Deltares
Enabling Delta Life

Risk management applied to tunnels

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21 November 2008

Contents

- Uncertainty and ground conditions, GeoQ
- Tunneling in the Netherlands
- Green Heart tunnel
- Souterrain tunnel

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Construction challenges

‘Europe is facing serious challenges. If we sit back and rest, by 2030, global warming will cause increasing number of disastrous damages from floods and storms. The systems for water supply and wastewater will be dilapidating all over Europe. Workers will continue to die on accidents at work. Traffic congestion problems will reach breaking point and seriously hamper the economic and social development of Europe... These challenges are for real. It is safe to say that the time for action is now’

Vision-2030 Report
European Construction Technology Platform, 2005.

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Who is going to pay?

photo Deltares

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Subsoil risk profile: some additional costs…

(2000 – 2004, figures from Munich Re, by Martin Knights, Jacobs and VP ITA)

Year	Project	Cause	Costs (m US$)
2000	Metro Teagu, Korea	Collapse	24
2000	TAV Bologna-Florence , Italy	Collapse	12
2002	Taiwan High Speed Railway	Collapse	30
2002	SOCATAP Paris, France	Collapse	8
2003	Shanghai Metro, China	Collapse	60
2004	Singapore Metro	Collapse	tba
	Total		> 134

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Ground dominates construction

Because of three types of ground uncertainty:

Random – lack of specific pattern
Fuzzy – imprecise definition
Incomplete – missing information

Caused by geological processes, ground behaviour, and ground-construction-human interaction

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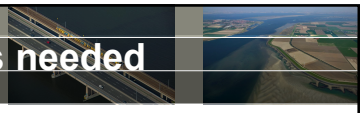
Management of ground risk is needed



1. to minimise failure and costs
2. to maximise purpose and quality

By:

1. in-depth *expertise* and *experience*
2. *cyclic* risk management *process*
3. *life cycle* cost and purpose *approach*
4. attention to the *people factor*

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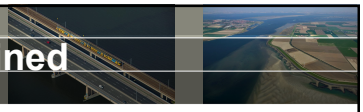
Ground risk management defined



Ground: soil, rock, and everything in between

Risk: probability times impact of unwanted event

Risk Management: set of practices in order to control risk

Ground conditions: ground, groundwater, pollution, man-made obstructions

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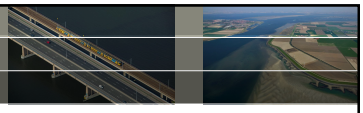
Risk - how to keep it simple?



Risk terminology, alphabetical order from a to e:

attitude, analysis, avoidance, awareness, calculation, causation, cause and effect reduction, combined, cause and effect relationships, checklists, client-sharing, concept, consequences, content, context, controllability, coordinator, criticality, definition, dominance, drowning, dynamic character, effect(s), effect criteria, effect reduction, elimination, environmental, event accelerators, event initiators, external factors, …

How to avoid drowning in risk and its management?

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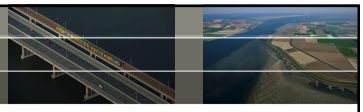
The cyclic GeoQ process



GeoQ

Risk management per *project phase* determines
which *ground information is* necessary
for a *successful* tunnel project

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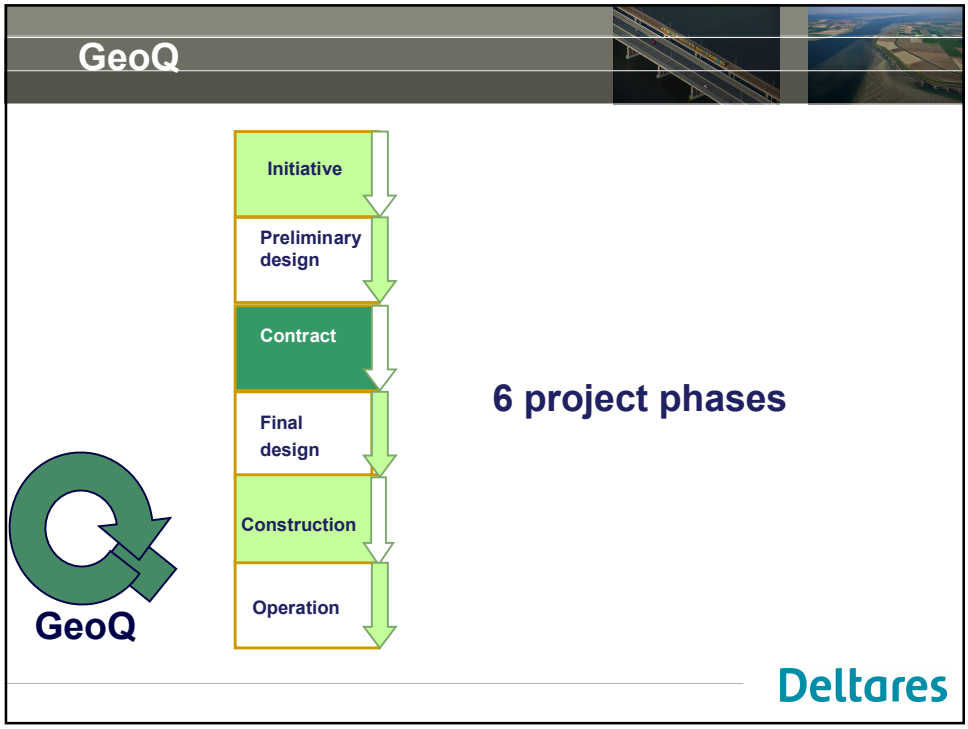
GeoQ
Initiative
Preliminary design
Contract
Final design
Construction
Operation
6 project phases
GeoQ
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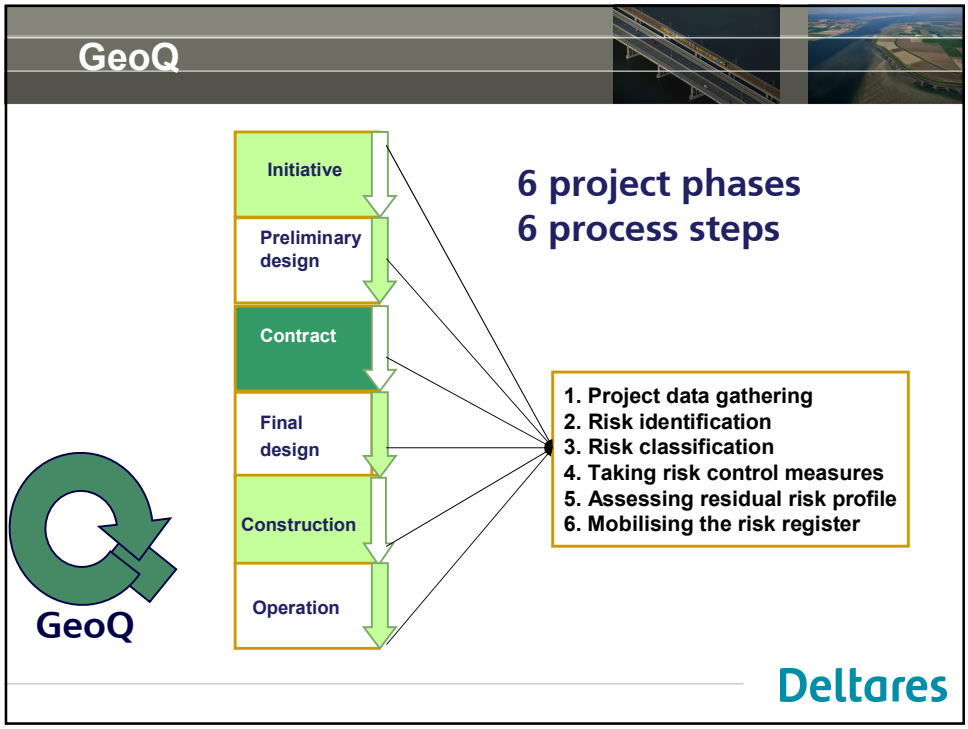
GeoQ
Initiative
Preliminary design
Contract
Final design
Construction
Operation
6 project phases
6 process steps
1. Project data gathering
2. Risk identification
3. Risk classification
4. Taking risk control measures
5. Assessing residual risk profile
6. Mobilising the risk register
GeoQ
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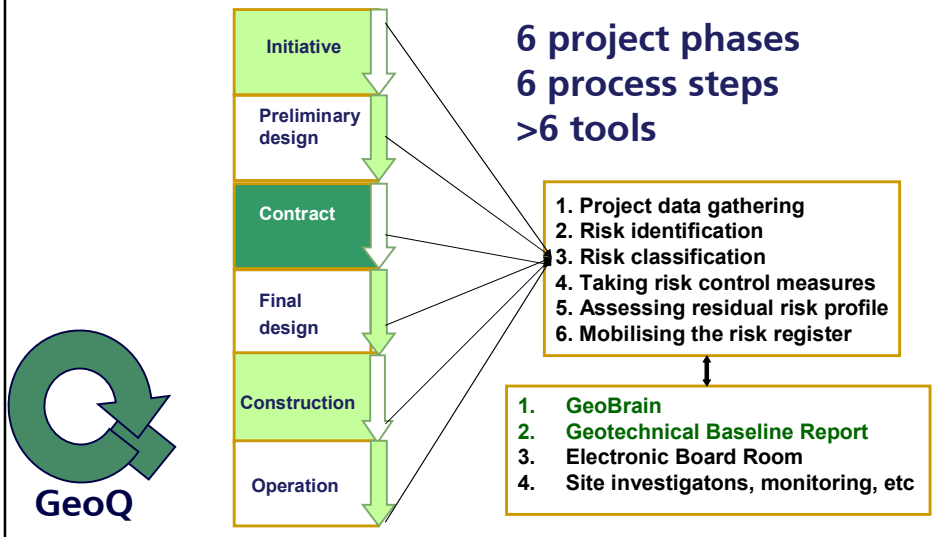
GeoQ



