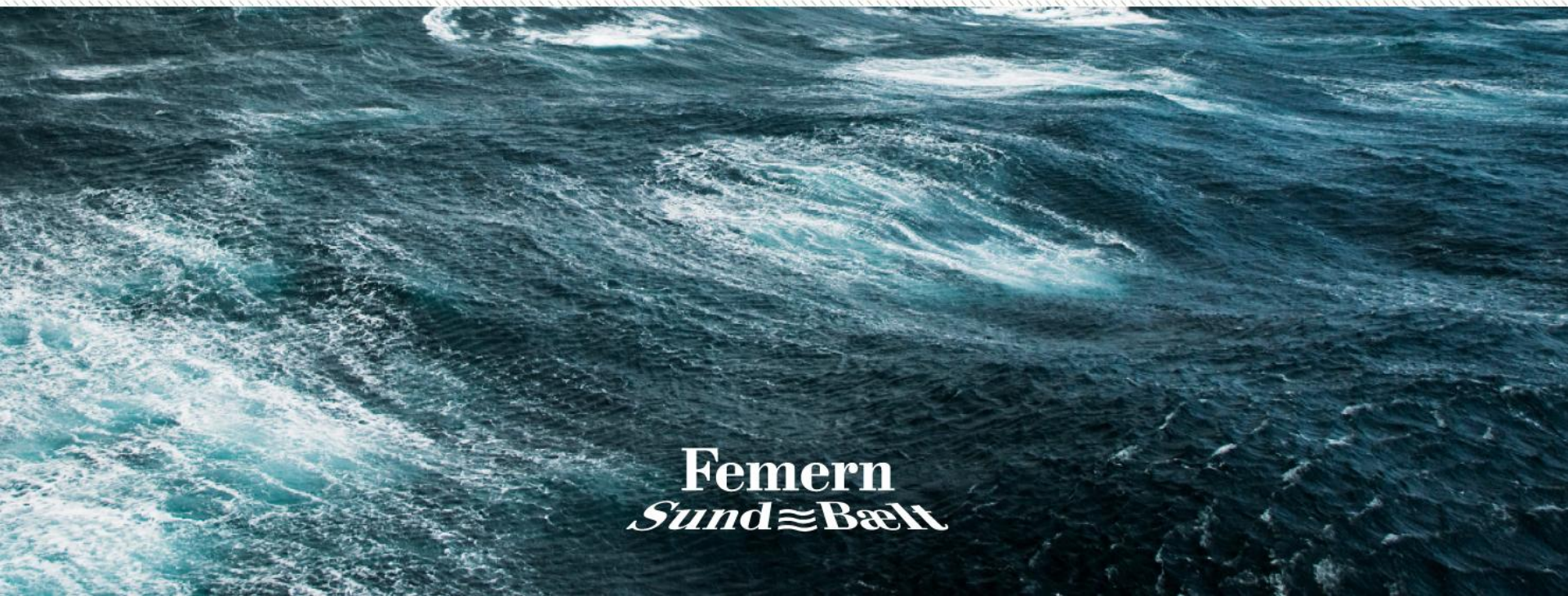
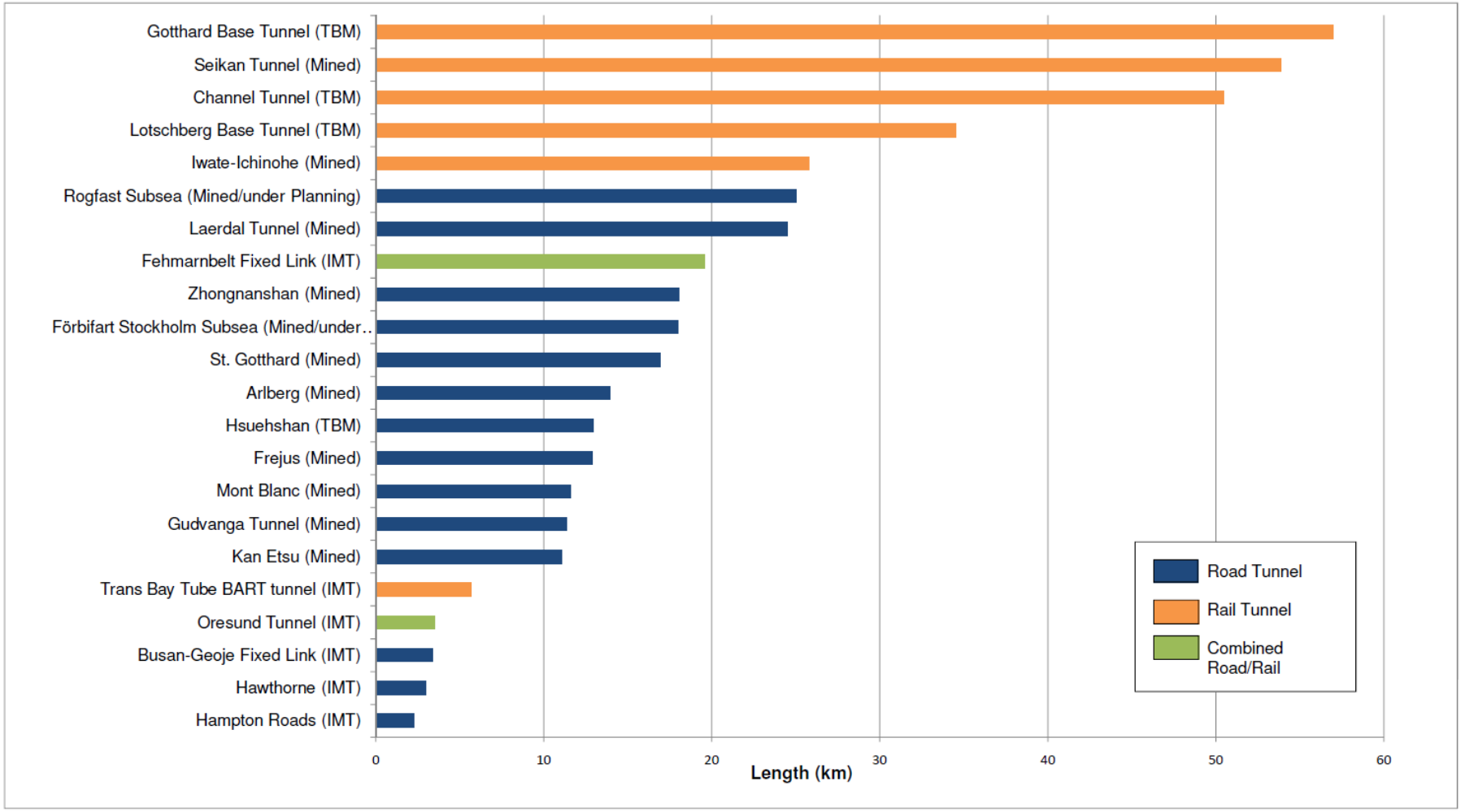
Steen Lykke, Project Director

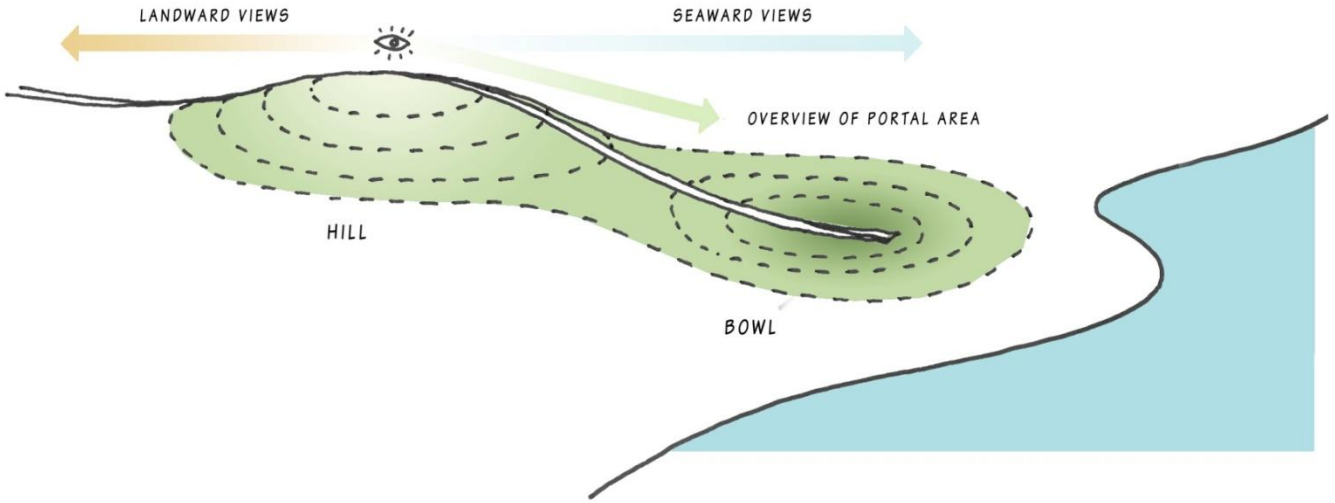
The Femern Tunnel Conceptual – Design



The longest Tunnels in the world



Femern Sund Bælt






Femern Sund Bælt

Femern

Femern
Sund Bælt

”En dyd af nødvendigheden”

Femern Sund Bælt

Femern Sund Bælt

Femern Sund Bælt

Outdoor

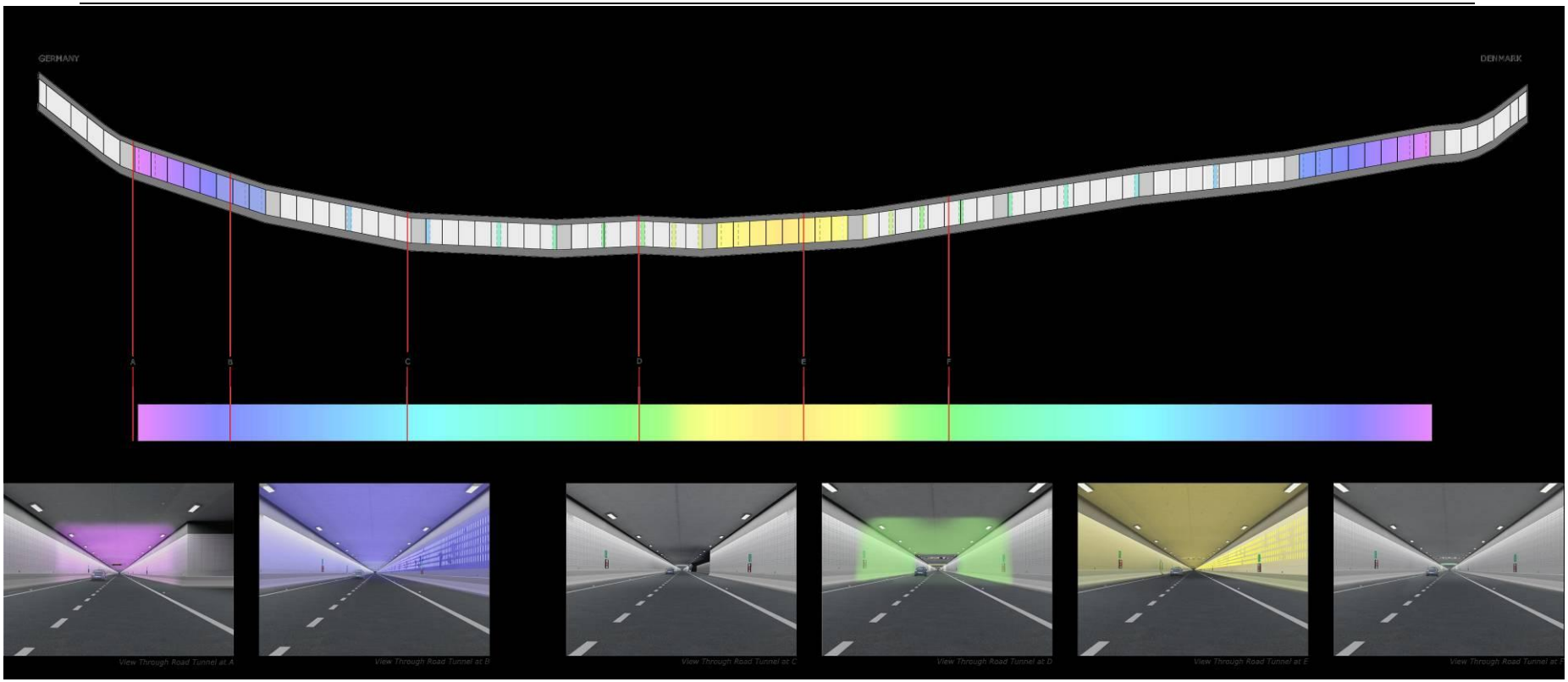
12 minutes

Outdoor

Femern Sund Bælt

Femern Sund Bælt

Femern Sund Bælt



Femern Sund Bælt

Fugleflugtslinien, lad os tage en tur fra Tyskland

Femern Sund Bælt

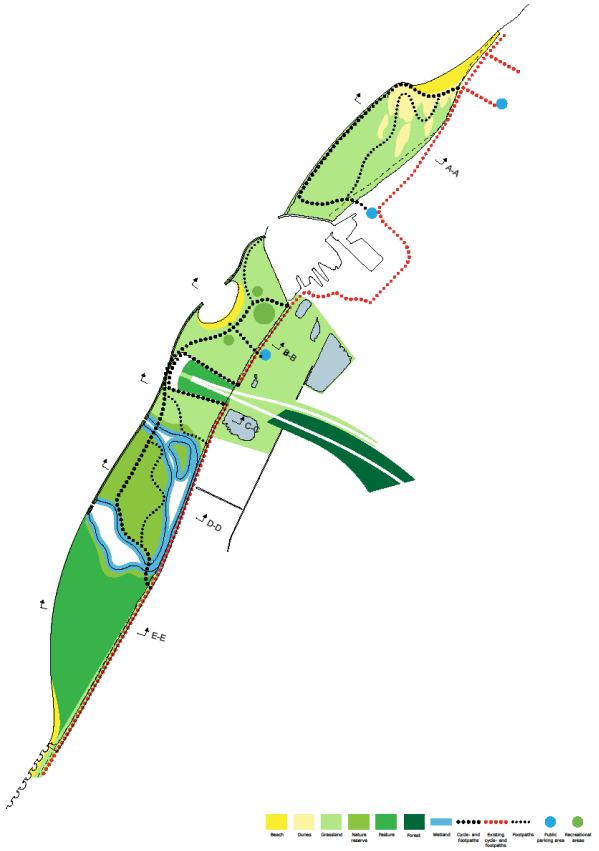
Portalbygning, Lolland, Man – made, strickt contours

