# An unusual tunnel collapse, the Hull Wastewater Transfer Tunnel

## Australian Tunnelling Society

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# *References:*

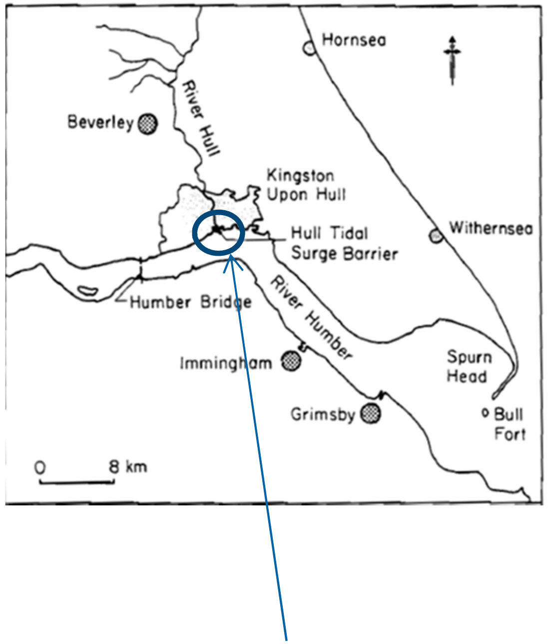

- *Chamley et al (2000) – North America Tunneling Conference, Boston June 2000. Published AUA News September 2000.*
- *Caiden, Chamley & Covil (2005) – RETC Proceedings, 2005*
- *BTS Informal Discussion at the ICE, November 2001, Tunnels & Tunnelling, March 2002*
- *Machon & Stevens (2004) - Proc. Institution of Civil Engineers, GE3*
- *Grose & Benton (2005) – Proc. Institution of Civil Engineers, GE4*
- *Various (2006) - Discussion:  Proc. Institution of Civil Engineers, GE2*
- *Munks, Chamley & Eddie (2004) – Proc. North American Tunnelling 2004*
- *Brown (2004) - Proc. Institution of Civil Engineers, GE3*
- *Tunnels & Tunnelling – March 2002*

- The project
- The failure
- The investigation
- Possible causes
- Remediation
- Implications for the insurance industry
- Lessons learned
- Questions (steve.macklin@ghd.com)

*An unusual tunnel collapse, the Hull Wastewater Transfer Tunnel*

# The project

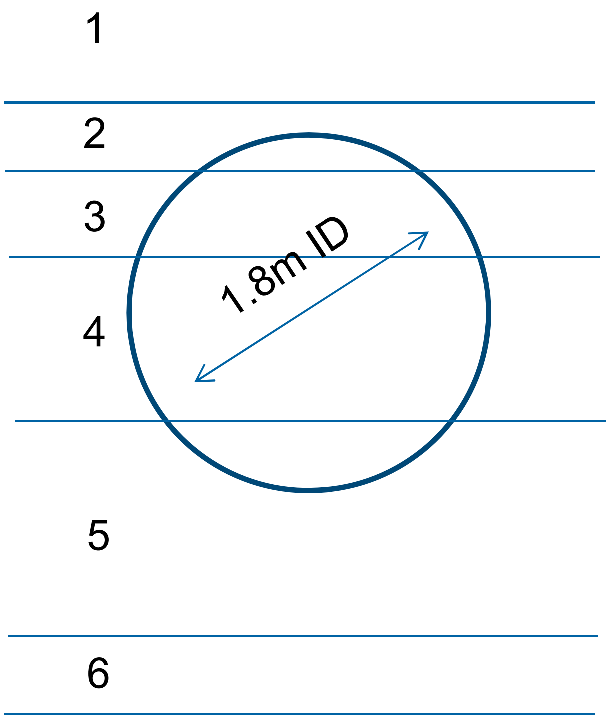
- 10.6km tunnels
- 10No. Shafts 7.5m to 12.5m int. diam.
- 2No. Jet grout “maintenance blocks”
- 6No. De-watering & comp. air stops
- 3.6m ID lining:  6No. Trapezoidal Segments, 1m long, 250mm thick
- Segments cast vertically




location

£50M contract to construct a 10.6km long tunnel for Yorkshire Water's £200M Humbercare sewage collection and processing scheme.

