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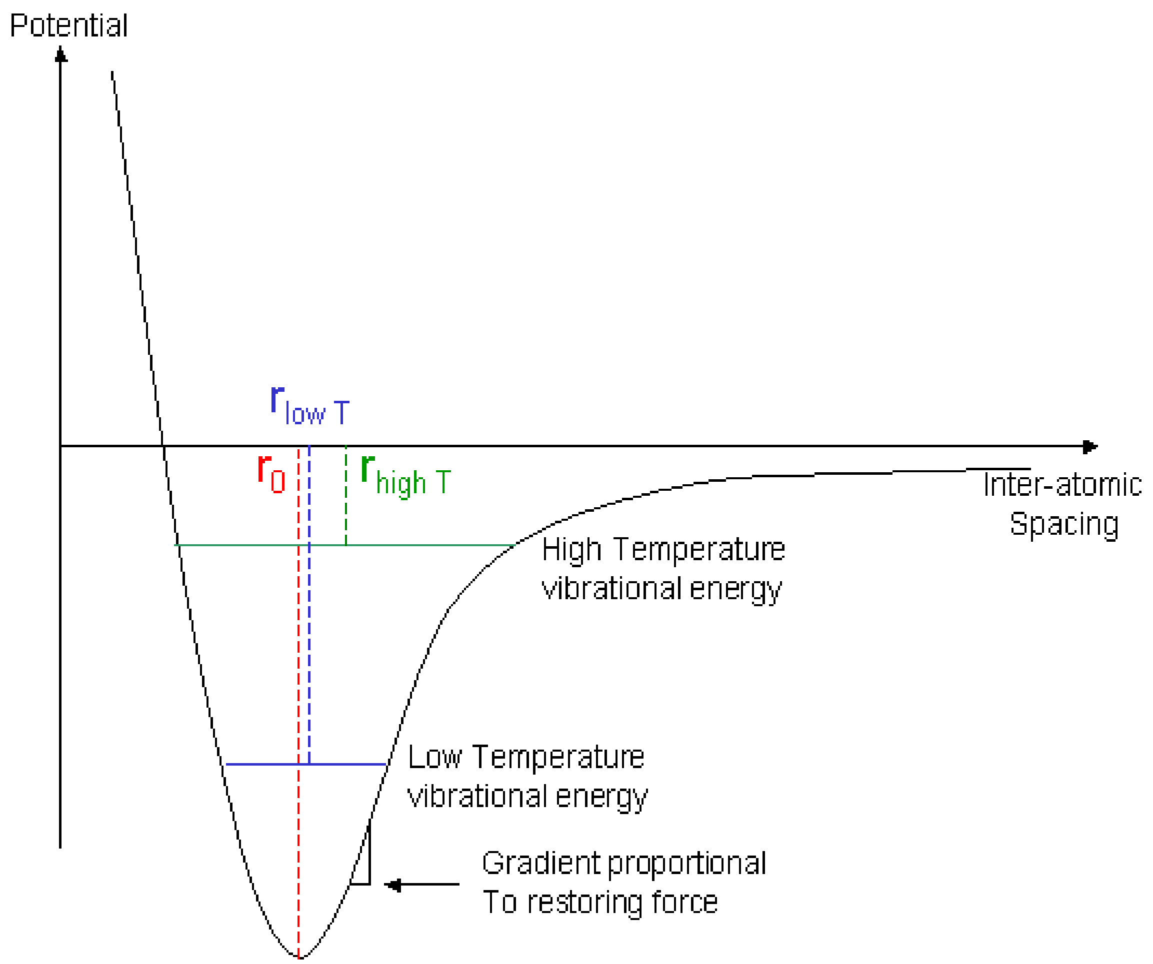
Online Training Event 2020
Thermal Expansion