Femern Sund Bælt

Aestetical Committee – Green and Soft solution

Femern Sund Bælt

Reclamation on Danish Side - Lolland



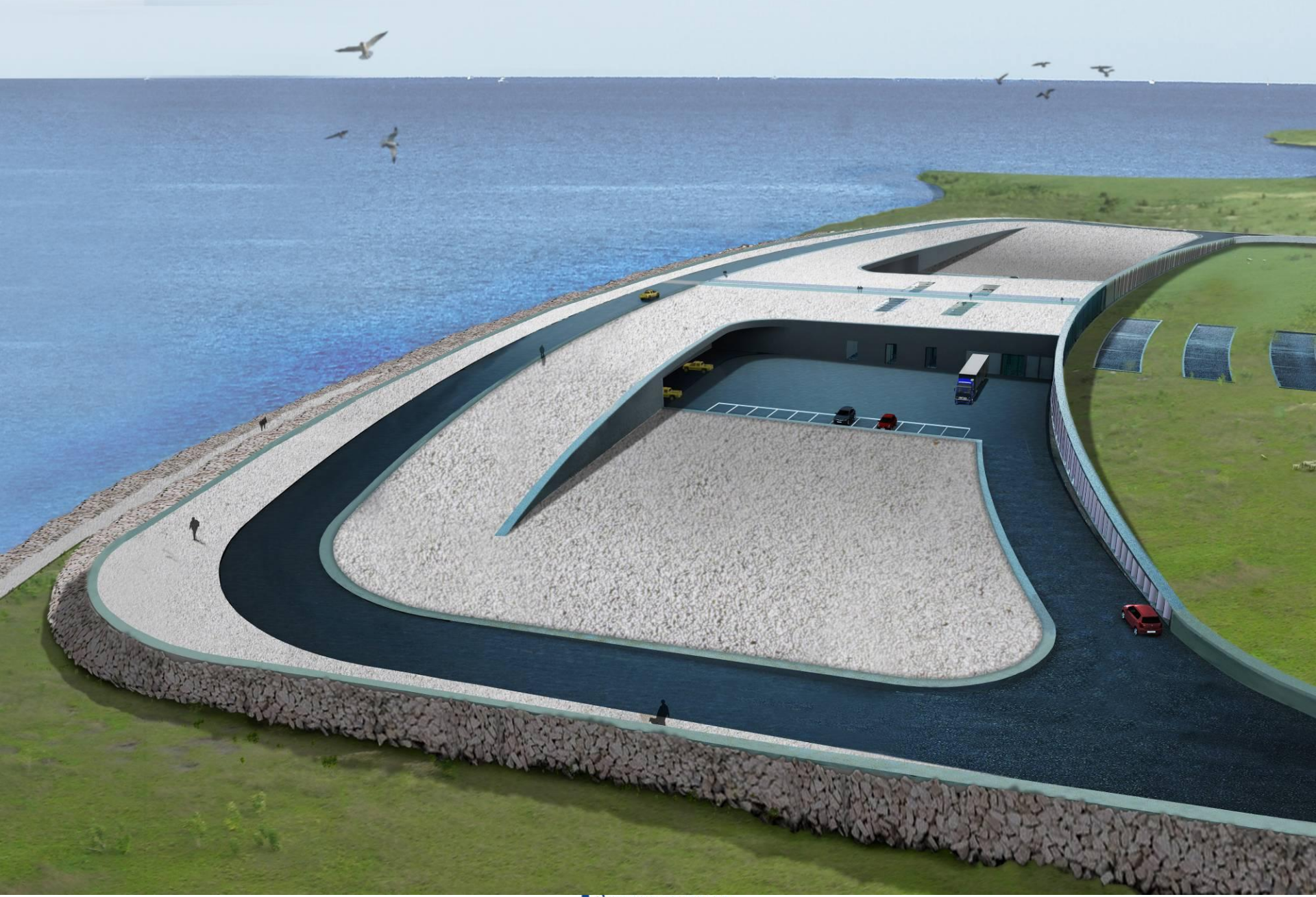
”Stadig en dyd af nødvendigheden”

Femern Sund Bælt

”Kvalitet” – forstyr så lidt som muligt

Femern Sund Bælt

Femern Sund Bælt

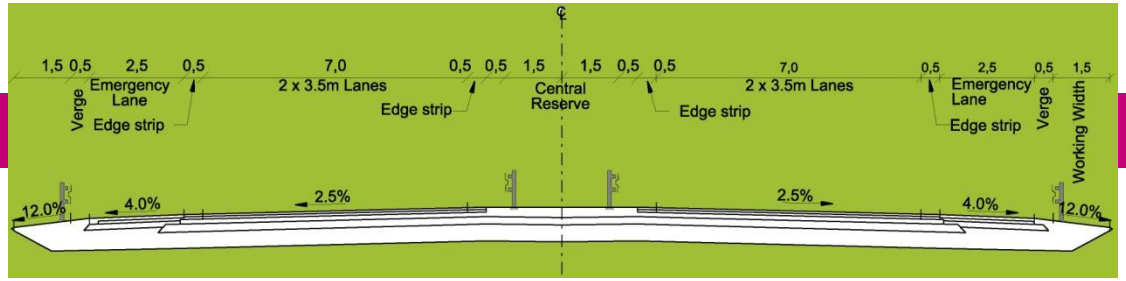


Femern Sund Bælt

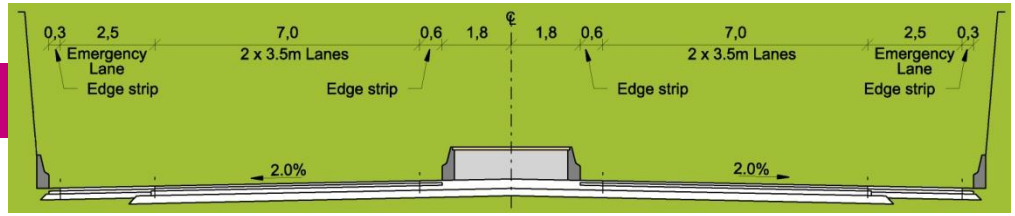
Vejprofiler i Tyskland og Danmark

Fehmarn

RQ 28

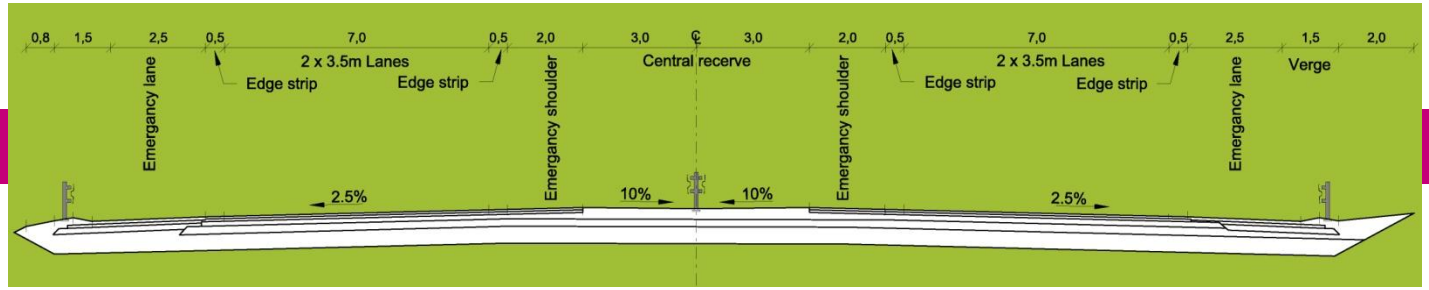


Ramps



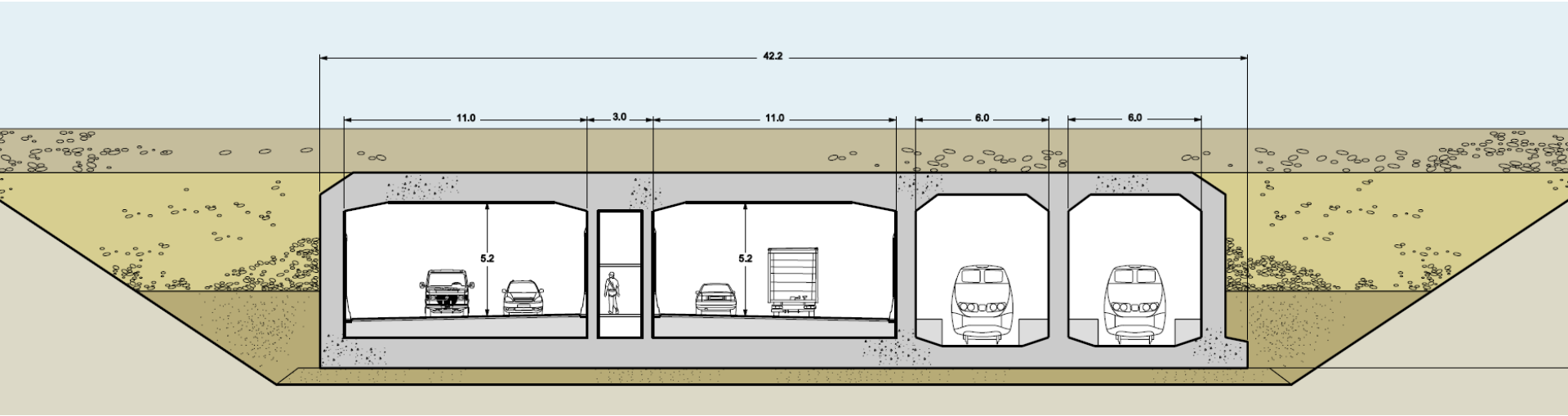
Lolland

4H



Femern Sund Bælt

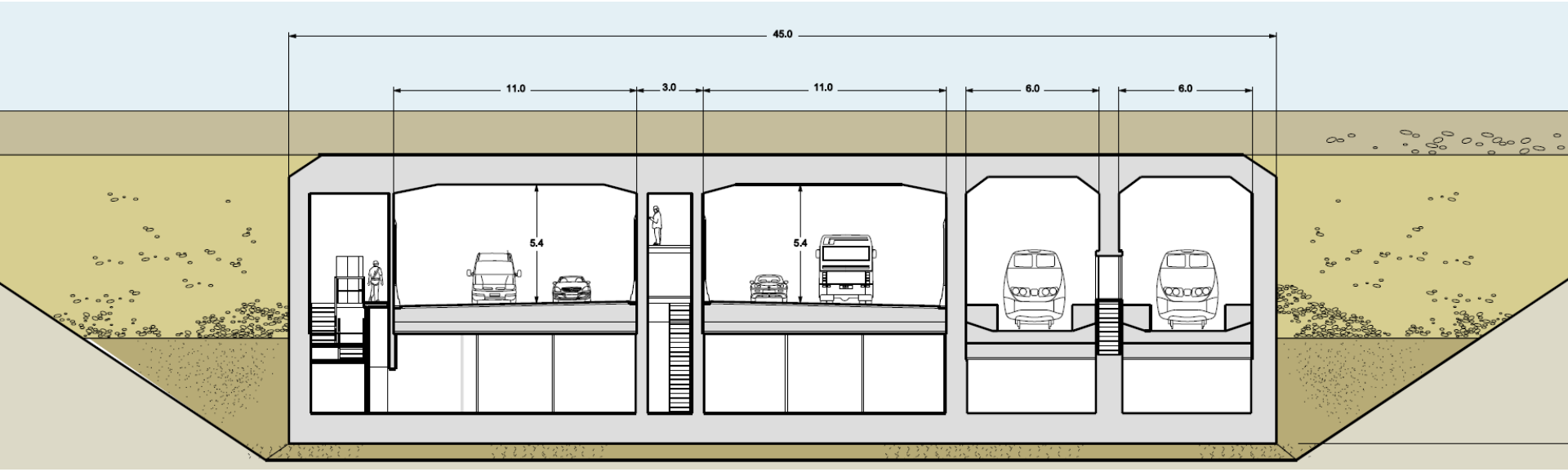
SÆNKETUNNEL
Standardelement



Femern Sund Bælt

SÆNKETUNNEL
Specialelement per ca. 1,8 km

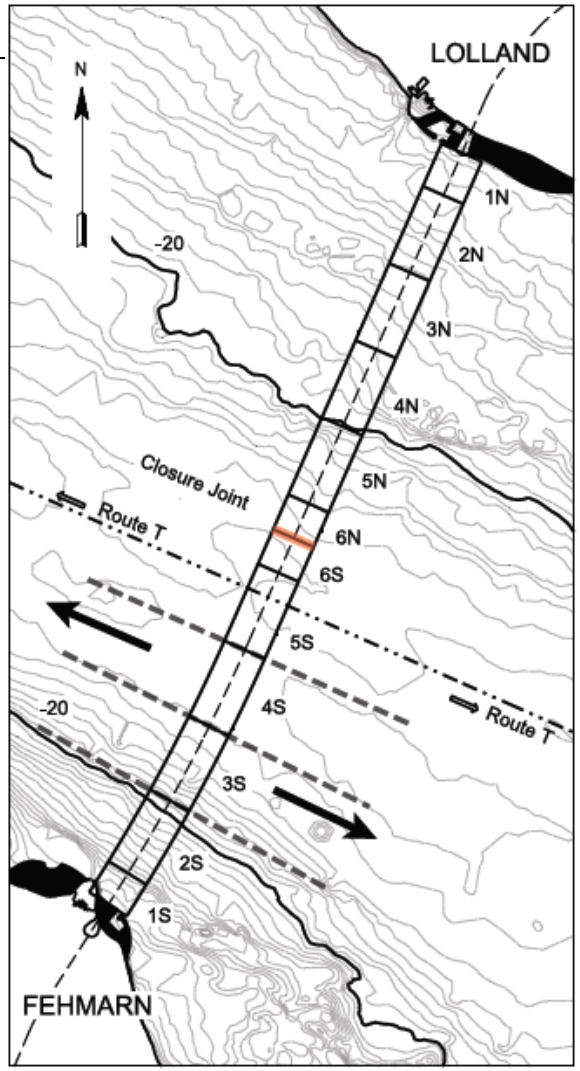
- Indeholder tekniske rum og pumpesumpe
- Giver mulighed for adgang til alle rør
- Eget parkeringsområde for driftspersonalet i det vestlige rør.



Femern Sund Bælt

Transport and Immersion

Working Area & Navigational Control



Femern Sund Bælt

Risici og statistikker

Femern Sund Bælt

Ulykkesscenarier i en tunnel?

