



Frederikssund Fjord High Bridge, Ouvrage et Art au Danemark.

Xavier Debruche et Rob Demeersman
CERES - Ulg - 6 Mai 2019



Frederikssund Fjord High Bridge



A. Introduction

B. Présentation du projet

C. Pont principal

1. Design Management et planning
2. Conception
3. Géotechnique
4. Construction des fondations et piles
5. Construction du tablier





Les principaux intervenants



- Design High-Bridge (Czech)



- Design Road & other civil works (Denmark)

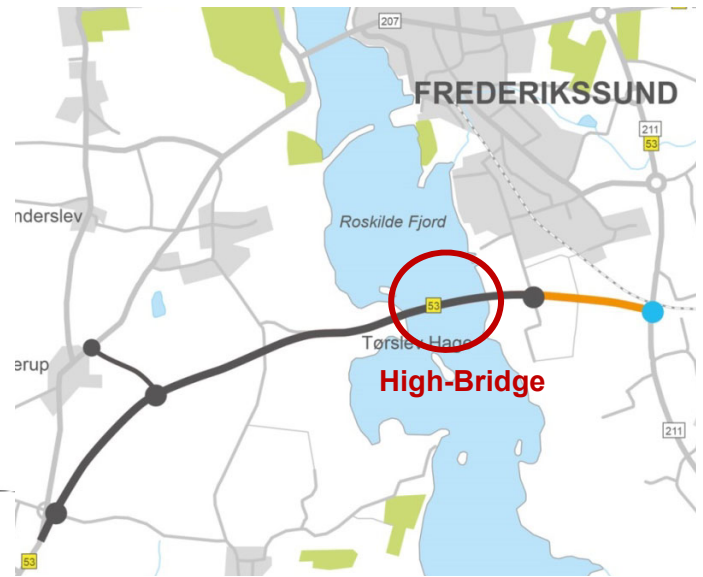
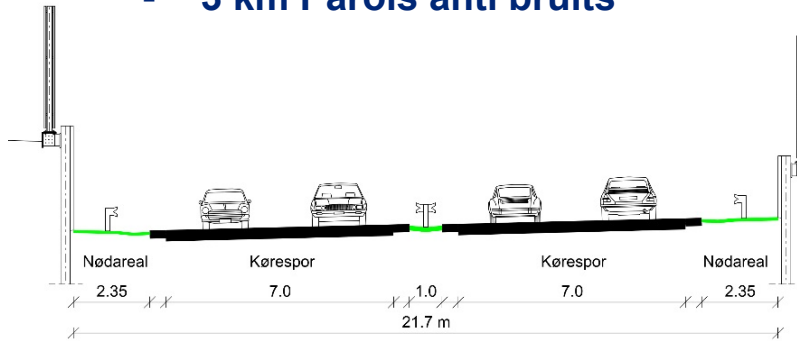


- Design Third Party Checker (Spain)



- Main Subcontractor (Denmark)

- 8.2 km d'autoroute
- 500.000 m³ de terres à déplacer
- 11 Structures secondaires
- 1 km Structure de soutènement
- 3 km Parois anti bruits

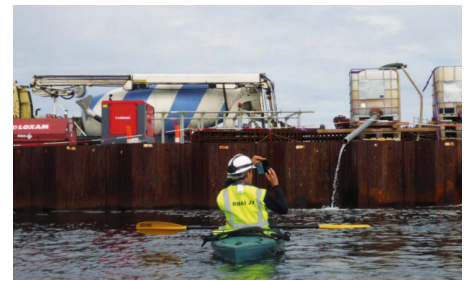


Environnement

➤ Natura 2000



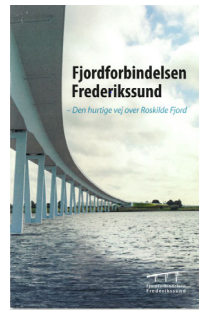
➤ Control strict de la sédimentation et de la qualité des eaux usées



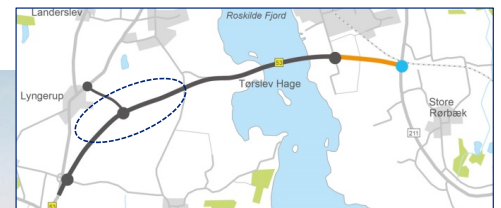
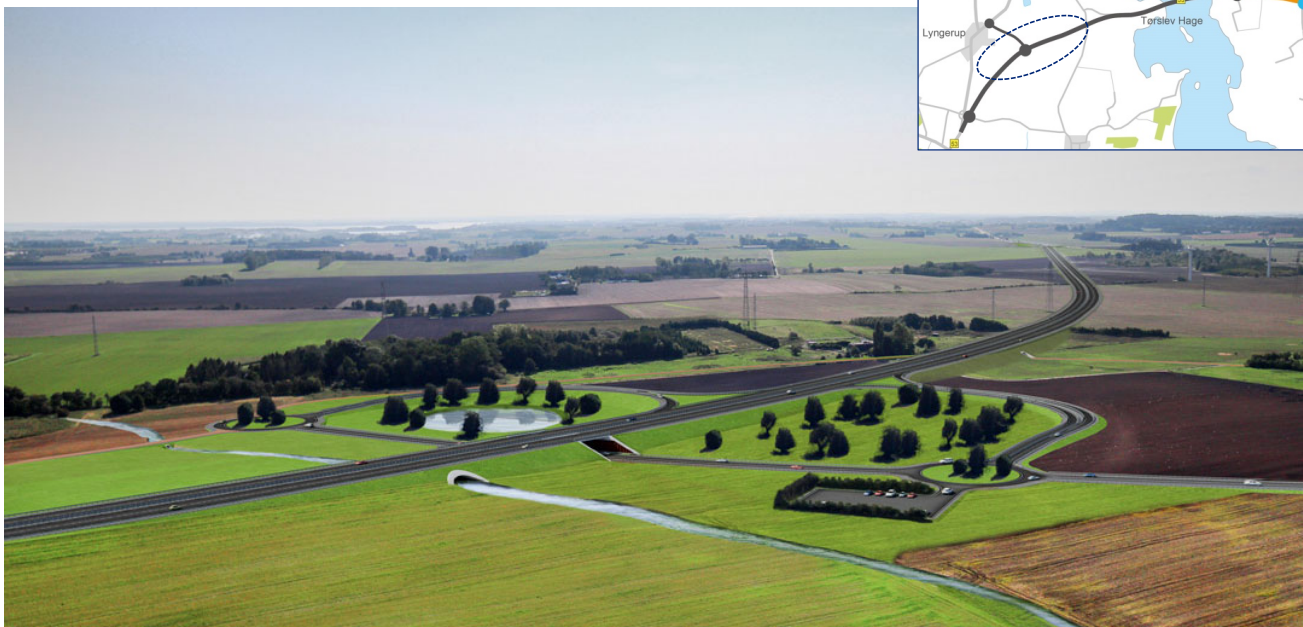
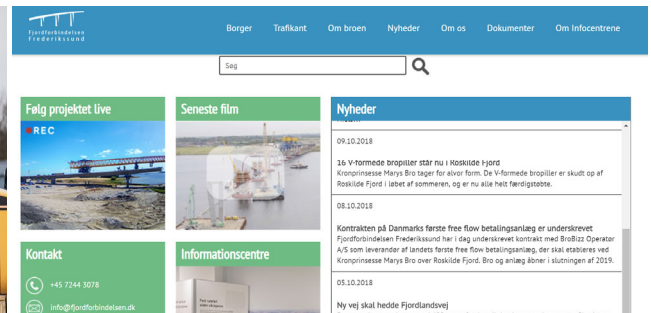
➤ Control strict des vibrations et du bruit (max. 70dB de jour, 40dB de nuit)

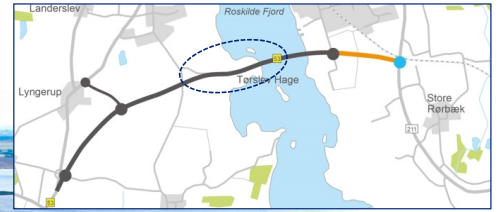
Stakeholders Management

Centres d'information



Website, réunions, visites de chantier,...





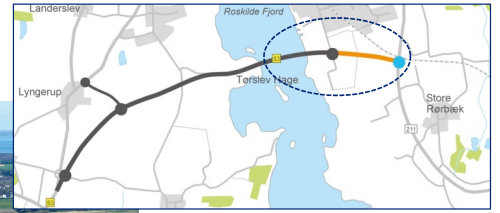
Avancement Avril 2019



Avancement Avril 2019



Avancement Avril 2019



Frederikssund Fjord High Bridge

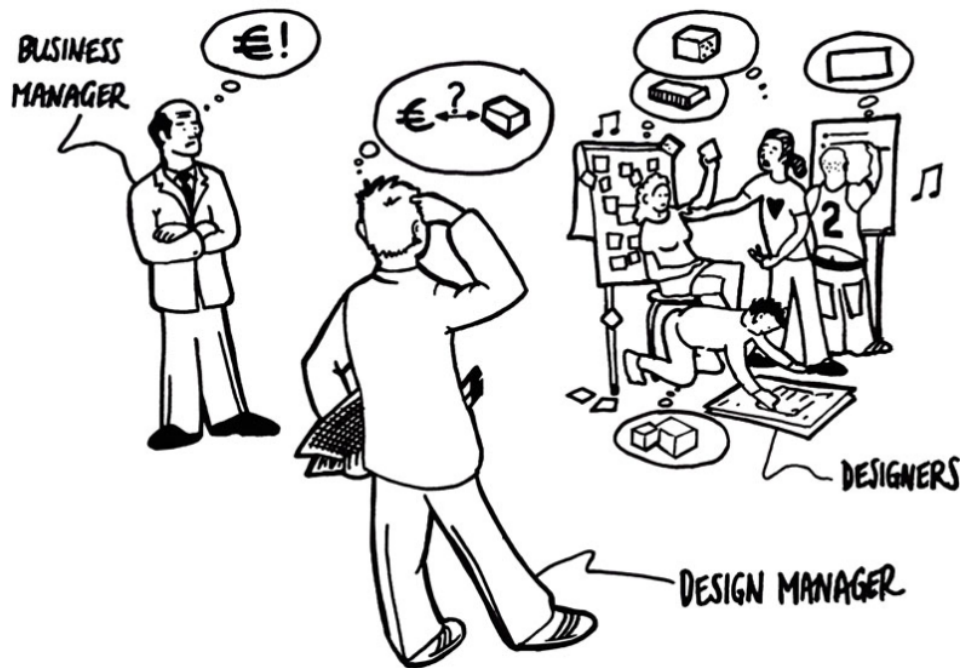
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Client requirements

