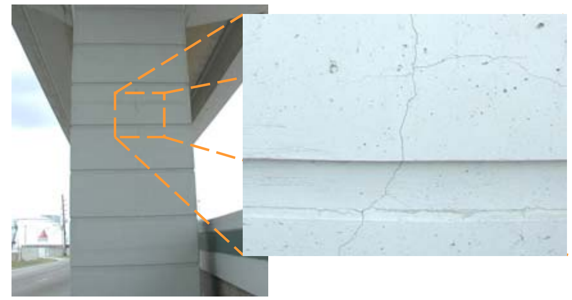
Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

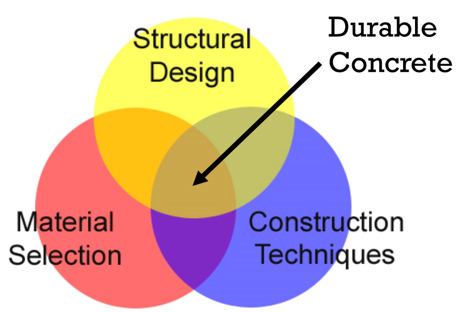
ConcreteWorks Software For Iowa Use

Thermal Cracking



Picture courtesy of J.C. Liu, TxDOT

Achieving Durable Concrete



Concrete Mixtures

Infinite number of combinations of:

- Aggregate type & quantity
- Type & amount of cement
- SCM use
- Admixtures

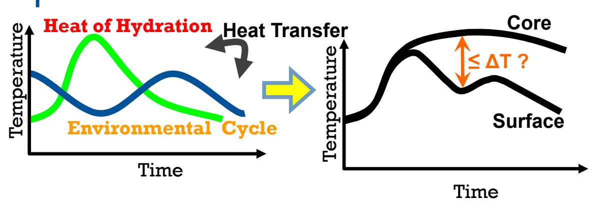
Why do we model temperature and stress?

- Quality concrete
- Multi-variate problem –
  - rules of thumb can be inaccurate or unconservative
- Preplanning
  - Engineer – Best during design
  - Contractor – Best during bidding
- Required by specification

Self-Generated Restraint

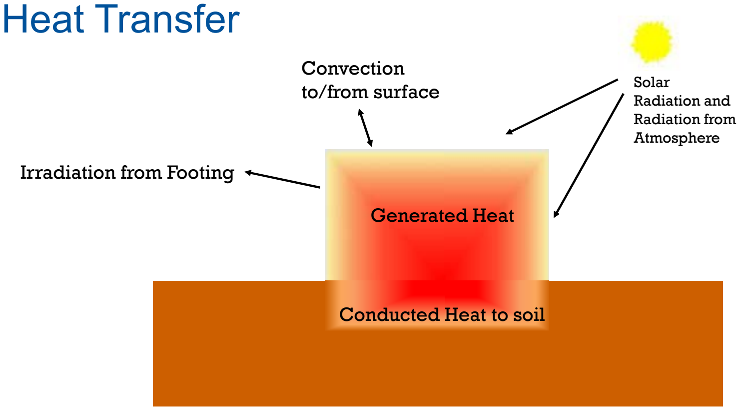
- Why is the bread surface cut before baking?

Temperature Prediction

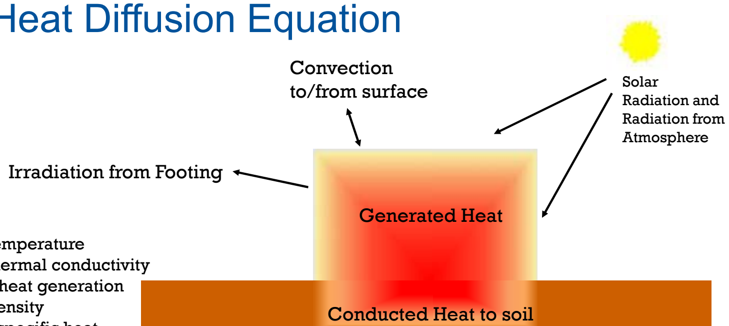


Material Factors	Construction Factors	Environment
Cementitious Types/Composition	Element Geometry/Size	Air Temperature
Cementitious Fineness	Insulation	Wind Speed
Cementitious Content	Form Properties	Relative Humidity
Chemical Admixtures	Curing Methods	Cloud Cover
w/cm	Surface Color	Solar Radiation
Fresh Temperature	Cooling Pipes	Soil
Aggregate Types		Water Submersion

