Immersed tunnels – uneven settlements and local rotations
Case study Kiltunnel

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Immersed tunnels

• To cross a water body (river, channel, harbour .....)

• Precast concrete elements (from ship or building dock)

• Elements follow soil layer settlements (tunnel flexible as a “chain”)

[Diagram showing immersed elements, abutment, soil/stone cover, river, and soil]
Immersed tunnels in The Netherlands

Concrete components design life: 100 years

Design codes used: 50 years

Increased concrete cover on the reinforcement & improved concrete mixture:
Concrete structure: 100 years is to be expected
Immersed tunnels in The Netherlands

tunnels start their second life phase: 50 -> 100 y.

source: Cobouw
Immersed tunnels in The Netherlands

Tunnels start their second life phase
Actions to be taken?

• inspection
• monitoring
• maintenance
• repair
• strenghtening
• ............

From RWS inspection data:
Soil settlements cause uneven deformations;
no “chain” response
Immersed tunnels – construction phase

Element

Segment joint

Segments

100 - 150 m
Immersed tunnels – construction phase

Segment joint

100 - 150 m

1.3 m  roof slab

1.6 m  floor slab

water stop
Immersed tunnels – construction phase

Tow the elements to their final destination

Element joint

GINA and OMEGA rubber profiles
Immersed tunnels – construction phase

Construction:
Element = set of individual segments

Transport (floating):
The element is a rigid body

After immersing:
Enable rotation of individual segments (“chain”)
Immersed tunnels – construction phase

Option:
Apply longitudinal element prestressing

• Support over full element length

• Longitudinal prestressing and local soil settlement

• No longitudinal prestressing and local soil settlement

=> Cut the prestressing after placing an element
Soil settlements

Vertical translation of a segment

Shear force

segment

Shear force
Soil settlements

Questions raised by RWS:

- magnitude of actual displacements and rotations?
- magnitude of the shear force?
- possible cracking at the connection?
- possible leakage through cracks?
Case study Kiltunnel
Case study Kiltunnel
Case study Kiltunnel

- Uneven settlements registered
- How much settlement / rotation is allowable?
Case study Kiltunnel

Settlements
Segment joint models - ATENA 2D

- 2D model
- Tunnel is 3D; use “effective” parts only
Segment joint models - ATENA 2D

effective width

side view of 2D model
Segment joint models - ATENA 2D

- Apply shear force in the joint
- Load transfer by contact pressure (floor slab) and vertical interface concrete–to–concrete friction (walls)
Segment joint models - ATENA 2D

Reduced joint friction coefficient:

- Load transfer by friction reduced; bottom slab connection heavier loaded. Increase of vertical loads on the walls.
- Cracking at the wall-bottom slab connection
Segment joint models - ATENA 2D

Possible weak spots in the segment joint:
Wall – roof slab and wall – bottom slab connections

Assumption made:

Recommendation: perform a 3D analysis
3-D model-DIANA FX+

Full-Tunnel cross-sectional view

Model includes reinforcement
3-D model-DIANA FX+

- Half cross-section
- Less computation time

Tooth of tunnel-Transfer of forces-Interface
Contact pressure-horizontal
Friction-vertical
Loads

Normal force
Water pressure
Increases from top to bottom

Shear-force
Applied at the tunnel end on the stiff plate

Tunnel side-view
Fixed on the right
Load applied on the left

Fixed on right
Load applied on the left end
Analysis-Water pressure

Linear increase in the stress from top to bottom

3-D view-C/S from the side of load application

[UNIT] N, mm
[DATA] Structural Nonlinear, Principal Stress 83 Nodes/0, Load Step 1/(f)
Analysis - Shear

Shear forces -
Higher near the walls

Side-view

Cross-section view
near tooth
Shear effect-steps
Ongoing work

Combination of Shear force & Compensating Bending Moment
Aim To Achieve

3-D model

- Too optimistic – compensating Bending Moment
- Distribution of shear forces - Comparison to Ivar’s approach
- Effective width - Contribution from slab and walls
- Forces - actual (soil)
- Non-linear analysis & Plasticity
Thank You