I-5 Tunnel Fire
California 2007

Femern
Sund≈Bælt

Sikkerheds strategi

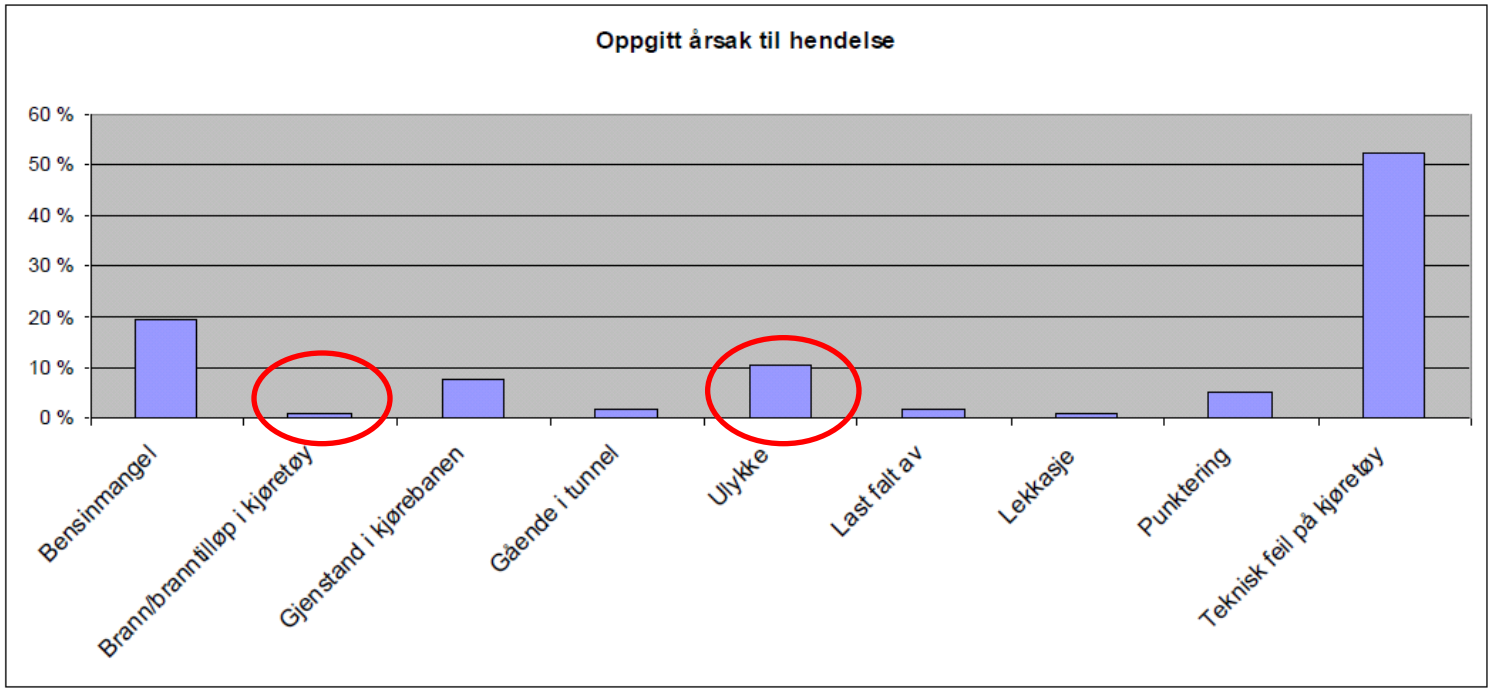
- Niveau 1: Forebyggelse
- Niveau 2: Selvredning, kontrol af situation
- Niveau 3: Rednings-Rydningsindsats

Femern Sund Bælt

Forskel mellem tunnel og åben vej

Femern Sund Bælt

Sandsynligheden for forskellige typer hændelser

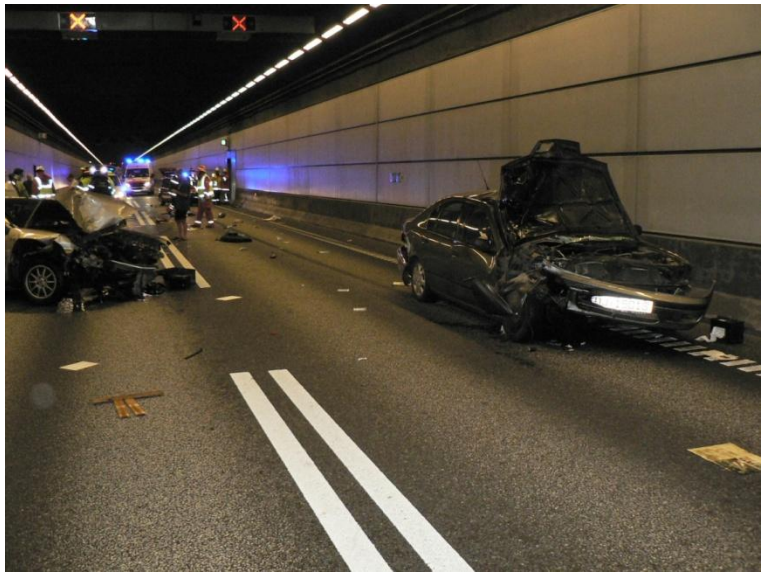


Amundsen/Engebretsen - Rapport 05/2005 Veg og trafikkavdelingen

Femern Sund Bælt

statistik fra Øresunds tunnel
- Efter 10 års drift

- Vejdel – Ialt > 50.000.000 køretøjspassager :
  1 brand slukket med håndslukker
- Banedel: Ingen ulykker



Femern Sund≈Bælt

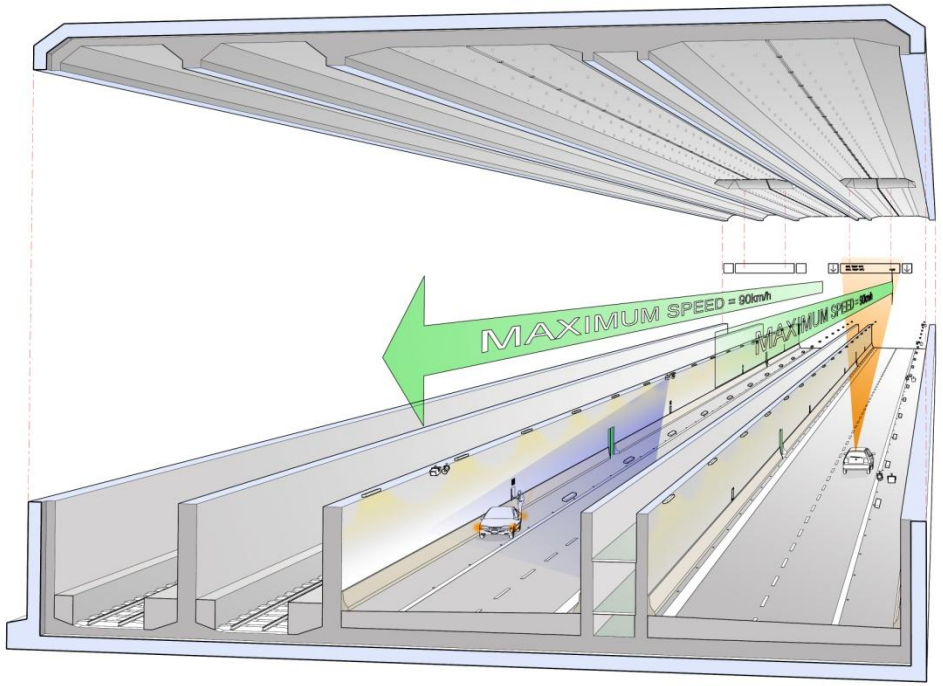
Forebyggelse af ulykker

Femern Sund Bælt

Niveau 1 – forebyggelse

Sikkerhedsforanstaltninger i designet

- Ensrettet trafik i tunnelrør (vej og bane) – ingen frontale kollisioner
- Landtunnel – ingen kødannelser
- Center galleri som tilflugtssted
- Intelligent trafikstyring
- Tætsiddende nøddøre
- Flere tunnelrør (4) for flugt, redning og brandslukning
- 2 kørebaner + nødspor i hver retning
- Lille fald/stigning på vej
- Døgnbemandede kontrolrum for vej og bane

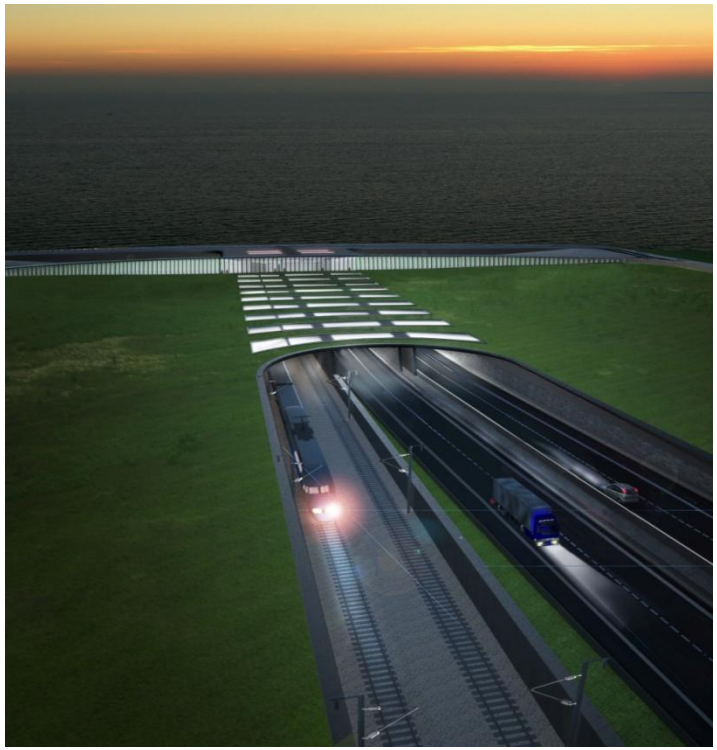


Femern Sund Bælt

Niveau 1 – forebyggelse

Sikkerhedsforanstaltninger i VEJ rør

- Elforsyning (Redundancy, short break og no break (UPS))
- SCADA
- Tunnelbelysning (normal-, sikkerheds- og flugtvejsbelysning)
- Afvanding/pumpeinstallationer
- Simpel, langsgående tunnelventilation
- Brandhaner samt brandbekæmpelse
- Kommunikation
- Branddetektering



Vejassistance køretøj

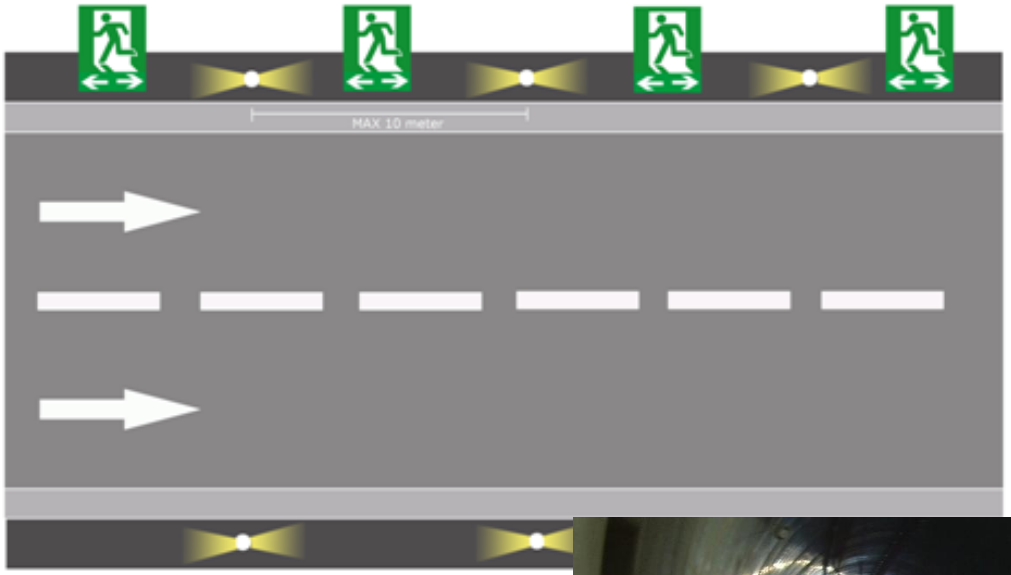
- Inspektion
- Opsamling af tabte genstande
- Vejassistance
- Først på stedet ved ulykker

Femern Sund Bælt

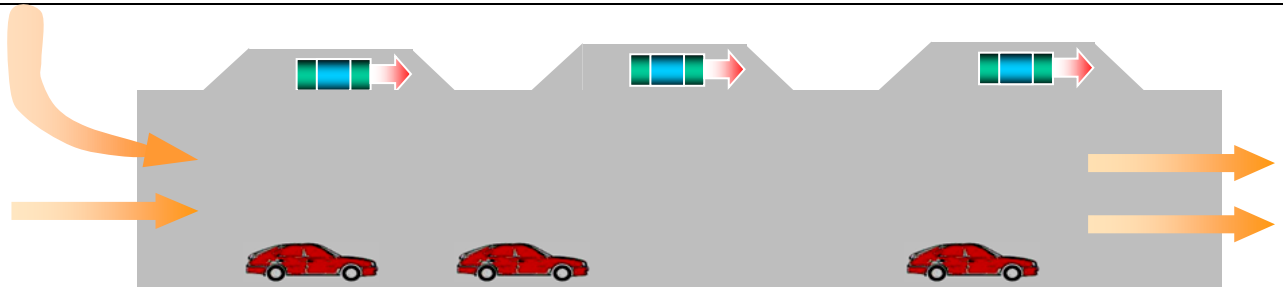
- Normalbelysning
- Sikkerhedsbelysning (no break forsynet)
- Nødbelysning (flugtvejsbelysning)

Femern Sund Bælt

Nød-/flugtvejsbelysning



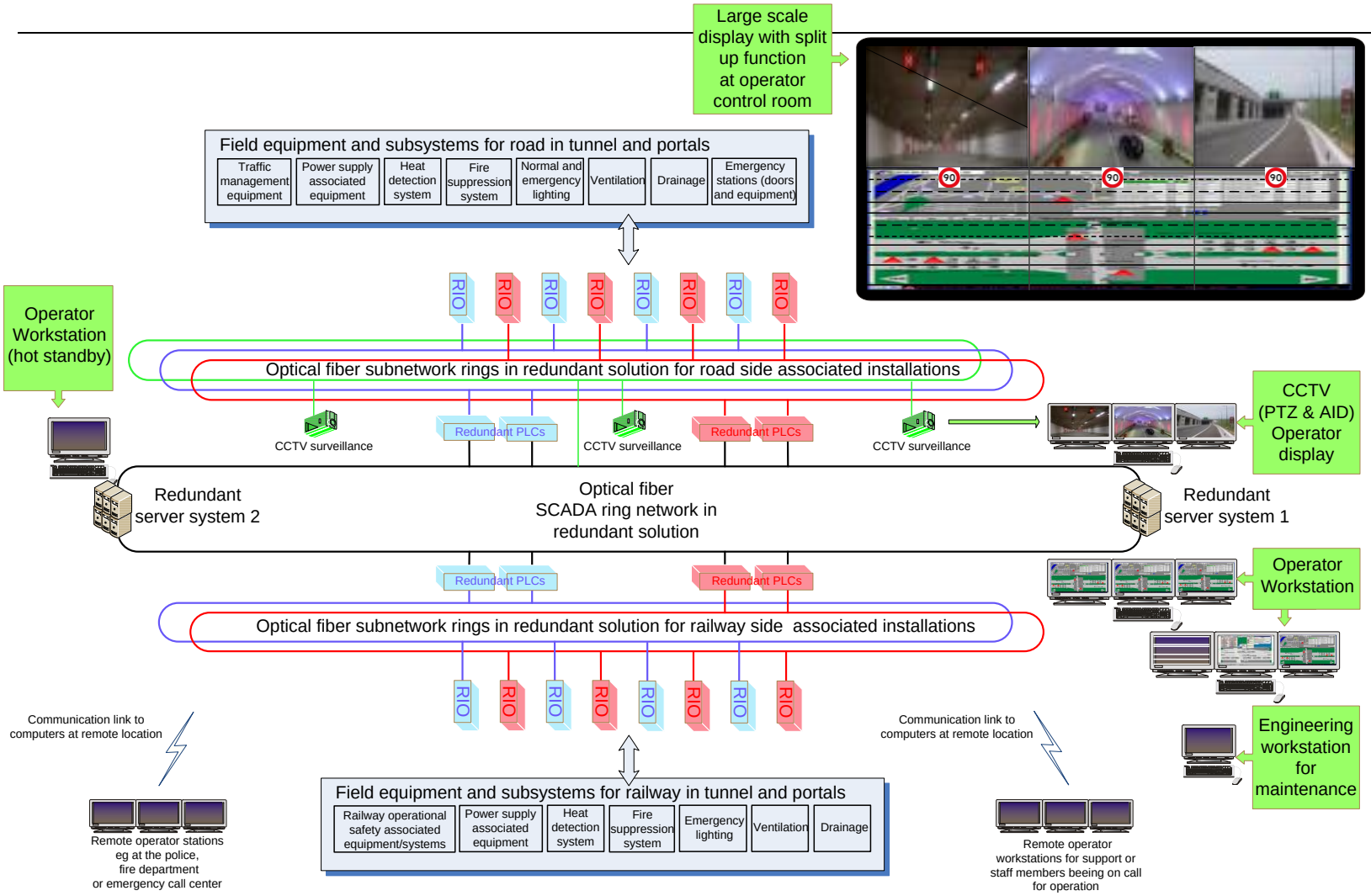
VENTILATION – Normal drift



- Langsgående ventilation – fra portal til portal
- Selvventilerende i normalsituation