Health and safety

Constructability

Quality and Risk

Time

source Wikipedia

Cooperation

Prisoner Dilemma

		Henry	
		Not Guilty	Guilty
Dave	Not Guilty	3 Months	Free 20 Years
	Guilty	Free 20 Years	5 Years

Optimal pay-off

Prisoner's Dilemma – Payoff Matrix

ROW →	COL ↓	Co-operate	Defect
		Co-operate	Defect
Co-operate		(3, 3)	(0, 5)
Defect		(5, 0)	(1, 1)

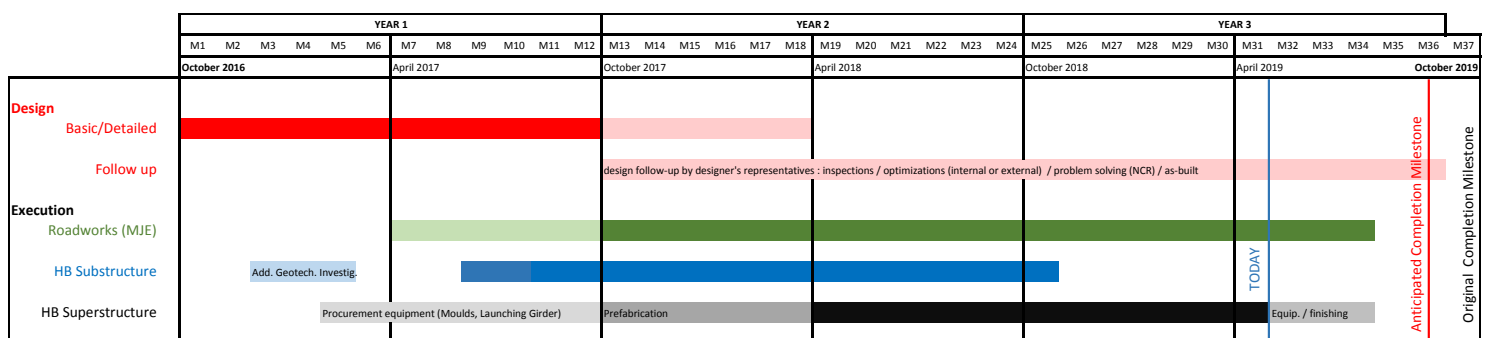
Preference to Move Based on Higher Payoff

Nash Equilibrium

Information



Planning and design coordination



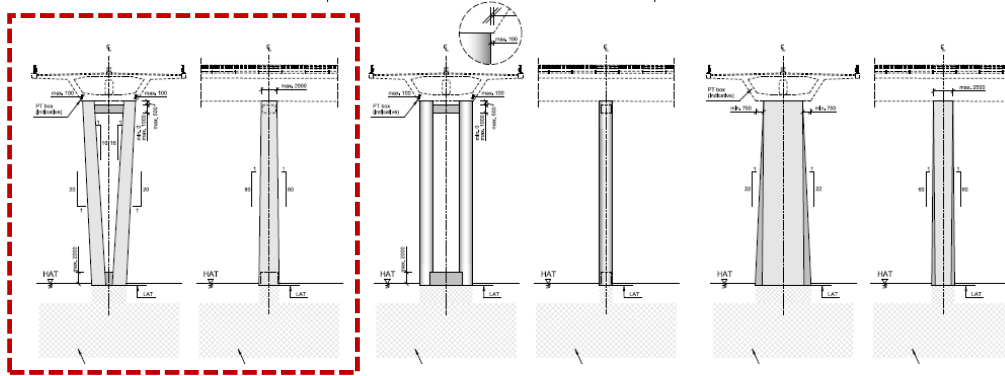
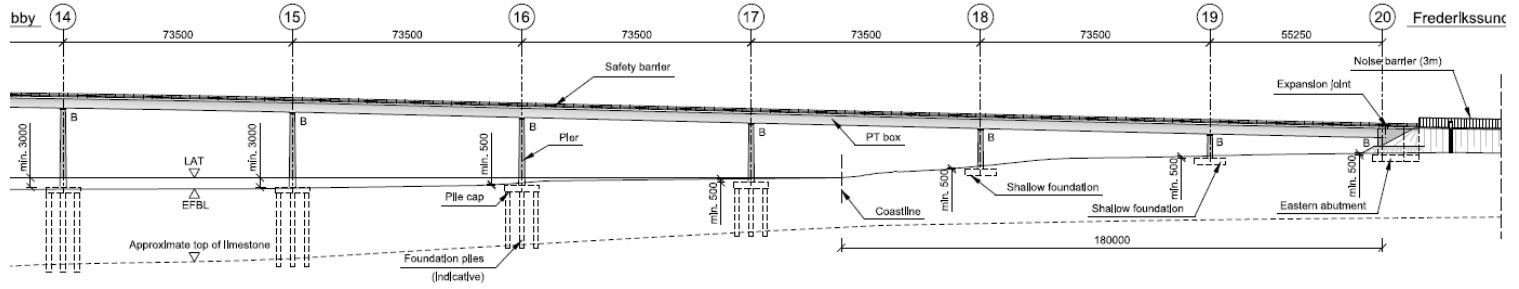
1st challenge : quick and efficient start

- Mobilization and Communication (DK / BE / SP / IT / CZ)
- Optimization (methods / procurement)
- Internal review (constructability / interphases / QHSE)

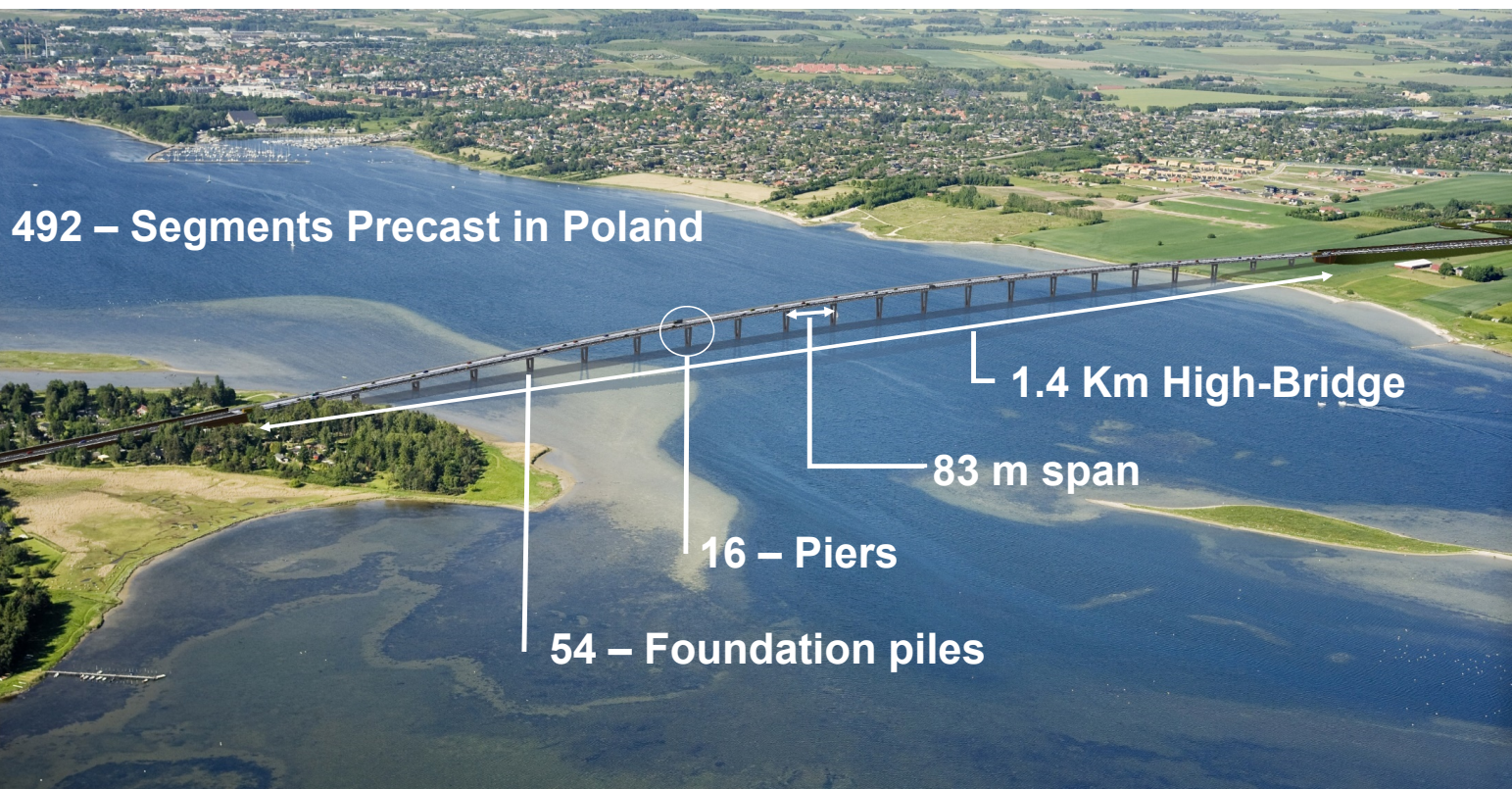
2nd challenge : overlap design and construction → priorities / risks management

- Review and approval by Client
 - Requirements management
 - Basic Design (30%) – Detailed Design (70% and 100%)
 - Deliverables list and design packages
 - Weekly design meetings