# The project




1. Medium dense silty, fine to medium alluvial **SAND** (non-tidal aquifer)
2. Firm to stiff and friable **PEATY CLAY/SILT**, with fragments of timber, aquitard, $k_h \leq 400k_v$
3. Upper alluvial **SILTY FINE SAND** grading down to **GRAVELLY SAND** to **SANDY GRAVEL**

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4. Soft to firm to stiff thinly **LAMINATED CLAY** (aquiclude, $k_h \leq 10k_v$)
5. Dense fine **AEOLIAN SAND**
6. glacial **SAND AND GRAVEL** (tidal aquifer)

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*"…. All tunnels leak to some extent, …… but when I was told of the enormity of this situation I couldn't understand what could have gone wrong…"*

Construction News, 14 September 2000

# The failure

Failure sequence:

- 19:00 – R2403 2L/min leak right knee
- 23:30 – 7L/min
- 00:30 – black organic smelling water, leaking around circle joint
- 01:30 – sand filling invert, rings buckling
- 02:20 – invert heaving, re-bolting attempted
- 02:45 – manrider derailed and abandoned
- 03:00 – segments crazing and spalling
- 03:30 – tunnel abandoned
- 04:00 – water main burst, ground cracking, shaft sinking
- 07:30 – tunnel inspected, filled with fine sand

60m diameter depression - maximum 2.6m settlement – the volume of the settlement depression was about 2600m$^3$ - tunnel filled with fine sand/silt approx. 200m either side of shaft

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*The investigation into the cause of the collapse demanded ….. urgent answers. Clearly, future tunnelling, and the previously constructed tunnel, were at risk until conclusions were available regarding the cause…"*

Grose & Benton, 2005

# The investigation

So why did an apparently stable, grouted-up lining fail weeks after construction? Was it:

- Something in the ground conditions (e.g. peat compressibility, mobile sands)?
- Hydrogeological effects (e.g. ‘”damming”, tidal fluctuations in water pressure)?
- A design flaw (e.g. segment capacity, shear pad failure, gasket bypassed)?
- Construction problems (e.g. ring damage during shaft entry, removal of circle joint bolts, annulus grouting, shaft disturbance)?

# The investigation

A comprehensive investigation was undertaken, this included:

- New ground investigations including:
  - 22 BHs, 71 CPTs, PM tests
  - Triaxials, Rowe Cells, oedometer, Pollen & species analysis, $C^{14}$ dating (Uni Hull) and LOI (in peat); Atterbergs; PSD; SEM (aeolian sand); dispersivity (laminated clay); water chemistry;
  - Centrifuge (Cambridge Univ. Eng. Dept.);
  - Hydro (piezo, 2No. Pump tests, tracer – Uni Sheffield)
- lining design checks
- 2D and 3D FEA modelling of possible failure mechanisms
- Witness statements to reconstruct sequence of events
- Examination of available construction records

# The investigations

Centrifuge tests limited by modelling simplifications required, however confirmed:

- Tunnel buoyancy caused longitudinal deformation relative to fixity at the shaft
- softening/ disturbance of soil local to the shaft
- Circle joint opening
- If laminated clay in invert stays intact – NO FAILURE
- But if fine single size SAND gains access – FAILURE

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*A relatively unusual feature of the collapse was that there was no immediately obvious cause ….. usually the blame is attributed to some design or construction aspect or ….. adverse ground conditions …. but in this case all seemed satisfactory…"*

