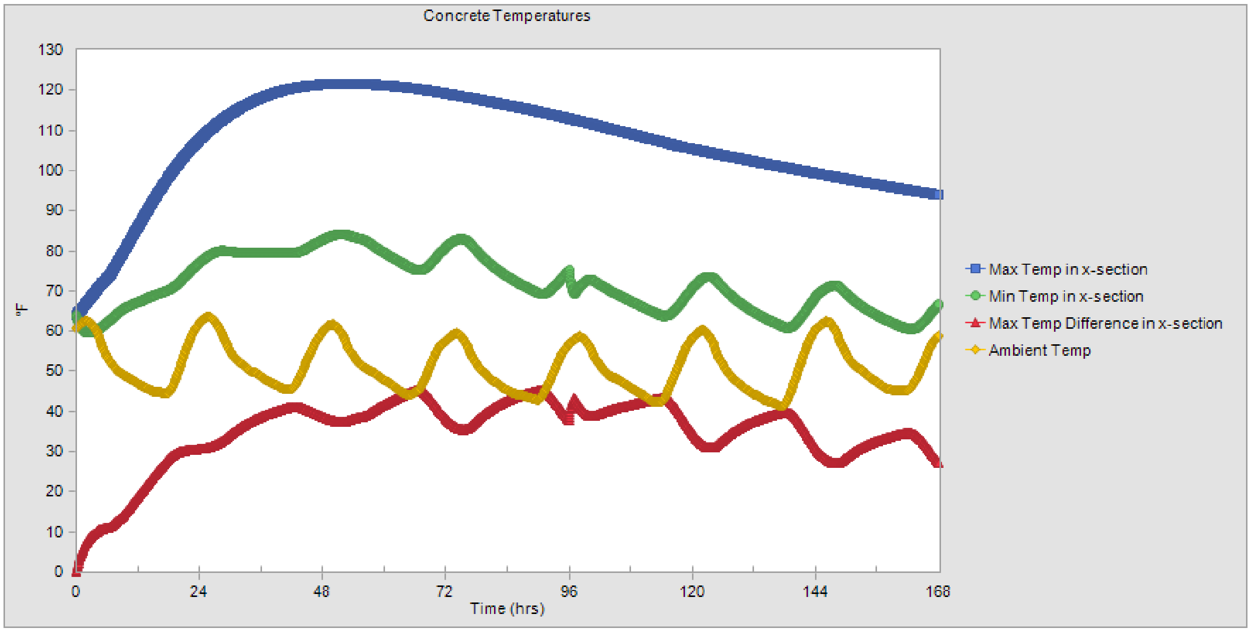


Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

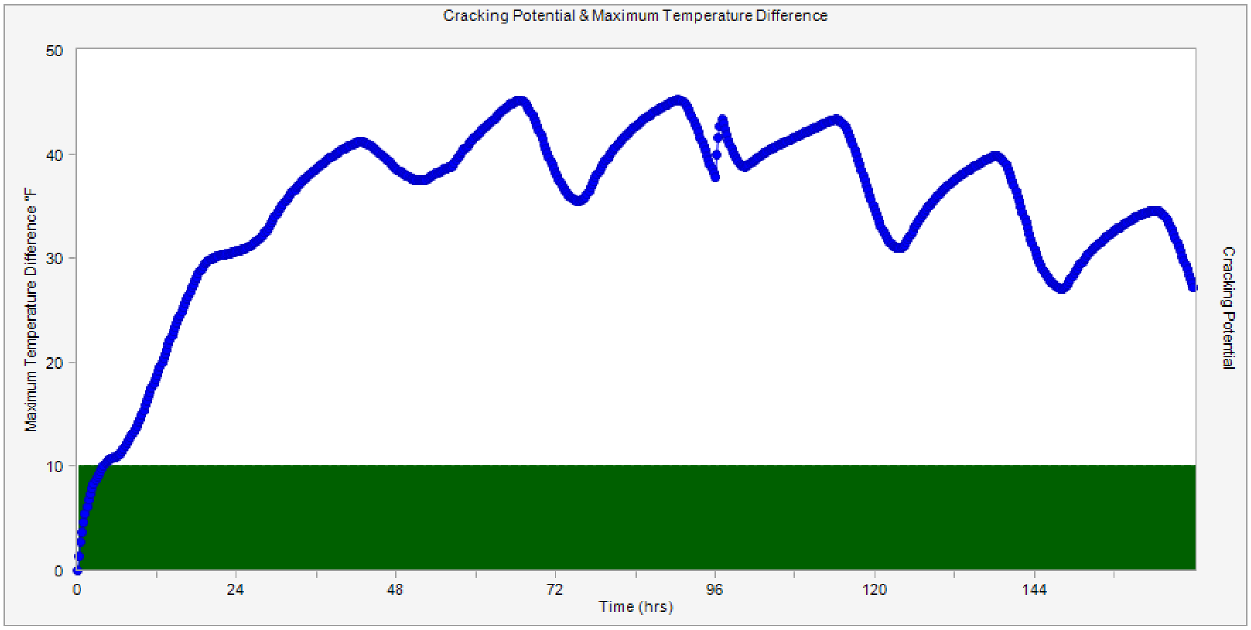
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Wet Curing Blanket

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	45	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	



Concrete Temperatures
130
120
110
100
90
80
70
60
50
40
30
20
10
0
°F
0
24
48
72
96
120
144
168
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp

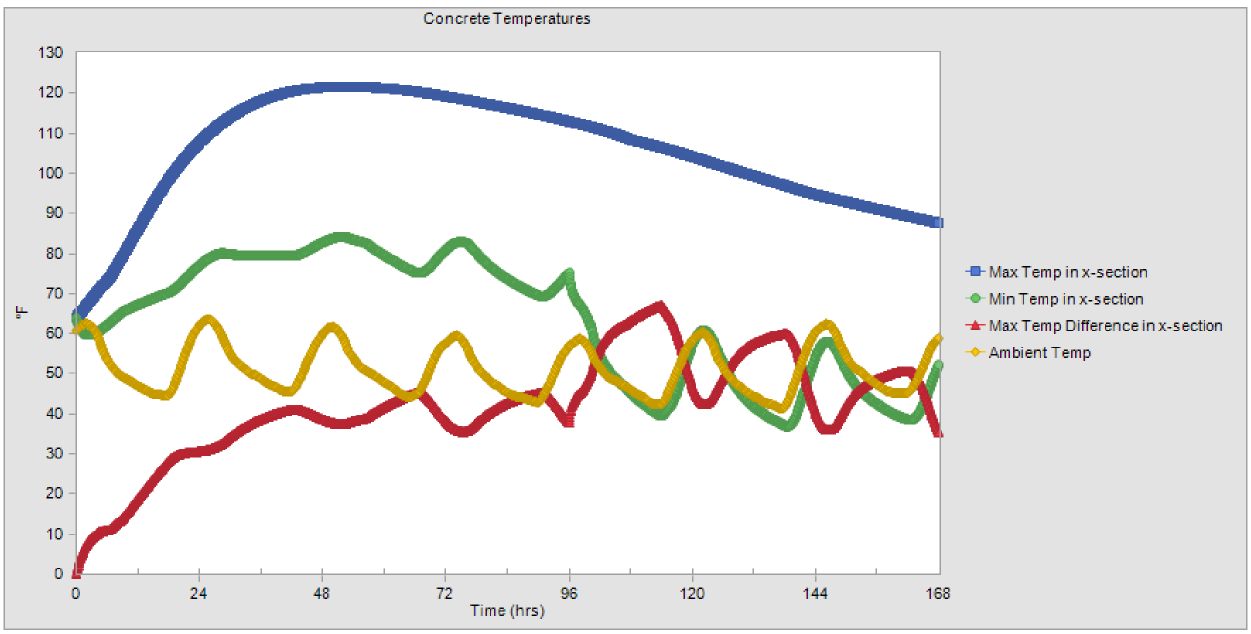


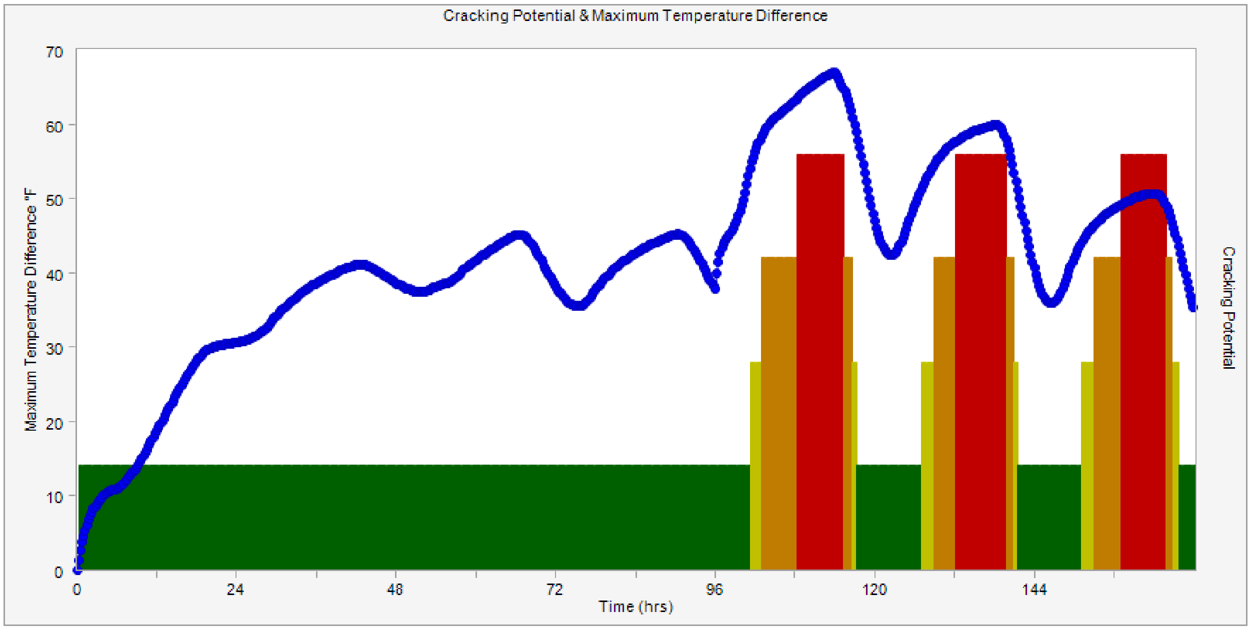
Cracking Potential & Maximum Temperature Difference
50
40
30
20
10
0
Maximum Temperature Difference °F
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential

Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

White Curing Compound

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	66	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



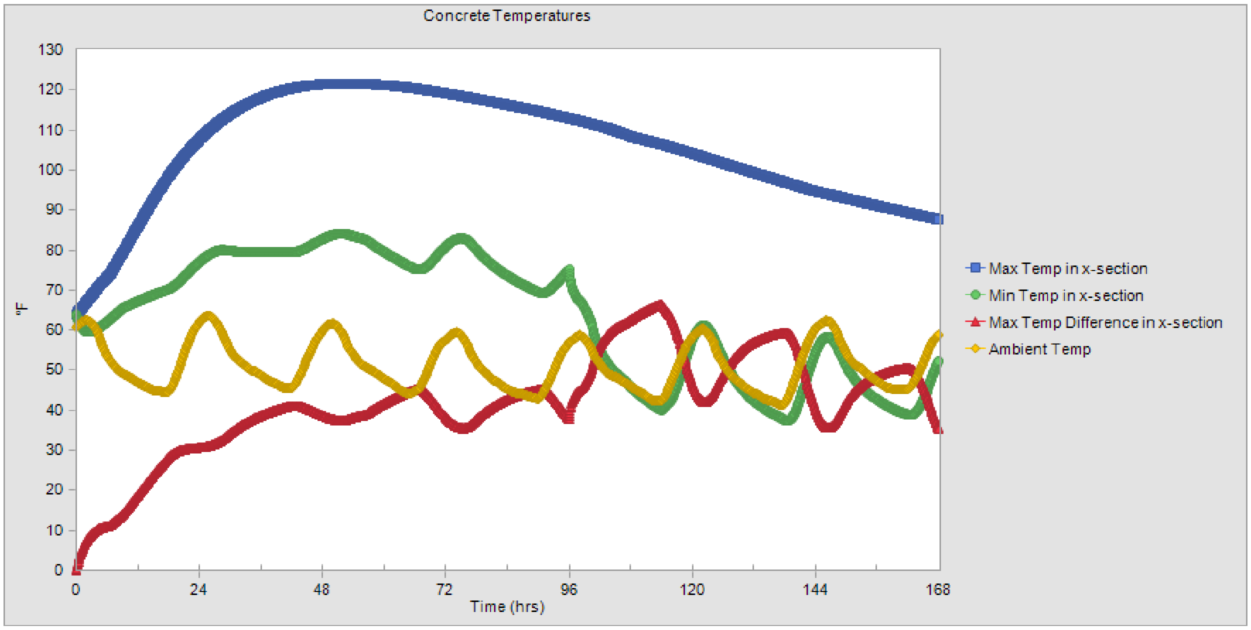


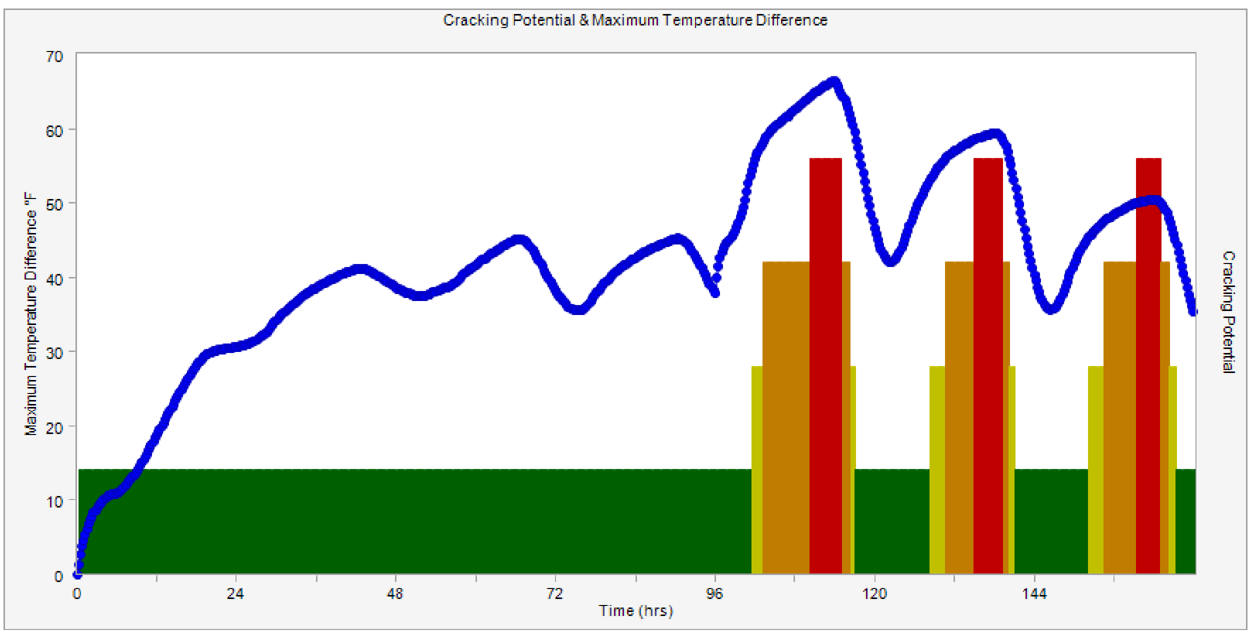
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Black Plastic

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	66	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



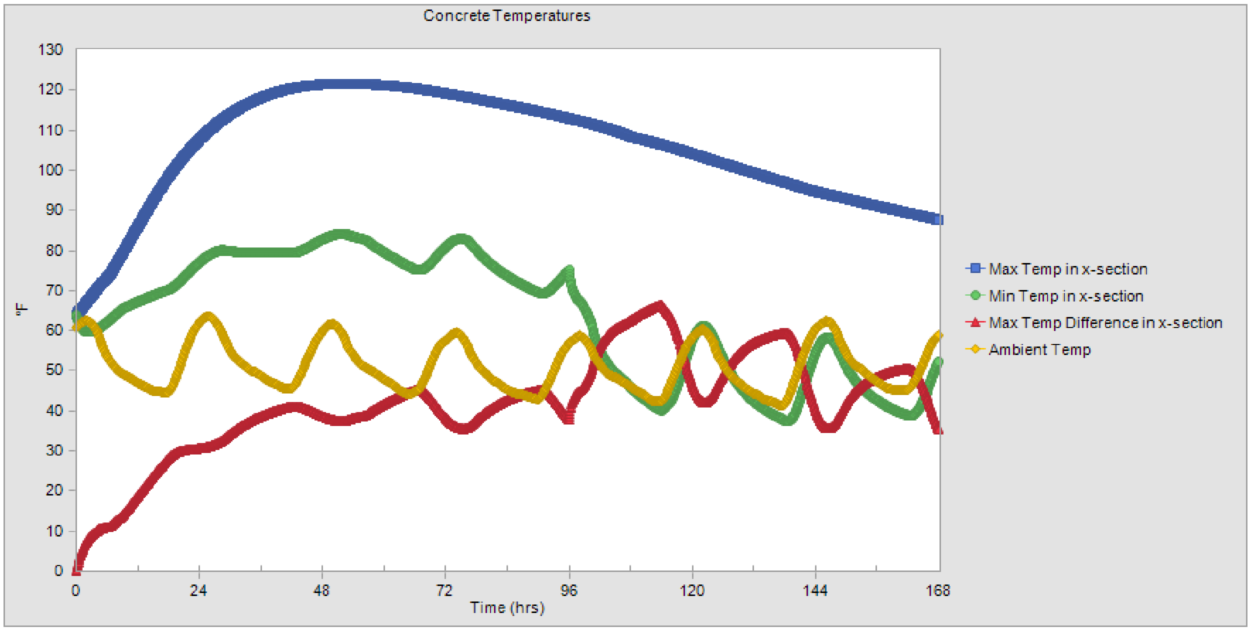


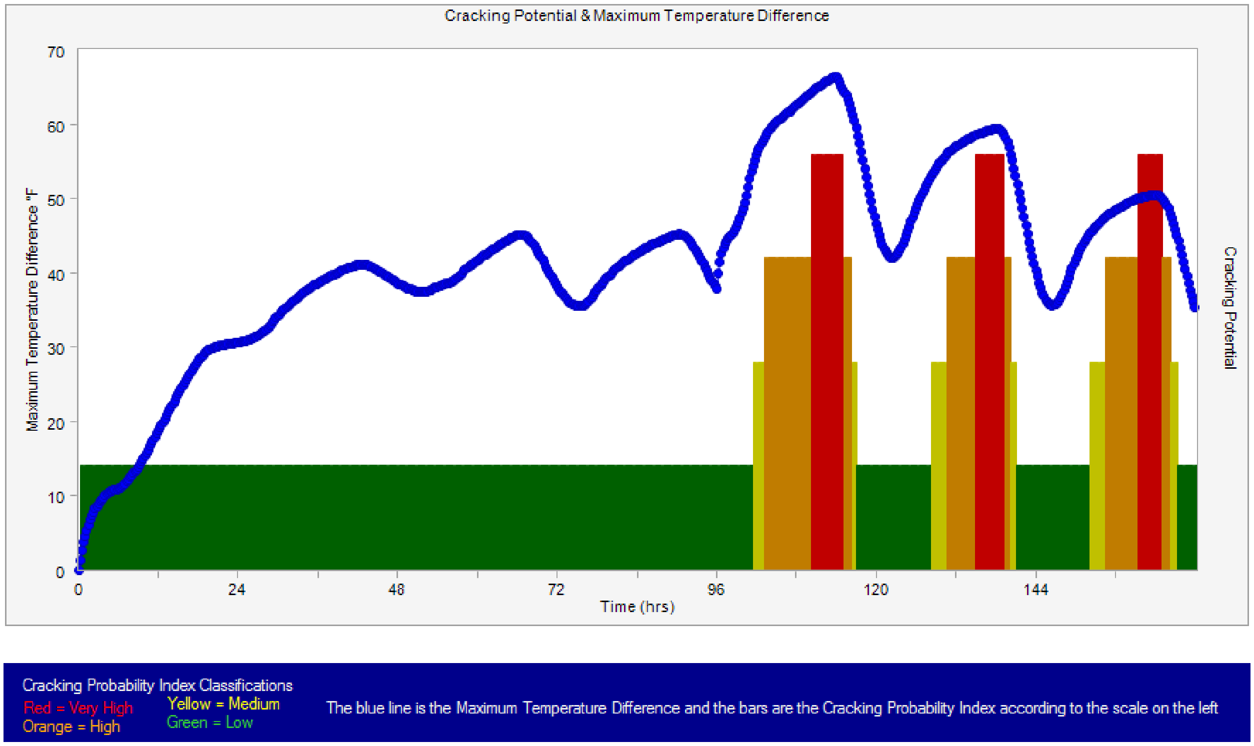
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Clear Plastic

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	66	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



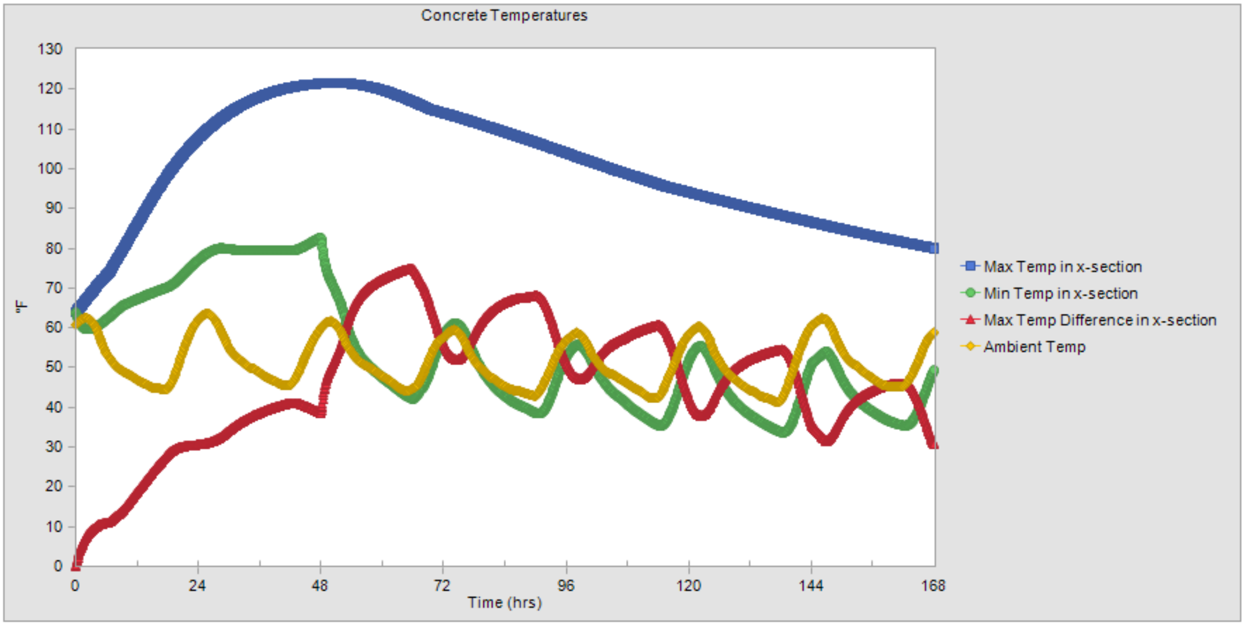


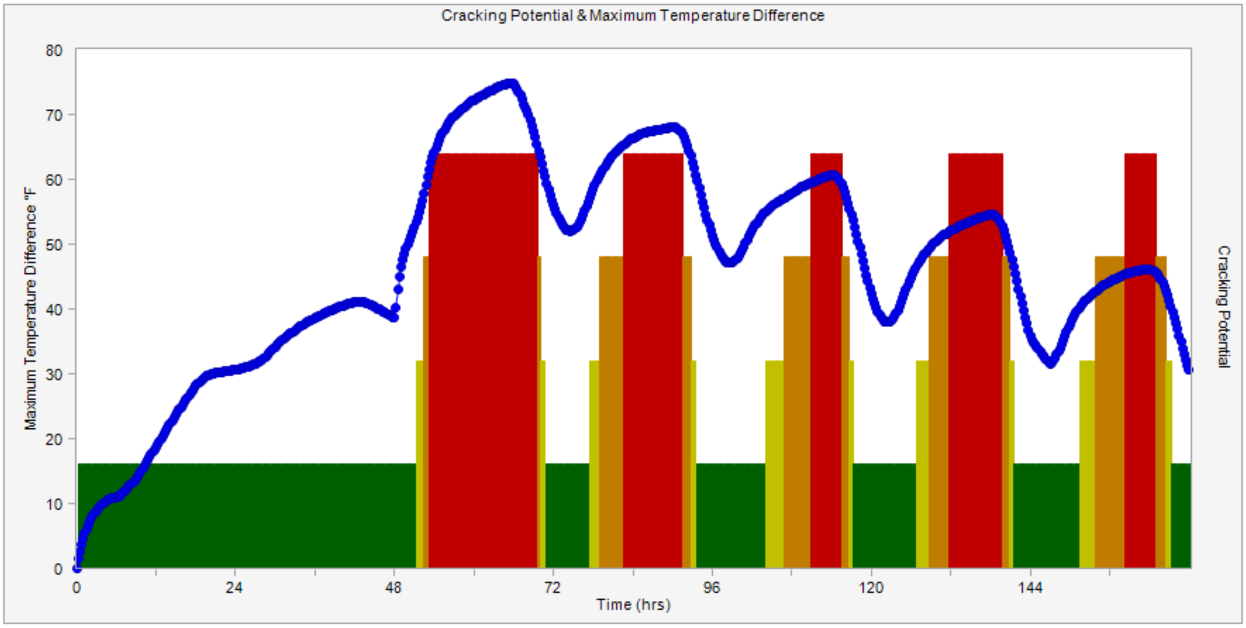
Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Form Removal Time

48 Hours

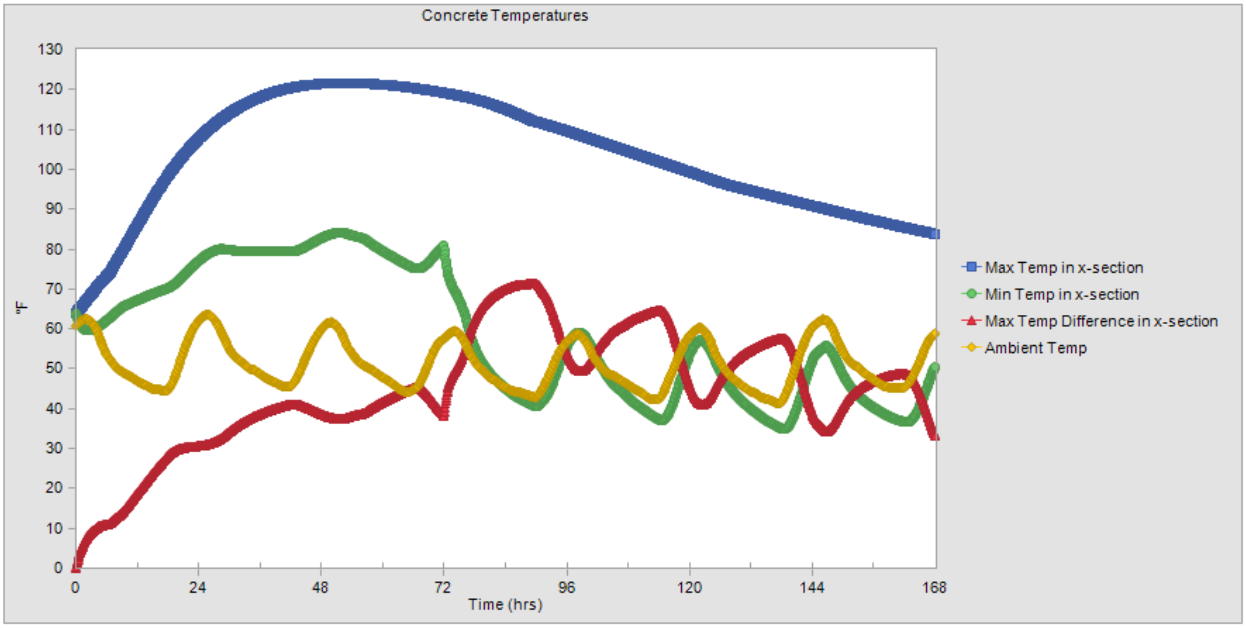
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	74	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

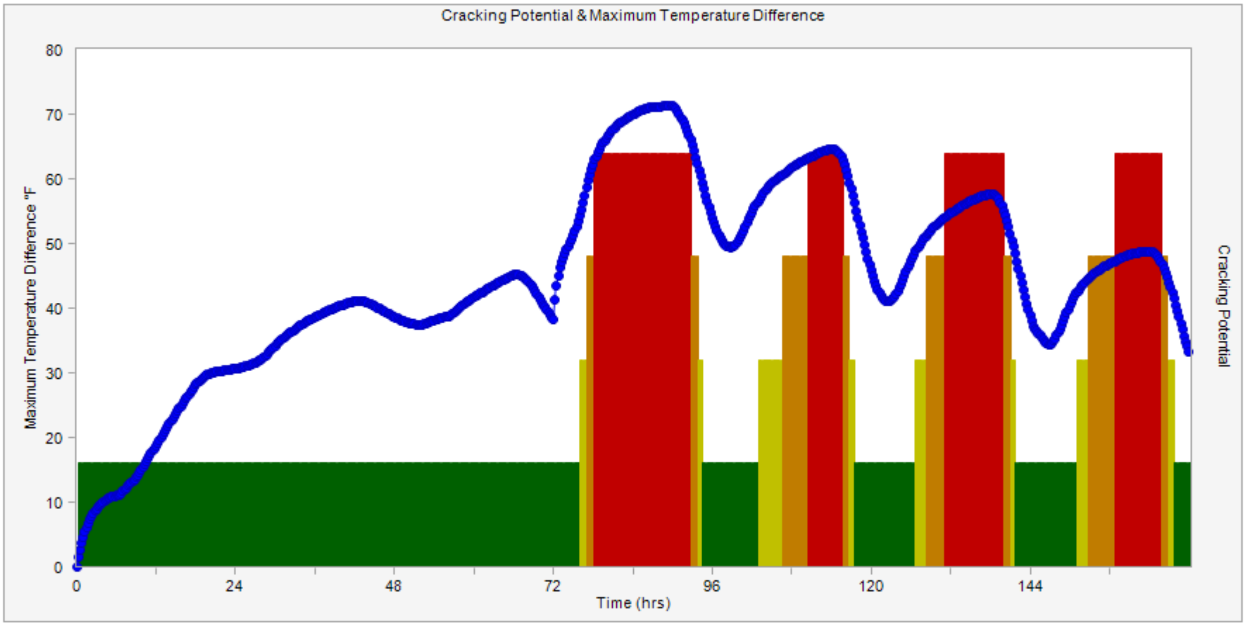




72 Hours

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	71	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