High Bridge – Tender Design Optimizations



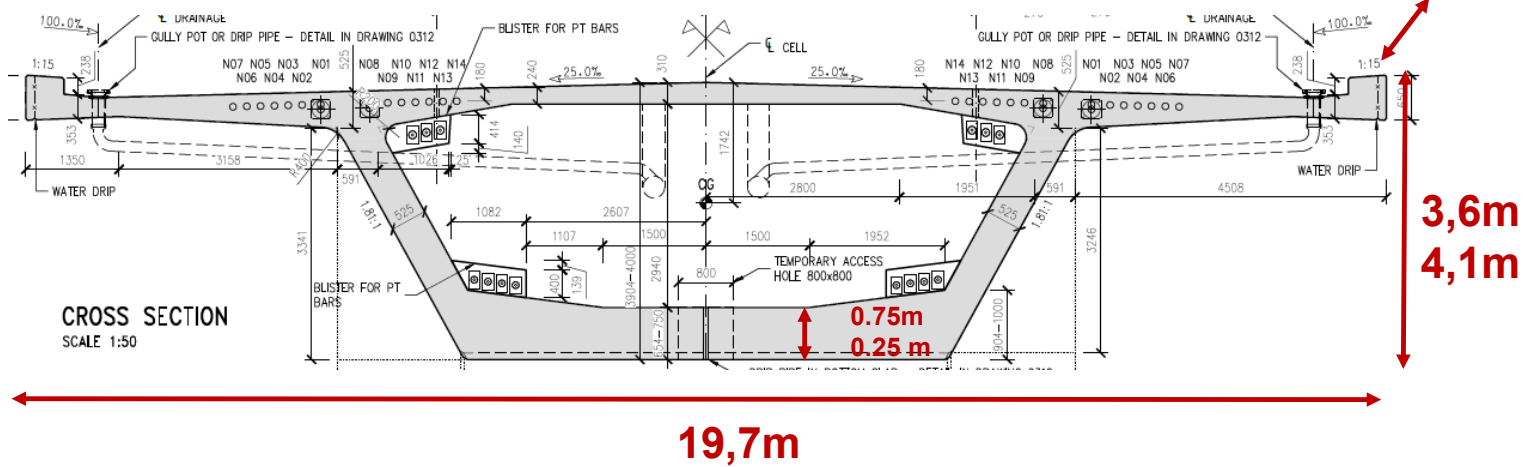
- Pile caps with **4 piles** instead of 12
- Typical Span enlarged to **83m**
- **4 semi-integral connections**
- **V-shaped piers**
- Segmental Balanced Cantilever Construction Method, with Launching Gantry



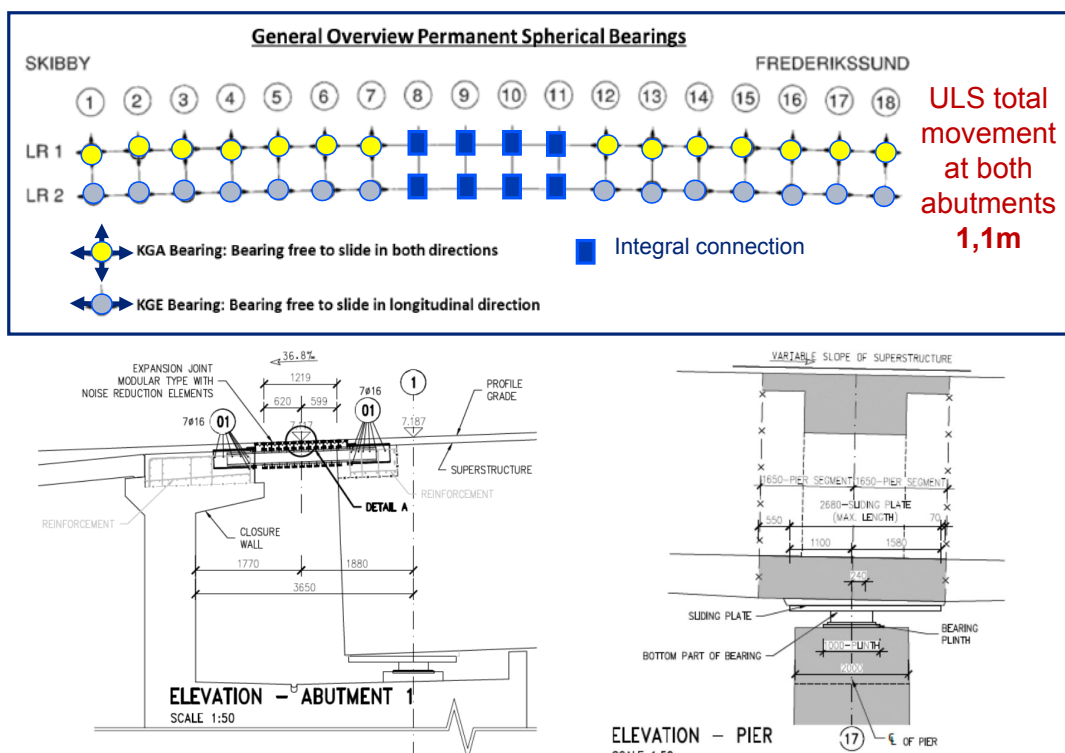
Typical Segments dimensions

90 Ton /110 Ton

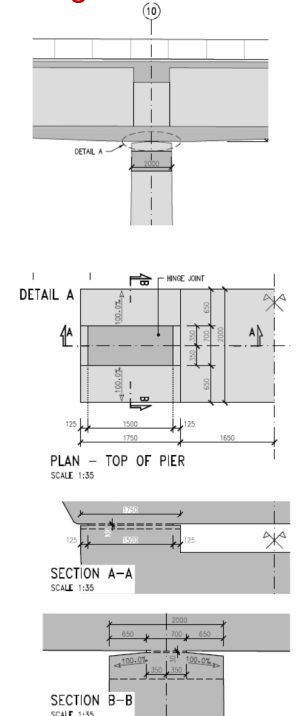
Width – 2,86m



Bearings and expansion joints

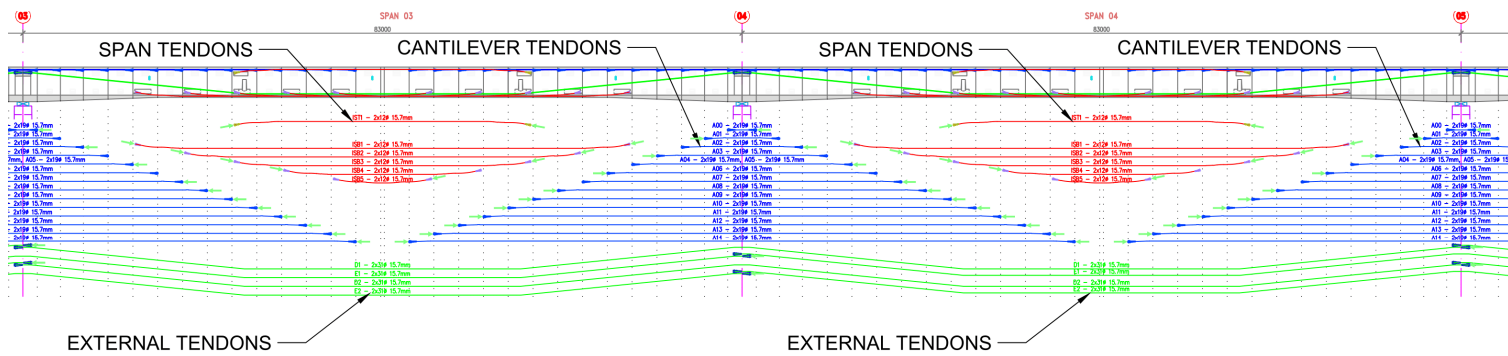


Integral connection

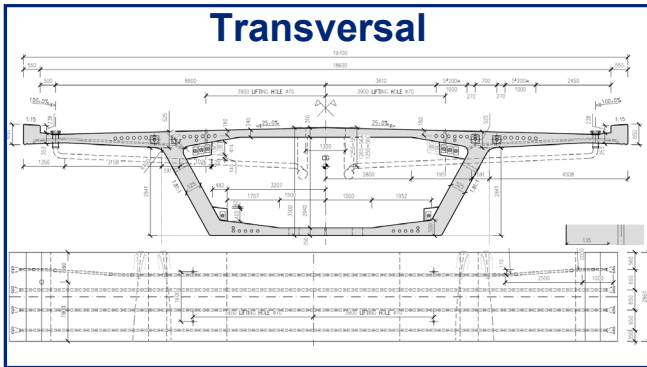


Post-tensioning

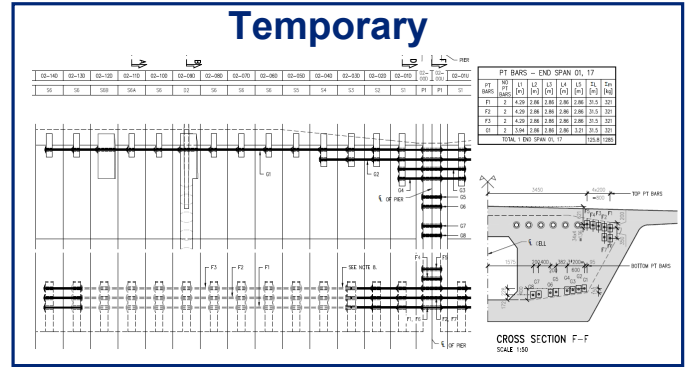
Longitudinal



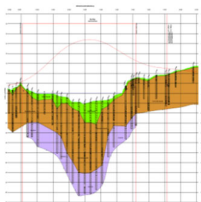
Transversal



Temporary

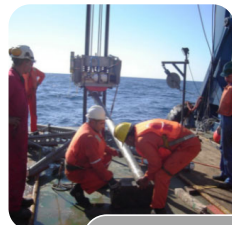


Geotechnical Design – Process



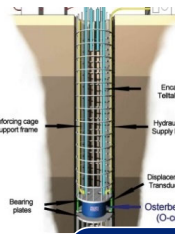
Tender

- Existing G I
- GBR
- GIR



Detail Design development

- Results of AGI
- GIR update
- Design elements fixed



Test Stage

- Test pile results
- GIR Confirmation
- Design adjustment



Construction Follow-up

- Construction Method
- Pile inspection
- Pile Integrity analysis

Geotechnical Design – Soil Investigations

- **Foundation concept**
 - Large diameter bored piles (diameter 1,5 to 2,0 m)
 - Resistance nearly entirely mobilised in limestone (50% shaft + 50% tip)
- **Available information for foundation design**
 - Reference projects in Copenhagen area : Metro, Oresund
 - Geotechnical investigations:

TENDER STAGE

- 15 boreholes
- ≈ 150 m in limestone
- Low recovery $\rightarrow$ Low RQD
- 12 UCS tests & 40 PLT