Grose & Benton, 2005

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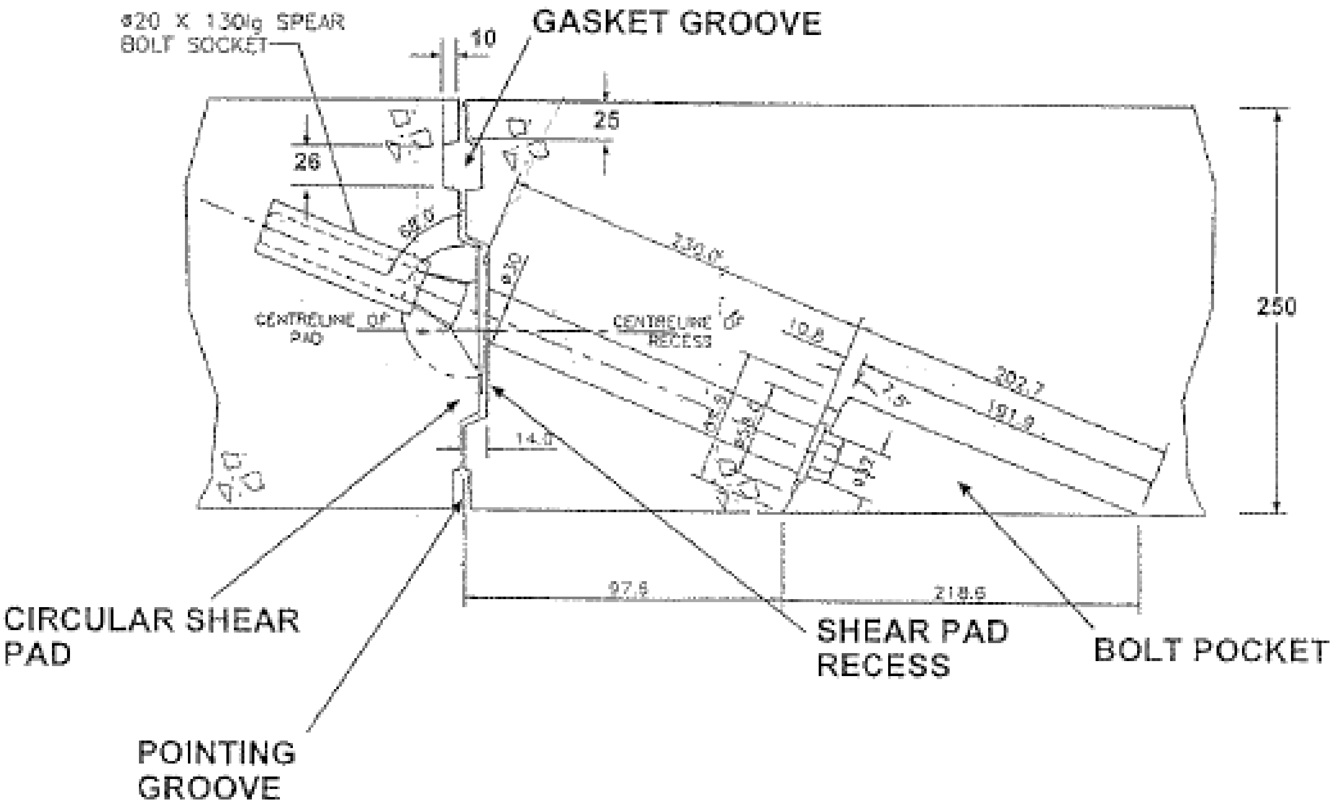
# Possible causes

Consequence of longitudinal movement: “top hat incident”? shear pads failure? Nib crushed – gasket bypassed?



# Possible causes

Highly mobile fine sand – silt in:

- In Holocene alluvium
- laminated clay
- Aeolian sands
- Previous problems:
  - Hull Tidal Surge barrier – (Fleming et al 1980 and McMillan, 1984)
  - Shaft tremmie problems with trapped silt sludge (T4)
  - Problems with ground anchor holes “piping”
- Possible glacial disturbance providing water path in laminated clay

The peat/organic clay:

- Disturbance and softening during shaft construction?
- Loss of confinement due to buoyancy, compression?
- leakage & consolidation at the early stages?

Groundwater pressure:

- Failure at HIGH TIDE
- “damming” by tunnel
- 2bar in lower aquifer but .....
- Upper aquifer no tidal response so lower pressure