M Frith

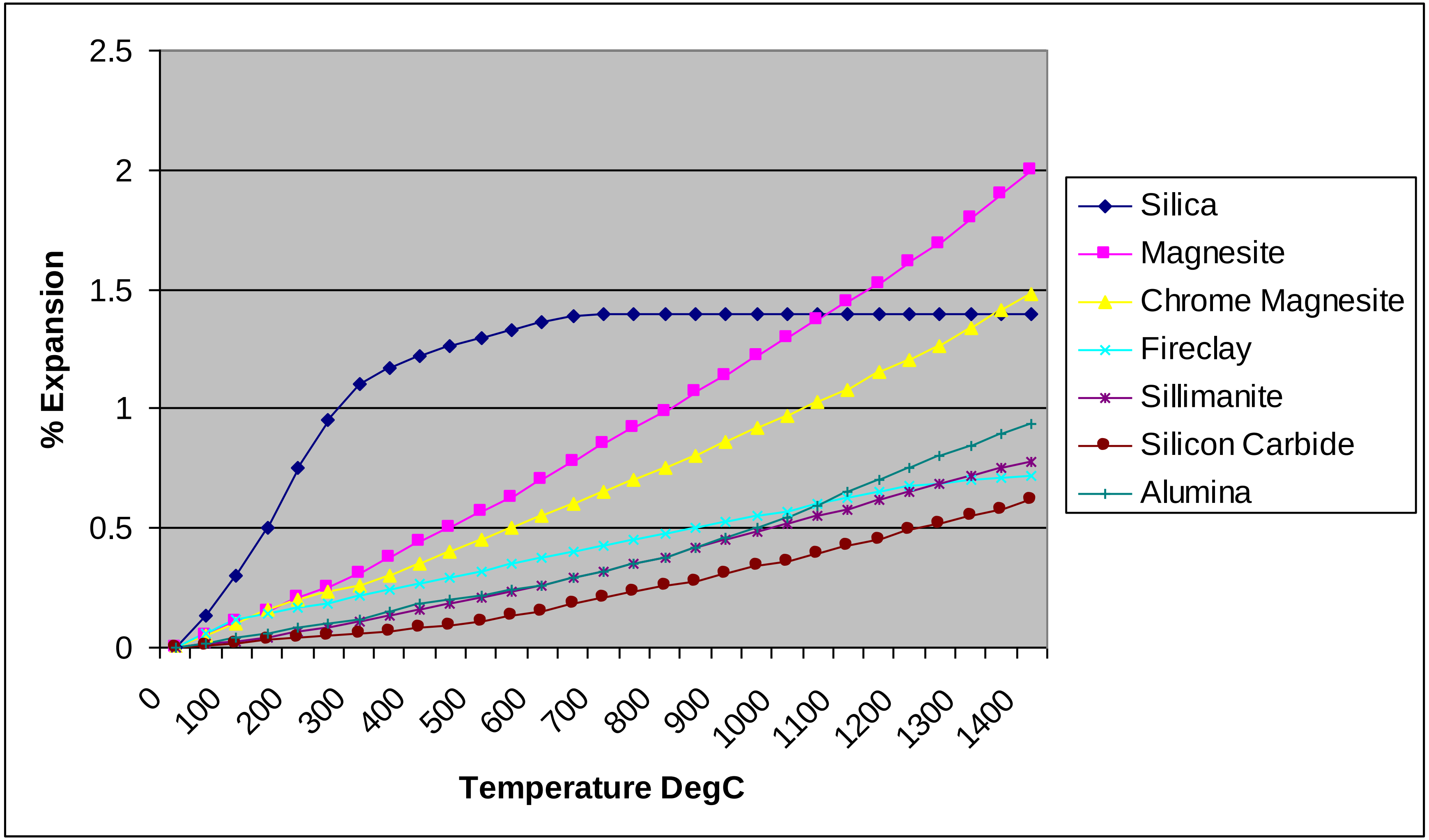
Contents

What is Thermal Expansion? The Science bit

- Thermal expansion is the tendency of matter to change in shape, area and volume in response to a change in temperature through heat transfer.
- Temperature is a function of the average molecular kinetic energy of a substance.
- When a substance is heated, the kinetic energy of its molecules increases. The molecules move more and usually maintain a greater average separation.



Thermal Expansion of Standard Refractory Materials



Thermal Expansion Coeffcient

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- A Material Property – independent of shape

- cte = $\frac{\Delta\ell}{\ell} \cdot \frac{1}{\Delta T}$

- $\Delta\ell$ is the change in length (expansion)
- ΔT is the temp change

$$\Delta\ell = \text{cte} \cdot \ell \cdot \Delta T$$

The Coefficient of thermal expansion (cte) describes how the size of an object changes with a change in temperature. Specifically, it measures the fractional change in size per degree change in termperature at a constant pressure.

Forces Involved in Thermal Expansion

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- Construction:
- Refractory lined duct 10m long, 2m in diameter
- Lined with 230mm thick fireclay brick
- Taken to a temperature of 1000°C.
- Elastic Modulus is ~ 20 GPa.
- The resultant thermal expansion is 55mm.

Restraining force for zero movement – 28,000tonnes

Methods of Dealing with Thermal Expansion: Golden Rule

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- If the unstoppable force meets the immovable object, something gets broken.
- Splitting of shell
- Weld failure
- Flange bolts stretch
- Shell Yields
- Insulation crushed
- Lining spalls

- It is therefore essential to make a suitable allowance for thermal expansion in any design.
- Several methods are commonly used.