Heat Transfer



Heat Diffusion Equation



T=temperature
k=thermal conductivity
Q_H=heat generation
ρ=density
C_p=specific heat
T=time

$$\frac{d}{dx}\left(k\cdot\frac{dT}{dx}\right)+\frac{d}{dy}\left(k\cdot\frac{dT}{dy}\right)+\frac{d}{dz}\left(k\cdot\frac{dT}{dz}\right)+Q_H=\rho\cdot C_p\cdot\frac{dT}{dt}$$

Temperature Prediction Methods

Increasing Complexity ↓

- Estimate Max Temperature
- Schmidt Method
- ConcreteWorks
- Proprietary software (Finite Element Analysis)

Heat Evolved at Each Time Step

(Schindler, 2002)

From Semi-Adiabatic Calorimetry

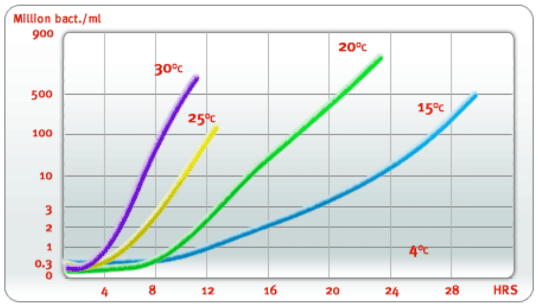
$$Q_h(t)=H_u\cdot W_c\cdot\left(\frac{\tau}{t_e}\right)^{\beta}\cdot\left(\frac{\beta}{t_e}\right)\cdot\alpha(t_e)\cdot\exp\left(\frac{E_a}{R}\left(\frac{1}{T_r}-\frac{1}{T_c}\right)\right)$$

From Literature

From Isothermal Calorimetry

Role of Temperature in Hydration

Temperature Sensitivity Example



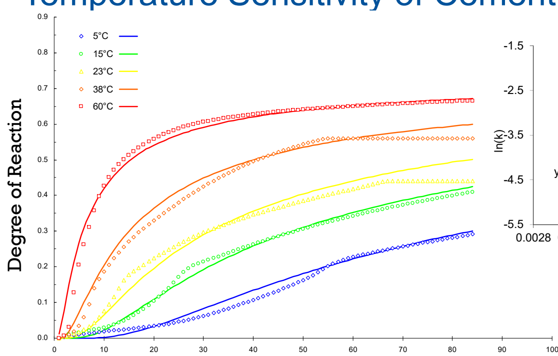
Effect of temperature on bacteria growth in milk

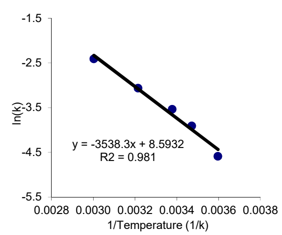
Arrhenius Equation

- Reaction Rate (S. Arrhenius, 1889)
  - Where
    - k = rate of reaction
    - A = constant (=0)
    - R = Universal gas constant (8.314)
    - T = reference temperature
    - E_a = Activation Energy

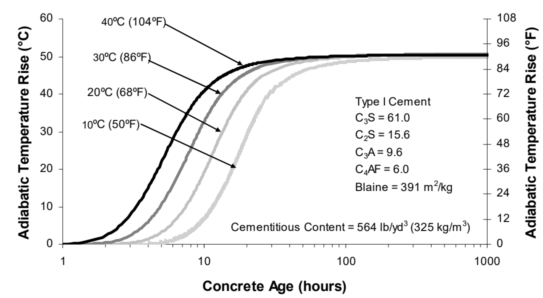
$$\ln k = \ln A - \frac{E_a}{RT}$$

Temperature Sensitivity of Cement Reaction





Effects of Curing Temperature on Adiabatic Temperature Rise



Heat Evolved at Each Time Step

(Schindler, 2002)

