Challenges for Design, Construction and Operation

Martin Knights
HALCROW a CH2M Hill company
& The International Tunnelling Association

17, 18 y 19 de Octubre 2012
Santiago, Chile

PIARC CHILE
Perspective

Sustaining and improving the quality of people’s lives

Brazil, Chile, Argentina, Panama
International Tunnelling & Underground Space Association

Our goals are:

To encourage **new uses** of underground space

To encourage studies of **underground alternatives** to surface construction

To have **resilient** infrastructure

To encourage the development of **guidelines**.

To **better** procurement and contracts

To encourage & stimulate **innovation**.

To improve **training**

To arrange **international exchange**

To **network**

To be the **global leader** influencing use of underground space

*In future our urban areas need to incorporate more sustainable underground solutions*
Always Act Safely

All of you here today have a role to play in the management and commitment to safety.

- Client
- Government
- Designers
- Coordinators for H&S
- Contractors
- TBM Manufacturers
- Workforce
- Professional Organisations
- Regulators and Standards makers
- Insurers

HALCROW
A CH2MILL Company
The most vital contribution to safety in any tunnel is …………………… a trained and disciplined workforce

Safety is the responsibility of every person on site, the office, & off site supply chain
Technology and Innovation are realising dreams.

Reality

Dream?

China—Taiwan

Dream?

Hong Kong—Macau—China Link

Reality
Moscow to New York by train?

Dream?

Proposed tunnel between Siberia and Alaska

The train standing on Platform 6 is the 7.20 for Paris, Moscow and New York – through the Bering Strait

Russia
Nick Holsworth Yakutsk

It might still be too soon to book your ticket from King’s Cross to Grand Central station in New York, but the prospect of such an epic rail journey has just moved a step closer.

The Kremlin gave its blessing this week to the greatest railway project of all time: a 65-mile (106km) tunnel linking Asia and North America under the Bering Strait and connecting railway lines that would allow a seamless train journey across the breathtaking wildernesses of Siberia and Alaska. It would be cheaper, faster and more secure than shipping goods around the world. It could carry about 3 per cent of the world’s freight, earning £7 billion a year.

Engineers say there is no technical reason why the tunnel could not be built and investors would break even within 15 years of its opening.

Mr Levinthal was among several Kremlin officials, including Vladimir Nekrutov, the deputy secretary of the Russian National Security Council, who were in the United States of taking a once-in-a-lifetime journey across the breathtaking wildernesses of Siberia and Alaska.
LOCATIONS OF MAIN NORWEGIAN SUB SEA TUNNELS

@30 tunnels built /range= 1km>20km
Overall view of the LHC experiments, CERN GENEVA
Brazils` High Speed Rail Project

- 6 years to plan and construct
- +90km tunnels—@50km >1km long(4>7km long)
- TBM and Conventional tunnelling
- Logistics and planning challenge
- Soft and Hard Ground
- Tunnelling= >30% of total construction cost
It's official--Tunnelling is now an Olympic and World Cup Sport!!>>
“Synchronised tunnelling”
Rio de Janeiro

Metro Line 4

Extension west from to (Olympics site) @16km
Busan Geoje immersed tunnel, South Korea
Dubrovnik, Croatia

Innovation in Tunnelling
More powerful Hydro energy, Rail and Road tunnel schemes in the Himalayas
The global challenges

Sustainable development

Transport

Energy

Urbanisation

Water scarcity

Population growth

Climate change

Civil Engineering infrastructure & use of underground space will provide solutions
Demographic Trend

Growth of Urbanisation

source: Sustainable Urban Infrastructure – Siemens
The Singapore URA Sustainable Urban Living R&D Programme

1. Create more underground space and optimise the use of underground space to expand Singapore’s land resources.

2. Hong Kong Strategic Cavern Storage Programme
Servicing Helsinki’s ‘Underground City’
ITACUS Committee for use of underground space

- Formed @ 5 years ago
- Promotes use of underground space
- Leading the debate at ITA WTC`s
- Networking with global non governmental agencies eg UN,
- Working with local and national government planners
- Meeting in Singapore November this year
New technical committee 2011

ITA will be more Industry driven in future
Activity Groups are organized along processes:

- Investigation
- Excavation
- Support
- Lining & Waterproofing
- Installation & Interior works
- Monitoring
- Rehabilitation
- Design (covering all processes)
Immediate flash coat application of Sprayed Concrete
On the newly excavated face and profile
Sprayed waterproof membrane