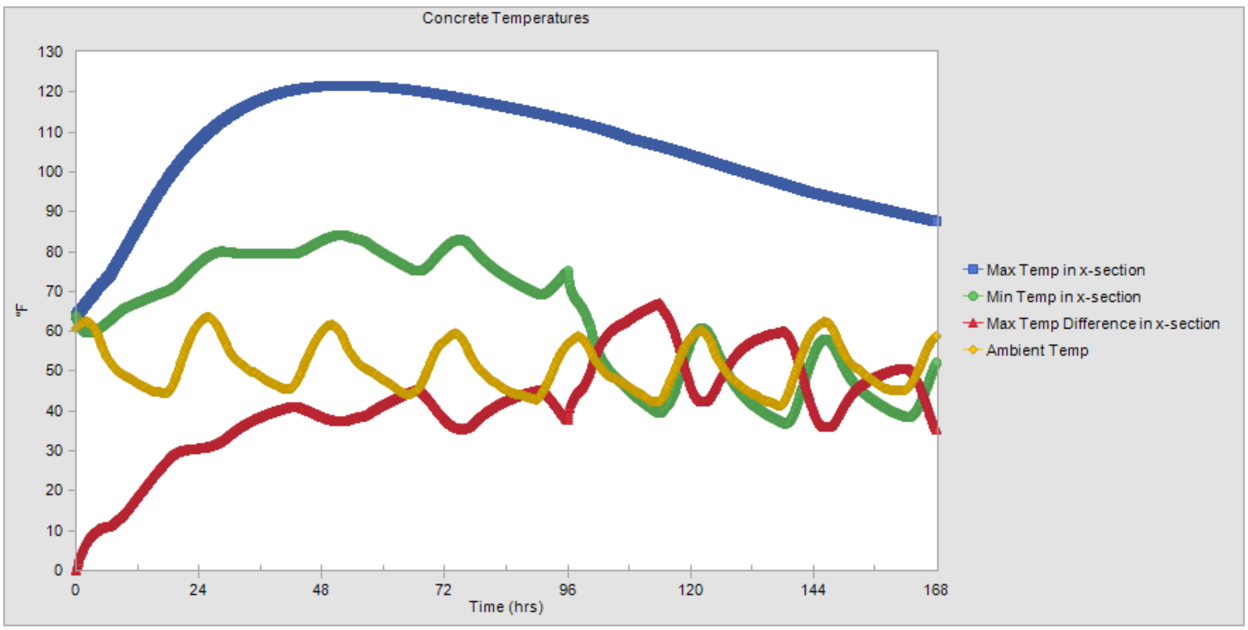

Concrete Temperatures
°F
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp

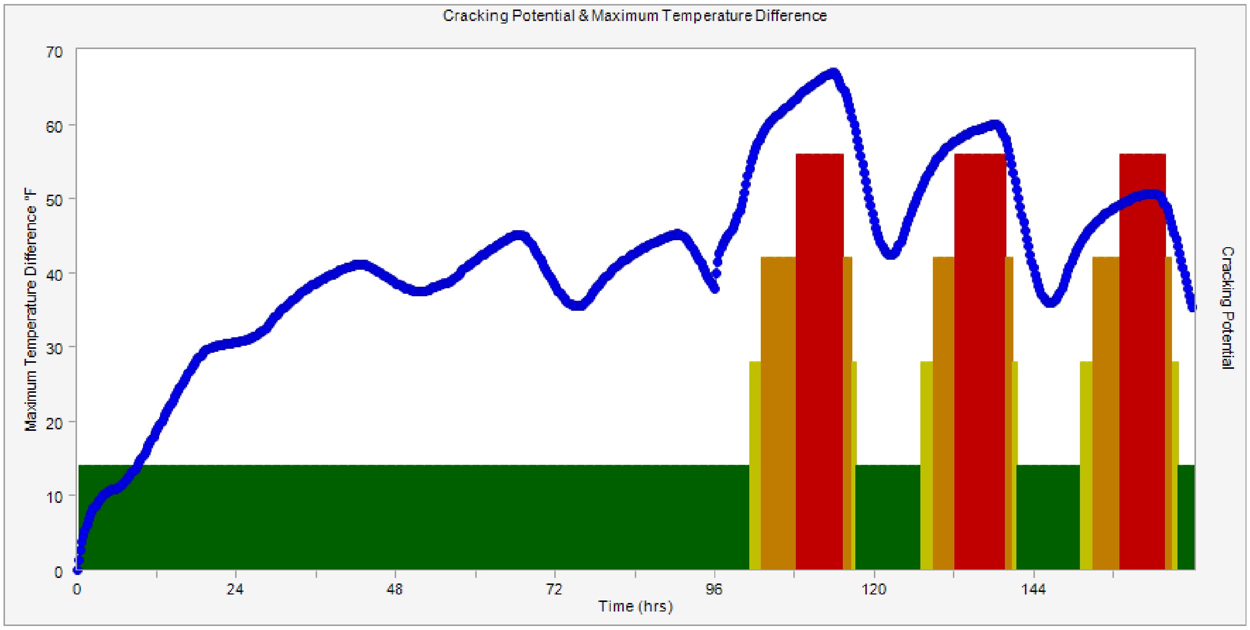

Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential


Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

96 Hours

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	66	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



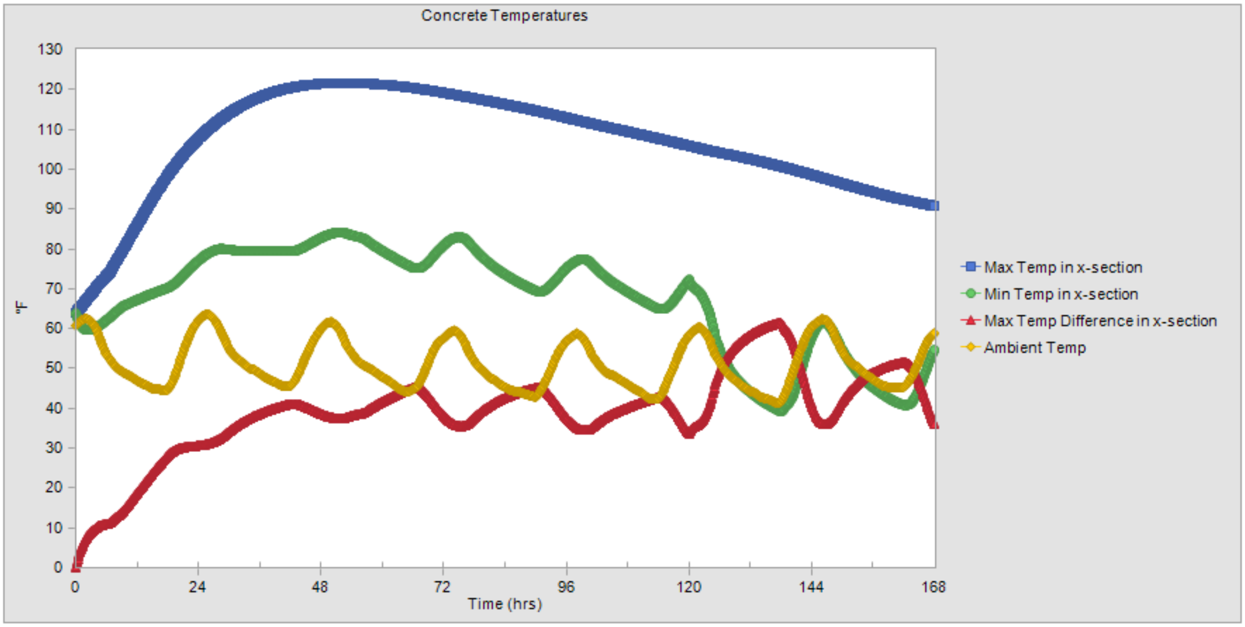


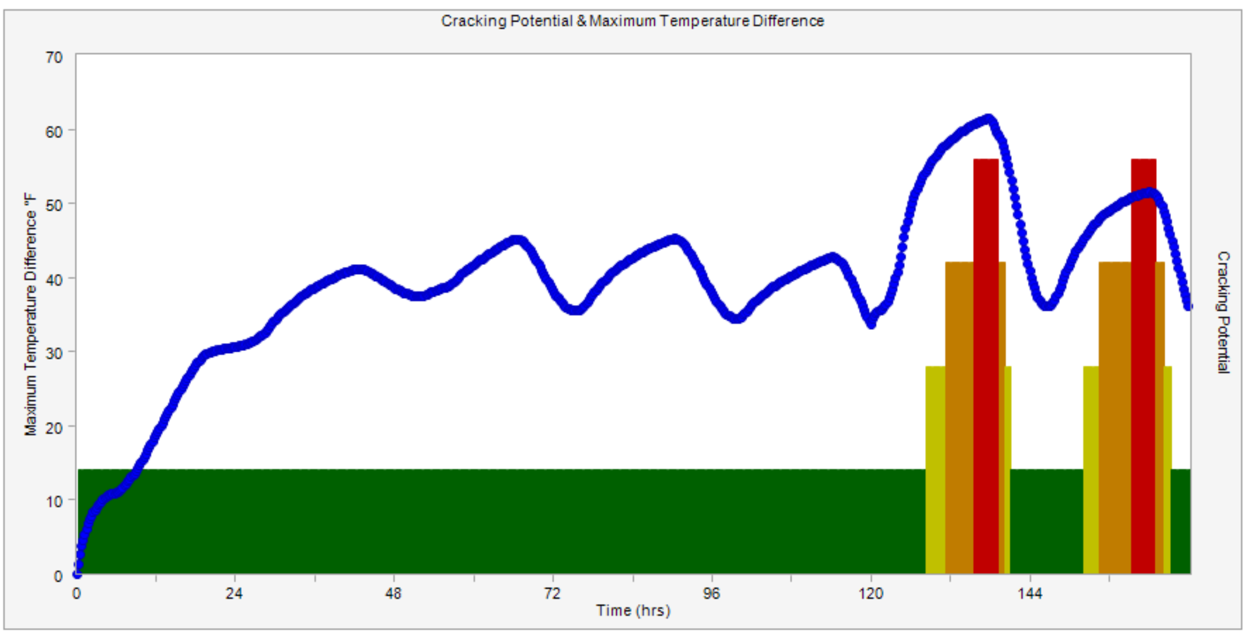
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

120 Hours

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	61	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



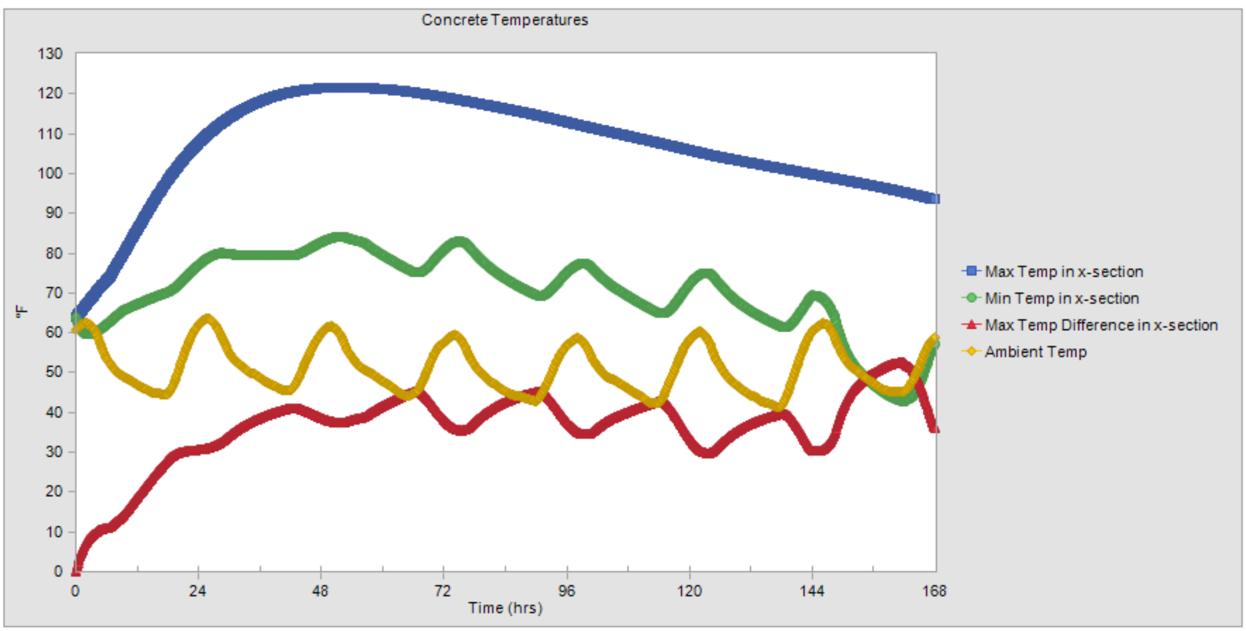


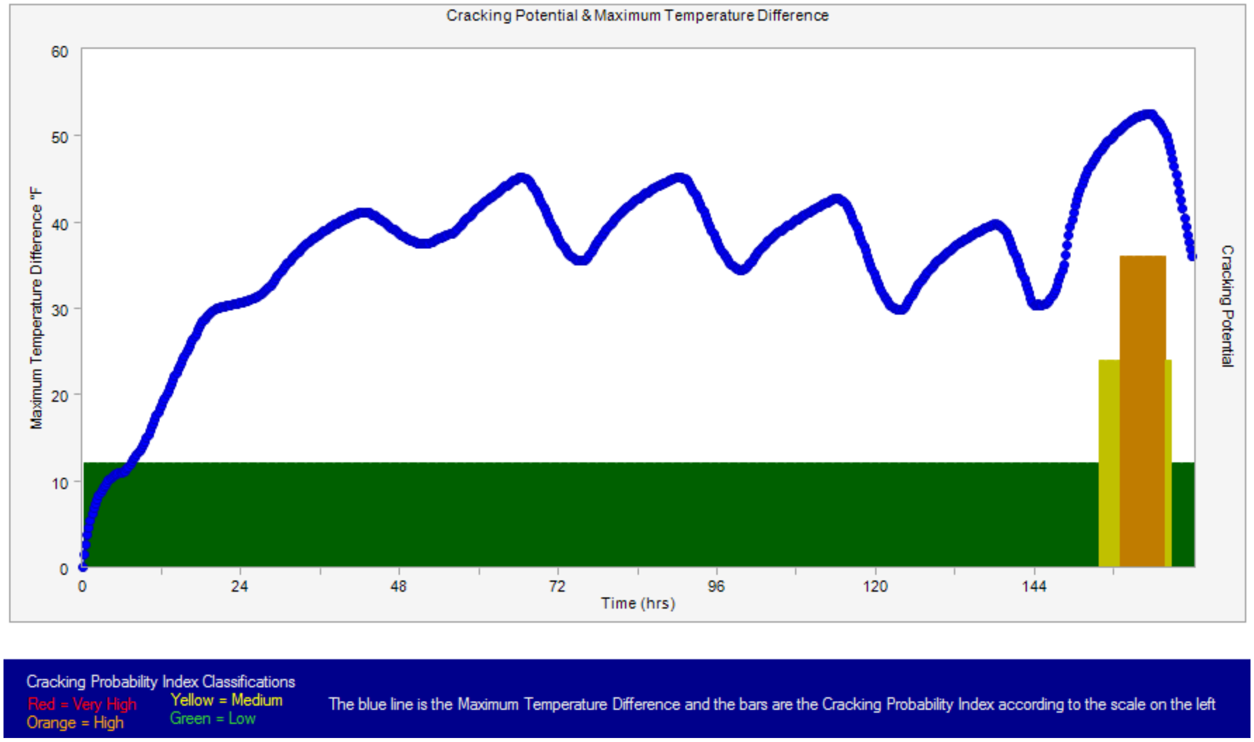
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

144 Hours

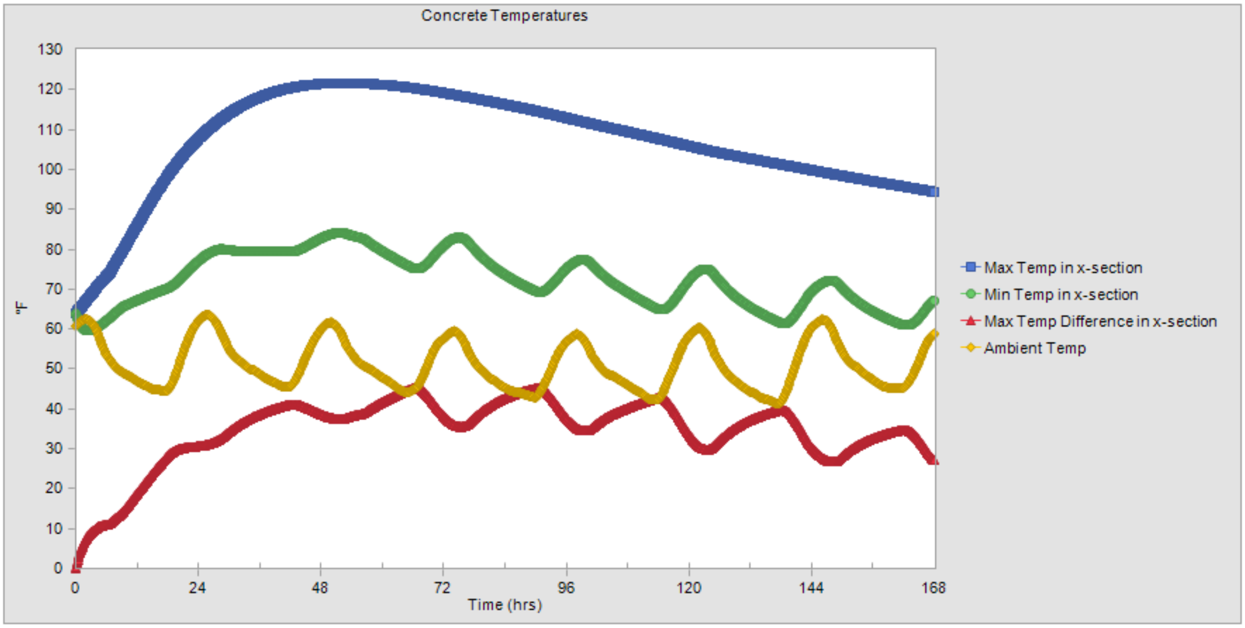
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	52	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	

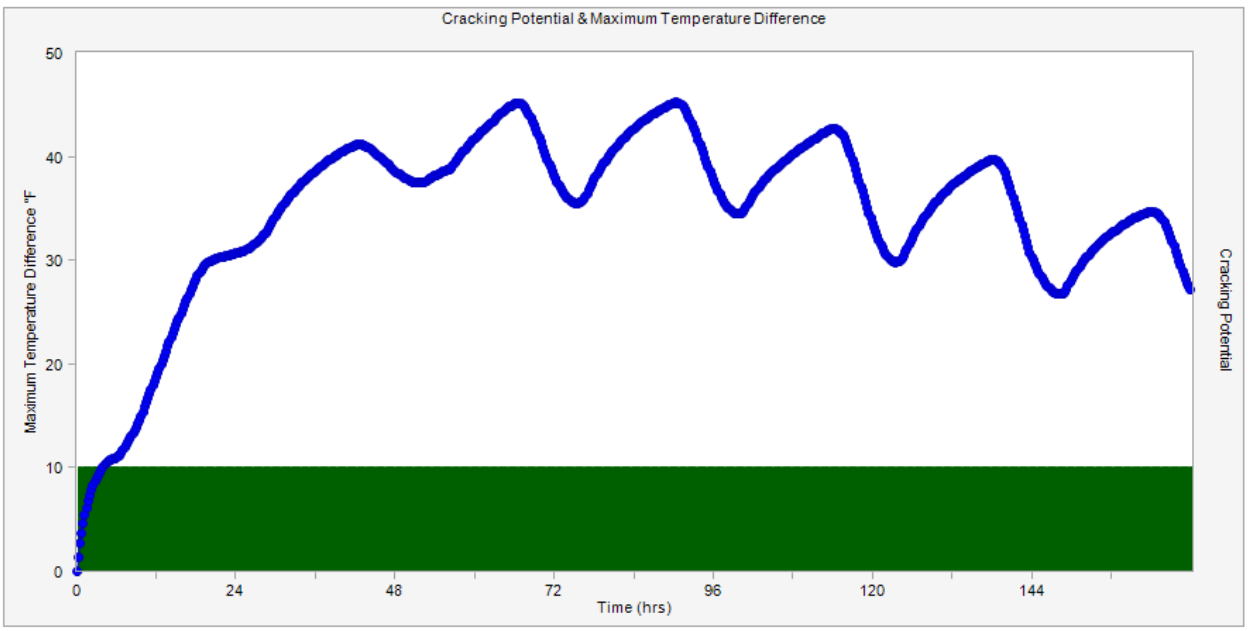


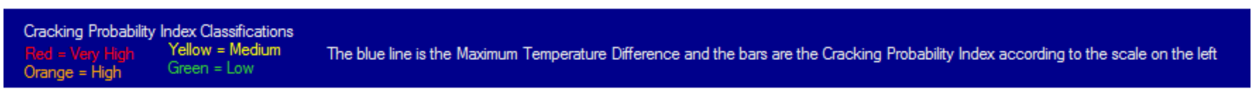


168 Hours

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	45	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	


Concrete Temperatures
°F
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168

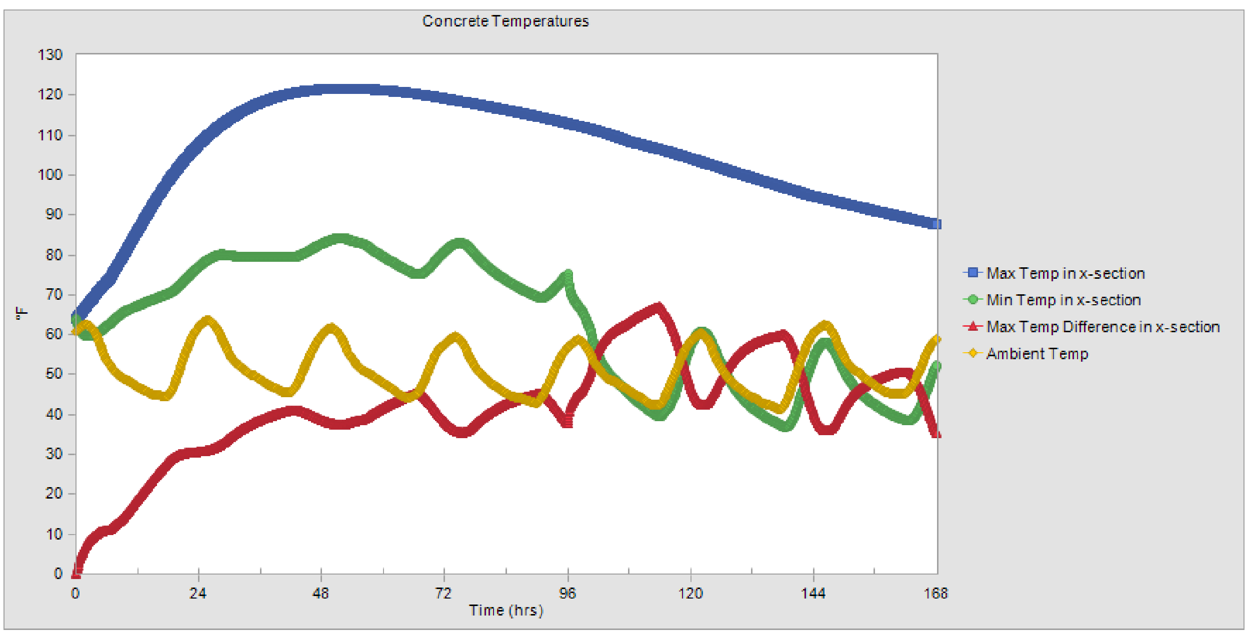

Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
Cracking Potential
Time (hrs)
50
40
30
20
10
0
0
24
48
72
96
120
144

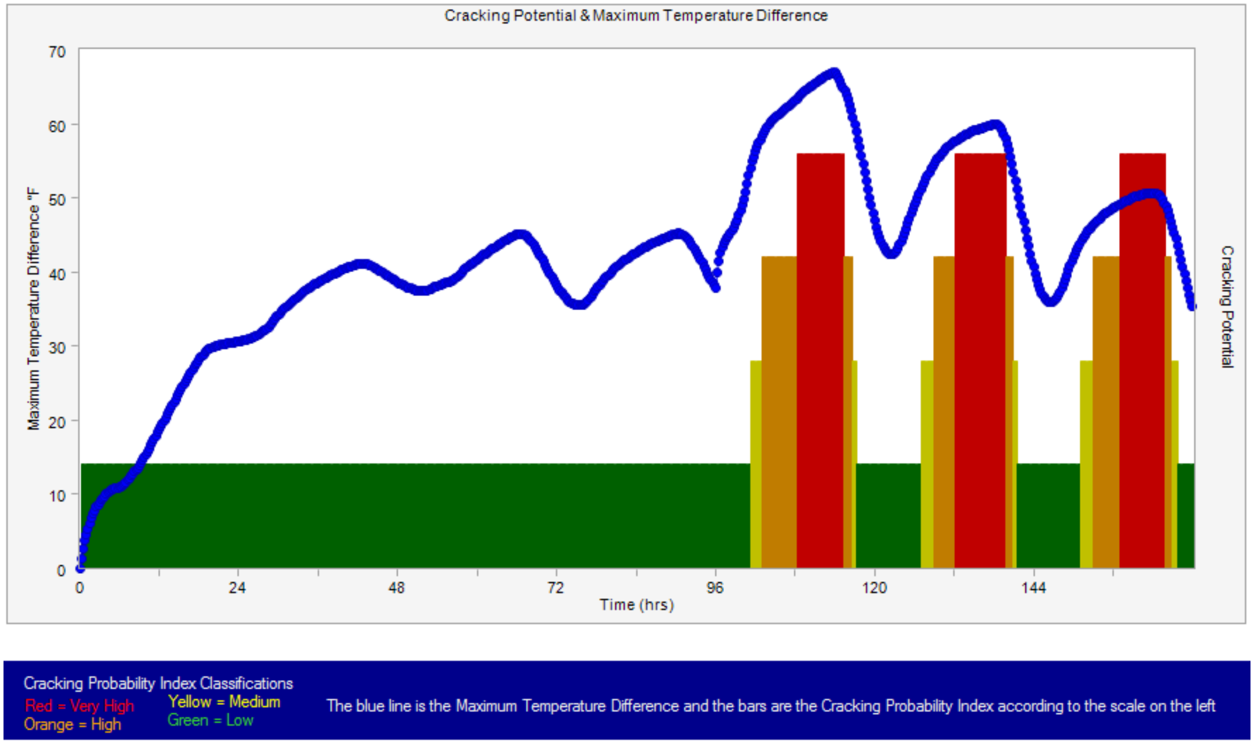

Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Forming Method—Three-Day Form Removal Time

Wood

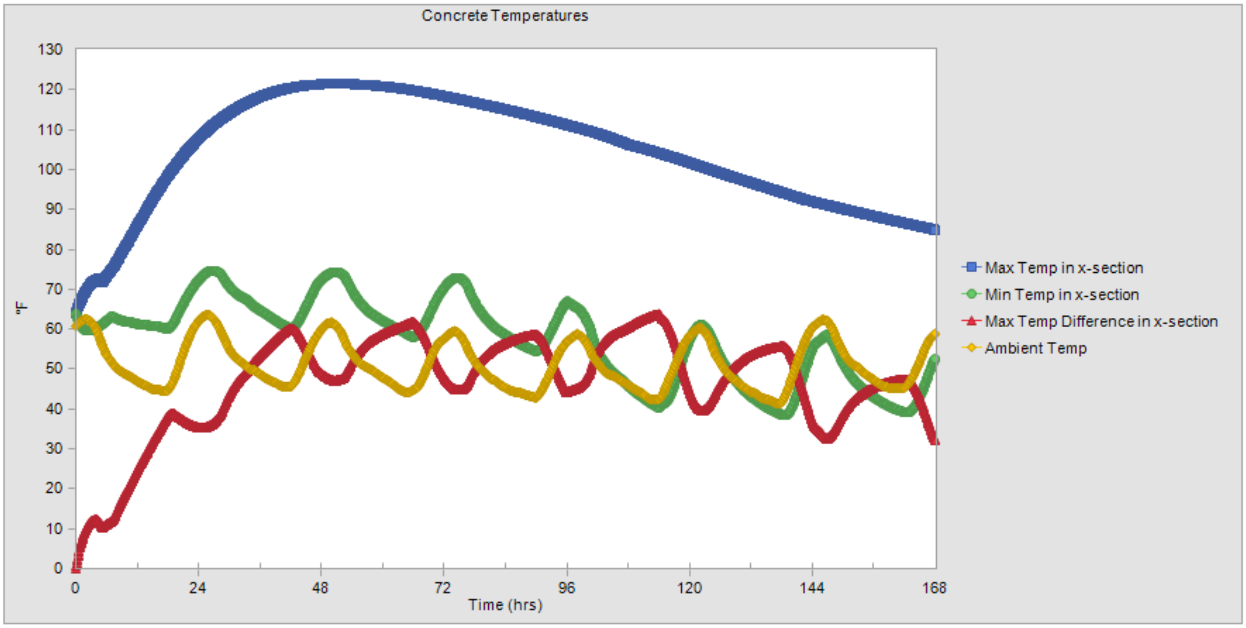
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	66	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	269	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

