George Massey tunnel

TUNNEL ENGINEERING CONSULTANTS (TEC)

Presentation TEC 4 April 2013 for

BC Ministry of Transport

Content

1 Introduction TEC
2 Recent developments
3 Massey Tunnel
4 Key Issues & Considerations
5 Discussion
TEC a sustainable JV by 2 Dutch Top Consultancies

TEC-Partners

The first project of TEC - 1988
Tunnel related Expertise

- Civil design and engineering related to
  - Immersed tunnels
  - Bored tunnels in soft soil
  - Cut & Cover tunnels
  - Special tunnel techniques
- Electro mechanical installations
  - Ventilation, pumps, lighting, power supply
  - Traffic control
  - Dynamic traffic systems
  - Operation
- Safety aspects
  - (Road) Safety analysis
  - Operational procedures
  - Scenario Analysis
  - Integral design in complex (urban) environment
  - Road and rail alignment design

Soft soil tunnelling experts

Services

Full range of services
- Policy formulation
- Master planning
- Feasibility studies
- Preliminary designs, detailed designs and tender documents
- Assistance during tendering
- Supervision of works
- Operation and maintenance
- Training
- Contract and project management
- Risk management & value engineering
- Maintenance Plans

Full project cycle consultancy
TEC’s business vision

Every tunnel is unique
- Selective portfolio
- Engineering challenge
- Realistic
- Reputation based on delivery
- Always the best quality

Setting the standard, every time again

Stretching the limits of tunnelling

Capabilities TEC-projects

- Immersed tunnels
- Bored tunnels
- Metro projects
- Other tunnel techniques
- Tunnel Systems / Tunnel Safety
- Artificial Islands
- Projects Parent Companies
Immersed tunnels

The Netherlands has 30% of all immersed tunnels in the world
TEC has had major contributions in 80% of all immersed tunnel projects globally in past 20 years

TEC is global market leader in immersed tunnel design & engineering
Immersed tunnels

The Netherlands (> 10 projects)

• Noordtunnel
• Wijkertunnel
• Calandtunnel
• Aqueduct Alphen
• HSL Oude Maas
• HSL Dortsche Kil
• IJ tunnel N-Z Lijn
• Piet Hein tunnel
• 2nd Coentunnel
• 2nd Benelux Tunnel
• Crossing Central Station Amsterdam
• IJ-tunnel (renovation)
• Blankenburg tunnel

Strong home market

Immersed tunnels

International (> 25 projects)

• Medway UK
• Øresund Denmark
• Maliakos Greece
• Harbortunnel Denmark
• Ningbo China
• Warnow querung Rostock Germany
• Daugava Crossing Riga Latvia
• River Tyne Crossing UK
• Busan Geoje Link South Korea
• Coatzacoalcos Mexico
• Oosterweel tunnel, Antwerp, Belgium
• Fehmarnbelt Denmark
• HZMB China

• Western Harbour Crossing HongKong
• River Lee Cork Ireland
• Isle Wight Crossing
• Quadalquivir Spain
• Harbour Valencia Spain
• South Hampshire Light Rail
• Coatzacoalcos Mexico
• Thessaloniki harbour tunnel Greece
• Limerick Ringroad Shannon Ireland
• Söderström Tunnel Sweden
• Shenzhen Crossing China
• Santos Crossing Brazil

Active around the globe
Immersed tunnel Coatzacoalcos Mexico

Söderström tunnel Stockholm
2nd Coentunnel, Amsterdam

Øresund link – Denmark to Sweden
Hong Kong-Zhuhai-Macao Link China
TEC project: Fehmernbelt Link between Denmark and Germany

Bored Tunnels
Projects Bored tunnels

The Netherlands

- NZ line Amsterdam
- HSL Groene Hart Tunnel
- 2e Heineenoordtunnel
- Westerschelde tunnel
- Betuweroute Pannerdensch kanaal
- Betuweroute Sophiatunnel
- Tunnel Northern Ring Road Den Haag
- Sluiskil tunnel