Methods of Dealing with Thermal Expansion
Method 1: FREE MOVEMENT

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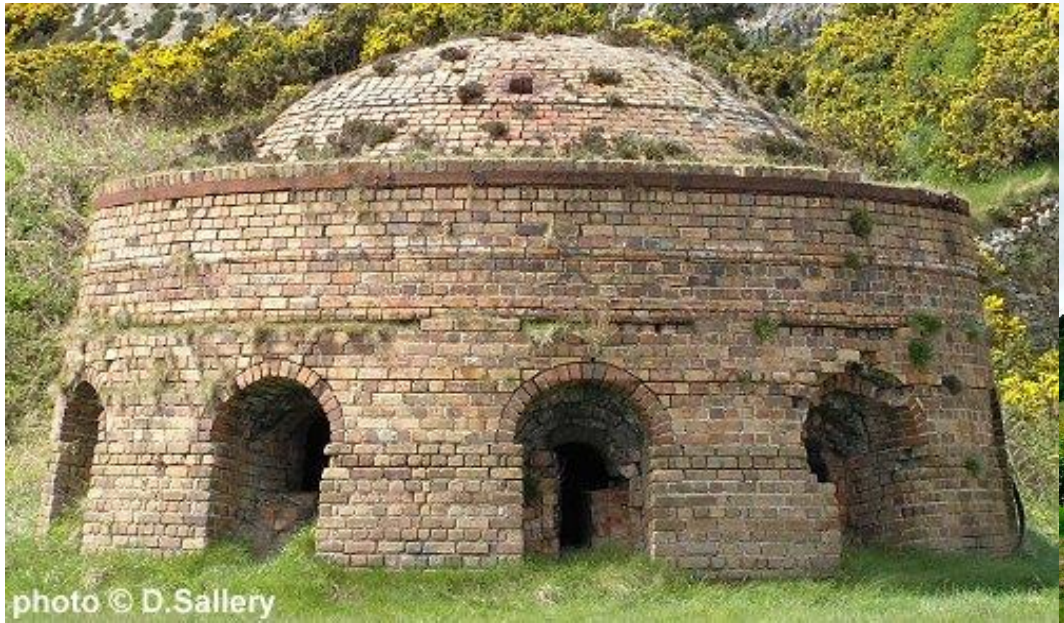
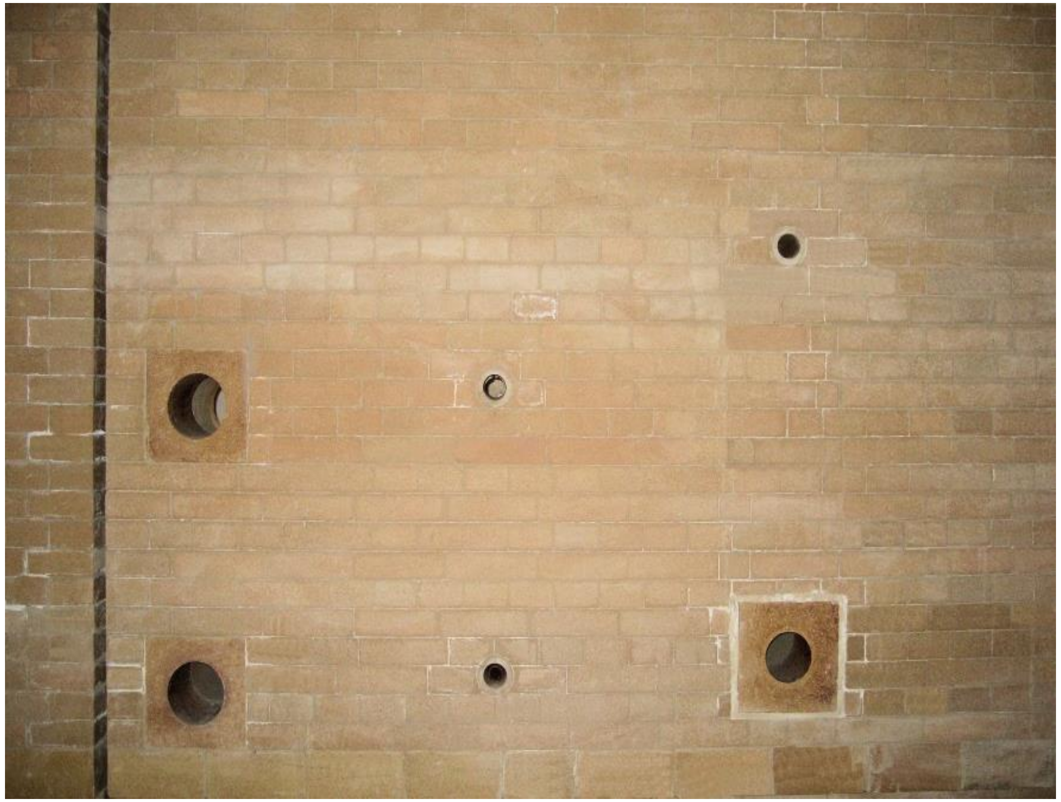
- Rarely used
- Movement is not predictable
- Applied to free- standing, unconstrained structures only
- Beehive Kilns
- Bottle Kilns



Methods of Dealing with Thermal Expansion
Method 2: Regular Gaps

- Leave gaps of pre-determined size
- These close up on heating
- Few, large gaps – typically 50mm

- What can go wrong?
- What happens at branches?



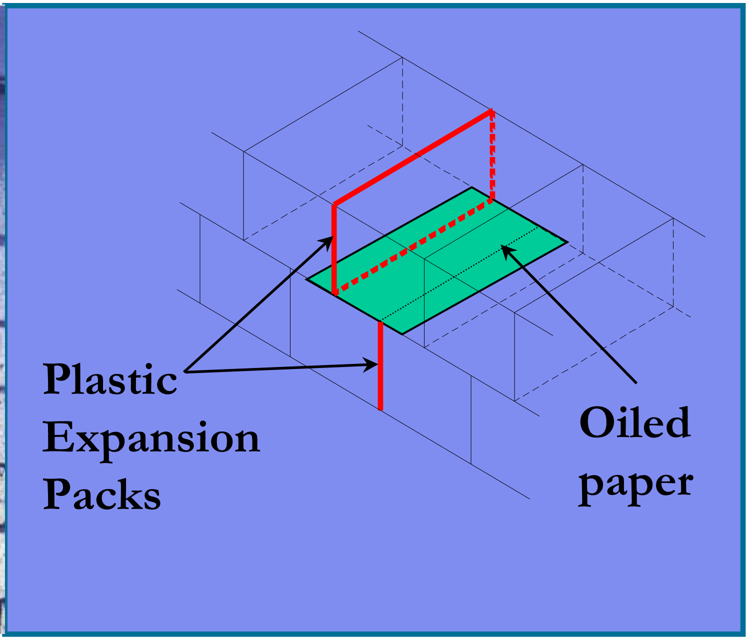
Methods of Dealing with Thermal Expansion
Method 3: Burn-Out Packs

Smaller gaps, placed more frequently and at regular intervals

Less risk of slipping

Less risk of problems from non-closure

What can go wrong?



