Distinguished speech:
Innovation in design and construction increases the opportunities of immersed tube tunnelling

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• Project cases / specials
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  • North / South Line, Amsterdam, The Netherlands
General introduction

Over 150 tunnels (road, rail, utilities) have been built worldwide:

- USA: Railtunnel Detroit River 1910
- Europe: Maastunnel (R'dam, NL) 1937-1942
- Asia: Aji River tunnel, Osaka, Japan 1944
Basic principle Immersed tunnels

- Tunnel able to be afloat
- Tunnel has adequate FOS against uplift after immersion (both constr. and operat. phase)
- Tunnel structure meets design codes in terms of strength and durability
Potential advantages in alignment design
- especially river crossings

General Introduction

Potential advantages in alignment design

High bridges with long approaches
- impact on (urban) environment
Potential advantages in alignment design

Low level bridges (with movable sections)
(high) impact on shipping and road traffic

Caland tunnel construction – The Netherlands
Immersed tunnel replacing low level bridge in Motorway A15

Potential advantages in alignment design

Bored tunnel – deep level, long approaches

Example concept design
Neva crossing St. Petersburg
Russia
Practically every shape

- rectangular, circular etc

- cost effective for wide tunnels

Practically every waterway
Summary Characteristics / Advantages

- Suitable for various and relatively poor soil conditions
- Parallel construction processes
- Relatively low and manageable risk profile
- Capable of dealing with (severe) seismic events
- 80-90% of all design and construction works can be done by local companies (limited input from international specialist consultants or subcontractors)

Disadvantages / Prejudices?

- Environmental impact of dredging
  - Contaminated soils → special dredging requirements / higher disposal costs
  - Sometimes rejected for the wrong reason and without detailed study. *(what about impact of annual maintenance dredging?)*
  - But also opportunities? → Land reclamations
- Construction impact on shipping
  - Limited and manageable impact (dredging, immersion and backfilling)
  - In practice often an issue that can be addressed properly by good communication
Pushing Boundaries

- Transportation and immersion conditions
- Soil conditions
- Dredging and environmental issues
- Construction facilities and locations
- Special project locations
- Structural concepts (construction related)

Offshore Transport

(self floating elements)

- Wijker tunnel, Piet Hein tunnel, Netherlands
- Sydney Harbour tunnel, Australia
- Bjørvika tunnel, Oslo, Norway

Piet Heintunnel – The Netherlands
Offshore transport North Sea (approx. 200km)

Bjørvika tunnel, Oslo, Norway
Offshore transport (500km) with 5 potential shelter locations
Offshore transport and immersion (crossing sea straits)

- Chesapeake Bay tunnel (2.2km), US (golden oldie – transport on barge)
- Øresund tunnel (3.3 km) / Femernbelt tunnel (18 km), Denmark
- Busan Geoje tunnel (3.3km), South Korea
- HZMB tunnel (5.9km), China

Challenges for immersion:
- Wave conditions (especially swell waves) in relation to the low buoyancy

Special equipment for immersion
- Accurate positioning of tunnel elements in challenging (swell) wave conditions
Offshore transport and immersion (crossing sea straits)

- Steel concrete / full sandwich
- Constructed in Shanghai (steel) and casting basin (concreting)
- Weight 6100 tons
- Installed within 1 day by 12,000 tons crane vessel

Special closure joint concept to allow rapid execution

Hongkong Zhuhai Macao Link, China

Offshore transport and immersion

Special transportation and immersion vessel – self propelled

Shenzhong Link, China
(very) Soft and variable ground conditions

- Immersed tunnels can be applied in relatively poor soil conditions without additional measures.
- In the past the risks associated with very poor soil conditions were generally mitigated with expensive pile foundations (but this is now considered only appropriate in smaller projects).
- In-depth and advanced geotechnical design strategies has resulted in more economical design solutions:
  - Soil treatment that can be used on a larger scale and suitable for long sea straits → especially in case of variable ground and /or load conditions (improvement ground properties and uniformity of geotechnical profile)
  - Advanced geotechnical analyses that can demonstrate that (even soft) soil conditions are appropriate → especially in case of very soft, but uniform soil conditions
- A selection of projects on the next slides

Pushing Boundaries

(very) Soft and variable ground conditions

- Large scale Cement Deep Mixing piles (heavy locking and back fill)
- SCP with preload in sections where tunnel protrudes above original sea bed

Busan Geoje Fixed Link, South Korea
(very) Soft and variable ground conditions

- Large scale sand compaction piles around islands and in the transition area between islands and tunnel

- 2 m uniform gravel bed layer in areas with soft material under the tunnel, additional to the “normal” gravel bed in berm arrangement

Hongkong Zhuhai Macao Link, China

(very) Soft and variable ground conditions

- Direct foundation in thick uniform clay layer
- Observational method, monitoring, settlement reservation in traffic envelope

Marieholm tunnel Gothenburg, Sweden

Marieholm tunnel
- Up to 100m thick clay layer
Dredging and environmental issues

Immersed tunnels are sometimes rejected for not the right reason and / or without detailed study.