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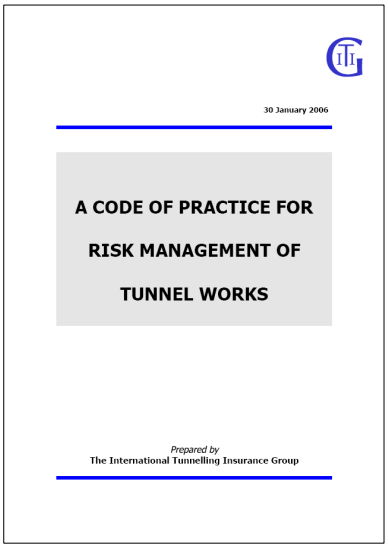
GeoQ aligns with existing codes

e.g. from International
Tunneling Insurance Group



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Example: GeoQ tooling

GeoBrain

Gathering experiences

Experience database

View experiences

\+ Expert Knowledge + Artificial Intelligence

Making Risk-predictions

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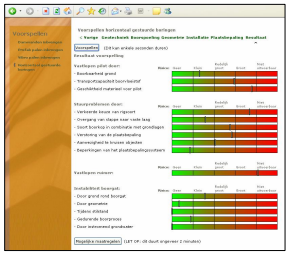
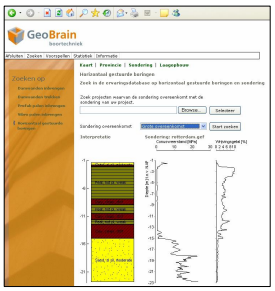
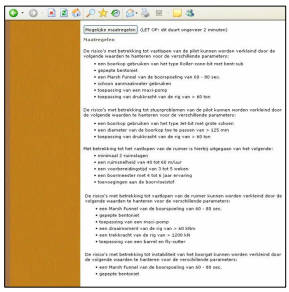
Example: GeoQ tooling
GeoBrain HDD







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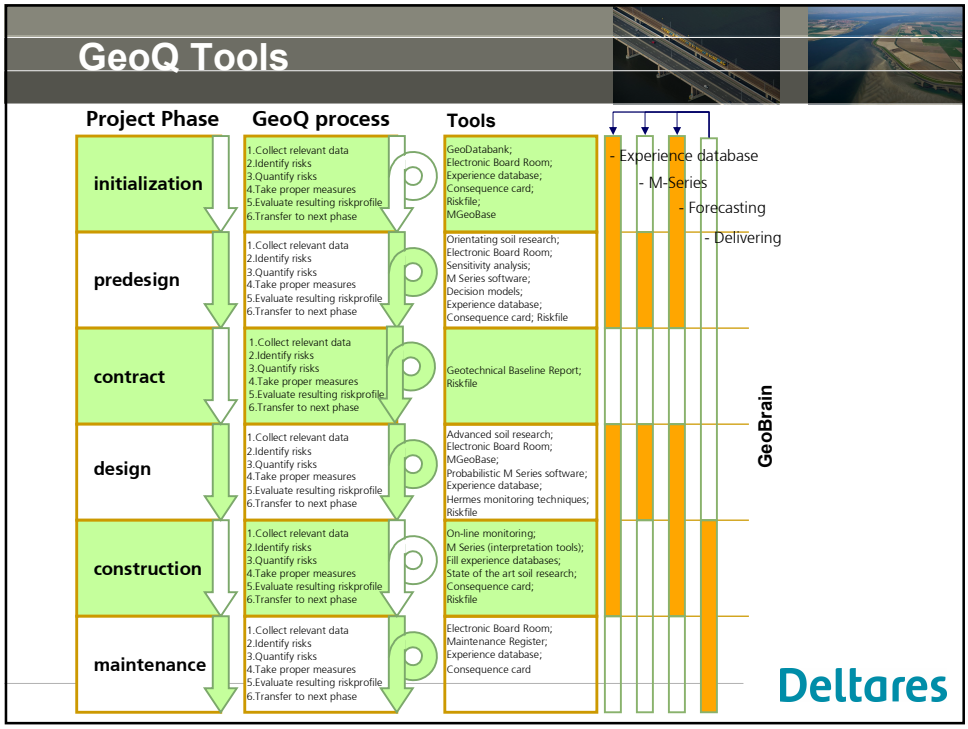
GeoQ Tools



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Project phase 1
Initiative

Risks in the ground:

- Greenfield site
- Brownfield site
- Greyfield site

GeoQ for go – no go decision
Example: bridge or tunnel?

Photos Martin van Staveren

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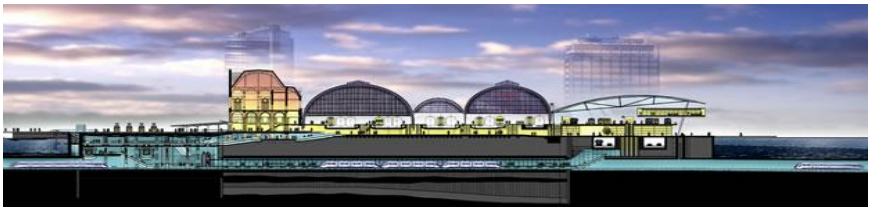
Project phase 2
Preliminary design

- GeoQ for scenario-analysis of alternative pre-design solutions
- Example: bored tunnel or cut-and-cover tunnel?



NorthSouth-metroline Amsterdam

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Project phase 3
Contract

Allocating contractual ground-related risk, despite fuzzy ground with random properties and insufficient information

Who pays for differing ground conditions

Example: Geotechnical Baseline Report (GBR) for a bored tunnel

Photo van Weele

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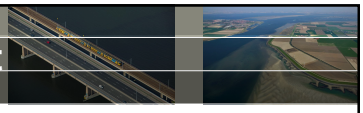
Geotechnical Baseline Report



RISK	KEY-RISK-DRIVER	BASE LINE	RISK ALLOCATION	
			CONTRACTOR	OWNER
GEOTECHNICAL				
Settlements	Clay layer thickness	5 m	<= 5 m	> 5 m
	Clay layer compressibility	6	>=6	< 6
Obstacles (old piles)	Number of piles	100 piles	<= 100 piles	> 100 piles
Building pit bottom collapse	Groundwater level	GL –1 m	Below GL – 1 m	Above GL – 1 m
Pile driving problems	Thickness intermediate sandlayer	10 m	<= 10 m	> 10 m
	Cone resistamce bearing sandlayer	35 MPa	<= 35 MPa	> 35 Mpa
Drainage volume	Additional costs	kEuro 25	<= kEuro 25	> kEuro 25
OTHER				
Polluted soil	Pollution category	Category 2	Category 1 or 2	Category 3 or more
Traffic intensity	Number of cars per day	50000	<=50000	>50000

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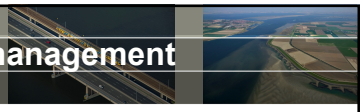
US experiences with ground risk management



Geotechnical Baseline Report used by:

- Washington Metropolean Area Transit Authority (WMATA)
- Alaska Power Authority
- Cities of New York, Los Angeles, Honolulu, Anchorage and Seattle
- Colorado Department of Highways

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Project phase 4
Design

Managing risks in the ground during design (cause reduction) or during construction or utilisation (effect reduction)

Example: Failure Mode and Effect Analysis (FMEA), followed by a detailed and risk-driven site investigation

Photo Deltares

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Six steps:
towards a risk-driven ground investigation

- Which type of tunnel construction?
- Which geotechnical mechanisms?
- Which geotechnical risks?
- Which design techniques?
- Which ground parameters?
- Which ground investigation?