Methods of Dealing with Thermal Expansion
Method 4: Compressible Layer

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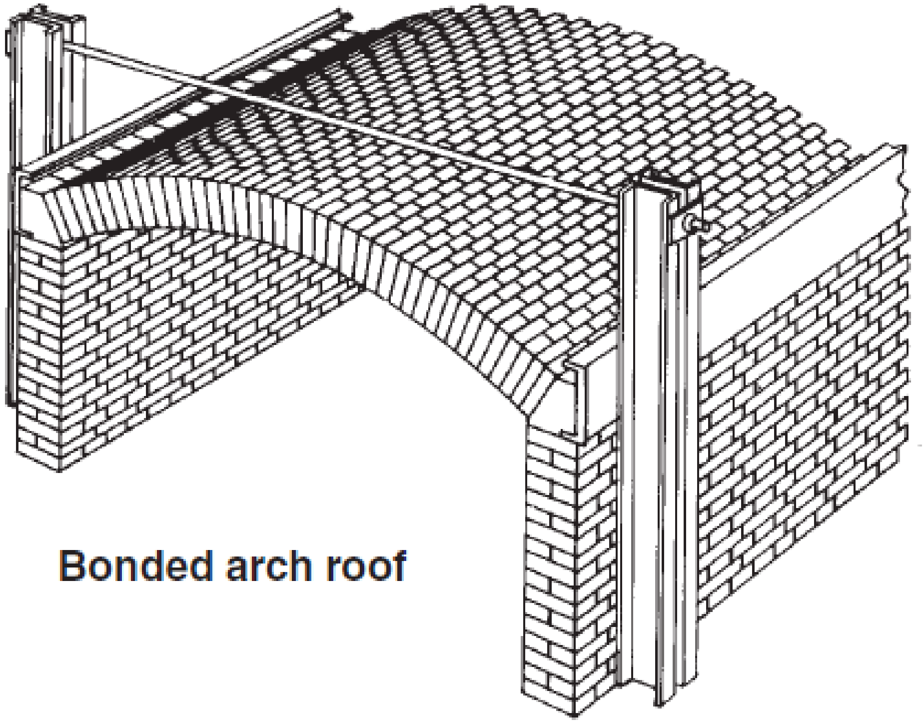
- Layer can be behind hot face in joints/gaps
  - Can eliminate gaps in hot face
- Range of compressible materials
- Compression is PLASTIC

- What can go wrong?

Methods of Dealing with Thermal Expansion
Method 5: Adjust Casing

- Only used in special cases
- Needs adjustment during warm up
- Needs adjustment during cool down
- Retains arch SHAPE

- What can go wrong?



Bonded arch roof

Methods of Dealing with Thermal Expansion
Method 6: No Specific Allowanc

- Mortar Creep
- Shell is hot and therefore expands
- Stress is developed in shell
- Used in rotary kilns

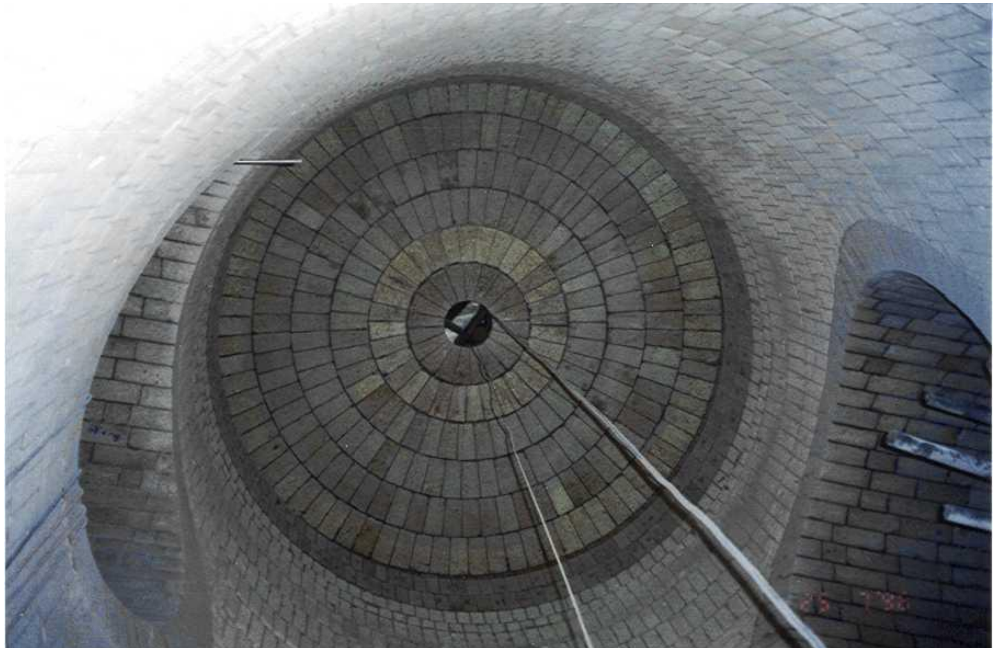
- What can go wrong?

