1st Hour
Tunnels
  • Immersed tunnels
  • Comparison Bored Tunnels (short)
  • Land tunnels

2nd Hour
Introduction in Shield tunnelling
  • Pipe jacking & tunnelling
  • Slurry & hydroshield
  • Slurry versus EPB
  • Principles of support pressure

Delft University of Technology, faculty of Civil Engineering
Ir. S. van der Woude
20 February 2009
Immersed tunnels

First immersed tunnel in the Netherlands; the Maas tunnel, 1942
IMMERSED TUNNELS IN EUROPE
Examples immersed tunnels in the Netherlands

Calland, Piet Hein and 2nd Benelux tunnel
Construction proces immersed tunnel

- Construction dock
- Tunnel elements (with temp. watertights bulkheads)
- Constructing the ramps with the transition structure
- Dredging the immersing trench
- Immersing
- Closure of the joints
- Founding and covering
Principle immersing

Phase 1
- closed tunnel
- waterway
- open exit
- construction dock with elements
- section A-A
- Building pit shore part

Phase 2
- connection trench
- still to be placed tunnel element
- section B-B
- immerse-trench

Situation 1
- temporary bulk head bracket
- ballast tank
- pontoon
- concrete tile

Situation 2
- pontoon
- bracket
- bottom submerge trench

Cross-section situation 2
- jacking pin
- ballast tank
- underwater pipe
- concrete tile
Construction dock
Water barrier
Transition structure
BULKHEAD – OUTSIDE VIEW

- Air-vent pipe
- Door
- Nose
- Ballast-water pipes
- Gina
Gina gasket
Coupling of the elements

- watertight bulkhead
- support ridge
- last placed element
- floor
- bottom immersing trench
- roof

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Closure joint

Detail final joint in the wall
1 = primary sealing, 2 = folded steel sheets, 3 = permanent sealing (rubber), 4 = steel support, 5 = fireproof cover, 6 = watertight cover, 7 = concrete protection
Cross section

- $F_{\text{upwards}} = A \times B \times \rho_w$
- $F_{\text{downwards}}$:
  - Concrete
  - Reinforcement
  - Ballast concrete
Design aspects immersed tunnel alignment

- Cross section
  - Horizontal and vertical clearance (dredged trench)
  - Force equilibrium

- Longitudinal section
  - Ramps
  - Joints
  - Transition structure
  - Horizontal and vertical curve radius
  - Cover
  - Maximum slopes
  - Water barrier
Design aspects Load cases

- **Permanent loads**
  - dead weight, water, earth pressure

- **Variable loads**
  - mobile loads due to transport, temperature

- **Accidental loads**
  - earthquake
  - explosion / fire
  - collision
  - falling and dragging anchors
  - stranding ships
Comparison bored/immersed tunnel

• Here we see the entrance of
  • Bored tunnel: The Botlek railway tunnel of the Betuwe route.
  • Immersed tunnel: The Botlektunnel Highway A15
Comparison bored/immersed tunnel
When to choose an immersed tunnel (with cut and cover ramps)

• **Primarily**
  - Crossing of rivers/canals

• **Advantages** compared with a bored tunnel
  - Shallower
  - Shorter ramps

• **Disadvantage** compared with a bored tunnel
  - Hindrance during construction caused by
    - Dredging,
    - Transport of elements, Immersing
  - Construction of the ramps are adjacent to immersed tunnel
  - Construction Dock
When to choose a bored tunnel (with launch and reception shaft)

• Primarily
  • Rivers Canals and any vulnerable object
    • Historic city centre (Amsterdam)
    • Residential areas (den Hague)
    • Infrastructure (also C&P)

• Disadvantage compared with an immersed tunnel
  • Deeper launching and reception shaft of TBM. Longer

• Advantages
  • Little hindrance during construction
  • Shafts can be located on optimal location.
Land Tunnels

- Cut and cover
  - Sheet piles or diaphragm walls
  - Excavation with struts or anchoring
  - Impermeable layer or dewatering or underwater concrete
  - Construction of the tunnel In situ or prefab.
- Top Down method
- Pneumatic caissons
Examples land tunnels in the Netherlands

HSL-zuid, Betuweroute tunnel Zevenaar and tunnel Giessen
Open building pit

De tekening geeft uitleg over de verschillende fases van de zogeheten ‘natte’ bouwmethod. Deze methode wordt (deels) toegespast vanaf Plein 1940-1945 tot aan de Thorbeckesingel in Schiedam.