Femern Sund Bælt

SCADA = SRO



Femern Sund Bælt

Niveau 1 – forebyggelse

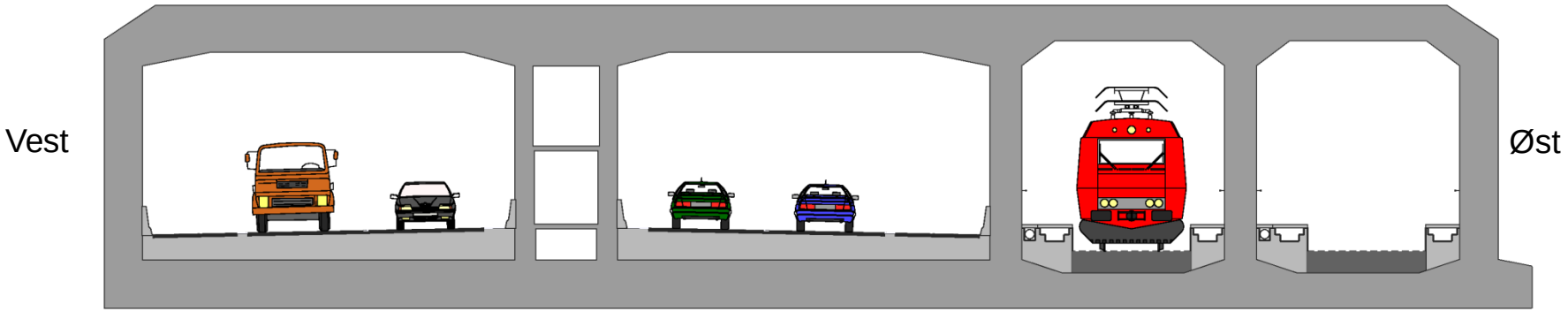
Sikkerhedsforanstaltninger i JERNbane rør

- Ingen skiftespor eller transversaler i tunnelrør eller nær portaler
- Hot box detection ved portals
- Afsporings sikring og detektering
- Detektering af stopped tog
- ERTMS-Level 2 tog styrings system

Femern Sund≈Bælt

Niveau 2 – selvredning og kontrol sikkerhedsforanstaltninger

- Nøddøre med 100m intervaller – meget synlige
- Flugtmulighed fra vejrør ind i det centrale galleri – sikkert område
- Fortove og nøddøre i banerør
- Høttaleranlæg, radio re-broadcast
- Skiltning af nøddøre, med afstand til nærmeste dør
- Anvisninger på skilte med variabel tekst
- Sikkerheds- og flugtvejsbelysning
- Nød stationer – hver 50m

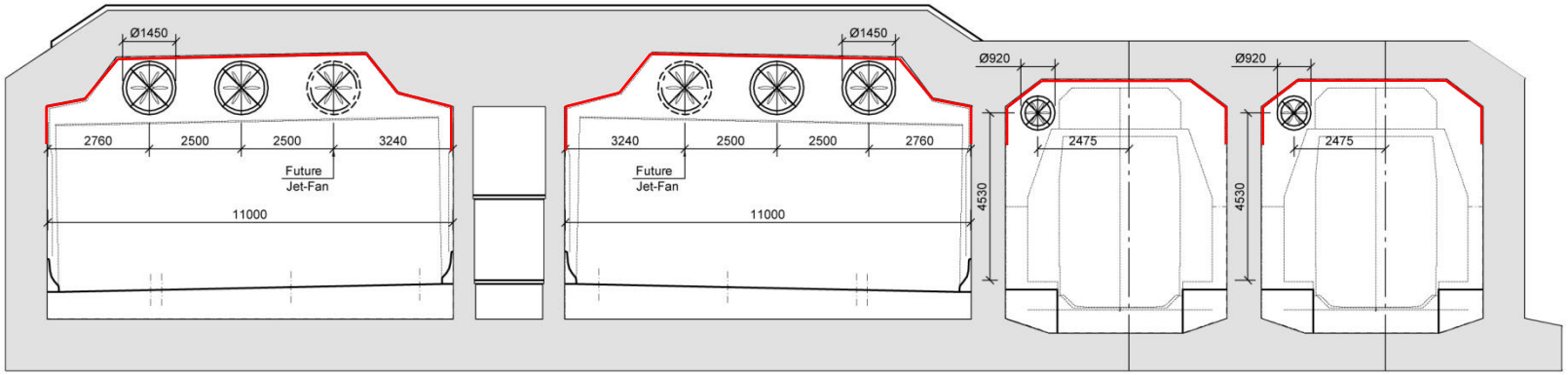


Niveau 2 – selvredning og kontrol sikkerhedsforanstaltninger

- Brandmodstandsevne af konstruktioner – RWS hydrocarbon kurve for alle kritiske elementer (stor benzinbrand)
- Brandslukningsanlæg – deluge system
- Langsgående ventilations system
- Nødstationer med håndildslukkere
- Overtryk i det centrale galleri

Femern Sund Bælt

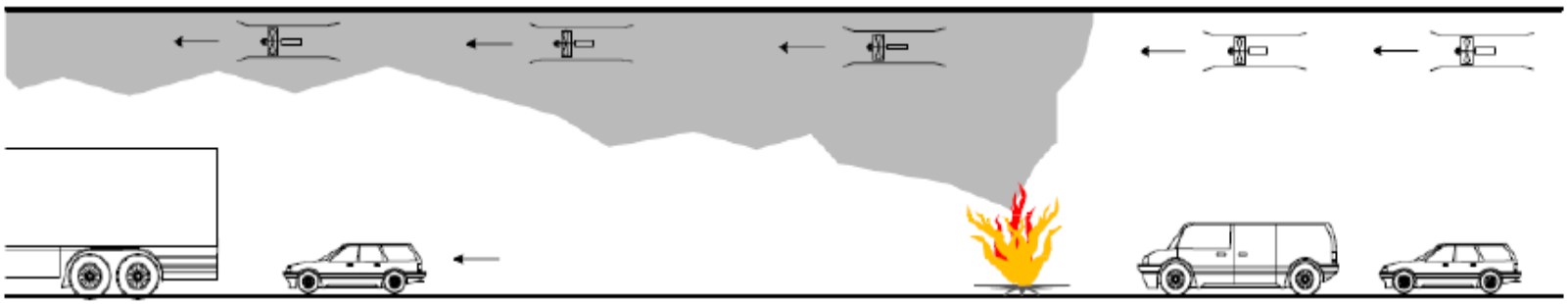
Brandisolering af konstruktioner (passivt system)



Ventilation – Brandsituation

- Impulsventilatorer (jet fans) hver 400m
- Sikrer røgudbredelse i én retning

- Simpelt og pålideligt system
- Kødannelser kan undgås



Femern Sund Bælt

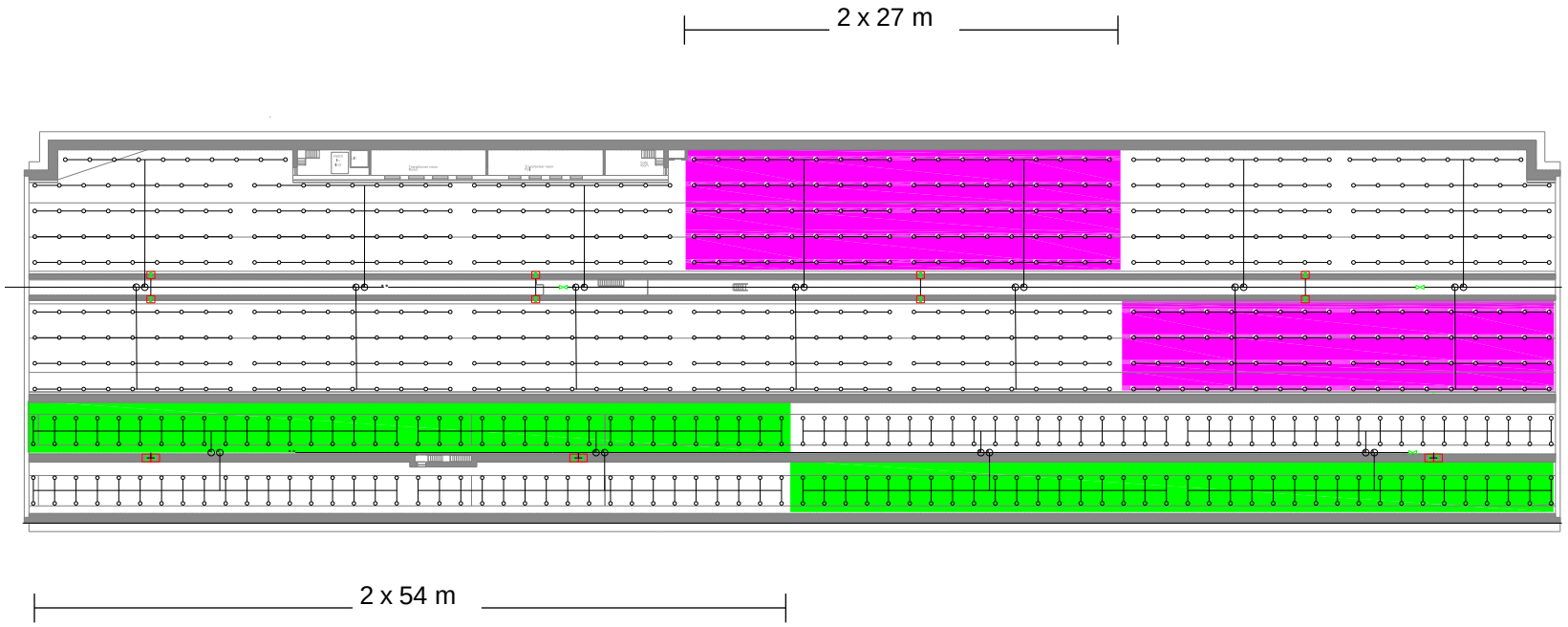
Brandslukningssystem – deluge (aktivt system)

- Forbedring af sikkerheden for personer i tunnelen
- Begrænsning af skader på tunnel installationer og beklædninger
- Bedre muligheder for slukningsindsats
- Kortere afbrydelser af de normale drift
- Formindskelse af reperationsomkostninger og driftstab

Deluge + længdeventilation – simpelt, pålideligt, robust!