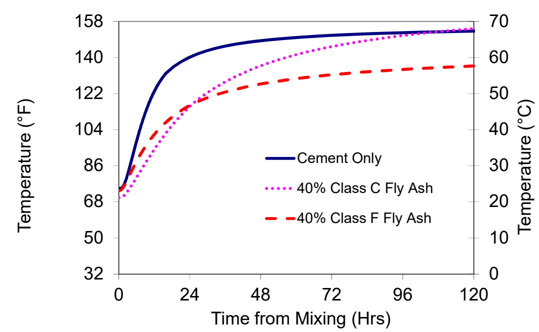
From Semi-Adiabatic Calorimetry

$$Q_h(t) = H_u \cdot W_c \cdot \left(\frac{\tau}{t_e}\right)^{\beta} \cdot \left(\frac{\beta}{t_e}\right) \cdot \alpha(t_e) \cdot \exp\left(\frac{E_a}{R}\left(\frac{1}{T_r} - \frac{1}{T_c}\right)\right)$$

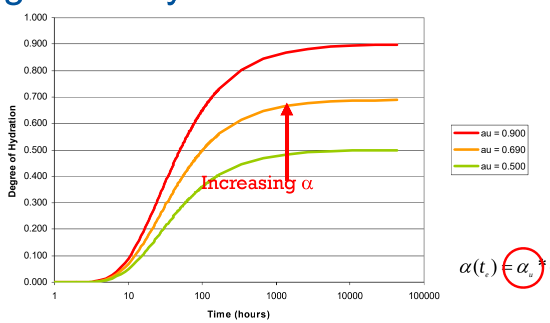
From Isothermal Calorimetry

From Literature

Adiabatic or Semi-Adiabatic Calorimetry



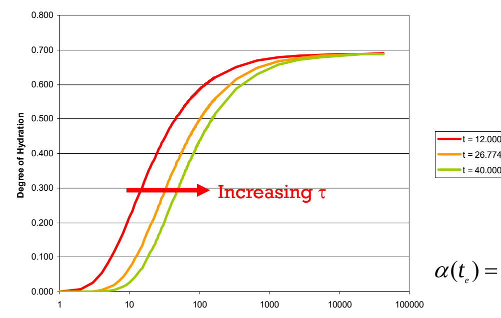
α –Degree of Hydration



$$\alpha(t_e) = \alpha_u * \exp\left(-\left[\frac{\tau}{t_e}\right]^{\beta}\right)$$

Figure Courtesy of Jonathan Poole

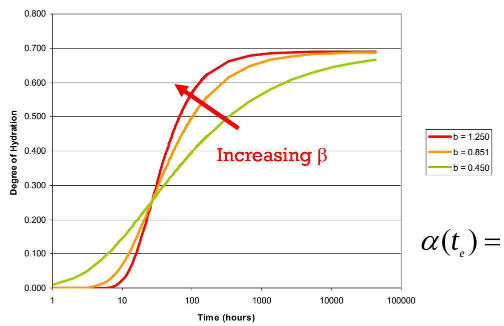
τ –Time Parameter



$$\alpha(t_e) = \alpha_u * \exp\left(-\left[\frac{\tau}{t_e}\right]^{\beta}\right)$$

Figure Courtesy of Jonathan Poole

β –Slope Parameter



$$\alpha(t_e) = \alpha_u * \exp\left(-\left[\frac{\tau}{t_e}\right]^{\beta}\right)$$

Figure Courtesy of Jonathan Poole

Model for Hydration Built From:

- E_a Trends – From 116x5 Isothermal tests
- α_u, τ, β, H_u Trends – From Semi-Adiabatic Data – 204 Semi-Adiabatic Tests
- Validation performed using data from Schidler (2005), Ghe Li (2006), and field sites – 58 Semi-Adiabatic Tests
- Variability of test methods is quantified – 63 Semi-Adiabatic Tests.
- A brief overview of the trends seen in the study is shown next.