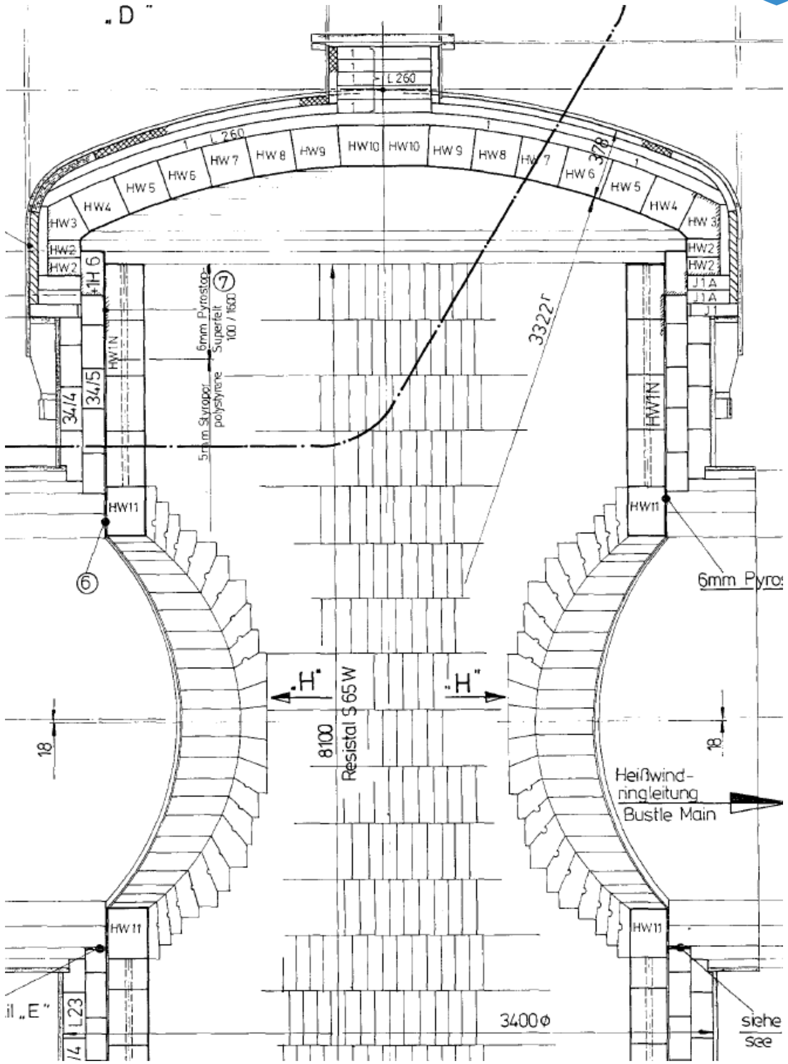
Methods of Dealing with Thermal Expansion
Methods in Combination

Often use different methods in combination

e.g. Hot Blast Vertical Riser Pot

- Walls – Radial expansion – Combustible Packs
- Walls – Vertical Expansion – Free growth
- Dome – Radial Expansion – No allowance
- Dome – Vertical Expansion – compressible layer





Thermal Stress

- The contraction and expansion process of a material with temperature can result in thermal stress if:
- There is interference from contacting another part,
- If the construction is made out of different types of materials that have different thermal expansion coefficients.

- e.g. Expansion of anchors can cause anchor to cracking
- cte 310 = 18x10-6/°C
- cte 1600 castable ≈ 6x10-6/°C
- Anchor temp is higher than refractory temp

Thermal Stress: A few Key Points

- Steel usually expands less than refractory (depends on thermal design)
  - Leads to the development of compressive and tensile thermal stress in the refractory lining
- No such thing as a ‘flexible’ refractory
  - Flexible products harden on heating
  - Compressible NOT elastic
  - Compressible refractory has little mechanical resistance
- Expansion Joints in steel
  - Often cause problems
  - Sliding joints are hard for refractories

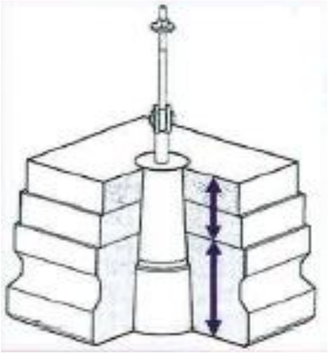
Thermal Stress: Analysis

- The level of thermal stress development in a refractory structure can be calculated via Finite Element Method (FEM) analysis
- This requires knowledge of the thermo-mechanical properties of the materials and the constructional aspects of the lining/container
- Thermo-mechanical properties:
  - Thermal expansion coefficient
  - Thermal conductivity
  - Modulus of elasticity
  - Failure stress and Failure strain
  - ETC.....

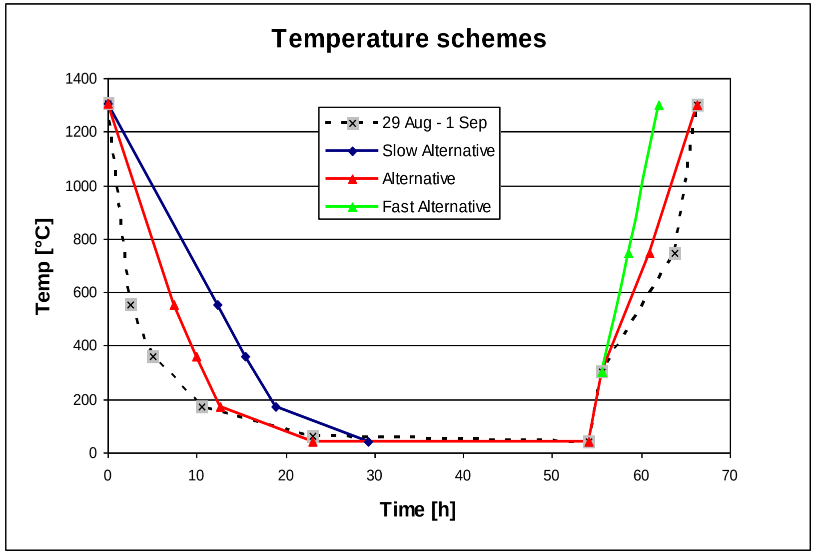
THERMAL MODEL → STRESS MODEL

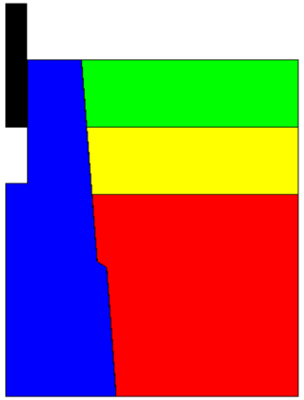
Thermal Stress: FEM Analysis REHEAT FURNACE ROOF