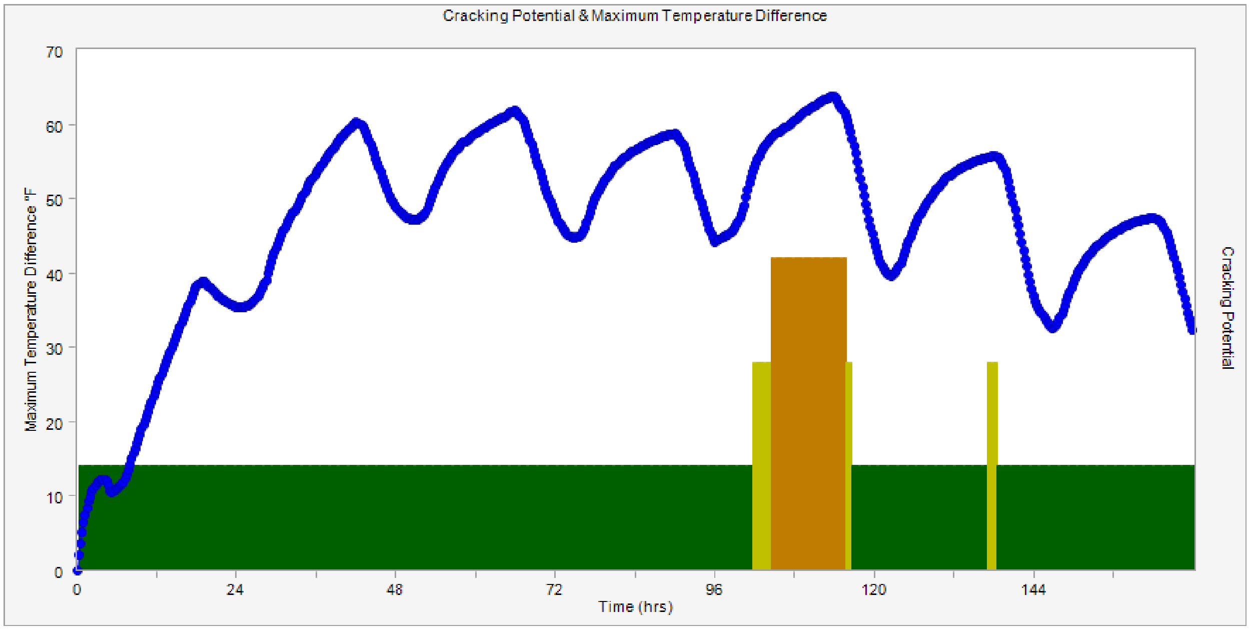




Steel

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	63	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	269	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	



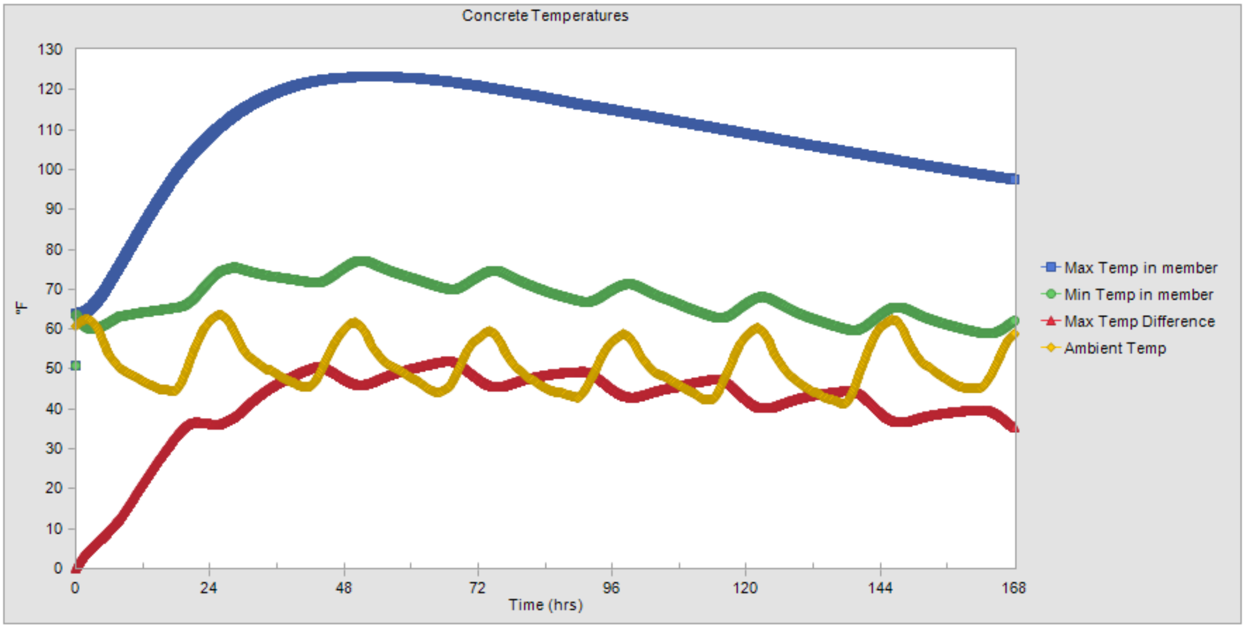


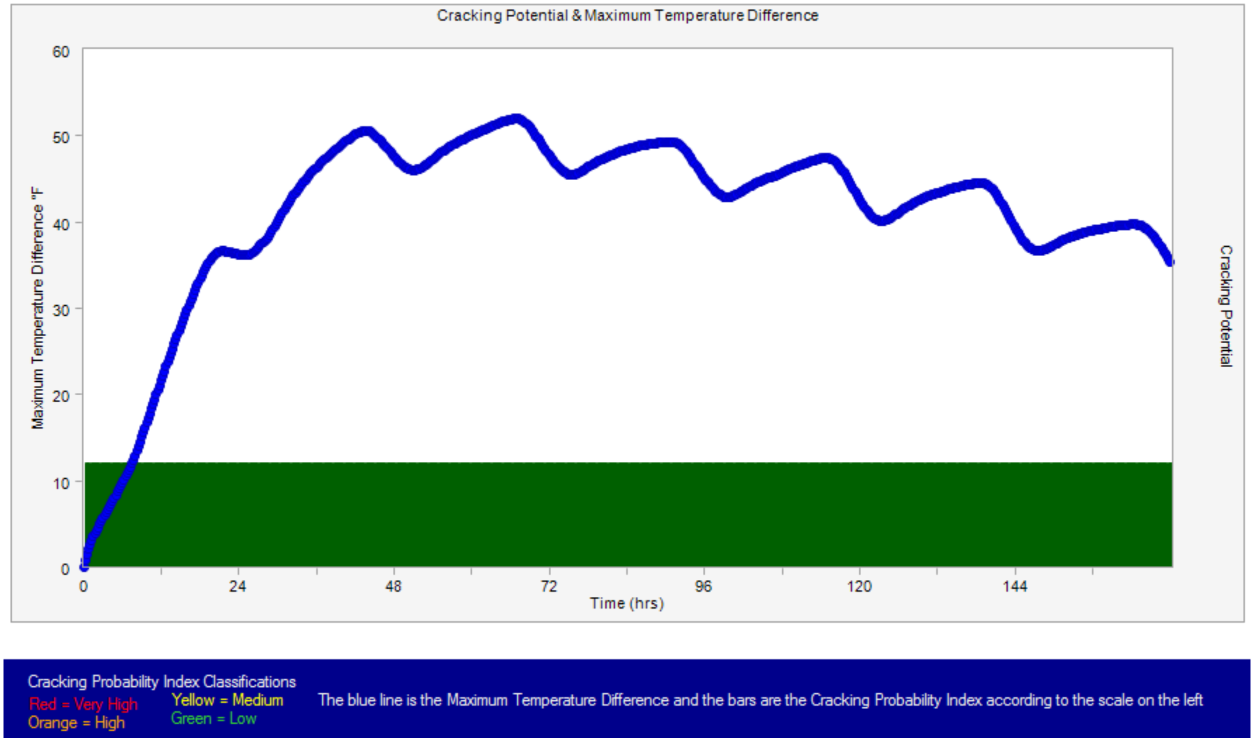
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Soil Formed

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	51	°F
Max Temperature	123	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	

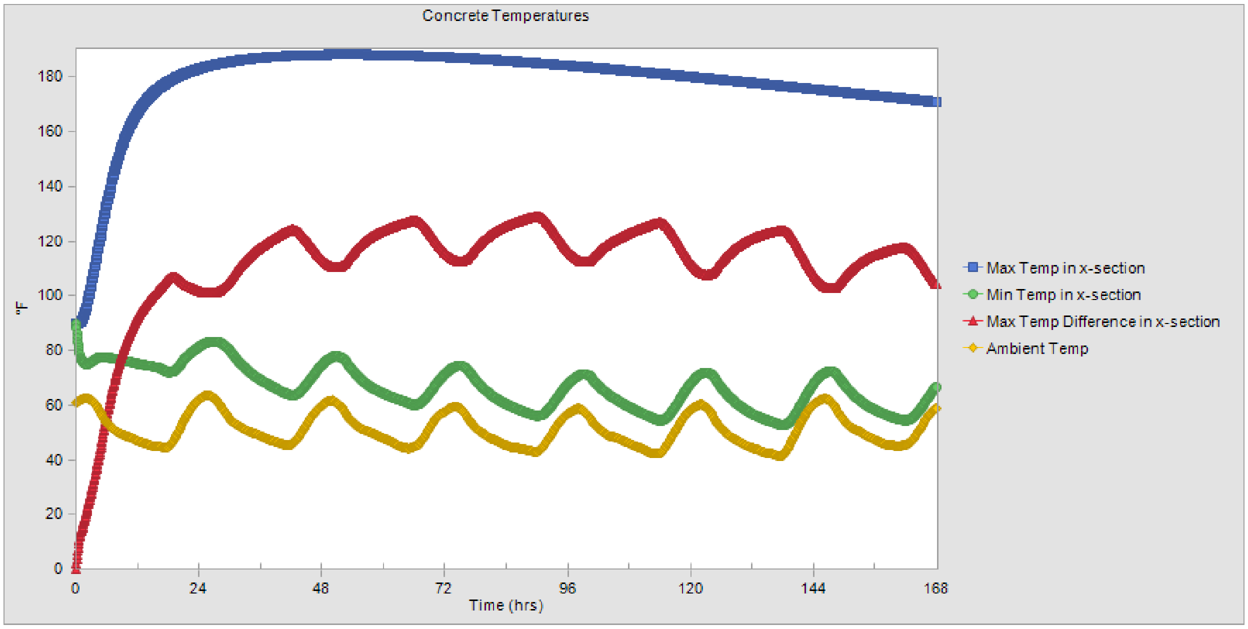


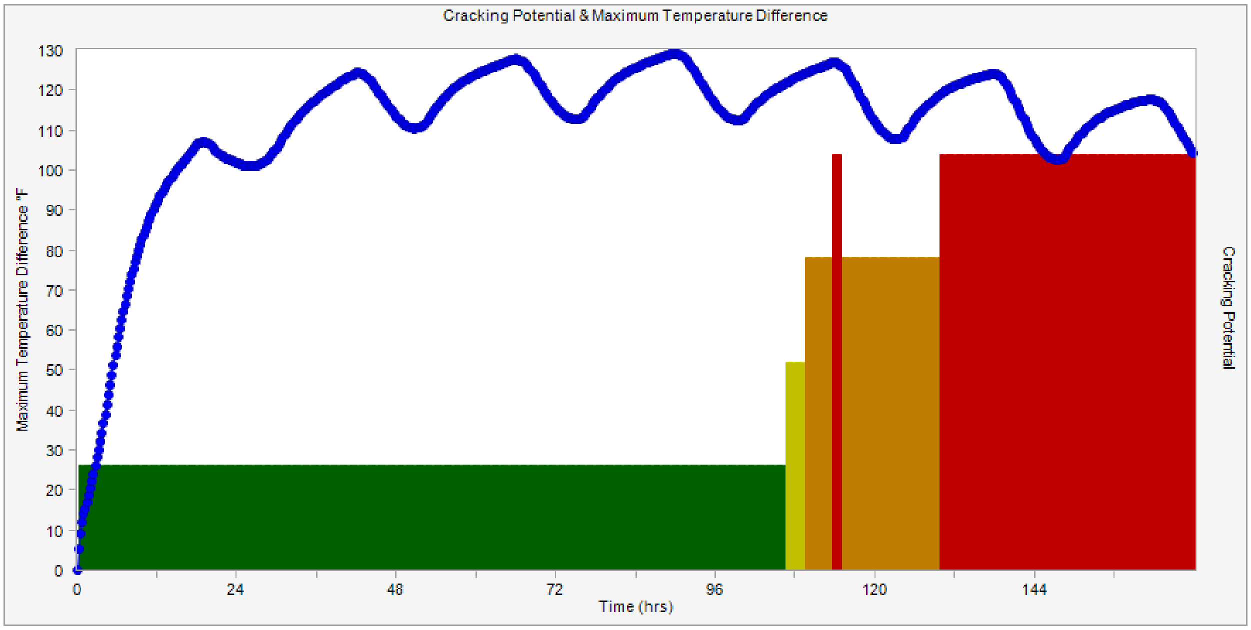

Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
Cracking Potential
Time (hrs)
0
10
20
30
40
50
60
0
24
48
72
96
120
144
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Forming Method—Seven-Day Form Removal Time

Steel Formwork

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	129	°F
Max Temperature	188	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	636	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	21	Years
Time to Concrete Damage From Steel Corrosion	27	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



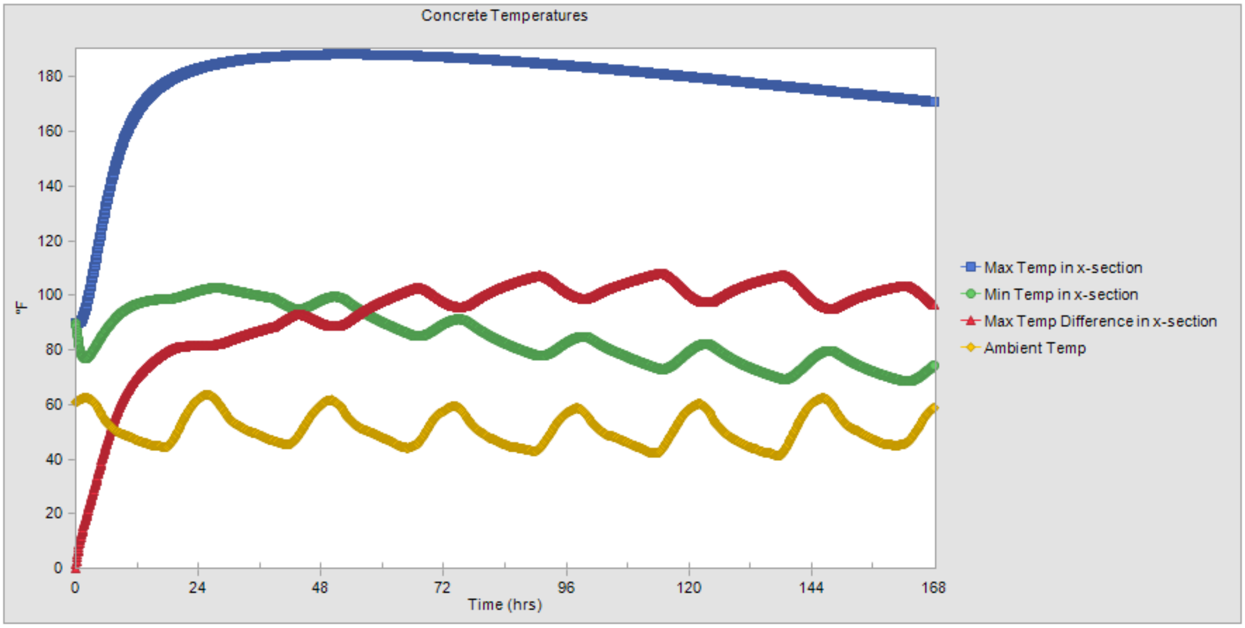


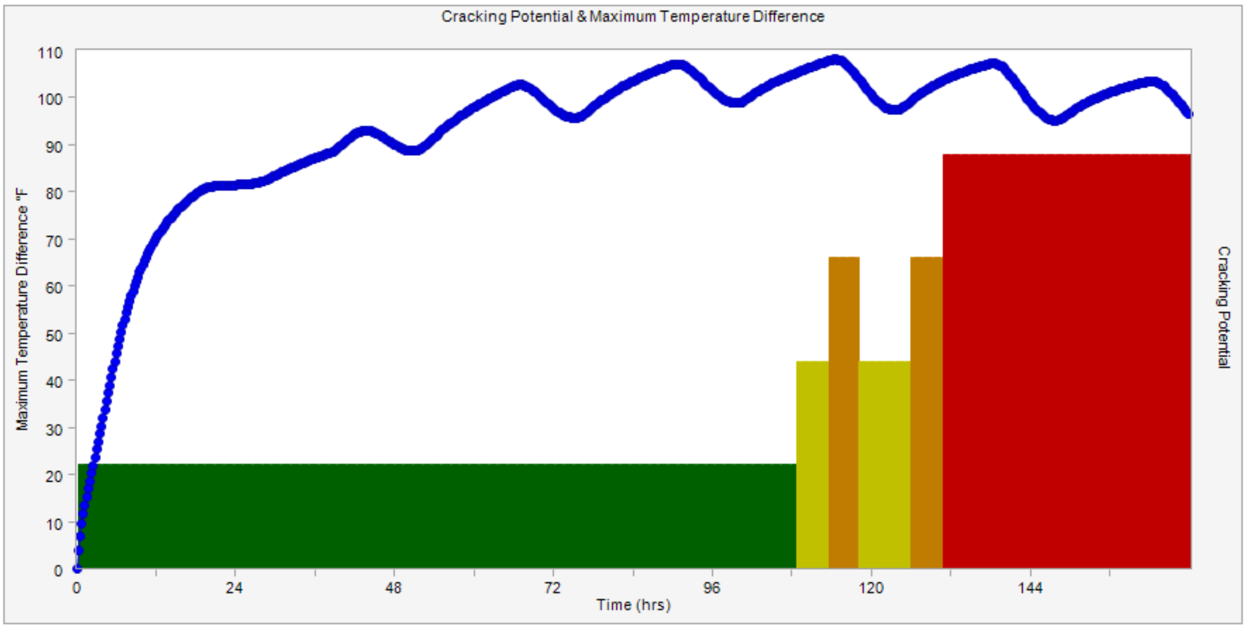
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Wood Forms

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	108	°F
Max Temperature	188	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	636	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	21	Years
Time to Concrete Damage From Steel Corrosion	27	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



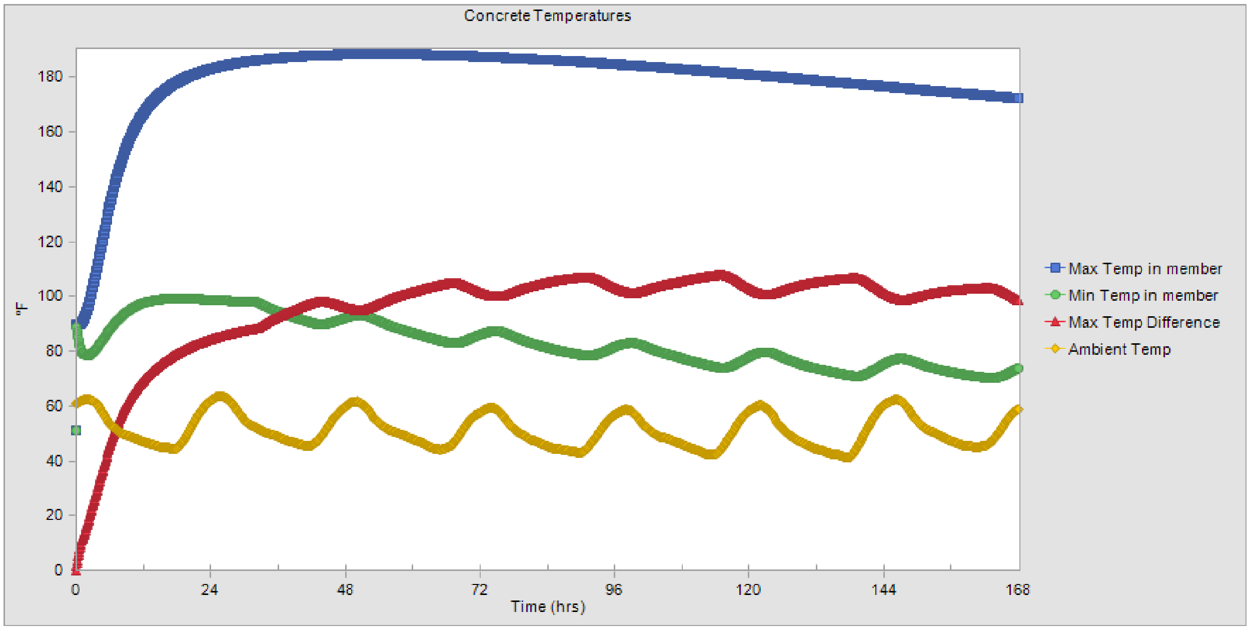


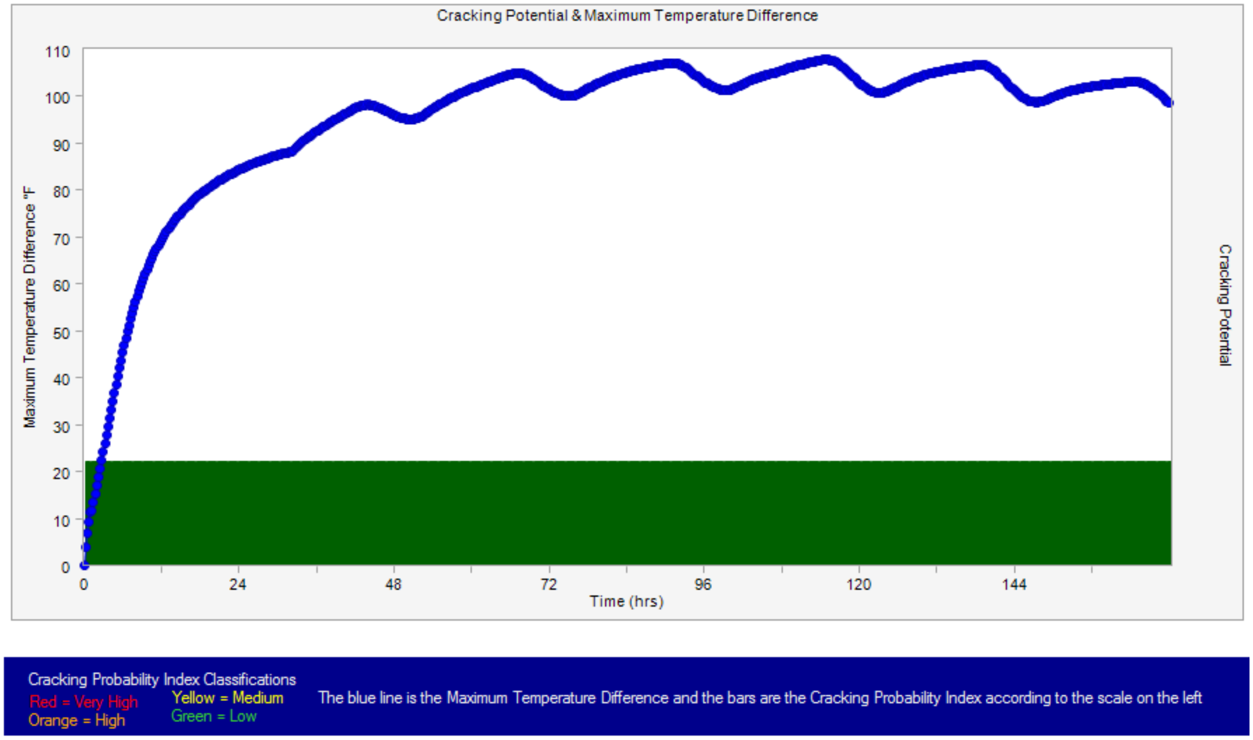
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Soil Formwork

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	107	°F
Max Temperature	188	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	614	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	

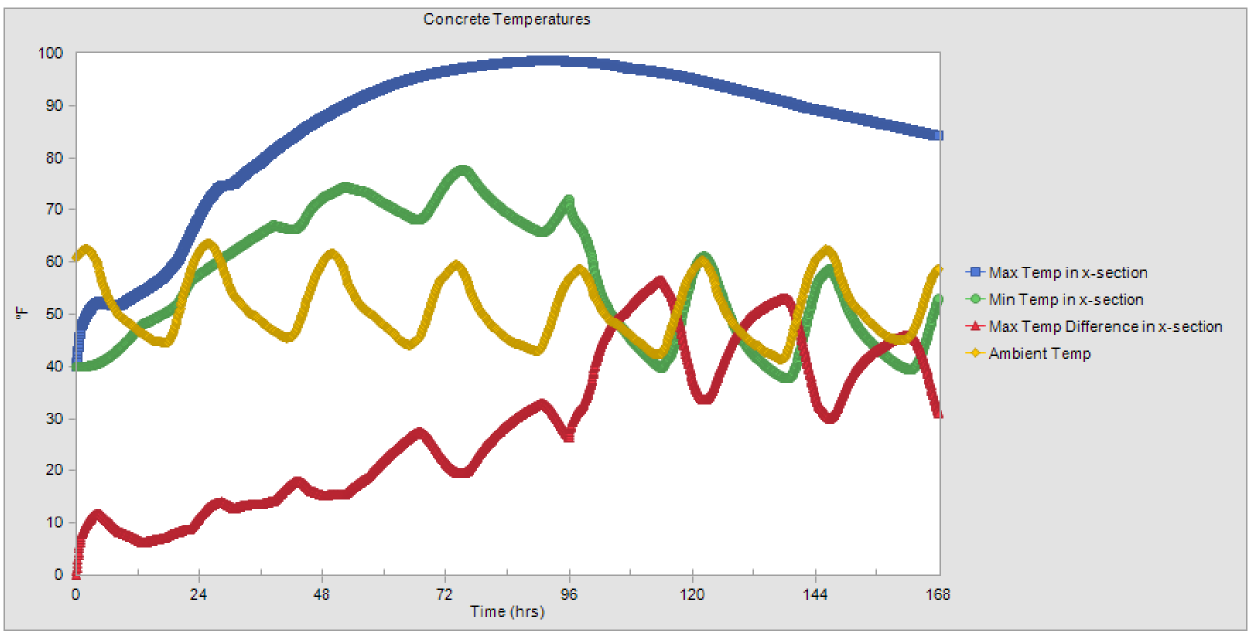


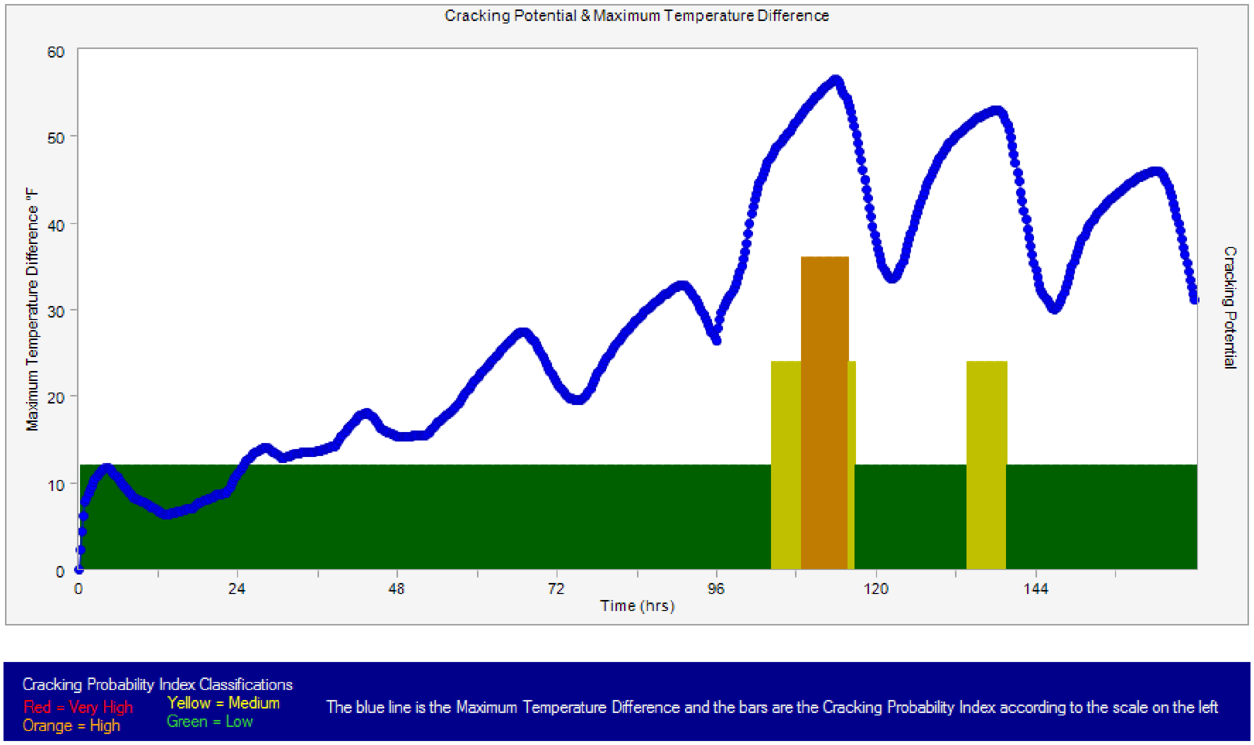

Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
110
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Placement Date and Placement Time

10/20/08—40°F Fresh Placement Temperature

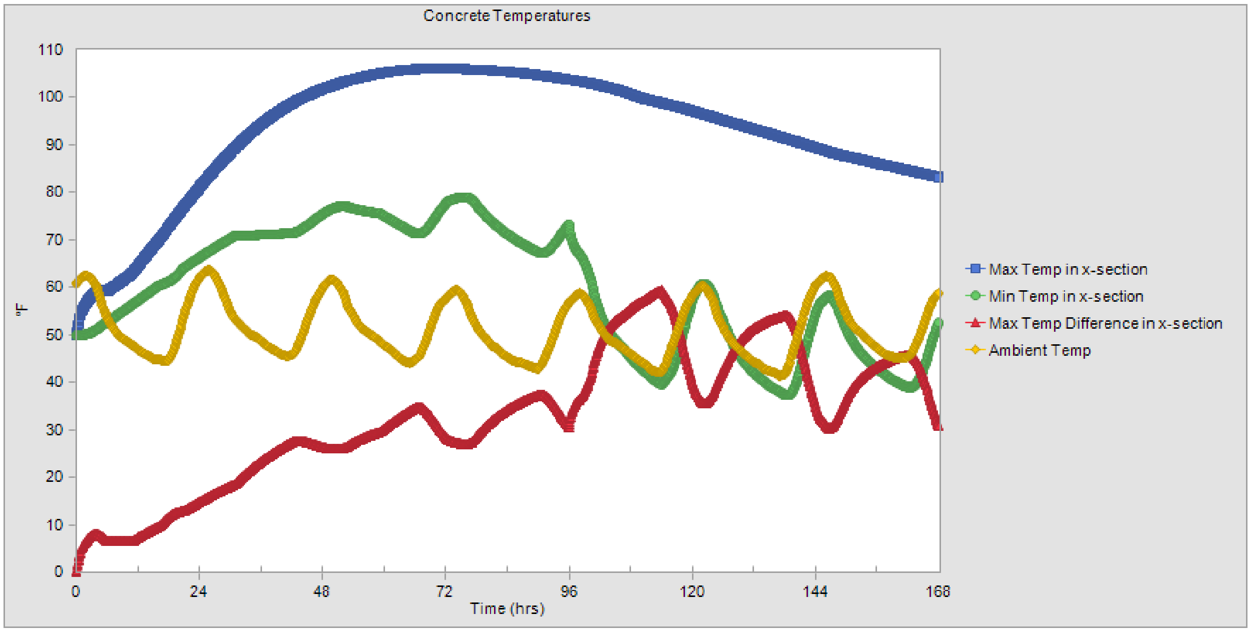
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	56	°F
Max Temperature	98	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	