- It has been noted that in projects the bored tunnel was selected over the immersed tunnel just because of environmental impact of dredging but without any quantification.
- And without considering a wider perspective: annual maintenance dredging in port areas generally much larger in volumes.

There is much to gain in costs and in integration of the tunnel in the area in case the immersed tunnel will remain in competition and is not rejected for the wrong reasons.

ITA Working Group 11, Environmental paper

Dredging and environmental issues

Where relevant and important environmental impact of dredging can be limited using

- Special dredging equipment
  - E.g. mechanical dredging instead of hydraulic dredging
  - Environmental dredging equipment for dredging contaminated soils (closed clamshell, adaptive auger head – innovation by “Dredge Yard”)
Dredging and environmental issues

Where relevant and important environmental impact of dredging can be limited using
- Additional measures
  - Dredging in certain periods (e.g. not in fish migration periods) - e.g. New Tyne Crossing
  - Silt curtains / bubble screens to contain polluted sediments – e.g. Bjørvika tunnel (polluted soil), New Tyne Crossing (polluted soils, maintain oxygen levels for fish)

Dredging and environmental issues

Where relevant and important environmental impact of dredging can be limited using
- Monitoring water quality prior to and during dredging operations

New Tyne Crossing:
Monitoring water quality (dissolved oxygen levels, turbidity, current velocity, sediment contaminants) with buoys starting 12 months prior to start dredging operations
Dredging and environmental issues

Where relevant and important environmental impact of dredging can be limited using
• Monitoring water quality prior to and during dredging operations

Continuous spillage monitoring and control at Øresund Link, Denmark

But also opportunities → Land reclamations from dredged material

Øresund Link Denmark
Artificial Island created from dredged material
Dredging and environmental issues

- But also opportunities → Land reclamations from dredged material

Femernbelt Link Denmark
Re use of dredged material

Production tunnel elements

Casting basin
Ship dock
Floating (full sandwich)
Slip way (steel)
Production tunnel elements

Factory method / Cast & Launch (Øresund, HZMB, Femernbelt)

Production tunnel elements

Submersible barge technique

Luntou - Shengwudaotunnel, Guangzhou, China
Production tunnel elements
Submersible barge technique / combined with factory method

Femernbelt Link Optioneering

Pushing Boundaries

Blankenburg Tunnel, Rotterdam, Netherlands

Courtesy of Femern A/S (Kim Smedegaard)
Special project locations

• Underneath buildings (North/South Line, Amsterdam - under passage Central station)

• Below runways - Schiphol airport, NL (under passage runway 09-27 to limit downtime)

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Structural concepts (construction related)

Passage shallow waters and narrow waters, Söderström, Stockholm)

Very wide tunnels / steel-concrete full sandwich (Shenzhen Link, China)
Structural concepts (construction related)

Staged construction in shallow dock and at deep water jetty (Marmaray)

Project Cases
FemernBelt Link, Denmark

- Approx. 20 km link / incl. approx. 18 km immersed section
- Currently prepared for construction

Challenges related to exceptional length:
- Optimization cross section – cost efficiency
- Efficiency production tunnel elements
- State of the Art safety concept

TEC project: Femernbelt Link (20 km) between Denmark and Germany
Cross section optimization

Standard element width 42.2 m, height 8.9 m, length 217 m.
Full segment casting, water tight concrete, no membrane
Toe for trimming and for uniform foundation pressure

Standard cross section

Cross section optimization

Need for transformers and other equipment in the tunnel
Standard elements do not have sufficient space.
Special elements to cluster mechanical and electrical equipment

• Better working conditions and higher safety for maintenance staff
• Installations and system divided into units
• Concentrate extra space in the tunnel at special elements

Special Elements allowed cross section optimization
Cross section optimization

Special elements for M&E and maintenance

- Size of elements [l/b/h]: 46,0 m/ 45,0 m/ 13,14 m
- 10 special elements
- O&M access, parking bay
- Access to installation rooms and the different tubes

Efficiency production tunnel elements

Reference Øresund Link: Production Yard - Standard Elements - Nordhavn
**Efficiency production tunnel elements**

Client reference design:
- 8 production lines for standard elements
- 1 production line for special elements

Number of lines optimized by D&C Contractor during tender

**Safety Concept**

Exceptional length requires state of the art and tailor made safety concept

Safety Strategy based on three levels:

- **Level 1** – prevention of accidents and fires through measures in design and operation (e.g. robust concrete structure, escape cell, traffic information, special lighting system)
- **Level 2** – control of incidents and self-rescue (e.g. closely spaced escape doors, ventilation system, measures to “control” fire (water deluge system))
- **Level 3** – facilities for emergency services response and rescue
Safety Concept – Ventilation design

Both road and rail tubes normally self-ventilated by piston effect

- **Longitudinal ventilation** – portal to portal
- **Same ventilation system** for
  - day-to-day operation
  - maintenance
  - emergency