Femern Sund Bælt

Brandslukningssystem – zoneopdelt deluge

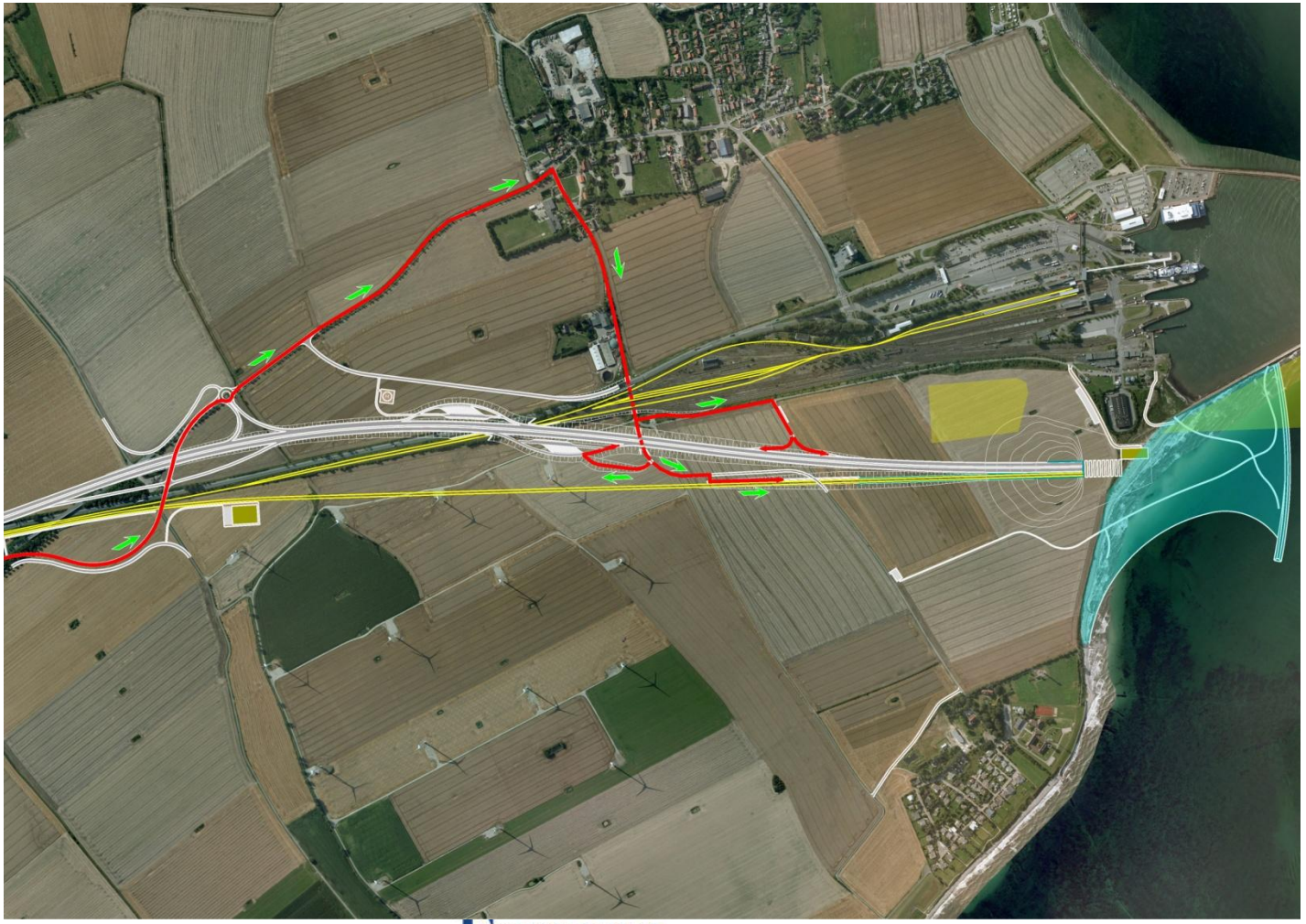


Femern Sund Bælt

Understøttelse af redningsindsatsen

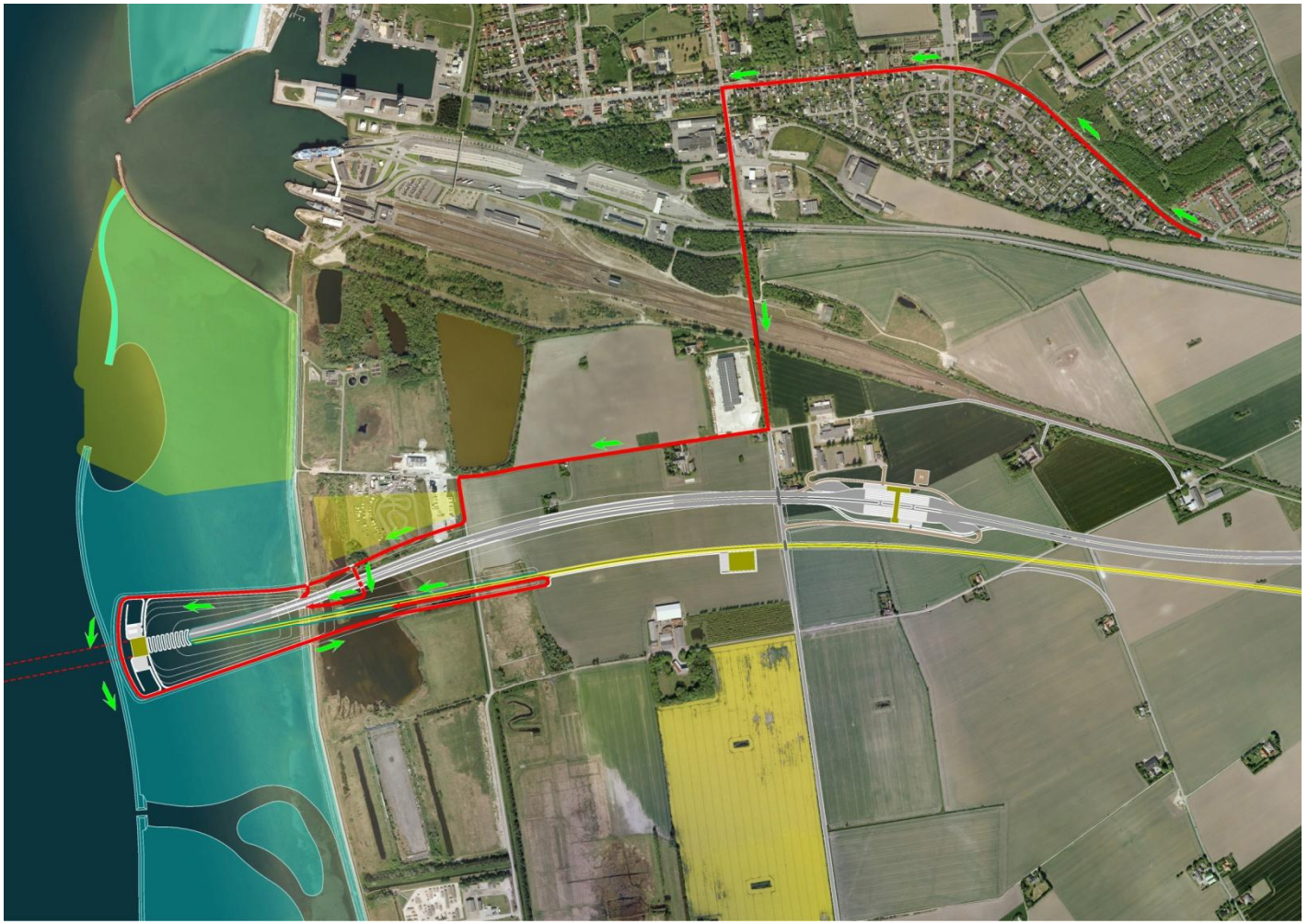
Femern Sund Bælt

Adgangsveje, Femern



Femern
Sund≋Bælt

Adgangsveje, Lolland



Femern Sund Bælt

Niveau 3 – understøttelse af redningsindsatsen

- En række kommunikations systemer– FM radio, mobil telefoni, nødtelefoner, TETRA radio system
- Hydrant system 1200l/min
- Adgang til tunnelrør ved portaler for redningskøretøjer
- Mulighed for manuel indgriben i kontrol af sikkerheds systemer
- Konstant bemandet kontrolrum
- Detaileret indsatsplan for brand, redning og rydning
- Adgang via sikkert rør pr ca 100 meter

Femern Sund Bælt

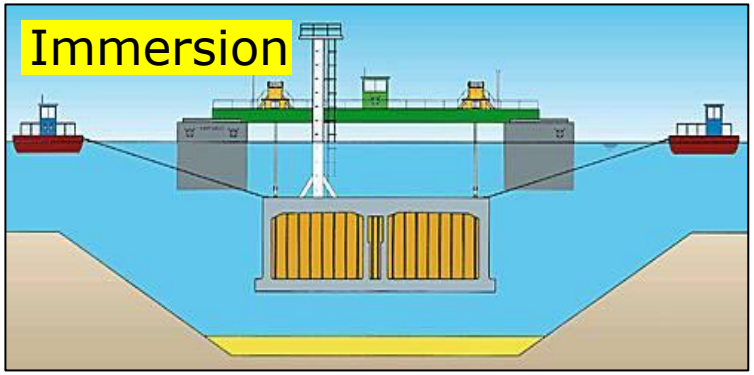


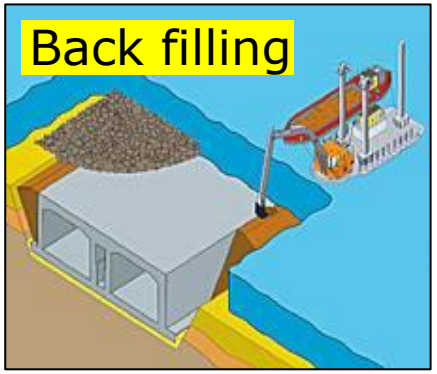
IMMERSED TUNNEL

O. P. Jensen

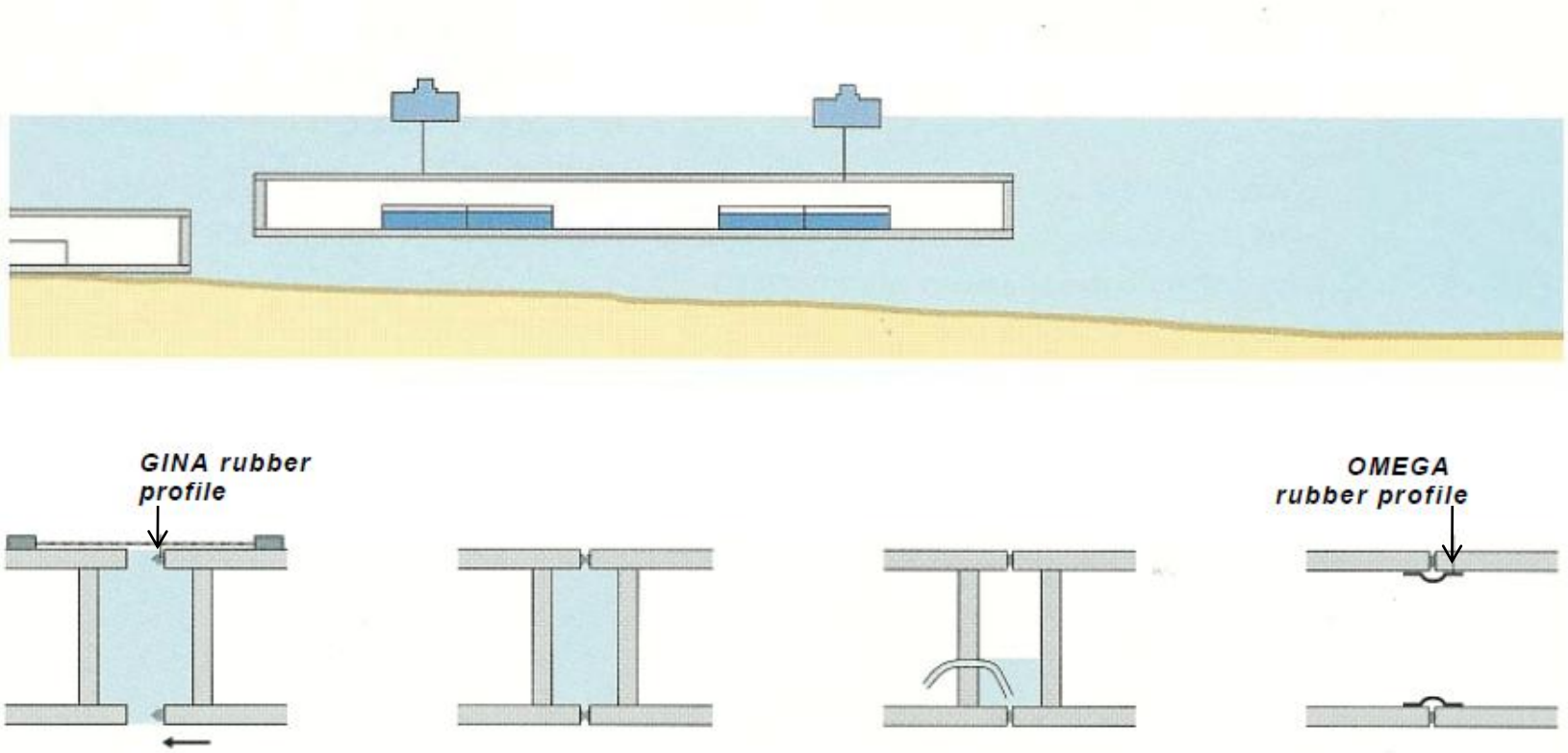
RAMBØLL
ARUP
TEC

MAIN PHASES FOR INSTALLATION OF IMMERSED TUNNEL ELEMENTS



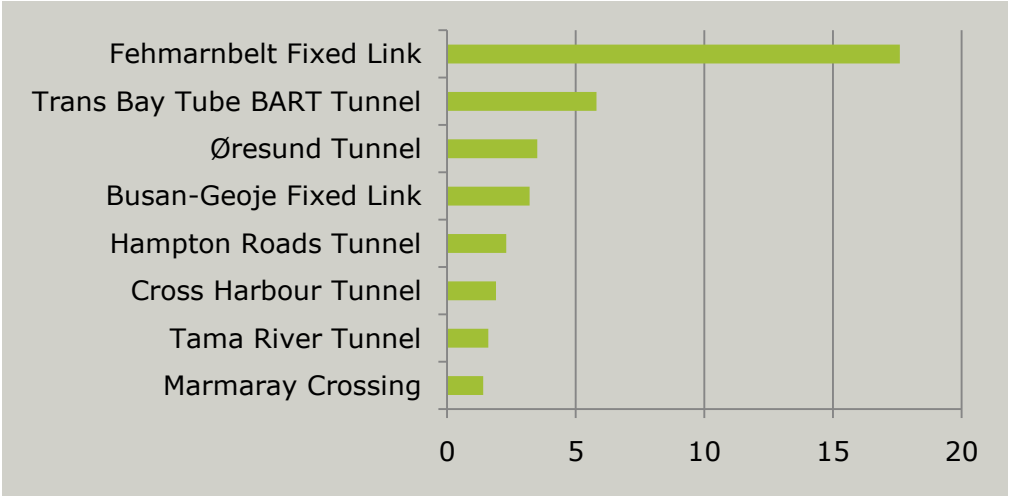


PHASES IN CONNECTION TUNNEL ELEMENTS



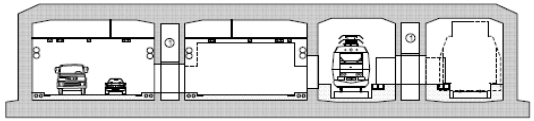
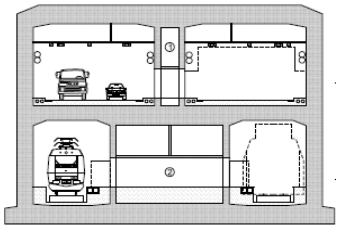
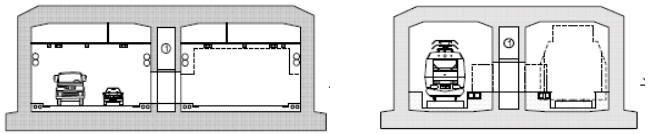
IMMERSED TUNNEL
TUNNEL LENGTH AND DEPTH

Tunnel Length	18.1km
Immersed Tunnel Length	17.6km
Tunnel Depth	40m



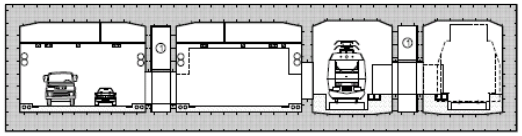
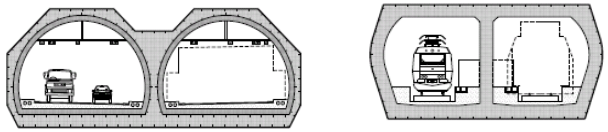
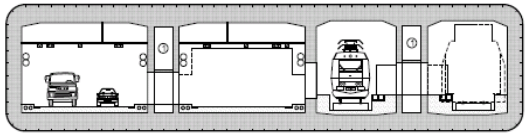
IMMERSED TUNNEL
SELECTION OF CROSS SECTIONS
Cross section types

Type A - C

A		One level concrete tunnel with combined road and rail.
B		Two level concrete tunnel with combined road and rail.
C		Concrete tunnels, separate road and rail tunnel.

IMMERSED TUNNEL
SELECTION OF CROSS SECTIONS
Cross section types

Type D - F

D		Steel/concrete sandwich tunnel. Japanese type
E		E2 Composite steel/concrete tunnels American type
F		Single shell composite steel/concrete tunnel.