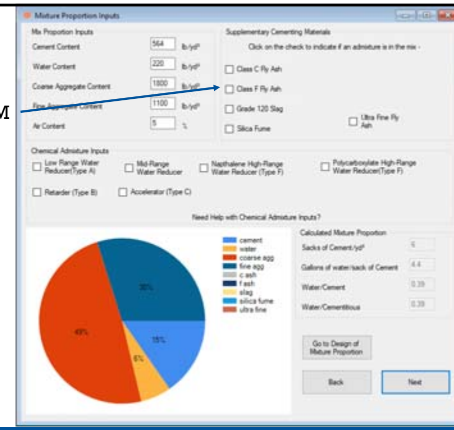
Variable	Range of Tests	Effect on τ	Effect on β	Effect on α_u
Fly Ash (%Replacement)	15-55%			
Fly Ash (CaO%)	0.7-28.9% CaO			Varies
GGBF slag	30-70%	Large	Small	Varies
Silica Fume	5-10%	None	None	Small

Variable	Range of Tests	Effect on τ	Effect on β	Effect on α_u
LRWR	0.22-0.29%	Varies	Small	Varies
WRRET	0.18-0.53%	Large	Large	Large
MRWR	0.34-0.74%	Large	Small	Varies
HRWR	0.78-1.25%	None	Small	Large
PCHRWR	0.27-0.68%	None	Small	Large
ACCL	0.74-2.23%	Small	None	Varies
AEA	0.04-0.09%	None	None	None

Variable	Range of Tests	Effect on τ	Effect on β	Effect on α_u
Increasing w/c	0.32-0.68	None	None	Large
Placement Temp	15-38 °C (50-100 °F)	None	None	None
Increase Cement Fineness	350-540 m^2/kg	Small	Small	Varies

Proportions

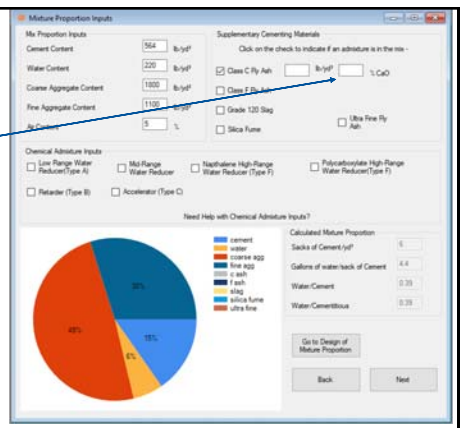
Click checkboxes to use an SCM



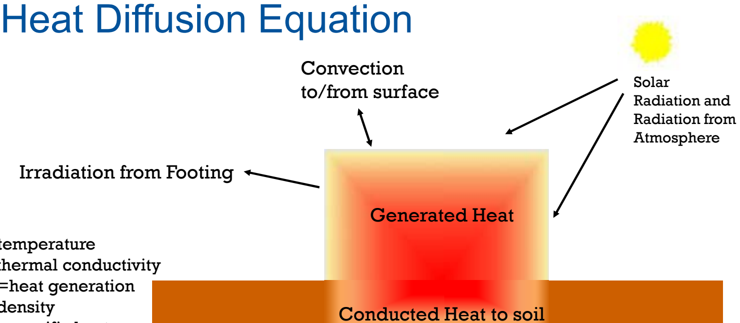
Proportions

Don't forget to enter CaO content of fly ashes

Check when admixtures used.