Involvement in the introduction of bored tunnelling in the Netherlands (research programs)

International

- Metro Lisbon
- Genoa Harbour crossing
- Dublin metro
- Fehmernbelt Link Denmark
- Shenzhen Crossing China
- Tuen Mun Chel Lap Kok HK
- Lantang Crossing HK

Bored Tunnels Betuweroute Cargo rail
North/South line Amsterdam

North/South line Amsterdam
Tuen Mun - Chek Lap Kok Tunnel Hongkong

Other tunnel projects

- Cut&Cover tunnels
  - Schiphol Airport tunnels
    - Fly-over Hoofdvaart Schiphol Airport
    - Aircraft taxiway viaduct Schiphol
    - Freight tunnel Kaagbaan
    - HOV tunnel Schiphol
    - Lightrail tunnel 09-27 Schiphol
  - Markt Maas project Maastricht

- Aqueducts
  - Naviduct Krabbersgat
  - Aqueduct Vliet
  - Aquaduct Gaag
Other tunnel projects

• Pneumatic caisson
  – Power station Linne
  – Concert Hall Den Bosch
  – North / South Line

• NATM / SCL method
  – New Tyne Crossing

Tunnel Systems, Tunnel Safety

• Tunnel De Noord
• Wijkertunnel
• Markt-Maas tunnel
• 2nd Coentunnel
• Piet Heintunnel
• North/South Metro Line Amsterdam
• Fehmernbelt Link (20 km immersed tunnel)
• Hong Kong Zhuhai Macao Fixed Link
Traffic Control Centres
Provence North Holland

Other structures by TEC and its partners
• Bridges
• Viaducts
• Artificial Islands

Open minded
Artificial Islands

- Øresund Link Denmark
- Hong Kong Zhuhai Macao Link China
- Fehmernbelt Link Denmark
- Dubai Palm Islands
- “The World” Dubai
- Hong Kong International Airport
- Eko Atlantic City Lagos Nigeria
Introduction Immersed tunnels

Brief description Tunnel technique

Basic principle Immersed tunnels
Basic principle: Immersed tunnels

[Images of immersed tunnels and construction sites]
Immersed tunnel Busan Geoje
South Korea

Foundation layer

- The “artificial” layer or foundation bed between the tunnel and bottom of the dredged trench
- Installed after immersion (tunnel on temporary supports)
  - Sand jet method → old tunnels
  - Sand flow method

- Installed before immersion
  - Gravel bed (berms)
- Combination of both (tunnel on temporary supports)
  - Gravel bed in combination with grouting
Summary Characteristics / Advantages

- Suitable for various and relatively poor soil conditions
- Shorter overall length – smaller footprint (explained later)
- Parallel construction processes and relatively low and manageable risk profile
- Capable of dealing with (severe) seismic events
- 80-90% of all construction works can be done by local contractors (limited input from international specialist subcontractors)

2 Recent developments in Immersed tunneling
Tunnel safety
• Femern (moving pictures)
• Separate tubes, emergency tube, no contraflow in one tube
• Technical Installations
• Ventilation (longitudinal)
• Development oriented (2nd Coentunnel)
• Interior (light, spacious)

Immersion technology
• Busan
• Amsterdam central station

Connections and gaskets
• General procedures

Earthquake resistance design
• Greece (stone columns)
• Busan (ground improvement)
• Marmaray Crossing ("compaction" grouting)
• Coatzocalcos (earthquake)

Building next to an existing tunnel
• 2nd Benelux tunnel
• 2nd Coentunnel
Fehmern Belt– The Longest immersed tunnel in the world

Facts:
- Fixed link between Germany and Denmark for road and rail traffic
- 19 km tunnel crossing the Fehmernbelt
- High safety standards apply
- Currently in design stage