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Project phase 5
Construction

- Managing ground risk and opportunities (*stronger* ground)
- *Dispute resolution* when conflicts about differing ground conditions
- Example: *observational method* for a bored tunnel (adjusting boring method to monitored settlements)

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Project phase 6
Operation and maintenance

- Life cycle costs & maintenance
- Dispute resolution about ground (settlements)
- Example: estimate settlements of houses at proximity of a bored tunnel

Photo van Weele

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About life cycle costs, purpose and maintenance

- Requires *thinking forward* through all project phases (scenario analysis)
- Life cycle cost reduction should be done *already* during design and construction
- *Who benefits*?
- Role of DBFM *contracts*
- *GeoQ* may facilitate life cycle costs assessment from ground risk perspective

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People from *complex* to *very* complex
(particularly when risk is involved)

- Individual
- Team
- Client
- Society

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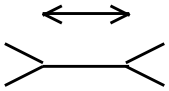
It is all about perception….

Which line is the longest?



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It is all about perception….

According to the ancient Greek philosopher Aristotle:

"You are what you see"

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Prof. Frans Barends
(Delft University of Technology)

'The effects of the individual interpretation of facts and data are underestimated"

Terzaghi Oration, 2005, Osaka, Japan.

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Amsterdam's trauma
C&C metro tunnel (1977)

Construction of Amsterdam's first metro line 1970-1977

North South metro line
(under construction)

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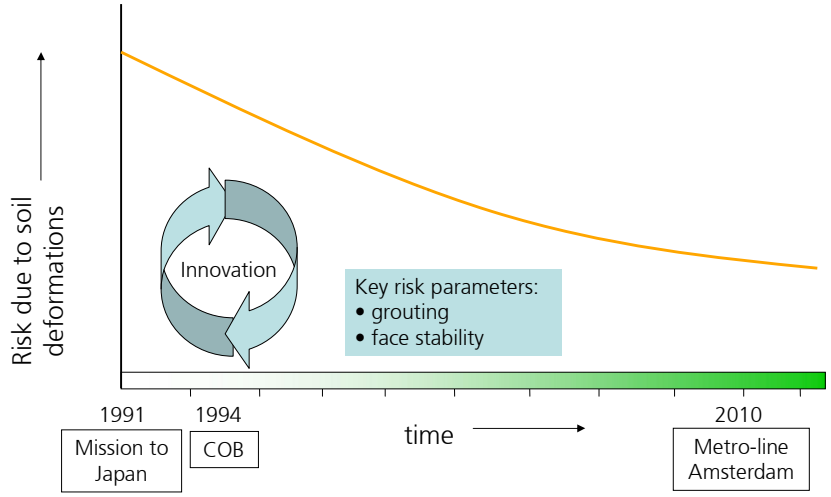
Risk management for the Netherlands

By: Projects, COB, DC, contractors, consultancy…….



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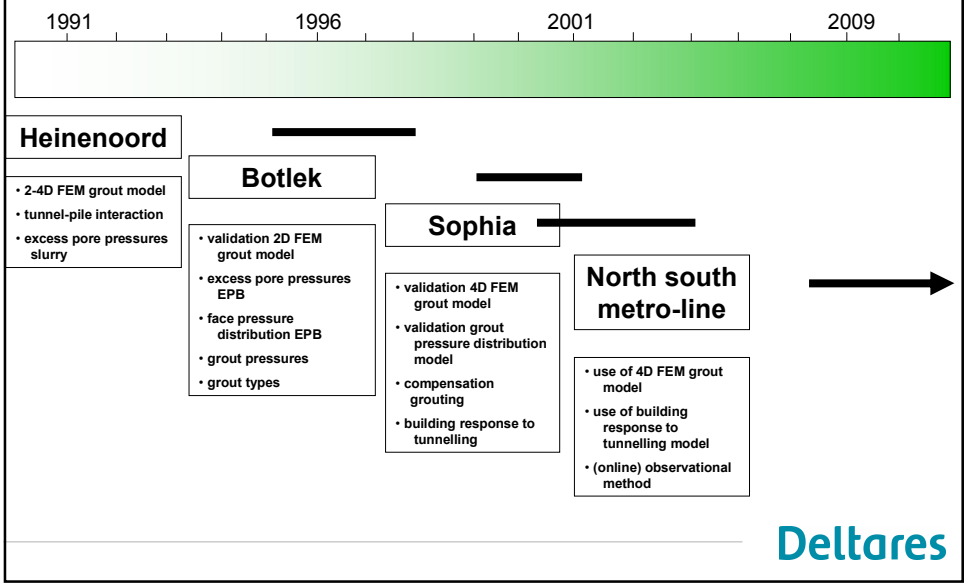
COB research on soil deformation



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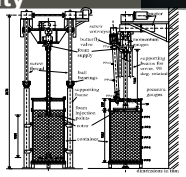
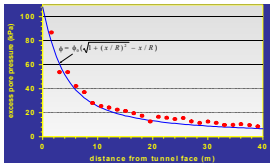
Risk of settlements
Innovation circle on face stability

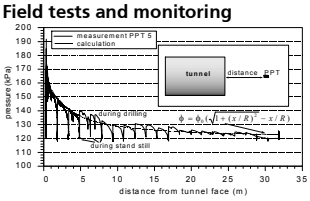



Model testing

Calculations



Field tests and monitoring



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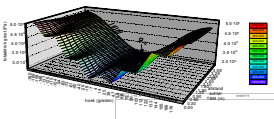
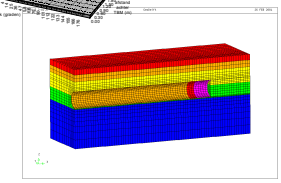
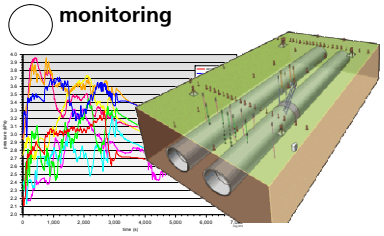
Risk of settlements
Innovation circle on grouting

Model testing

Calculations

Field tests and monitoring



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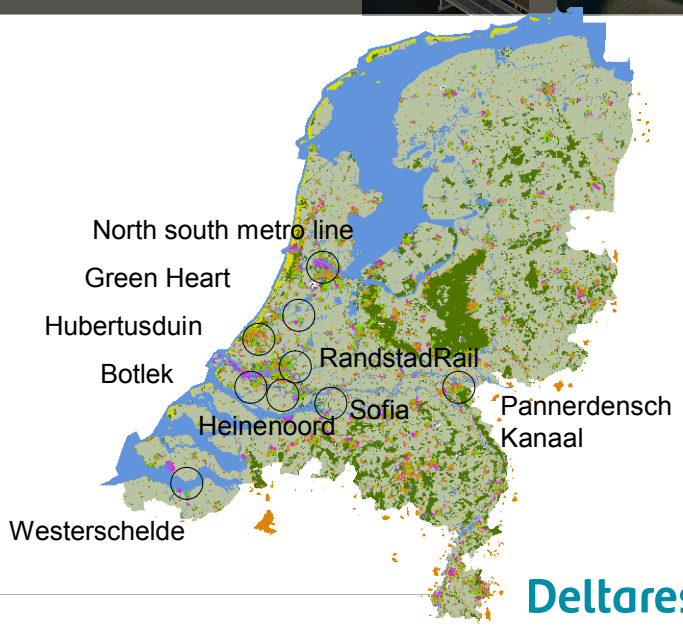
Shield tunnels in the Netherlands (D > 6.5m)



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Shield tunnels in the Netherlands

Project	TBM	L [km]	Water way	D [m]	u_{max} [kPa]
Heinenoord	Slurry	2x1.0	Yes	8.3	400
Botlek	EPB	2x1.8	Yes	9.7	300
Green Heart	Slurry	7.1	Yes	14.9	400
Pannerdens kanaal	Slurry	2x1.9	Yes	9.7	250
Western Scheldt	Slurry	2x6.5	Yes	11.4	600
Sophia	Slurry	2x4.2	Yes	9.7	300
Amsterdam metro	Slurry	2x3.8	Yes	6.5	350
Rotterdam metro	Slurry	2x2.4	Yes	6.5	300
Hubertusduin	Slurry	2x1.5	No	9.7	200

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What did we learn on settlement control?