Limited information in the Limestone



Simplified Approach

ADDITIONAL INVESTIGATION

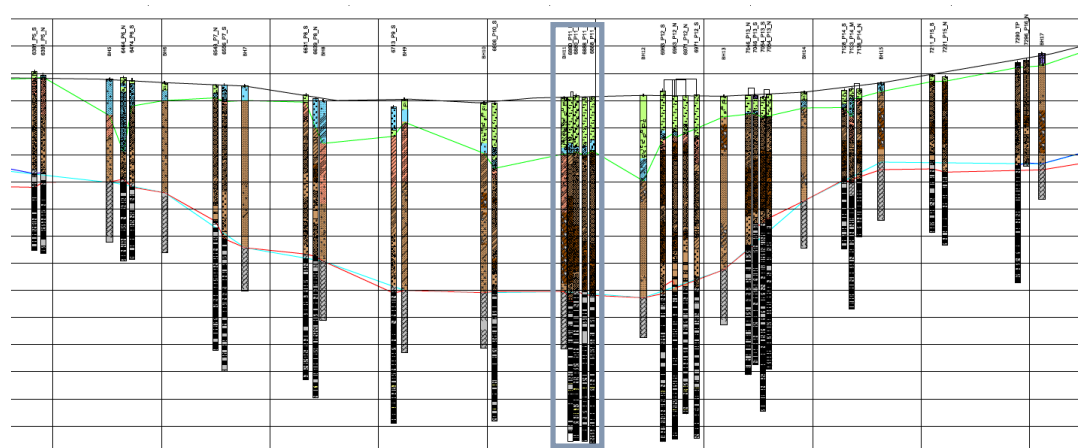
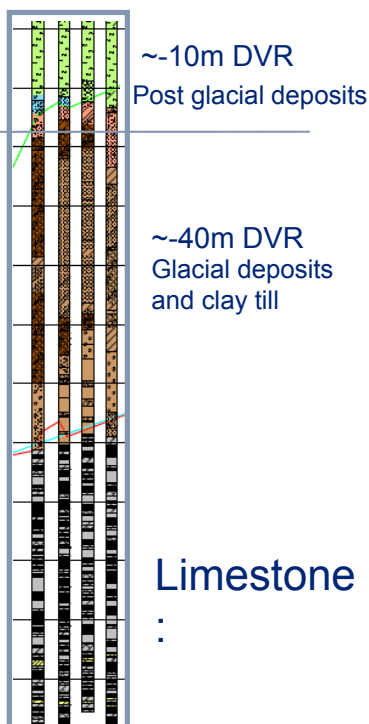
- + 25 boreholes (at pier allocations)
- + ≈ 725 m in limestone
- High recovery $\rightarrow$ Higher RQD
- > 250 UCS tests & >600 PLT

Extensive Investigation of Local Limestone

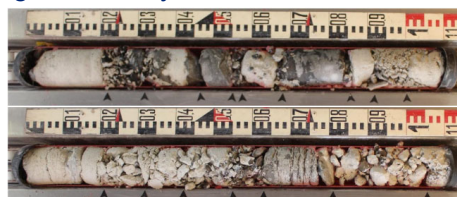


Statistical approach - pier by pier assesment

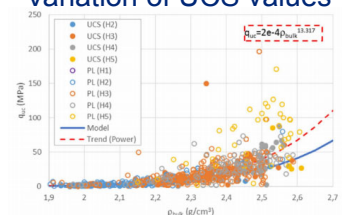
Geotechnical Design - Typical profiles (P12)



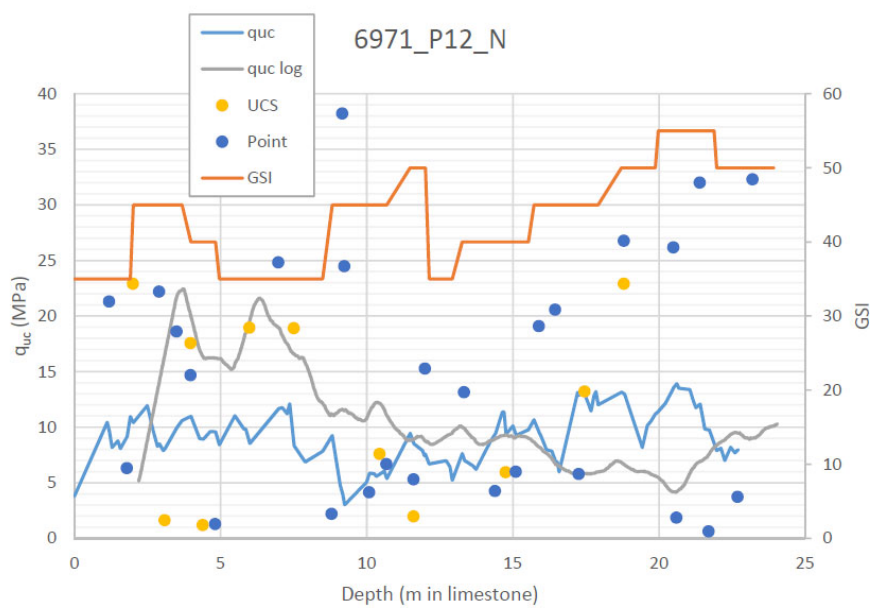
High variability in hardness classes



Variation of UCS values



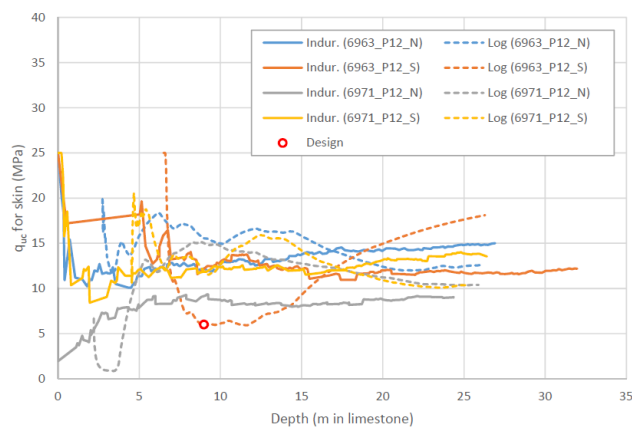
Geotechnical Design – Strength Profile



Geotechnical Design – Strength Profile

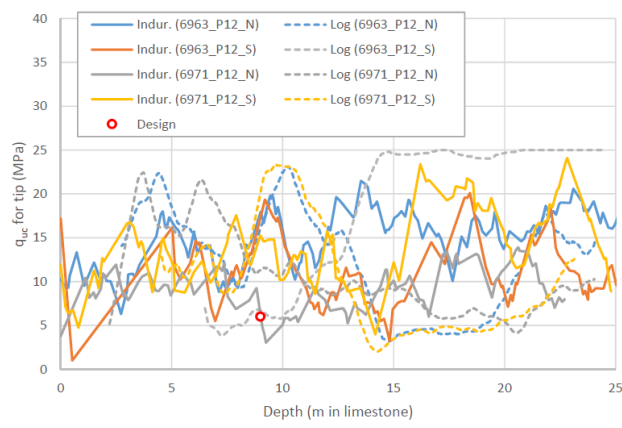
SHAFT

Pier 12

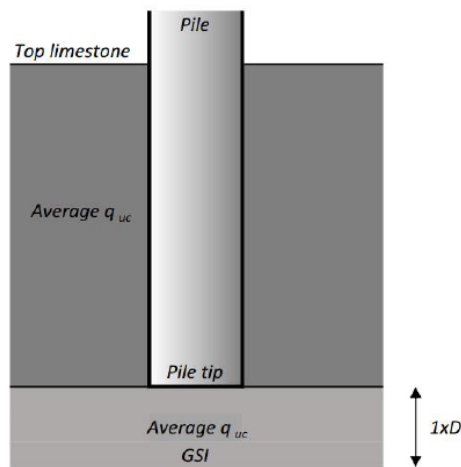


Base

Pier 12



Geotechnical design – resistance



Compressive Resistance:

$$R_c = R_s + R_b$$

Shaft resistance (Zhang):

$$R_{s,ber}/A_{si} = \eta_c \cdot \alpha \cdot q_{uc}^{\beta} \cdot \gamma_m$$

- q_{uc} = strength
- η_c = construction factor

Base resistance (Serrano-Ollala)

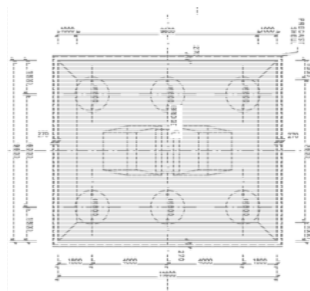
- Hoek-Brown (UCS, GSI)
- 100% pile tip contact

Geotechnical Design – Foundation

TENDER OPTIMIZATION

Onshore : 4 piles D1800mm/pier →

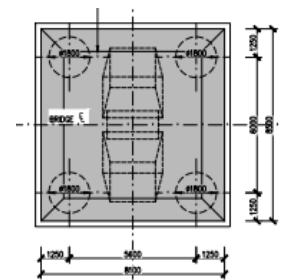
Offshore : 6 piles D1800mm/pier ➔



DETAILED DESIGN

4 piles D1500mm/pier

4 piles D2000mm/pier



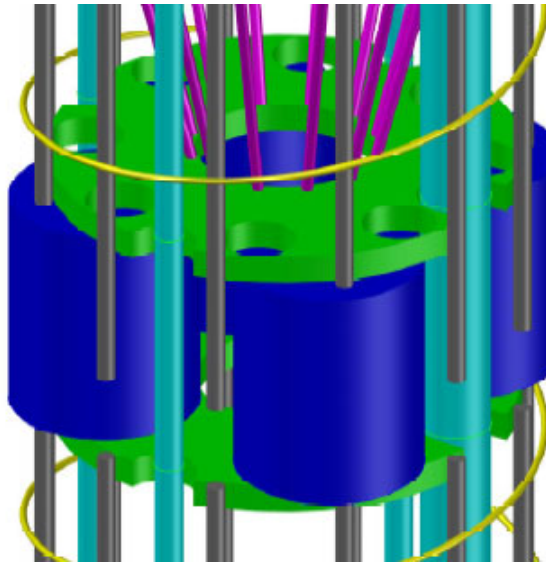
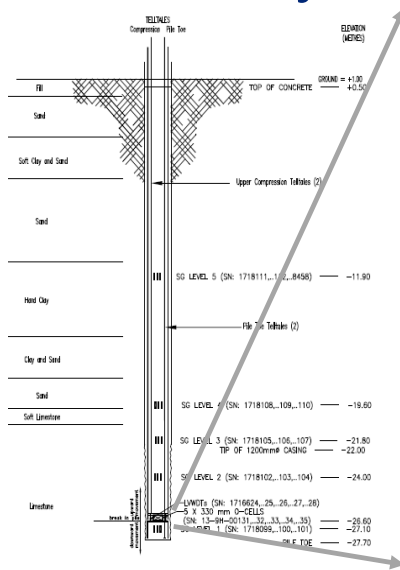
Design Load :