Heat Diffusion Equation



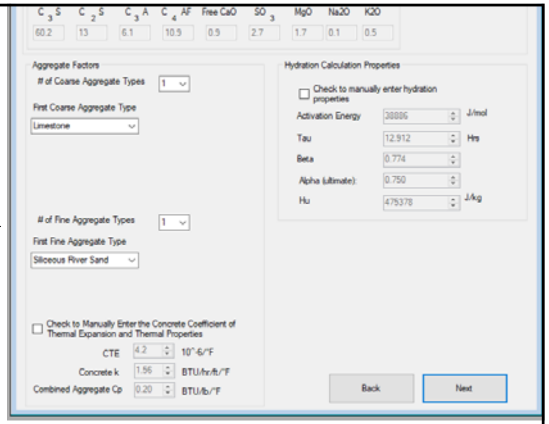
T=temperature
k=thermal conductivity
Q_H=heat generation
ρ=density
C_p=specific heat
T=time

$$\frac{d}{dx}\left(k\frac{dT}{dx}\right)+\frac{d}{dy}\left(k\frac{dT}{dy}\right)+\frac{d}{dz}\left(k\frac{dT}{dz}\right)+Q_H=\rho\cdot C_p\cdot\frac{dT}{dt}$$

Aggregates

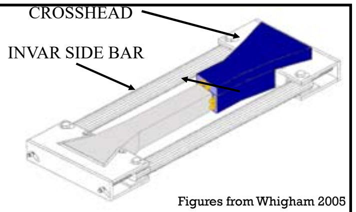
Material Properties Input Screen

- Concrete thermal properties based on aggregate combination selected
- Can input your own thermal properties by checking box (for example, to use lightweight aggregate)

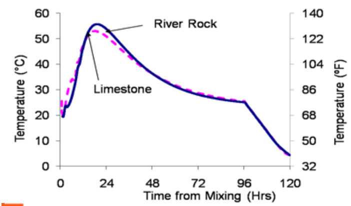


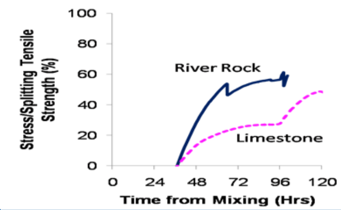
Aggregate Type

Coarse Aggregate	Concrete CTE
River Rock	10.5 με/° C
Limestone	6.6 με/° C



Figures from Whigham 2005





Aggregates

$$\alpha_{cteh} = \frac{\alpha_{ca} \cdot V_{ca} + \alpha_{fa} \cdot V_{fa} + \alpha_{p} \cdot V_{p}}{V_{ca} + V_{fa} + V_{p}}$$

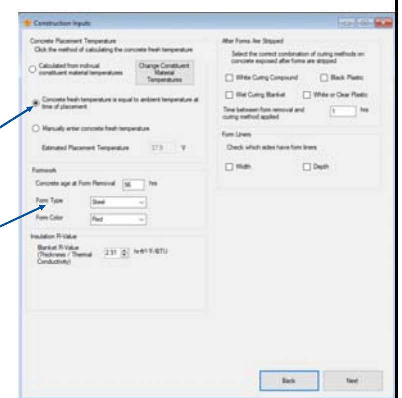
Material	Coefficient of Thermal Expansion values used in ConcreteWorks (με/°C)	Coefficient of Thermal Expansion from Emanuel and Hulsey, 1977 (με/°C)
Hardened Cement Paste	10.8	10.8
Limestone Aggregate	3.5	3.5 - 6
Siliceous River Gravel and Sand	11	11 – 12.5
Granite Aggregate	7.5	6.5 – 8.5
Dolomitic Limestone Aggregate	7	7 - 10

Construction Inputs

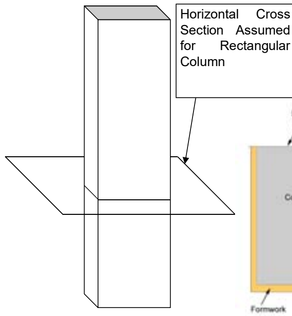
Default is use air temperature at placement

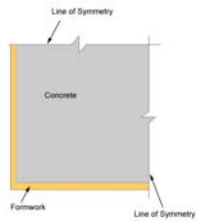
Options: steel, wood, and insulated steel formwork

