



**In cooperation with: BME Faculty of Civil Engineering  
Department of Construction Materials and Technologies  
Department of Structural Engineering  
Department of Structural Mechanics**

**In cooperation with: BME Faculty of Architecture  
Department of Mechanics, Materials and Structures**

**and**

**Hungarian Chamber of Engineers, Dept. Structures (MMK TT)**

# Design of marine concrete structures

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# A little bit about Norway and the sea

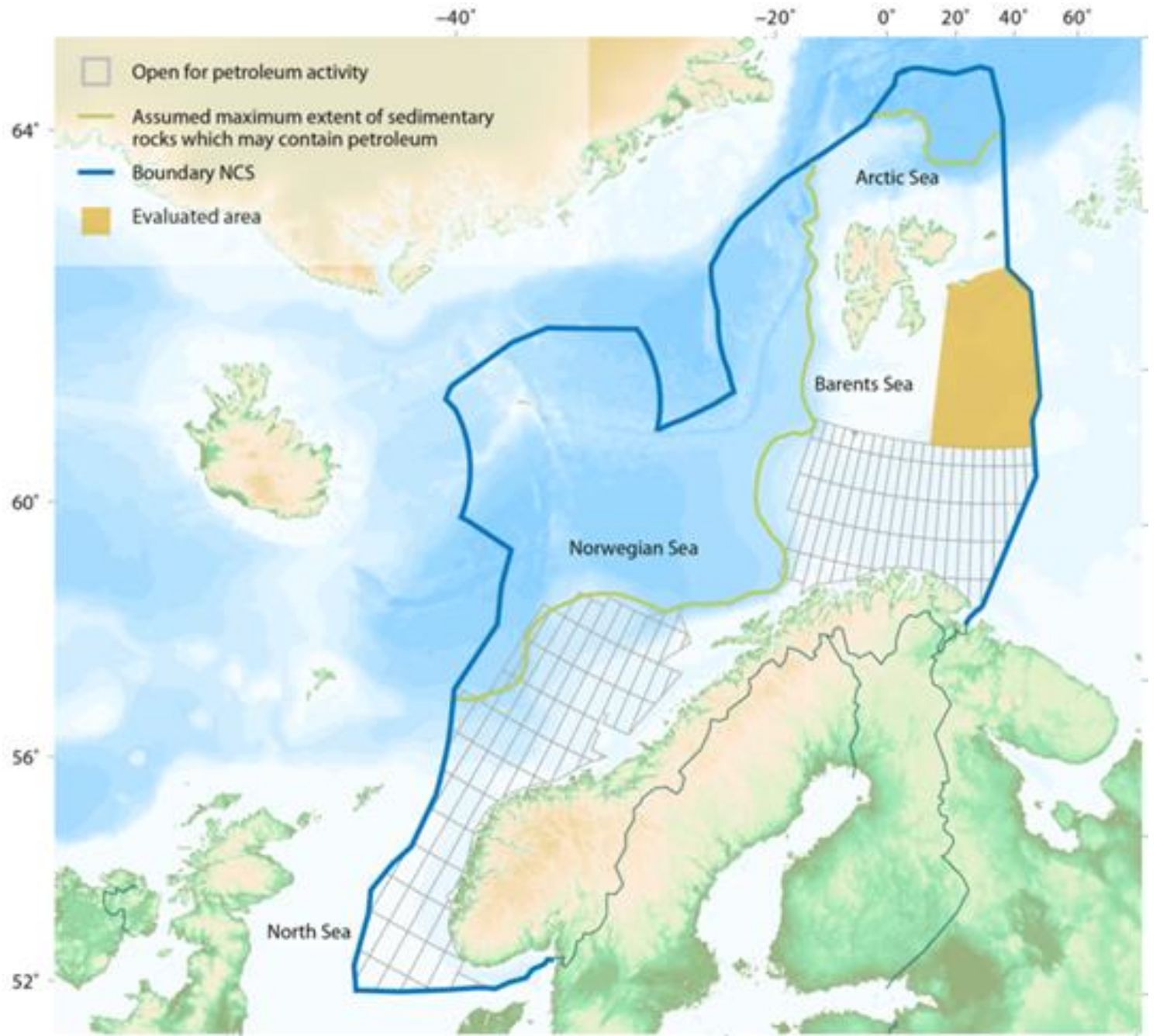


With a long coast, and a lot of sea water

The sea represents more than 2/3 of Norway's export income, particularly Oil&Gas, seafood, shipping and energy



If you include the Norwegian Continental Shelf, Norway becomes much larger



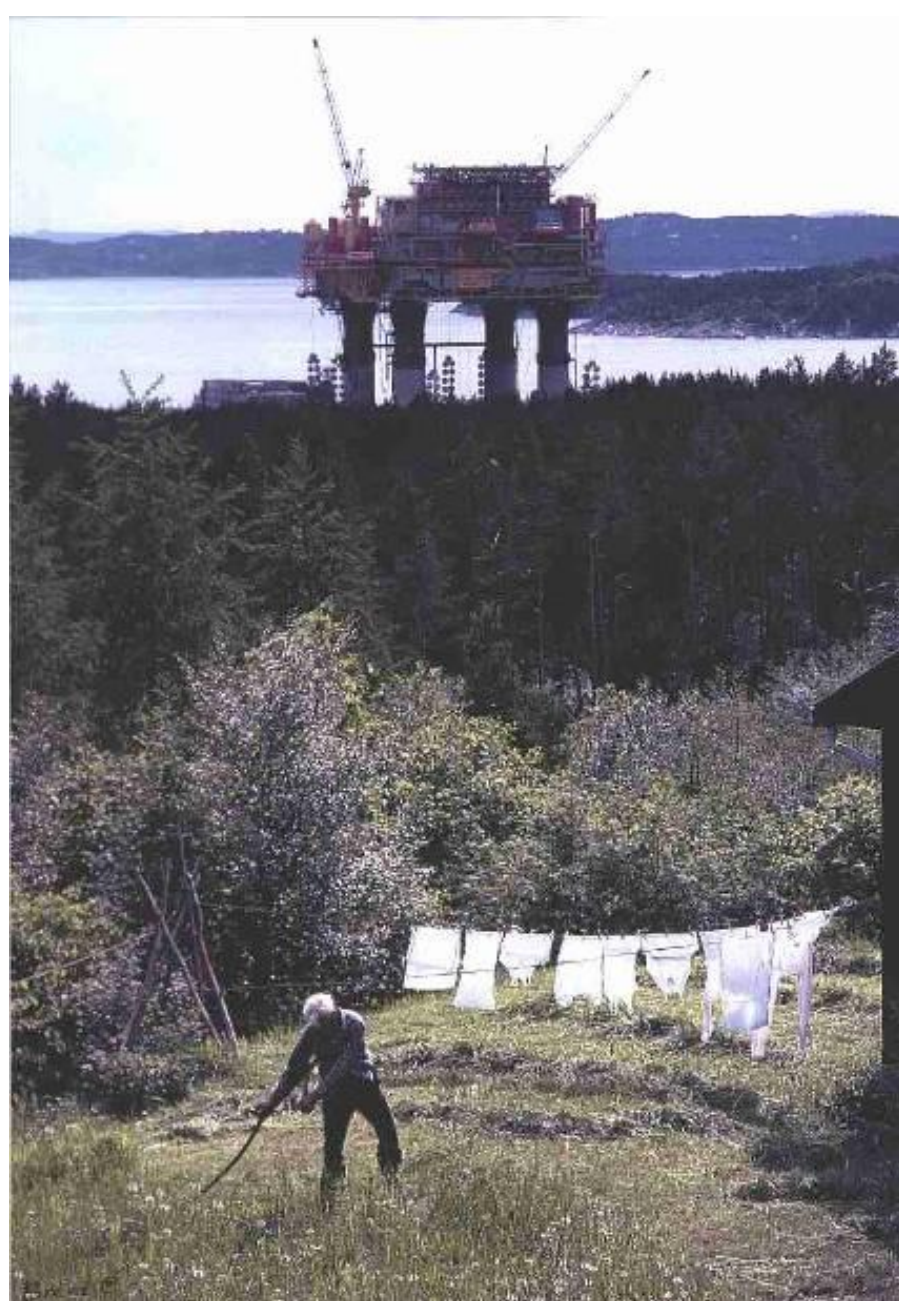


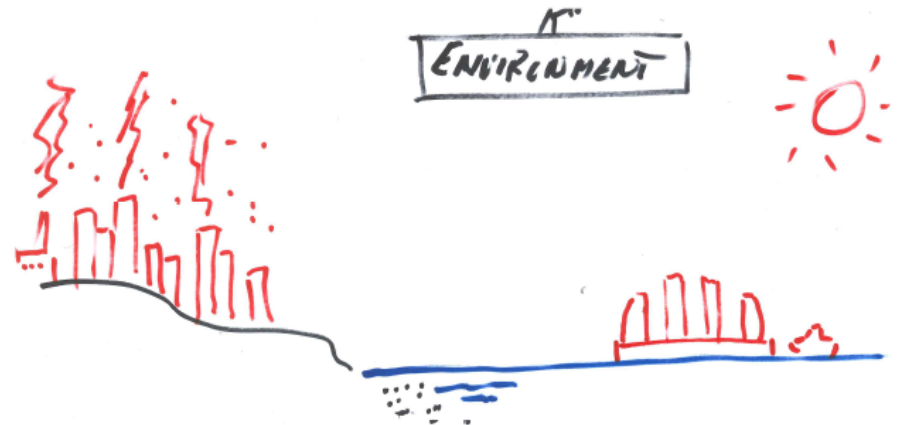
Foto: Johan Brun

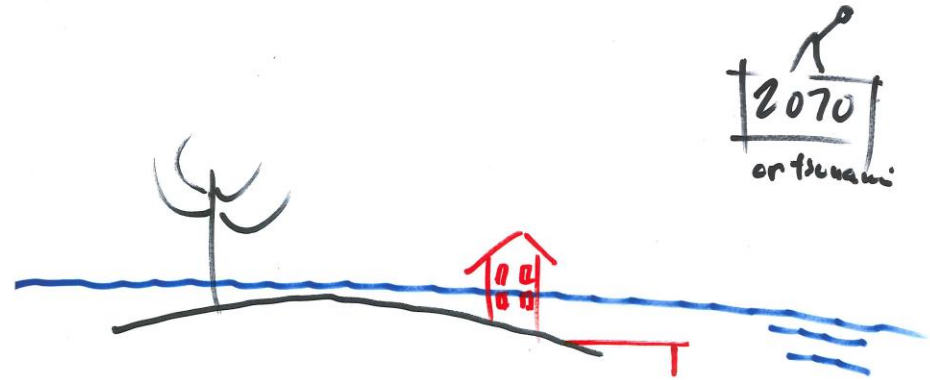
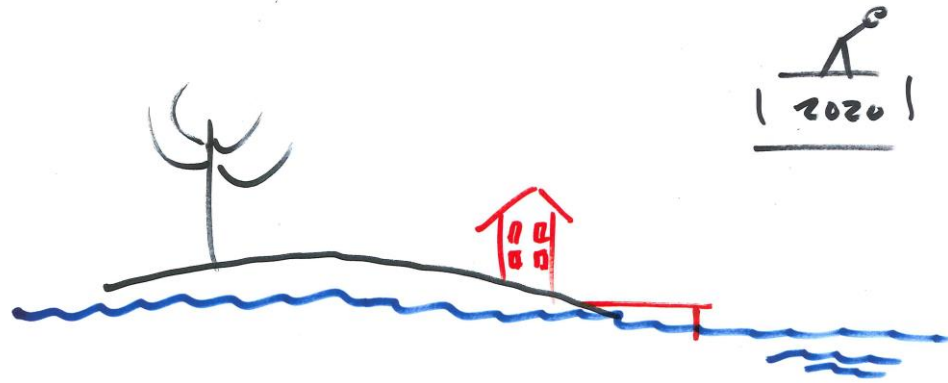
# Why Marine structures?

- **World population will keep increasing**
  - 1960: 3 billion
  - 2015: 7 billion
  - 2050: 9 billion
- **Urbanization will also continue – world population living in cities:**
  - 1950: 30%
  - 2010: 51%
  - 2050: 70%
- **Concrete can contribute to the solution:**
  - Infrastructure
  - Building on land
  - **Floating structures**

Cities:

- Most cities are close to the sea
- Many of them at low altitude







1. Food
2. Infrastructure
3. Energy
4. Environment
5. Dwellings and urban development
6. Nearshore industrial development
7. Offshore industrial development
8. Storage
9. Vessels
10. Recreation
11. Catastrophes
12. Military actions
13. Other

Can we design and build  
marine concrete structures?