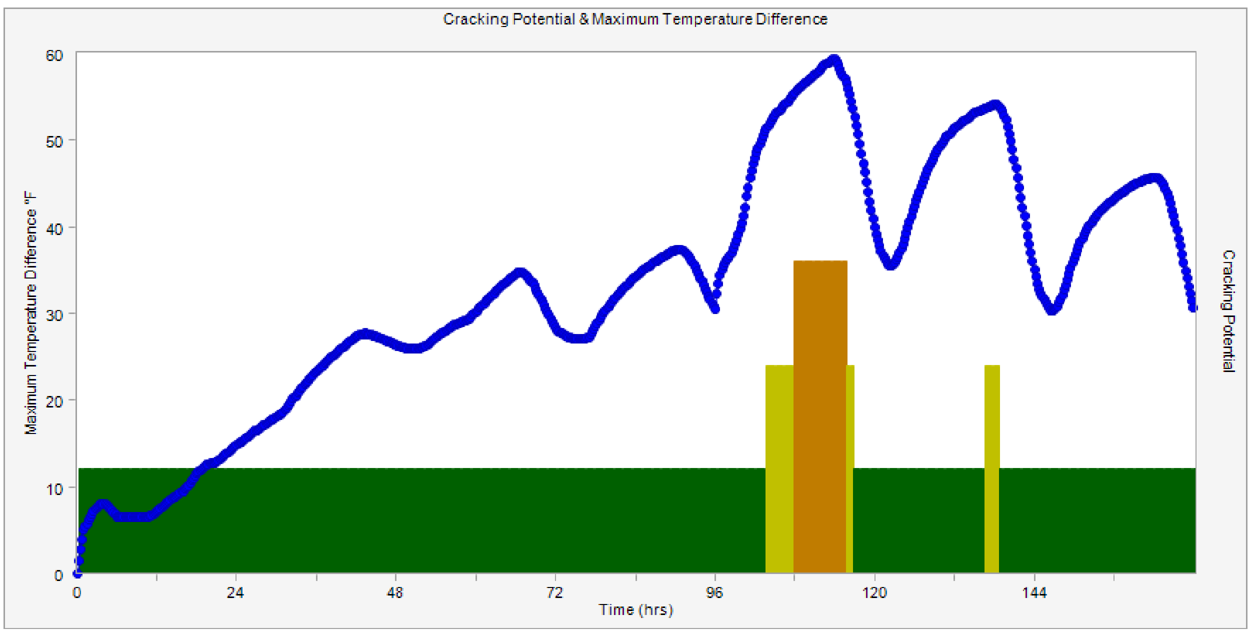




10/20/08—50°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	59	°F
Max Temperature	106	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	



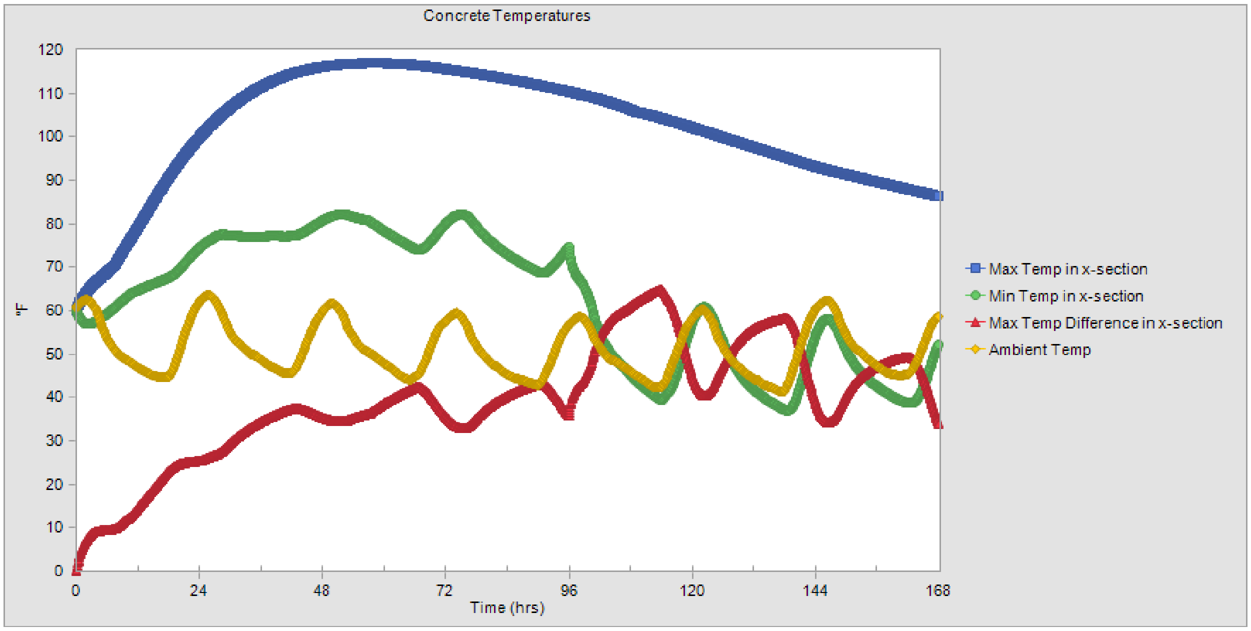


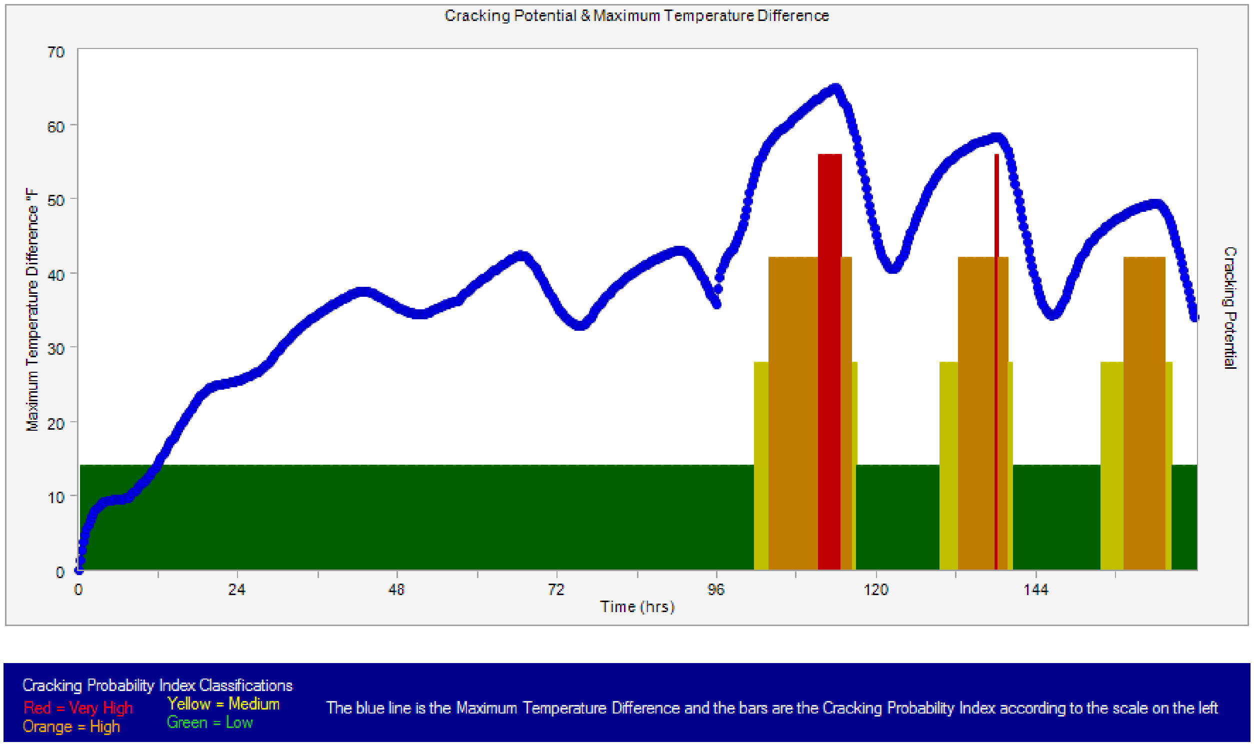
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

10/20/08—60°F Fresh Placement Temperature

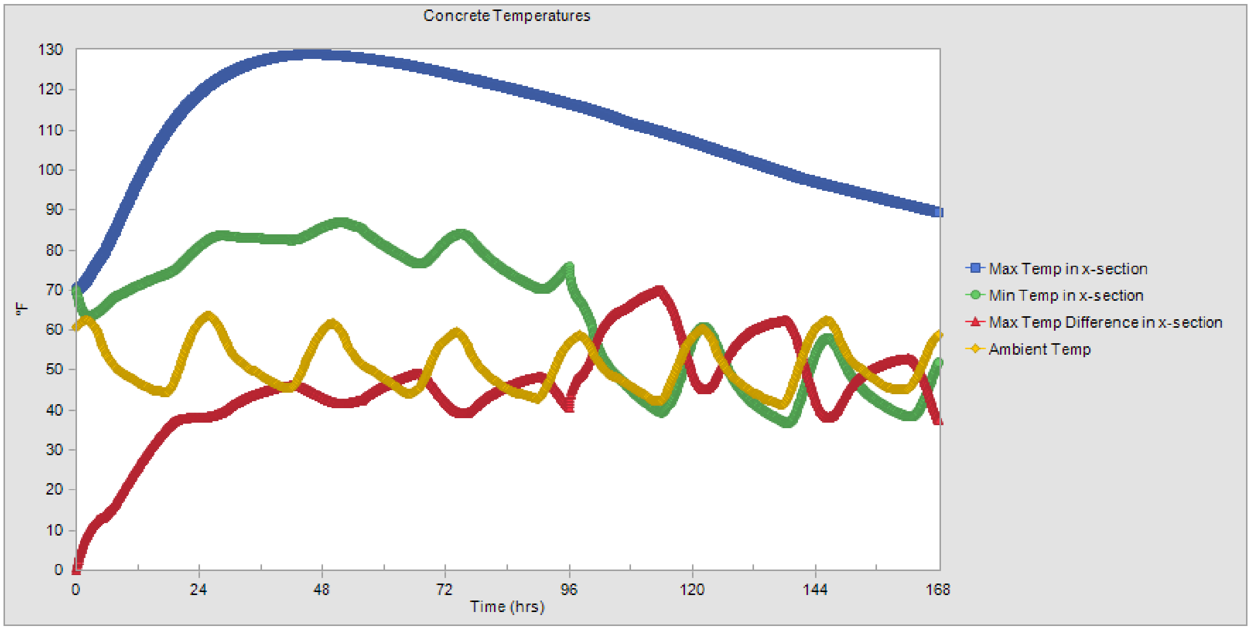
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	64	°F
Max Temperature	116	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

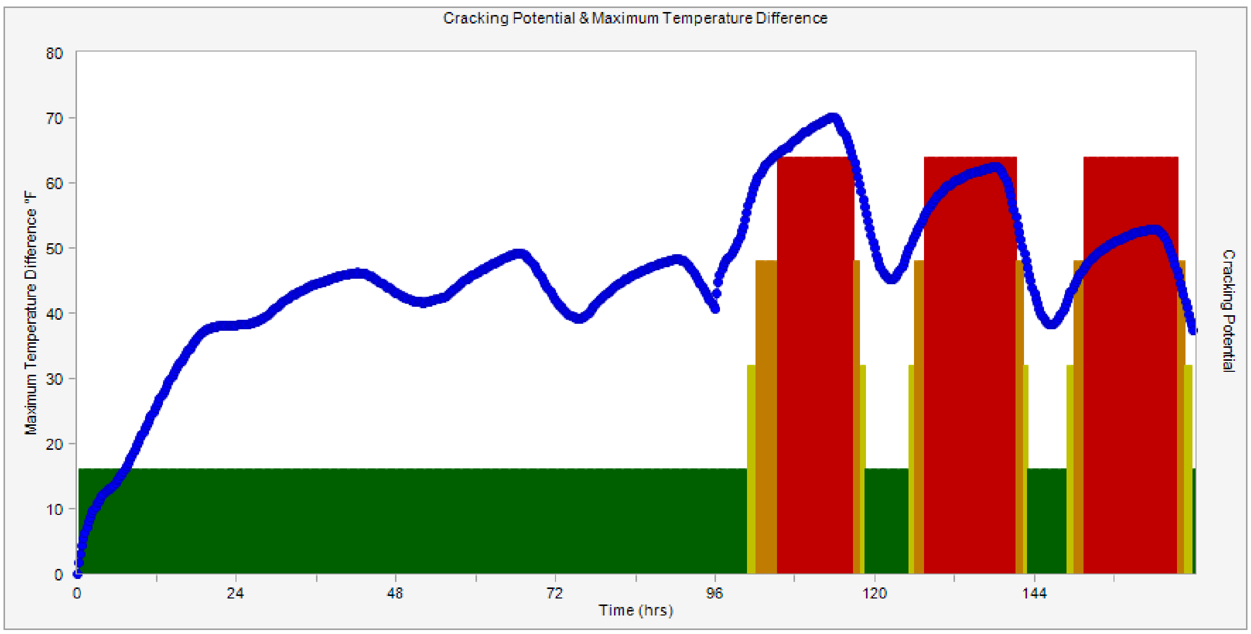




10/20/08—70°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	70	°F
Max Temperature	128	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



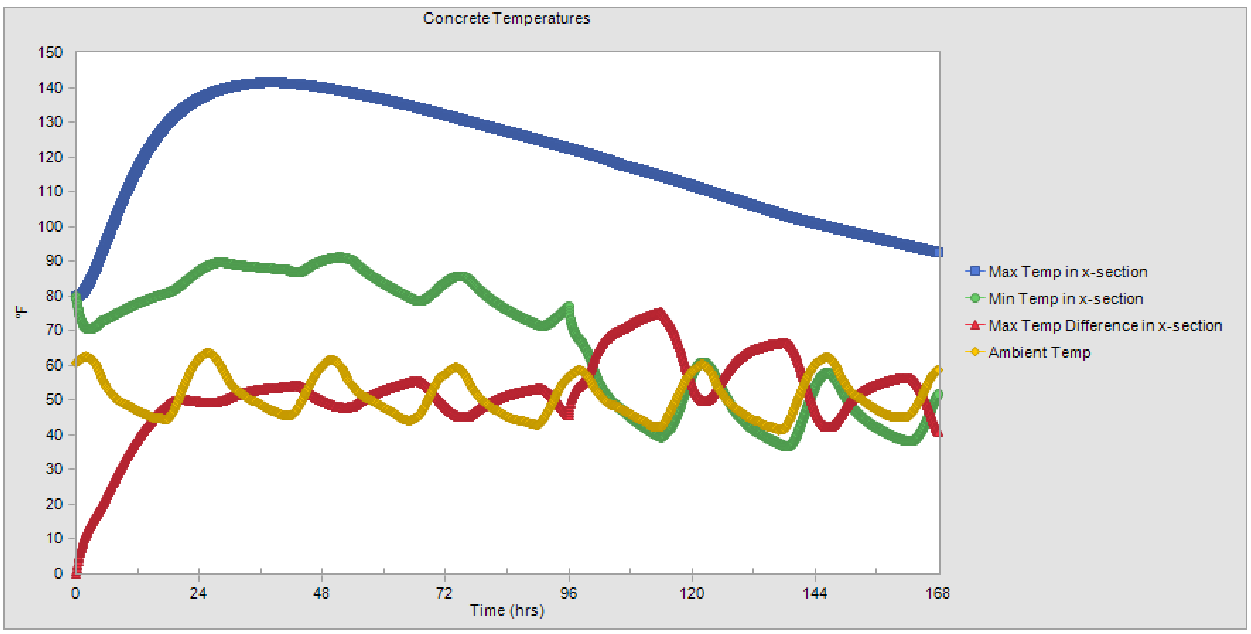


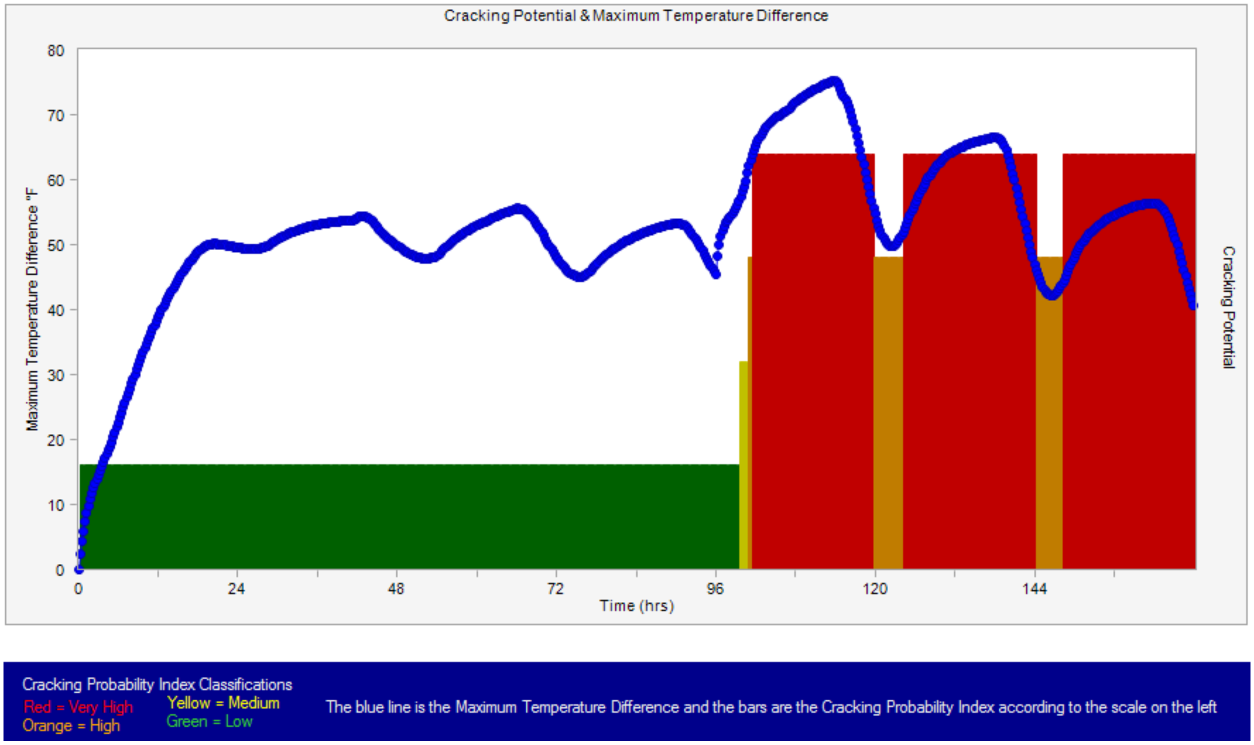
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

10/20/08—80°F Fresh Placement Temperature

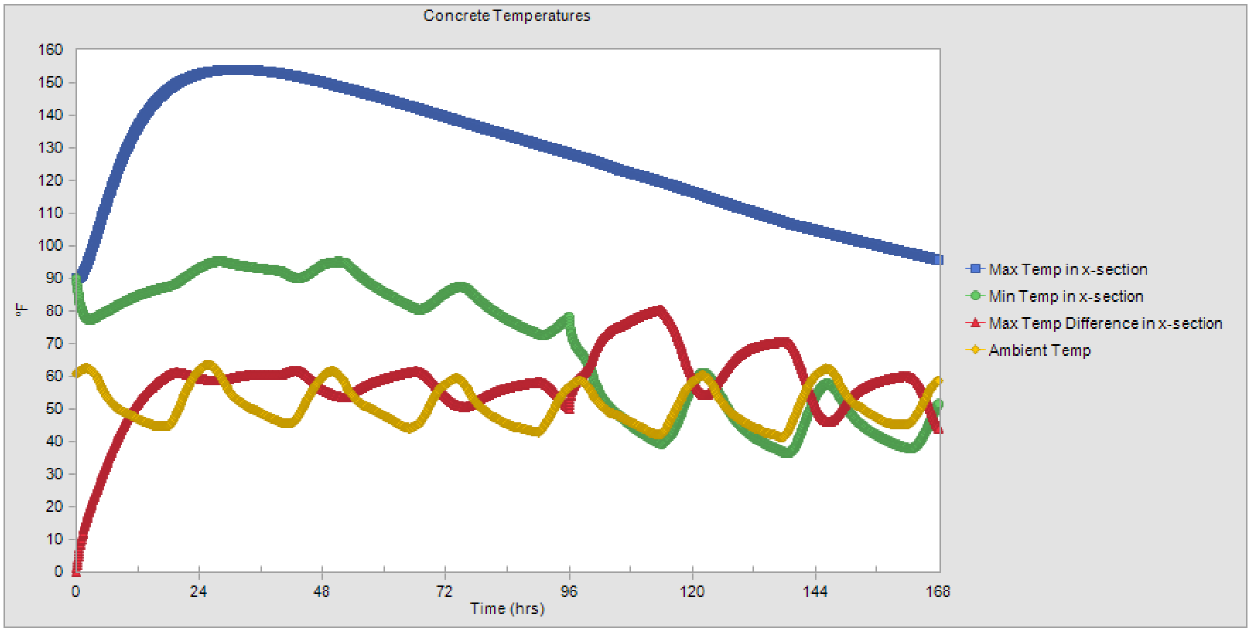
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	75	°F
Max Temperature	141	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

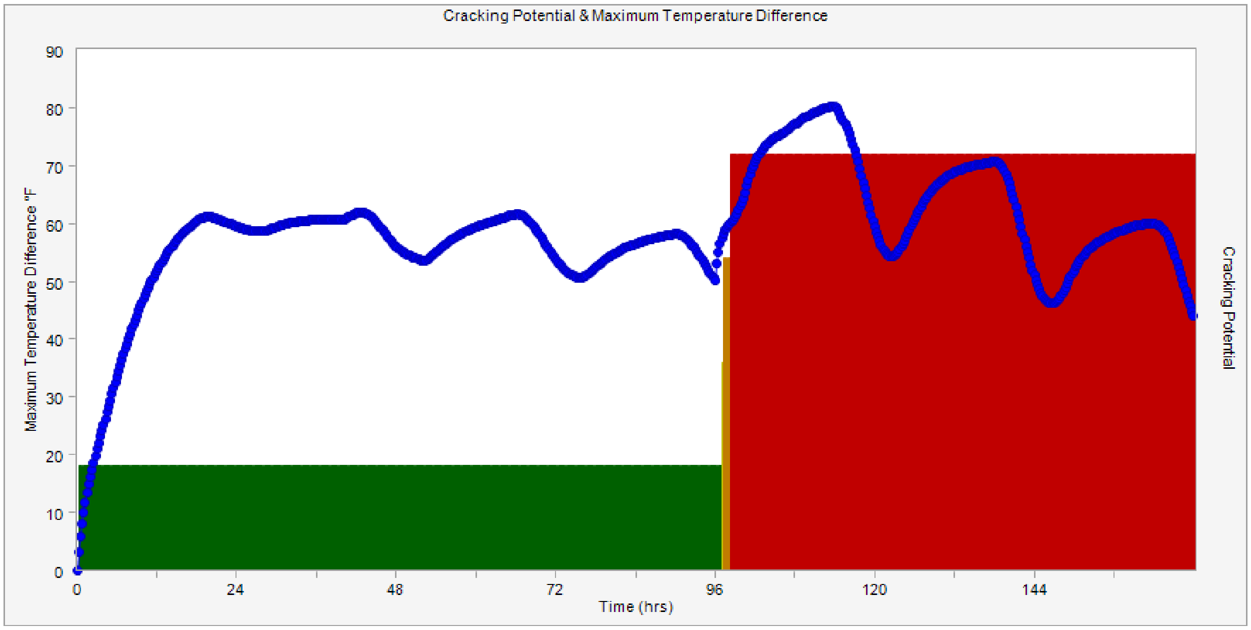




10/20/08—90°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	80	°F
Max Temperature	154	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

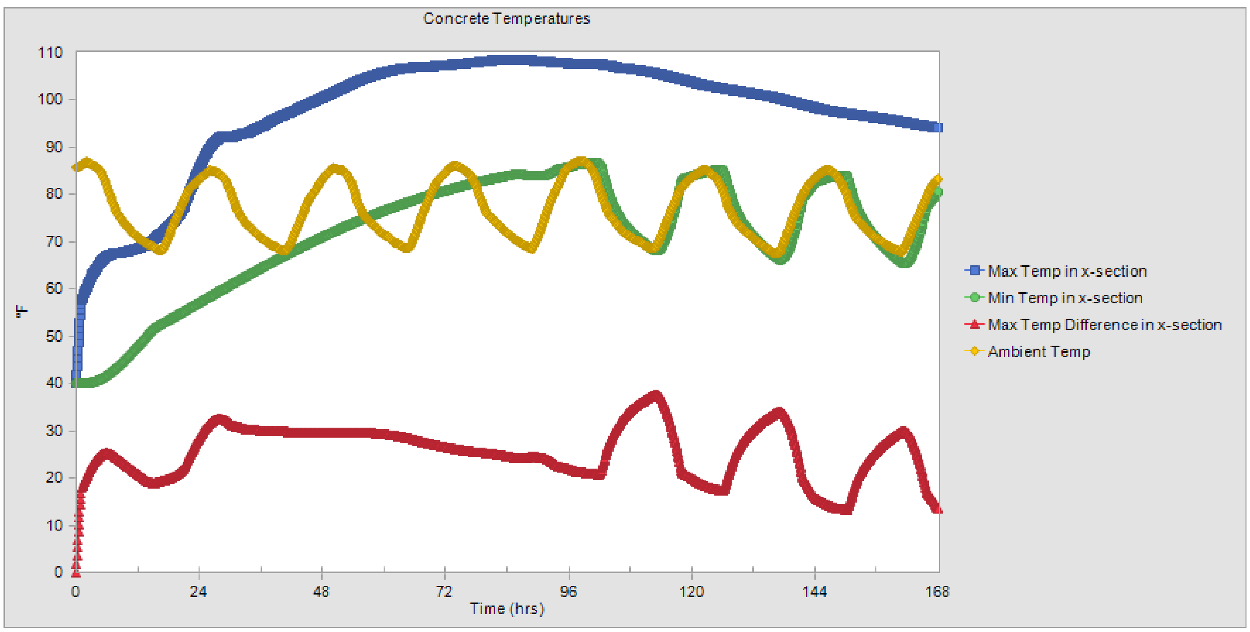

Concrete Temperatures
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
°F
0
24
48
72
96
120
144
168
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp

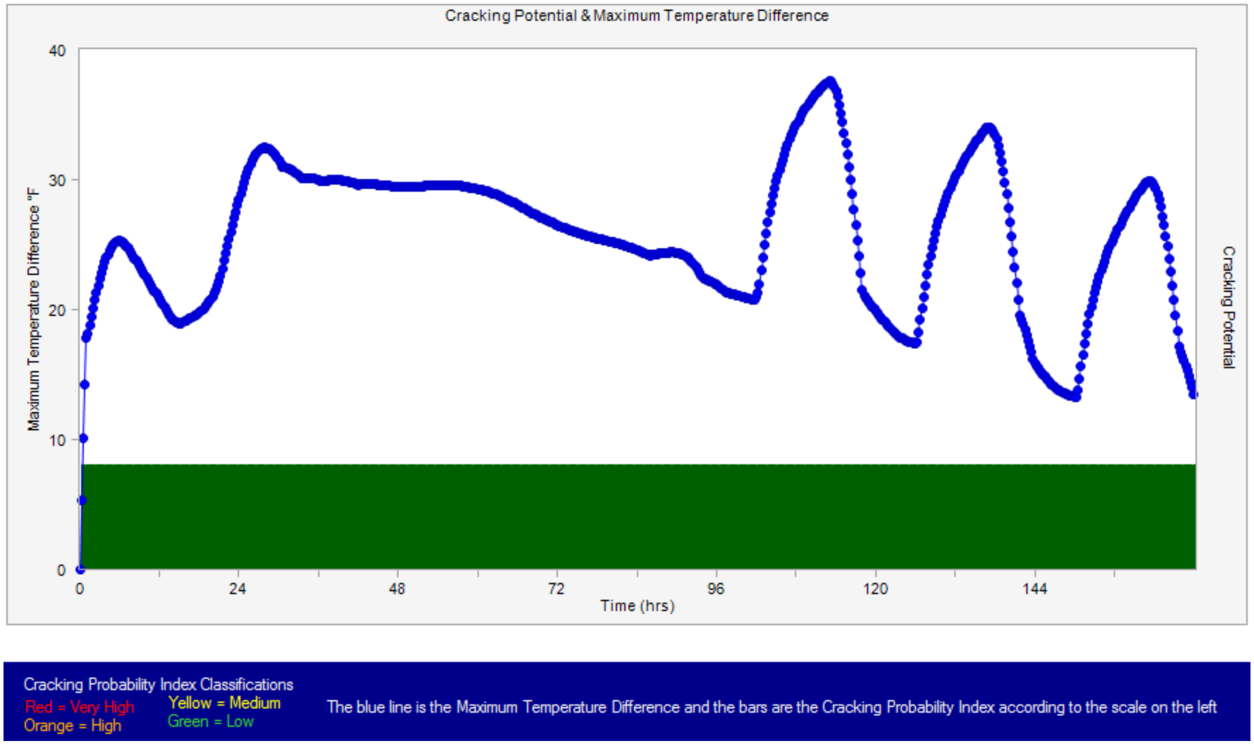

Cracking Potential & Maximum Temperature Difference
90
80
70
60
50
40
30
20
10
0
Maximum Temperature Difference °F
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential


Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

7/20/08—40°F Fresh Placement Temperature

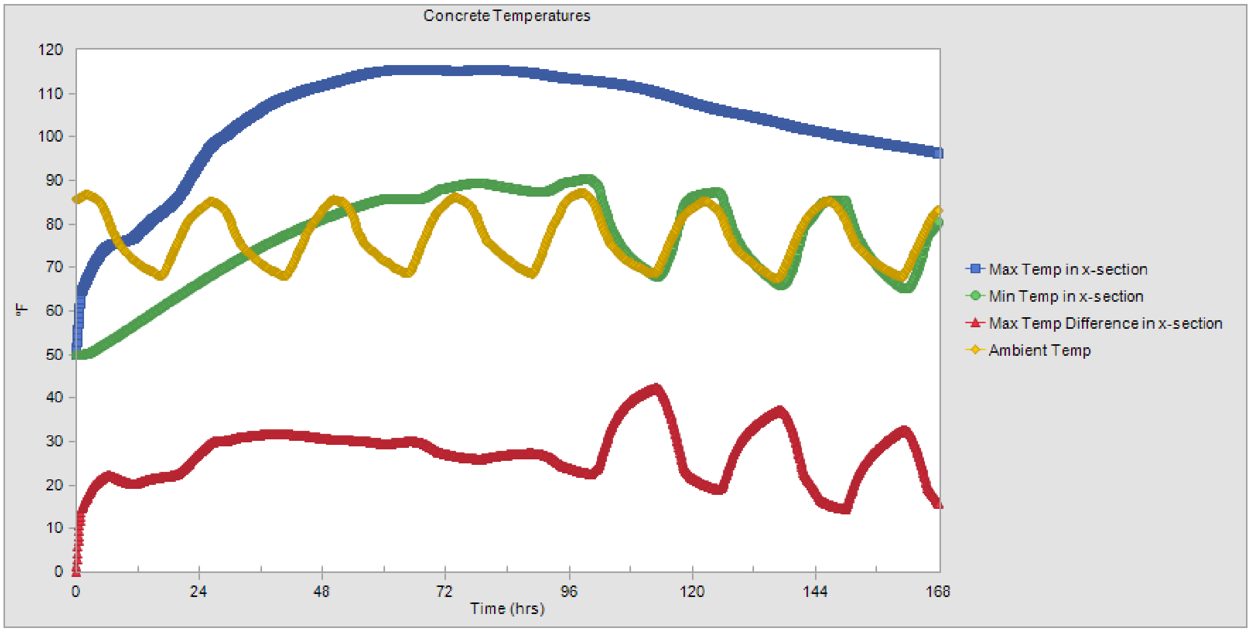
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	37	°F
Max Temperature	108	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	

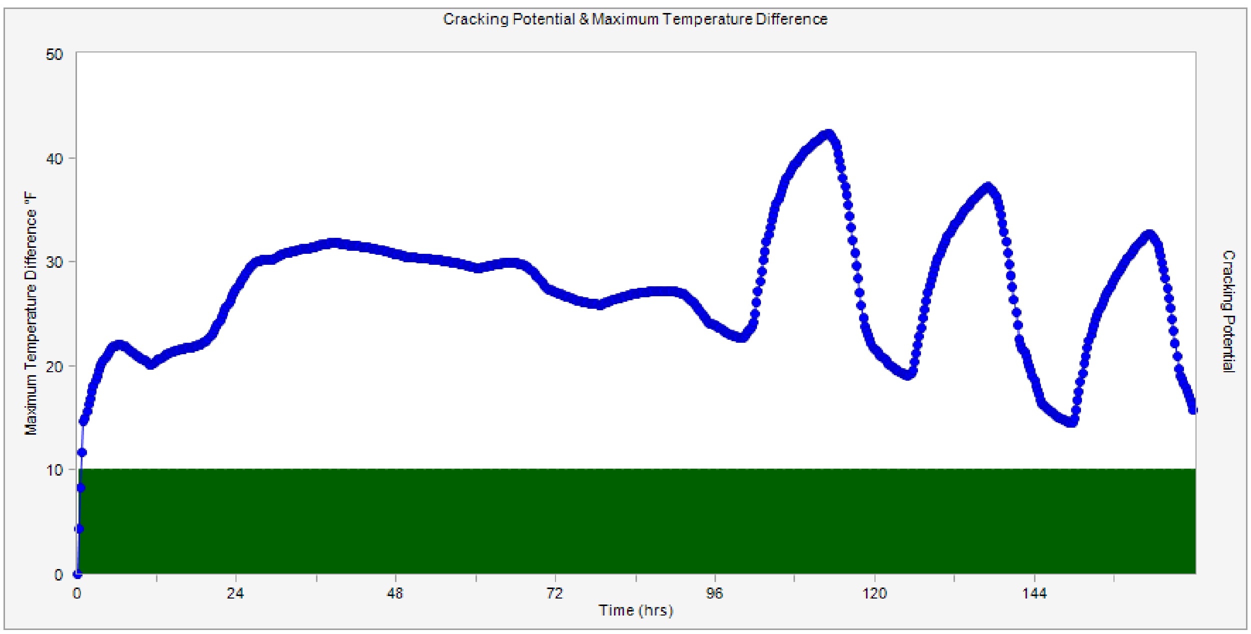




7/20/08—50°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	42	°F
Max Temperature	115	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	



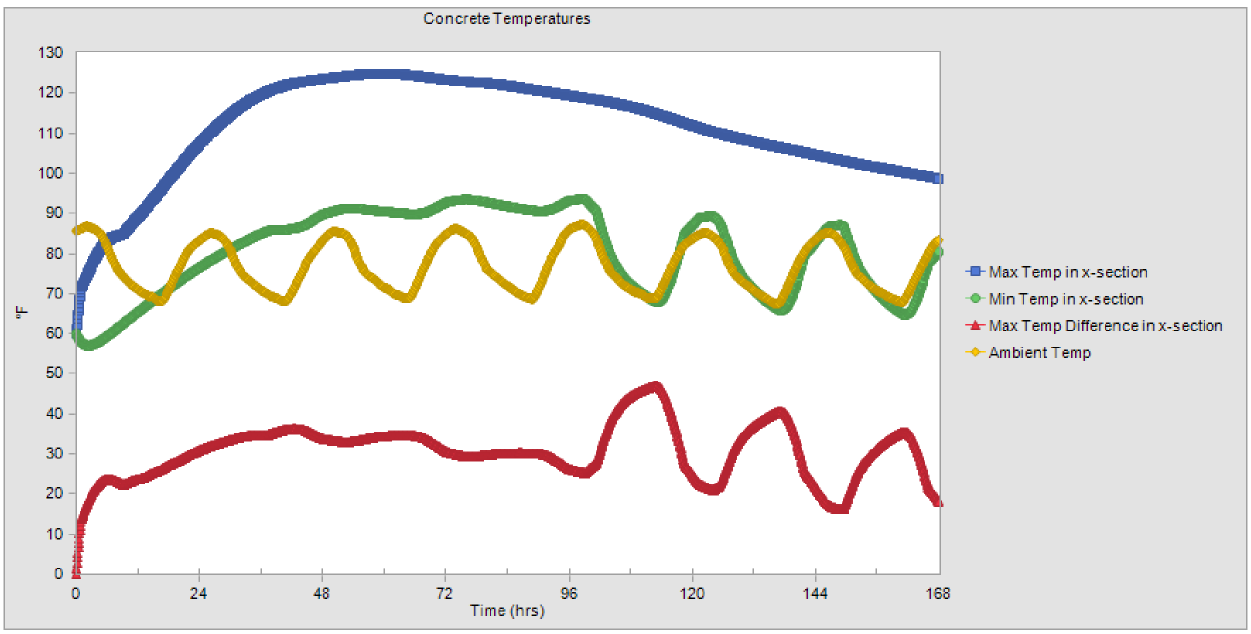


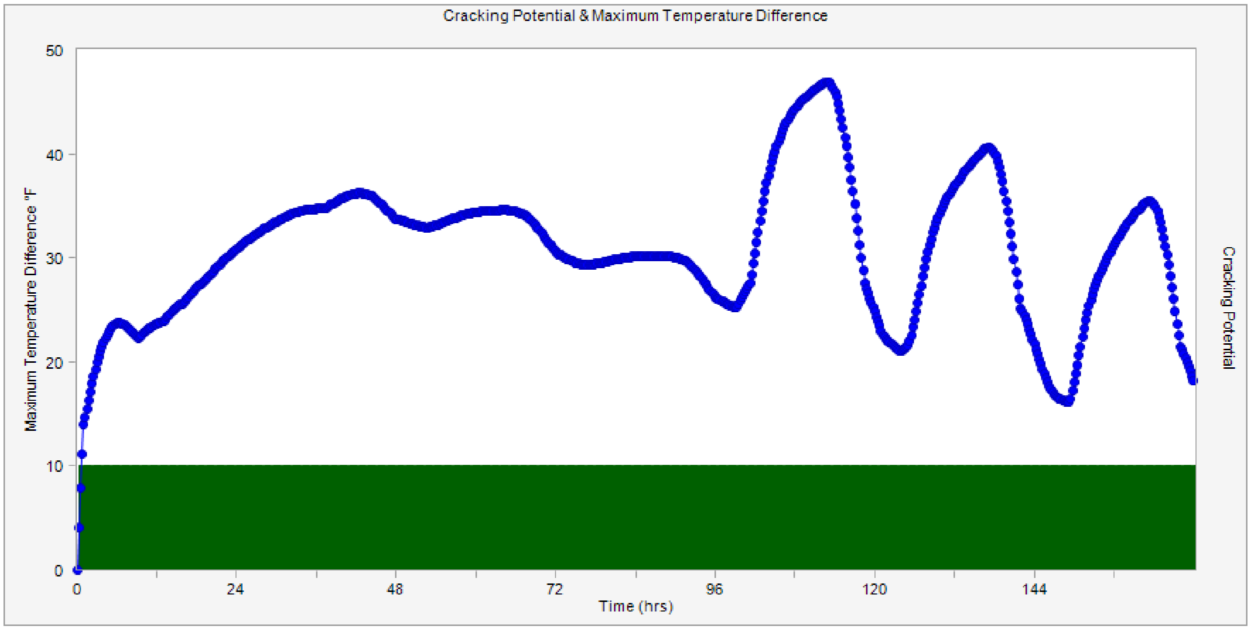
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

7/20/08—60°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	46	°F
Max Temperature	124	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	



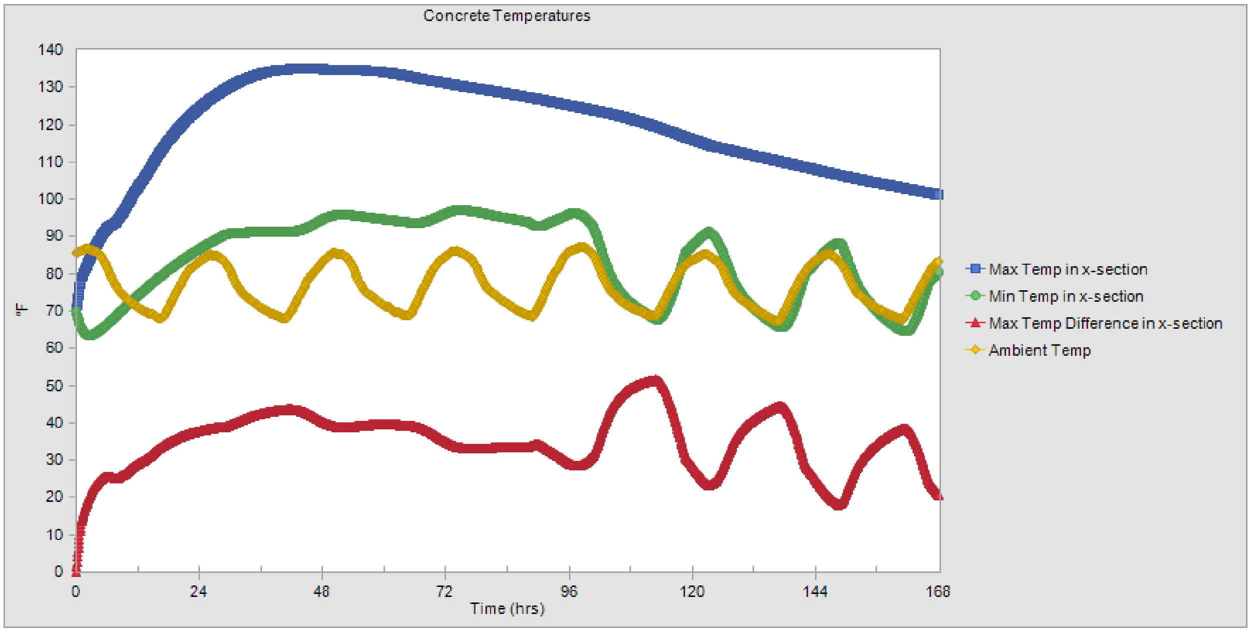


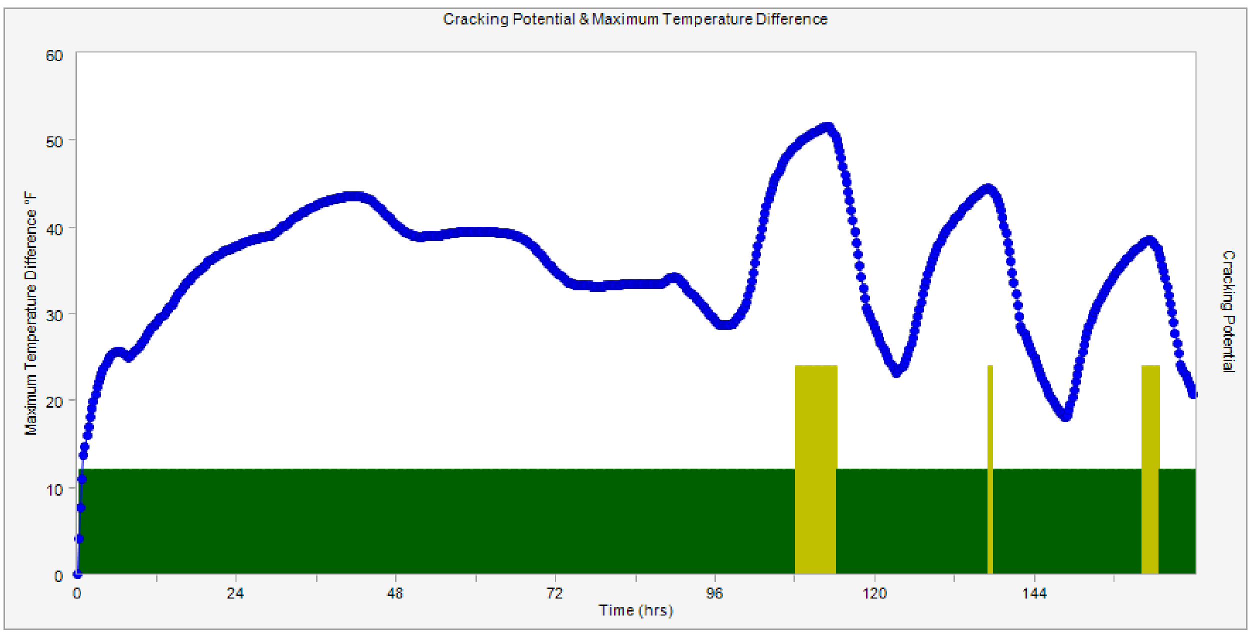
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

7/20/08—70°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	51	°F
Max Temperature	134	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Medium	



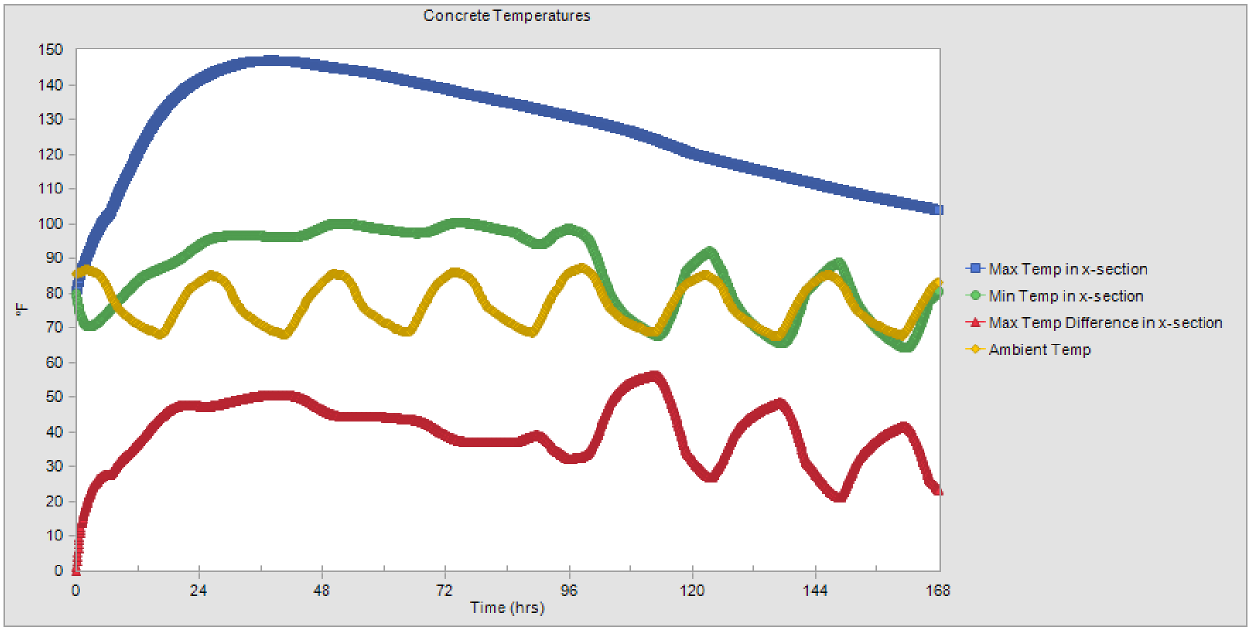


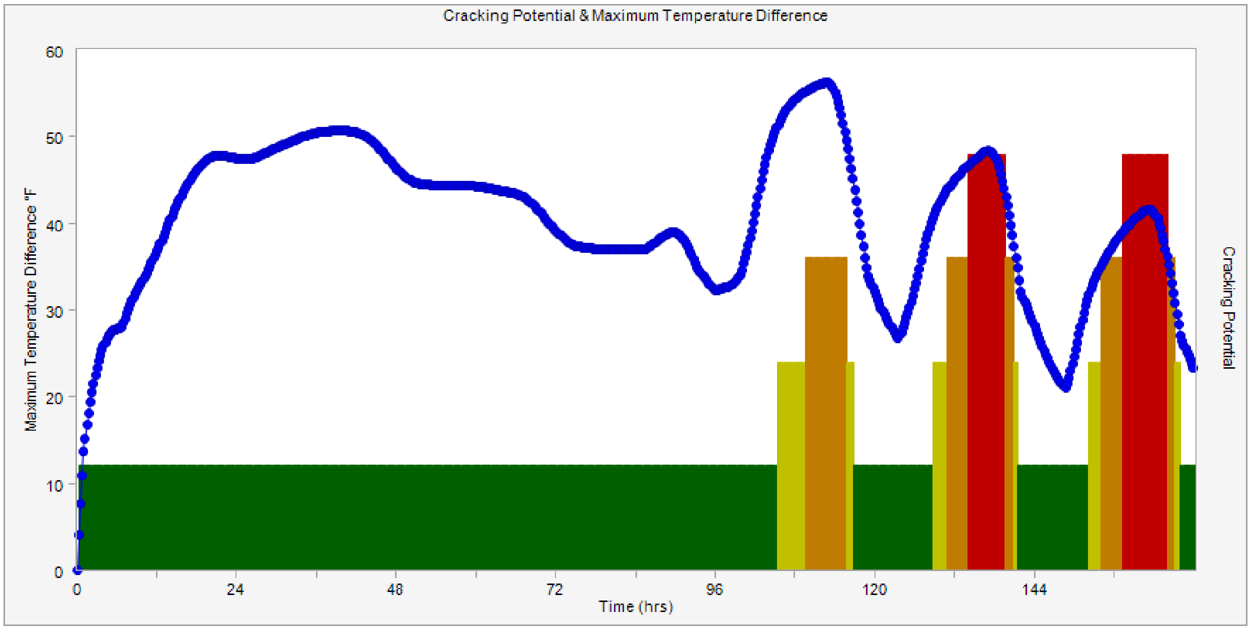
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

7/20/08—80°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	56	°F
Max Temperature	146	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



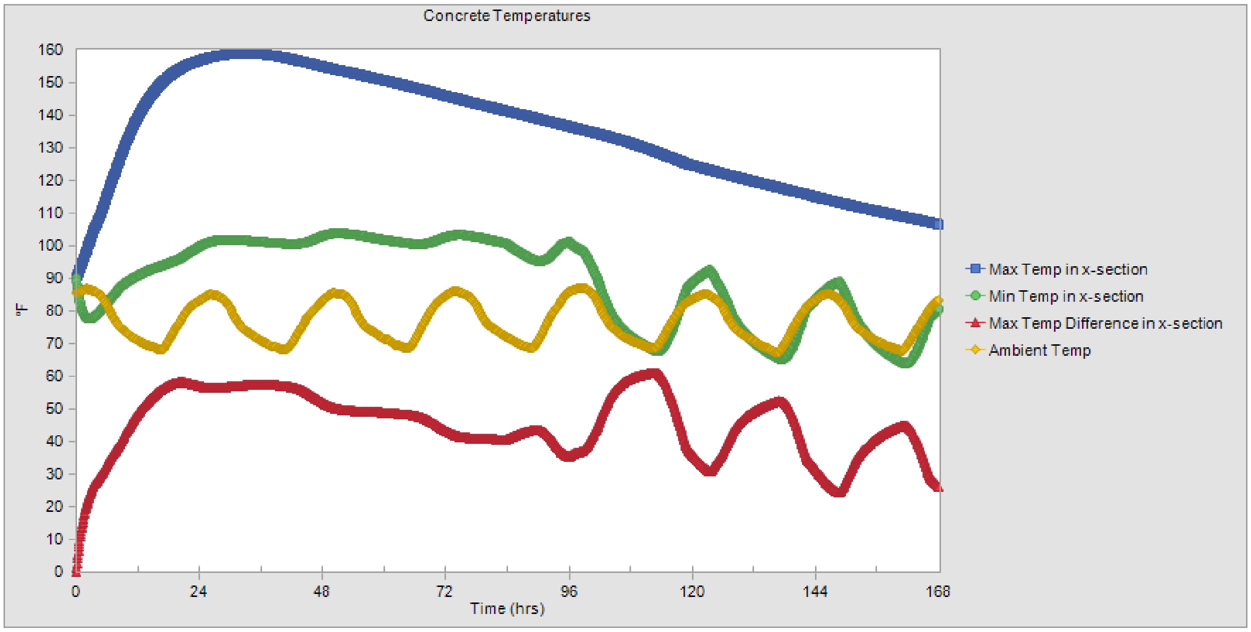


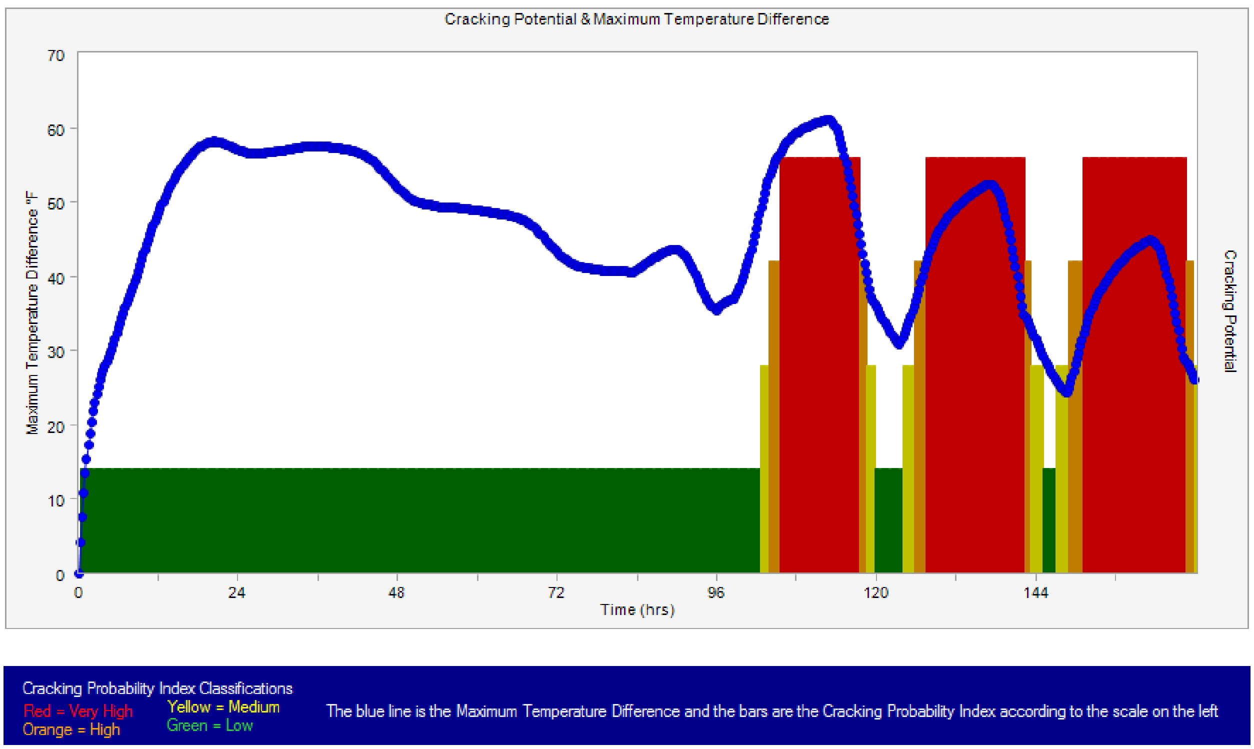
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

7/20/08—90°F Fresh Placement Temperature

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	61	°F
Max Temperature	158	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	291	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 75	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 81	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

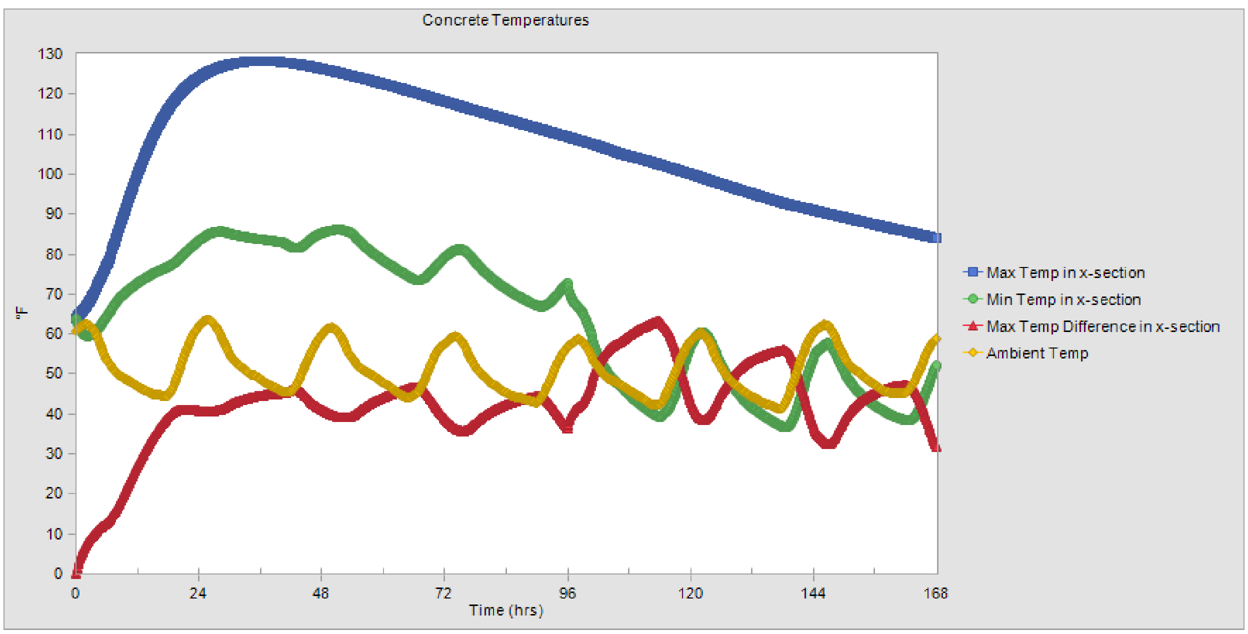

Concrete Temperatures
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
°F
0
24
48
72
96
120
144
168
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp

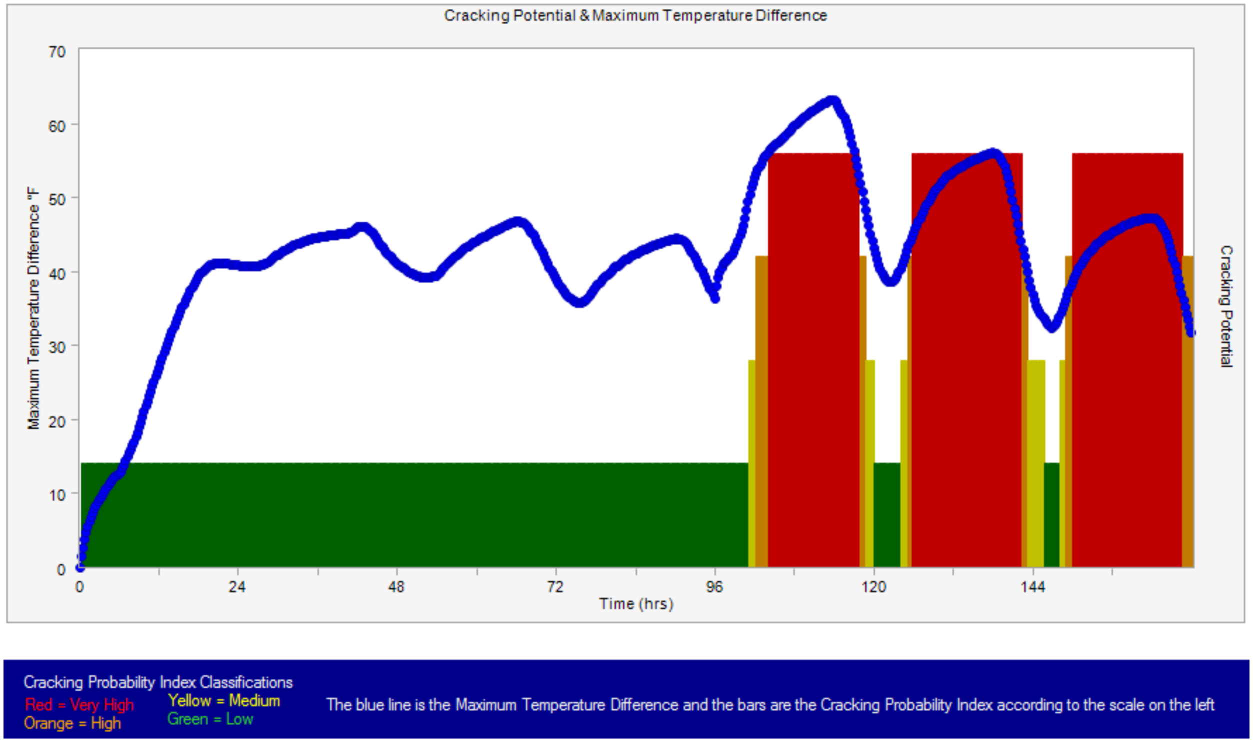

Cracking Potential & Maximum Temperature Difference
70
60
50
40
30
20
10
0
Maximum Temperature Difference °F
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Cement Content