*If insulated steel forms used, form insulation value appears

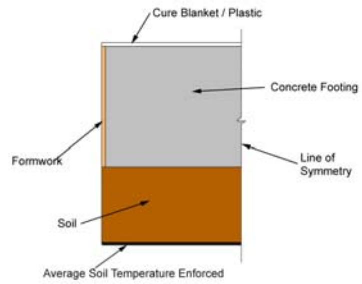


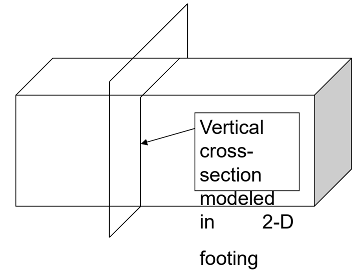
ConcreteWorks Geometry: Columns





ConcreteWorks Geometry: Footings



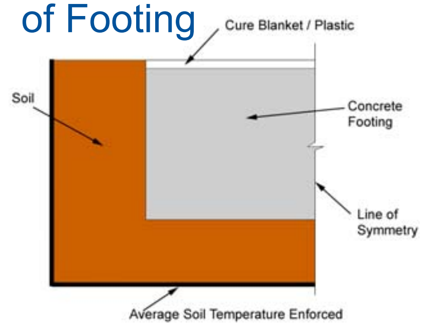


Foundation Thermal Properties

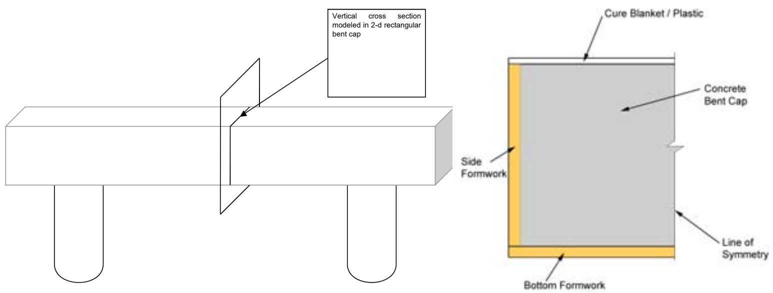
Subbase Material	Density (kg/m3)	Thermal Conductivity (W/m/K)	Specific Heat (J/kg/K)	Reference
Clay	1460	1.3	880	
Granite	2630	2.79	775	
Limestone	2320	2.15	810	
Marble	2680	2.8	830	
Quartzite	2640	5.38	1105	
Sandstone	2150	2.9	745	
Sand	1515	0.27	800	Incropera and Dewitt, 2002
Top Soil	2050	0.52	1840	
Concrete*	-	-	-	

*Concrete is assumed to have the same thermal properties of the concrete used on the footing, with a degree of hydration equal to 0.6.

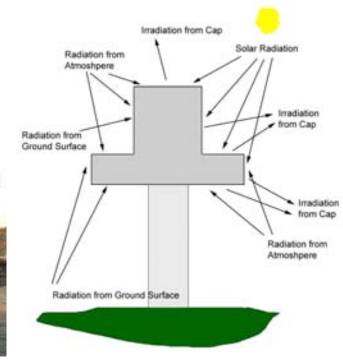
ConcreteWorks Geometry: Soil on Sides of Footing