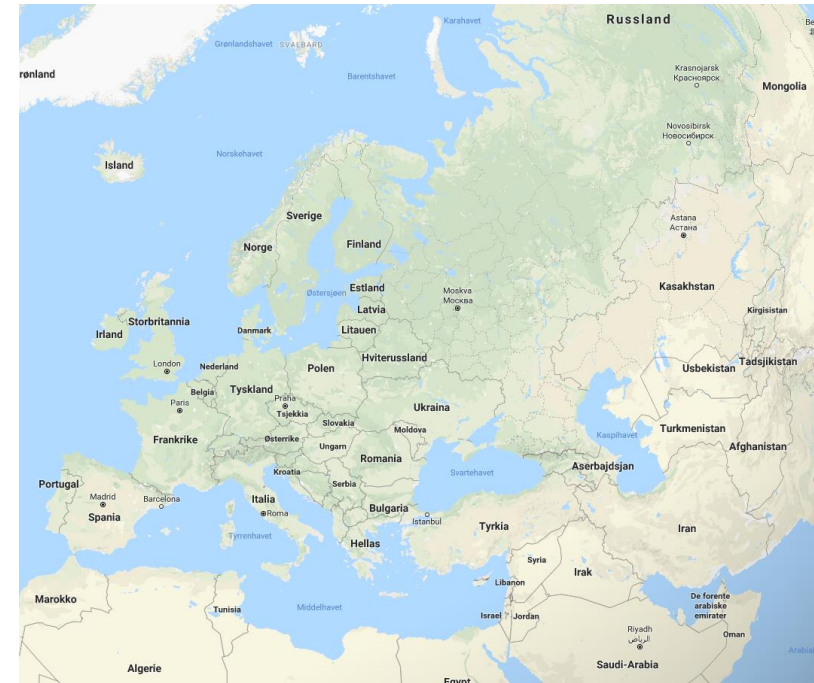


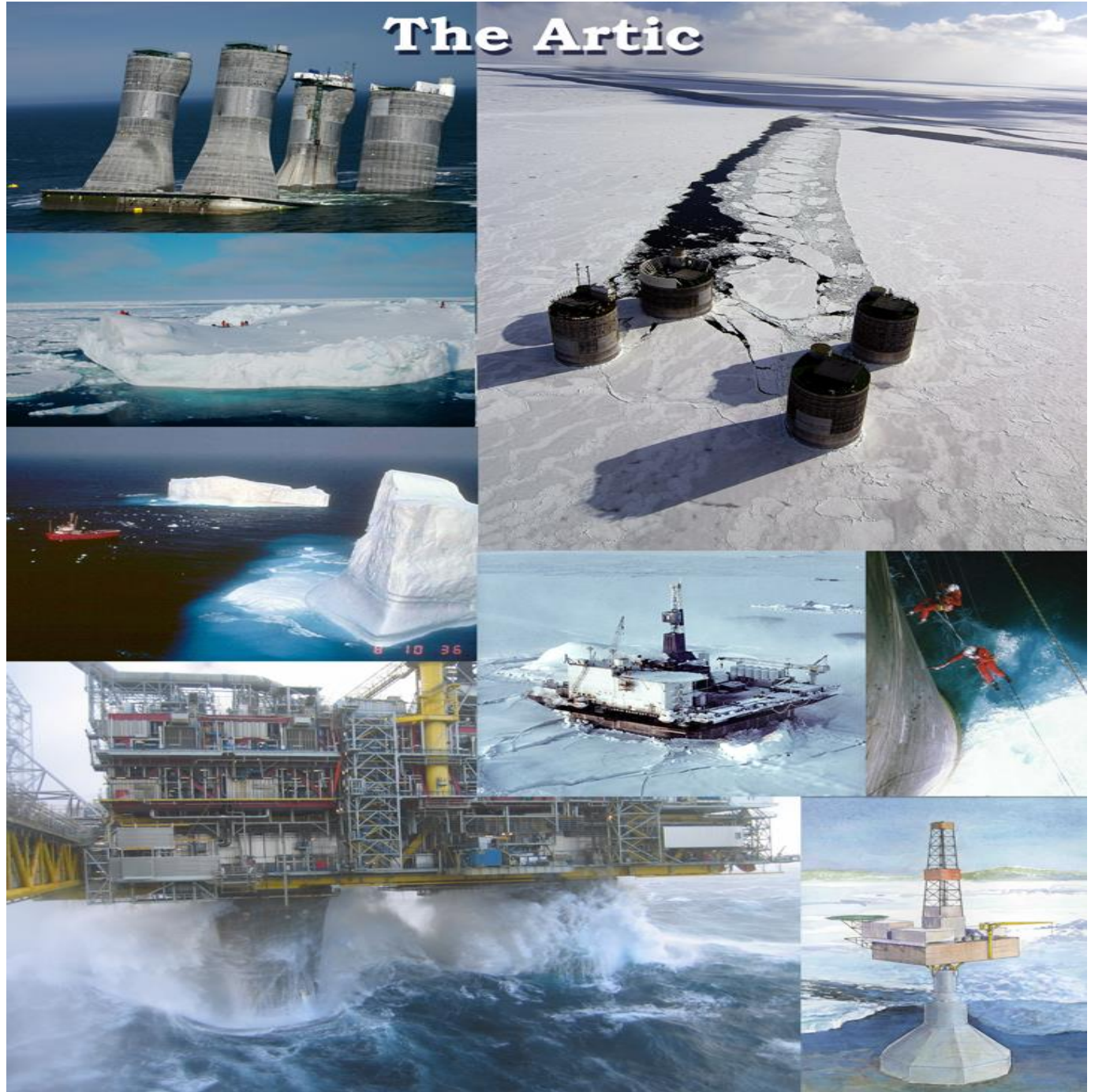
# Lambot's concrete boat from 1848





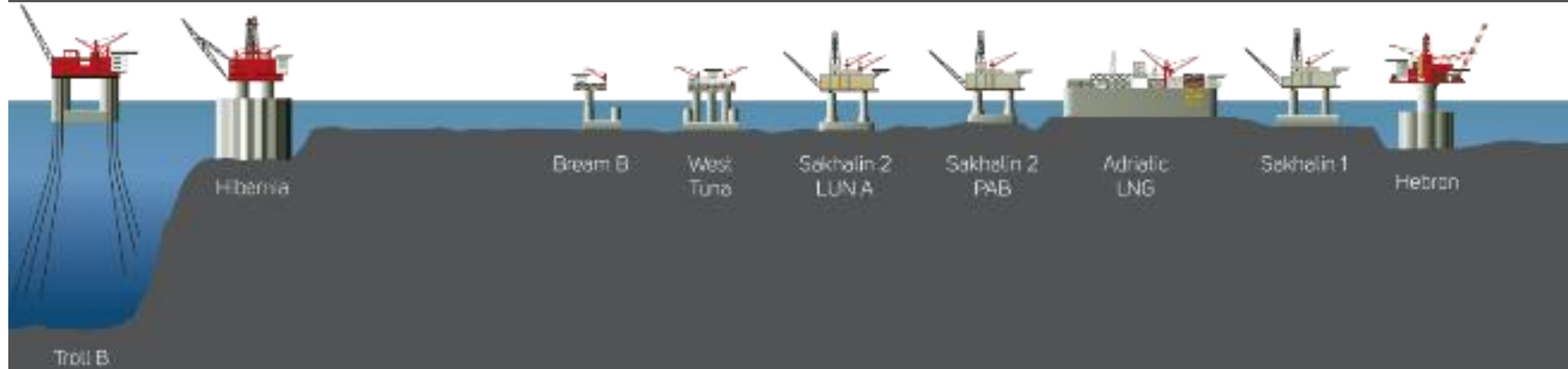
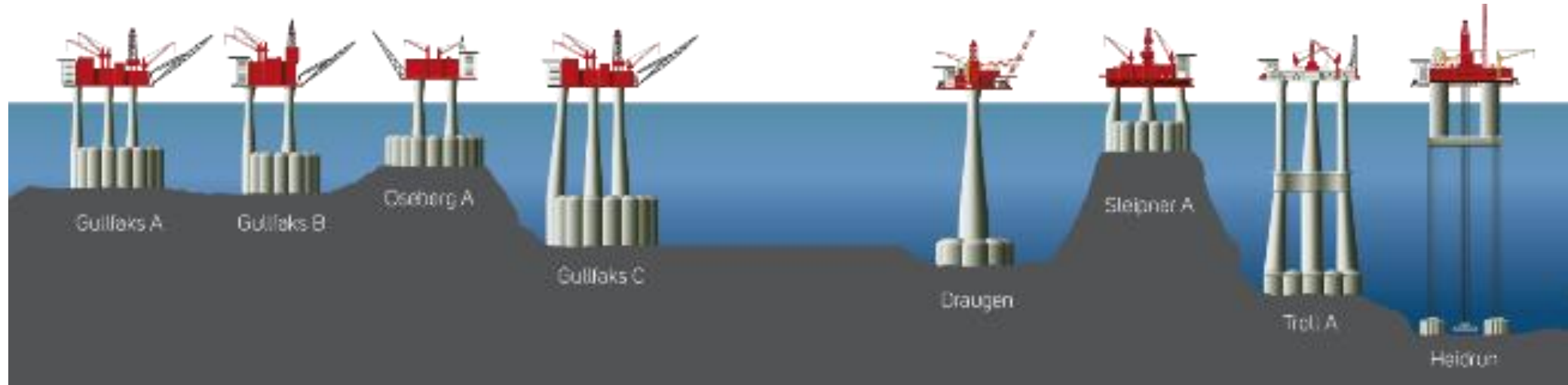
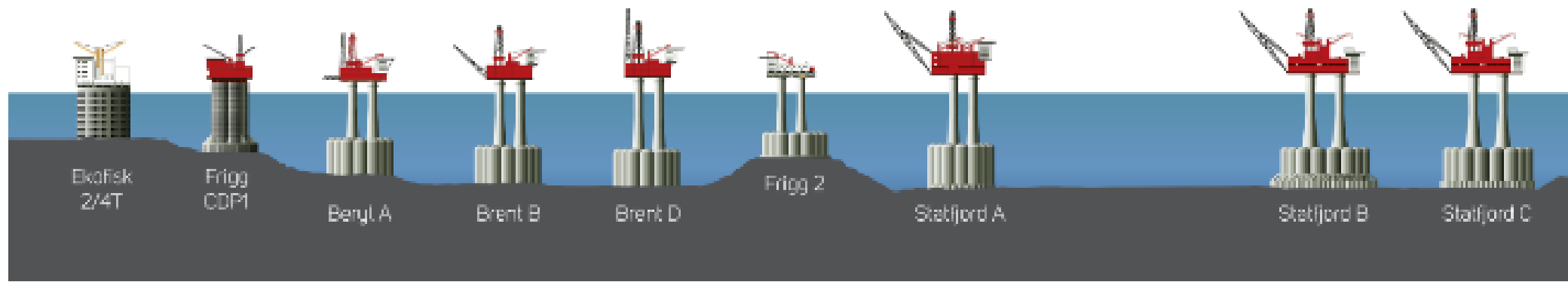
Mulberry Harbour, Arromanches, Normandy, France





[www.RaKon.no](http://www.RaKon.no)





Two very important properties  
of the sea:

- Buoyancy
- You can travel on/in it

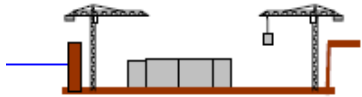
And there are many more



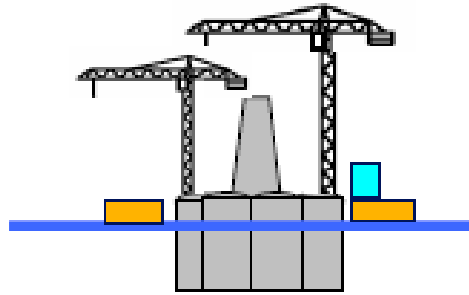




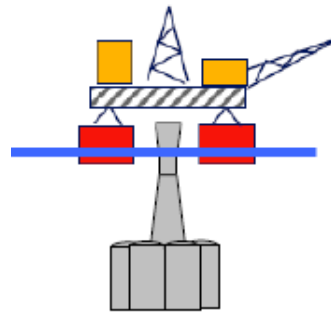
Construction in dry dock



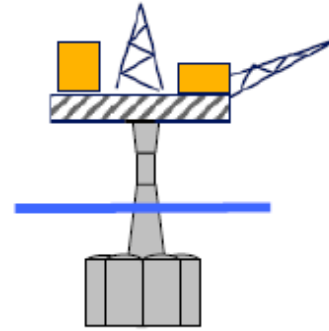
Deepwater site



Deckmating



Tow to field



Operation





A quick look at the  
construction sequence

Jun 90





Sept 90



Des 90



Mar 91

# «INGENIØRLEGENDE HEDRET I STAVANGER»



- «På mange måter vil jeg si at det var Olsen som brakte oljeeventyret til Stavanger»

- -fagsjef Finn Sandberg ved Norsk Oljemuseum

Jun 91





Sept 91



Sept 92



Des 92



Mar 93







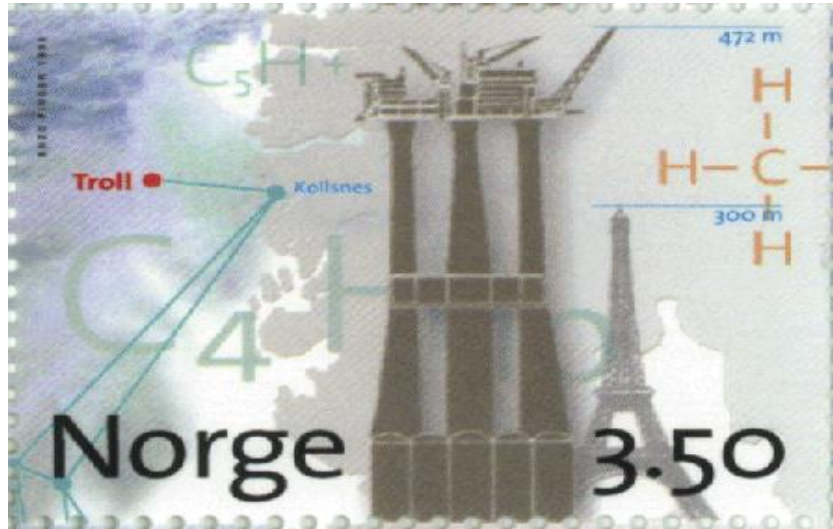


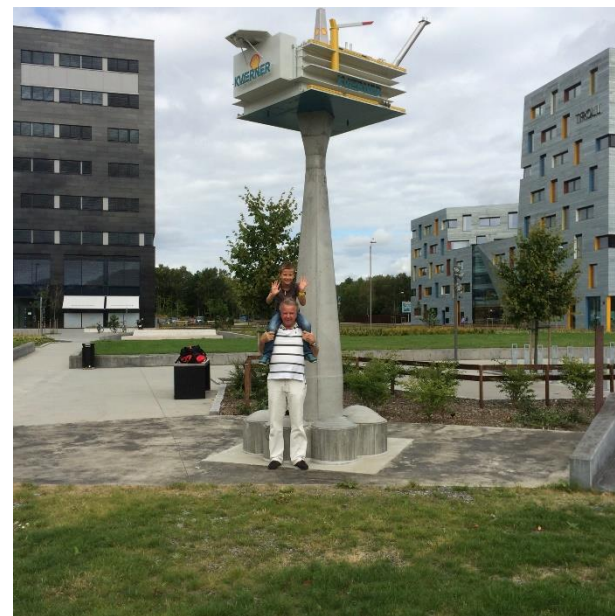
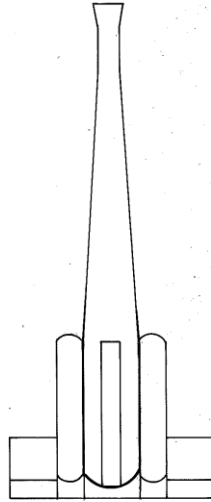






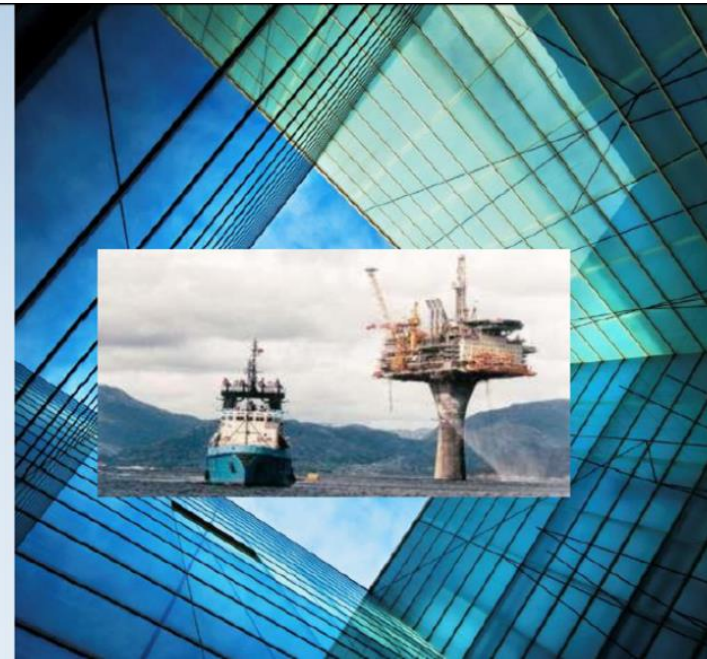






UNESCO  
Verdensarv  
Industrielle kulturminner

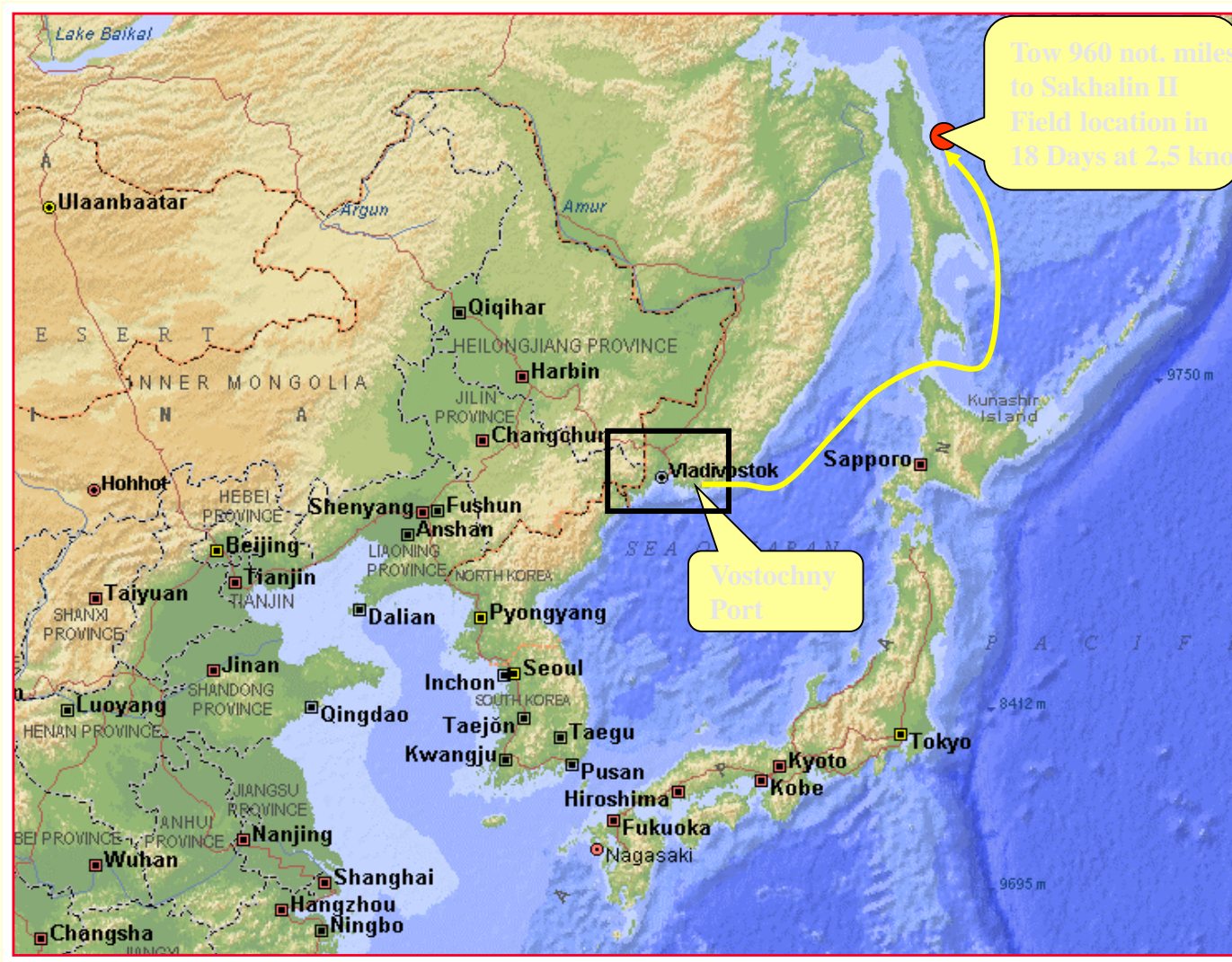
Kan Draugen-plattformen være  
norsk oljeindustri bidrag?





**Facts and figures:**  
Storage capacity: 1 mill bbls  
Concrete volume: 21.000 m<sup>3</sup>  
Overall hull diameter: 98m  
Total hull height: 47m  
Draft empty: 14,2m  
Draft full: 32,0m





**Sakhalin II Phase 2 Reservoir**

- 4 billion barrels Oil
- 20 trillion c.f. Gas
- PA-B is Oil Field
- LUN-A is Gas Field
- w/ ass. Condensate
- & multiphase to OPF.

**Water depth**

- PA-B = 30,8 m
- LUN-A = 48,2 m





# After designing 3 mill. cubic metres of marine concrete structures, some key experiences:

- Concept is important, and conceptual design
- Understanding the real use of the structure is important
- Understand the loads
- Understand the environment
- Weight is important
- Design and construction must be well integrated
- Construction management is important
- Construction method is important
- Design and design tools are important

# After designing 3 mill. cubic metres of marine concrete structures, some key experiences:

- **Concept is important, and conceptual design**
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- **Weight is important (and weight control)**
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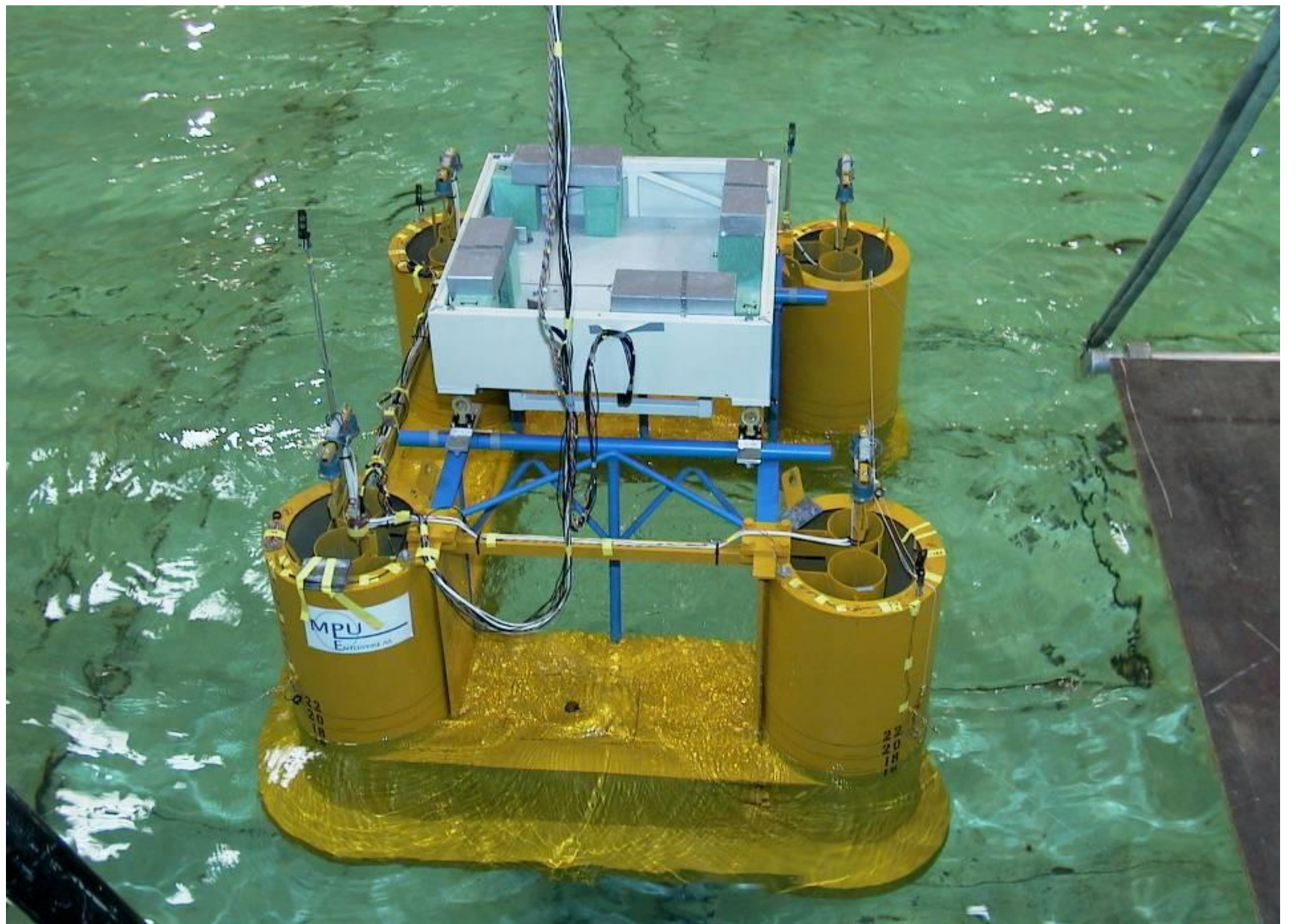