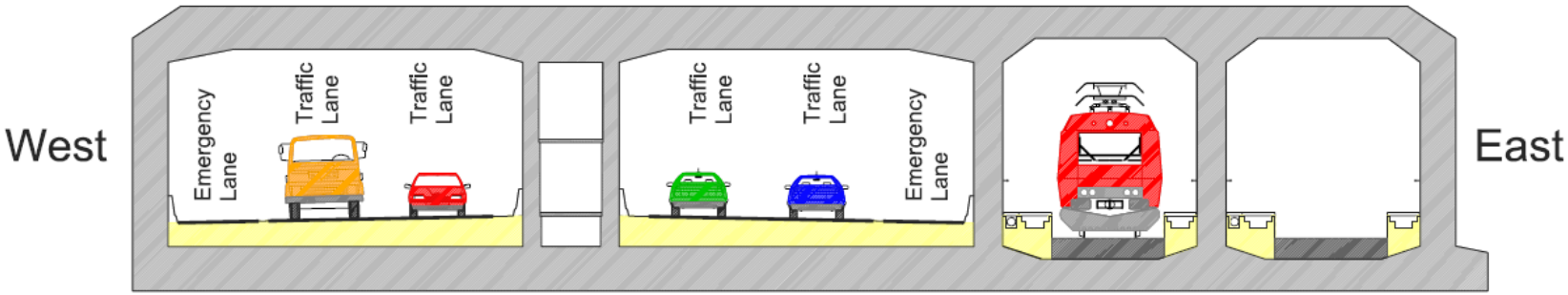
IMMERSED TUNNEL CROSS SECTION

Construction

- Element production method
- Transport, immersion and foundation
- Construction cost
- Construction time

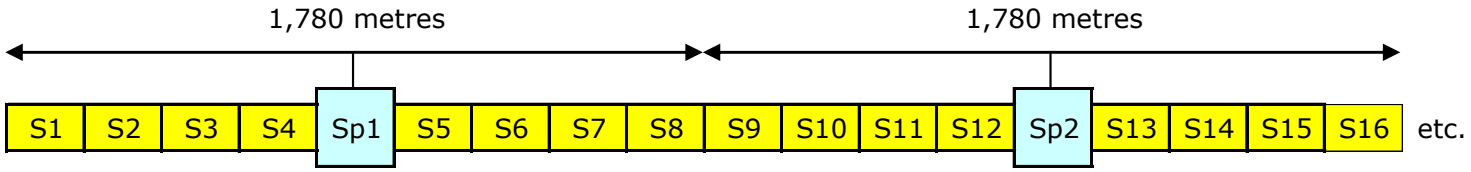
Other aspects

- Ventilation
- Mechanical / electrical installations
- Fire safety and emergency escape
- Railway safety



The idea of introducing special elements

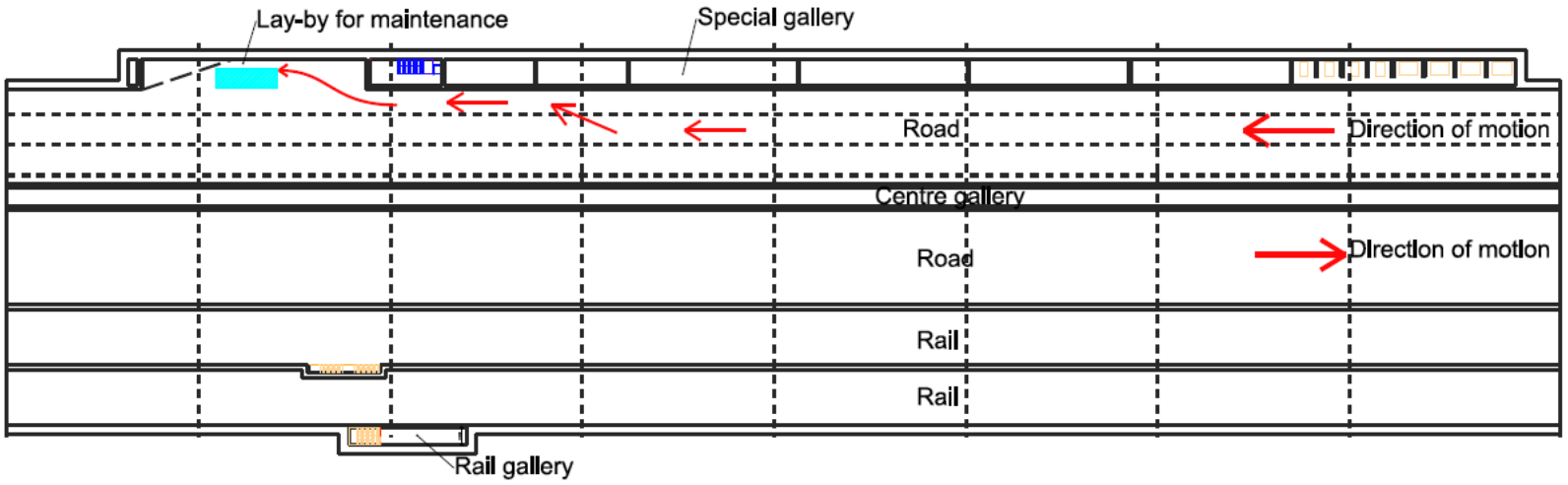
- Need for transformers and other equipment in the tunnel
- Standard elements do not have sufficient space.
- Special elements to cluster mechanical and electrical equipment

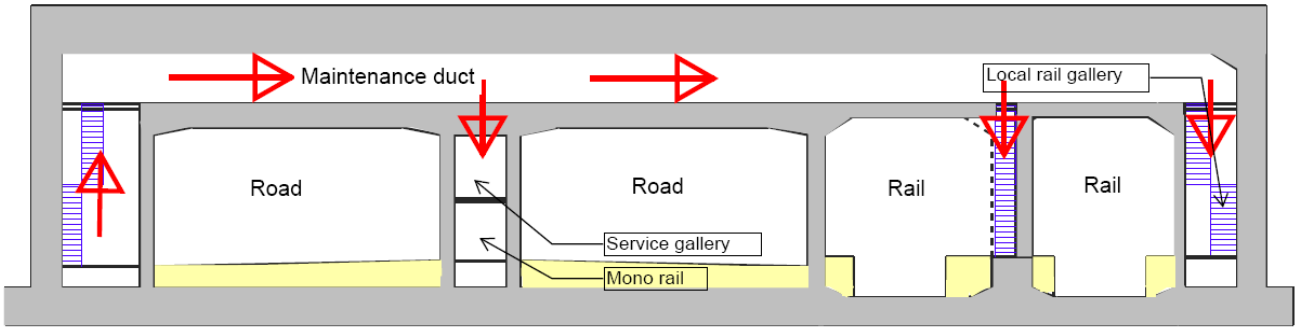


- Maintenance staff better working conditions and higher safety
- Installations and system divided into units
- Concentrate extra space in the tunnel at special elements

IMMERSED TUNNEL
CROSS SECTION DEVELOPMENT

Installations and maintenance access

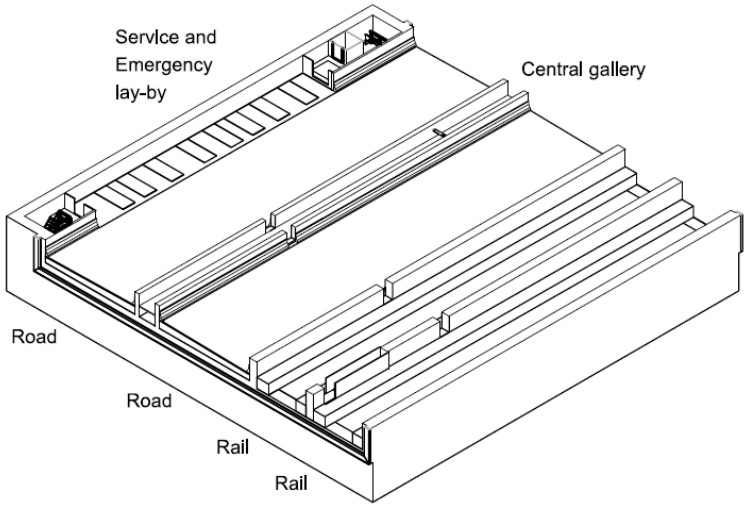


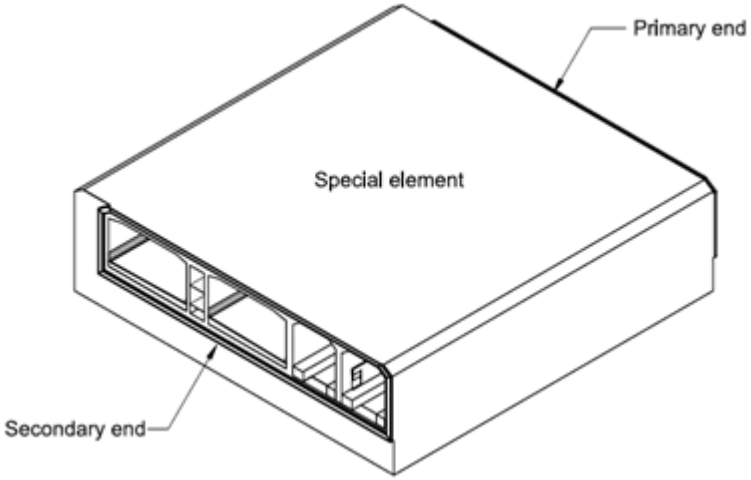


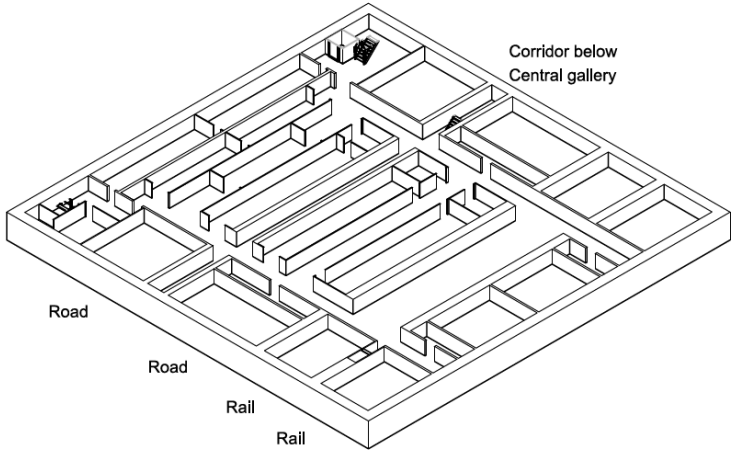
RAMBØLL
ARUP
TEC

IMMERSED TUNNEL
SPECIAL ELEMENT

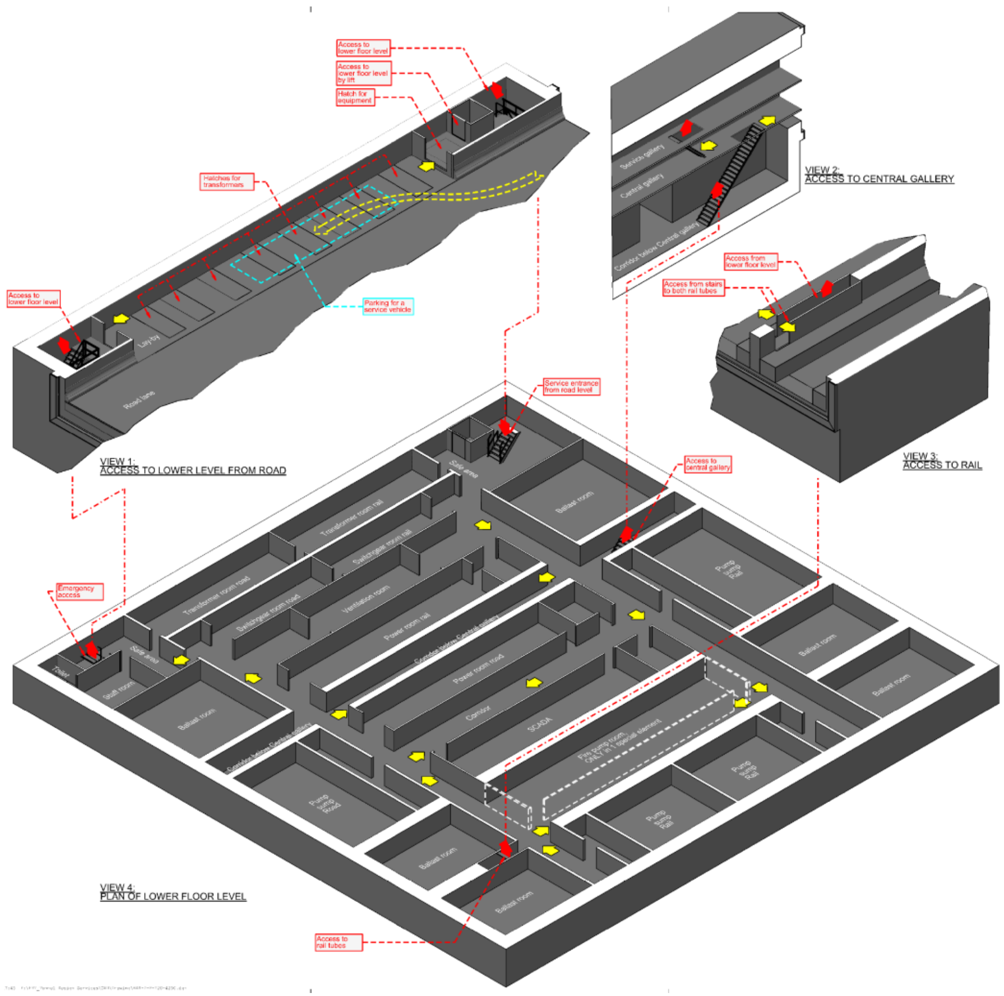
- 10 special elements, length 46 m, width 45 m and height 13.14 m
- All changes of vertical alignment are made at special elements

