Geothermal Tunnel Linings

Principles of Geothermal Tunnel Linings

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  - Fire
- **Building market for tunnel heat**
Background – Ground Sourced Heat Energy

Open Systems
- Water wells
- Extract water
- 500kW / hole

Closed Systems
- Vertical or horizontal loops
- Extract heat
- 3.5kW / hole

Source: Commercial Earth Energy Systems (Canada Natural Resources)
Thermal Piles and Sprayed Lining

Geothermal Piles at One New Change, Arup (2009)

Austrian Sprayed concrete lining at Lainzer Tunnel, After Brandl (2006)
Other Infrastructure Projects

- Loops are used in:-
  - Diaphragm walls
  - Base slabs
  - Linings of the station tunnels, eg metro NATM tunnel lining,
  - Channel Tunnel heat-exchange pipes

Crossrail – Stations boxes

- Thermal diaphragm walls
- Thermal piles

Diaphragm wall, Brandl (2006)
Concept - Thermal Tunnel

Access points at 500m centres for each tunnel
Concept - Segment Connections

- Segment to segment
- Box-outs
- Ring to ring
- Header pipes below walk way
- Control valves
- Pressure regulator values (if two pipes)
Concept - Pipes and Box-Outs

- **PE-Xa grade plastic pipe provides:**
  - Durability – 120 yrs at operating temperatures pressure.
  - Permanent mechanical joint for segment to segment - fast.
  - Good bend radius.

- **Box-out provides:**
  - Connection space.
  - Joint rotation / extension.
  - Mortar filler option.
Concept - Circuit Diagram

- 11 metres of pipe per segment
- 6 segments to one ring
- 5 rings to one circuit
- 33 circuits to branch
- 4 branches to one shaft
- Shafts at 500m centres

Reverse return header pipe:
Three pipes - no pressure regulator valve - Control values
Concept - Thermal Loops Inside Segment

Position of pipes inside tunnel segment

Box out section for the pipe connections.
Concept - Cold Tunnels

Cold Tunnels:
- No tunnel heat source
- Tunnel air temperature low
- Provides building heating and cooling
- Heat energy mostly from soil mass not tunnel

Cold Tunnel locations
- Short road and rail tunnels
- Cold climates
- Good natural air ventilation
Cold Tunnel Example – Janbech Tunnel

Details to be given by Dr Franzius from Züblin
Segment – Reinforcement

- Fibre Reinforcement – just pipe support cage
  - Crossrail

- Steel Cage
  - Janbech Tunnel

- Segment mould effects
- Production and testing
Concept - Hot Tunnels

Hot Tunnels:
- Tunnel air temperature higher than ground
- Heat Energy mostly from tunnel
- Mainly for building heating
- Helps to cool the tunnel
- Not efficient for cooling building

Hot tunnel locations :-
- cable tunnels,
- foul sewers,
- Deep/long rail and road tunnels

Crossrail train motors – 1MW heat
Trains at 2.5min intervals
Concept – Effect of Ground

- **Tunnels in Clay:**
  - Heat stays, - local conduction
  - Access boreholes - easy to construct

- **Tunnels in Sand:**
  - Heat dissipates with ground water flow (Advection)
  - Access borehole are difficult to construct – water bearing sand
Design Development Process

- Develop concept – overall economics / carbon savings
- Identify design issues – many disciplines
- Tunnel design issues :-
  - Linking header pipes to surface
  - Lining construction
  - Design Process
    - Segment heat transfer model
    - Tunnel ventilation model
    - Tunnel thermal stress model
- Fire

- Surface heat market
- Costings / carbon savings
Linking Header pipes to surface

- **Existing access points**
  - Shafts, stations, entrances,
- **Dedicated access points**
  - Boreholes
Heat Supply to surface buildings

Supply district A

Supply district B

Supply district C

Shaft

borehole to cross-passage

boreholes to tunnel
Vertical Drilling

• Connect cross passage or tunnel
  • 202 borehole casing with 110mm pipe
• Verticality tolerance
  • 1 in 200 (+/-100mm at 20m depth)

• 2 boreholes per access point for header and return
• ~ £40K for a pair
Borehole to tunnel connection

- 110 mm flow & return pipe
- 500mm opening
Impacts on Tunnel Construction

Impact on:-

- Segment construction
- Segment erection
- Space use inside tunnel
- Construction cost
- Tunnel maintenance

Header pipes
Ring to ring connections
Tunnel Design Process – Hot Tunnels

Revised 1-D model with tunnel wall cooling

Existing 1-D Tunnel ventilation model

Lumped mass thermal model

Preliminary FE thermal model

FE stress analysis thermal model

Eastbound Station Temperatures: 32 Trains/dirn. Peak Service

100 m$^3$/s UPE at Each Platform, with 75% Capture Efficiency

Crossrail, London, UK

Mott MacDonald
Segment Thermal Model (DYNA)

- Model represents a 1m length of tunnel with soil
- Builds on under floor heating

Pipe wall (2mm thick)
Temperature contours in tunnel lining

Model considers:

• Air temperature in tunnel
• Boundary condition in soil 15°C at 150m
• Assign extraction rates from pipes
Temperature variation in the pipe – continuous extraction

Pipe Average Temperature (Deg C)

No flow period
end of summer
end of winter

Time (Years)

Pipe Average Temperature (Deg C)

10W
30W
Heat extraction rate vs. fluid temp

For 10W/m² and 1000m of tunnel, output = 200kW

For 30W/m² and 1000m of tunnel, output = 600kW

Fluid temp half-way along tunnel

Fluid temperature (degrees C)

Output (W/m²)
Tunnel Ventilation Model (Motts input)

- Heat exchange from draught relief airflows
- Heat from trains
- Heat flow to cooling pipes
- Outside air
- Tunnel air
- Heat from trains
- 5 rings of surrounding ground
- Distant ground temp fixed
- Calculated temperatures
Ventilation Modelling (1)

Tunnel Air Max temp

Tunnel Wall Max temp

Outside Air Max temp

Typical tunnel temperature for service pattern SP1B (240m trains, 30TPH peak hour service frequency- 2076)
Ventilation Modelling (2)

Predicted tunnel temperature with heat extraction system operating
Case 45: Constant cooling 15 W/m², Early service, UPE 50%

Tunnel temp generally above Outside air temp – little condensation
Tunnel Cooling Effect – Local Installation

800m demonstration tunnel - East of Tottenham Court Road Stn
West bound tunnel – Summer peak
Best to focus tunnel cooling either side of stations
FE model – tunnel segments with pipe

- Model of one segment ring + Soil
- Plastic pipes
- Curved segment bearing surfaces
Stress reduction - Due to cooling round pipes

Stresses reductions combined with earth pressures – (contraction round the outer face)
Joint Rotation Effects and Box Out length

- Max ring deformation = 1% of dia.
- Joint rotation is 1.45 degree
- Joint opening = 150mm tan 1.45°
  = +/- 3.8mm
- Combined box out lengths = 300mm
Segment joints and box-outs – Caulking groove and bearing

Based on hand calculations – anti bursting reinforcement needed for tunnel depths >31m with box-out, or 35m without box-out.

Concrete Section loss - Pipe diameter is 20mm and lining is 300mm - 6.7% loss
Fire

- Fire load - EUREKA fire curve
- Spalling margin of the segment
- Stakeholders: To consider PE pipes
  - LU 1-085 Fire Safety of Materials
- PEX-a Pipes: Durability 100 years at 20°C and 15 bar (according to DIN 16892/16893, EN ISO 15875) incl. FoS 1.25
- Check ventilation capacity to remove smoke
Fire – Segment Pipes and Header pipes

- Pipes melt at header pipes and box outs
- Gas given off – low load for segment pipes – Header pile in concrete?
- After fire - Repair header and omit damaged rings
Market for Tunnel Geothermal

- Low grade energy source – use locally

- Residential buildings – heating demand + Hot water
- Office blocks – cooling and heating demands

- Old buildings - refurbishment – heat + Hot water
- New buildings - renewable source requirement
  - Helps at Planning Stage with Part L
- Cools tubes / ground – reduces ventilation costs
Typical London Residential Building

- **Typical 5 Storey – refurbished buildings**
  - heating needs – 40-50W/m² of floor.

- **Say 16 flats /building unit**
  - Space heating – 40kW. – seasonal
  - Hot water – 25kW. – continuous

- **Similar to 50 to 100m long tunnel section.**
Tunnel Heat Market and Assess Points

- All qualifying buildings within 100m of tunnel alignment
  - Tier 1: hotels, large residential, hospitals – 34 no.
  - Tier 2: schools, colleges, libraries, museums – 4 no.
  - Tier 3: offices, leisure centres, retailers – 327 no.

- Circles – centred on shaft / cross passages - 500m dia.
- Heat is 200 to 600kW for 500m of twin tunnel
- Heats about 100 apartments per circle. – Link with ESCOS
Market for Tunnel Geothermal

- **Building options:**
  - **Existing buildings:** residential housing dominated by space heating over the cold season, with DHW through out year
  - **Existing building:** office/retail complex, heating and cooling
  - **New buildings** - heating and cooling

- **Base Load and Peak Load**
  - Combined heat pump and gas boiler

- **GIS mapping of potential users along tunnel alignment**

- **Cheaper the GSHP borehole loops and higher COP**

- **Link with ESCO – District heating – sell heat**
Crossrail increase ground temp at Oxford Street

- Ground temperature at tunnel level
- Next to tunnel temperature 19°C
- Temperature drops to ~15°C at about 90m from tunnel
Conclusions

1. Thermal tunnels – similar to GSHP systems
2. Concept - Well developed - Janbech tunnel
4. Shaft access preferred – Boreholes provide flexibility.
5. Detailed design issues:
   - Thermal and ventilation models
   - Concrete stresses
   - Joint rotation
   - Fire impacts
7. Commercial case:
   - Cheaper than GSHP borehole loops to install
   - Save tunnel / station cooling costs
   - High COP when used at low flow rates – carbon efficient
   - Work with ESCO district heating provider
Thank you for your attention

Any Questions?