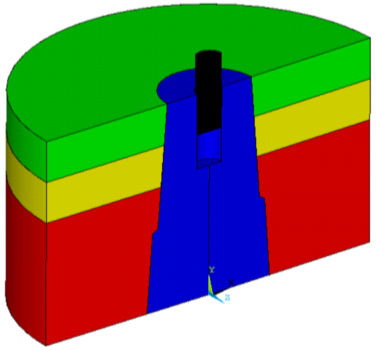
- Furnace cycled between 1300c and 900c every 12 hours
- Furnace switched off every Friday, and relit prior to rolling Monday
- Fast cool down the rate
- Fast heat up rate
- Areas of premature wear/failure
  - Block anchors in the roof witnesses as splitting
  - Block anchors in the Discharge sloping roof
  - Bull nose sloping roof slippage



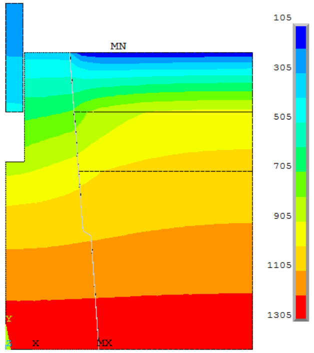
Thermal Stress: FEM Analysis REHEAT FURNACE ROOF





