Coentunnel project

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Content

• Basic concept
• Coentunnel project
• Production and installation
• Calculations immersed tube tunnel
  - Load cases
  - Models
• Analysis structural integrity 1st Coentunnel
• Tunnel equipment
Immersed tube tunnels

• Crossing rivers, lakes and estuaries
• Places just below river- or seabed
• Short landside approaches
Immersed tube tunnel
Definitions
Immersed tube tunnel
Joints
Phase 1: Transport
- tugboats for pulling (1-3) and manoeuvring (4,5)
- ballast tanks (6) empty
- pontoons (7) on roof
Positioning

Phase 2: On location
- gradient-cables (1 to 6) fixed
- cables 2 and 4 absorb streamforce 7
Immersion

Phase 3: Immersing
- water in tanks (1)
- slacking vertical cables (2)

top view

longitudinal section
Placing and coupling

Phase 4: Placing and coupling
- placing on temporary supports (1 to 3)
- pulling against previous element
- pumping out room 4, therefore compressing (5)
  by hydrostatic pressure (6)
Construction joint

- Neoprene-steel waterstops
- Shear keys for transfer of vertical, horizontal and torsion loads
Immersion joint

- Gina gaskets for transfer of horizontal loads and first waterproofing
- Omega gasket for secondary waterproofing
Foundation
Sandflowing
Ballasting and back filling
Project; Coentunnel location
Existing Coentunnel 1
2 tubes with 2 traffic lanes
Two tunnels:  
2 x 2 lanes in one direction  
3 lanes in the other direction  
+ 2 tidal flow lanes
Overview
Coentunnel

Characteristics

- Construction site Amsterdam
- Casting Basin in Barendrecht (Rotterdam area)
- Crossing North-Sea Shipping Canal
- Navigation depth 15 meter
- Length closed section 820 meter
- 6 lanes configuration (4 + 2)
- Service channel/escape route
- 4 elements of 178 meters
- 30 meters wide
- 8.7 meters height
- Clearance height 4.50 meter
- Maximum slope 4.5%
- Longitudinal ventilation
Production of tunnel elements

Traditional casting basin

- Tunnel floor and walls/roof cast separately
- Traditional formwork
- Tunnel elements can be curved
Casting yard in Barendrecht
Countermoulding of the tunnelfloor
Casting yard
Casting yard
Traditional formwork
Early age crack control

Hydratation stresses

- Actual stress ≤0.5 fctm
Busan Geoje Fixed Link
Casting yard
Busan Geoje Fixed Link
Moving formwork
Oresund production facility
Production facility Oresund
Formwork
Sea transport
route Barendrecht - Amsterdam
OTAO
Sailing route tunnel elements

Waves:
Operational transport criterium:
Hsig <= 2.0 m
Tz <= 4.5 s, Tp = 6.0 s
HTE3 <= 0.20 m
Survival conditions
Hsig = 3.5 m
Tz = 7.0 s, Tp = 9.0 s
HTE3 = 0.40 m
Bulkheads with pivot supports
Bulkhead supports
Concrete bulkhead and Gina gasket
Sea transport
2\textsuperscript{nd} Coentunnel
Transport phase, Amsterdam locks
Supports of the tunnel elements

bovenaanzicht:

zijaanzicht:

legenda:

= voorlopig =

TYPES OPLEGGINGEN
Immersion with pontoons
Immersion with pontoons
OTAO
Immersion Tunnel Element 1
OTAO
Immersion Tunnel Element 1
Primary support of the tunnel element
Secundary supports
Secondary supports
Ballast tanks
Ballast tanks
Immersion process
Immersion of Tunnel Element 4
Immersion operation
Foundation
Sand flowing

- Temporary foundation blocks
- Hydraulic jacks for controlling the vertical position of the element
- Flow pipes cast in the Structure
Sand pancakes
Scraded gravel bed
• Gravel is placed in ridges across the tunnel trench
• Vertical accuracy is controlled by a heave compensation system
Gravel bed
Concrete wedges
Closure joint

- Installation of underwater formwork
- Sprayed concrete
Sprayed concrete application in closure joint
Immersed tube tunnel
Structural design

• Bouyancy and uplift stability
• Permanent loads:
  - Self weight
  - Water pressure
  - Earth pressure
  - Ballast concrete
• Temperature variations
• Traffic loads
• Special load cases
  - Falling anchors
  - Sinking ships
  - Shear keys
Bouyancy and uplift stability