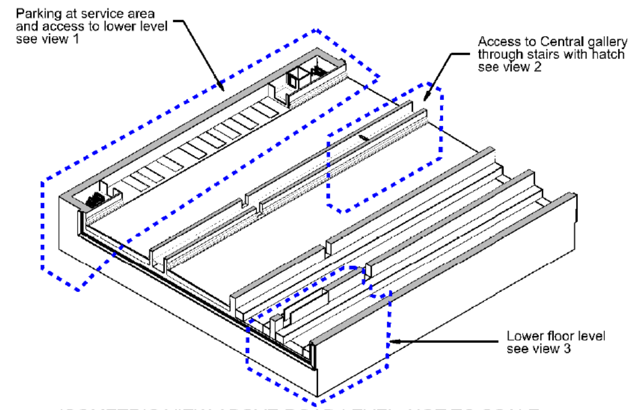




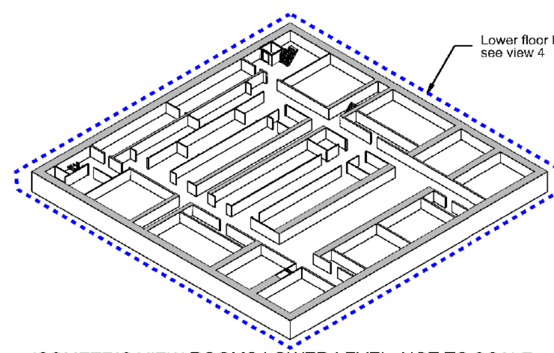


IMMERSED TUNNEL
SPECIAL ELEMENT



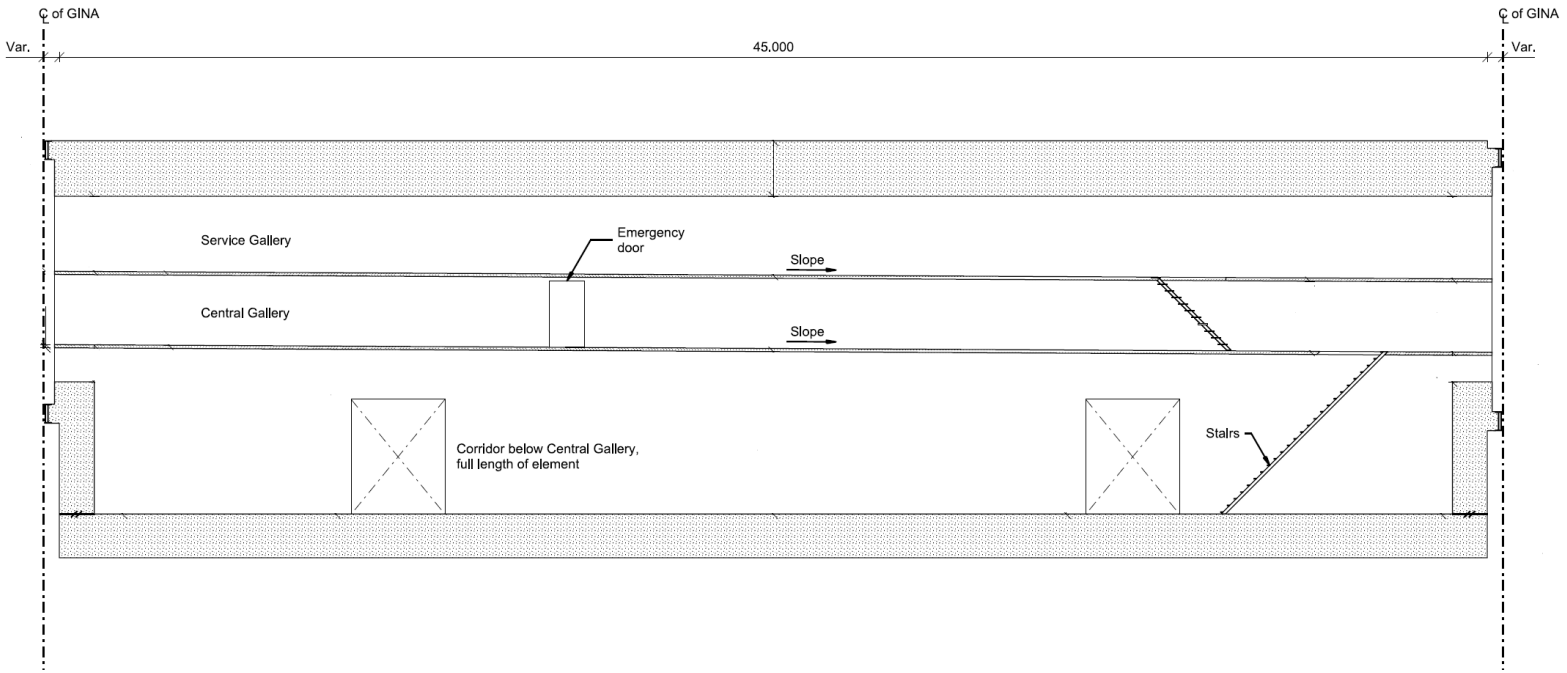


ISOMETRIC VIEW ABOVE ROAD LEVEL, NOT TO SCALE



ISOMETRIC VIEW ROOMS LOWER LEVEL, NOT TO SCALE

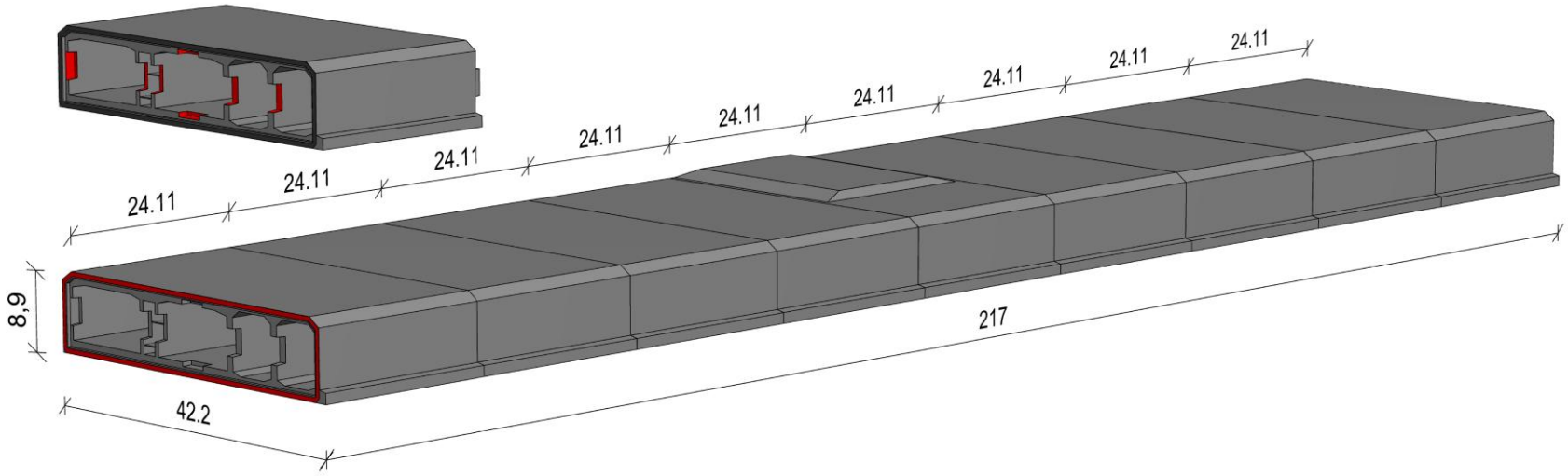
IMMERSED TUNNEL
SPECIAL ELEMENT



RAMBØLL
ARUP
TEC

STANDARD TUNNEL ELEMENTS

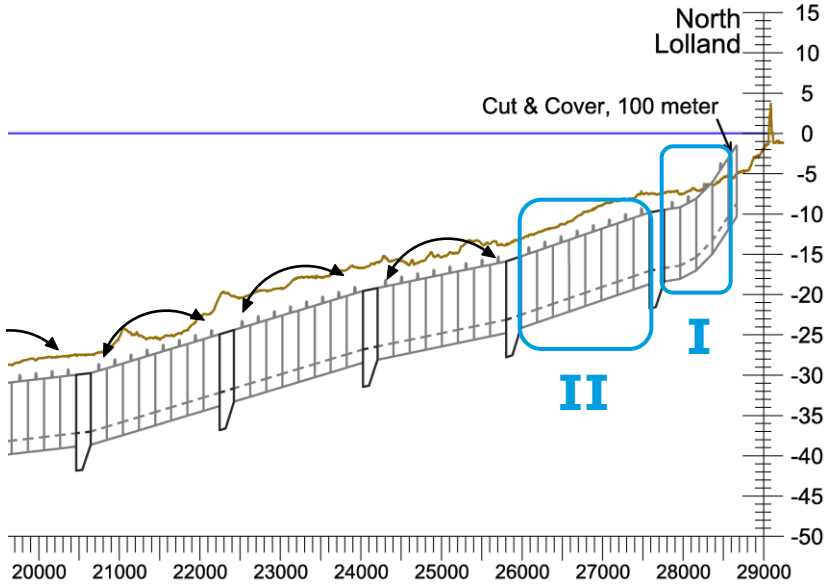
- 79 Standard elements divided into 9 segments of 24.11 m, total length 217 m
- Niche at centre of the element for ventilation or traffic information signs
- Same layout for all standard element e.g. Box-outs, cast-in items, cable ducts, etc.



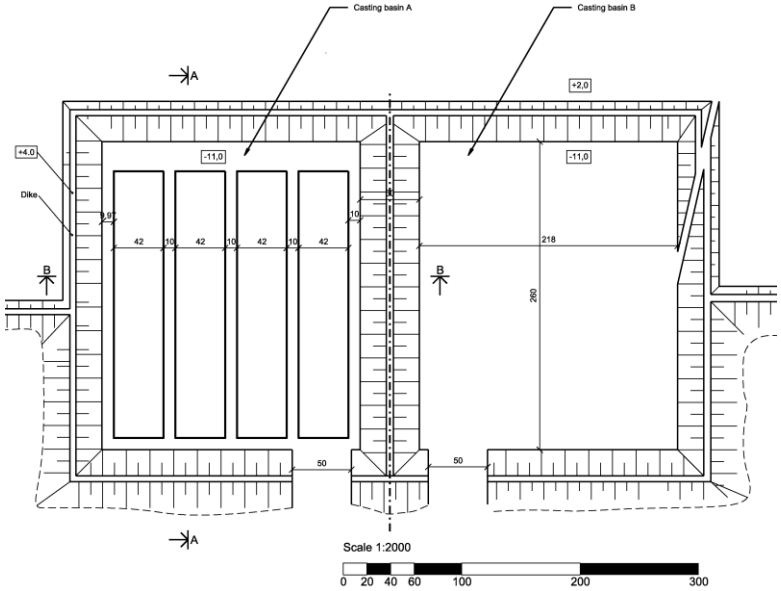
STANDARD ELEMENT

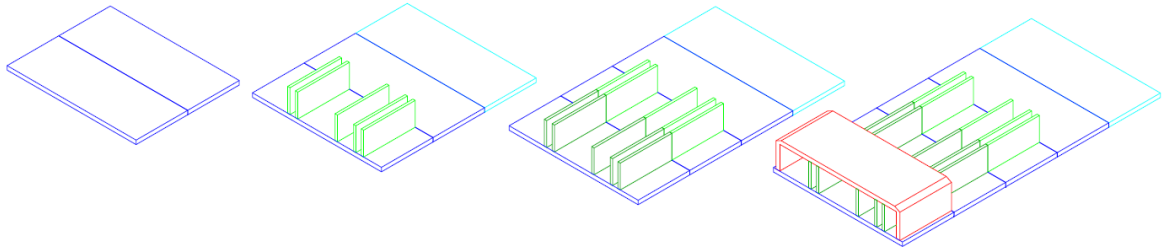
- Section I – Standard elements with angled end frames must be immersed in correct order.
- Section II – Standard elements with perpendicular end frames and variation in amount of reinforcement – elements are not interchangeable.

- All remaining standard elements have perpendicular end frames and in between two special elements same amount of reinforcement and are therefore interchangeable



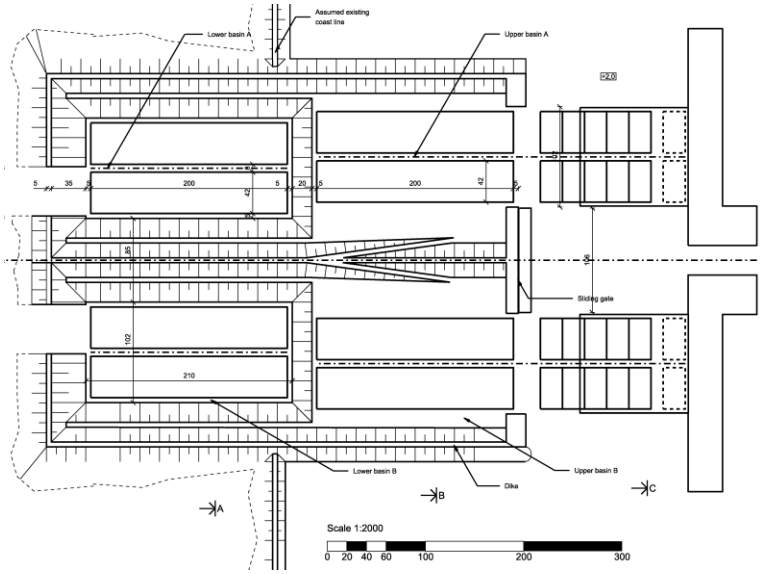
IMMERSED TUNNEL
PRODUCTION PLANNING
Production methods

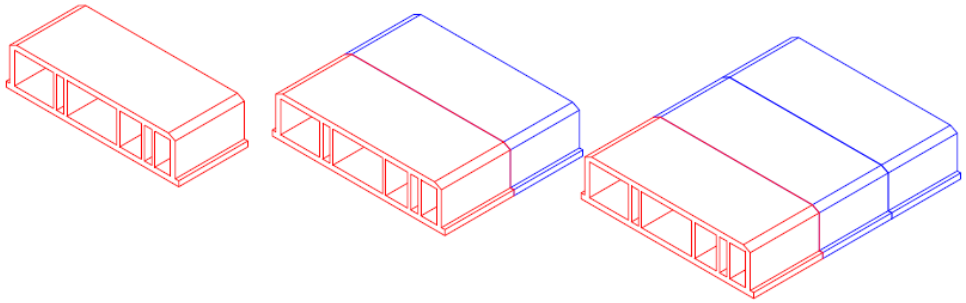




IMMERSED TUNNEL PRODUCTION PLANNING

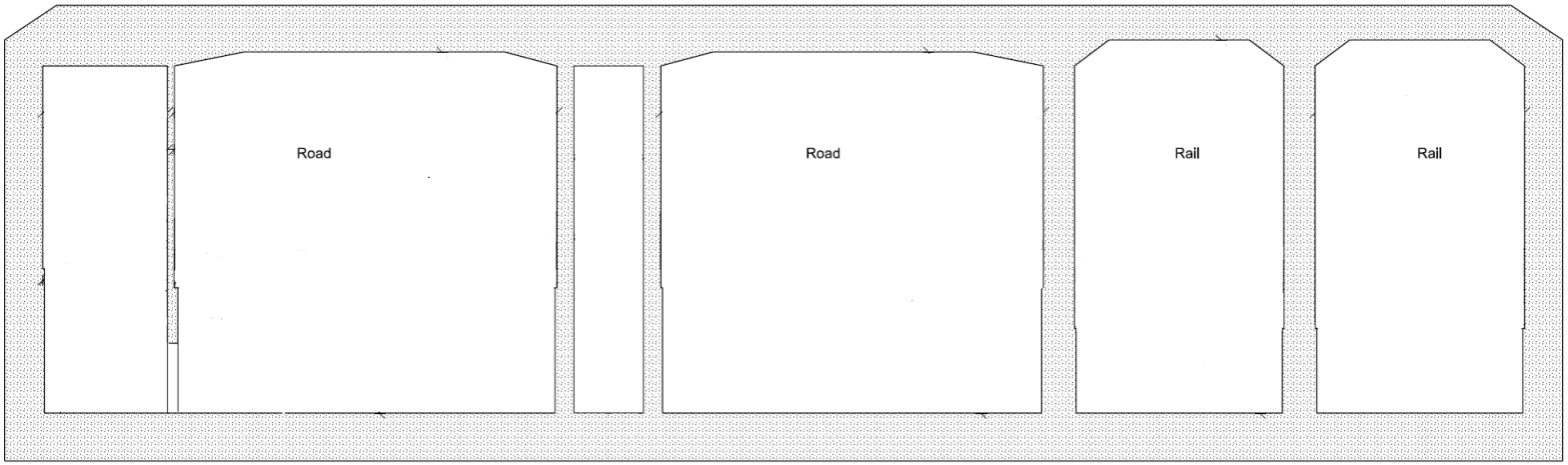
Production methods



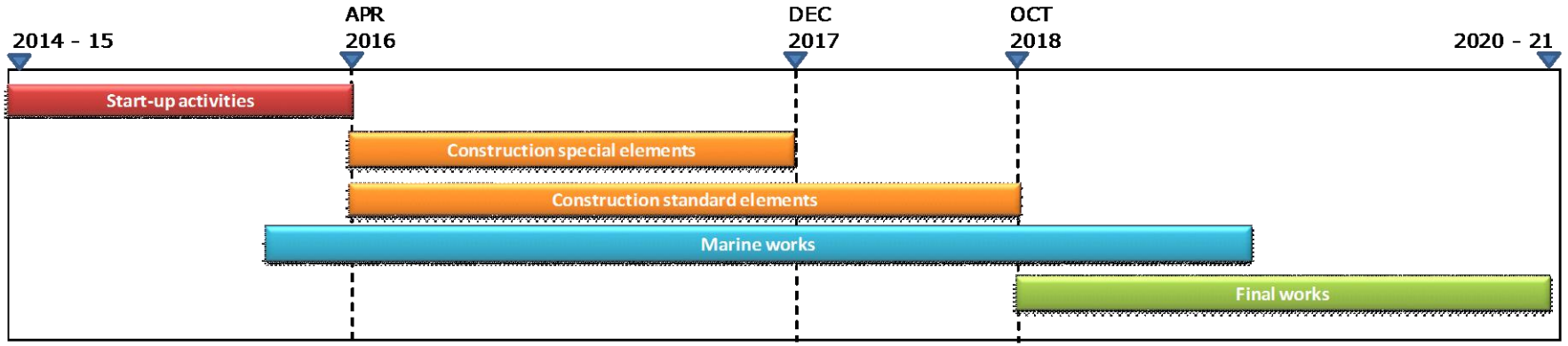


CONSTRUCTION PHASES

SPECIAL ELEMENT CONSTRUCTION



TIME SCHEDULE



Construction of 10 special elements ≈ 21 months

Construction of 79 standard elements ≈ 31 months

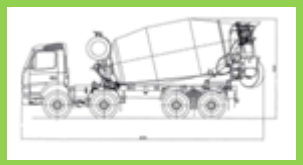
QUANTITIES FOR STANDARD ELEMENTS

Required amount of materials per week

Concrete	24,000 m³
Reinforcement	3,200 tons
Water	4,400 m³
Cement	8,000 tons
Sand	16,800 tons
Gravel	28,800 tons