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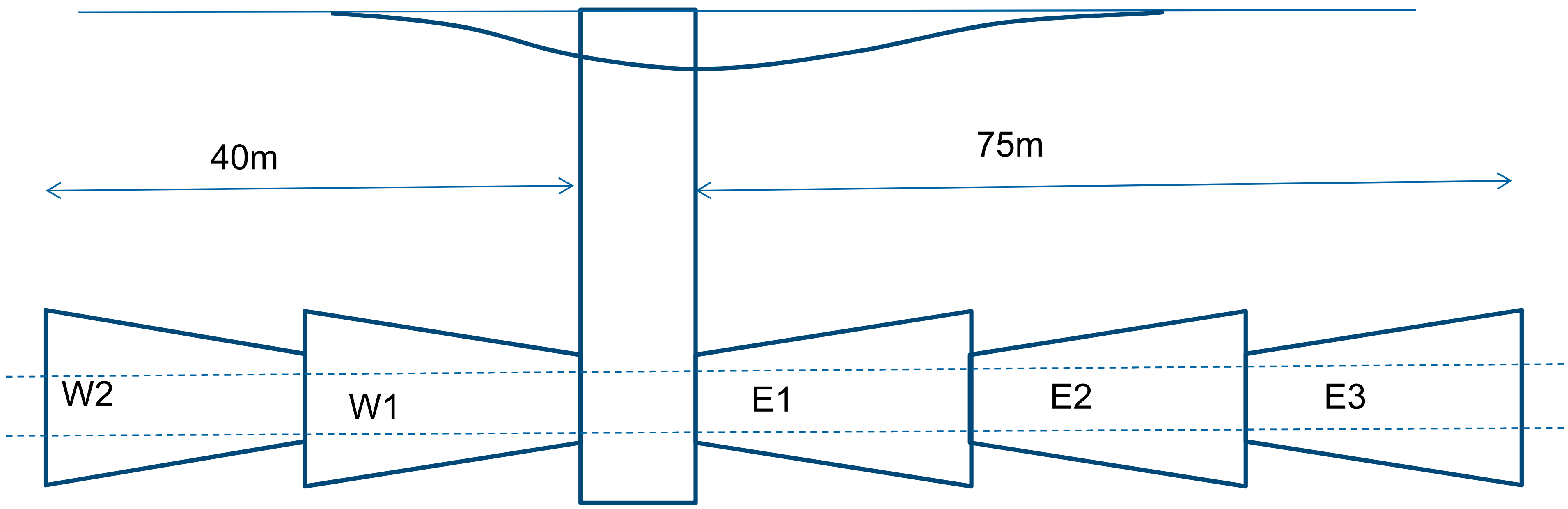
*"…. The use of liquid nitrogen to create a stable environment in which to rebuild the tunnel was a technically challenging option. Cost and programme implications were significant…"*

Brown, 2004

# Remediation




Re-mining using AGF to form 1.5m ice-walls around tunnel

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*"Underwriters reluctant to Insure Tunnel Projects without adoption of Joint Code of Practice …… please provide your views and comments"…*

*June 2003, E-Mail from AON , KCRC's Insurance Brokers (Jesudason HKIE, download March 2014)*

# Insurance implications

Chamley et al (2000):

- The Construction All Risks (CAR) insurance policy covered both client and contractor - protected against the damage repair costs.
- ACCELERATION INSURANCE addressed the measures necessary to get the construction back on track to meet the completion date.
- Where the CAR policy does not cover the remedial works and programme mitigation costs, the COST OVER-RUN INSURANCE limited the clients' financial liability.
- Client saw little impact and the anticipated outturn cost was within the original estimate.

# Insurance implications

- Munich Re - Wannick (2006)

| Date | Project | Event | US$ millions |
|---|---|---|---|
| **1994** | Great Belt Link, Denmark | Fire | $US 33 million |
| **1994** | Munich Metro, Germany | Collapse | $US 4 million |
| **1994** | Heathrow Express Link, GB | Collapse | $US 141 million |
| **1994** | Metro Taipei, Taiwan | Collapse | $US 41 million |
| **1995** | Metro Los Angeles, USA | Collapse | $US 9 million |
| **1995** | Metro Taipei, Taiwan | Collapse | $US 29 million |
| **1999** | Hull Yorkshire Tunnel, UK | Collapse | $US 55 million |

- BTS closed face tunnelling report on Hull and Portsmouth collapses – May 2002
- BTS – ABI JCOP – published September 2003 - International Tunnelling Insurance Group (ITIG) by 2005

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*…four key risks during construction are… safety (life and economic), cost, time and quality. These can all be identified, assessed, valued, mitigated and then apportioned to the appropriate project stakeholder…*

*Covil et al (2005)*

# Lessons learned

- Carry out detailed “geo-hazard” risk assessments and risk management processes early (e.g. identifying previous issues with the “mobile sands”)
- Keep on top of TBM data logging – never know when you need the data – note the Closed Face working party (2002) recommendations (4.2)
- Ensure annular grouting and take a “zero tolerance” to leaks
- Smooth transition from “rigid” shaft to “flexible” tunnel – design for permanent bolts or some other means
- Are shear pads (for build accuracy) a good idea? Distance between EPDM gasket and extrados?
- Segment design and casting – adequate cover and joint quality
- Monitoring (e.g. ground movement, water pressures) in “critical” locations - difficult around a working shaft but this is a key risk area
- Design for sufficient redundancy /”robustness” – avoid false economies

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*…buoyancy …and tidal variations caused repeated cyclic movement of the tunnel …even with a fully grouted annulus. This …. may have created both a path for the sand to travel towards the tunnel and …compromised the gasket.*

*Grose & Bentley (2005)_Discussion*

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