Fehmern Belt Link
Fehmern Belt– Longest tunnel in the world

Challenges:
- Design competition with bridge option
- Longest immersed tunnel in the world
- Safety concept and ventilation needs new design philosophy
- Construction logistics in relation to time schedule
- Maximum availability of the crossing

Cost efficiency

<table>
<thead>
<tr>
<th>Project</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fehmern Belt Link</td>
<td>2020</td>
</tr>
<tr>
<td>Shenzhen Crossing</td>
<td>2020</td>
</tr>
<tr>
<td>Hong Kong-Zhuhai-Macao Bridge Link</td>
<td>2016</td>
</tr>
<tr>
<td>Trans Bay Tunnel BRIT Tunnel</td>
<td>2009</td>
</tr>
<tr>
<td>Øresund Tunnel</td>
<td>2001</td>
</tr>
<tr>
<td>Busan Geoje Fixed Link</td>
<td>2010</td>
</tr>
<tr>
<td>Hampton Roads Tunnel</td>
<td>1976</td>
</tr>
<tr>
<td>Cross Harbour Tunnel</td>
<td>1972</td>
</tr>
<tr>
<td>Tama River Tunnel</td>
<td>1994</td>
</tr>
<tr>
<td>Marmaray Crossing</td>
<td>2009</td>
</tr>
<tr>
<td>Piet Hein Tunnel</td>
<td>1997</td>
</tr>
</tbody>
</table>

SAFETY and VENTILATION
BROAD SAFETY CONCEPT

• Level 1 – prevention of accidents and fires through design and operation
• Level 2 – control of incidents, and self-rescue
• Level 3 – facilities for emergency services response and rescue

Leads to integrated safety strategy linking design, maintenance and operations

LEVEL 1

• Uni-directional tunnels (road and rail) – no head-on collisions
• Robust, concrete structure
• Traffic information system
• Electronic messaging and voice alarms
• Drivers awareness lighting
• Road and rail control rooms (24/7)
### LEVEL 2
- Escape cell between road cells with regular access
- Voice alarms, radio re-broadcast
- Safety and emergency lighting and signage
- Emergency stations – every 54m
- Structural fire resistance – RWS hydrocarbon curve for all critical elements
- Automatic suppression – water deluge system
- Longitudinal Ventilation System

![Diagram of Level 2](image)

### LEVEL 3
- Range of emergency communication systems – FM radio, mobile phones, emergency telephones, TETRA radio system
- Hydrant systems every 50 m, 1200l/min
- Access to tunnels at portals for first response and brigade vehicles
- Fire systems controls at portals
- Dedicated control rooms (two plus auxiliary)
- Comprehensive fire and emergency response plan

![Image of emergency response](image)
“Safer than open highway”

Also relevant for shorter tunnels
• Separation of traffic flows
• Escape gallery
• Robust design, use the driver’s perspective
• Traffic control and traffic management systems (SCADA)

Safe passage

Fehmern Belt Link

Immersion Technology
Busan Geoje South Korea

Facts:
- 8 km fixed link between Busan and Geoje Island
- For main navigational channel immersed tunnel applied
- One of deepest tunnels in the world (upto 48 m)
- With a length 3.2 km also a very long tunnel → new survey techniques were developed for adverse offshore conditions
- In operation since 2010

Challenges:
- Unfavorable ground conditions
- Adverse immersion conditions (offshore, swell waves) → new techniques had to be developed
- Seismic conditions

Busan – Geoje Crossing
Risk based approach for transport and immersion

3D physical test (DHI)  
Numerical wave modelling

3D numerical test (Zentech)  
Numerical current model

Decision model: Wave forecasting system

[Images and diagrams related to wave modelling and decision models]
Special equipment for transport and immersion

Special equipment for survey

Innovations: Remote Survey

BGFL Korea

ITA 2010-05-19
Amsterdam metro line, Central Station – Highest complexity

Facts:
- 9 km new metro line through city centre of Amsterdam
- 8 stations of which 4 in old city centre
- Historic buildings with poor foundation
- High safety standards apply
- Currently under construction