Cement Content—560 Pounds per Cubic Yard

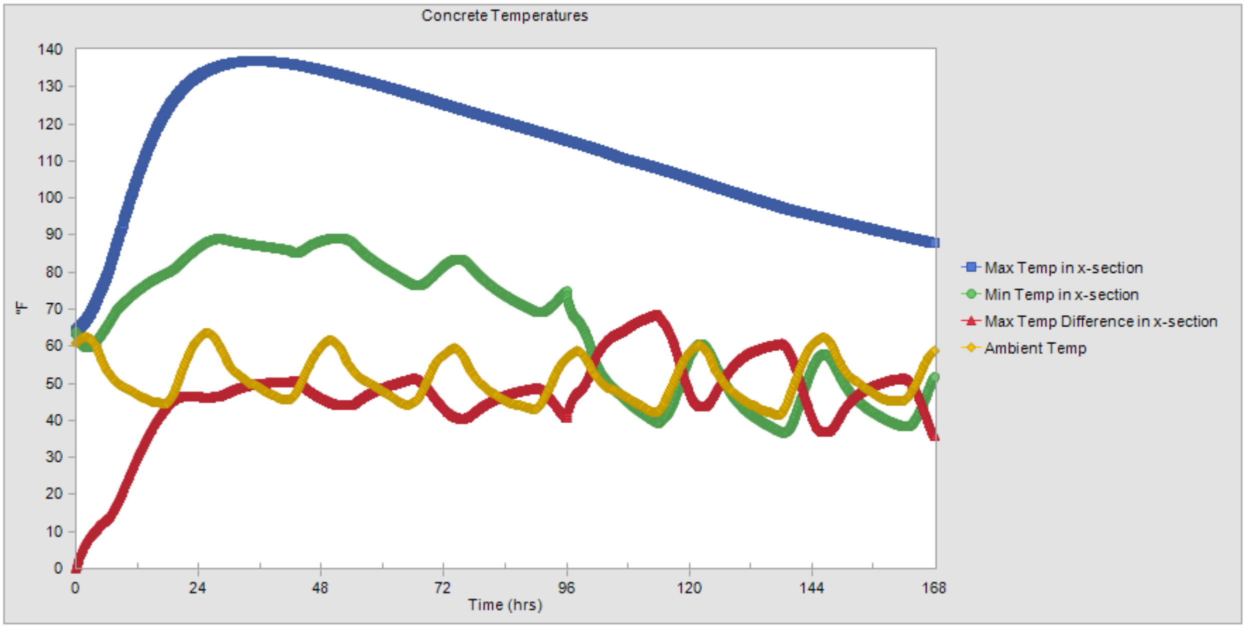
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	63	°F
Max Temperature	128	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	496	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	16	Years
Time to Concrete Damage From Steel Corrosion	22	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

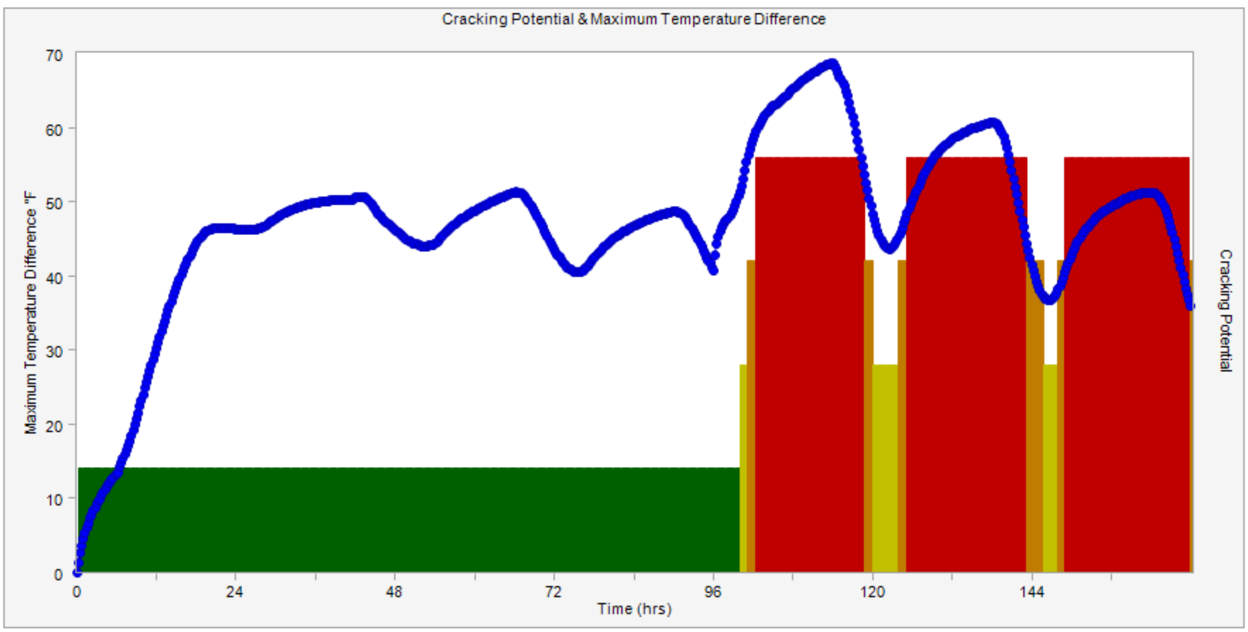




Cement Content—660 Pounds per Cubic Yard

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	68	°F
Max Temperature	136	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	558	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	19	Years
Time to Concrete Damage From Steel Corrosion	25	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



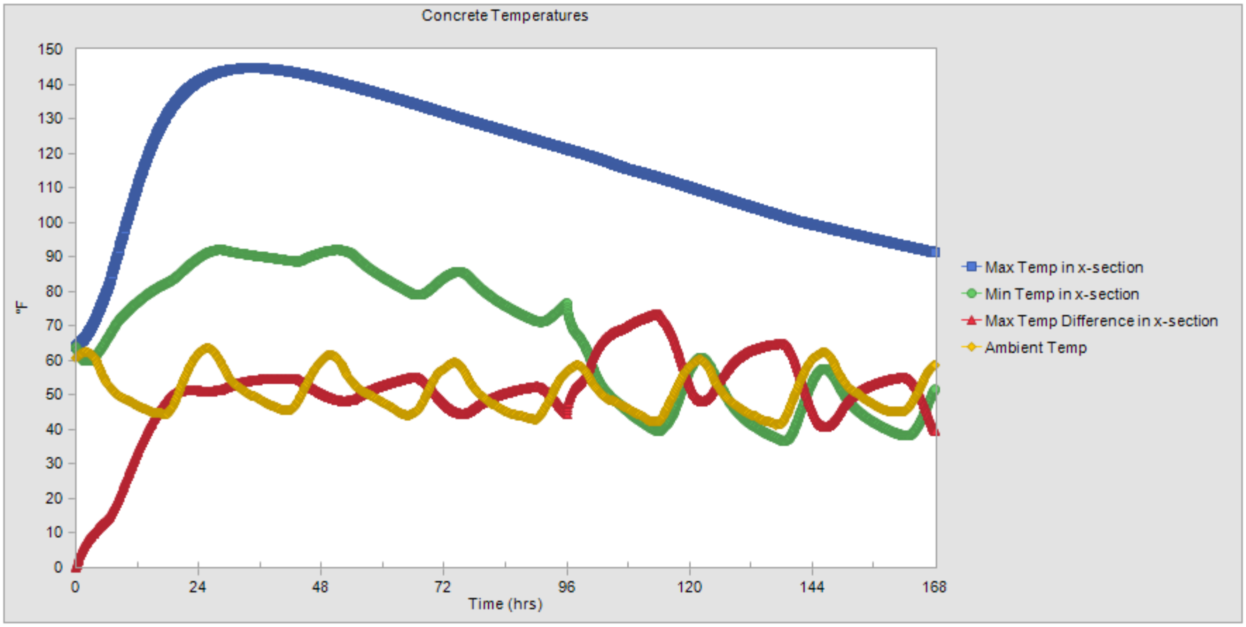


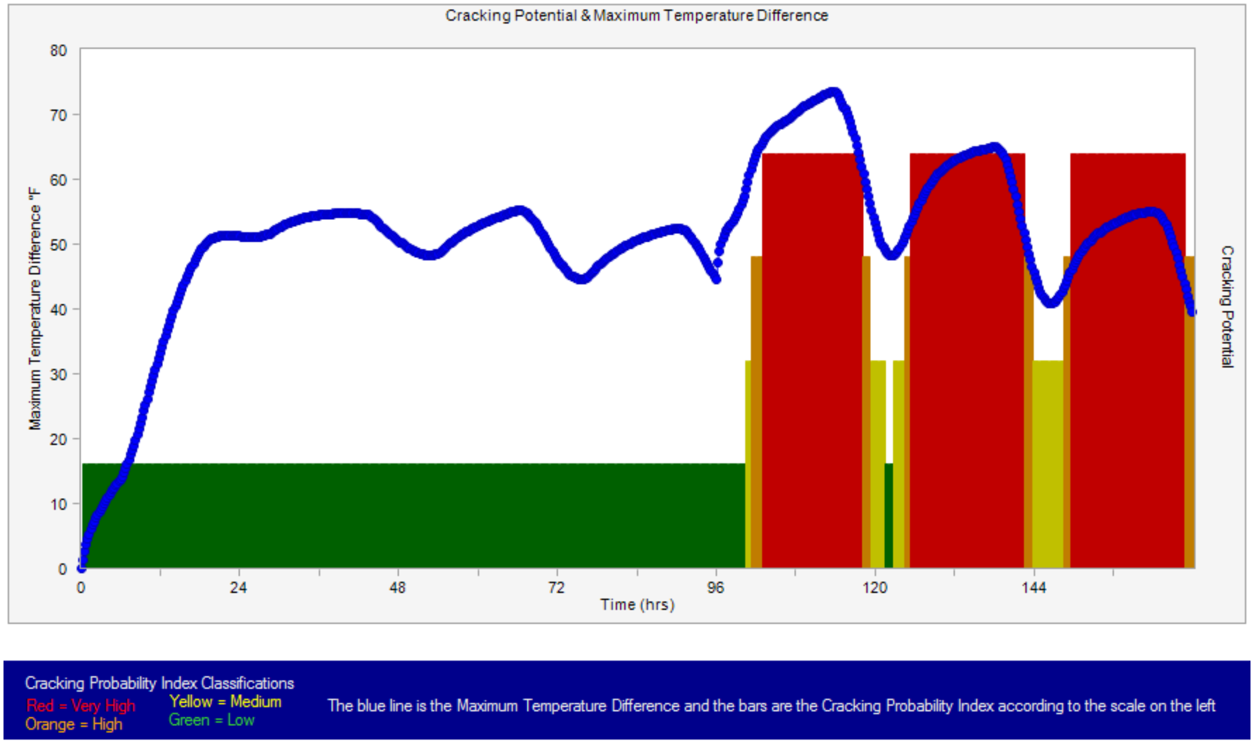
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Cement Content—760 Pounds per Cubic Yard

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	73	°F
Max Temperature	144	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	642	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

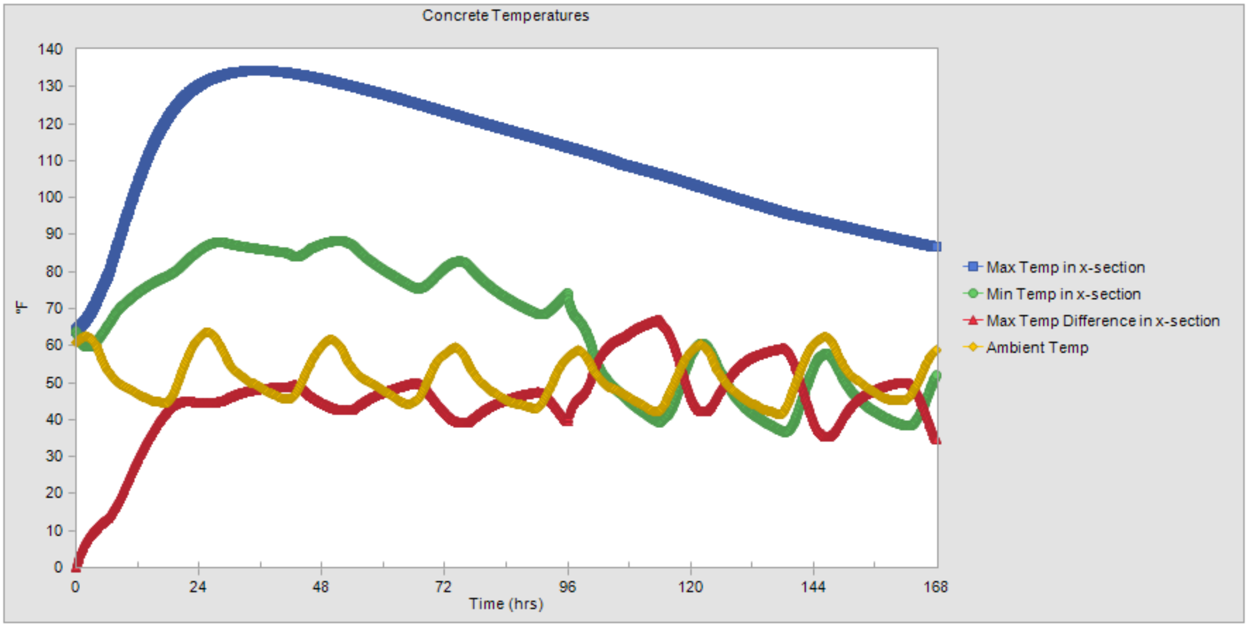


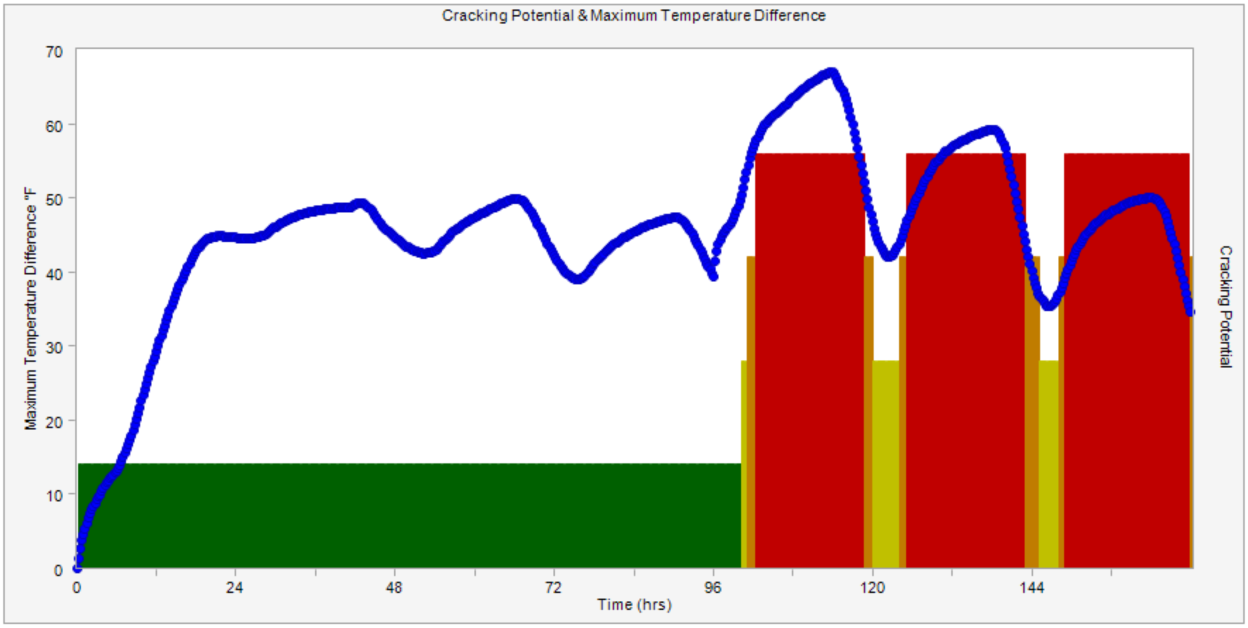

Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
Cracking Potential
Time (hrs)
0
24
48
72
96
120
144
0
10
20
30
40
50
60
70
80
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Fly Ash

Class F Fly Ash 0 Percent Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	67	°F
Max Temperature	134	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	564	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	18	Years
Time to Concrete Damage From Steel Corrosion	24	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



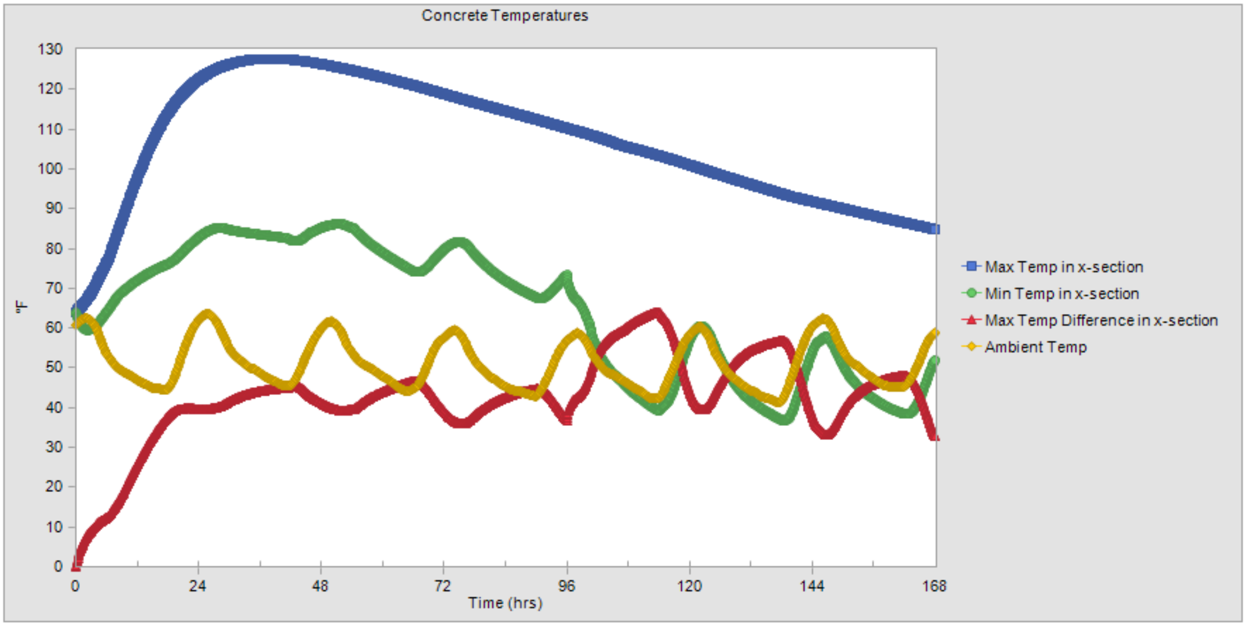


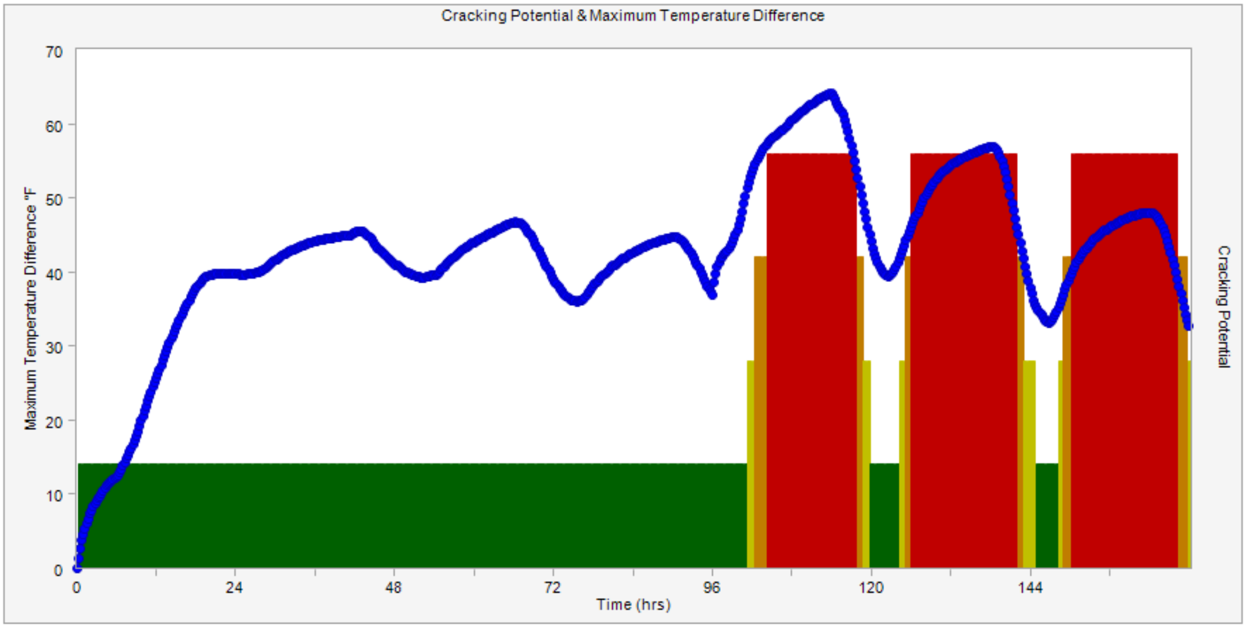
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Class F Fly Ash 10 Percent Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	64	°F
Max Temperature	127	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	479	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



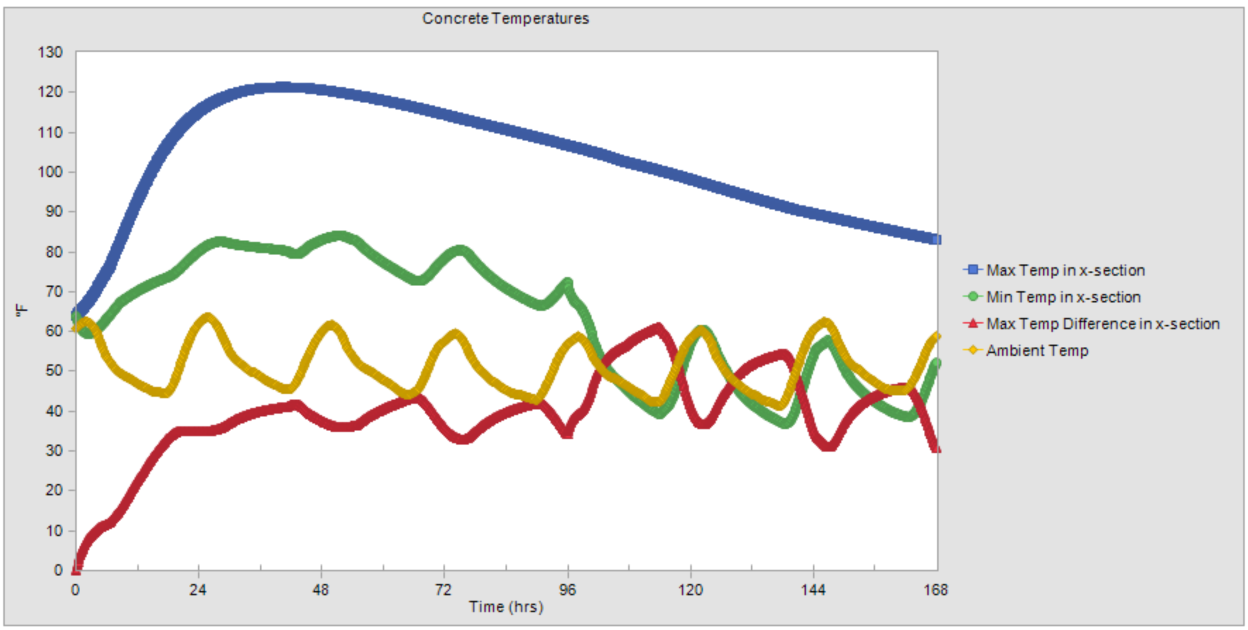


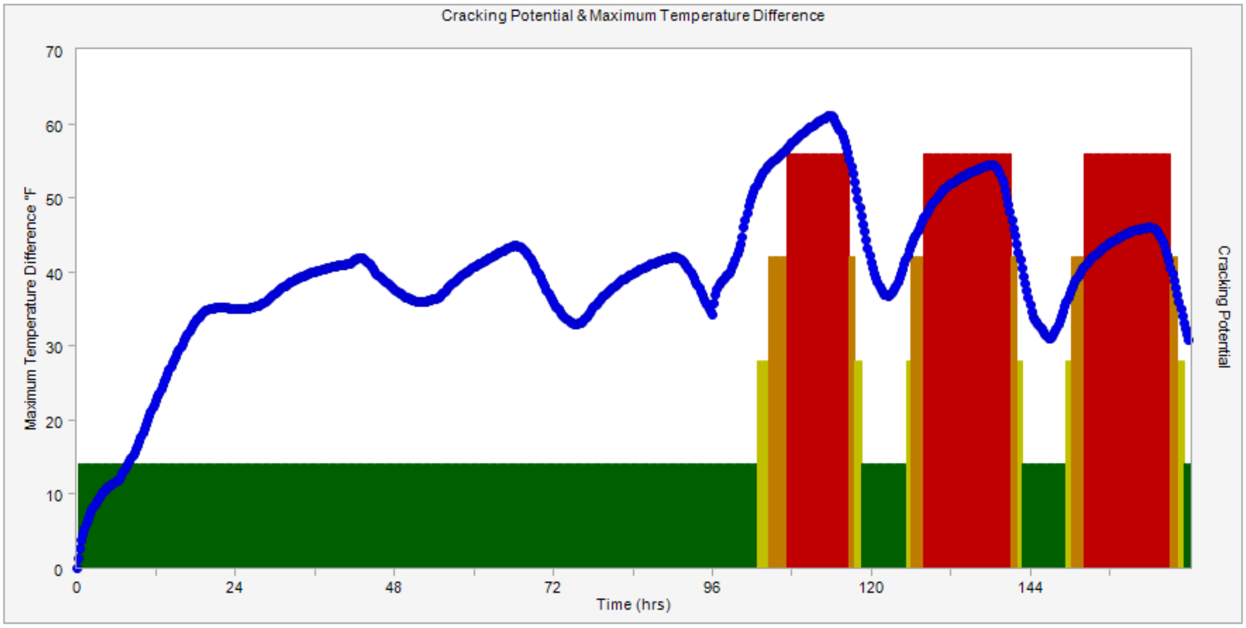
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Class F Fly Ash 20 Percent Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	61	°F
Max Temperature	121	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	426	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



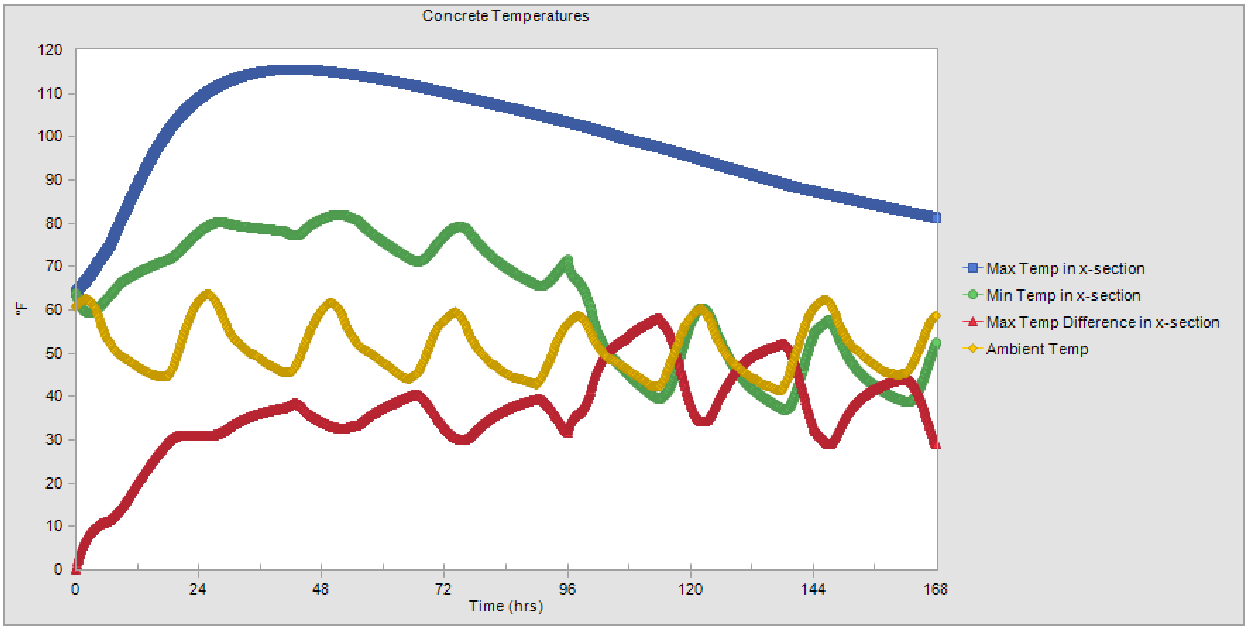


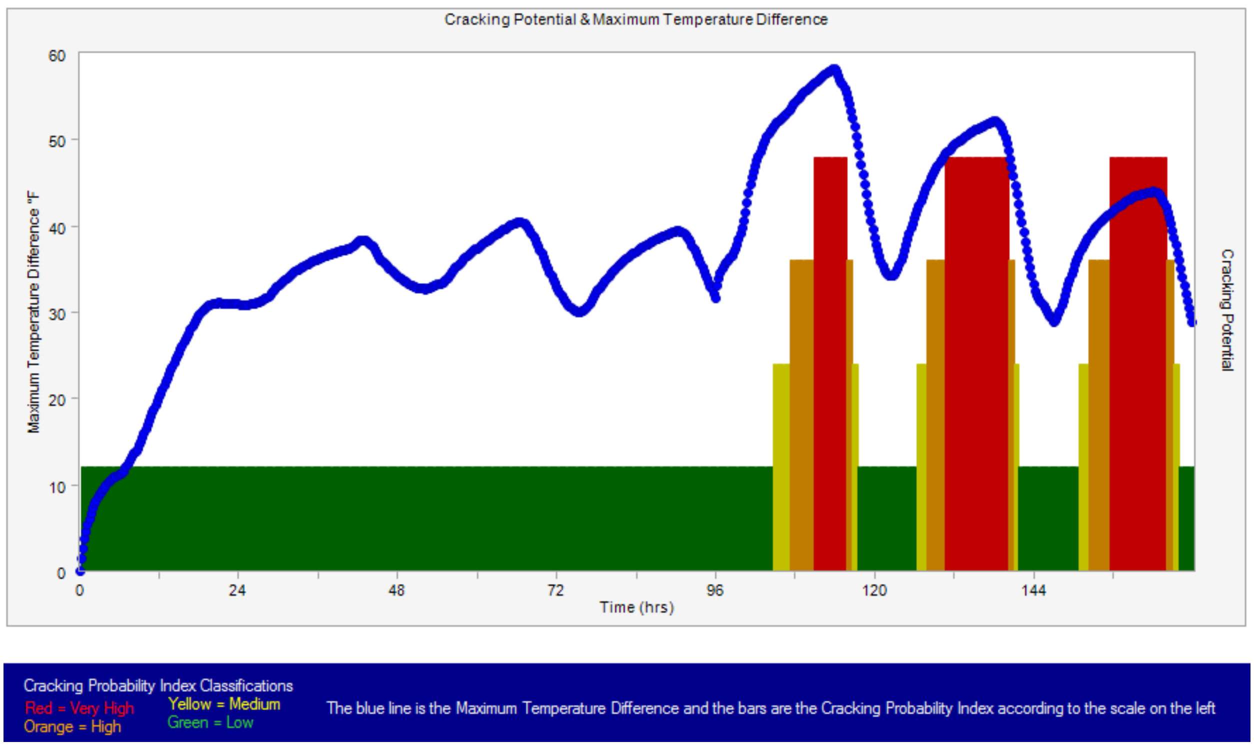
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Class F Fly Ash 30 Percent Substitution