Settlements can be controlled down to 10 - 25 mm
even for a tunnel diameter of D = 15 m

Setting strict settlement demands even in meadows of 25 mm
(D = 15 m) leads to a good process control

1 excessive settlement per 4 km shield tunneling
causes:

- low cover
- start of project
- hyperbaric conditions
- human error

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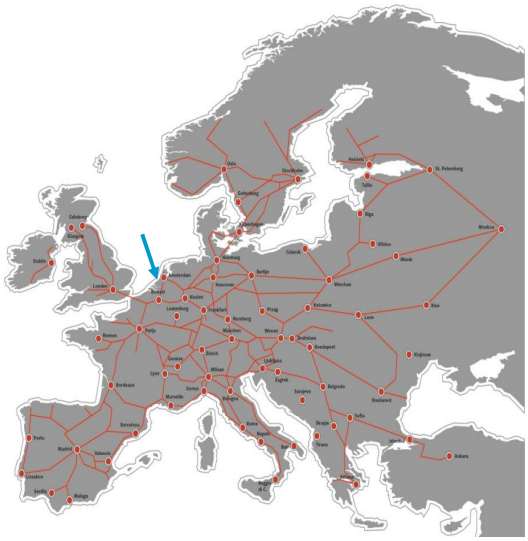
The Green Heart tunnel case

Political choice in the initiative phase for a bored tunnel



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Preliminary design

based on risk management control

Some of the key risks items where:

- tunnel safety
- air pressure waves
- sonic boom
- structural integrity
- conservation of the “national park” Green Heart
- time

For all these items, special research was initiated

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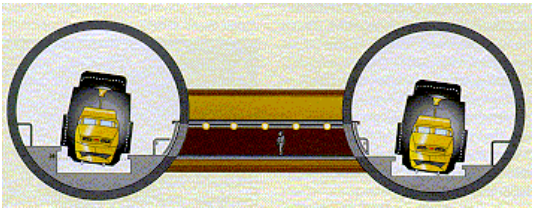
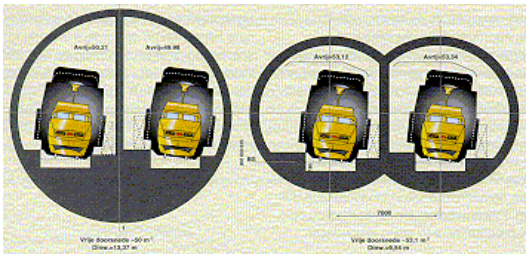
Preliminary design
v = 300 km/h



Reference Design HSL
- 5 air shafts
- 3 escape shafts
- every 250 m a cross passages

Alternatives



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Gain time and quality

In advance of the contracting phase a symposium was held to inform the market about the tunnel project and all of the key risk items

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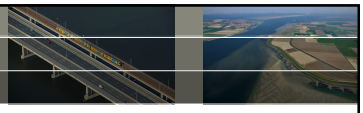
Contracting
Target: Low Life Cycle Costs (LCC)



LCC is defined as the overall estimated cost of a single project alternative over a defined period

LCC variables:

- initial project costs (Design & Construct)
- annual operating and maintenance costs (refurbishment)
- periodic maintenance costs (refurbishment and replacement)
- salvage value (value of maintenance costs and the tunnel after 50 years

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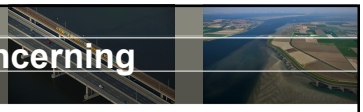
HSL South objectives (1997) concerning
Green Heart Tunnel



- Safety
- Functionality
- Reliability
- On time
- Within the budget
- Manageable
- Low risk profile
- Low design and construction costs
- Low operating and maintenance costs
- Innovative

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Experience with the shield driven tunnels worldwide (1997)

- Safety - few standards, total safety is impossible
- Functionality - many reparations, delays, higher costs
- Reliable - lot of calamities, damages, deformations, collapses
- On time - very few projects, no geotechnical problems
- Within the budget - not even one, always unpredicted work
- Manageable - average, mostly legal issues, permits
- Low risk profile - some, mostly unpredicted risks
- Low design and construction costs - few projects
- Low operating and maintenance costs - very few projects
- Innovative - mostly Japanese, military purposes, pilot projects

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High Speed Line South - Amsterdam Paris
Green Heart tunnel - D/C contract

Negotiation Procedure

based on:
Design & Construct Contract

added in later stage:
Co-operation Client - Contractor

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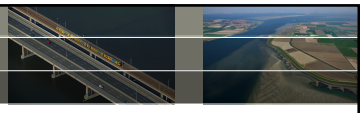
Contracting



- Prequalification Phase
- Invitation to consultation
- Consultation Phase
- Invitation to offer
- Offering Phase
- Submitting Offer
- Evaluation Phase
- Invitation to negotiation
- Negotiation Phase
- Awarding

1 year

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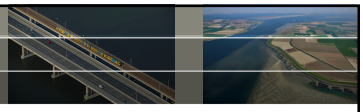
Risk Control



- Searching for an ‘optimal’ share of risks between client and constructor
- Taking away unacceptable risks
- Agree on the way of control and supervision of the risks

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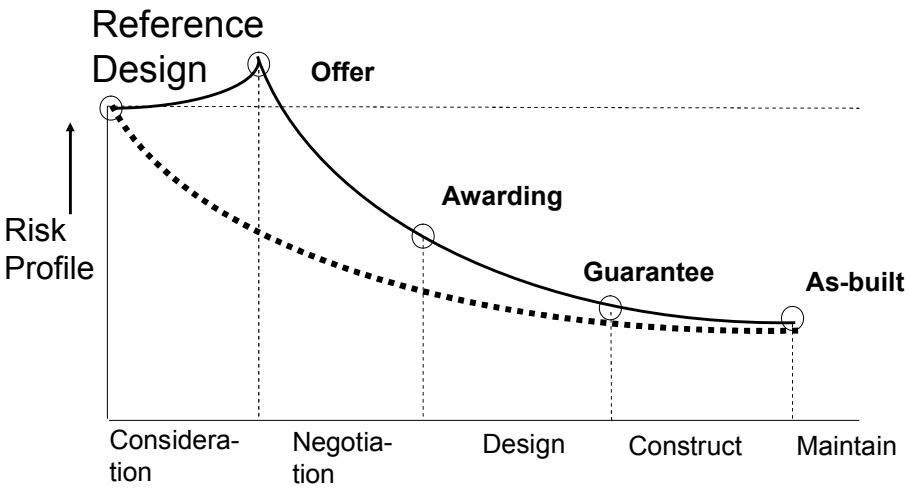
Risk Management



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Refurbishment & Maintenance costs

- Traditional - 18% - 22%
- D&C without RMC - 14% - 18%
- D&C with RMC - 6% - 10%

Savings about 12% of the total construction costs

Exclusive operational costs (20%-30%)

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Risk Management Control (RMC)
(prevent and avoid problems)

- Approved tunnel design philosophy verified in practice and laboratories
- Appropriate mitigation (design, procedures, control)
- Advantageous philosophy of applied construction method
- Sophisticated monitoring system
- Human factor

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Many tunnels have cracks….