Challenges:
- No damage to historic buildings → A’dam CS is listed building
- Minimise city life disruption and Dutch Rail operations
- Public opinion
- Aesthetics for underground space
- Central Station stretched the limits of immersion technologies

Amsterdam North/South Metro line
Amsterdam North/South Metro line

Supporting structure
Sandwich wall
Microtunneling wall
Interned tunnel

Amsterdam North/South Metro line
Connections and Gaskets

Principle immersed tunnels
Principle immersed tunnels

Principle immersed tunnels
Gina gasket

Principle immersed tunnels
Watertightness Immersion Joint

- Immersion joints
  - Joint components
  - Concrete tunnels

Earthquake Resistance Design
**Moderate to severe seismic areas may require special design approaches**

Key issues

Geotechnical
- Original soil → soil treatment?
- Foundation layer → gravel bed?

Structural
- Monolithic or segmental tunnel elements?
- Provisions in immersion joints?
  - post tensioning
  - Special GINA Gasket (damping purposes)

**Earthquake resistance Design**

- **Geotechnical Issues**
  - Soil layers sensitive to liquefaction may require treatment:
    - Stone columns (Aktio Preveza – Greece)
    - Compaction with grout columns (Marmaray – Turkey)
    - Cement deep mixing piles (Busan Geoje – South Korea)
    - Sand compaction piles (HZMB China)

- **Foundation layers**
  - Gravel bed installed in berms (Busan Geoje South Korea, HZMB China, Coatzacoalcos Mexico)
  - Continuous gravel bed with fat grout (Marmaray Turkey)
• Structural solutions to deal with heavy seismic events
  • Monolithic tunnel elements with a limited length in combination with heavy GINA gaskets for a more flexible response
  • Permanent prestressing in combination with crack inducers
  • Post tensioning across the immersion joint to ensure compression in GINA gasket

• Structural solutions to deal with heavy seismic events
  • Earthquake early warning systems (monitoring)
  • Special collar developed in Japan to deal with extremely heavy earthquakes (focus on flexible rather than rigid behaviour).
Aktio Preveza tunnel Greece

Marmaray Crossing Turkey
**Soil Improvement Works at the Bottom of Bosphorus**

**Improved Area:** 471 m x 20.5 m, Depth: 4 - 10 m under the Tunnel

**Details of Soil Improvement Works at Bosphorus**

Soil Volume Improved: 74,500 m³  
Number of CPG Columns: 3,264  
Grout Volume: 11,000 m³  
Improvement Percentage: 13.3%
Gravel bed in combination with grouting

- Methodology:
  - Installation gravel bed (full area)
  - Immersion tunnel element on temporary support
  - Inject space between gravel bed and tunnel with (fat) grout not penetrating the gravel bed
- Suitable in heavy seismic areas
- Off shore

Illustrations ITA Presentation WG 11 W. Grantz  Levelling equipment tested in the dry

Soil treatment of poor soils

Busan Geoje South Korea
Sand compaction piles

Hongkong Zhuhai Macao Link, China

Coatzacoalcos tunnel, Mexico
Results seismic analyses:

- Element length of 138 m requires special GINA
- Passive prestressing across the immersion joints
- Special design construction joints (between segments)
- Heavy shear keys in immersion joints (due to poor soil conditions)
- Gravel bed as foundation to avoid liquefaction

Coatzacoalcos tunnel, Mexico

- Permanent pre stressing in tunnel elements
  - No tension allowed in operational phase
  - Max allowable tension stress during earthquake (MDE) 2 N/mm²
- In case of cracking during earthquake (> MDE) → crack inducers and injection tubes at construction joints
Gravel bed (berms)

Building next to an existing tunnel
2nd Benelux tunnel
2nd Benelux tunnel
2nd Coentunnel

[Diagram of Coentunnel]