Design values for **2m** diam. piles : **31MN** in ULS

23MN in SLS

Geotechnical resistance : **>70MN** (7000T)

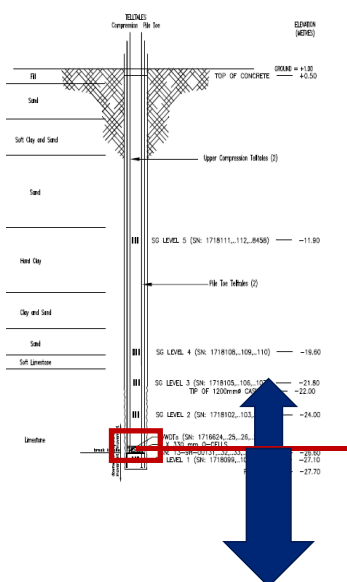
Pile Test by O-cell method



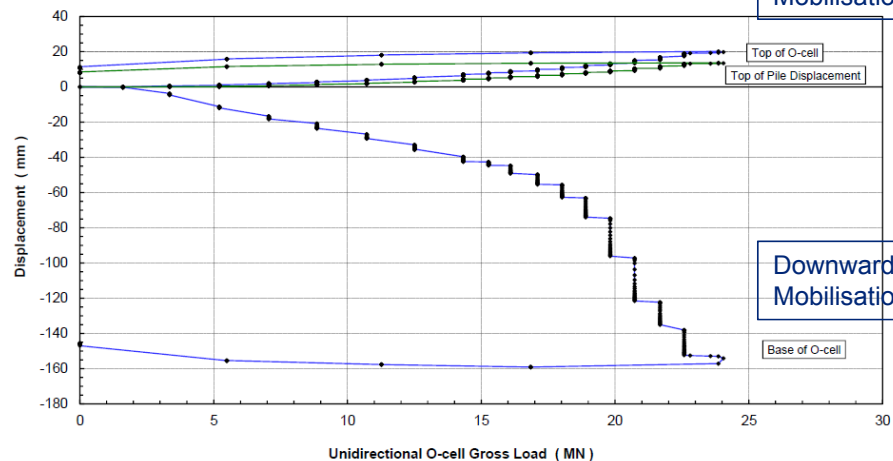
Pile Test Results

Mobilised test load :

- 22MN Upwards
- 22MN downwards



Osterberg Cell Load-Displacement
TP1 (Pier 14) - Fjord Link Frederikssund (Roskilde) Bridge - Denmark



Upward movement :
Mobilisation of shaft

Downward movement :
Mobilisation of tip

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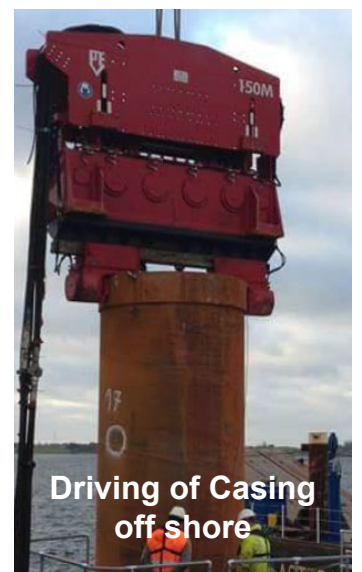
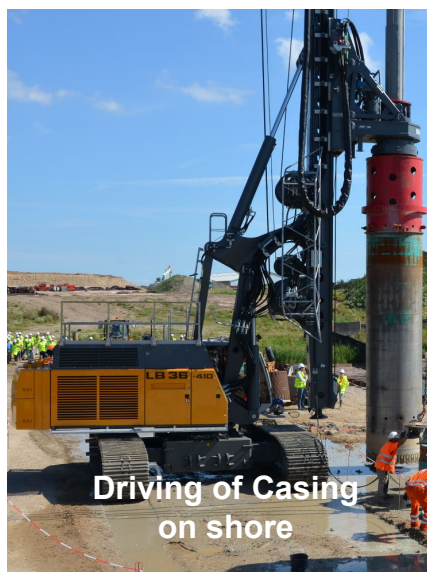
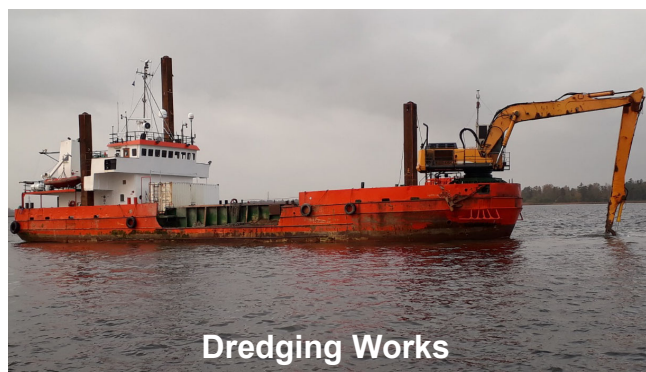
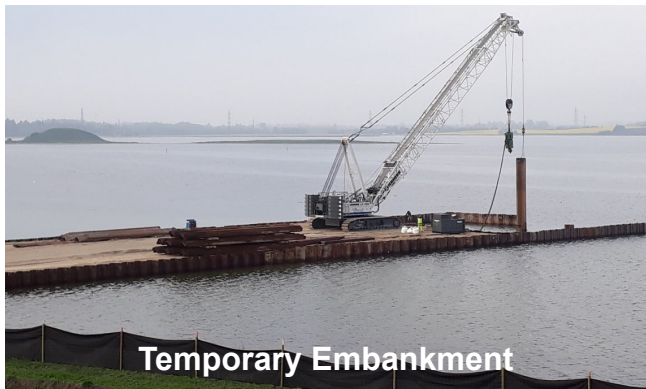
Construction of Piles, Pile Caps and Piers in the Fjord



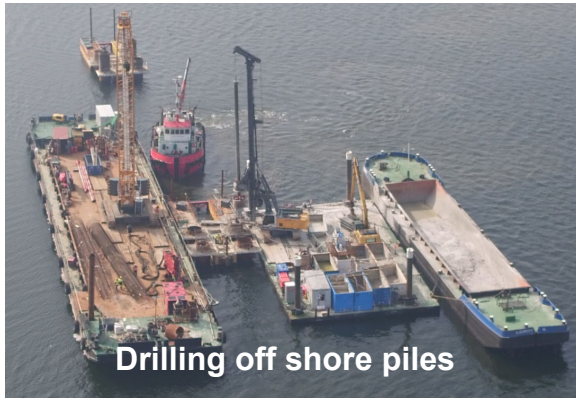
2017 FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC 2018 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC 2019 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT

HIGH
BRIDGE

Fondations



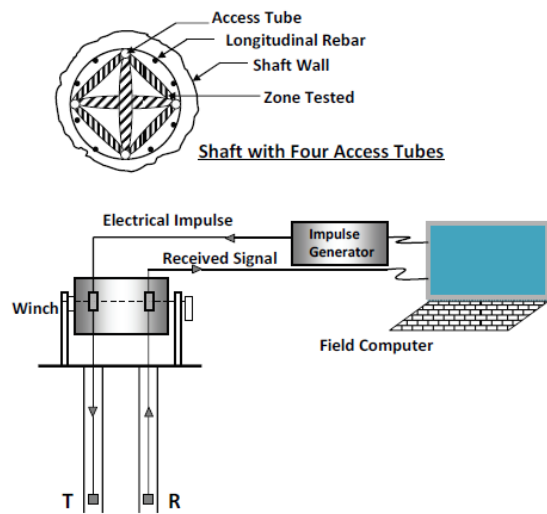
Fondations



Fondations profondes – Offshore



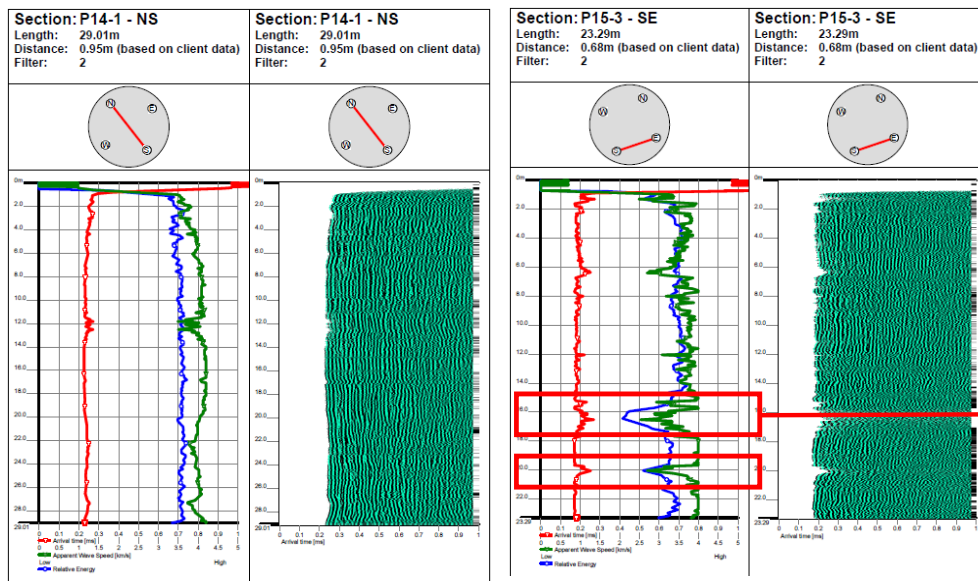
Crosshole Sonic Logging (CSL)



Tubes Included in rebar cage for testing



Crosshole Sonic Logging (CSL)

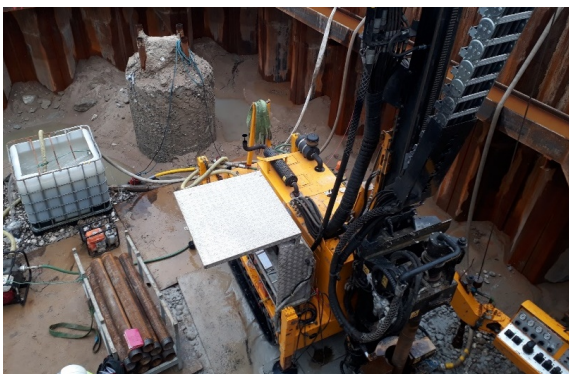


Anomaly in pile if deviation of measured wave speed and measured energy

➔ Further Investigation

Pile Integrity

1. Further Investigation of pile integrity – Pile Coring
2. Pile Cores show concrete segregation at multiple levels



Gravel nests(> 70cm)