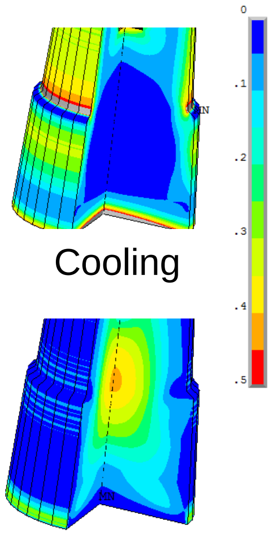


Thermal Calculations



Ceramic anchor block
Cools more rapidly than
the roof block

Mechanical Calculations

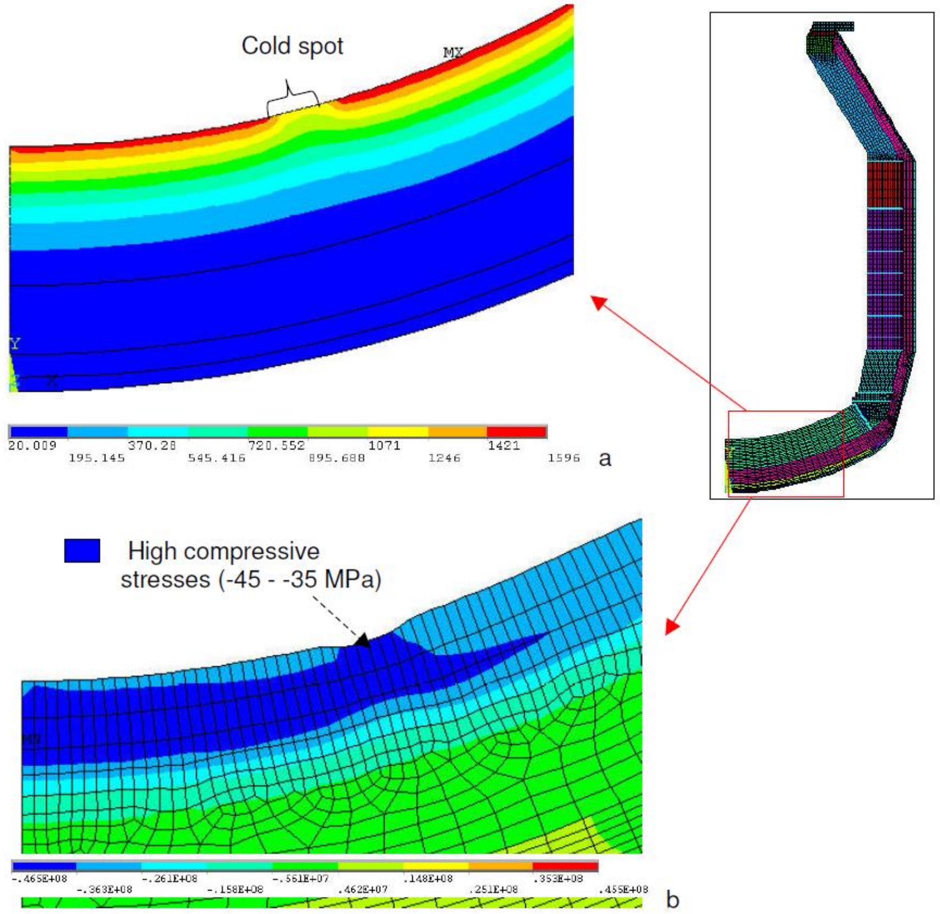


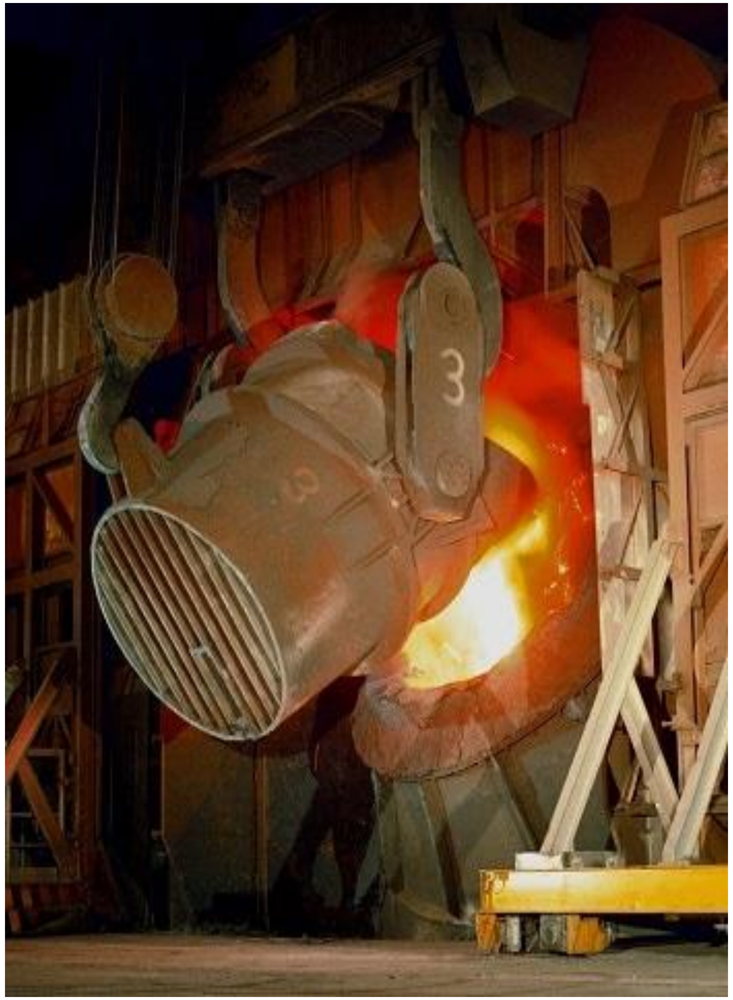
Cooling

Heating

Tensile stress generation at the transition zone of the ceramic anchor – leads
to cracking of block and loss of the front face