- Rebar in RC minimum: 2.04% 160[kg/m³]
- Rebar in RC maximum: 2.55% 200[kg/m³]
- Minimum volume weight concrete: 2310 [kg/m³]
- Maximum volume weight concrete: 2382 [kg/m³]
- Total volume weight RC minimum: 2423 [kg/m³]
- Total volume weight RC maximum: 2521 [kg/m³]
- Minimum volume weight water: 1000 [kg/m³]
- Maximum volume weight water: 1030 [kg/m³]

- Required SF Bouyancy: 1.04
- Required SF uplift stability: 1.06
Floating stability during sea transport

Requirements from Det Norske Veritas:
• The metacenter must be at least 1 meter above the buoyancy point
• Up until an angle of 30 degrees a stabilizing moment must be present
Floating stability

rotatie 30 graden
Oppervlak boven water = 10.97 m²
Oppervlak onder water = 249.25 m²
Floating stability

rotate -30 graden
Oppervlak boven water = 10.95 m²
Oppervlak onder water = 249.28 m²
Scale model tests in wave tank
Special load cases: Falling anchors

Design procedure

- Determine the number of ship movements per year over the tunnel for each ship class, and anchor weight.
- Determine the probability of anchor loss per ship's movement
- Determine the probability that a ship is over the tunnel
- Determine the anchor mass based on the acceptable residual risk
Falling anchors
Design anchor load probability $1E^{-6}$

max. binnenvaartanker: 2500 kg
Falling anchors
Valank study
Falling anchors
spread of the load
Special load cases: Sinking ships
Load modelling of high ships
Sinking ships
Load modelling of low ships
Sinking ships
Loading zones

zeeschepen
binnenvaart
zinkvoeg/sluitvoeg
mootvoeg
Sinking ships
Statistics

• Cumulative probability distribution of sinking ship load

Conclusion:
• For seafaring ships an acceptable risk of $1 \times 10^{-6}$ equals a load of 122 kN/m$^2$ on the tunnel. Dutch guidelines specify 150 kN/m$^2$.
• For barges the maximum load is 50 kN/m$^2$. 
Shear key loads
Longitudinal behavior of the tunnel

- Temperature effects
- Differential settlements
- Uneven loads
Immersion joint with Gina gaskets
Stiffness Gina gasket

Gina type 2: ETS-200-260-SN

![Graph showing force vs. deflection for Gina type 2 gasket](image)
Soil spring variations

- ROBK guideline:
  - One sand body missing
  - Room for interpretation -> variation of stiffness of 50%
- 3D-analysis and beam model
Shear key loads
Sand flow pancakes
Loads and section forces
## Soil spring variations

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<th>Bedding</th>
<th>Variant</th>
<th>Opmerkingen</th>
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- Damwand op ¾ van de moot.
- Damwand op ½ van de moot.
Water stops
Shear key forces
Shear key forces

TAND- EN BLOKKRACHTEN, MAXIMALE BELASTING
van links naar rechts: onderblokkracht, bovenblokkracht, tandkracht

Tand- en blokkrachten max. belasting grondaanvulling oevers

Tand- en blokkrachten max. belasting insteekhaven

Tand- en blokkrachten max. belasting vaargeul
Shear key forces

Shear key load in a 2D framework calculation is the difference in shear force $\Delta V$ over one meter of the 3D model.
Framework calculation
Framework calculations
Rounding off of bending moments

\[ Q_w = \frac{V_1 + V_2}{b_w} \]

\[ M_2 = Q_w b_w^2 \]
Design of the shear keys

- Bearing pressure
- Longitudinal reinforcement
- Pressure in the diagonal
- Confinement of the diagonal
- Combination of compression and bending
Prestressing of the tunnel element
Prestressing

- Influence factors
  - Length tunnel element
  - Point loads bulkheads
  - Curvature tunnel element
  - Waves
  - Location support jacks
  - Distribution ballast tanks
Roughened face of TE for increased friction
Loading situation in floating condition

![Diagram showing loading situation in floating condition with labels such as \( q_{\text{Buoyancy}} \), \( \Delta q_{\text{Ballast}} \), etc.]