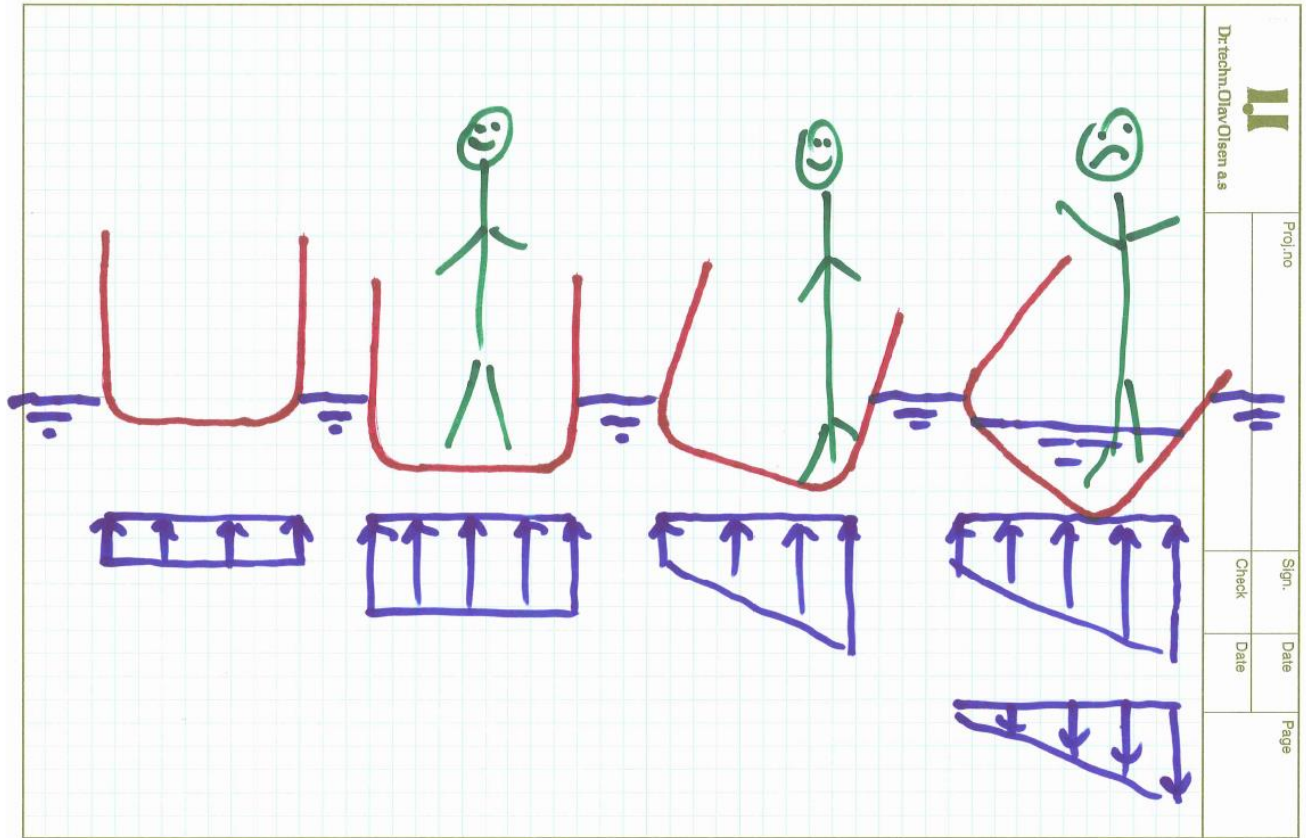






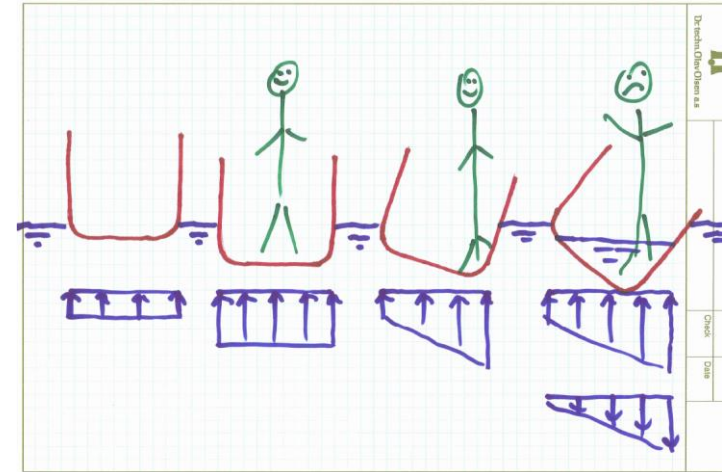
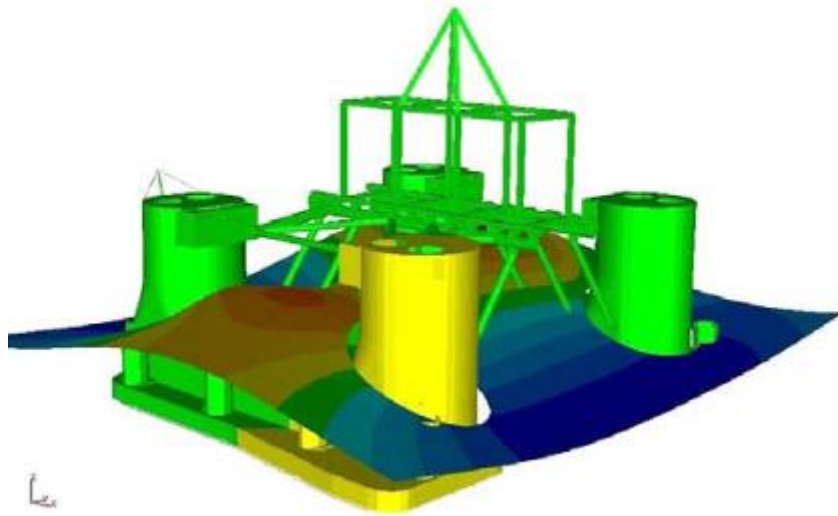
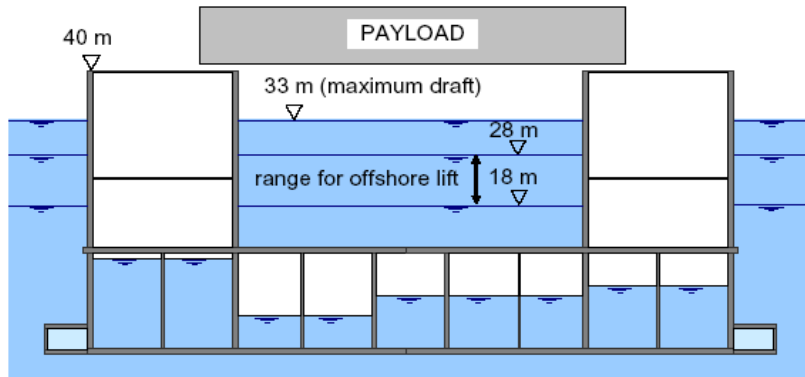






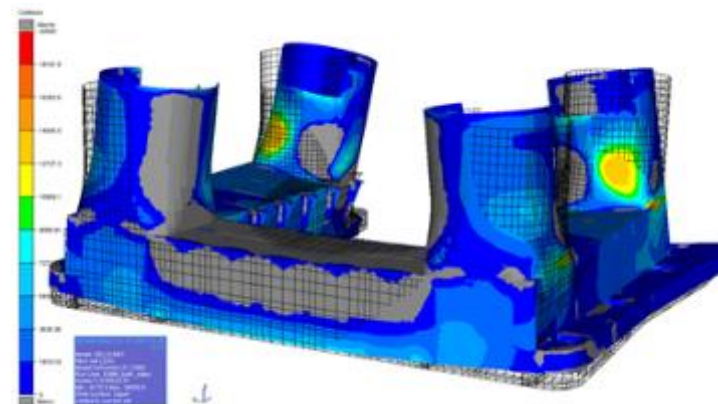
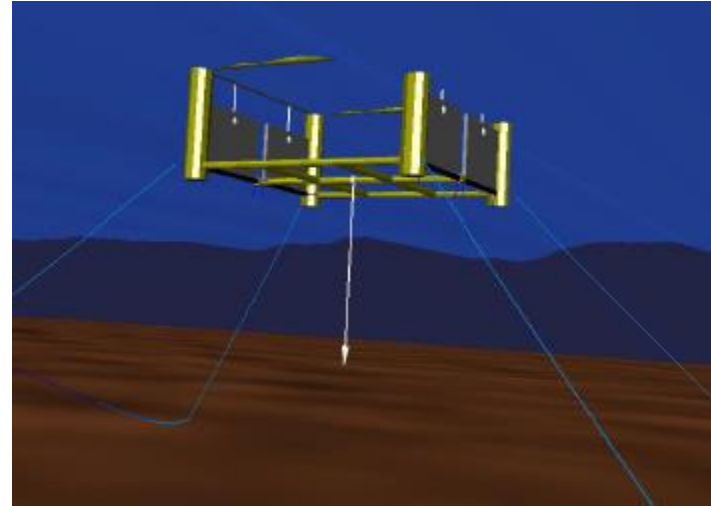
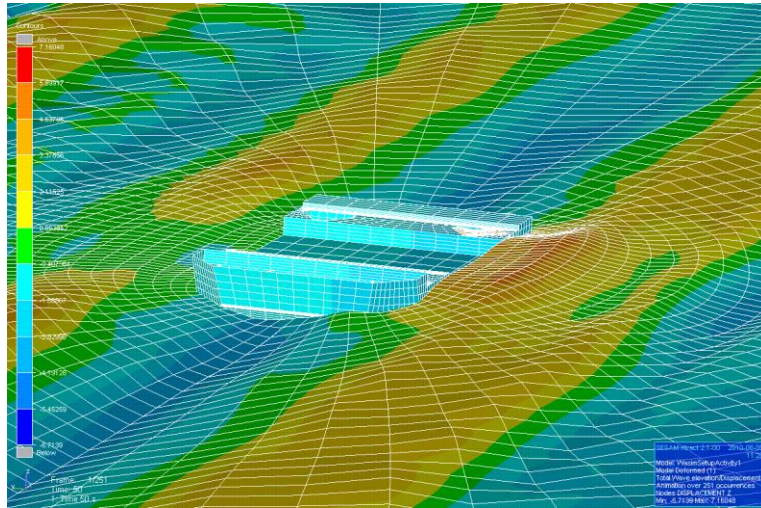
Dr. Techn. Olav Olsen as		ii	
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# Loading



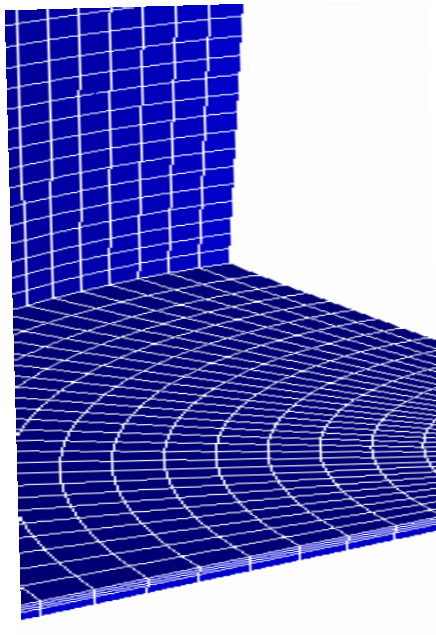
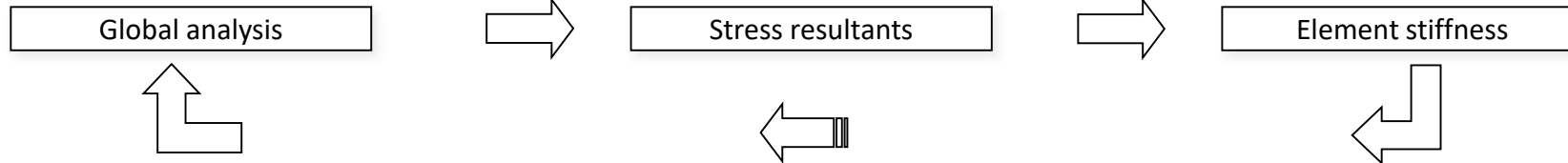
- Weights (self weight and live load)
- Hydrostatic pressures (External and internal)
- Payload (results from time-domain analysis applied as static loads),
- Post-tensioning,
- Design wave pressures
- Acceleration (inertial forces).

# Hydrodynamic analyses

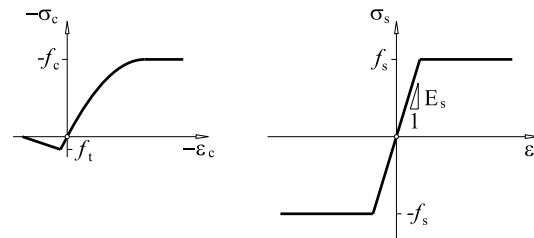
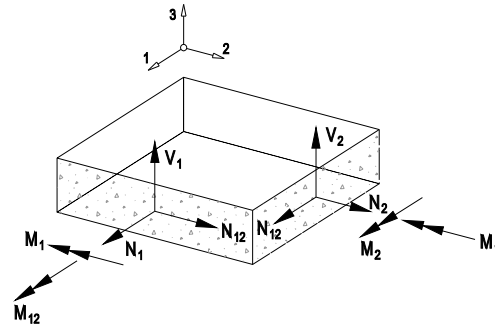


# ShellDesign

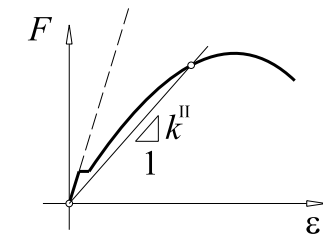
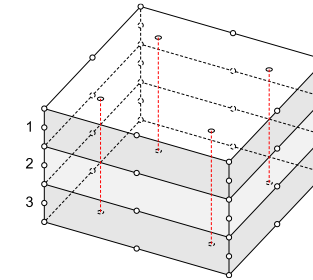
## Iterative non-linear analysis and design



Linear FE analysis



Shell section analysis



$$F = k^{II} \cdot \varepsilon$$

Stiffness formulation

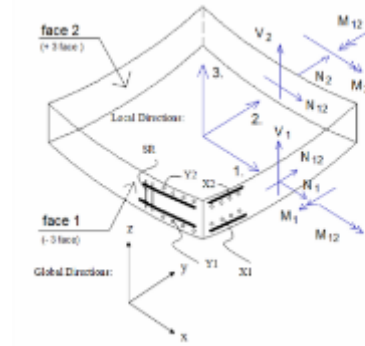
# Structural analysis and design - State of the art



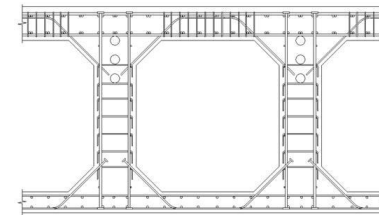
Structure



Linear elastic global FE analysis

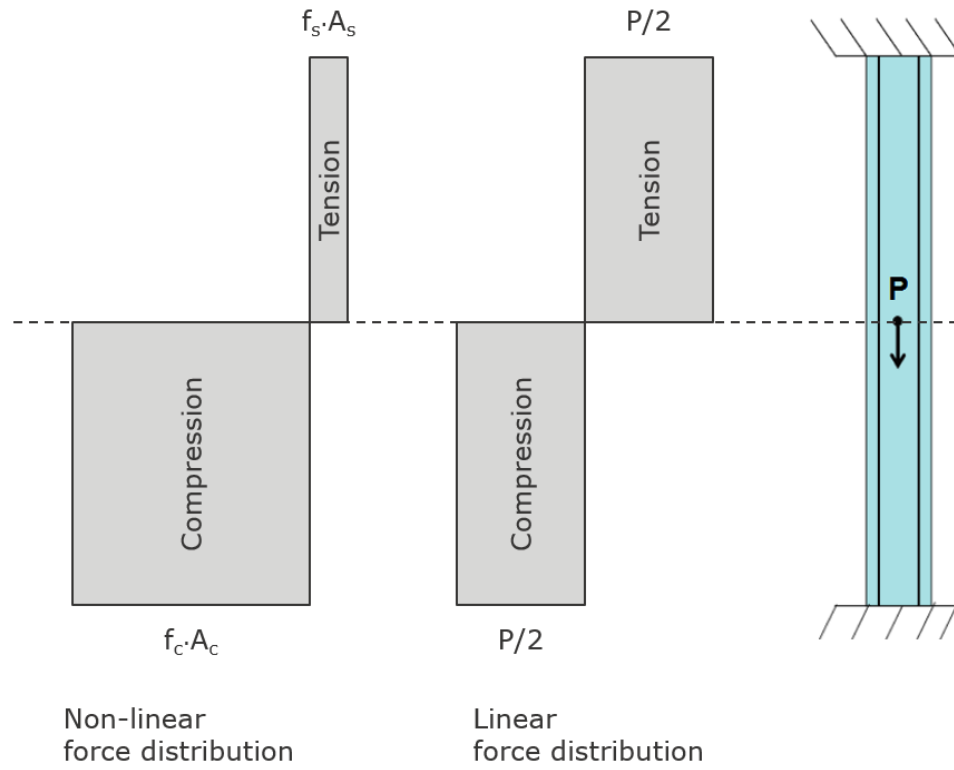


Sectional design



Reinforcement layout





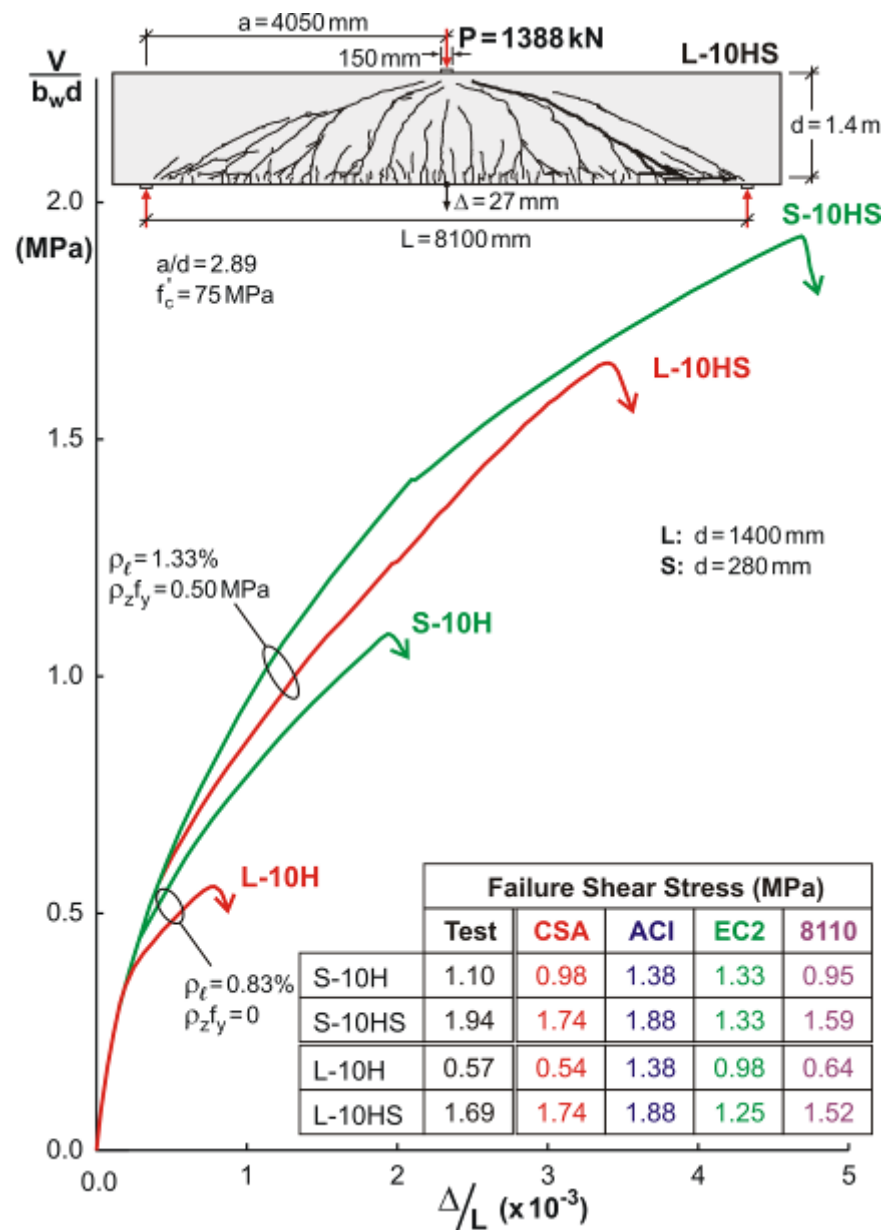
# THE Modified compression field theory

- Rational and consistent shear design
- Design codes overestimate the shear capacity
- in combination with axial compression and
- Design Codes underestimate the shear capacity in combination with axial tension
- MCFT will, in addition to providing a more correct answer, give engineers a tool that increases the understanding of the structure's behaviour.
- Status for implementation:
  - The iterations work well – the calculation of strains is okay.
  - The calculation of stresses in cracks for membrane cases (2D) works fine and correspond remarkably well with test results from Toronto.
  - The completion of calculation of stresses in cracks for triaxial cases (3D) is ongoing.