(1 day = 24 hours)

Delivery of concrete



16 trucks every hour

Or

Delivery of materials

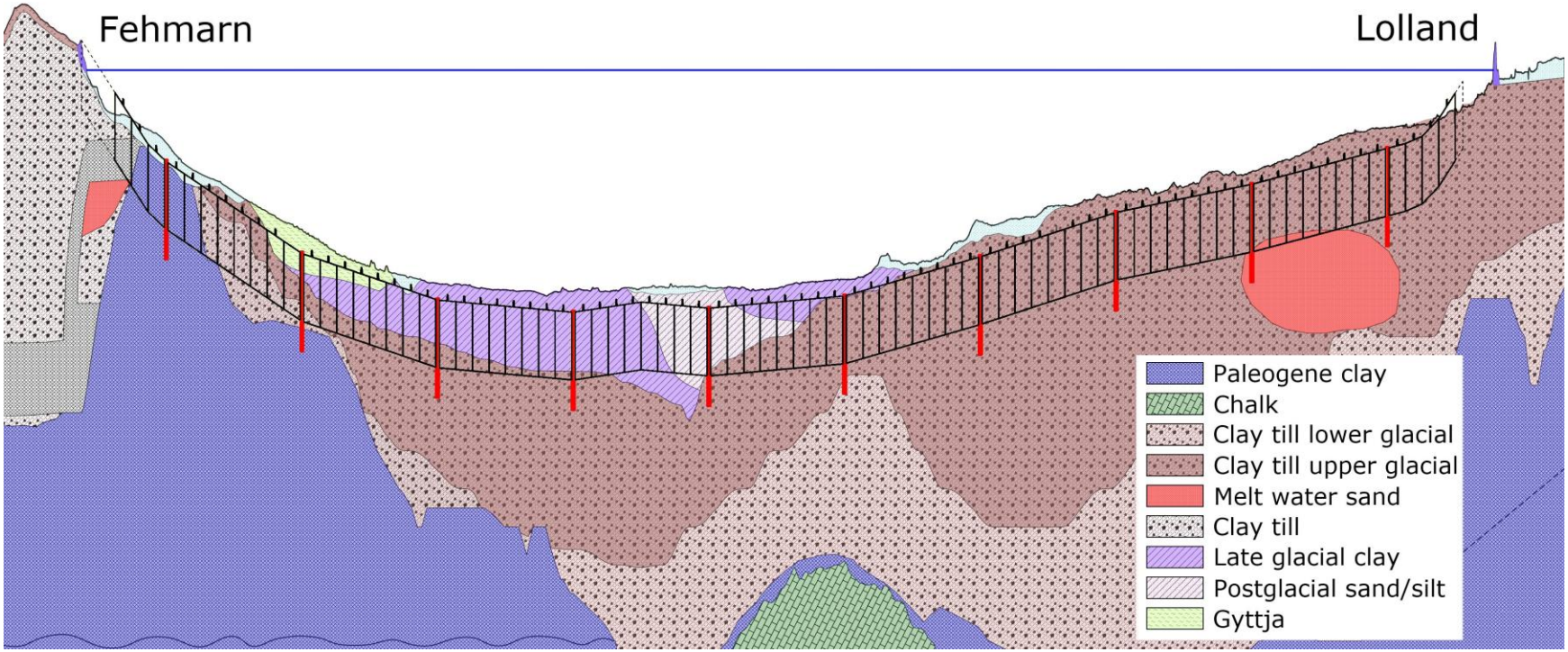
1 coaster every day

WEIGHT OF ONE STANDARD ELEMENT

During transport 766 x  ≈ 76,600 tons

Final position 835 x  ≈ 83,500 tons

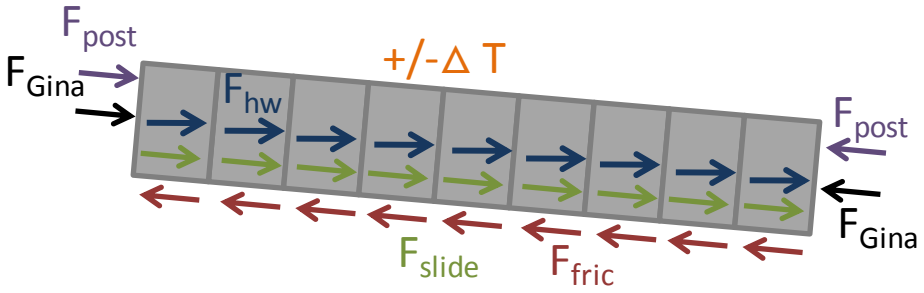
TUNNEL FOUNDATION



- Foundation pressure ≈ 2.2 kN/m²
- Axial force in tunnel elements ≈ 3,600 – 12,800 tons

LONGITUDINAL MOVEMENT

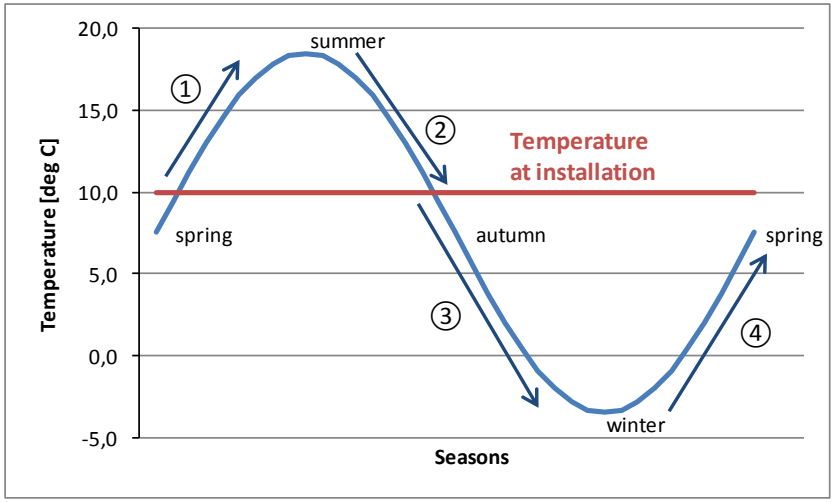
Movement due to yearly variation in temperature

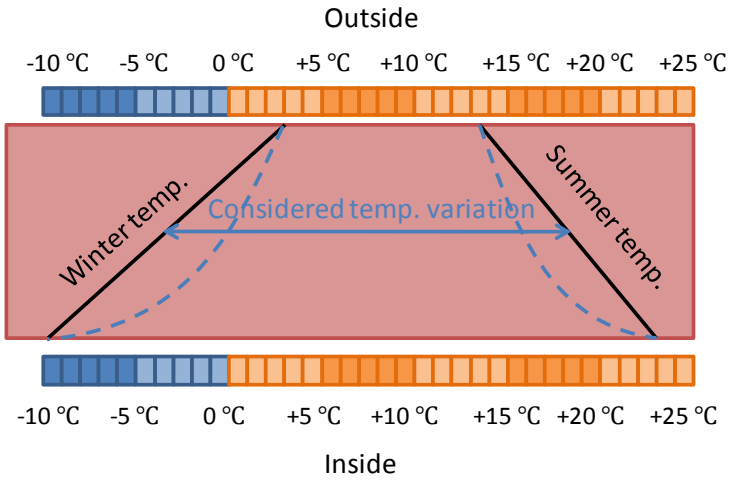


- Temperature variation
- Friction
- Horizontal water pressure
- Gravity force
- Post tensioning
- Gina gasket force
- Creep and shrinkage

LONGITUDINAL MOVEMENT

Temperature variation

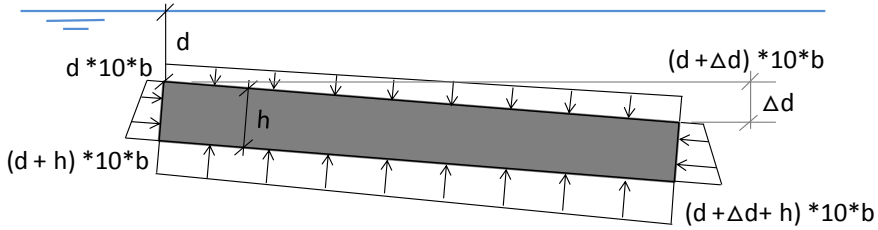


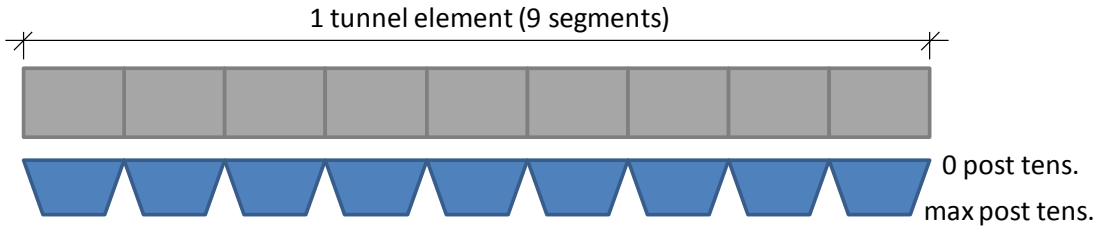


$$\Delta L = \alpha * \Delta T * L + \frac{\Delta N * L}{A * E}$$

LONGITUDINAL MOVEMENT

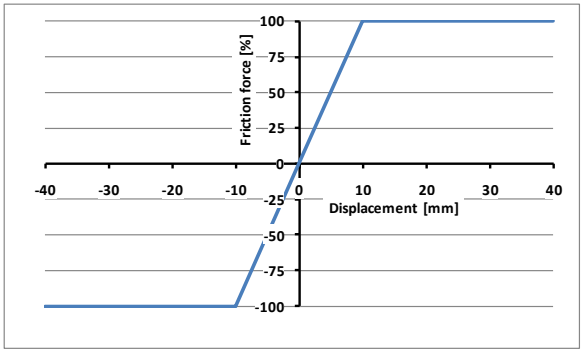
Variation in water depth and release of post tensioning





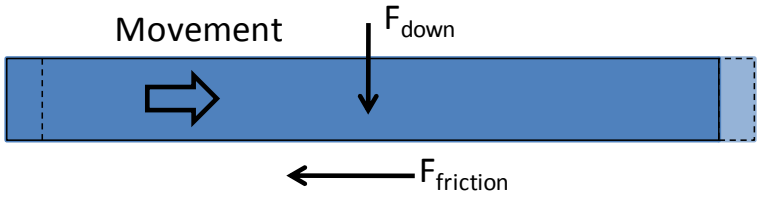
LONGITUDINAL MOVEMENT

Friction and gravity force



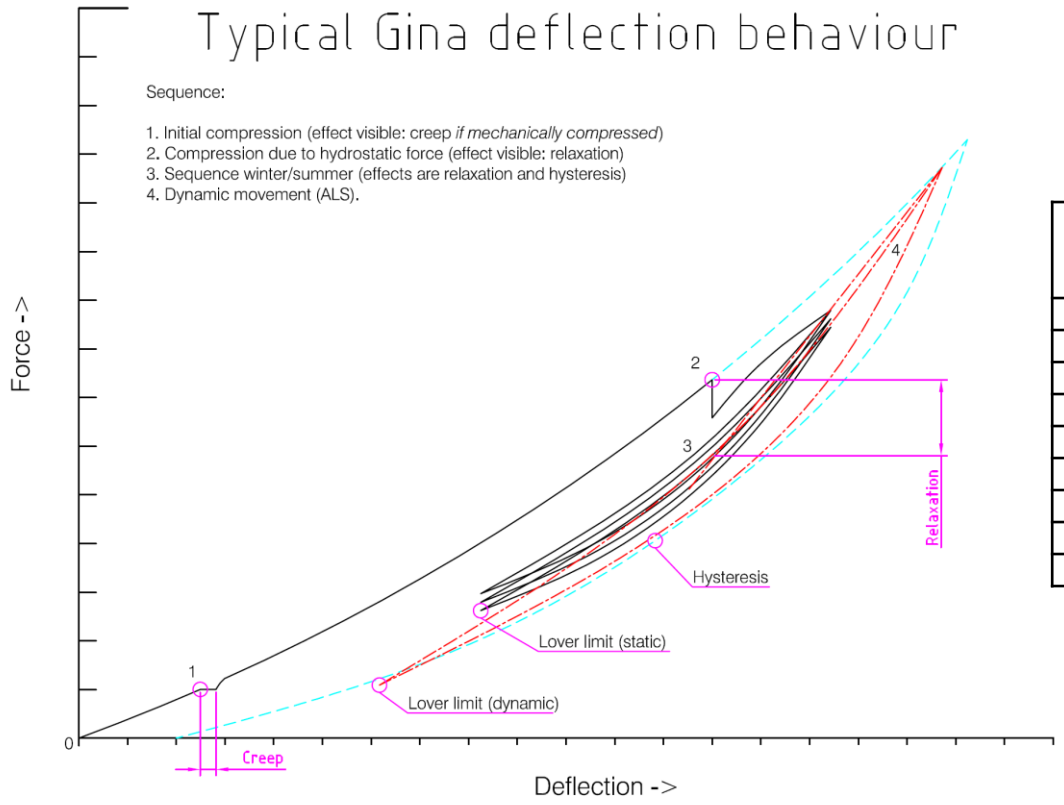
Friction coefficient: μ	φ = 30°	φ = 40°
m = 0.8	**μ = 0.46**	μ = 0.67
m = 1.0	μ = 0.58	**μ =0.84**

$$\mu = m * tan\varphi$$



LONGITUDINAL MOVEMENT

GINA force / deflection



Time after immersion [min]	Time [year]	Relaxation [%]	% of original force
1	0	0	100
10	0	6	94
100	0	12	88
1,000	0	18	82
10,000	0.02	24	76
100,000	0.19	30	70
1,000,000	1.9	36	64
10,000,000	19	42	58
100,000,000	190	48	52

LONGITUDINAL MOVEMENT

Creep and shrinkage

Creep due post tension

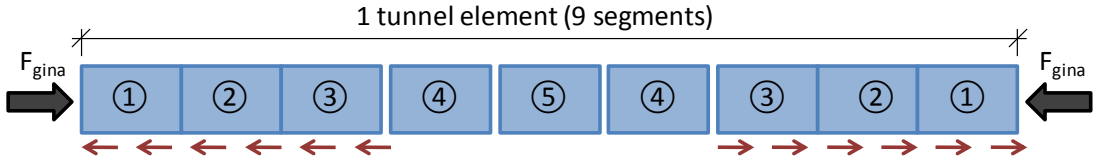
$$\epsilon_{cc}(\infty, t_0) = \varphi(\infty, t_0) * \frac{\sigma_c}{E_c}$$ (~ 2 mm)

Shrinkage

Concrete C40/50
Before immersion 80-90% humidity ~ 0.1 – 0.17 ‰
After immersion 80-100% humidity ~ 0.05 ‰

(Total ~ 1.2 mm)

LONGITUDINAL MOVEMENT



Immersion joint (GINA) ±2 cm

Segment joint maximum 0.5 cm


THANK YOU FOR YOUR
ATTENTION