Increasing traffic volumes but cleaner cars
Safety Concept – Ventilation design

- Rural conditions (no exits or entrances close to tunnel portals)
- Advanced safety measures (state of the art traffic information systems)
- Risk of having two fire incidents in the tunnel at the same time (traffic trapped inbetween) extremely low (based upon advanced risk analyses)
- Traffic ahead of the incident can leave the tunnel

Longitudinal ventilation concept is appropriate
- Jets fans every 400m
- Critical velocity of 3.1m/s
- Minimum cross section
- Simplicity, reliability and resilience
- Combined with safety and escape provisions

Results in Cost Efficiency

- Longitudinal ventilation as a result of tailor made safety concept
  - No ventilation island
  - No ducted system (no separate ventilation duct)
  - No ventilation provisions at the portals

Feasibility study concept
Results in Cost Efficiency

- Cross section optimization
  - Safety concept → longitudinal ventilation / no separate duct
  - Maintenance concept with special elements allowed for reduction of M&E space in the cross section
  - Factory method allowed for long cost efficient elements

Results in Cost Efficiency

- Re-use of dredged material by creating land reclamations in the project
- Land reclamations allowed to move the Lolland portal off shore → reduction in tunnel length

Confirmation by:

Use cost and planning records of previous projects to produce reliable cost estimates (e.g. Oresund cost records)
Why an immersed tunnel for Femernbelt?

Preferred over a bridge:
- Costs (incl. life cycle costs)
- Availability (adverse weather conditions / state of the art maintenance)
- Hydraulic Impact
- Visual and environmental Impact
- Involvement local contractors (economy)

Why an immersed tunnel for Femernbelt?

Preferred over a bored tunnel:
- Costs (incl. life cycle costs) → M&E costs much higher
- Maintenance / availability
- Construction risks
- Operational safety
Immersed tunnel under historic building A’dam

Station Island overview

North/South Line, Amsterdam
Stations’ design

Why an immersed tunnel?

- **Boundary conditions and Employers Requirements**
  - Undisturbed operation of public transport (train, tram, bus)
  - Guarantee safe and good access to A’dam CS for travellers
  - No significant damage to listed buildings and structures of A’dam CS
  - High quality public transport in the operational phase

- **Criteria for design and construction**
  - Impact on environment (disturbance), Risks (design, construction, listed buildings), Operational Quality, Costs

- **In preliminary design stage several tunnel techniques were studied, such as:**
  - Cut & cover tunnel
  - Bored tunnel
  - Jacked tunnel in combination with freezing techniques
  - Immersed tunnel
Why an immersed tunnel?

- Lowest level of construction activity at Central railway station – construction on two locations
- Tunnel on the highest possible level (track at -15m), which improves the operational quality of the metro station
- Only limited lowering of water table needed in this sensitive area
  - Small deformations of building pit walls
  - Low risk of influencing water table outside building pit

Underpass railway station

- create a canal under the railway station
- construct building pit walls in very confined spaces
- support structures over building pit to carry buildings and structures of railway station
Advanced building pit concepts for immersion canal

Sandwich wall at old masonry building

Support structures
Immersed tunnel
Under water concrete
Body of jet grout columns
2 rows of steel piles

Body of north/south Line, Amsterdam

Construction of Sandwich Wall
Advanced building pit concepts for immersion canal

Microtunneling at the tracks and platforms

Vertical boring machine installs pile wall, diameter 1.82 m in a limited headroom of 2.8 m to a level of 60 m

Excavation 1st phase Microtunneling wall
Structural aspects

• One tunnel element of 136 m, width 21 m, height 7.9 m

• Segmental tunnel with sections of 14 and 21 m
• Large ground cover of approx. 9 m
• Centre wall with large open spaces for social safety reasons

Structural aspects

• Two closure joints to realize more flexibility in the construction planning of the adjacent section of the metro station
Construction dock on the north bank

Transport tunnel element 11 km
(temporary mooring at Suezhaven)
Narrow entrance at A’dam CS

Level of structure

Normal water table

Water table on photo -3.0m

Transport & Immersion Process

Guiding structure

Longitudinal winch

Station building

15 railway tracks and 6 platforms

Sluice/cofferdam

Separation wall

Lock gate 1

Lock gate 2
Immersion Stages
(images courtesy of Strukton Immersion Projects)

Under water struts challenging for transportation and immersion

Immersion Stages

North/South Line, Amsterdam

Primary suspension beam
Secondary suspension beam
Suspension Beams
Pontoons
Conclusions

- Innovations were introduced in immersed tunneling on a large scale over the past decades.
- This has increased the possibilities of the use of immersed tunnels for
  - Long sea straits
  - Difficult ground conditions
  - Specific project conditions (below buildings, runways etc.)
  
  **AND**

- In which environmental issues can be properly addressed

**BUT**

- Always perform a fair assessment (strong and weak points in project specific conditions) of various tunnel techniques (bored, immersed, cut&cover) in selection process \(\rightarrow\) this is in the interest of your Client
Thank you for your attention

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