Finite Element Method Thermal Stress Analysis – BOS Converter





Incorrect Expansion Allowance ‘when we get it wrong! - Examples

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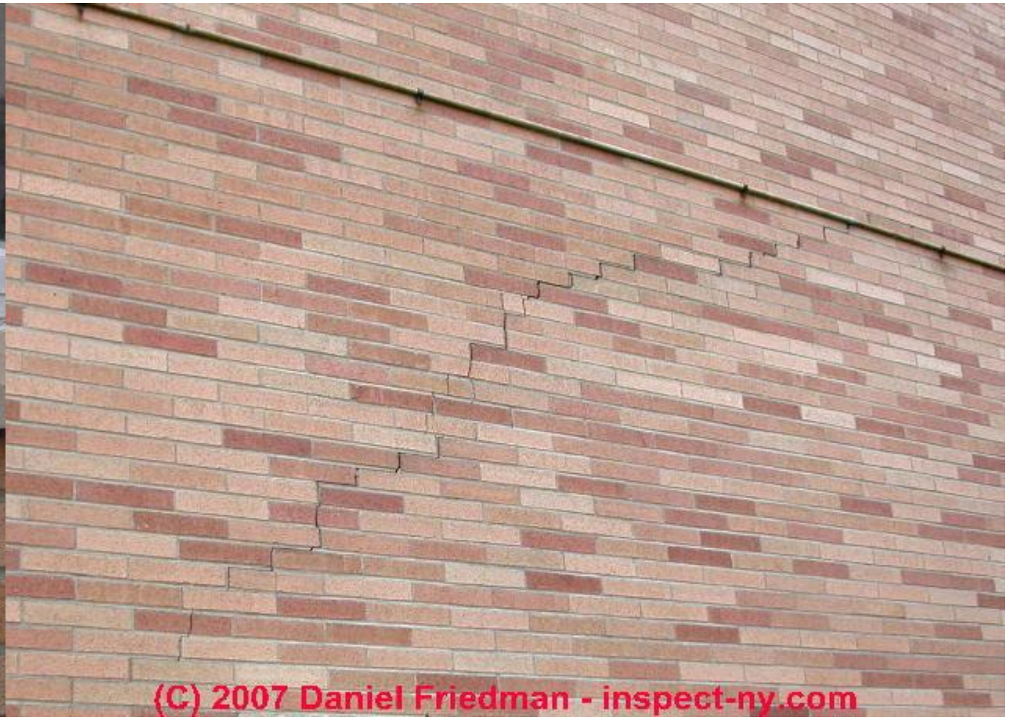
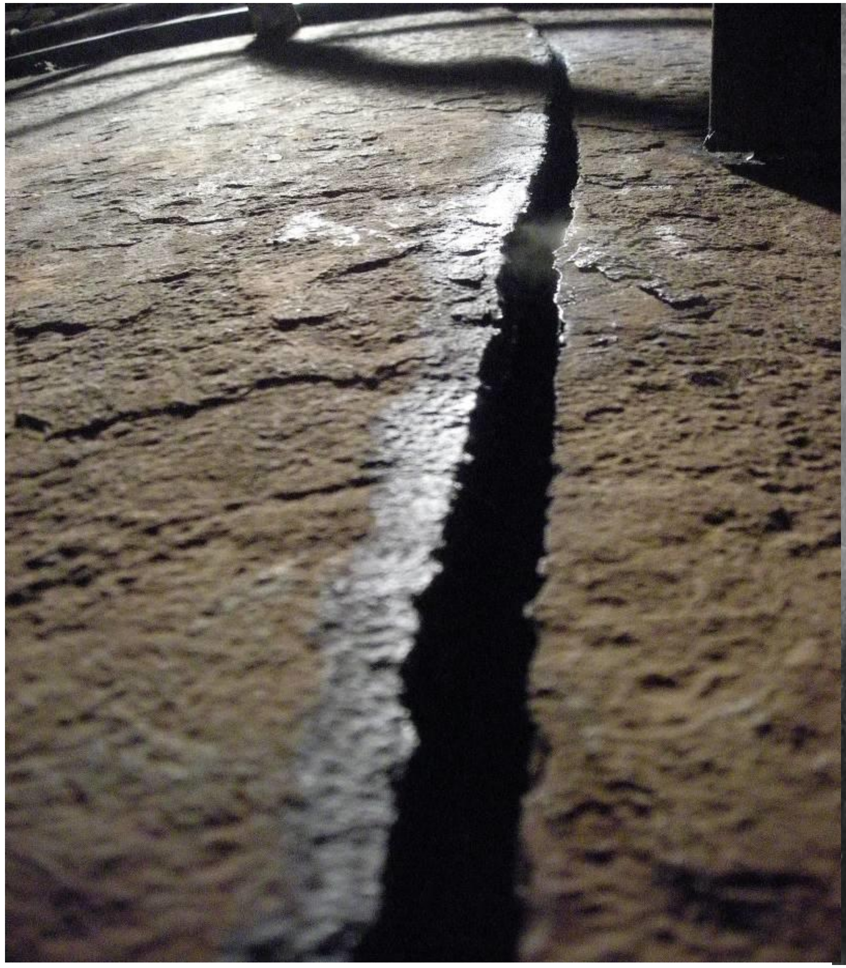
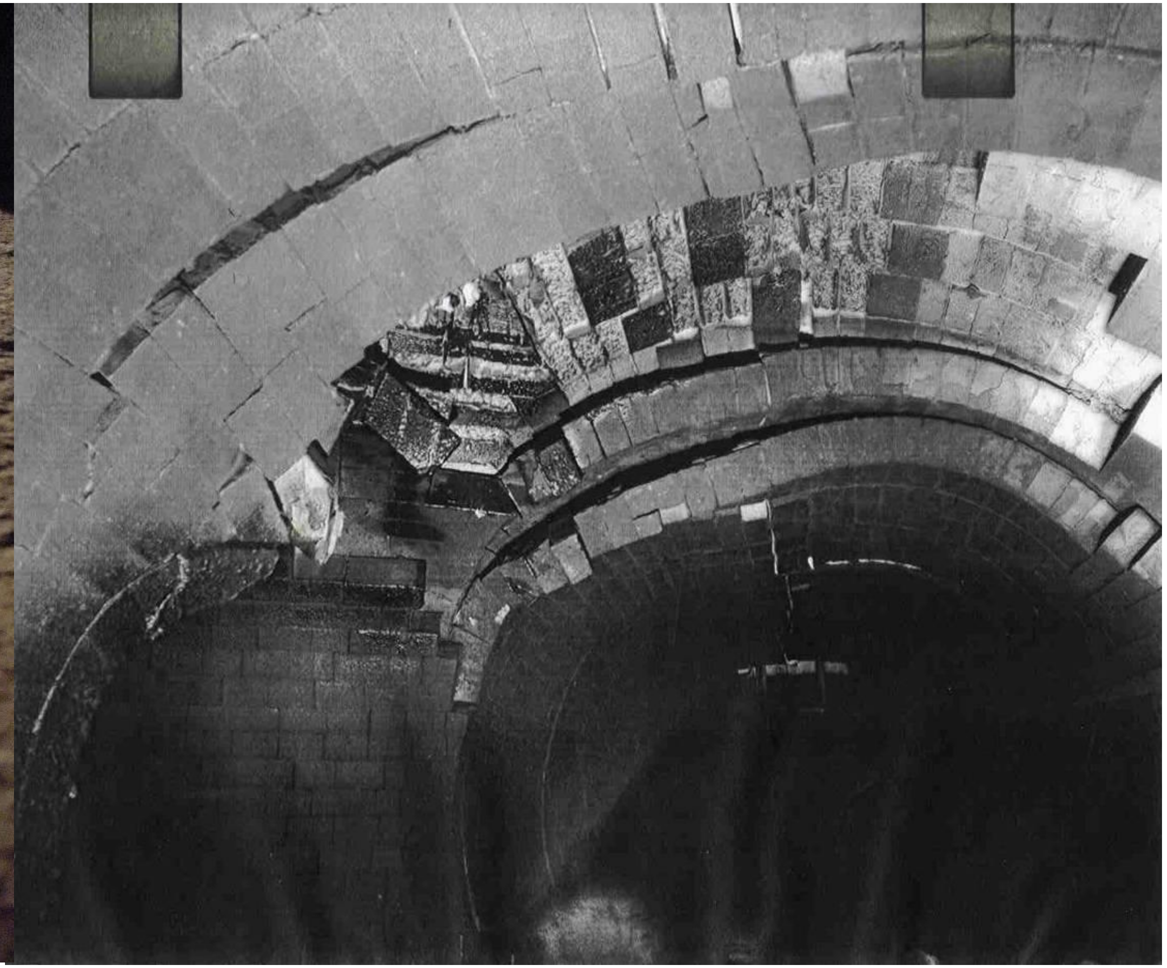
Thermal Expansion of railroad track due to excessive heating. Yes, they would close the track at this point! (Notice the derailed car in the background.)

Incorrect Expansion Allowance ‘when we get it wrong! - Examples



Incorrect Expansion Allowance ‘when we get it wrong! - Examples





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Incorrect Expansion Allowance ‘when we get it wrong! - Examples

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Thank you

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