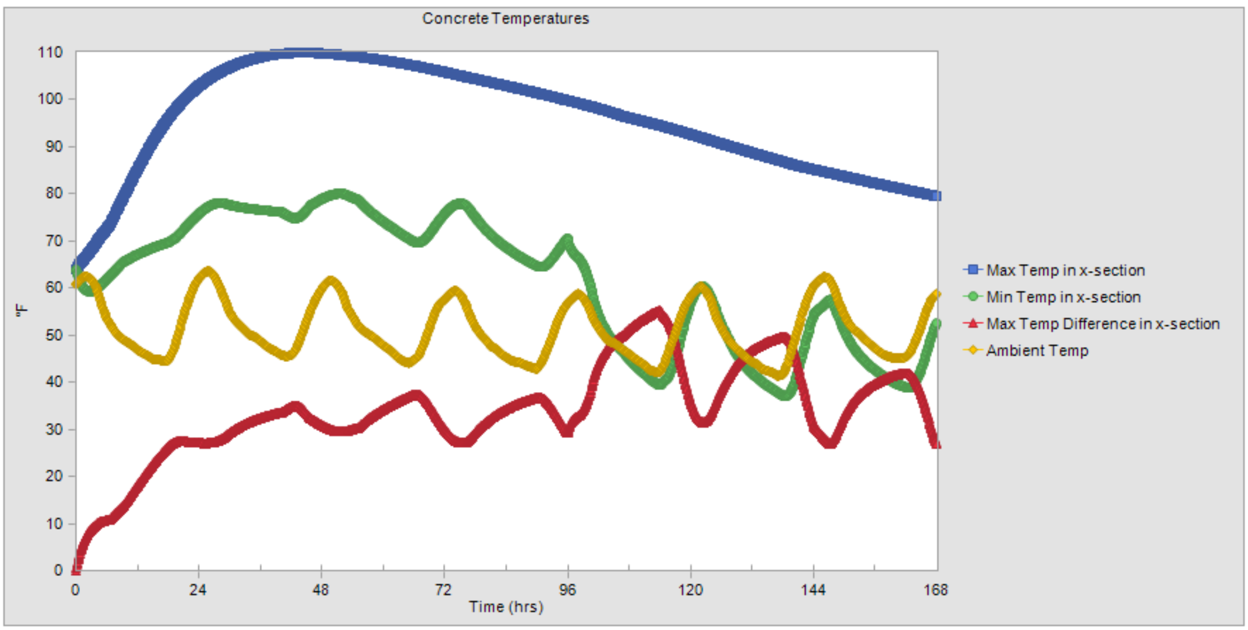
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	58	°F
Max Temperature	115	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	374	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

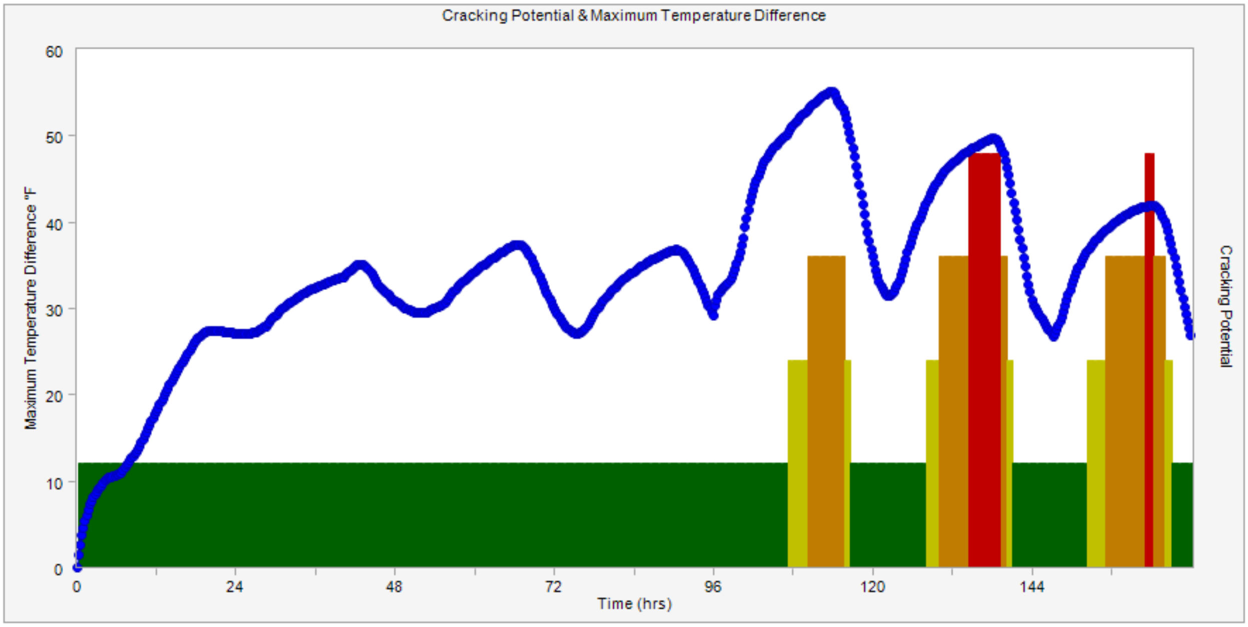

Concrete Temperatures
120
110
100
90
80
70
60
50
40
30
20
10
0
°F
0
24
48
72
96
120
144
168
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp


Cracking Potential & Maximum Temperature Difference
60
50
40
30
20
10
0
Maximum Temperature Difference °F
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Class F Fly Ash 40 Percent Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	55	°F
Max Temperature	109	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	321	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



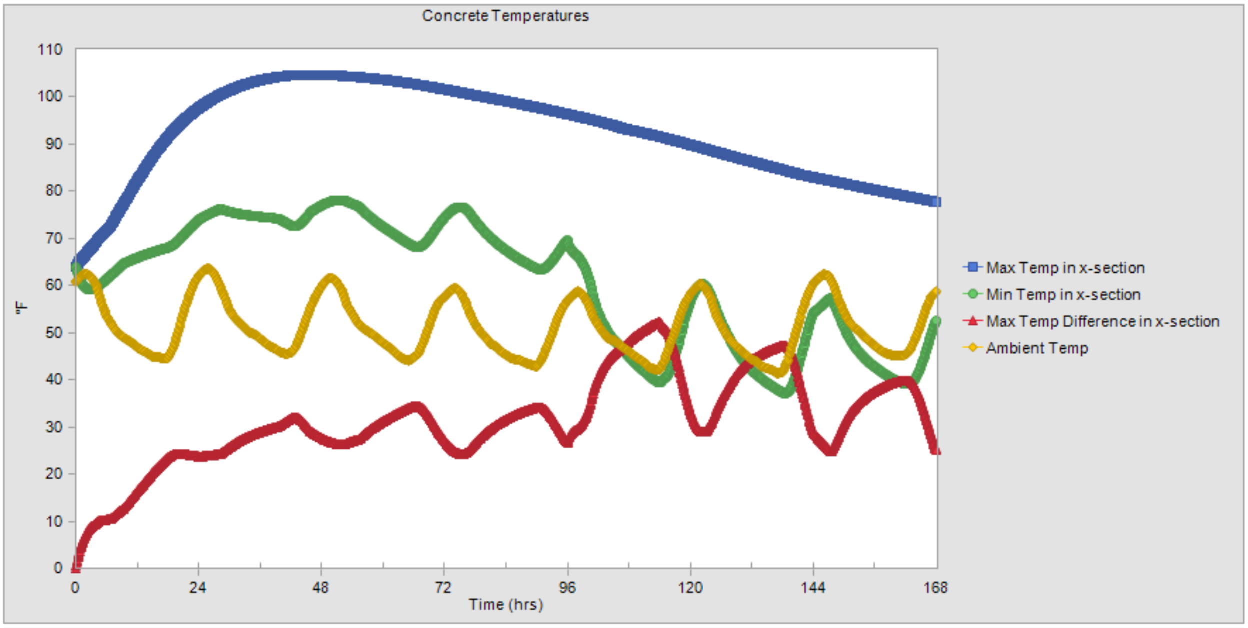


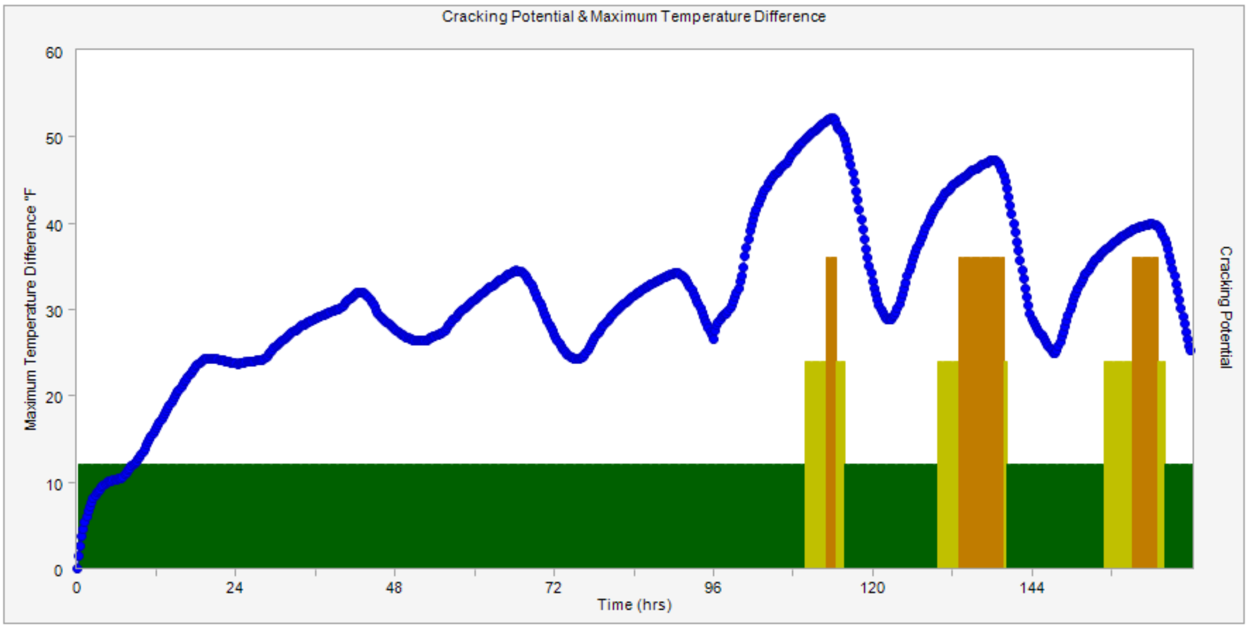
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Class F Fly Ash 50 Percent Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	52	°F
Max Temperature	104	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	268	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	High	



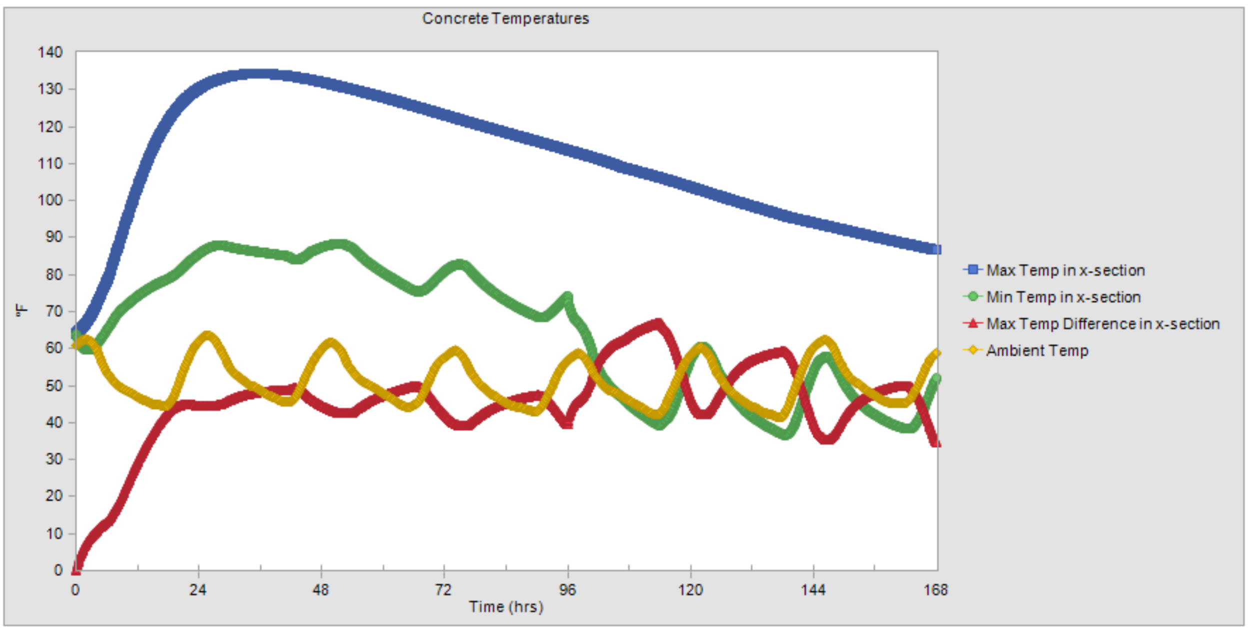


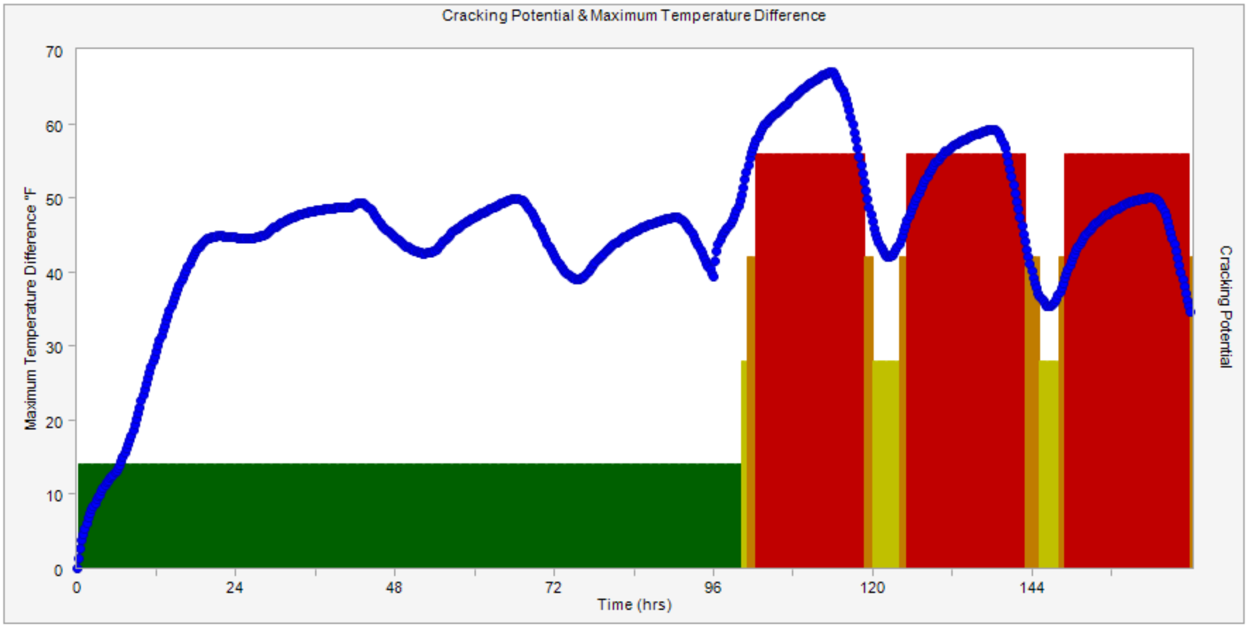
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Class C Fly Ash 0 Percent Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	67	°F
Max Temperature	134	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	564	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	18	Years
Time to Concrete Damage From Steel Corrosion	24	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



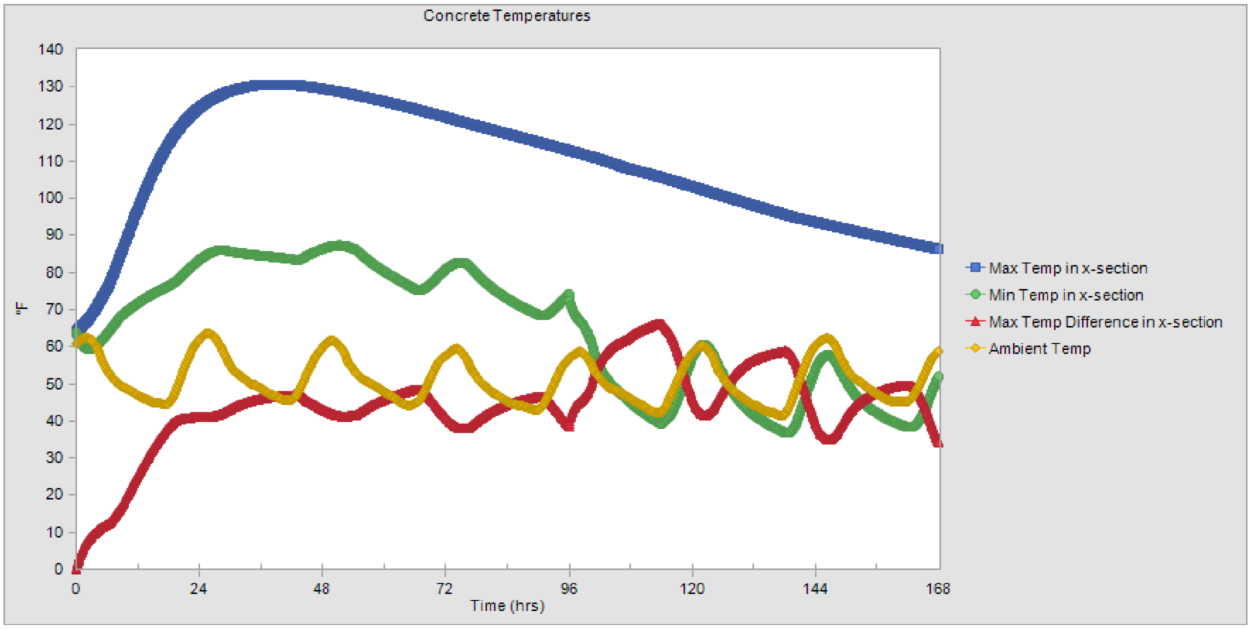


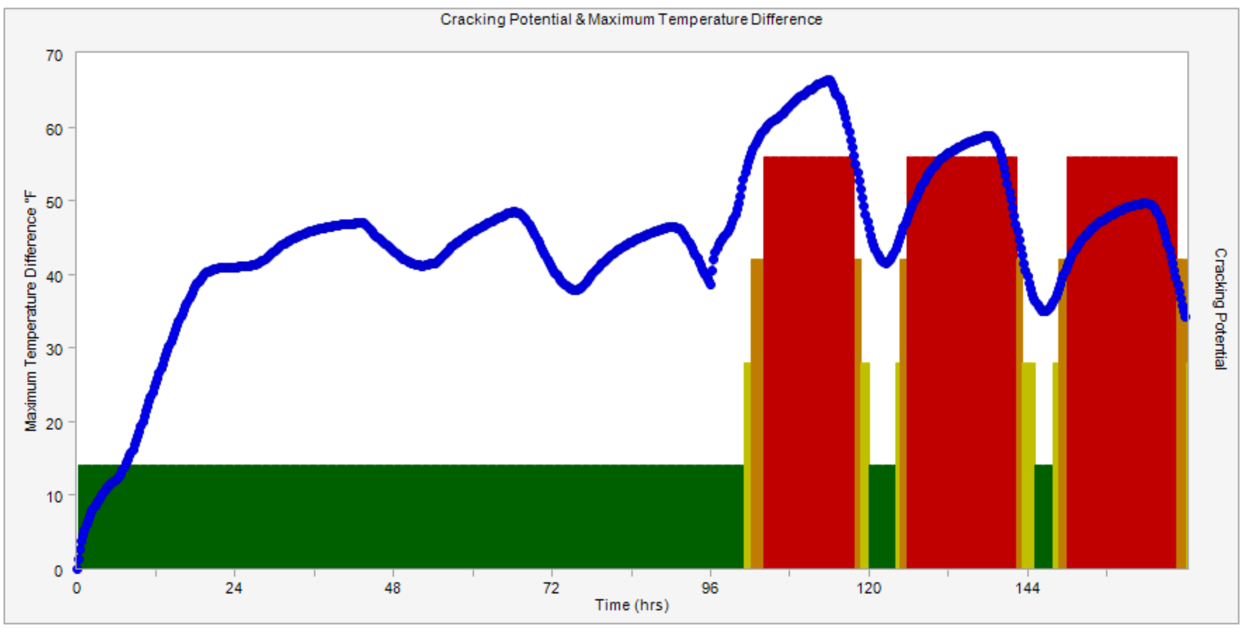
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Class C Fly Ash 10 Percent Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	66	°F
Max Temperature	130	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	479	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



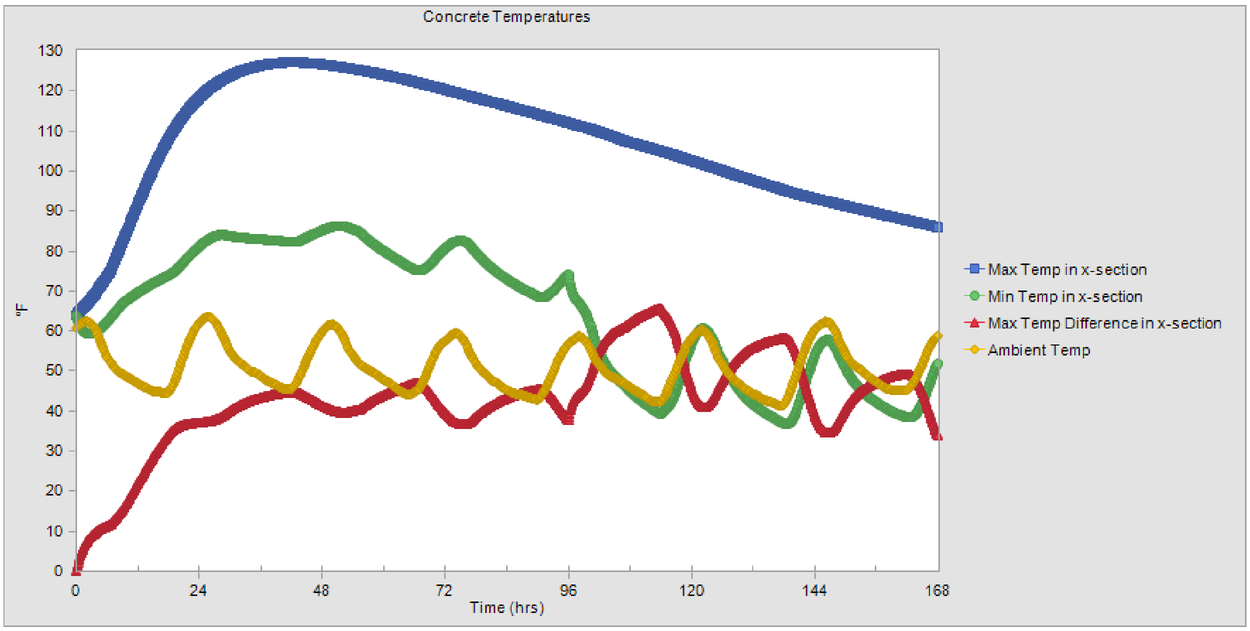


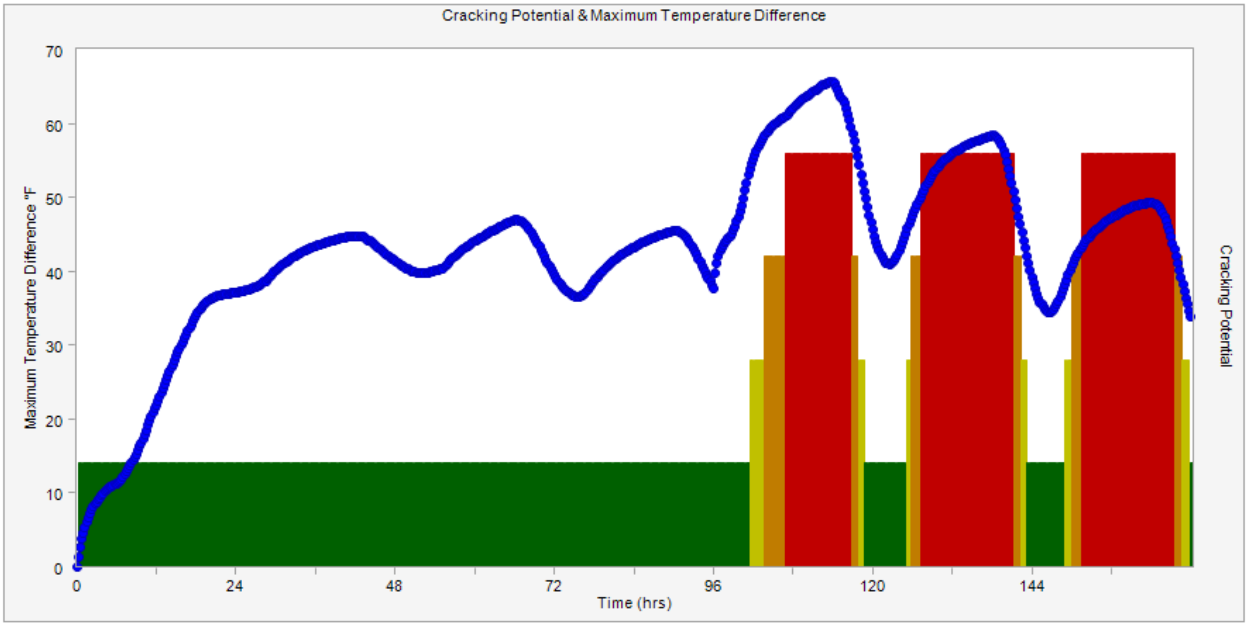
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Class C Fly Ash 20 Percent Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	65	°F
Max Temperature	127	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	426	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



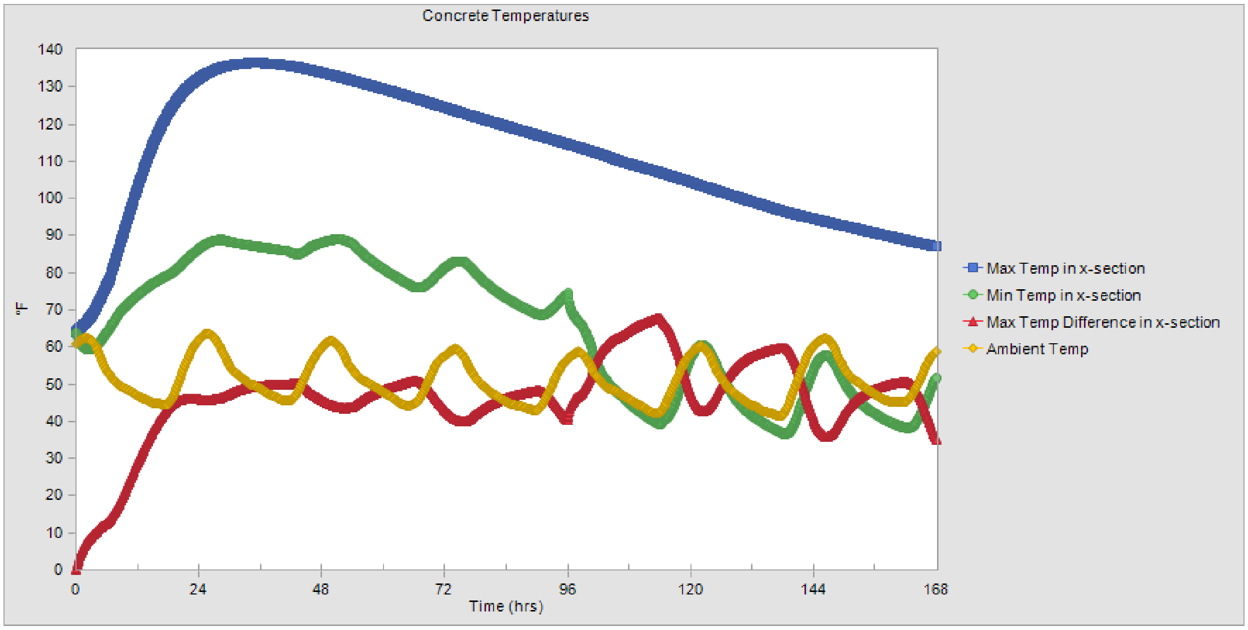


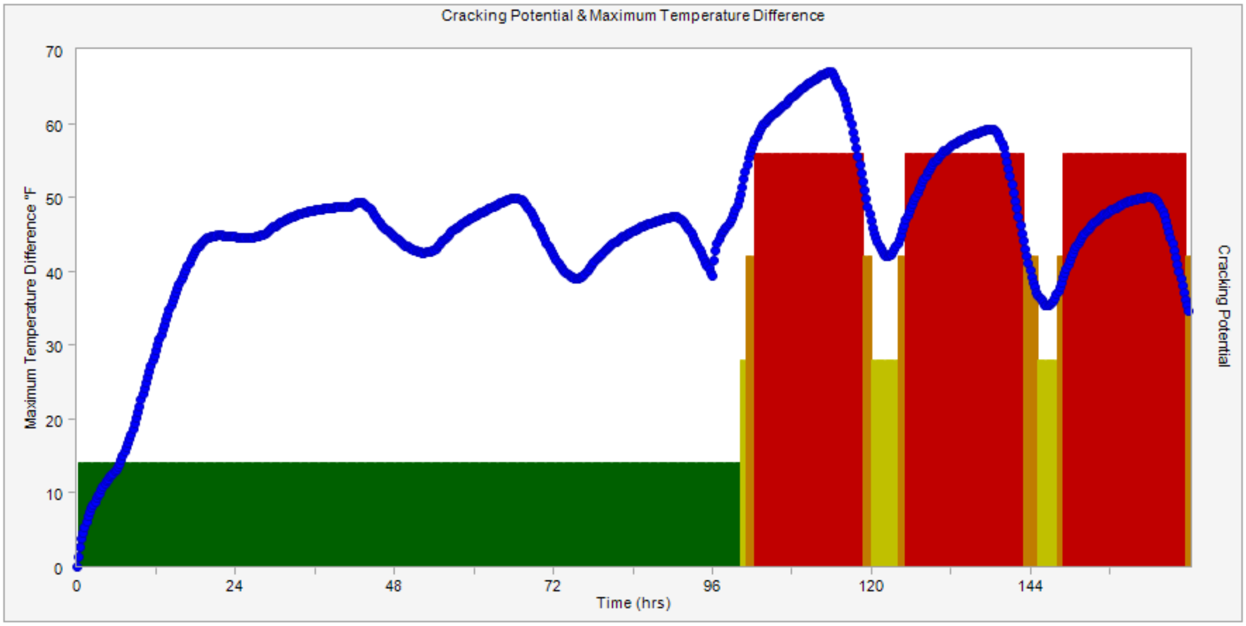
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