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Floating tunnel elements
Prestressing

Operational condition
Wave: $H_s = 2\,\text{m} \quad T = 6\,\text{sec}$

\[
\sigma'_b = \frac{-F_p}{A_c} + \frac{-F_p \cdot e_p}{W_{y,i}} + \frac{F_x}{A_c} + \frac{M_y}{W_{y,i}} + \frac{M_z}{W_{z,i}} \leq -0.2\,\text{N/mm}^2
\]

Survival condition
Wave: $H_s = 3\,\text{m} \quad T = 9\,\text{sec}$

\[
\sigma \leq 0.8\,f_p
\]
Prestressing

Longitudinal section: pre-tension from head surface to head surface

Longitudinal section: pre-tension from block to block

wedge plate for rib anchors (to be equipped with cover plate)

apply anchors and pour

wedge plate for rib anchors

pre-tension

spiral reinforcement

spiral reinforcement
Design for fire loads
CFD-calculations
Design for fire loads
RWS-fire curve

**STANDARD RWS fire curve (hydrocarbons)**

T-rebar < 250 °Celsius
T-concrete < 380 °Celsius
Design for fire loads

Temperature gradients in the structure with heat resistant cladding
Fire test
1st Coentunnel integrity + separation-wall

Cross-section
Loading and boundary conditions
Severe scenario’s

- Realistic approach (PLAXIS-calculations)
- Worst-case approach
Scenario calculations

• Results:
  - Displacements
  - Bending moments and shear forces
  - Input for 3D-model
Deformations?

Rigid body motion

Curvature

$\Delta u_{30}$

90 m
3D-model 30 m

- Damage assessment
  - Current situation (normal crack-pattern)
  - Add. WC-forces (no additional cracks…)
  - …and diamond cases (damage)
- Robustness assessment
  - Damage boundaries
Incomplete foundation
Immersion joints

Gina

Roof

Shear key (ring-shaped dowel)

Floor
Immersion joints

Large cracks expected before reinforcement activation. Ω gasket will not function anymore.
Immersion joints

Large cracks expected before reinforcement activation.

Ω gasket will not function anymore.
Immersion joints

Large cracks expected before reinforcement activation.

$\Omega$ gasket will not function anymore.

$V_{\text{failure}}$: 2800-3400 kN
$V_{\text{real}}$: 600-1200 kN
$V_{\text{worst case}}$: 3570 kN
Concluding…

• Robustness analysis points out:
  - Robustness calculated in DIANA agrees with RWS risk diamond
  - No significant damage in tunnel parts due to worst case scenario’s
  - Immersion joints and closure joint are weak parts due to possible shear failure, which leads to water inflow.
Typical cross section with separation wall
Separation wall

- Tubes are screwed in
- Tubes have Larssen interlock connections
- The void on the in- and outside is filled with grout
Plaxis FEM calculation
Free water surface around a sailing ship

- Bed level – attenuated bow and stern wave pressure gradients
- Attenuated pressure (dhs)
  Pressure change zone length (Ls)
- Zone for stern wave slope Lss
- Zone for bow wave slope Lfs
- Attenuated pressure (dhf)
  Pressure change zone length (Lf)
- Lowered steady pressure
- Bow wave gradient zone
- Stern wave gradient zone
2nd Coentunnel
Current effect on separation wall

Return flow
Tunnel Technische Installations:

• MTM(traffic management)
• Power supply
• Lighting
• Drainage
• Ventilation
• Fire suppression
• Communication
Traffic management system

• Motor vehicle Traffic Management (MTM) (Verkeersmanagement)
  - Automatic signalling based on traffic image
  - Traffic lights and matrix indicator panels
  - Height detection
  - CCTV camera observation:
    - Speed control
    - Traffic control
    - Smoke detection
Traffic systems

- Traffic control
- Optimizing traffic flow
- Detection of accidents
- Control during calamities
Electrical power supply

- low voltage distribution device
Tunnel lighting

• Entrance lighting
• **purpose:**
  - Prevent black hole effect
  - Traffic safety
Drainage pumps & pump sumps

- **Goal:**
  - To prevent aquaplaning at rainfall
  - Safe disposal of liquid fuel 4m²/min
Drainage system precipitation curves
Drainage system

Effective area of pump sump: 150 m²
Pump capacity: 50 l/s
Tunnel ventilation & over-pressure installation escape gallery

- Longitudinal ventilation with jet fans
- over-pressure ventilation of escape gallery and staircases
  - Escape doors to the central gallery every 100 meter
- Purpose:
  - Traffic emission
    - Reduction of NOx, CO, Benzene concentration
    - Maintain visibility
  - Smoke control during fire:
    - Smoke free evacuation of passengers
    - Smoke free access of emergency services
Ventilation, clusters of jet fans
Escape doors

- Designed:
- 1 hour @ 1100-1350 °C
- Hydrocarbon fire
Firefighting
Communication, Control & transmission

- **Communication**
  - Intercom in emergency cabinets
  - HF radio antenne
  - Load speakers
  - Pictograms for escape routes

- **SCADA, (central) control systems & transmission**
  - PLC’s, copper of glass fibre connections in the tunnel, service buildings and traffic control center
Imagine the result … and thanks for your attention.