Hindhead-A3 Road Tunnel, England
<table>
<thead>
<tr>
<th>Year</th>
<th>Country</th>
<th>Project</th>
<th>TBM Manufacturer</th>
<th>Diameter</th>
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<tr>
<td>1994</td>
<td>Japan</td>
<td>Trans Tokyo Bay Highway Tunnel</td>
<td>8 Kawasaki, 3 Mitsubishi, 1 Hitachi, 1 IHI</td>
<td>14.14m</td>
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<tr>
<td>1997</td>
<td>Germany</td>
<td>Hamburg 4th Elbe River Highway Tunnel</td>
<td>1 Herrenknecht Mixshield</td>
<td>14.2m</td>
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<td>2000</td>
<td>The Netherlands</td>
<td>Groenehart double-track rail tunnel</td>
<td>1 NFM Technologies</td>
<td>14.87m</td>
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<td>2001</td>
<td>Russia</td>
<td>Moscow Lefortovo Highway Tunnel</td>
<td>1 Herrenknecht Mixshield Ex-Elbe project machine</td>
<td>14.2m</td>
</tr>
<tr>
<td>2004</td>
<td>Japan</td>
<td>Tokyo Metro</td>
<td>1 IHI EPBM</td>
<td>14.18m</td>
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<td>2004</td>
<td>China</td>
<td>Shangzhong Road Subaqueous Tunnel, Shanghai</td>
<td>1 NFM Technologies Ex-Groenehart machine</td>
<td>14.87m</td>
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<td>2004</td>
<td>Russia</td>
<td>Moscow Silberwald Highway Tunnel</td>
<td>1 Herrenknecht Mixshield Ex-Elbe project machine</td>
<td>14.2m</td>
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<tr>
<td>2005</td>
<td>Spain</td>
<td>Madrid Calle 30 Highway Tunnels</td>
<td>1 Herrenknecht, 1 Mitsubishi</td>
<td>15.2m, 15.0m</td>
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<tr>
<td>2006</td>
<td>Canada</td>
<td>Niagara Water Diversion Tunnel*</td>
<td>1 Robbins hard rock gripper TBM Rebuilt Manapouri tailrace tunnel machine</td>
<td>14.4m</td>
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<tr>
<td>2006</td>
<td>China</td>
<td>Shanghai Yangtze River Tunnel</td>
<td>2 Herrenknecht Mixshields</td>
<td>15.43m</td>
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<td>2006</td>
<td>China</td>
<td>Jungong Road Subaqueous Tunnel, Shanghai</td>
<td>1 NFM slurry shield Ex-Groenehart machine</td>
<td>14.87m</td>
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<td>2008</td>
<td>China</td>
<td>Nanjing Yangtze River Tunnel*</td>
<td>2 Herrenknecht Mixshields</td>
<td>14.93m</td>
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<tr>
<td>2009</td>
<td>China</td>
<td>Yingbingsan Road Tunnel, Shanghai</td>
<td>1 Mitsubishi EPBM Ex-Bund Tunnel machine</td>
<td>14.27m</td>
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<tr>
<td>2010</td>
<td>China</td>
<td>Qianjiang Subaqueous Tunnel, Hangzhou Second tube currently under construction</td>
<td>1 Herrenknecht Mixshield Ex-Shanghai Yangtze River Tunnel machine</td>
<td>15.43m</td>
</tr>
<tr>
<td>2011</td>
<td>Spain</td>
<td>Seville SE-40 Highway Tunnels*</td>
<td>2 NFM Technologies EPBMs</td>
<td>14.00m</td>
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<tr>
<td>2011</td>
<td>Italy</td>
<td>A1 highway tunnel*</td>
<td>1 Herrenknecht EPBM</td>
<td>15.55m</td>
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<td>2011</td>
<td>China</td>
<td>Hong Mei Road, Shanghai</td>
<td>1 Herrenknecht Mixshield</td>
<td>14.9m</td>
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<tr>
<td>2011</td>
<td>China</td>
<td>Weisan Road Tunnel, Nanjing*</td>
<td>2 IHI/Mitsubishi/CCCC slurry TBMs</td>
<td>14.93m</td>
</tr>
<tr>
<td>2011</td>
<td>USA</td>
<td>Alaskan Way elevated highway replacement tunnel*</td>
<td>1 Hitachi Zosen EPBM (Letter of intent)</td>
<td>Approx 17.6m (58ft)</td>
</tr>
<tr>
<td>2011</td>
<td>Russia</td>
<td>Orlovsky Tunnel, Saint Petersburg*</td>
<td>1 Herrenknecht Mixshield Engineering started 2009, order confirmed 2011</td>
<td>19.25m</td>
</tr>
<tr>
<td>2011</td>
<td>New Zealand</td>
<td>Waterview motorway connection tunnel, Auckland*</td>
<td>1 EPBM to be ordered</td>
<td>Approx 14m</td>
</tr>
</tbody>
</table>