Ground Granulated Blast Furnace Slag

0 Percent GGBFS Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	67	°F
Max Temperature	136	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	564	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	18	Years
Time to Concrete Damage From Steel Corrosion	24	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Low	



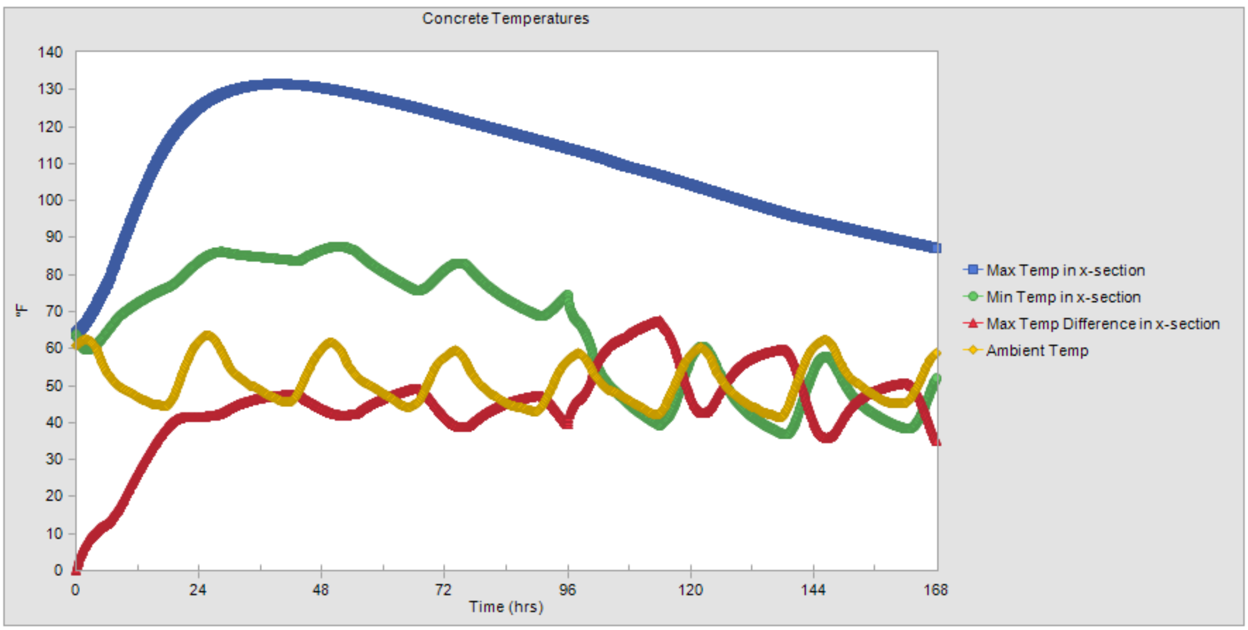


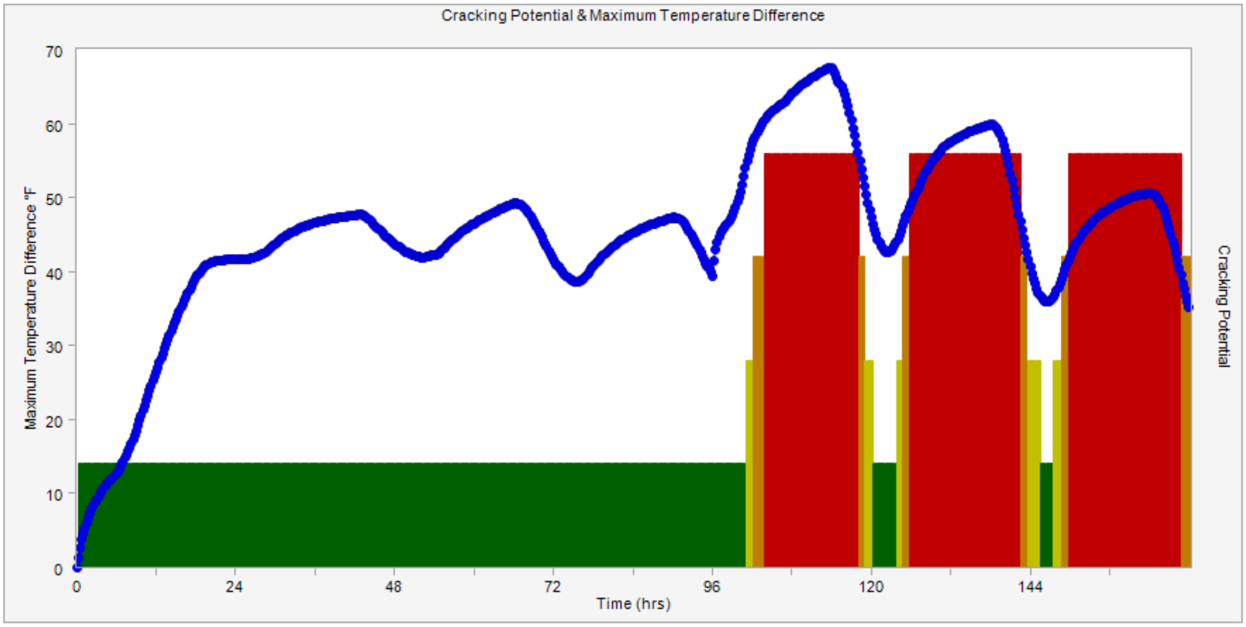
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

10 Percent GGBFS Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	67	°F
Max Temperature	131	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	485	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



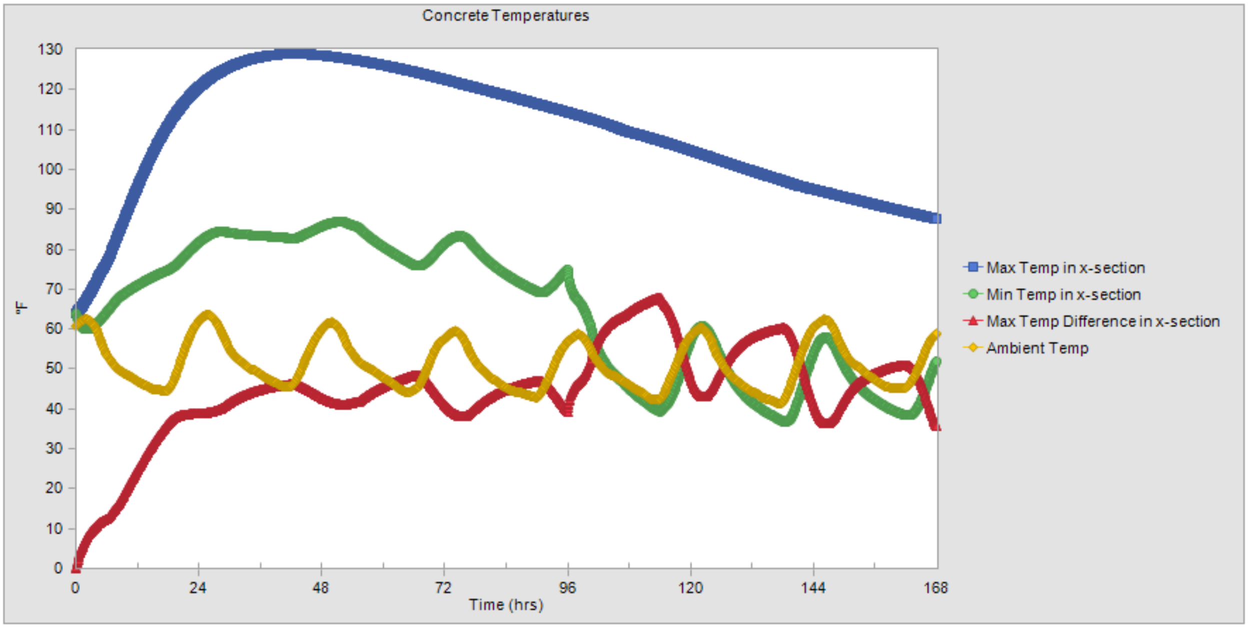


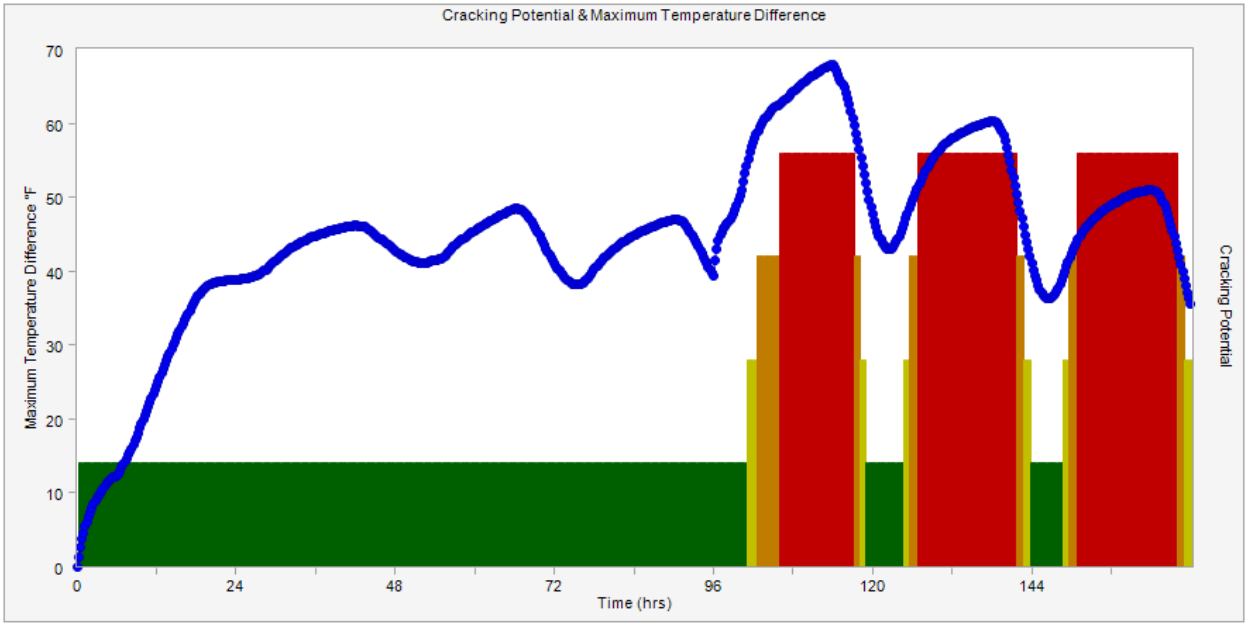
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

20 Percent GGBFS Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	67	°F
Max Temperature	128	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	439	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



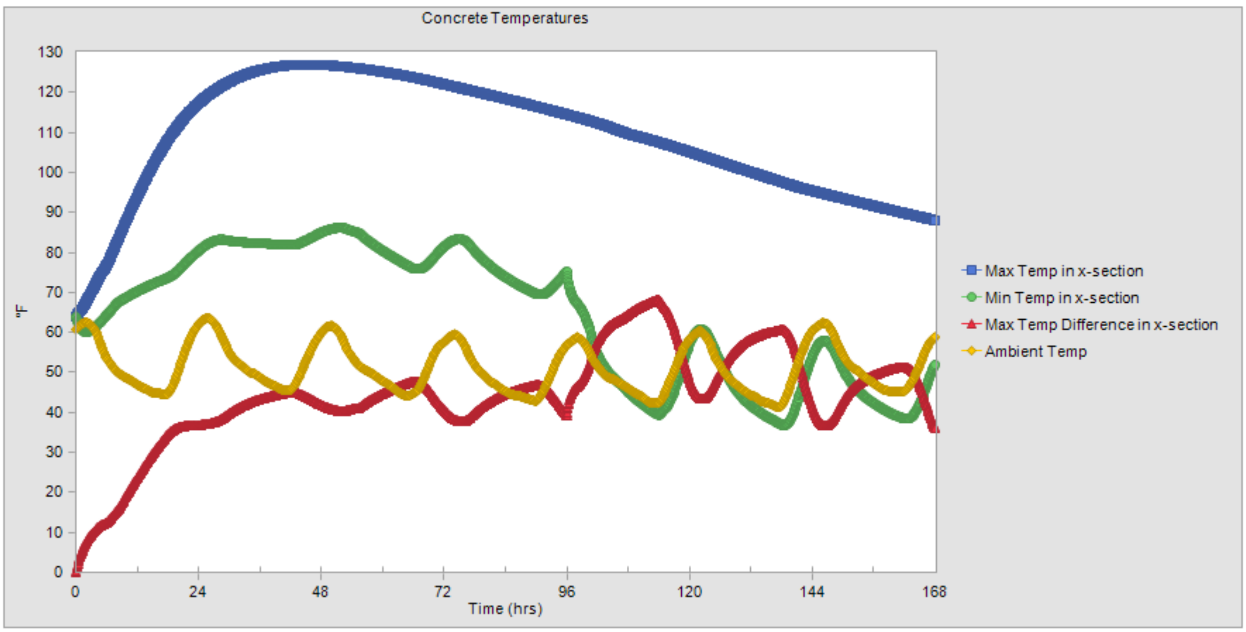


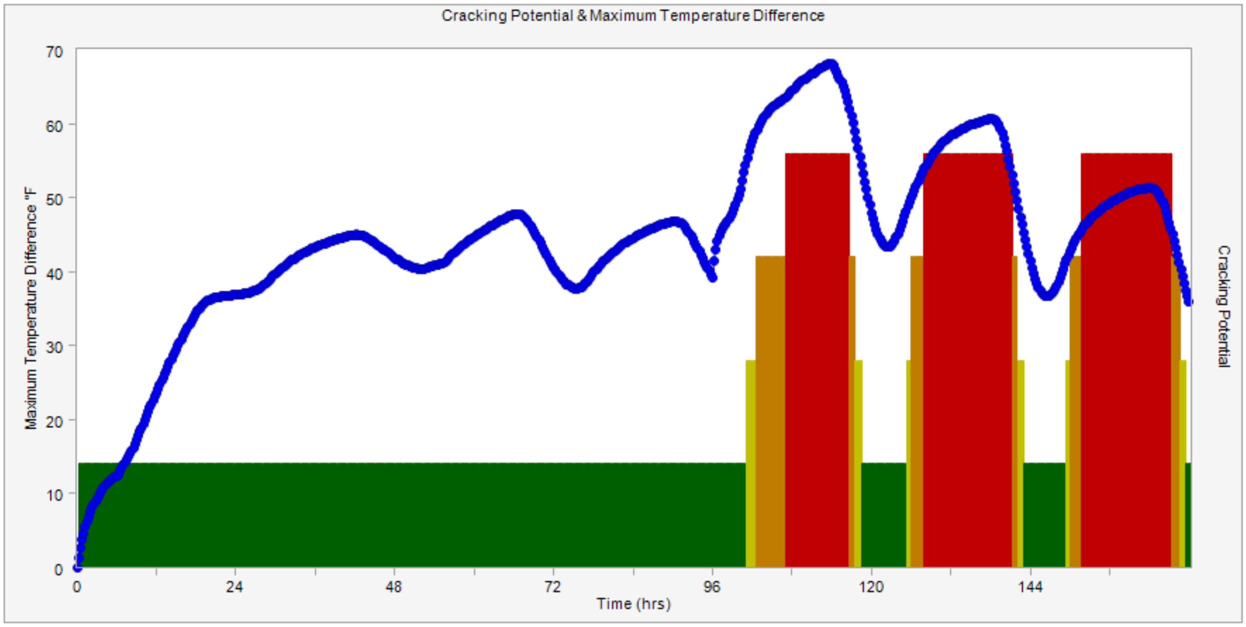
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

30 Percent GGBFS Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	68	°F
Max Temperature	126	°F
This mix is ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	394	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	



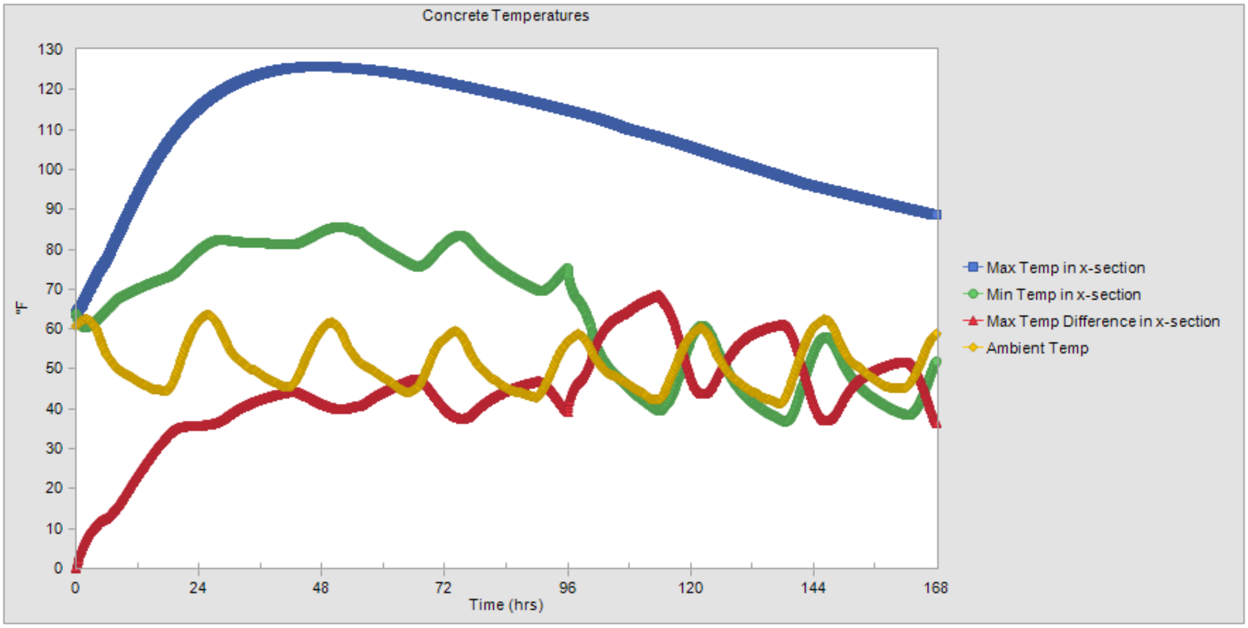


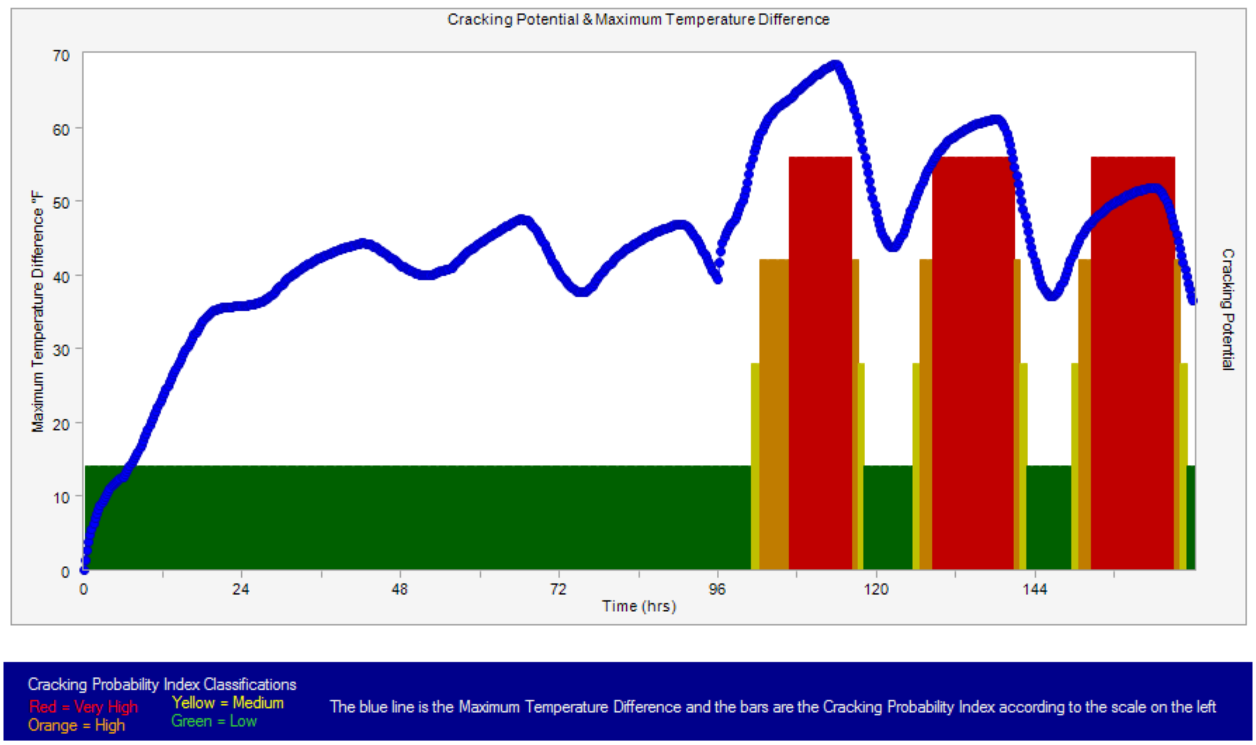
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low

The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

40 Percent GGBFS Substitution

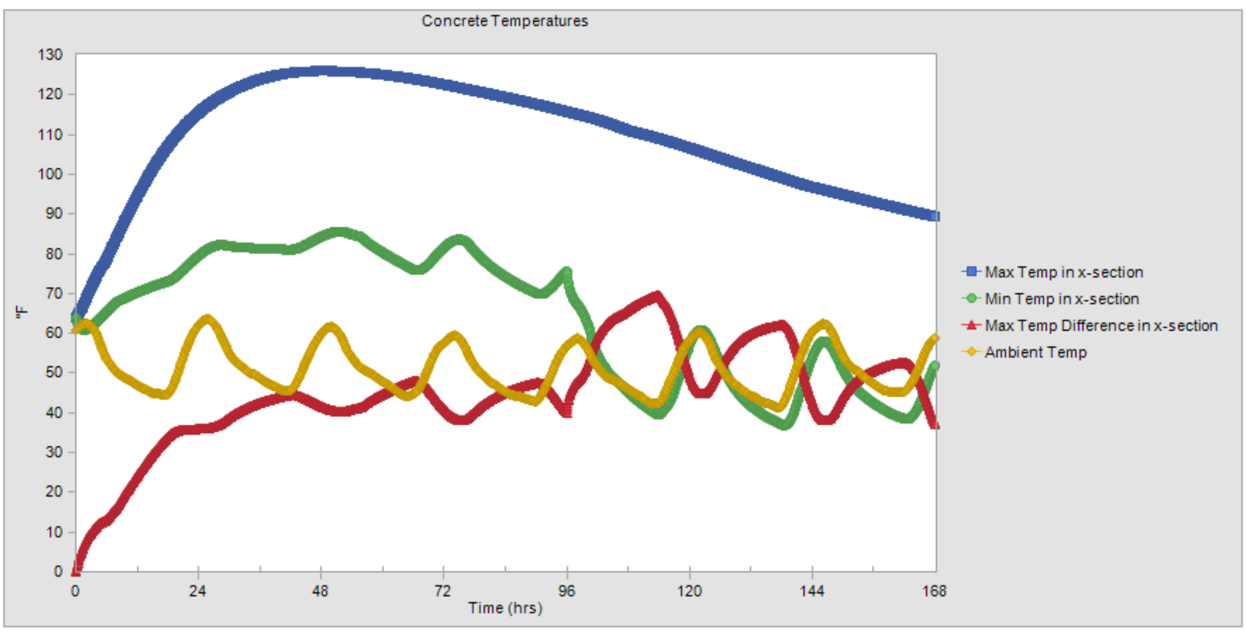
Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	68	°F
Max Temperature	125	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	347	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	

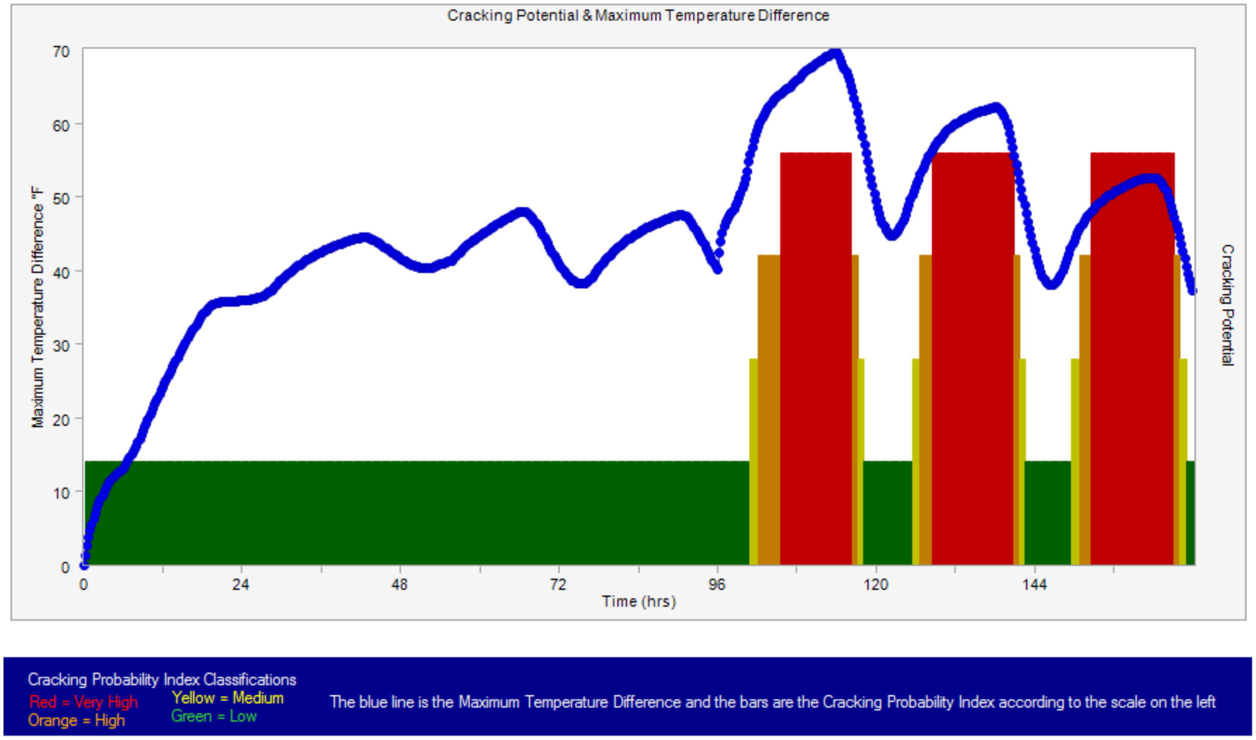

Concrete Temperatures
130
120
110
100
90
80
70
60
50
40
30
20
10
0
°F
0
24
48
72
96
120
144
168
Time (hrs)
Max Temp in x-section
Min Temp in x-section
Max Temp Difference in x-section
Ambient Temp


Cracking Potential & Maximum Temperature Difference
70
60
50
40
30
20
10
0
Maximum Temperature Difference °F
0
24
48
72
96
120
144
Time (hrs)
Cracking Potential
Cracking Probability Index Classifications
Red = Very High
Orange = High
Yellow = Medium
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

50 Percent GGBFS Substitution

Parameter	Value	Units
Results		
TxDOT 2004 Specifications Used		
Max Temperature Difference	69	°F
Max Temperature	125	°F
This mix is not ASR susceptable as defined by:	TxDOT	
Original Concrete Materials CO2 emissions	301	lb/yd³
Steel Corrosion Results		
Time to steel Corrosion	> 20	Years
Time to Concrete Damage From Top Mat Steel Corrosion	> 26	Years
Cracking Probability Index		
*Caution: A low cracking probability classification does not gaurantee that cracking will not occur.		
A low cracking probability classification only indicates that the concrete member may have a lower		
probability of cracking than one with a higher cracking probability classification.		
Cracking Probability Classification	Very High	





Cracking Potential & Maximum Temperature Difference
Maximum Temperature Difference °F
Cracking Potential
Time (hrs)
0
24
48
72
96
120
144
0
10
20
30
40
50
60
70
Cracking Probability Index Classifications
Red = Very High
Yellow = Medium
Orange = High
Green = Low
The blue line is the Maximum Temperature Difference and the bars are the Cracking Probability Index according to the scale on the left

APPENDIX D. DIFFERENCES BETWEEN CLASS C AND CLASS F FLY ASH

Class C and Class F fly ashes are supplementary cementitious materials commonly used for a variety of applications. Class F is a low-calcium fly ash with a CaO (also known as lime) percentage of less than 10 percent, while Class C fly ash has higher calcium content with CaO values of 10 to 30 percent. Class F fly ash also contains more carbon (up to 10 percent), compared to Class C fly ash (up to 2 percent). Generally Class F fly ash is a by-product of burning anthracite and bituminous coal, while Class C is usually the result of burning subbituminous coal or lignite.

A distinguishing factor between Class F fly ash and Class C fly ash is that Class F is exclusively a pozzolanic material, while Class C is both a pozzolanic and cementitious material. The difference between a pozzolanic and a cementitious material is that a cementitious material will hydrate in the presence of water. A pozzolanic material requires additional calcium for hydration to occur.

Both Class C and Class F fly ash mixes experience delayed setting times as well as higher ultimate strength when hydration is completed. Class F fly ash is a common cementitious material for high-performance concrete, along with applications experiencing high sulfate exposure. Class C fly ash is used in situations where sulfate exposure is not a concern and generally makes up a smaller percentage of the mix. Class C fly ash also produces more heat during hydration in comparison to Class F fly ash. Class C fly ash generally develops strength more rapidly compared to Class F. Class F fly ash has the capacity to decrease Alkali-Silica Reactions (ASR) of a concrete. The ASR reduces the durability of the concrete by causing cracks.