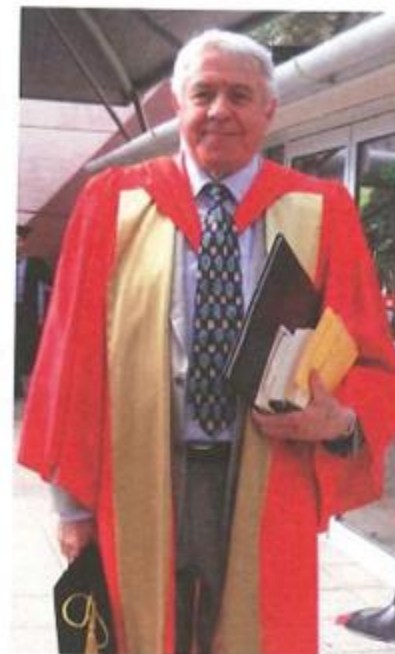
### Professor Michael Collins Receives Higher Doctorate for Lifetime Achievement

Prof. Michael Collins has been honoured with Higher Doctorate designation by his alma mater, the University of New South Wales.

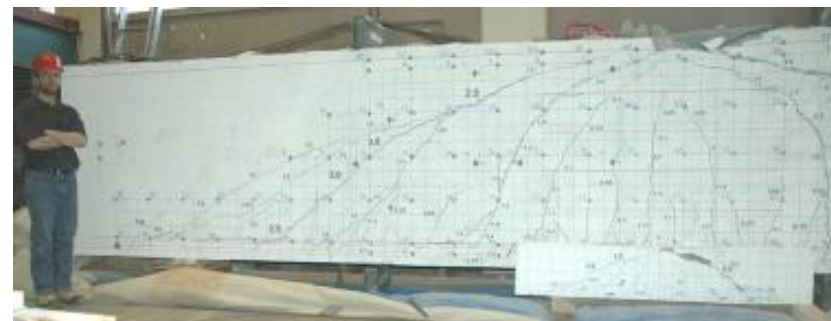
The recognition was bestowed in Sydney today at their annual convocation ceremony, citing a lifetime of research and academic achievement.

Prof. Collins also had the opportunity to deliver the Occasional Address to the graduating class of engineers from that University.

The Higher Doctorate designation is presented to an academic of high distinction and gives formal public recognition to scholars who have made substantial, original, and distinguished contributions to knowledge in their field of expertise. 🌟



Prof. Michael Collins attends convocation at the University of New South Wales.



Collins, M. P., Mitchell, D. and Bentz, E.C., "Shear Design of Concrete Structures", The Structural Engineer, London, Vol. 86, No. 10, May 2008, pp 32 - 39.

BIAXIAL EXAMPLE

INFLUENCE OF AXIAL STRESS ON SHEAR STRENGTH

- Six nominally identical reinforced concrete elements representing web regions of girders or walls were loaded under different ratios of longitudinal axial stress to shear stress.

*Table 1 Comparison of observed and predicted shear failure with the newly implemented MCFT in ShellDesign.*

Panel	$f_x/v$	Observed		Predicted Values			$V_{u-EXP}/V_{u-PRED}$		
		$v_u$ [Mpa]	$f_{xu}$ [Mpa]	EC2	MCFT-B	MCFT-SD	EC2	MCFT-B	MCFT-SD
PL4	-2.75	4.81	-13.2	2.46	4.98	4.93	1.96	0.97	0.98
PL1	-2.00	4.31	-8.66	2.46	4.15	4.25	1.75	1.04	1.01
PL2	-1.00	3.21	-3.22	2.46	3.42	3.47	1.30	0.94	0.93
PL5	0.00	3.21	0	2.46	2.96	3.15	1.30	1.08	1.02
PL3	1.00	3.04	3.05	2.46	2.74	2.79	1.24	1.11	1.09
PL6	2.98	2.47	7.36	1.94	2.06	2.47	1.27	1.20	1.00

## 2013 Achievement Award for Young Engineers

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From left to right:  
*Gordon Clark, Bente  
Skovseth Nyhus, Aurelio  
Muttoni, Fernando Stucchi*

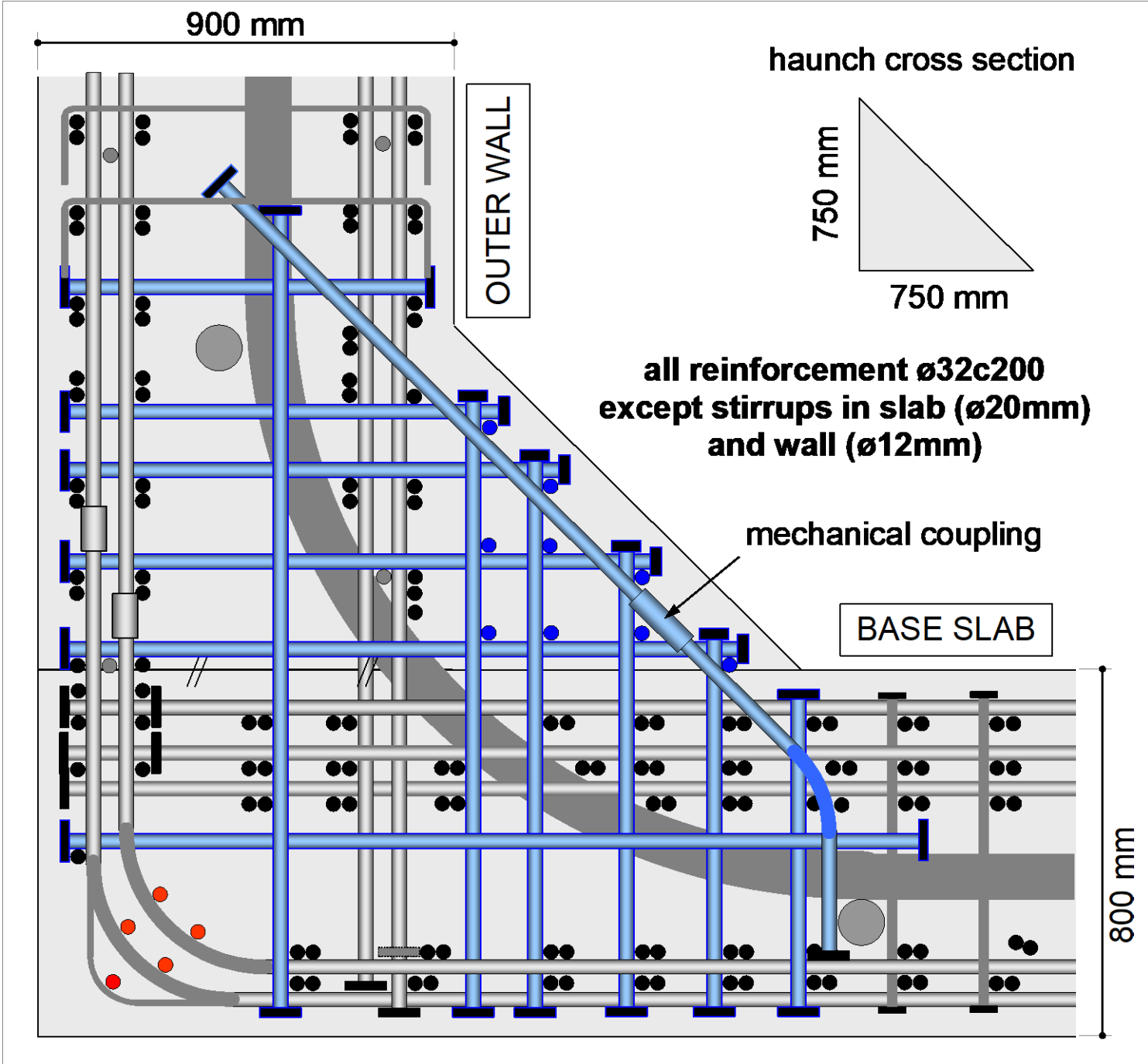
Since 2001 the *fib* Achievement Award for Young Engineers is given every second year at the *fib* Symposium to engineers under 40 years of age, in recognition of their outstanding contributions to structural concrete in the fields of research and of design and construction.

was unfortunately unable to come to Tel Aviv to present his work and receive his award in person. The work realized for his thesis “Structural behavior of deteriorated concrete structures” was shown as a recorded presentation.

# Field trials







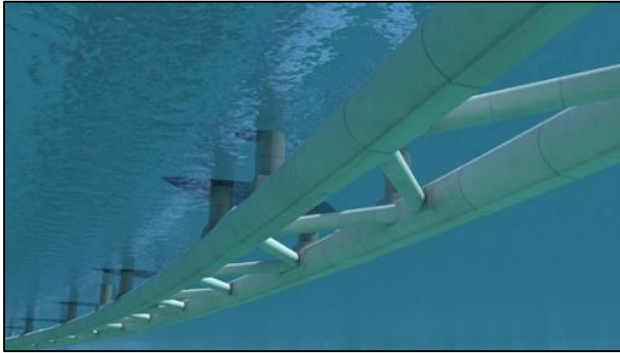


# Fergefri E39 - fjordkryssinger



- Totale investeringer E39: > 300 mrd kr.
- 8 større fjordkryssinger
- De 5 lengste krever ny teknologi
  - Ca 60 Ph.D. tilknyttet prosjektet

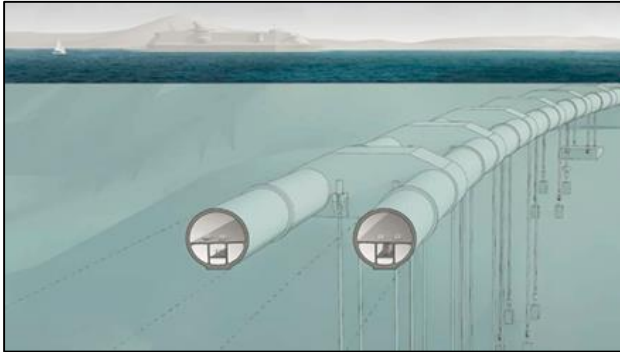
# Strait crossings – some of our projects



*Sognefjorden  
submerged floating  
tunnel bridge  
(SFTB)*



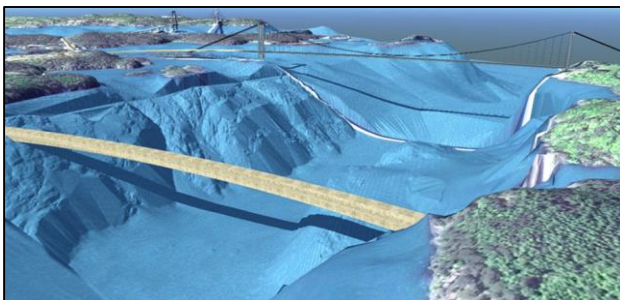
*Bjørnafjorden  
floating bridge*



*Bjørnafjorden  
submerged floating  
tunnel bridge*



*Rovdefjorden  
hybrid floating  
bridge/submerged  
floating tunnel bridge*

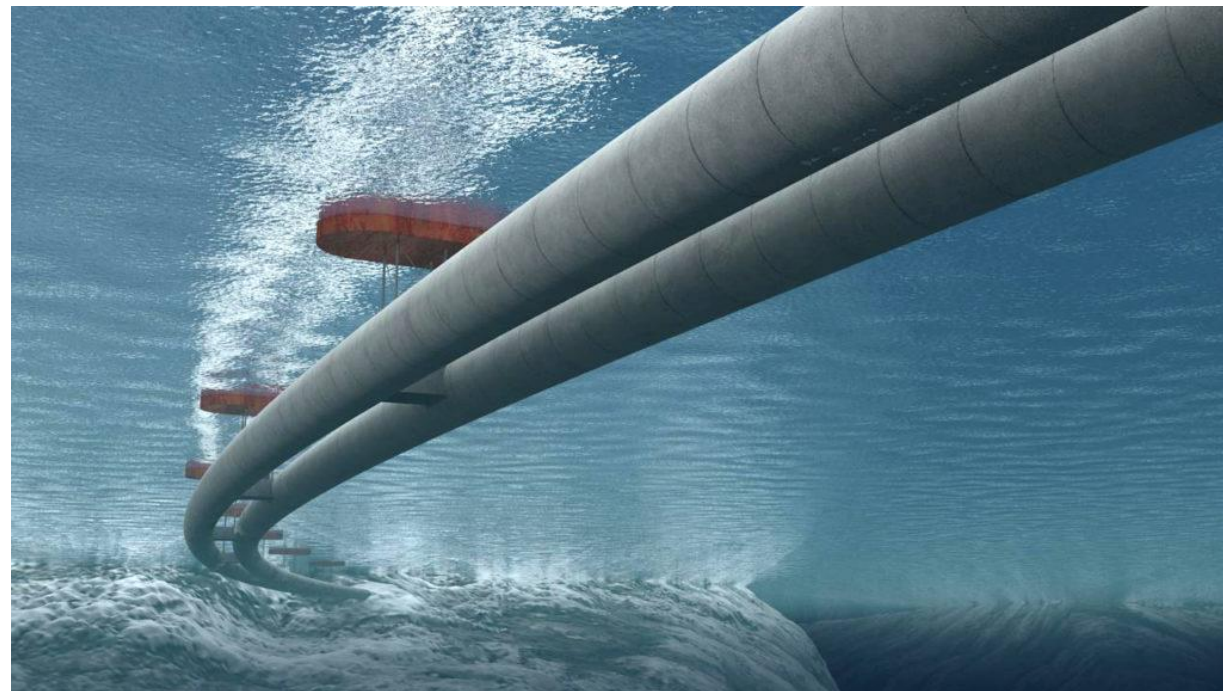
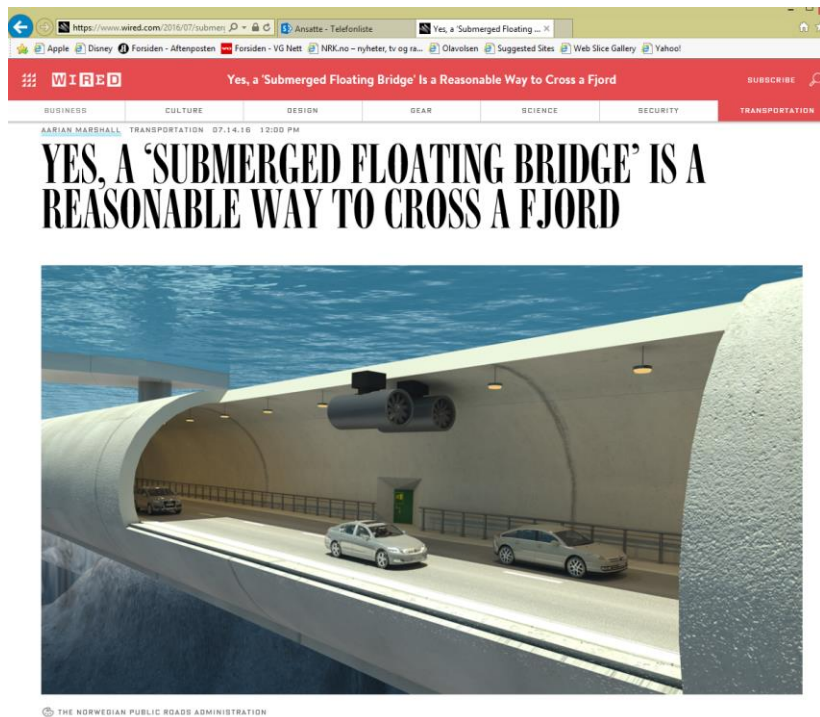


*Digernessundet  
submerged floating  
tunnel bridge*



*Sulafjorden  
submerged floating  
tunnel bridge*

# Ferryfree E39 gets international attention!



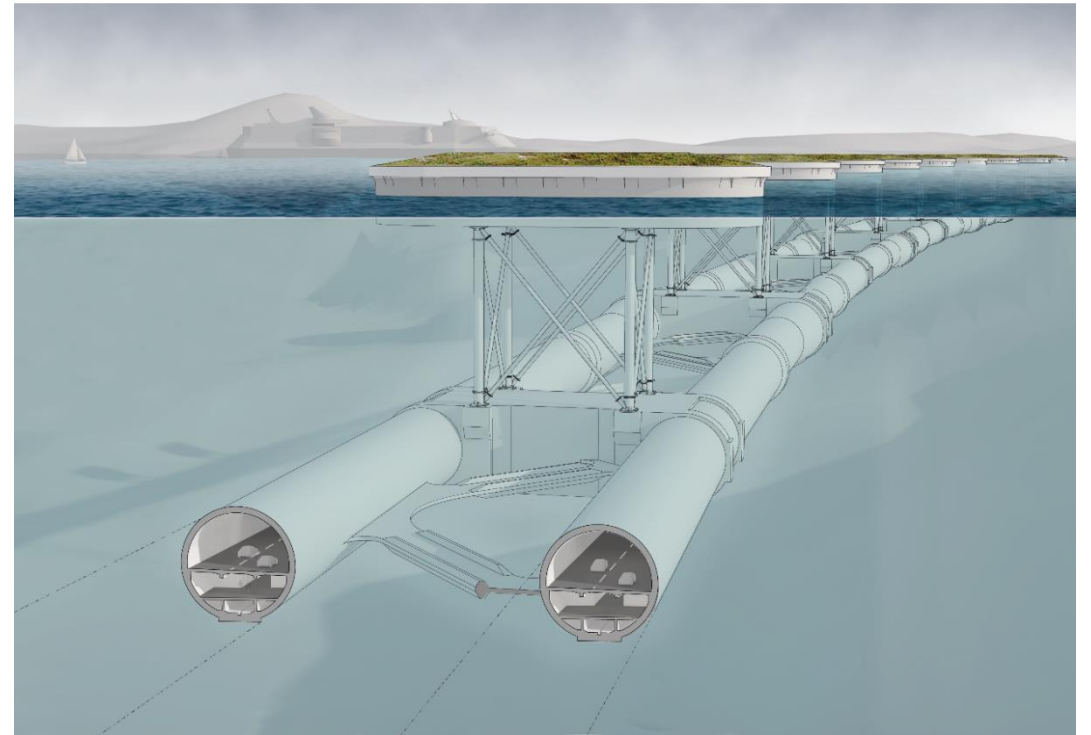
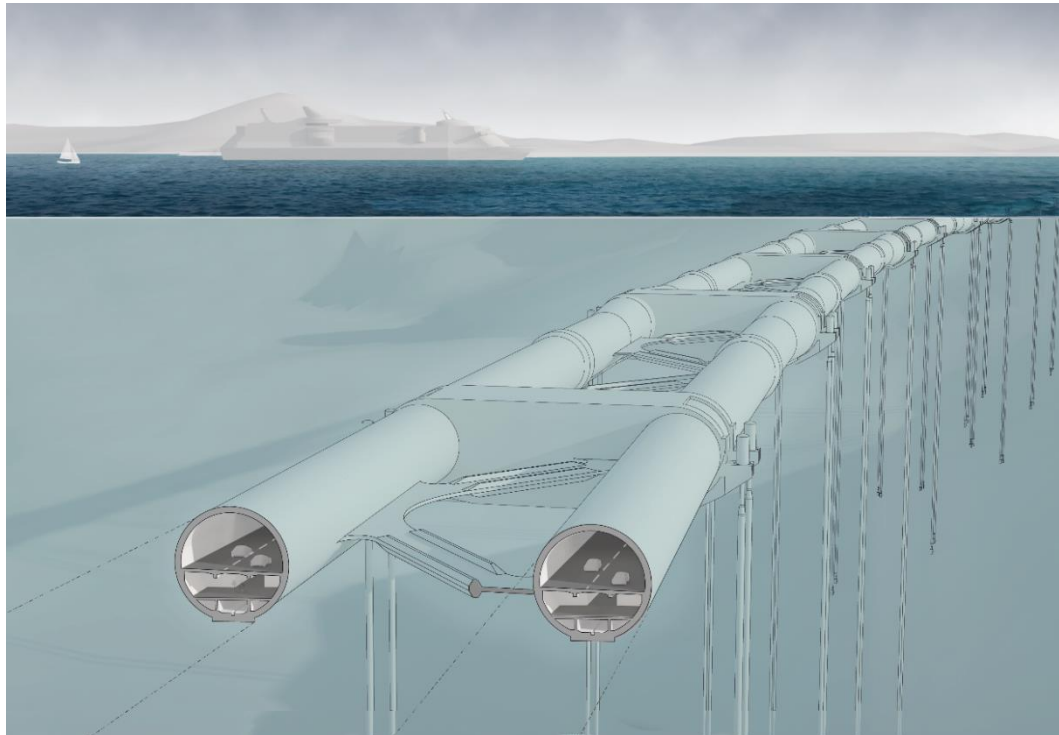
• «...*The Norwegians might be braver **and** better at engineering than you.*»