**Size of TBMs**

**Masters of the Universe?**

**Tunnel talk**
Traditional Delivery

The traditional TBM factory assembly
JIN PING II – CHINA
OPEN, HARD ROCK HP-TBM

JinPing Mountain (4420m) viewed towards the west

Yalong River Valley
Deep & narrow canyons with very steep walls
JIN PING II
INTERNATIONAL SOURCES

- Job Site
- Shipments from Shanghai
- Shipments from Dalian
- Shipments from Chengdu
- Imported parts

Other Location

Europe

USA
Cutterhead Welding
Cutterhead must be welded at site. This is required even for factory assembled machines.
Presentation to World Bank 13th June 2012, Washington DC

World Bank Group Hydropower Community of Practice - Working Group on Tunneling & Underground Works

Procurement, risks & contracts

Martin Knights

Halcrow Group
A CH2MH Company

International Tunnelling Association
12th June '12
Aims of the International Tunnelling & Underground Space Association

One of ITA goals include:

**better procurement and contracts** ~

*In future our urban areas need to incorporate more sustainable underground solutions*
Current Global HEP Market

Market now growing again

Political interference slows progress

Procurement is slow & needs overhaul

Procurement typified by phases of intermittment surge`s of activity followed by long interim phases of no action

Interim Gap being filled by thermal power

Procurement & Contracts need to be appropriate

Funders need to address, benchmark & influence….now.

Need to agree consistent approach to procurement of HEP underground works…now

Long term planning /less politics/ more enlightened
Intention of Seminar 1

• discuss issues of procurement in contracting and try to see how to resolve some of the challenges in delivering sustainable hydropower projects........
Intention of Seminar 2

• .....collectively discuss issues of procurement in contracting and try to see how to resolve some of the challenges in delivering sustainable hydropower projects. risk management & risk sharing mechanism, use of standard bidding documents, EPC versus traditional methods of contracting and capacity building, do the procurement rules of the Banks provide flexibility? for efficient contracts.
World Bank Seminar Themes

- EPC v Traditional
- Risk ownership and management
- Competitive bidding v Strategic Partners
- Eligibility & prequalification
- Training and capacity building
- Least cost v Value for money
- What WB needs to do in future
Managing Risk!!

Risk......=

The Contract

Lawyer?>>>
Consultant?>>>

The Procurement vehicle>>
Hydro Projects
Perceptions levels of Geological Risk?

<table>
<thead>
<tr>
<th>Structure</th>
<th>Level of geological Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td></td>
</tr>
<tr>
<td>Dam</td>
<td></td>
</tr>
<tr>
<td>Surface Power House</td>
<td></td>
</tr>
<tr>
<td>Underground</td>
<td></td>
</tr>
<tr>
<td>Cavern</td>
<td></td>
</tr>
<tr>
<td>Shafts</td>
<td></td>
</tr>
<tr>
<td>Long tunnels</td>
<td></td>
</tr>
</tbody>
</table>
So.....Is tunnelling `risky`?
Tunnelling is not risky! The risks just need to be removed, mitigated, planned for, and managed….

….methodically by experienced and competent companies & people using the right equipment AND PROCUREMENT.

No!

Simple!? Well not always!
No construction project is risk free. Risk can be managed, minimised, shared, transferred or accepted. It cannot be ignored
www.britishtunneling.org

www.imia.com (Being updated now by ITA & ITIG)
Basic message of Risk Ownership

• The party who ‘owns’ a risk will pay for it if it materialises
• ‘Who Pays’ for risk is a contractual issue
• Who Manages’ a risk is non-contractual – and is determined by who is best to manage.
• Risks should not be `dumped` onto party least able to manage the risk
• Usually - risks should be owned by party with best ability to influence the outcome
Hydro Schemes

As geotechnical information can be **sparse** due to cost of drilling boreholes in mountainous terrain the Client can manage ground & other risks by 3 options.