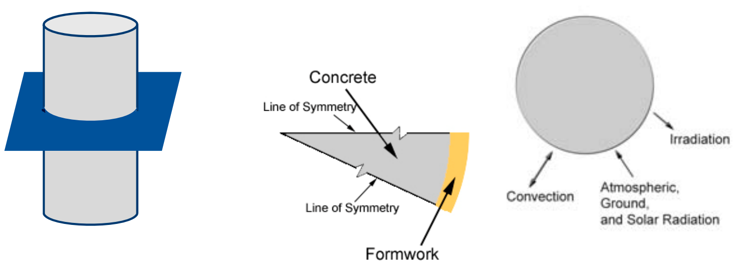
Bent Cap



T-shaped Bent Caps

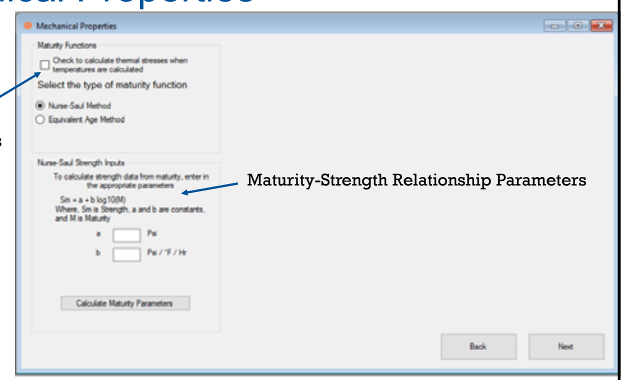


Circular Column/ Drilled Shaft



Mechanical Properties

Check to calculate stresses – can be slow, not recommended for more than 4-5 days of analysis

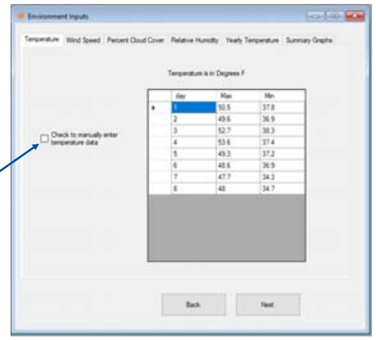


Maturity-Strength Relationship Parameters

Environment Inputs (Weather)

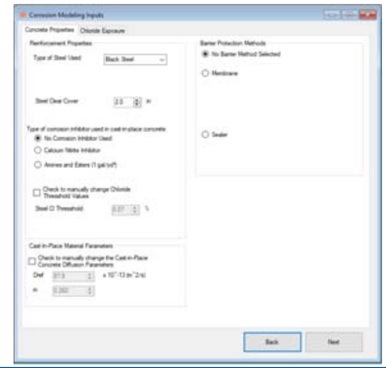
Weather data based on 30 year average values

Click here to manually change values



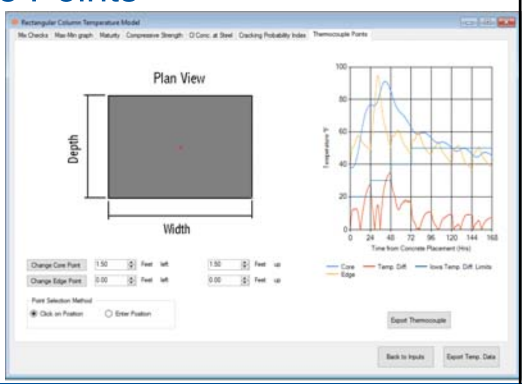
Service Life Modeling

Used for corrosion service life model inputs



Thermocouple Points

Allows the user to select where sensors would be placed to give realistic estimate of values they would measure



Acknowledgements

- TxDOT (original software development) & IDOT for providing funding for this work

Problems to Work Out After Lunch

- Design a concrete control plan for a 8 ft by 10 ft column placed in Ames in August 2020 to meet IDOT standards.
- Next, determine any changes that would be needed to place the same column in January, 2021 in Ames.

*Pay attention to the difference it makes where the temperature sensor is placed

Problems to Work Out After Lunch

- Design a control plan for concrete footing that is 20 ft by 30 ft by 8 ft thick in Des Moines in March. Use limestone subbase. What difference do you get between 1D and 2D analysis?
- What about with a 10 ft wide footing – what difference do you get between a 1D and 2D analysis?

Problems to Work Out After Lunch

- You want to place a concrete footing that is 30 ft by 20 ft by 6 ft thick. It is August in Des Moines, and you expect a storm after 2 days to lower the high temperature to 60° F and the low temperature on day 2 to 45° F. Design a system that will still meet IDOT standards.