• -Aarian Mashall, Wired magazine July 14th, 2016

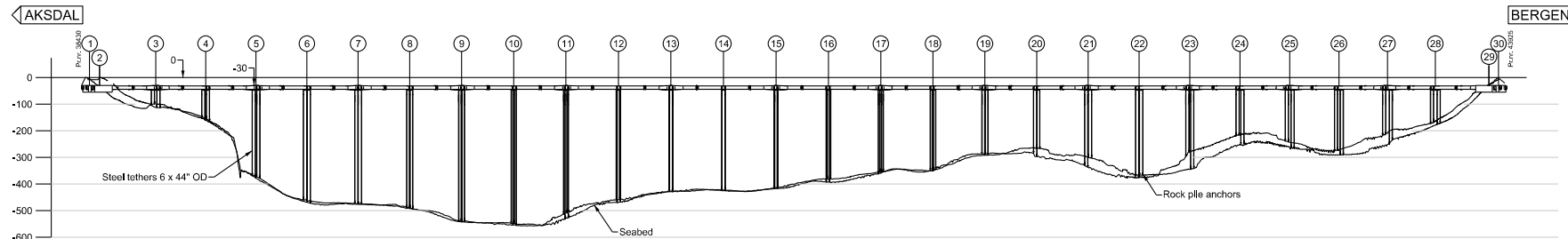


# Bjørnafjorden SFTB

Two alternatives, one tension legged and one pontoon anchored



# Hovedkonfigurasjon stagforankret rørbru



Ikke synlig fra land eller havoverflaten  
Ingen begrensning på skipstrafikk  
Netto oppdrift i rørbrua – lokalisert i tverrforbindelser



Teknologi skaper muligheter

73

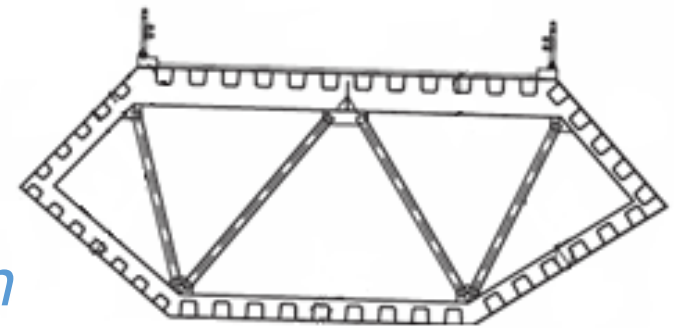
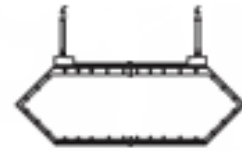
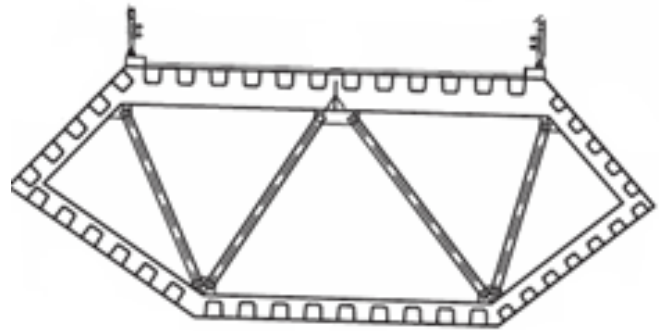
## Bjørnafjorden "endeforankret Flytebru"



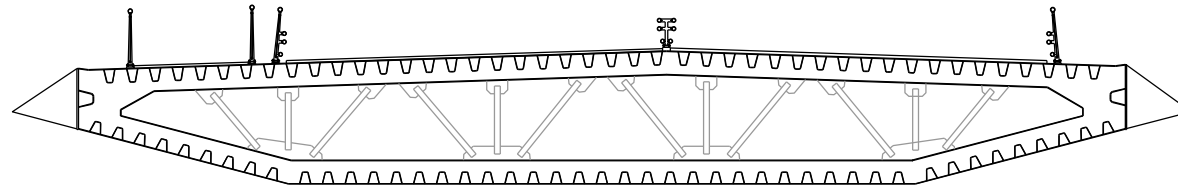
*Kombinasjon av skråstagsbru og flytebru, 5800 m*

Eksempler på viktige grep:

Brukasse før og etter – i målestokk



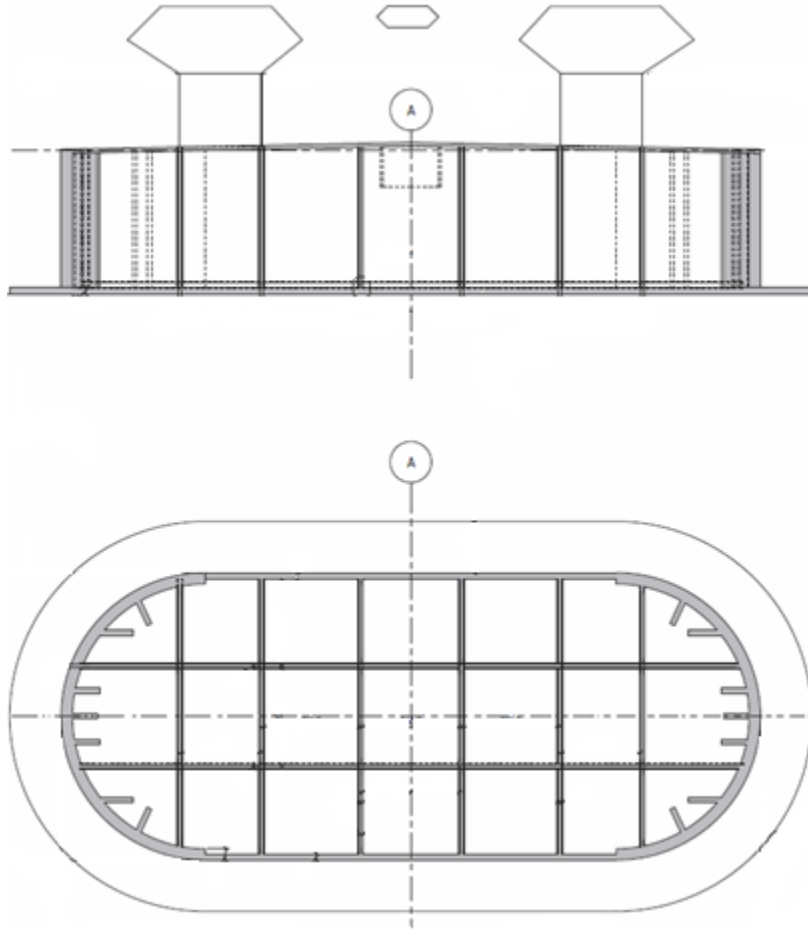
*Brukasse fase 2: 25 t/m*



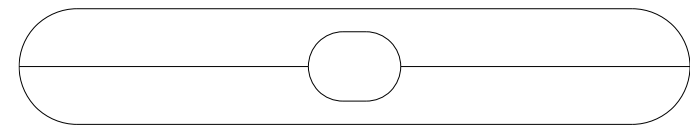
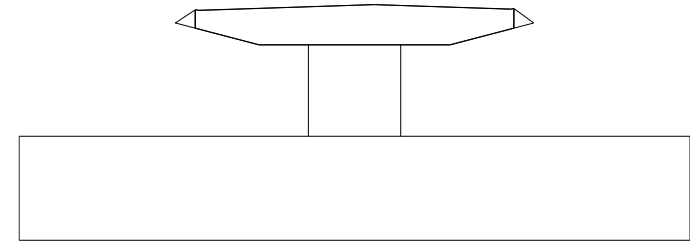
*Brukasse fase 3: 13 t/m*

Eksempler på viktige grep:

Pontonger før og etter – i målestokk



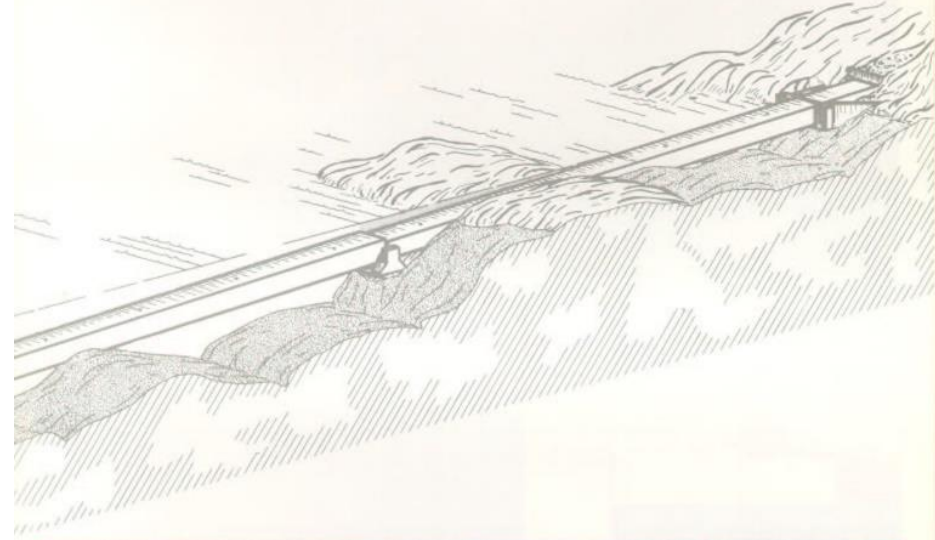
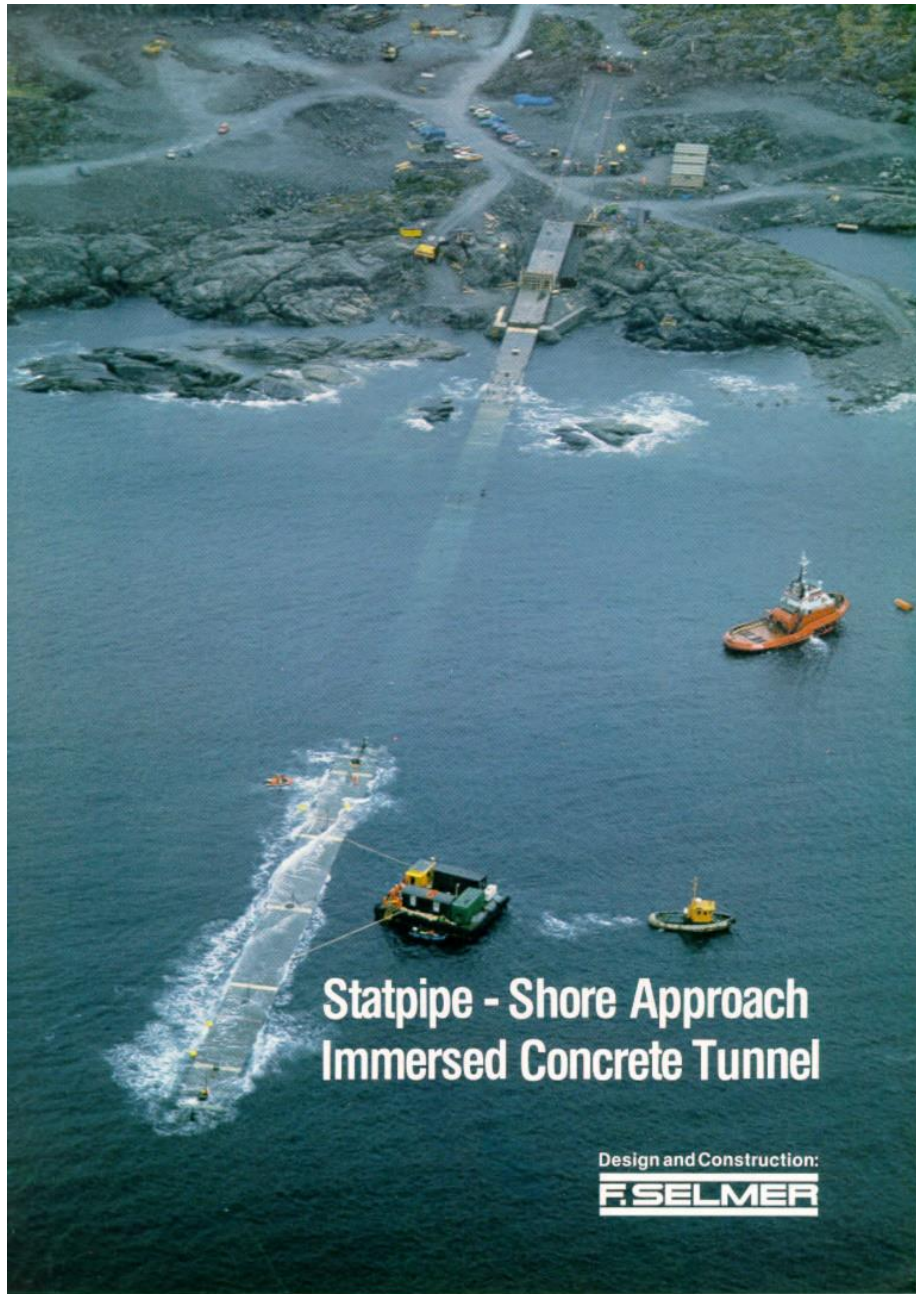
*Pontong fase 2*



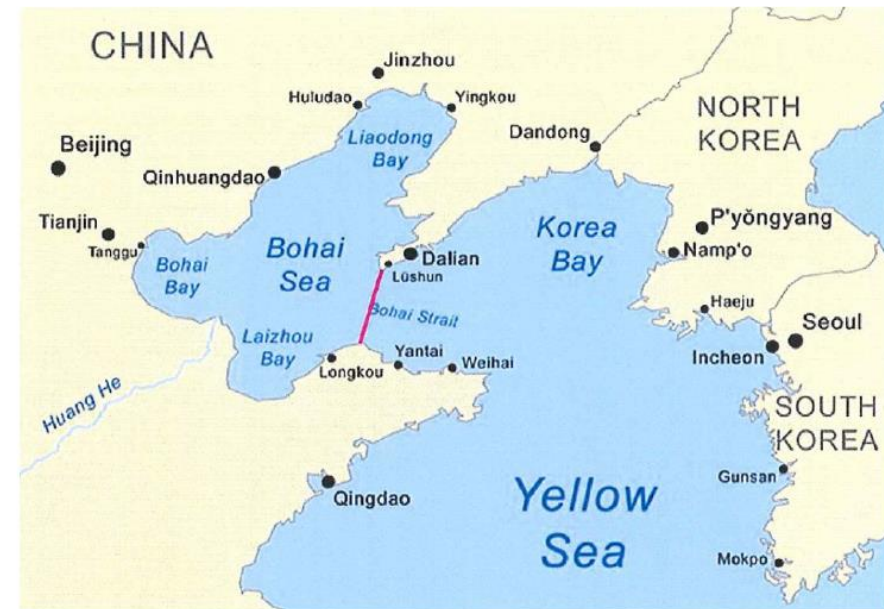
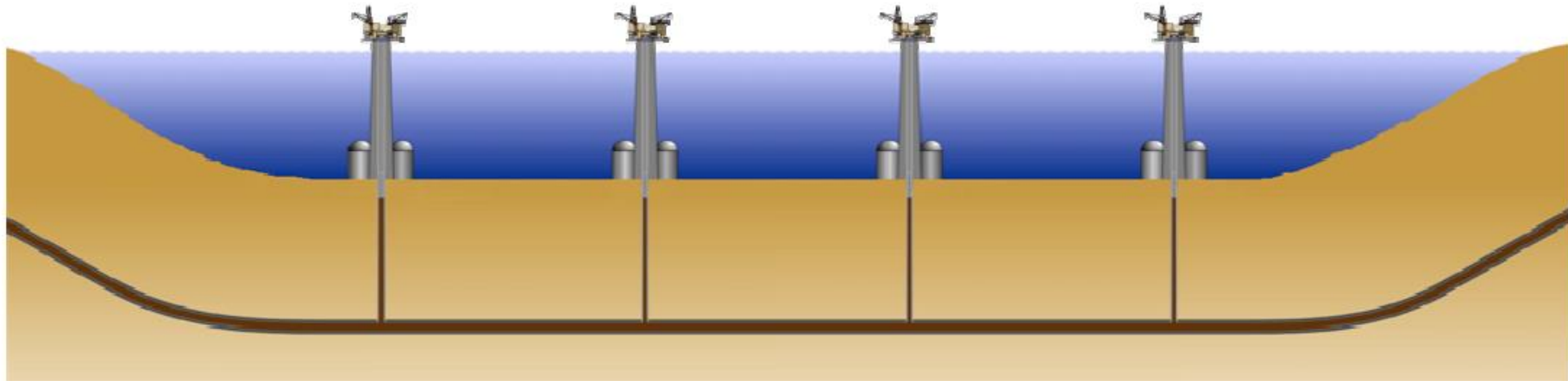
*Pontong fase 3*

# Statpipe Shore Approach





# Draugen 3, 4, 5 og 6 utenfor Kina

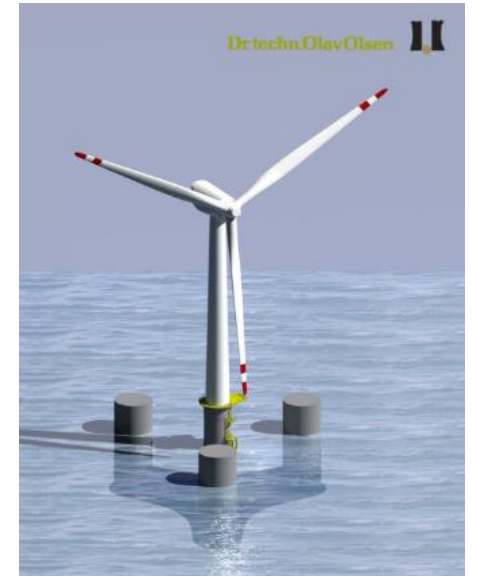
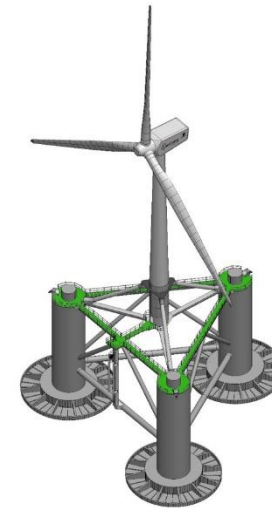
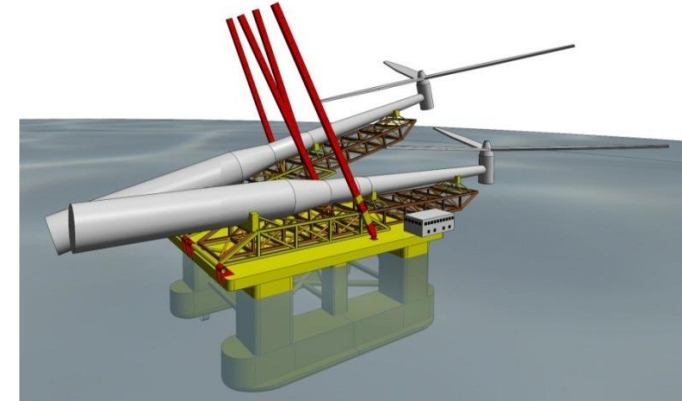
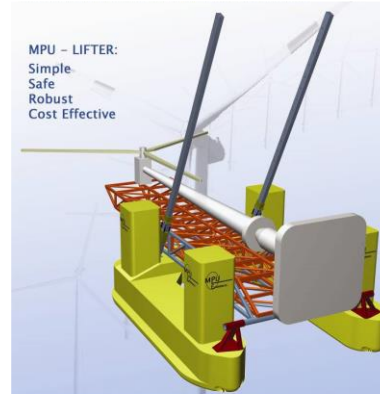