1) **Passing** all ground **risks over to contractor** – this will **increase cost** of project & generate an **adversarial approach & you get what you deserve!**

2) Preparing a **Geotechnical Baseline Report** & asking the contractor to price within predefined limits. These need to be narrow. This will help to **share risk** through an **Engineer’s design** with alternatives allowed or a **Design & Build** approach to a reference design

3) **Engaging the contractor at an early stage & jointly manage the risks** from the outset of the project. This should lead to the most economical solution through a target cost approach. **This is not always appreciated by Clients.**
Prof Evert Hoek:

pragmatic observations

- **Difficult to** apply traditional SI`s for long deep tunnels
- **Justified expenditure** on sophisticated SI for Large Underground Power Houses
- Seldom can either party agree on interpretation of ground as tunnelling proceeds.
- Sees increased use of TBMs long tunnels
- **Success** of an underground project is less to do with the Contract and more to do with Client and Contractor relationship and objective, non confrontational & competent behaviour of engineers.
- **Flexible procurement** needed
- **Baselining** of ground conditions
KISHANGANGA HYDROELECTRIC PROJECT
Jammu & Kashmir, India

Risk Management Approach

Special Measures Criteria for Critical Conditions
(Long TBM driven tunnel)

Summary information
Squeeze control !
PROJECT DETAILS

Started : January 2009
Completion : January 2016
Client : National Hydropower Commission  NHPC
Generated Power 330MW

Contractor: HCC
Designer /Engineer : Halcrow
PROJECT LAYOUT

Headrace Tunnel @24km ( > 70% by Double Shield TBM)
General geological conditions

The formations where squeezing may be significant are:
Tragbal and Hafkhalan Formations
Hasthoji Formation
parts of the Razdhan Formation.
Squeezing and critical conditions

The occurrence and extent of squeezing is related primarily to parameters to be monitored:

- rock mass quality, GSI
- unconfined compressive strength (UCS) of intact rock pieces
- \textit{in situ} stress ratio ($k_o$) in the plane of the tunnel cross section
- depth and rock density.
TBM for the Headrace tunnel

SELI Double Shield with Honeycomb pcc tunnel segments
What is squeezing?

- significant time dependent deformations resulting from tunnel excavation

Figure 1. Squeezing rock reduces the tunnel cross section. This is shown in this photograph where re-profiling of a highly deformed cross section is taking place in the Saint Martin access drift (Lyon-Turin Base Tunnel).

St Martin Access Tunnel
(Lyon-Turin Base Tunnel, Alps)

Nathpa Jhakri HEP
(India, Himalayas)
Why is squeezing important to the TBM tunnel?

- great depth (up to 1400m)
- weak rock in places
- stresses concentrate around tunnel
- rock is overstressed
- rock fails – becomes ‘plastic’
Long term loads

- initial segment load increases with time
- creep mechanisms superimpose on rock failure
- long-term loads may be 2 to 3 times the initial loads
What are critical conditions?

TBM:
- geological conditions – particularly squeezing - which might impair or prevent forward progress of the TBM and/or compromise the structural capacity of the segmental lining

Segmental lining:
- geological conditions – particularly squeezing - which might compromise the structural capacity of the segmental lining

A risk management approach to design and construction is needed
What are ultimate contingency measures?

- measures that may have to be taken in the ultimate case of critical conditions in which the TBM becomes entrapped and/or
- the lining becomes, or is predicted to become, overstressed

In these ultimate conditions, it may not be feasible to construct sections of the tunnel using the TBM - the method of tunnel construction may need to be changed temporarily.

Contingency plans need to be made.
Halcrow wanted to provide guidance to site personnel on:

- the severity of squeezing to be anticipated along the length of the TBM tunnel
- monitoring requirements
- criteria to be followed during construction
- special measures to be implemented

in order to allow the TBM to be used to construct as much of the planned length of the tunnel as possible - with minimum risk to the project
Risks to the TBM and segmental lining

Risk to the TBM:
- collapse of the rock face
- significant groundwater inflow, possibly forming mudflows
- squeezing of the ground onto the TBM shield with sufficient pressure to prevent TBM progress without special measures being taken

Risk to the segmental lining:
- squeezing of the ground onto the segmental lining with sufficient pressure to exceed the structural capacity before special measures can be taken
- particularly severe squeezing conditions in which the structural capacity of the segmental lining is predicted to be exceeded even if the full range of special measures was to be implemented
Special measures  (risk to TBM)