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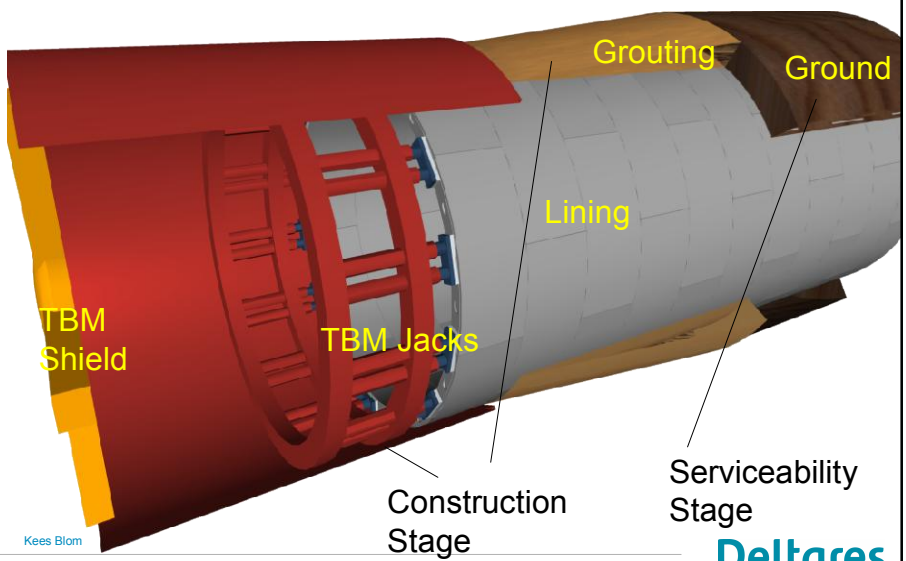
Shield driven tunnel



Kees Blom

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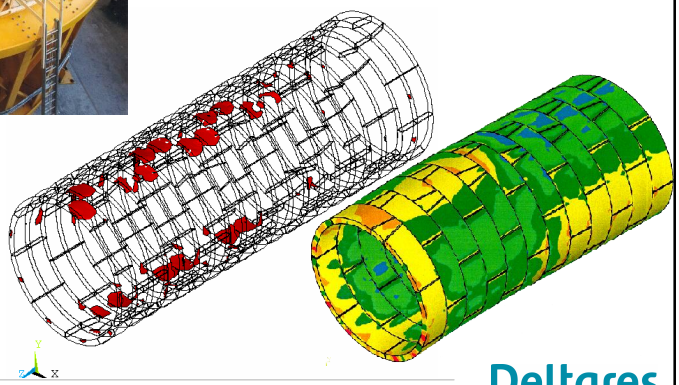
Full scale lining test and FEM



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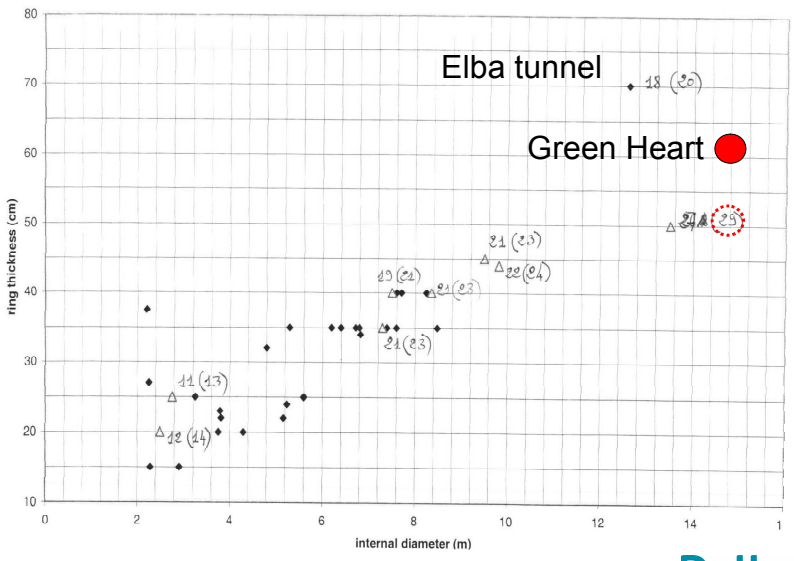
The world largest diameter



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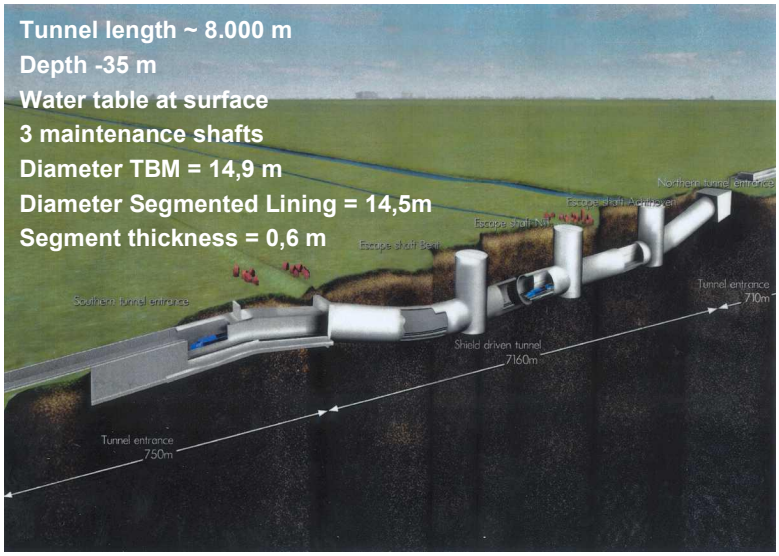
Characteristics



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Design phase

- Weekly a open constructive technical meeting between client and contractor
- Every 2 weeks a jointed site visit
- All risk where ranked
- Only discussions about top ranking risks

	negligible
	large
	critical

- No technical audits only process audits

rank	probability	Effect in time [month]	Effect in money [m€]
1	rare (<0.1%)	< 1	0.5
2	unlikely (2%)	1 - 3	0.5 - 2.5
3	The is a chance are, but not very large (%)	3 - 6	2.5 - 5
4	there is a real chance(25%)	6 – 12	5-10
5	almost certainly(10(50%)	>12	> 10

effect / prob	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

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Construction phase

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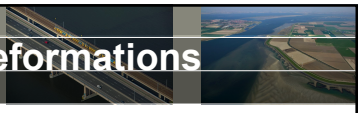
Reasons for restricting soil deformations



- Interaction with objects buildings, roads and pipelines
- Process control for a good constant face stability and grouting

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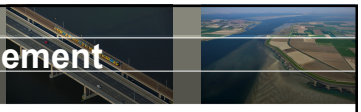
Why make the ground level settlement
a key output process control parameter?



- A client should not interfere how a contractor runs his TBM
- A client want's no delays and a good embedded lining

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No delays and a good embedded lining

Small settlements are only possible with
- a good face stability
- a good grouting

The result
- the will be limited chance on instabilities (calamities)
- good filled tail void



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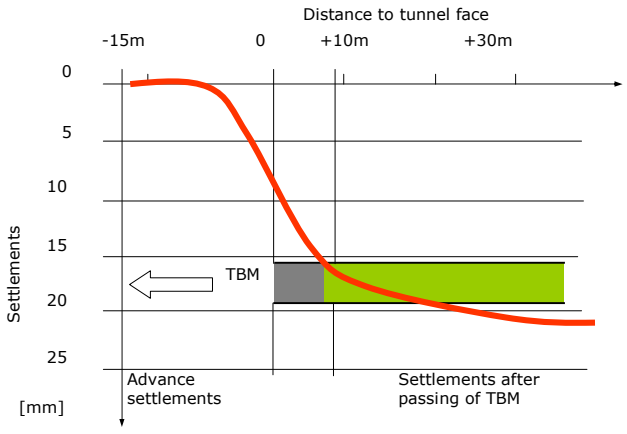
Settlements