# Stad ship tunnel

- Avoiding harsh conditions in the Norwegian Sea
- World's first ship tunnel
- World's largest tunnel cross section
- Enabling year-through ship transport

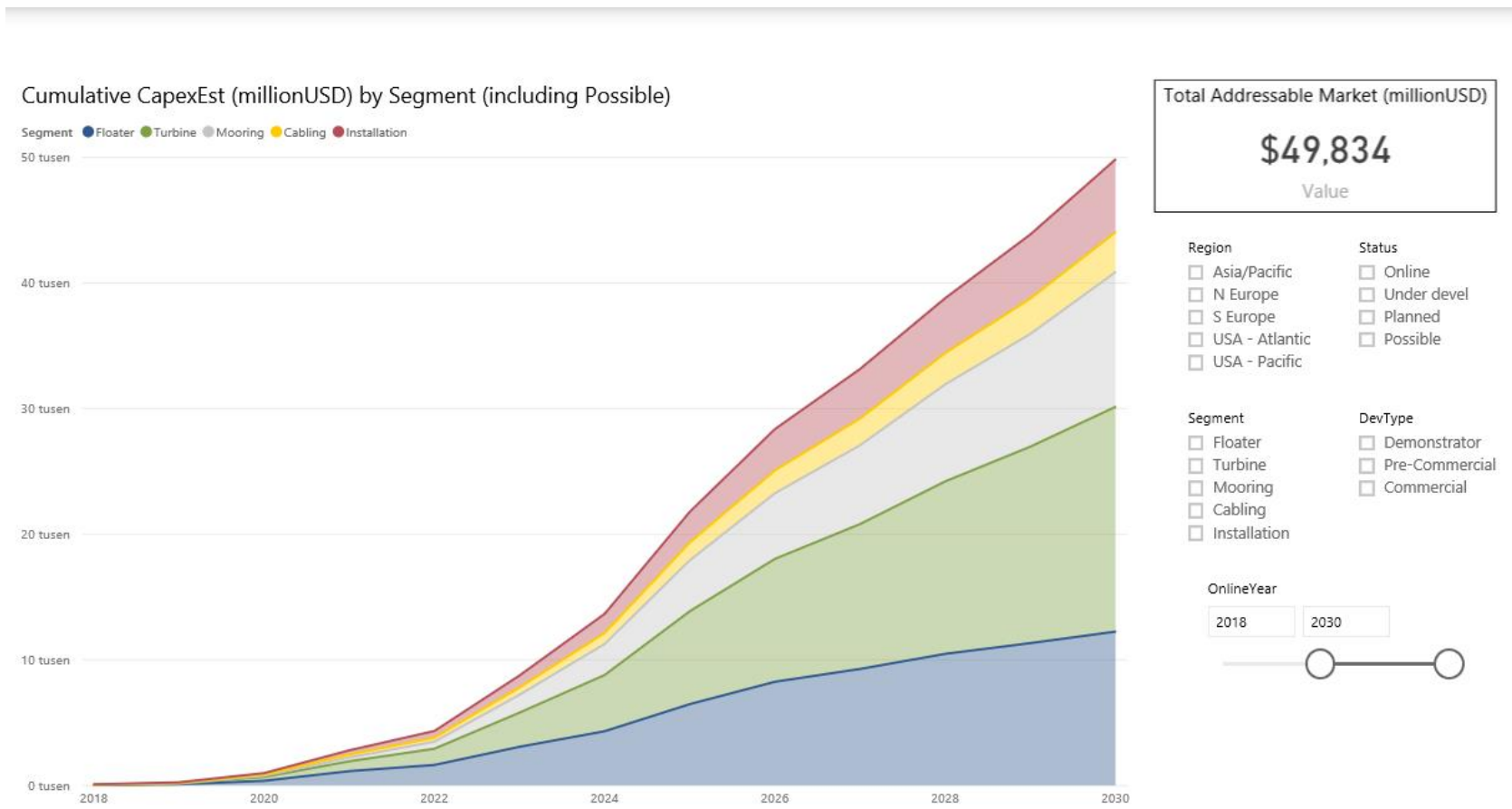


# Olav Olsen - Offshore wind





# SIGNIFICANT FLOATING OFFSHORE WIND MARKET EMERGING

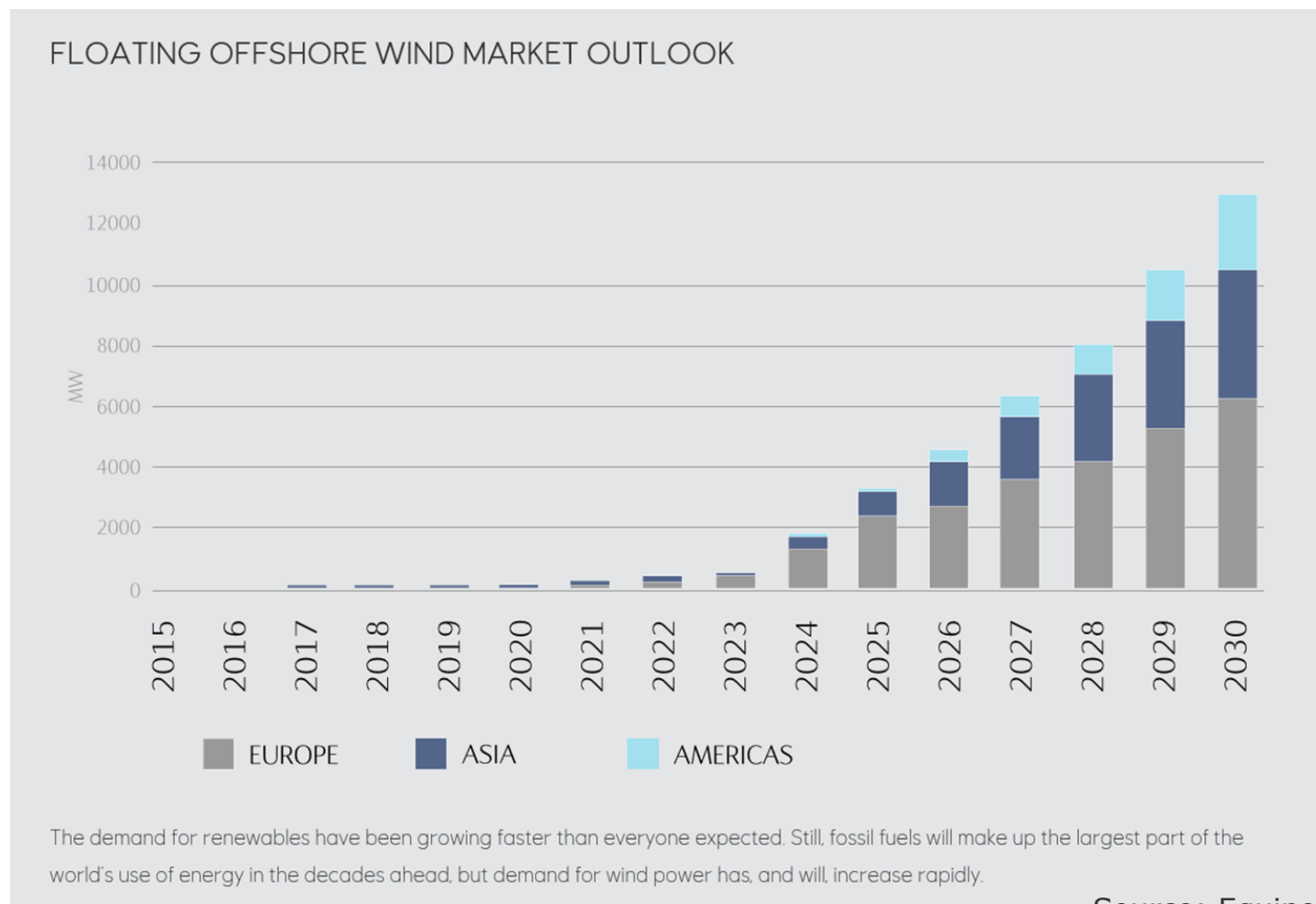


© 2018 Quest Floating Wind Energy, LLC



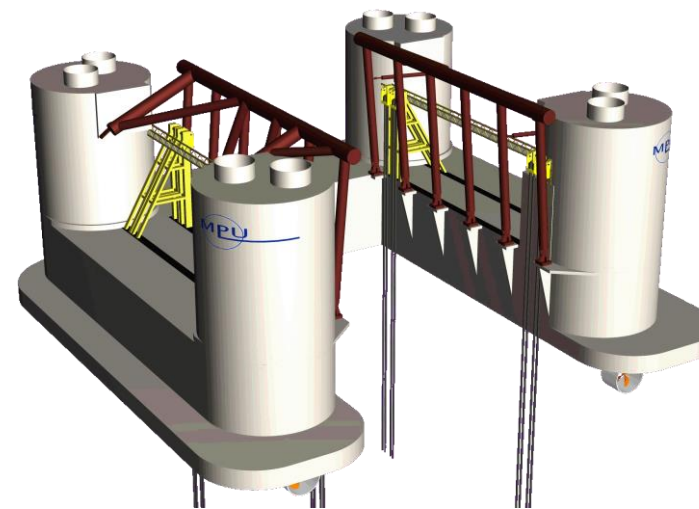
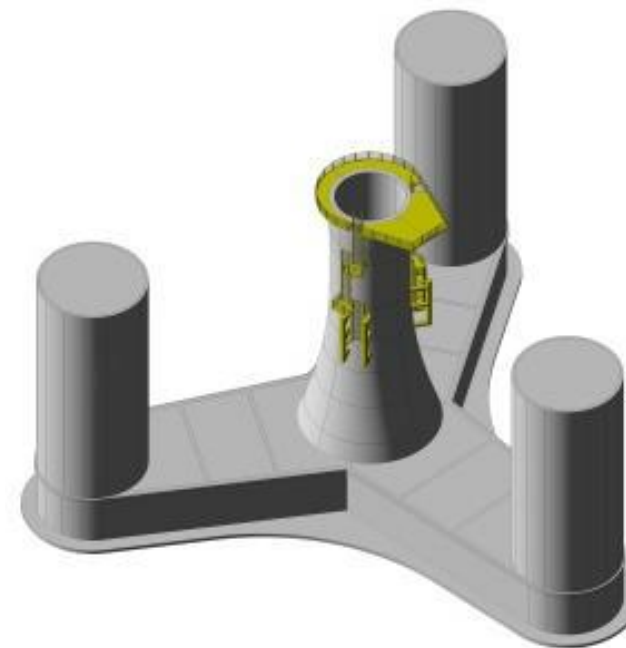
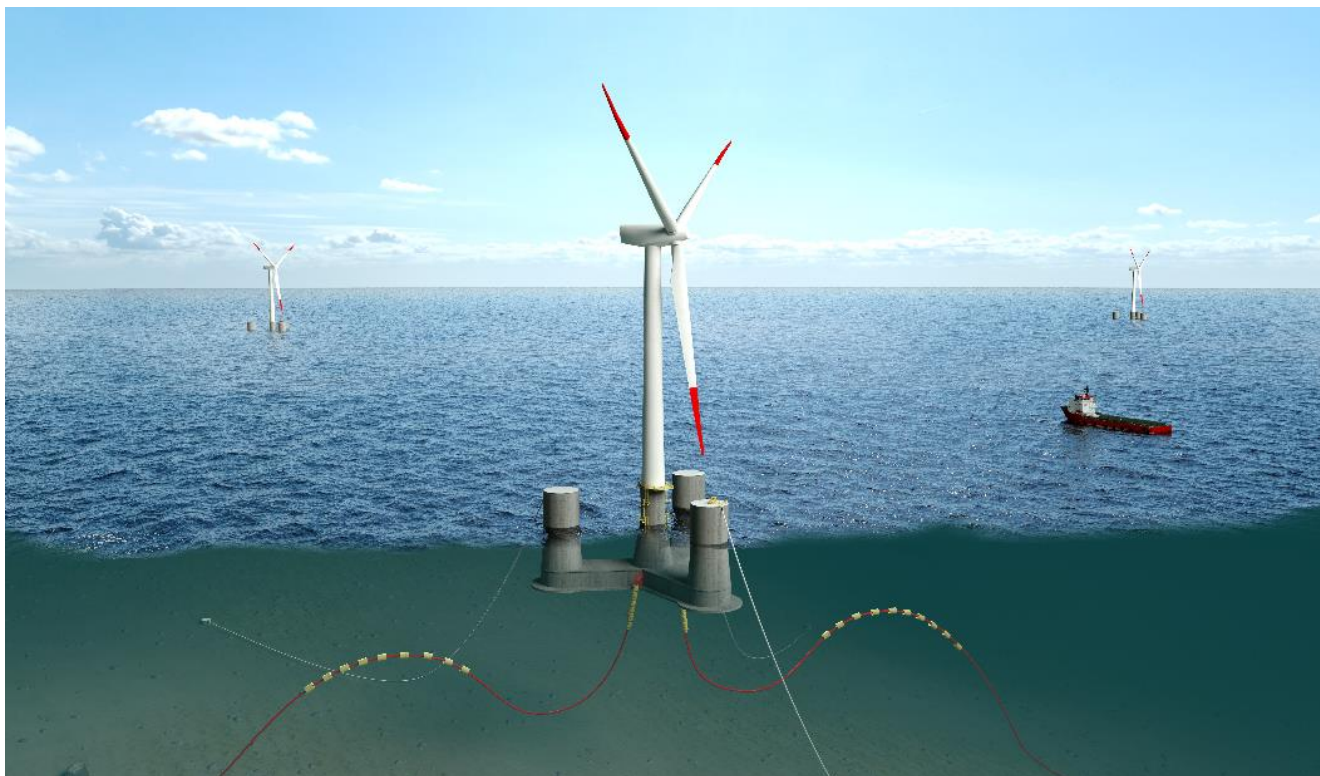
# THE MARKET NEEDS DEPLOYABLE SOLUTIONS BY 2024

## ...FAVOURING CONCEPTS WHICH ARE ALREADY WELL-DOCUMENTED





# The concept – OO STAR

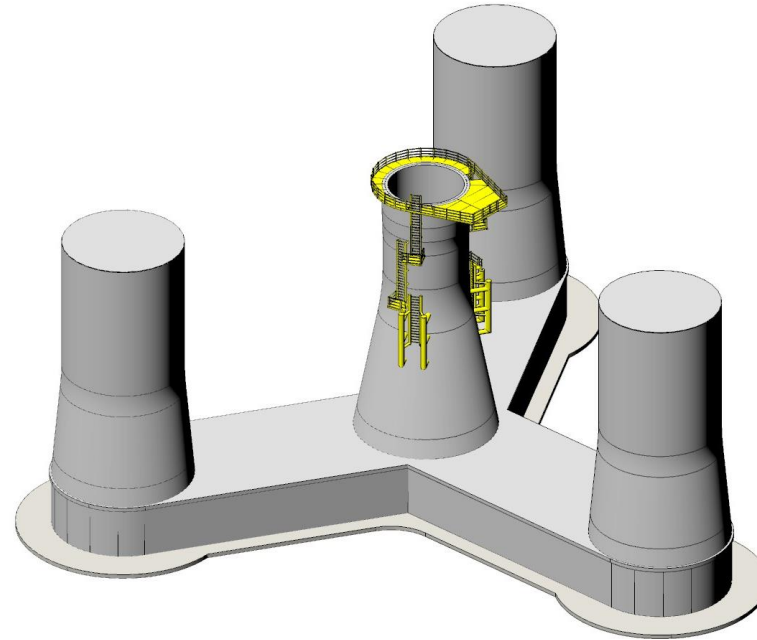


# OO-Star Wind Floater in a Nutshell

## Origin

Designed by Dr. techn. Olav Olsen  
Developed in-house in 2011  
Further developed in

- RCN project 2013-14 and
- H2020 project 2015-18



## Maturation

Based on proven North Sea offshore concrete technology with 45 years track record.  
Successfully tested at SINTEF Ocean.  
Benchmarked against Spar on Tampen

"Simple, Safe, Robust, Durable and Scaleable"

## Features

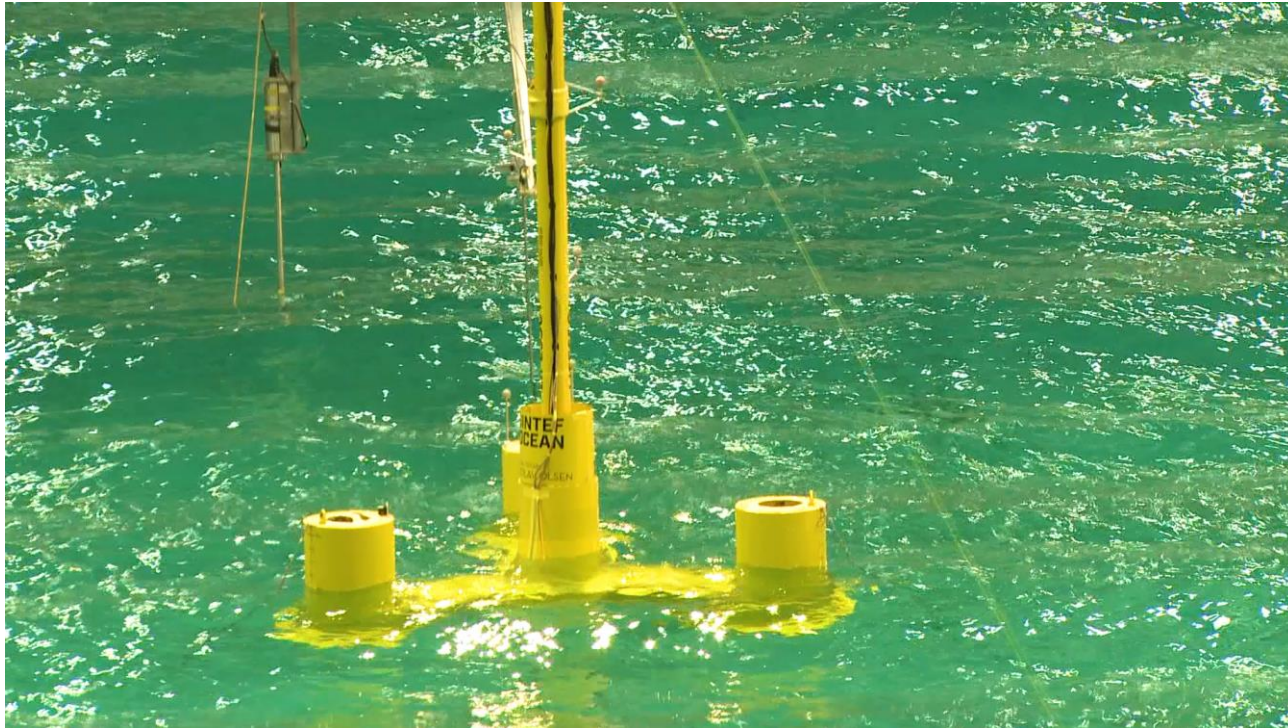
- Concrete hull
- Clean and simple geometry
- Spread mooring
- Symmetric, central WTG/tower
- Shallow draft; 8m inshore, 20 m operational
- No active ballasting

## Benefits

- "All" environmental conditions
- Excellent sea motions
- Long design life (100 yrs)
- Efficient scaling
- Quayside completion
- Worldwide fabrication
- High local content