Mortar Inclusions (> 40cm)



Caissons préfabriqués



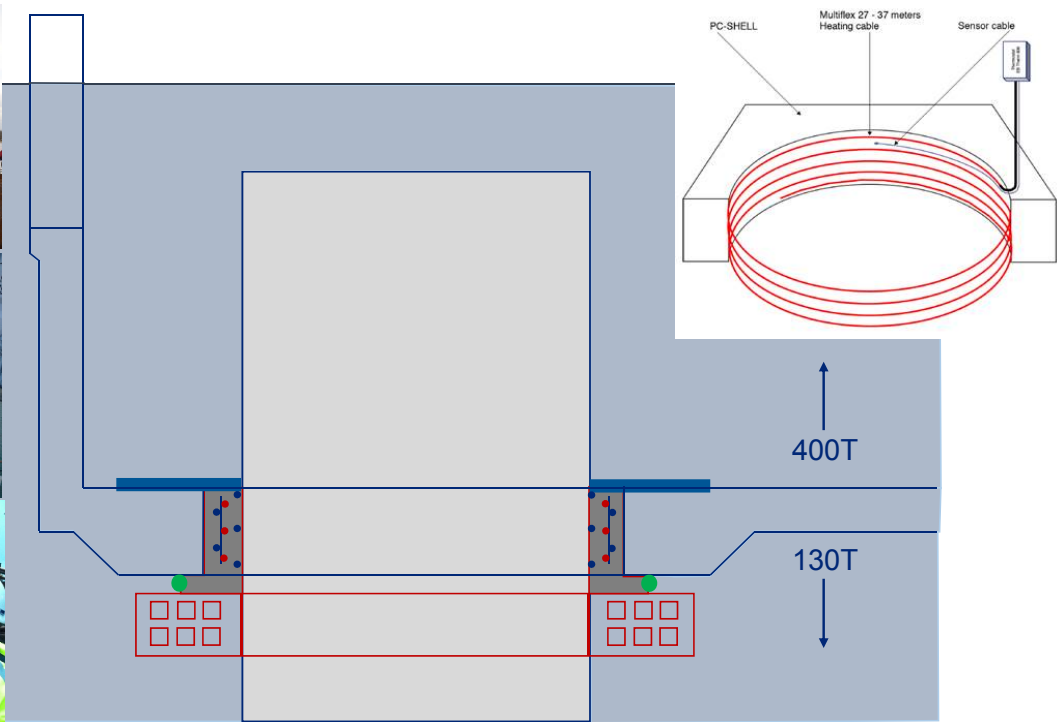
Caissons préfabriqués



Caissons préfabriqués

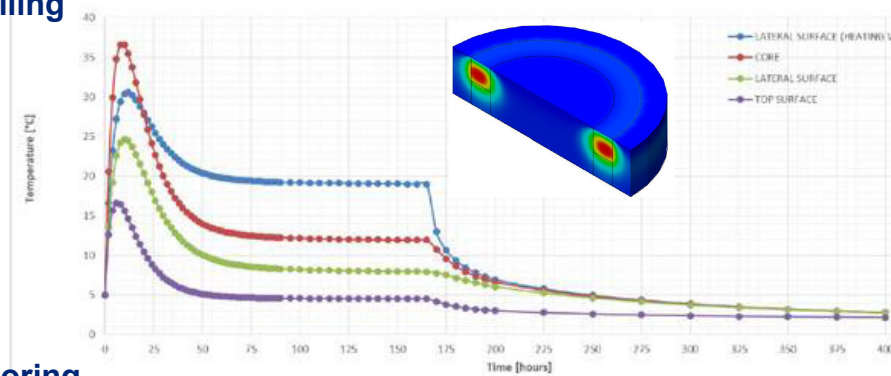


Caissons préfabriqués – connection aux pieux

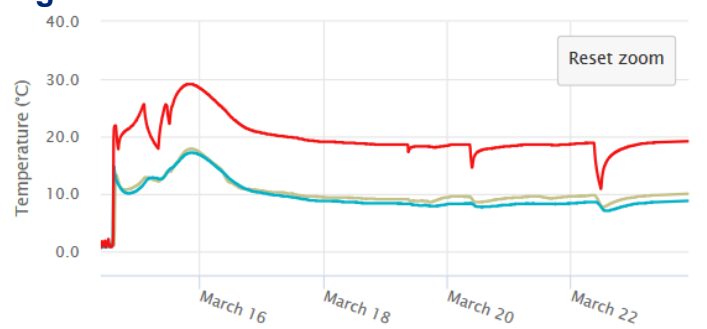


Caissons préfabriqués – connection aux pieux

1) Modelling



2) Monitoring



Caissons préfabriqués - installation



Recépage des pieux



Tête de pieux



COFFERDAM DEWATERING



START OF ON SHORE PILE CAP

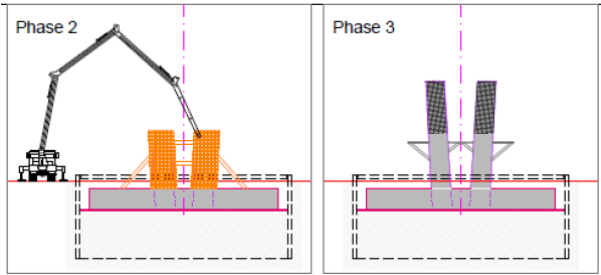
COFFERDAM	AS BUILT
Cofferdam Fabrication	17 days/PS fabrication
Cofferdam Installation	3 days/PS installation



PILE CAP REINFORCEMENT OFF SHORE

Piles

PIER	AS BUILT
Each Phase	6 days/Phase Pier



Piles





Frederikssund Fjord High Bridge

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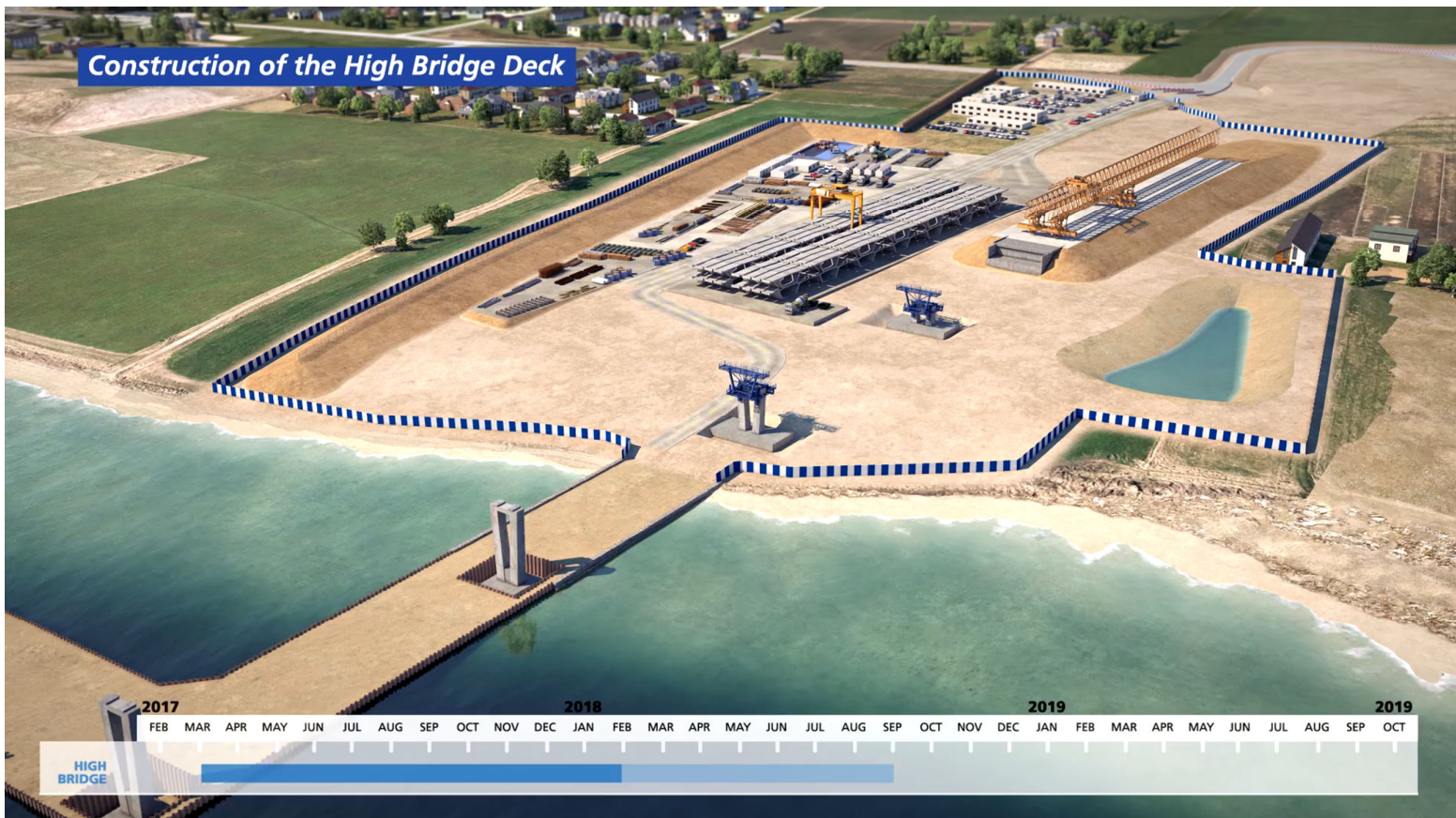
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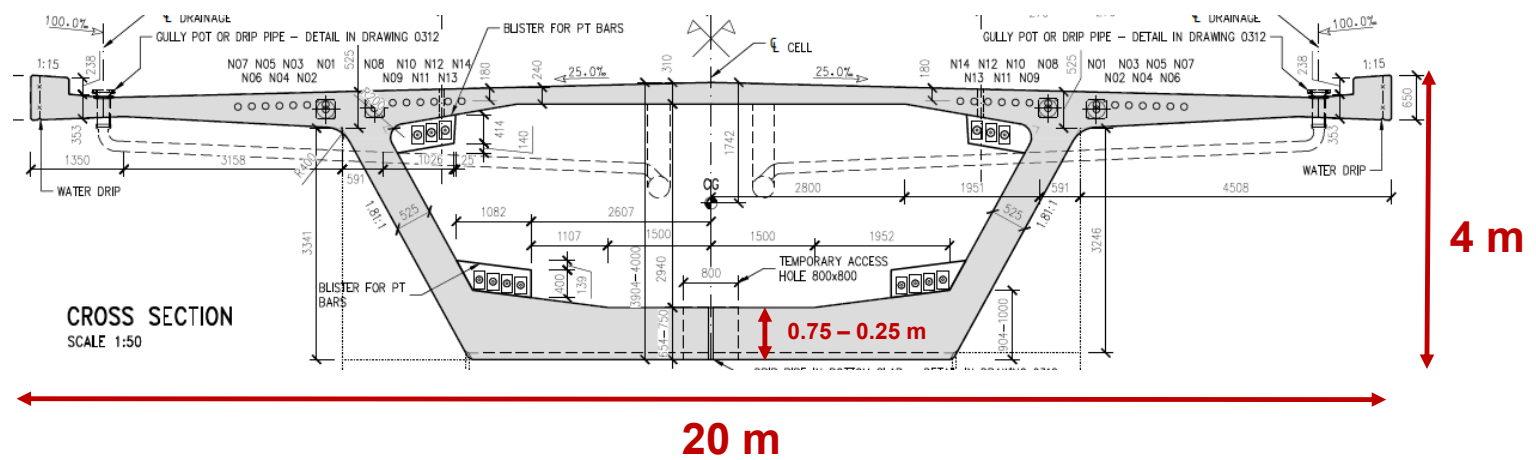