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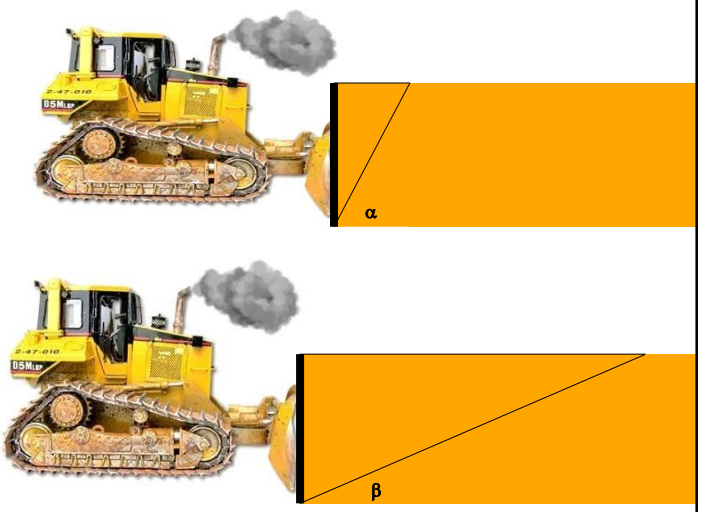
To correct after “failure” is hard

It is the difference between active and passive



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Case Green Heart tunnel

Level 2 probabilistic analysis

- Detect critical area’s
- Determine the bandwidth in settlements to be expected

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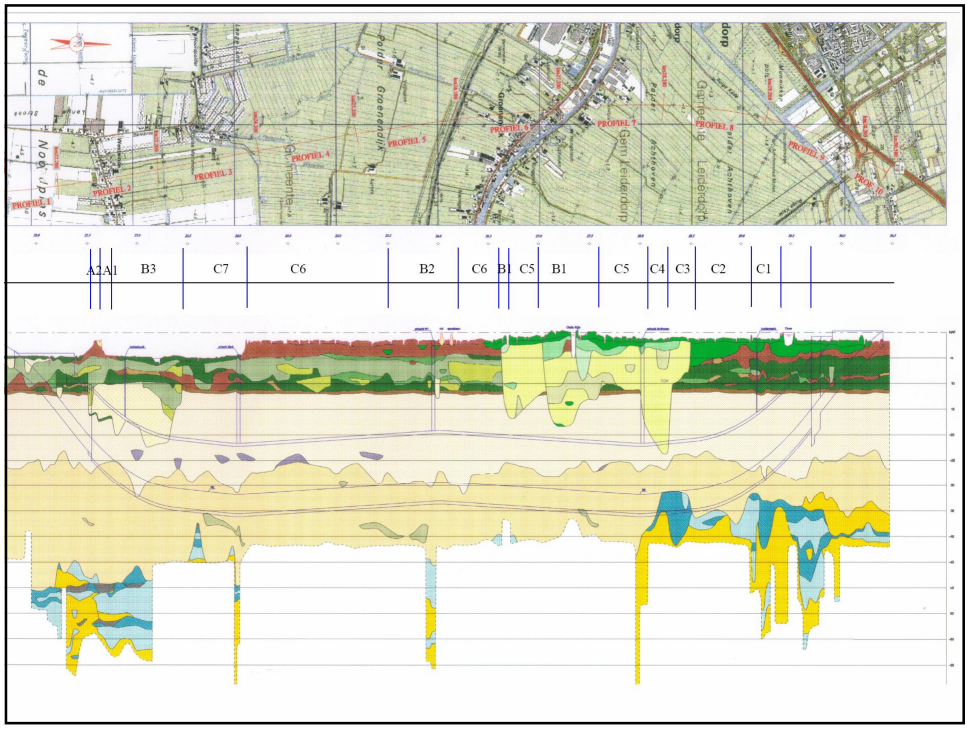

Level 2 probabilistic analysis

2D phased FEM calculation with variation in

- Soil stiffness and strength of individual soil layers
- Pore water pressure
- Effective overburden pressure
- Grouting pressure
- Slurry pressure

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Adoptions in design based analysis

- The effective confinement P'_f pressure (a key process parameter in the TBM) has also become a function of the effective stress in side the various tunnel sections
- In the deep polder a surcharge was installed over ~1 km length

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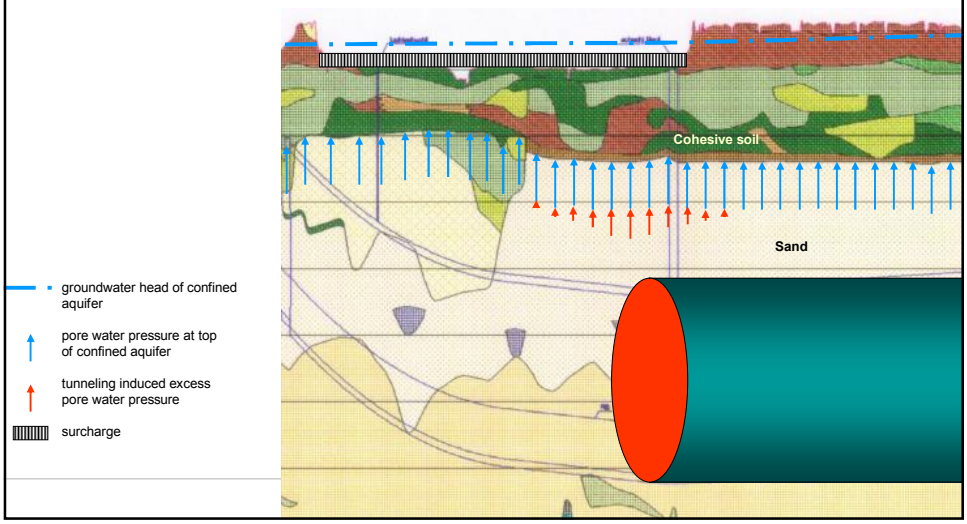
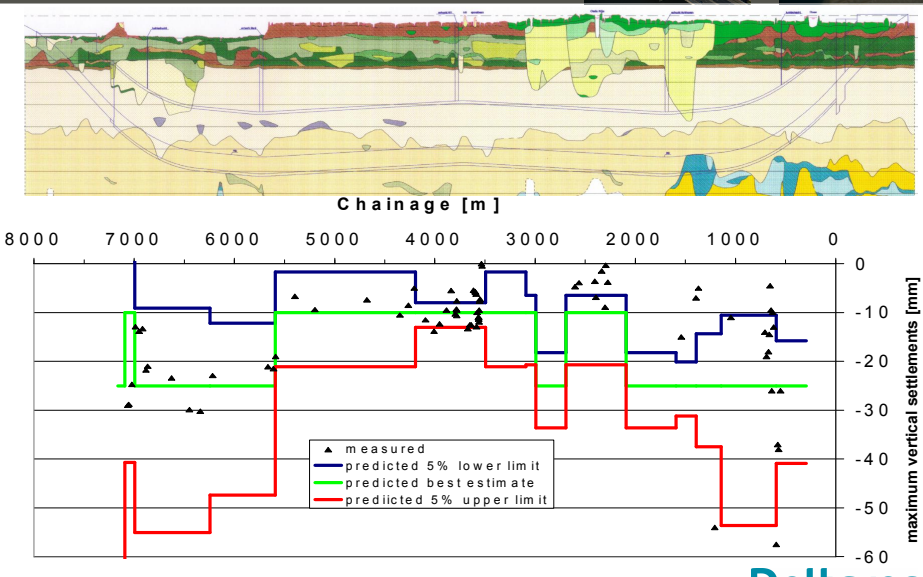
There is no standard tunnel project
Case Green Heart tunnel vertical instability



Predicted and observed settlements



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Advice

- See ground deformation models as risk management tools and not as the truth
- Always apply ground deformation models in combination with the observational method