Doorsnede t.p.v. km 17.00

[Additional images of Coentunnel construction and overhead view]
3 Massey tunnel
Current tunnel
Replacement project / scenarios
Massey Tunnel

- Completed in 1959
- 2 x 2 lanes
- Two traffic tubes, two ventilation cells
- Total length of the tunnel is 1.3 km
  - Northern approach 370 m
  - Immersed section 629 m (6 tunnel elements)
  - Southern approach 335 m
- (semi) transverse ventilation with two ventilation towers on each bank
- Variable ground conditions

- Highly congested
- Height limit 4.15 m
- In 1989 counterflow system introduced to meet increasing traffic demands

Basic Data
Indicative soil profile at the Massey tunnel

Fraser River
- Important gateway to Port Metro Vancouver
- Unlimited height access up to Alex Fraser Bridge
- River width about 600 m
- Channel depth 11-12 m
- Main cargo: bulk carriers (cement), cars, containers
Potential Crossing Scenarios

Various bridge and tunnel options have been considered

- Maintain existing crossing
- Replace existing tunnel with a new bridge or a new tunnel
- Maintain existing tunnel and build new crossing (bridge or tunnel) along the existing Highway 99 corridor
- Maintain existing tunnel and build new crossing (bridge or tunnel) in a new corridor
Key Issues and considerations

Selection of appropriate option
Possible cross section lay-outs
Options for future use of existing tunnel

Selection of appropriate option
Potential advantages in alignment design

Alignment considerations

• Accessibility of port area (high bridge)
• River width is 600 m
• Panamax bulk carrier (required height >50-60 m)

Requires bridge bigger than Fraser bridge (span about 450m, vertical clearance 55 m)

High bridges with long approaches?
Bored tunnel – deep level, long approaches
- Case Caland tunnel Rotterdam

Comparison of Immersed and Bored Tunnel

Bored tunnel – deep level, long approaches
Neva Crossing, St. Petersburg
Practically every shape → cost effective for wide tunnels

• Cost effective for wide tunnels → example Fehmernbelt
Other criteria
- Air quality
- Noise
- Accessibility for slow traffic
- No restrictions for ship access to port area (no changes)

Criteria for Femern tunnel
- Reliability of connection (availability)
- Safety for shipping
- Visual impact (landmark vs. visual disturbance)
- Reuse of dredged material for land reclamation and nature development
- Comparable costs (life cycle)
- Reliability of constructing time

Possible cross section Lay-outs
Various options (1):

• Add 2 + 3 lanes to allow for 5 lanes in each direction of which two are tidal lanes

• Add 3 x 2 lanes to allow for 6 lanes in each direction of which two are tidal lanes

Maintaining existing tunnel

Various options (2):

• Add 2 x 2 lanes and 2 tubes for trains or transit

• Add 2 x 2 lanes a separate cell for pedestrians and 2 tubes for trains or transit

• Existing tunnel can also be used for slow traffic or trains / transit → expansion with 2 x3 lane tunnel may be appropriate as well

Maintaining existing tunnel
• 2 x 3 lane option (ref. Wijkertunnel, Caland tunnel)

• 2 x 3 lane option with separate cell for pedestrians and cyclists (ref. Oosterweeltunnel Antwerp)

• 4 x 2 lane option (ref. Drecht tunnel), with the possibility to concentrate heavy trucks in the outer cells

What about the existing tunnel?

• Leave the abandoned tunnel in place? → fill with water?

• Remove the tunnel (reverse immersion operation) to increase water depth and allow for the passage of bigger ships?
Introduction of tunnel access for pedestrians and cyclists

Include slow traffic

Options for future use of the existing tunnel
• Assess structural integrity and durability
• Increase river depth by replacing riprap with asphalt matrass
• Introduction longitudinal ventilation and use current ventilation ducts as escape cell and for the passage of pedestrians and cyclists
• Move ballast concrete to ventilation ducts and increase internal height of tunnel

Future use of existing tunnel
Thank You

www.tec-tunnel.com