- Cracking due to volumetric changes
  - Shrinkage
  - Thermal
  - Autogenous
- Mass concrete is a concrete where thermal stresses is a concern.
- Basic mechanism for thermal stresses
  - Stage I: Generation of heat due to cement hydration.
  - Stage II: After the hydration process, there is a decrease in temperature.
Concrete Technology

Mass Concrete

Thermal Stresses in Concrete

- Factors affecting thermal stresses
  - Elastic modulus $E = V_a E_a + V_p E_p$
  - Coefficient of thermal expansion $\alpha = V_a \alpha_a + V_p \alpha_p$
    - where: $V_a$ & $V_p$ = volume fraction of aggregate and paste
      $\alpha_a$ & $\alpha_p$ = coefficients of thermal expansion of aggregate and paste
  - Adiabatic (no heat loss through the boundary) temperature rise

Adiabatic temperature rise in mass concrete containing 376 lb/yd$^3$ cement of different types

Thermal Stresses in Concrete

- Where:
  - $\sigma = \text{Thermal stresses}$
  - $R = \text{Restraint (0 < R < 1)}$
  - $E = \text{Modulus of elasticity}$
  - $\alpha = \text{Coefficient of thermal expansion}$
  - $\Delta T = \text{Temperature drop}$

- You have control on:
  - $\frac{E}{\alpha}$ because they are function of aggregate available on site

- The only control you have is the amount of temperature drop, $\Delta T$. 

(Hooke's law) (Thermal Strain) (Thermal Stress)
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Mass Concrete

Thermal Stresses in Concrete

- Computation of $\Delta T$:

\[
\Delta T = \text{Placement temperature of fresh concrete} + \\
\text{Adiabatic temperature rise} - \text{Ambient temperature} - \\
\text{Temperature drop due to heat losses.}
\]

- “Wish list” to minimize thermal stresses:
  1. Aggregate with low coefficient of thermal expansion
  2. Cement with low $C_3A$
  3. Insulating forms
  4. Cast concrete at night / early morning
  5. Use ice instead of water
  6. Pre-cool aggregate and cement
  7. Post cooling - embedded pipes
  8. Provide joints (for expansion and movement
  9. Less amount of cement
  10. Use pozzolans
  11. Use liquid nitrogen
  12. Use thin layers
  13. Use large size aggregates
Applications
- Hoover Dam 1935 2.4 million m$^3$ of concrete
- Grand Coulee Dam 1942 8.0 “ “
- Shasta Dam 1945 4.5 “ “
- ASTM Type IV low heat portland cement
- Concrete was post-cooled by circulating cold water through the embedded pipes.
- The heights and schedules of placement were controlled.

⇒ All three dams remained free of objectionable cracks and leakage.
- In construction of Glen Canyon Dam (1963), Dworshak (1973), and Liberty Dam (1975) pre-cooling and post-cooling were used in combination (in all, $\Delta T < 14^\circ C$)

Post-cooling in Hoover Dam (early 1930s) was the first major application. The cooling was achieved by circulating cold water through thin-wall steel pipes embedded in the concrete.

The first use of pre-cooling of concrete materials to reduce maximum temperature of mass concrete was at Norfolk Dam (early 1940s). A part of mixing water was introduced into concrete as crushed ice so that the temperature of in-place fresh concrete was limited to 6°C. Generally, the lower the temperature of concrete when it passes from a plastic state to an elastic state, the less will be the tendency toward cracking.

Surface Insulation. The purpose of surface insulation is not to restrict the temperature rise, but to regulate the rate of temperature drop so that the stress differences due to steep temperature gradients between the concrete surface and the interior are reduced.
Large Dams

[Image of a dam]

Large Dams

[Image of another dam]
Large Dams
Large Dams

Heat Loss from Solid Bodies

\[ h^2 = \frac{k}{c\rho} \]

- \( \theta_0 \) = Initial temperature difference
- \( \theta_m \) = Final temperature difference
- \( h^2 \) = Thermal diffusivity
- \( k \) = Conductivity
- \( c \) = Specific heat
- \( \rho \) = density
At a certain elevation, an arch concrete dam is 70 ft. thick and has a mean temperature of 100°F. If exposed to air at 65°F, how long will it take to cool to 70°F?

Assume thermal diffusivity of concrete, $h^2=1.20$ ft$^2$/day.

Sample Problem Solution
Sample Problem Solution

\[ \theta_0 = \text{Initial temperature difference} = 100^\circ\text{F} - 65^\circ\text{F} = 35^\circ\text{F} \]
\[ \theta_m = \text{Final temperature difference} = 70^\circ\text{F} - 65^\circ\text{F} = 5^\circ\text{F} \]
\[ \frac{\theta_m}{\theta_0} = \frac{5}{35} = 0.142 \quad \text{Slab} \]

From the “Heat loss for solid bodies” chart:
\[ \frac{h^2 t}{D^2} = 0.18 \]
\[ t = \frac{0.18D^2}{h^2} = \frac{0.18(70)^2}{1.20} = 735 \text{ days} \]

Three Gorges Dam in China

- **Goals**
  - Flood control
  - Navigation improvement
  - Power generation

- **Location**
  - Yangtze River downstream from Three Gorges

- **World’s Largest:**
  - Height 181 meters
  - Power 18 200 MW
  - Reservoir volume 39.3 billion m\(^3\)
  - Concrete volume 27.94 million m\(^3\)
Three Gorges Dam Timeline

- 1919 - Sun Yat-sen proposed project
- 1931 and 1935 - Floods killed over 200,000 people
- 1944 - J. L. Savage, the chief designer of both the Grand Coulee and Hoover dams, sent by United States Bureau of Reclamation to survey area and consult with Chinese engineers
- 1970 - Construction began on Gezhouba dam
- 1992 - Chinese Government adopted official plan for the dam project
- 2009 - Expected completion of the TGP

Three Gorges Dam Stages of Construction

- **Phase 1 (1993-1997)**
  - Water diversion channel
  - Construction of transverse cofferdams
- **Phase 2 (1998-2003)**
  - Construction of the spillway, left powerhouse and navigation facilities
- **Phase 3 (2004-2009)**
  - Construction of the right bank powerhouse
Three Gorges Dam

Structure of Gravity Dam

- Triangular shape
- Vertical Upstream face
- Uniformly sloped Downstream face
- Grout curtain

Sedimentation

- Major concern for engineers
- Potential cause of:
  - Abrasion of spillway and structure
  - Accelerated wear of turbine runners
  - Increased pressure on dam structure
- Prevention measures:
  - Dikes to prevent sediment from settling
  - Silt-flushing outlets in the water intakes
  - Erosion prevention via tree planting
  - Dredging to remove build up
Impacts of the TGP

- **Positive**
  - Flood control
  - Power generation: 18,200 MW installed capacity
  - Navigation improvement: sea-faring ships able to travel additional 630km upriver

- **Negative**
  - Population relocation: 1.2 million people must move
  - Loss of farmland
  - Flooding of cultural relics: historical landmarks and remnants of ancient civilizations