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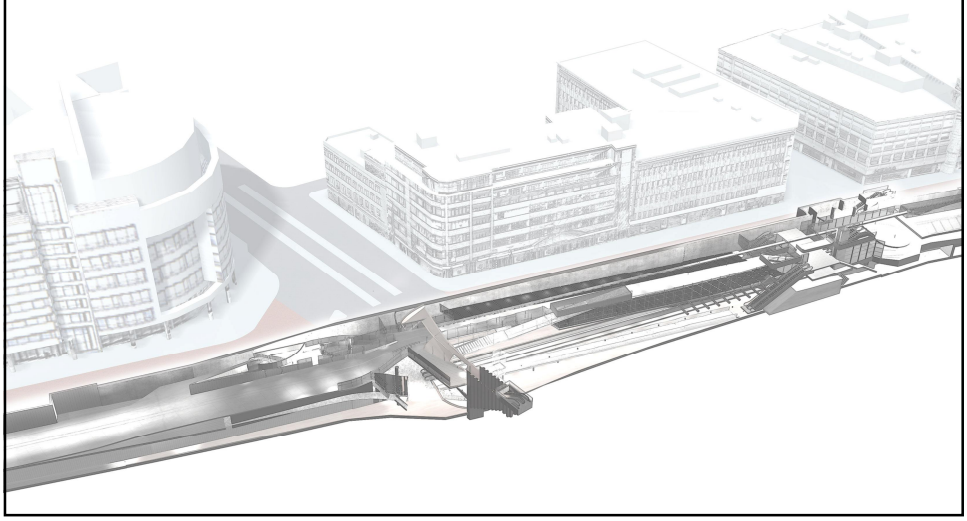
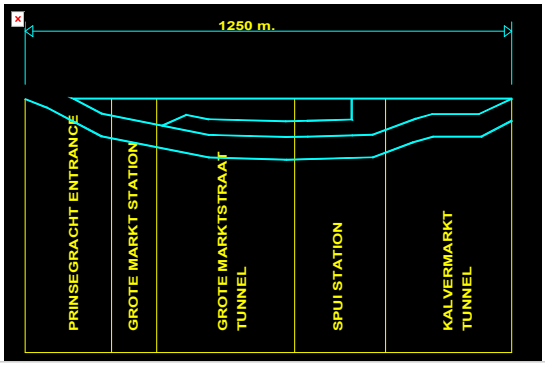
SOUTERRAIN CASE



Extreme optimised

The original design approach aimed to minimise construction costs by taking into account the variable width and depth of the tunnel over its length. By using different construction techniques depending on local depth and width of the tunnel, an optimized construction scheme was defined.



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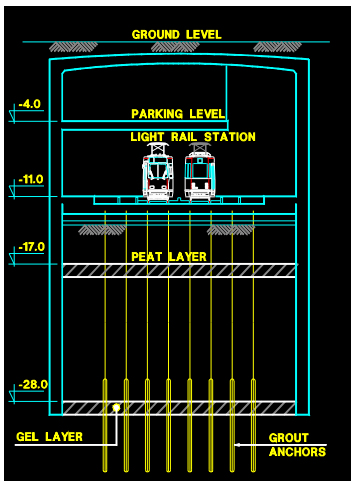
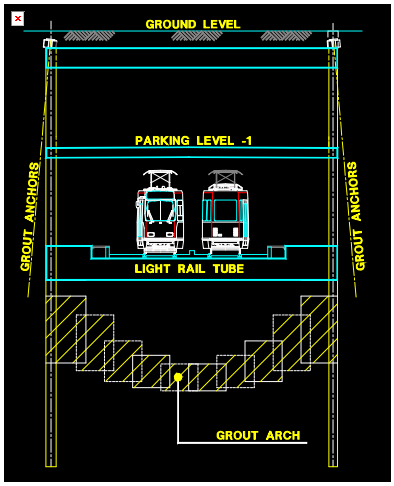
Soft gel
function: waterproofing



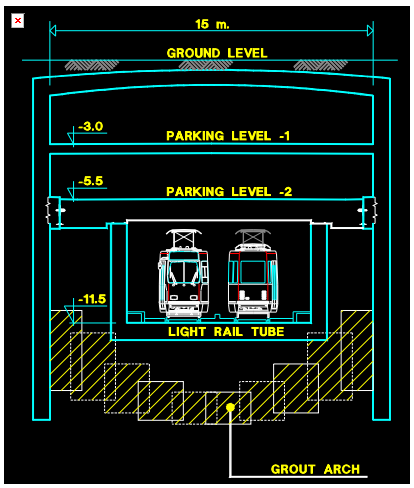
Deltares

Jet grout arch
function: strut and water proofing



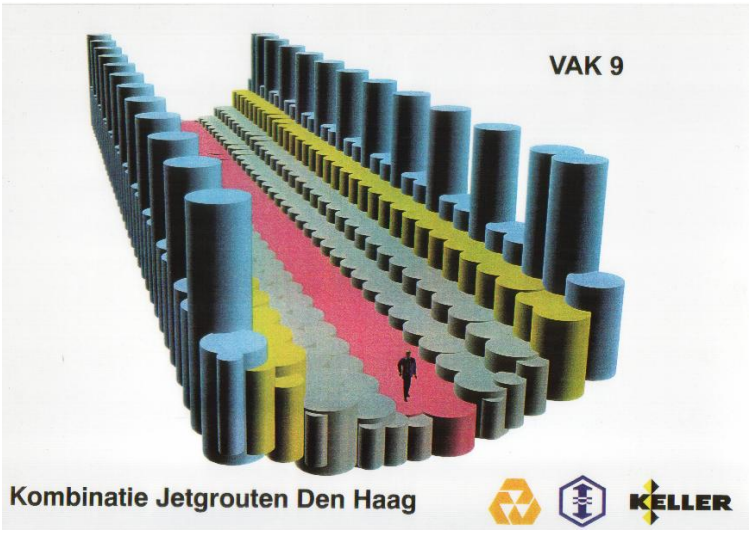
Deltares

Jet grout arch
function: strut and water proofing



Deltares

Jet grout arch: high probability of leakages
The overlap of the deep columns was not sufficient



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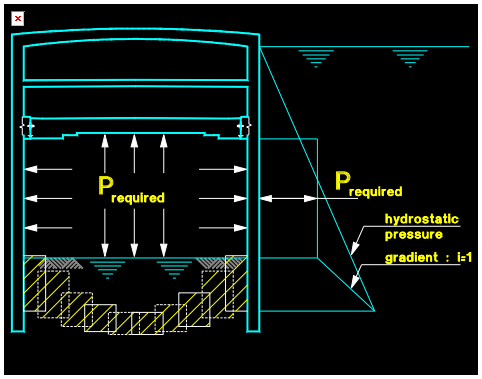
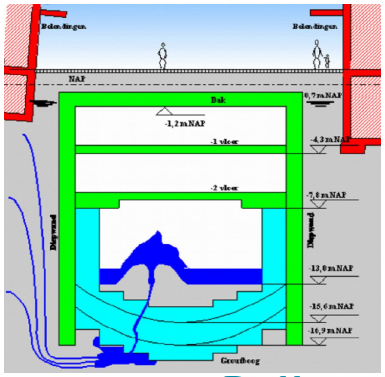
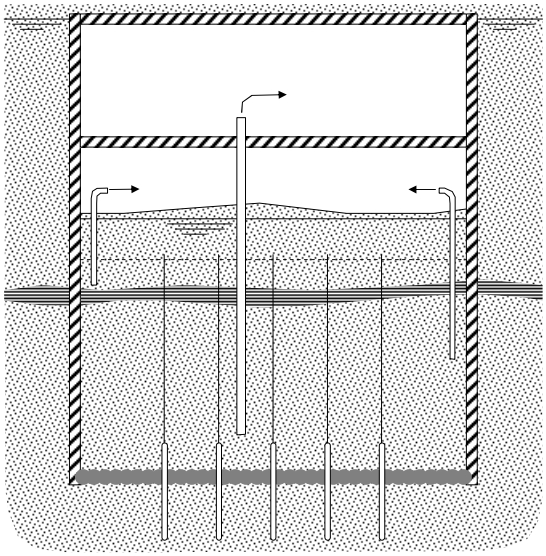
A leak in the jet grout arch led to sand erosion the tunnel had to be flooded. Construction restarted after 2 years under compressed air





Deltares

Due to the 2 year stand-still the deep wells in station Spui had lost much of their capacity to de-water



Deltares

Construction at station Spui became difficult

Deltares

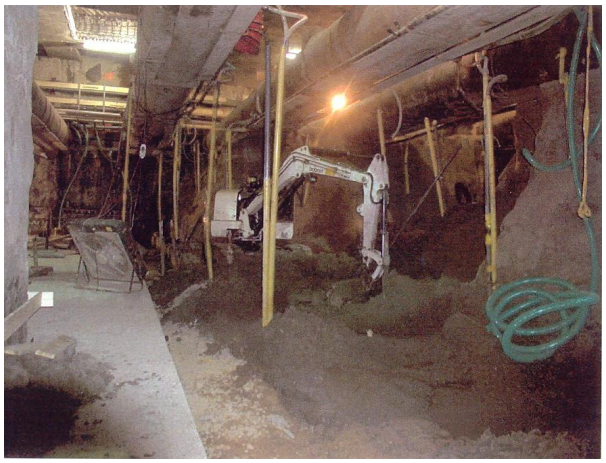
Construction in station Spui became difficult