Construction of the High Bridge Deck

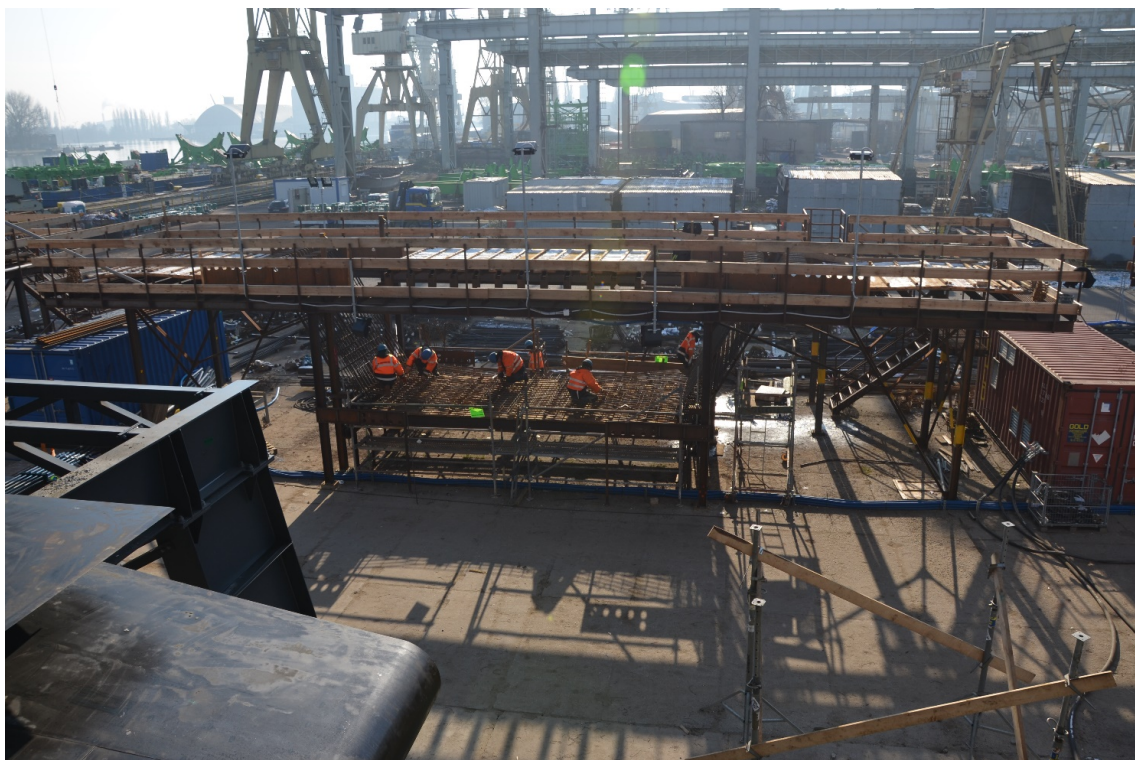


Voussoirs

100 Ton



Préfabrication des voussoirs



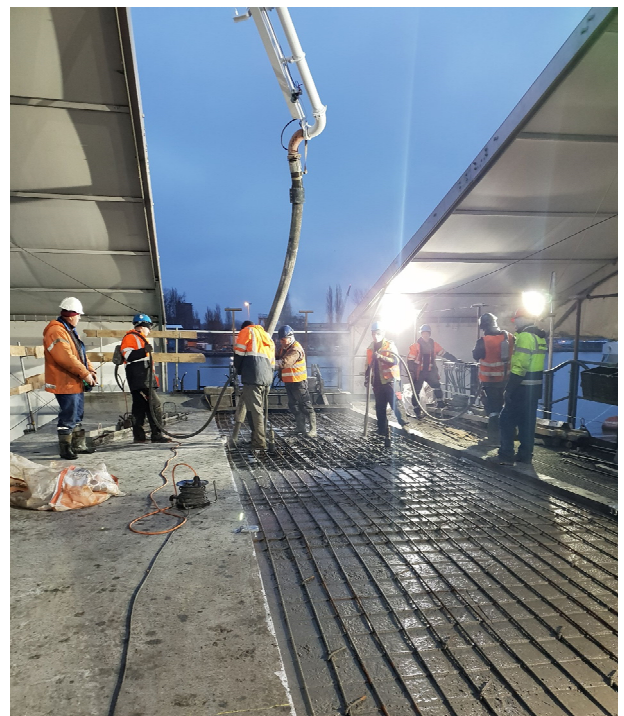
Préfabrication des voussoirs



Préfabrication des voussoirs



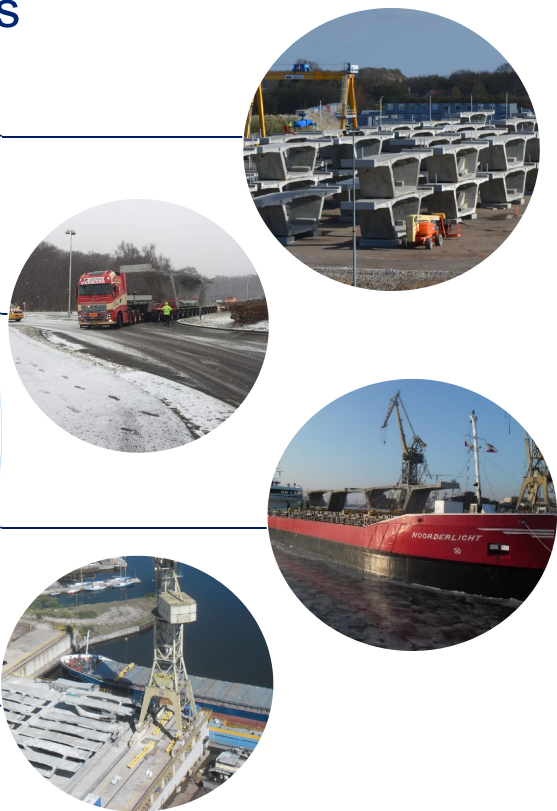
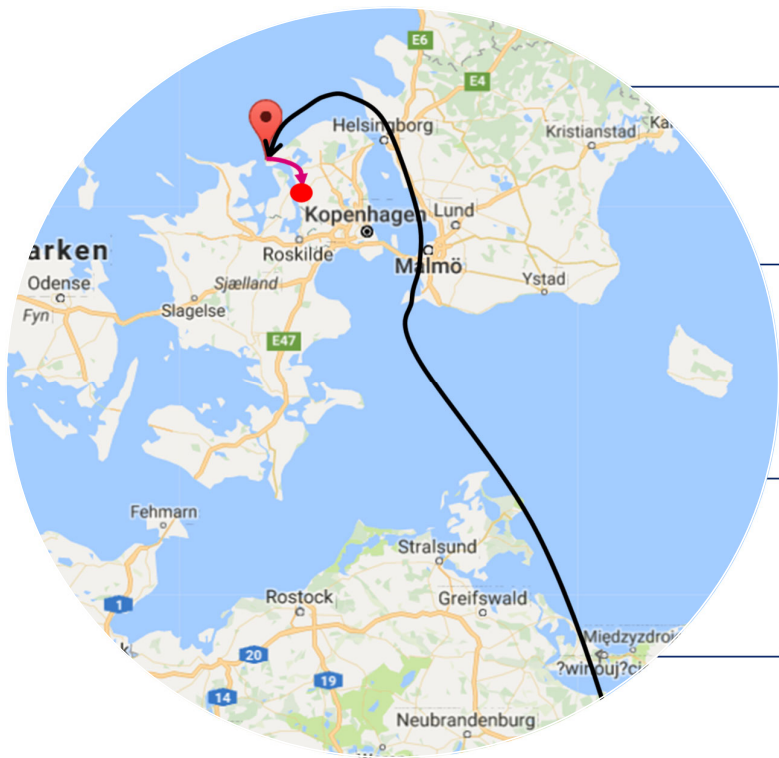
Préfabrication des voussoirs