1. Introductie bouwmethod.
2. Ontgraven tot de niete dieptepunt.
4. Doorgaan schoonmaken.
5. Houden van zilfo-ribbeklaag.
7. Verstrooien met beschermende milieubepaal.
10. Wassen van tunnelbovensteellen en tunneldeuren.
11. Tunnelbepaal.
12. Tunnelbepaal.
13. Tunnelbepaal.
Cut and Cover Top down method

Building from ground level:
A constructing diaphragm walls
B excavating and building roof structure

Building below the roof:
C excavating and building floor -1
D excavating and building floor -2
E excavating and building floor -3
Cut and Cover / Top Down method

- Tram tunnel The Hague
Cut and Cover Grout arch; Tram tunnel top down method

>>> lecture 9
Principle pneumatic caisson method

CAISSON METHODE

excavate

construction caisson

install equipment

immerse

remove equipment

finishing
Caisson method

• East line Metro Amsterdam
Prefab shell tunnel

- Metro Rotterdam
Bored Tunnels Introduction

Tunnel-construction under the St. Clair River more than 100 years ago.
Bored Tunnels in the Netherlands

Hubertustunnel, the Sophia tunnel, and the Botlekrail tunnel.
Constructing a tunnel with a TBM

Functions of a TBM:

• Controlled excavation of the ground.
• Support the ground/rock. (The shield)
• Construct the tunnel
• Facilitate the logistics (Transport of soil & tunnel elements & power, etc.).
Constructing a tunnel with a TBM

Pipejacking versus Tunnelling

Shield and tunnel pushed

- D = 0.8m to ca. 3m
- Limited length
- Lining = pipe
- No sharp curves!

Shield pushes against tunnel

- D > 3m
- Unlimited lengths
- Lining = segmented ring
- Sharp curves!
- 2 additional processes
Pipejacking

>>> lecture 12
Tunnelling

2 additional processes:

- Ring erection in the shield
- Shield tail injection (mortar injection)
Tail-sealing-mechanisms

- Wire brush fixing
- Wire brush
- Intermediate chambers filled with sealant
- Grout supply line
- Tailskin sealant supply line
- Concrete segments
- Water pressure and Earth Load
Curves in pipe-jacking
Curves in Tunnelling

\[ \tan \varphi = \frac{B}{R} = \frac{K}{D} \]
Different shield types depending on the Geology and other boundary conditions

- **Open Face** *(atmospheric pressure)*
  - In Rock; **hard rock TBM** *(with grippers)*
  - In Soil conditions limited
    - only small diameter and above ground water

>>> lecture 12
L1*-Arbeitsbereich / Working area
Different shield types depending on the Geology and other boundary conditions

- **Closed Face** (support pressure)
  - In soft soil conditions and in mixed geology
  - Depending on soil conditions different types of support medium
    - Support with bore fluid (bentonite)
      - Slurry shield
      - Hydro shield
    - Support with excavated soil
      - Earth pressure balance shield (**EPB-shield**)
    - Support with Air (only special occasions)
TBM: cutting elements and obstacles
Selection criteria for type of TBM:

- Geological profile of the project.
- Groundwater pressures (support pressure is normative).
- Depth, horizontal- and vertical alignment of the tunnel.
- Surrounding area (settlements, ground-deformations).
- Logistic / available space.
Bentonite = Bore fluid (is the support medium)

Functions of the bore fluid

- Maintaining support pressure
  - Building a membrane and/or
  - Creating an invasion zone (plug the pores)
- Transport of the soil particles to the Separation plant
Slurry shield principle of support pressure
Slurry shield versus Hydro shield

Slurry shield
- Vulnerable for errors pumps
- More simple TBM
- Japan and pipe jacking

Versus

Hydro shield
- Air bubble levels out
- Accurate support pressure
- Europe
Principles of slurry shield and EPB
EPB shield

Transport of excavated ground

Screw jack

Work chamber

Cutter wheel
Earth Pressure Balance (Elastic soil mixture from excavation face)
Slurry

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Separation plant (cost factor)