Deltares

Construction at station Spui became difficult

Deltares

Construction at station Spui became difficult



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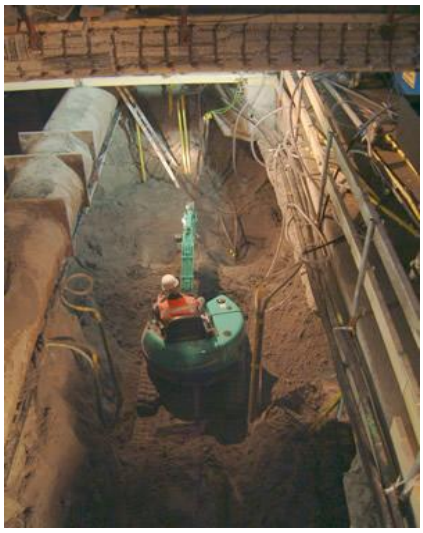
Construction at station Spui became difficult



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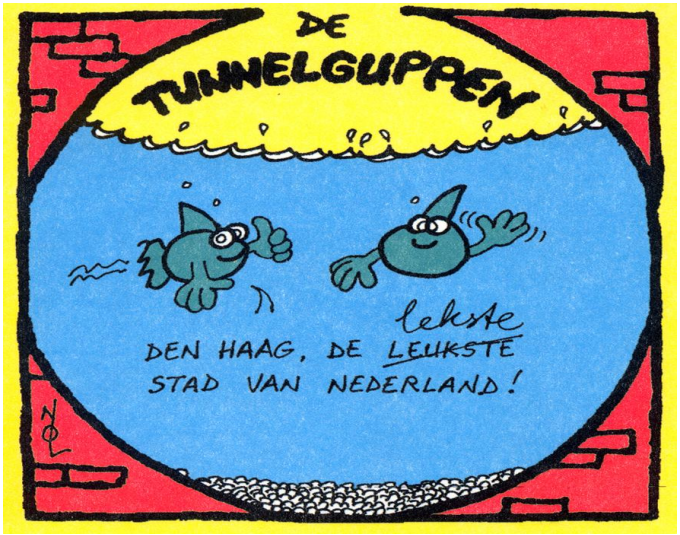
Public opinion



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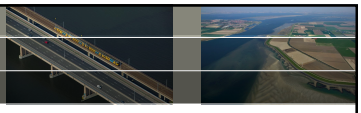
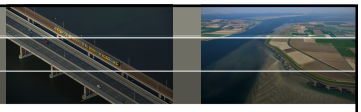
Lessons learned



- Construction cost can triple
- Minimize the amount construction types as transitions between types always significantly increase the risk profile
- Make an in-depth what-if scenario analysis, especially if a system is extremely optimized

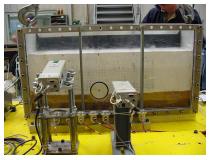
Deltares



Thank you
for your attention

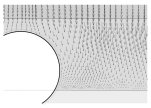
Deltares

Bonus
Innovation circle: Tunnelling in settling soil



Model testing

Calculations



Field tests and monitoring

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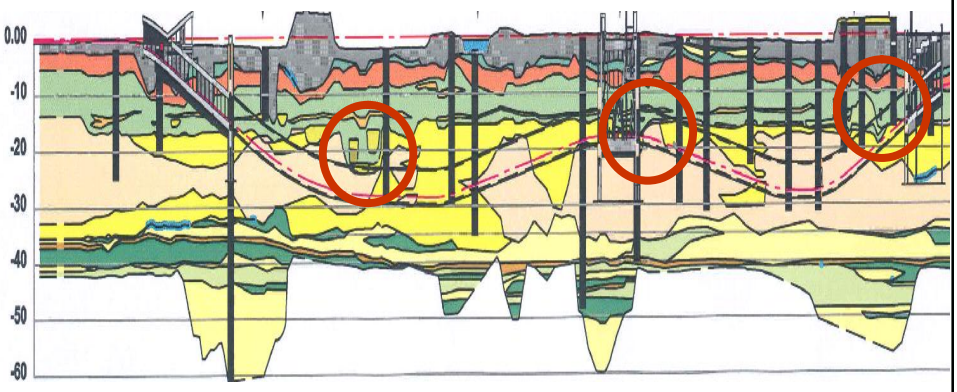
Tunnelling in soft soil, invert in sand layer
$\Delta w_{100\ years}$ over half of the tunnel height ~0.25 m



Randstad rail , Rotterdam

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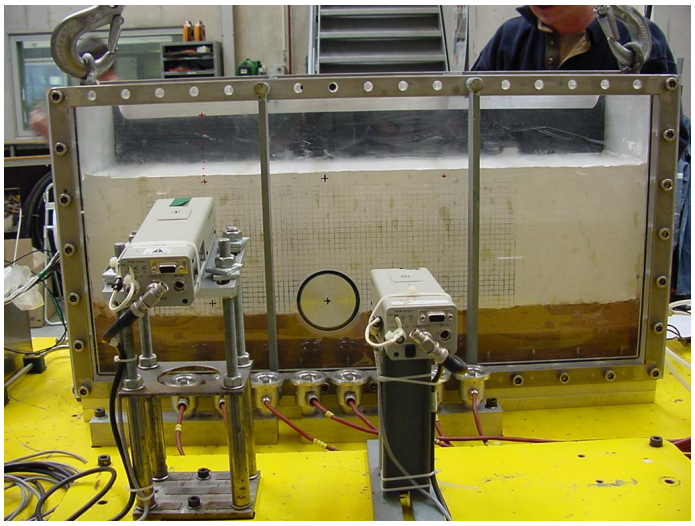
Centrifuge model of tunnel



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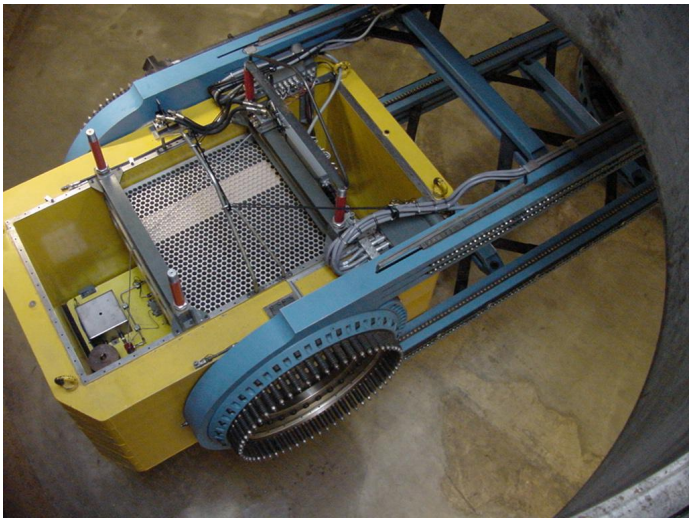
Model placed in centrifuge



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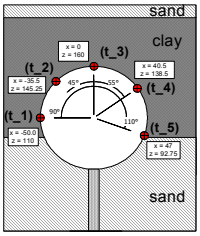
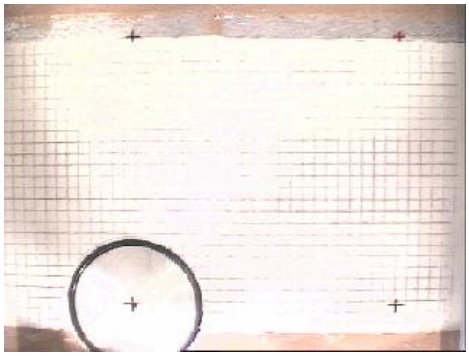
Time-dependant behavior of soft soil on lining





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What did we learn?

- Pressure increase dominant in design of tunnelling as the vertical increase is significantly more than the horizontal
- The pressure increase in time ΔP_{100}~45-85 kPa
- Source of settlement is mainly creep but also supplementary heightening
- Stress change difficult to monitor
  ε_z =0,0006/year ➔ $\Delta\sigma$~0.6 kPa/year
- Risk is so significant ➔ steel segments applied

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Thank you
for your attention

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