• more cutterhead motors
• 43MN thrust
• conical shields with increasing clearances to rock
• over-cutting
• operational special measures
• forward probing
• pre-excavation grouting
• access to outside of shield
• external grout plant
Special measures (risk to segments)

- over-cutting
- early consolidation grouting
- pre-exavation grouting
- instrumented segments
Ultimate contingency measures (1)

TBM cannot be used or becomes entrapped:
• ‘park’ TBM and proceed with hand mining/drill-and-blast methods
• oversize tunnel with deformable temporary support
• when conditions improve, move TBM through the mined tunnel
• re-start TBM

• permanent lining with segments backfilled with concrete or
• permanent cast concrete lining
Segmental lining cannot be used in these circumstances:

- critical conditions **are** detected ahead of the TBM and indicate that the segmental lining cannot be used through a section of tunnel without an unacceptably high risk of overstressing before other mitigating measures can be implemented, *i.e. the lining may become overstressed over the length of the back-up train*.
  
  In this case the TBM and segmental lining method should not be used; change to drill-and-blast with deformable temporary support.

- the critical conditions **are not** detected and the lining is used, but becomes, or is predicted to become, overstressed before other mitigating measures can be implemented at the rear of the back-up train.
  
  In this case install instrumented segments to monitor load development to ensure tunnel remains safe as TBM moves forward.
Squeezing and critical conditions

Results of the time dependent numerical modelling based on specialist laboratory testing (Turin, Italy)

Some key conclusions from time dependent (visco-plastic) modelling:

• effects of squeezing are greater at slower advance rates
• over-cutting is an effective special measure, and most likely to be needed to prevent squeezing of the TBM, but pre-excavation grouting may also be required
• pre-excavation grouting will affect advance rates and therefore squeezing
• consolidation grouting behind the back up train is generally too late to be effective in preventing squeezing, but it limits further development of squeezing pressures
Behaviour of the rock mass and special measures required

**Hal4 / Hal5 Report**

- **10m per day**
  - **Ucs**
    - 80
    - 60
    - 40
  - **Gsi**
    - 95
    - 60
    - 50
    - 40
    - 30
    - 20
    - 10
  - **Special Measures**
    - Over-cutting not required
    - Over-cutting required
    - Pre-excitation grouting and over-cutting required

**Ko = 1.5**

**Hasthoji Formation**

- **UCS**
  - 80
  - 60
  - 40
- **Gsi**
  - 95
  - 60
  - 50
  - 40
  - 30
  - 20
  - 10
- **Special Measures**
  - TBM may be stuck based on sliding friction co-efficient of 0.25 and/or the segmental lining is overloaded in the long term - pre-excitation grouting and over-cutting may not resolve the problem, monitoring of the lining required

**Razdhan Formation**

- **UCS**
  - 80
  - 60
  - 40
- **Gsi**
  - 95
  - 60
  - 50
  - 40
  - 30
  - 20
  - 10
- **Special Measures**
  - TBM may be stuck based on sliding friction co-efficient of 0.25 and/or the segmental lining is overloaded in the long term - pre-excitation grouting and over-cutting are unlikely to resolve the problem
### Consolidation grouting requirements

#### Ko = 1.5

<table>
<thead>
<tr>
<th>Chainage</th>
<th>Invert</th>
<th>GL</th>
<th>Depth</th>
<th>Consolidation Grouting</th>
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<td>3200</td>
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</table>

**R** = Routine consolidation grouting (i.e. location to suit the Contractor’s operations and programme)

**E** = Early consolidation grouting required (i.e. grouting to be undertaken at the rear of the TBM back-up train)

**E* = Early consolidation grouting required, but requirement may be reviewed on referral to Halcrow**

#### Ko = 1.5

### Chart

- **Consolidation grouting not required**
- **Routine consolidation grouting**
- **Early consolidation grouting required**
Halcrow & ITAtech
Govt Clients: NHPC/CBIP/JKSPDC

3 Workshops
March April September 2012
Colourful meetings!
Finally some overall summary thoughts

- Get procurement strategy *sorted out early* ie what are the owners key requirements?
- Consider the appropriate Contract Document
- Manage the *interfaces*
- Do not *over specify* ie allow market to `add value`.
- Management of Risk, Quality and Safety are key considerations *in deciding procurement route.*
- Procurement is the *weakest link* in Global HEP
- Got to *change.*
Thank you
Thank you from Halcrow and ITA!