Separation plant Groene Hart, 2500m³/hr supplied by MS in 1998
Slurry versus EPB

Slurry-shield versus EPB-shield
non cohesive versus cohesive

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EPB versus Slurry

<table>
<thead>
<tr>
<th>Körnungslinie</th>
<th>Schlämmkorn</th>
<th>Siebkorn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>fein, mittel, grob</td>
<td></td>
</tr>
<tr>
<td>Schluff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>fein, mittel, grob</td>
<td></td>
</tr>
<tr>
<td>Kies</td>
<td>fein, mittel, grob</td>
<td></td>
</tr>
</tbody>
</table>

Korn durchmesser d (mm)
Kornverteilungslinien verschiedener Lockerböden

Siebrückstand in Gew. %
- Orange: Hydro-Schild
- Grün: EPB-Schild
Support pressure EPB- versus Slurry

Safety against excavation face collapse:

\[ P = 1,5 \times \sigma'_h + 1,05 \times \sigma_w \]  
(all levels of cross section top and bottom)  
The bottom is normative

Safety against blow out:

\[ P_{\text{max}} = \sigma'_v / 1,1 \]  
(for all levels)  
the top is normative

>>> CT 5305 & CT 5330  
Foundation Eng. and Underground Construction

>>> CT 5305 & CT 5330  
Foundation Eng. and Underground Construction
Support pressure EPB- versus Slurry

Ideal situation for support pressure

“worst case” air support

Support with bore fluid

Support with earth paste EPB
### Summary Slurry versus EPB

<table>
<thead>
<tr>
<th>Slurry shield</th>
<th>EPB-shield</th>
</tr>
</thead>
<tbody>
<tr>
<td>support with (bentonite) fluid</td>
<td>support with the excavated soil</td>
</tr>
<tr>
<td>minimum cover +/- 1 D in non-cohesive soil</td>
<td>minimum cover +/- 0.5 D in cohesive soil</td>
</tr>
<tr>
<td>extraction with pumps</td>
<td>extraction with screw conveyor and ?</td>
</tr>
<tr>
<td>Pressure can be adjusted accurately</td>
<td>pressure fluctuations</td>
</tr>
<tr>
<td>Separation plant</td>
<td>-</td>
</tr>
<tr>
<td>simple TBM</td>
<td>complex TBM (high torque, more wear, conveyors)</td>
</tr>
<tr>
<td>overall higher costs</td>
<td>overall lower costs</td>
</tr>
</tbody>
</table>
Extend the use of EPB in unfavourable geological conditions
Extend the use of EPB in unfavourable geological conditions
Botlek Tunnel EPB in sandy soil
Summary

• Immersed tunnels
• Building techniques for land tunnels.
• Functions of a TBM
• Pipe jacking versus tunneling
• Slurry versus Hydroshield
• Principle of support pressure
• Slurry versus EPB
• Extending the use of an EPB TBM

>>>>>chapter 7, 8, 9, 10 of the reader
CT 3300 in relation to other courses

- CT 3300 Use of underground space.
  - Broad introduction
  - “Inleiding ondergronds bouwen”
- CT 4780 Special Topics
  - New developments on UC
- CT 5305 Bored and immersed tunnels
  - In detail
- CT 5330 Foundation Eng. and Underground Construction
  - Amongst others Bored tunnels in detail
- CT 5740 Trenchless Technology
  - Pipeline construction techniques In detail
Tail-sealing-mechanisms (S1 seal)

- Rubber tail sealing mechanism
Principle of the drilling fluid

- Slurry support
- Compressed air and slurry support
- Compressed air support

Clogging of the pores
Air
Drilling fluid
Transport
“Filter-cake”
Penetration of the drilling fluid
**Slurry shield**

1. Cutting wheel
2. Air bubble
3. Bentonite suspension
4. Drive unit
5. Stone crusher
6. Push cylinder
7. Air lock
8. Steering cylinder - Shield tail
9. Erector
10. Segment conveyor
11. Slurry pump
12. Segment crane
13. Main electric panel
14. Cable reeling drum
15. Discharge line
16. Feed line
Segments tunnel lining

• Variation of the position of left and right segments change the direction of the tunnel
• Keystone closes the arch
Next year,

- boulder clay foto TBM delfzijl.
- Foto groene Hart
- Tunnel lining Engineering