Numerical Modeling of Heat Transfer in Reinforced Concrete

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Project Overview

Fire engineering has become increasingly important in recent years because of outdated building design codes. Currently, U.S. Building codes do not consider fire as a design condition and only specify regulatory requirements for fire performance of building components. To improve the safety of buildings, this research studied the temperature distribution within a commonly used structural wall.

Objective

Analyze the heat transfer within a reinforced concrete wall subjected to the ASTM E119 standard fire time-temperature curve using the finite element code LS-DYNA.

Modes of Heat Transfer

Conduction

- From conservation of heat energy:
  rate of increase of heat in V = rate of heat conduction into V across S + rate of heat generation within V

The basic governing equation for a nonlinear transient problem is:

$$\frac{\partial}{\partial x}\left(k(T)\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k(T)\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k(T)\frac{\partial T}{\partial z}\right)+Q=\rho c(T)\frac{\partial T}{\partial t}$$

Natural Convection

- Was considered at the boundary between the concrete wall and the air
- The boundary condition is given by the equation

$$q'' = h(T - T_\infty)$$

- where h – convection heat transfer coefficient

Radiation

- the energy emitted by the wall to the environment at the wall boundaries
- Taken as a boundary condition, the equation is

$$q'' = \mathrm{f}\left(T_{surf}^4 - T_\infty^4\right)$$

- f=εσ, ε-emissivity and σ-Stefan Boltzmann constant

Problem Statement

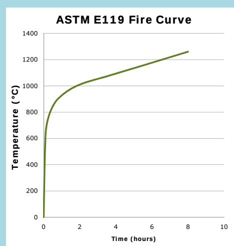
Structural Wall

- Dimensions – 10ft height, 40in length, 15in thick
- Made of Concrete with a compressive strength of 4.5 ksi
- Reinforced with Steel Rebar with a ¾in clear cover
  - Vertical Reinforcement – #8 bars equally spaced at 7.3in along the length and 11.3in along the thickness
  - Horizontal Reinforcement – #4 bars spaced 9in along the height
  - Transverse Reinforcement – #4 bars spaced evenly at 7.3in along the length

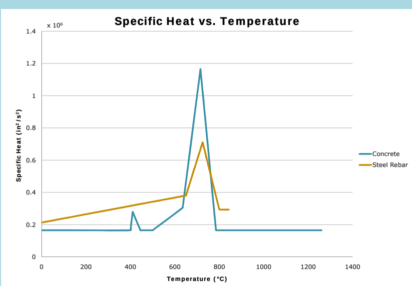
Conditions

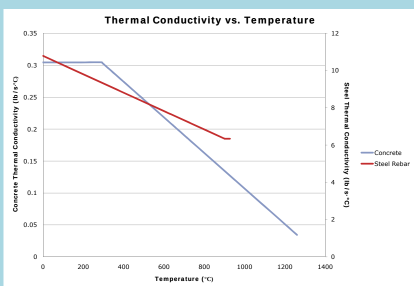
- Load
  - Apply ASTM E119 standard fire curve to the wall from the foundation up 5ft and along the entire length
- Initial Condition:
  - Entire wall is at room temperature (23°C)
- Boundary Conditions:
  - Bottom – Heat Sink
  - All other sides – subject to radiation and convection

$$h = 0.14275\,\frac{lb}{in\cdot s\cdot {}^{\circ}C},\ f = 2.74\times10^{-10}\,\frac{lb}{in\cdot s\cdot K^4}$$

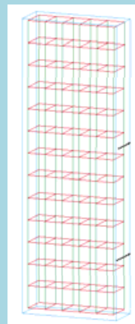


Thermal Properties of Concrete and Steel Rebar Materials





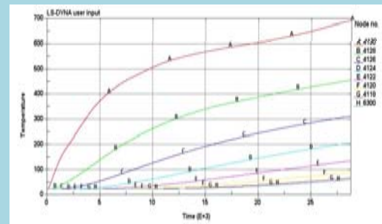
Results

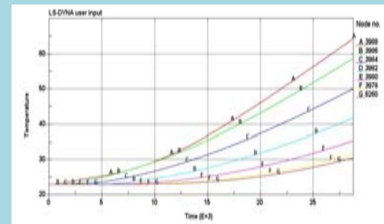


Top Nodes from Left to Right
3988, 3986, 3984, 3982, 3980, 3978, 6260

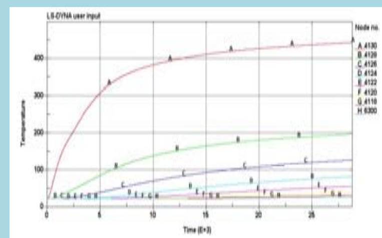
Bottom Nodes from Left to Right
4130, 4128, 4126, 4124, 4122, 4120, 4118, 6300

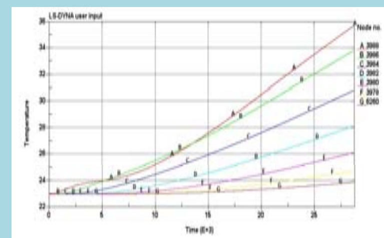
Conduction Effects Only





Conduction, Radiation, and Convection Effects





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