Préfabrication des voussoirs



Transport et stockage des voussoirs



Installation des voussoirs



Installation des voussoirs



Installation des voussoirs



Installation des voussoirs



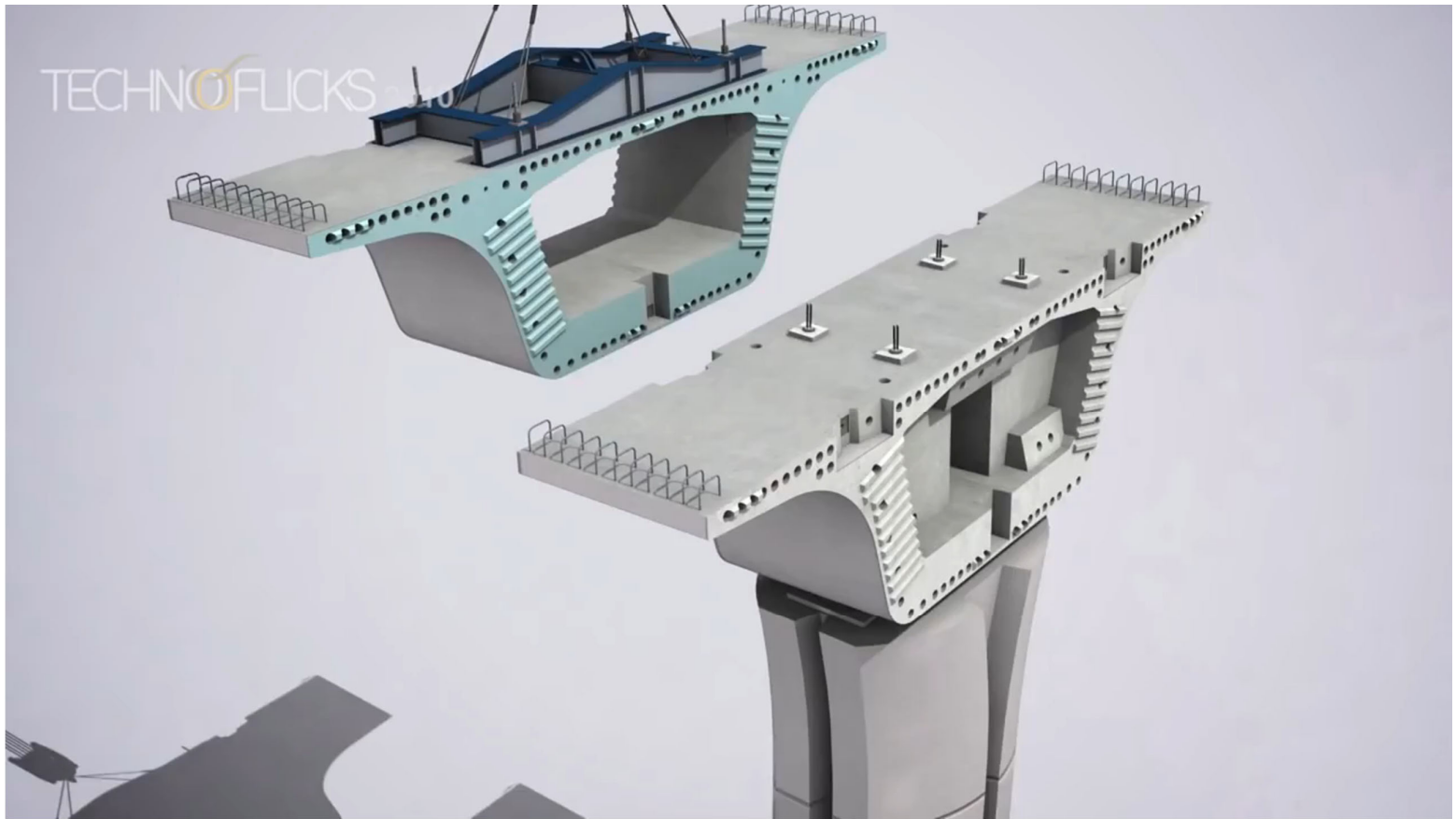
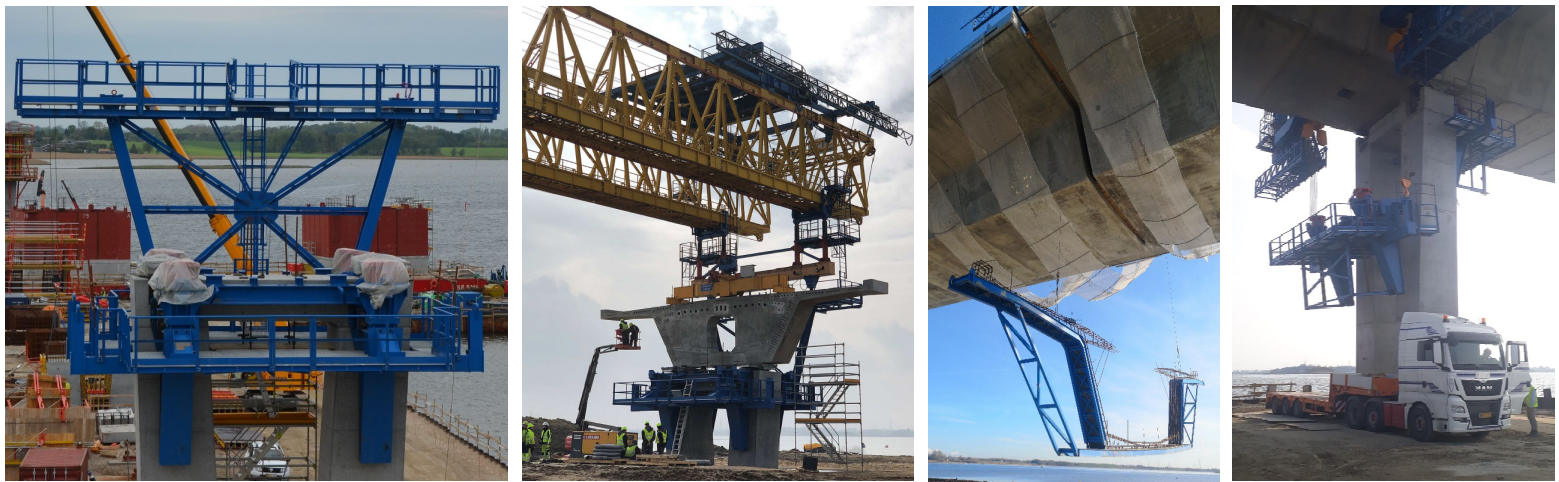
Installation des voussoirs



Installation des voussoirs



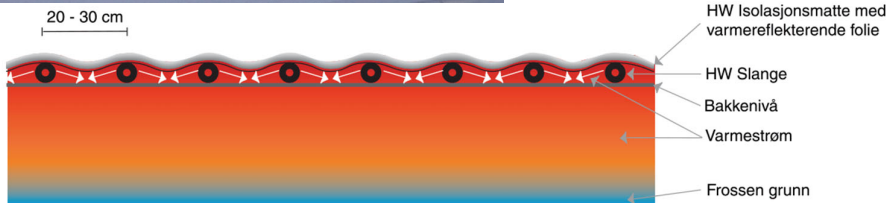
Installation des voussoirs



Précautions contre le froid



Hydronic heater



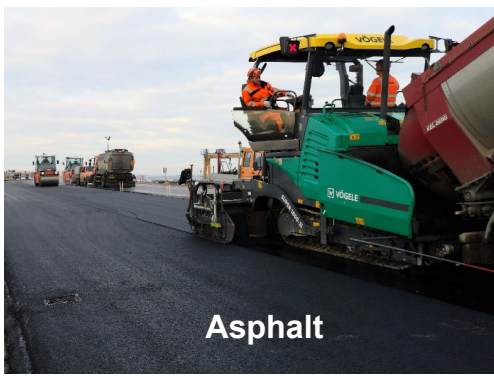
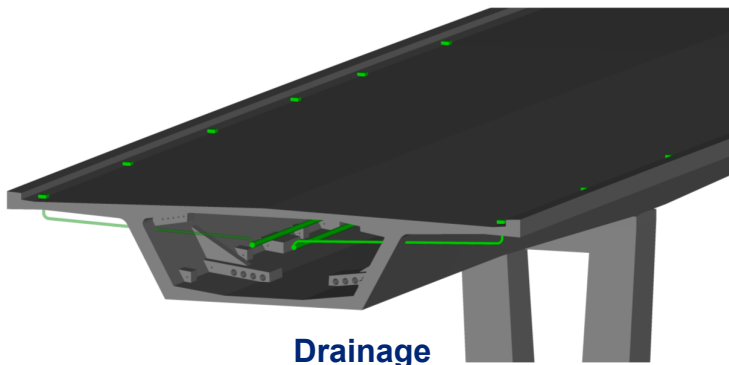
Prévention du froid



Démontage des batardeaux



Finitions





October 2016



September 2017



8

February 2018



8

April 2018



8

July 2018



8

October 2018



8

January 2019



8

April 2019

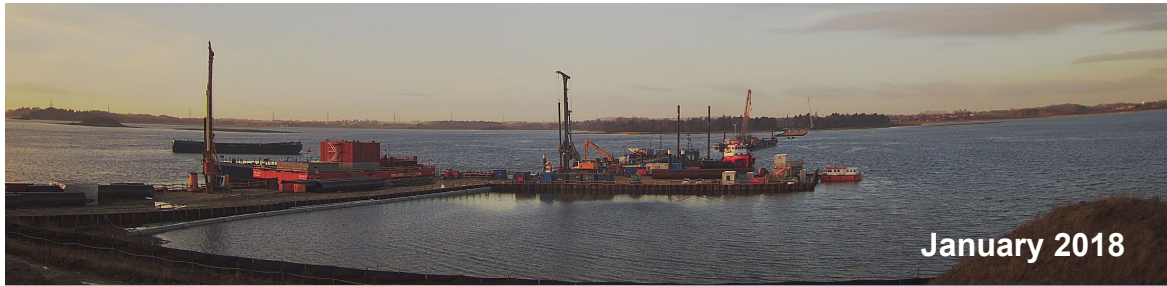


8

26 April 2019



8



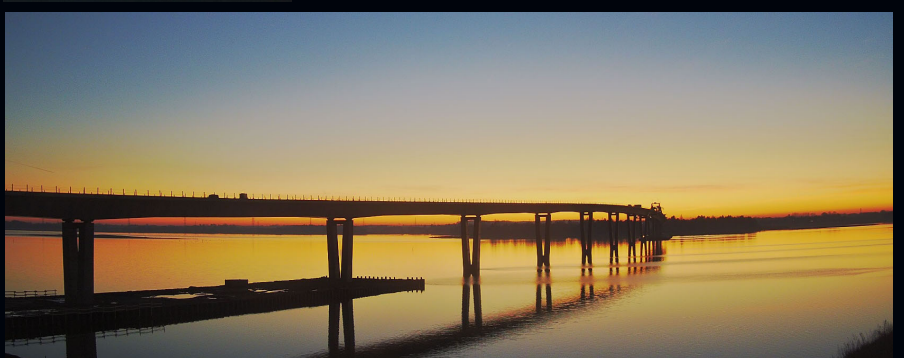
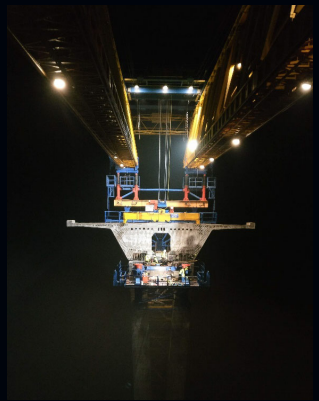
January 2018



September 2018



April 2019





©Photography by René Rasmussen

Merci pour votre attention!



Illustrations de l'introduction par Emilie Dubois - www.elimie.com