# Successful Model tests verify concept

...even for sea states well above design criteria



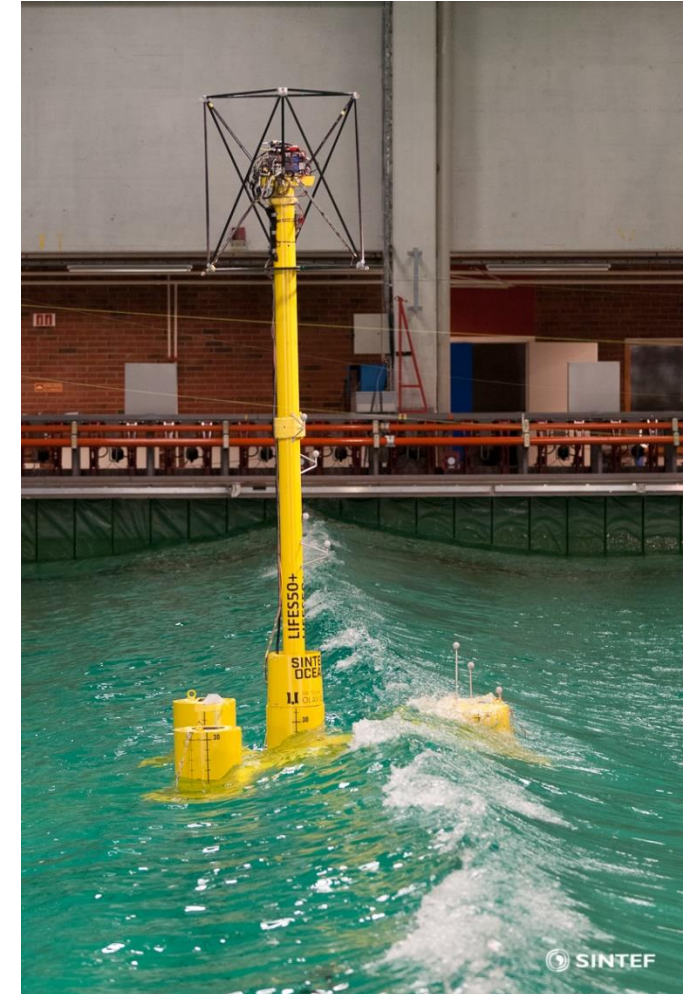
- > RCN project (2013-2014): Wave basin test in Nantes
- > Lifes50+ (2017): Wave basin test at Sintef Ocean in Trondheim
- > Lifes50+ (2018): Wind tunnel test at Politecnico di Milano

[Video: Wave basin testing at Sintef Ocean](#)

[Video: Wind tunnel test at Politecnico di Milano](#)

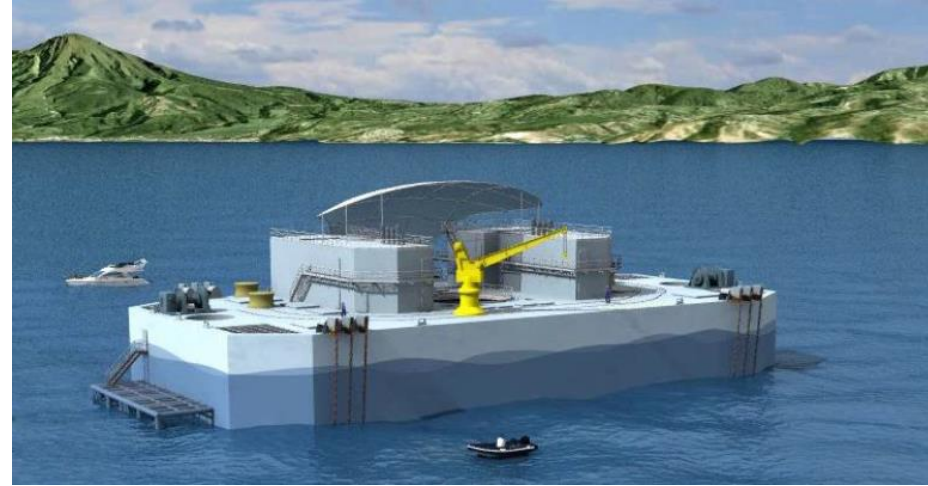
# L50+ Model test – Main conclusions

- Excellent motions
- Low heave/pitch response in extreme sea states.
- Extreme values compare well with computer simulations.
- Good second order scaling of wave response
- No instability from wave overflow at corner columns (validated with extreme wave)



# Renewable energy Projects other than offshore wind

- Floating solar energy
- Wave energy
- Tide energy
- Ocean Thermal Energy





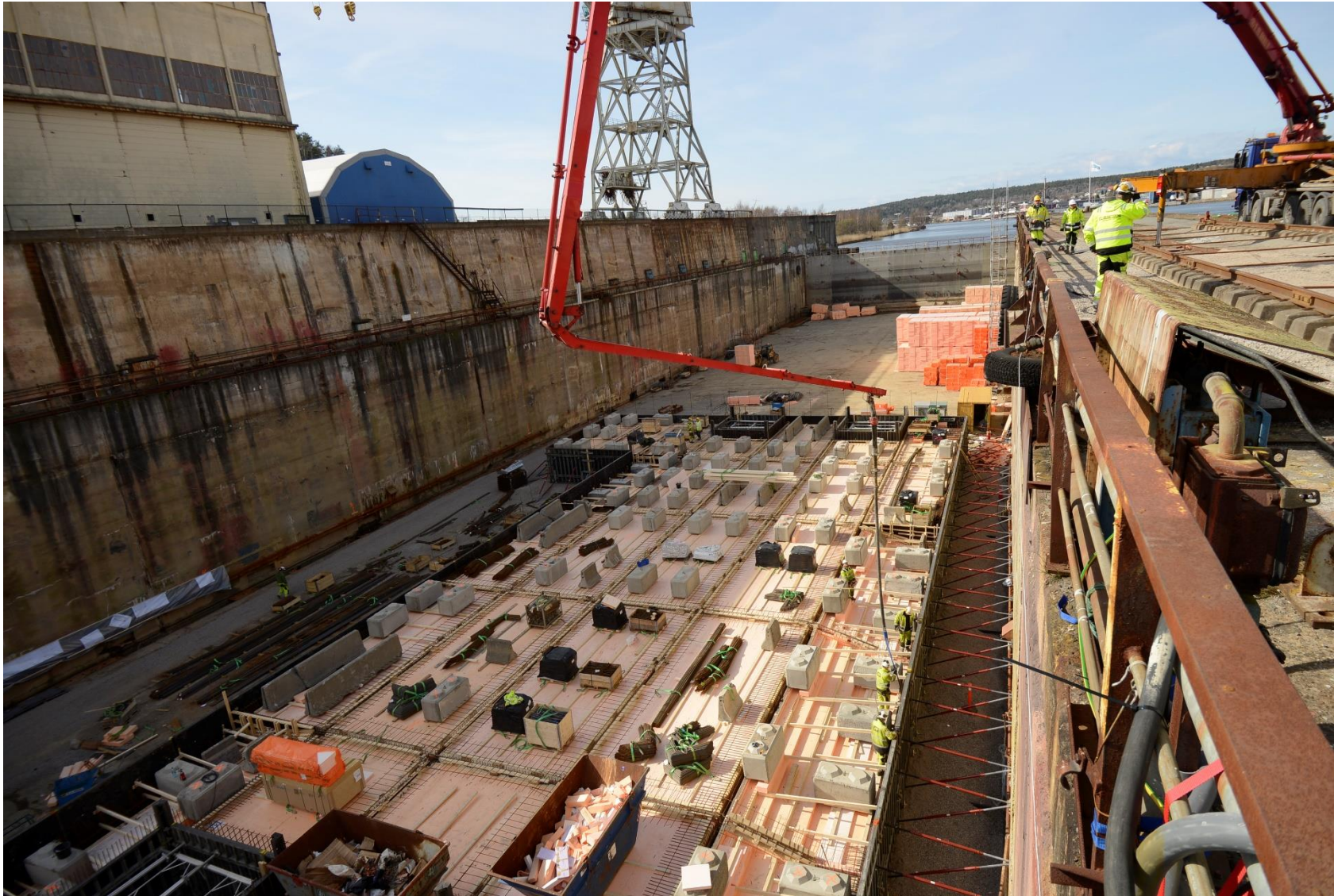
# Sjøbadet – Sørenga - Byutvikling

Sørenga – Fra havn til bomiljø

Foto: 1971, Oslo Byarkiv



# Utførelse – Bygging i Fredrikstad



# Utførelse – Bygging i Fredrikstad

Ut av dokk



# Utførelse – Installering på sørenga

Installert  
november 2014

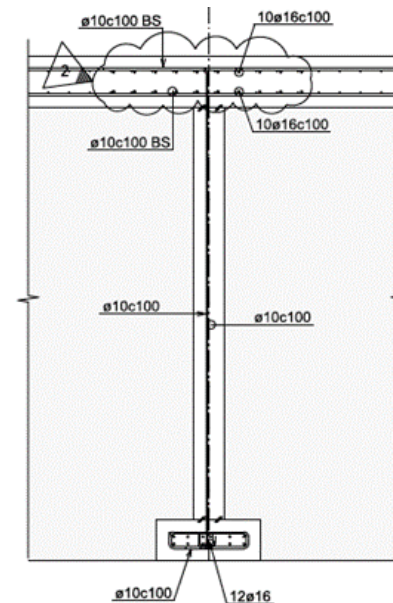
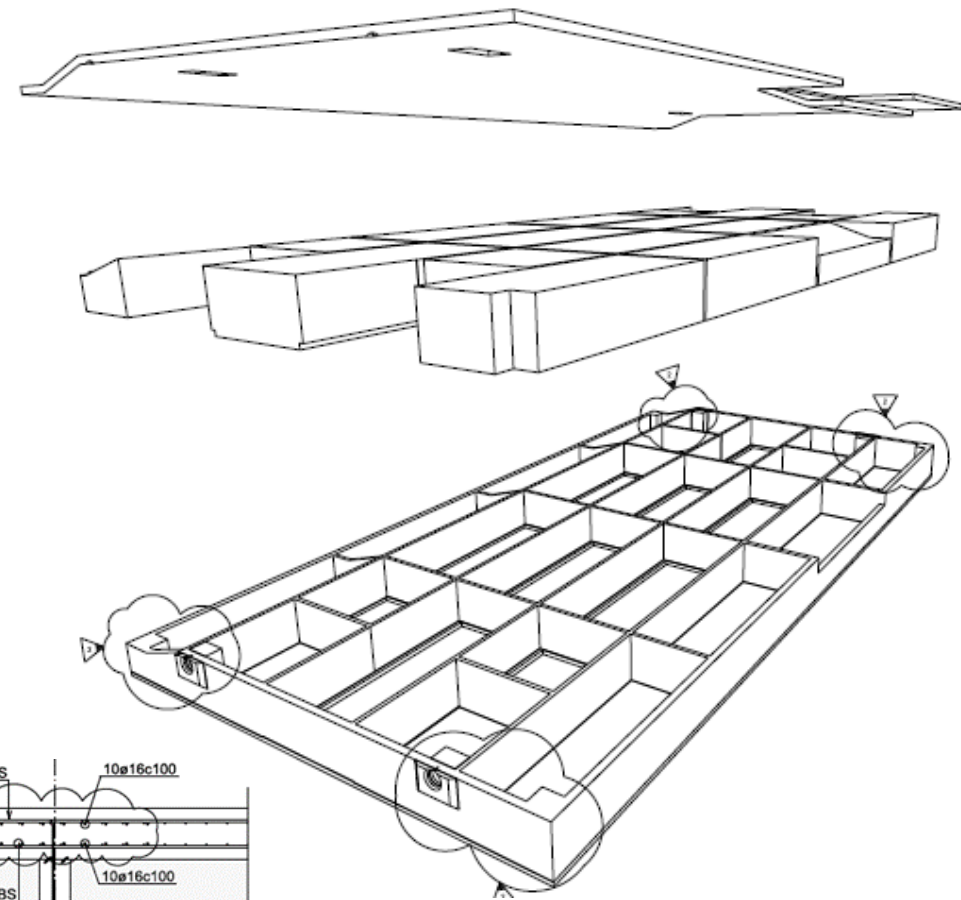
[Video](#)



# Main principle

Weight is important for floating structures.  
Weight increase needs more buoyancy.  
More buoyancy needs a larger structure,  
needs more buoyancy, needs.....

- XPS gives buoyancy
  - EPS not sufficiently sustainable
- Top slab and walls/ribs give structural strength.
- Bottom slab skipped to save weight
- Central one layer of reinforcement

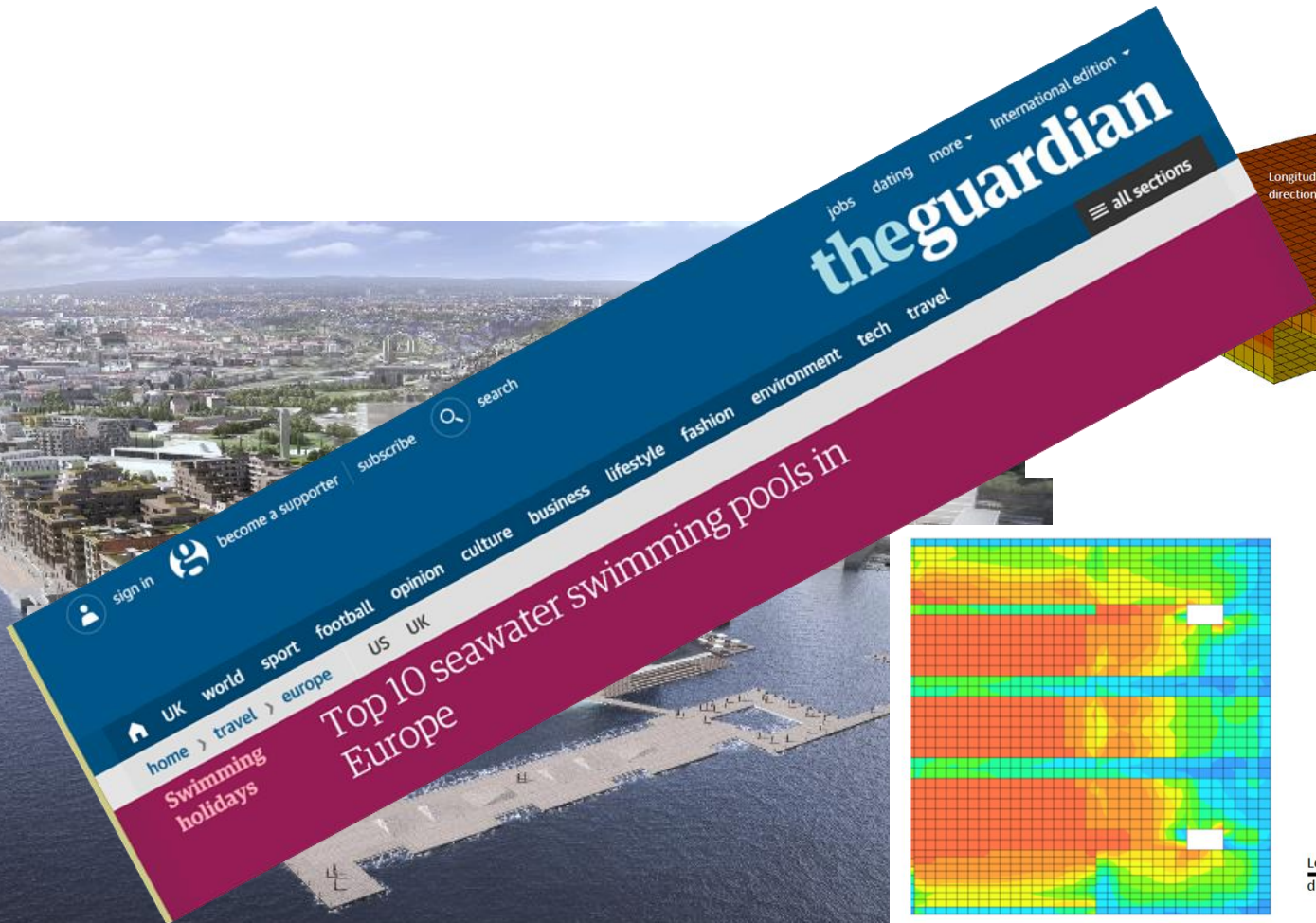
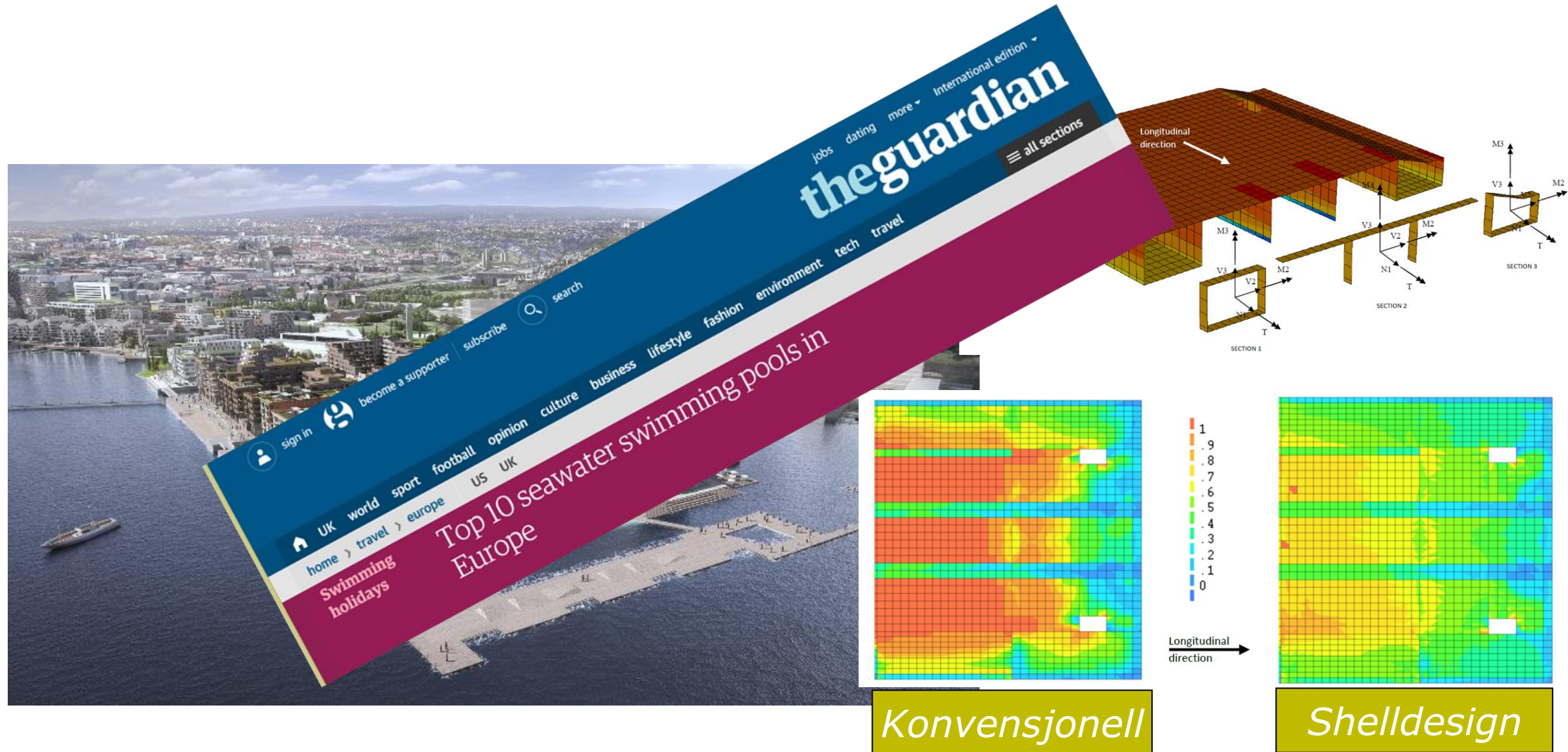


TYPISK LANGSGÅENDE  
INNERVEGG



<http://www.osloby.no/nyheter/Folkefest-under-apningen-av-nye-Sorenga-sjobad-8072665.html>

# CASE: SHELLDESIGN OG SJØBADET SØRENGA



Konvensjonell

Shelldesign

# Construction in Fredrikstad, Norway

Effective ribs

Single layer of reinforcement





# Suksessfaktor: Synergier mellom prosjekter



*OO Star Wind Floater*



*Sjøbadet flytende park*



*Fjordkryssinger*

## Fellespunkter

Forankring

Vind

Bølger

Dynamikk

Struktur

Byggemetoder

Marine operasjoner

Core competence applied on new areas:

# Urban development by and on the water



Sørenga og Bispevika



Floating hotel

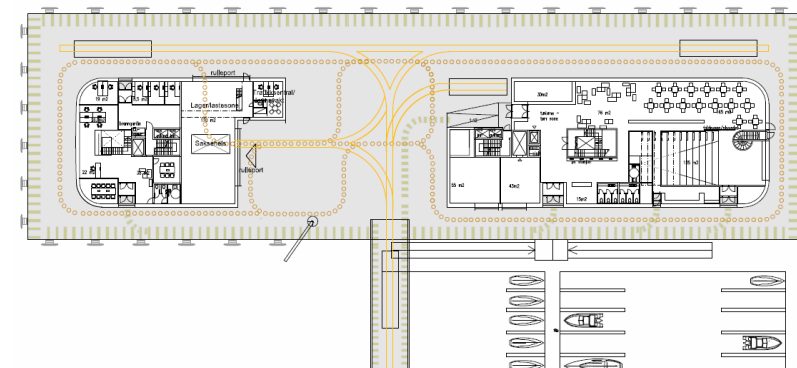


Floating homes

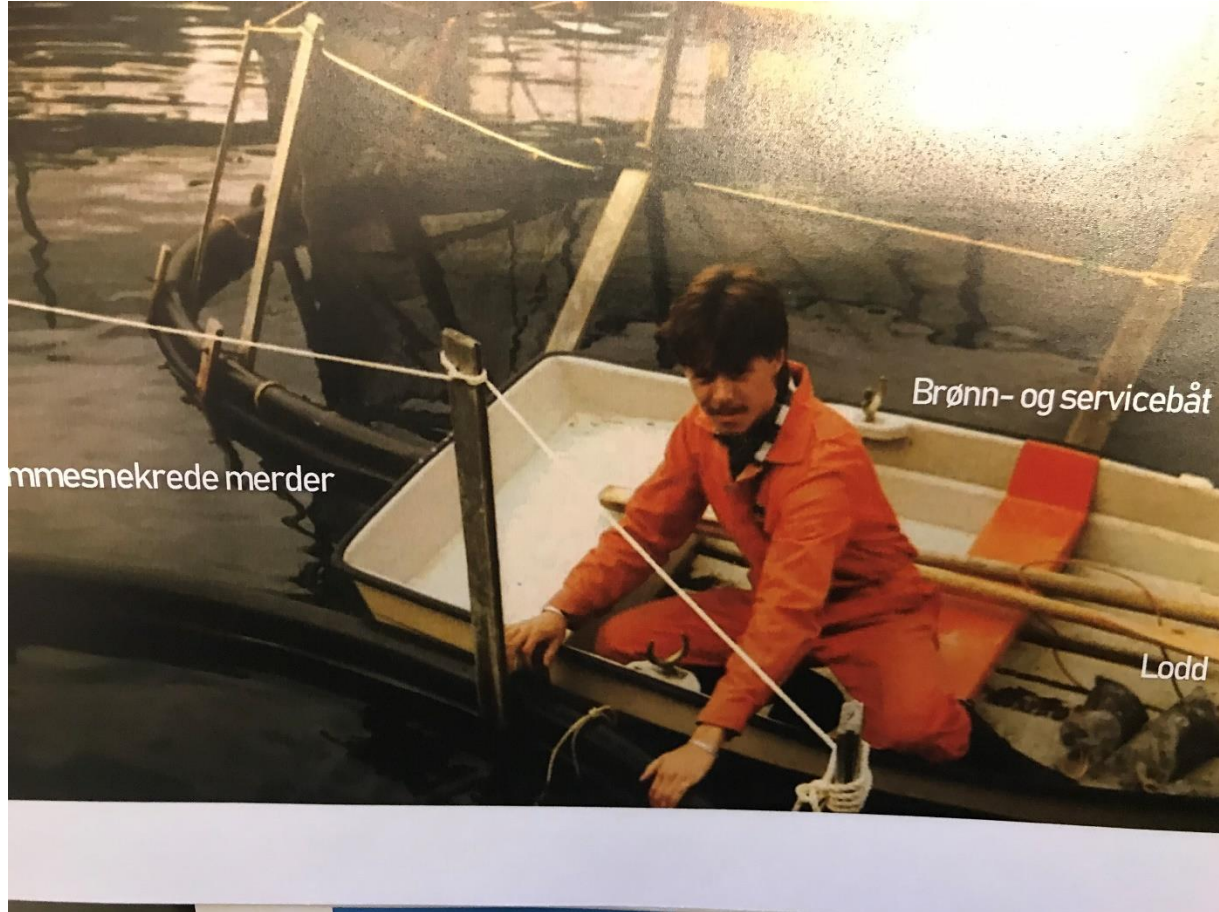




# Floating Qey Longyearbyen 120x35x9m







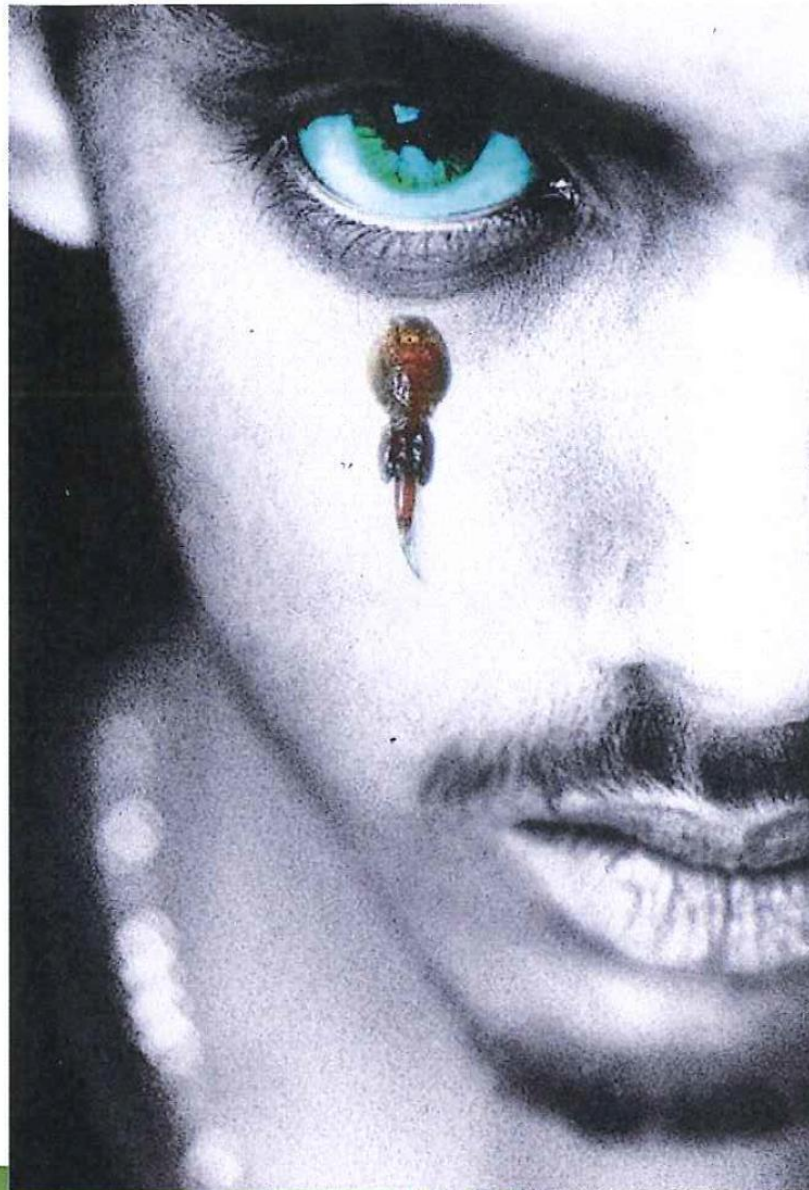
mmesnekrede merder

Brønn- og servicebåt

Lodd

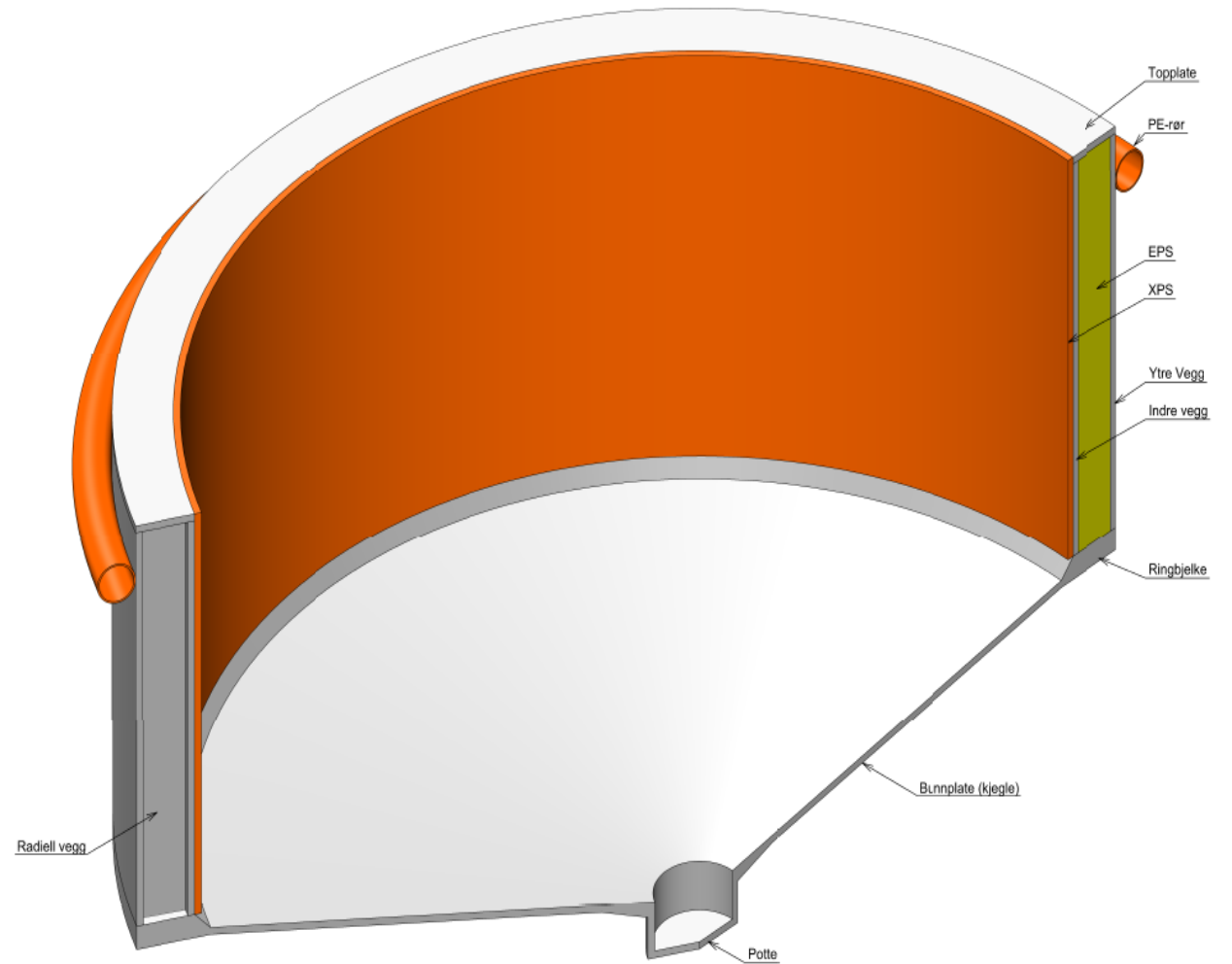
# Utfordringar:

- Lus
- Rømming
- Forureining/næring
- Før
- Areal
- Sjukdommar
- .....

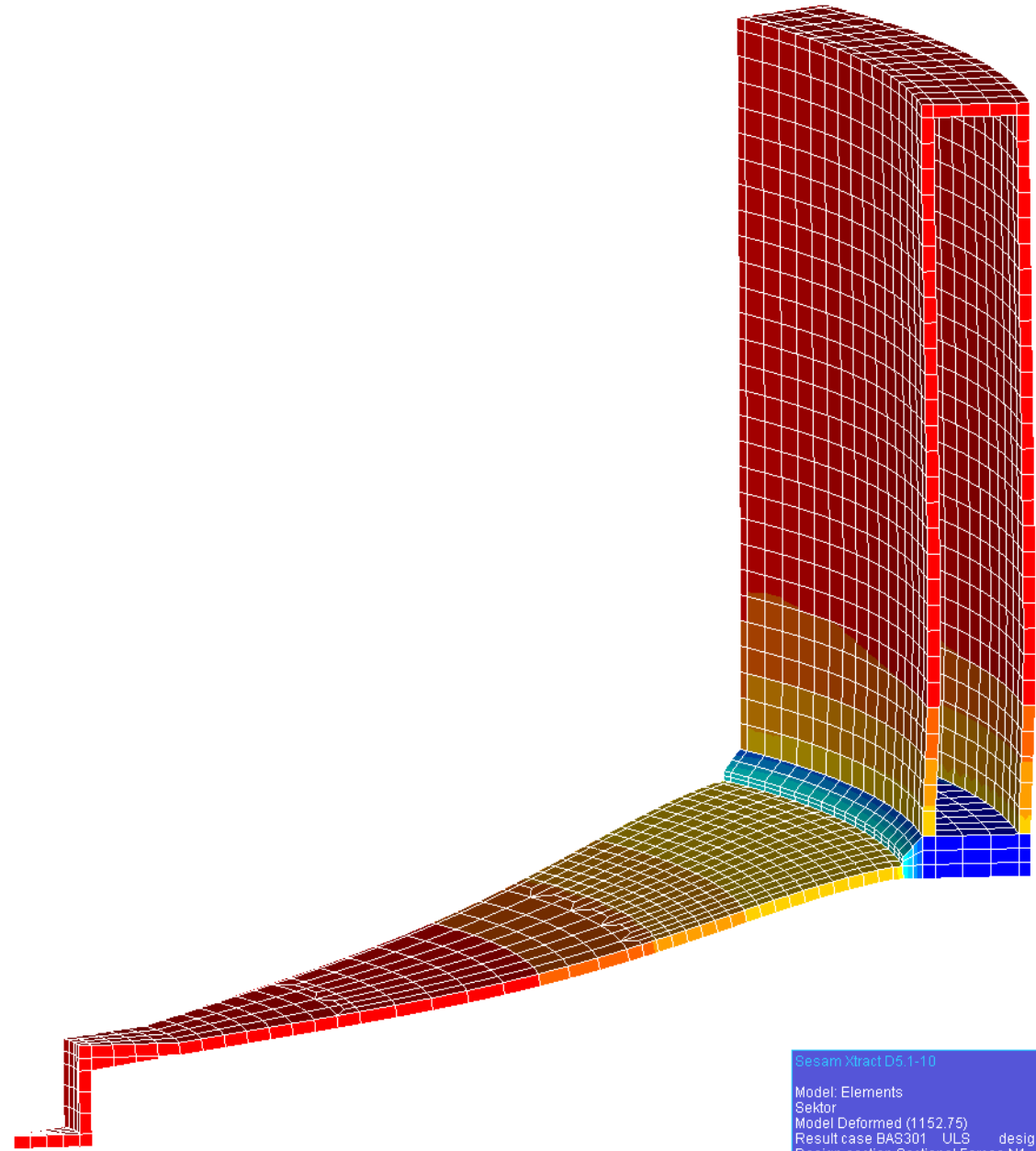
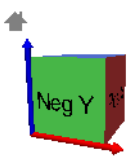
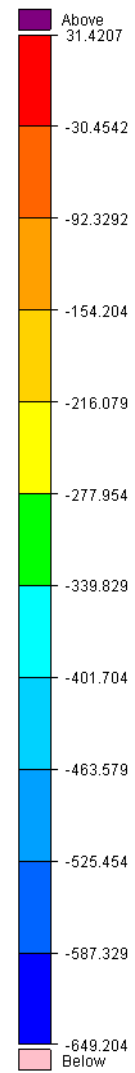




# FishFarming Innovation

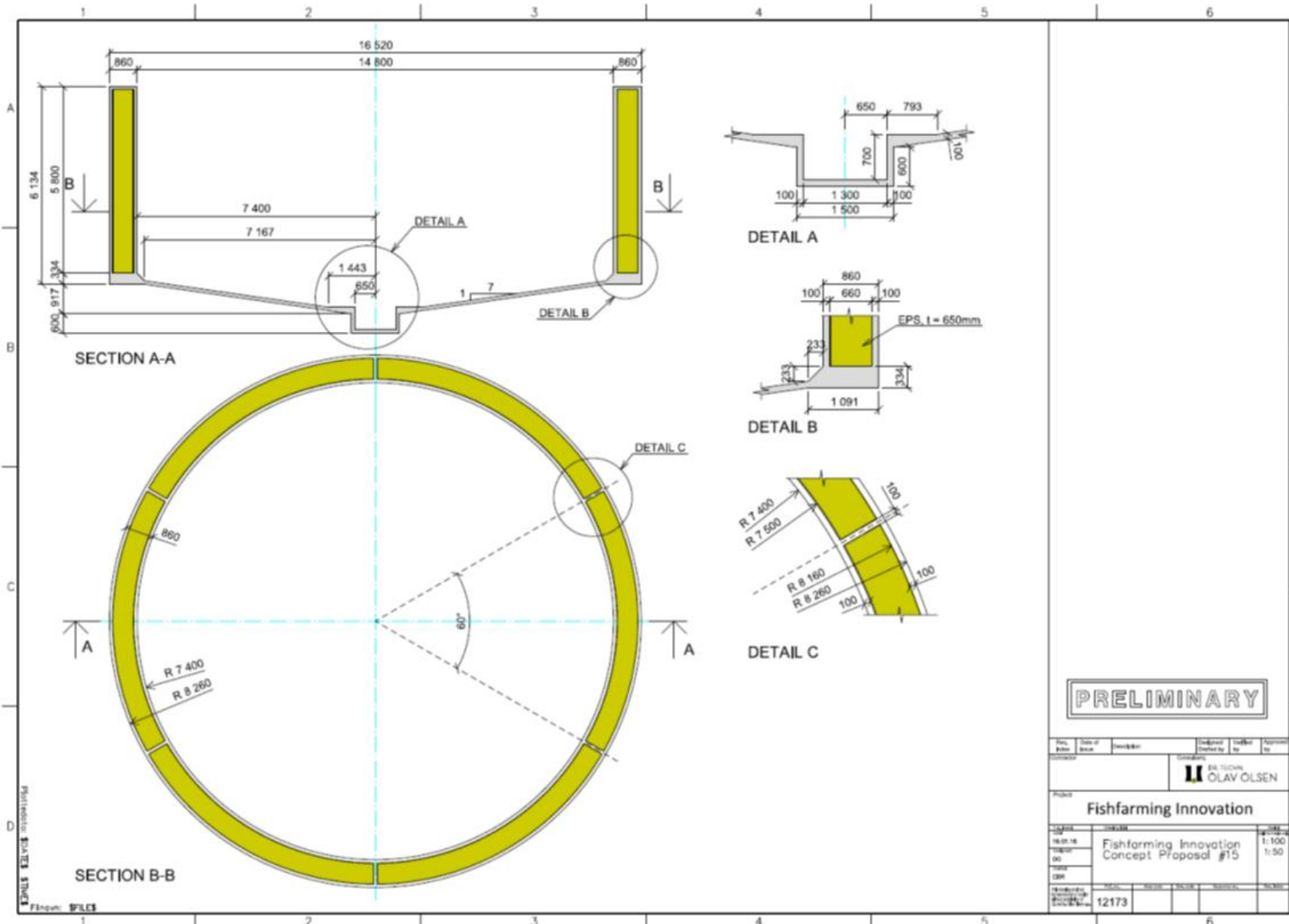


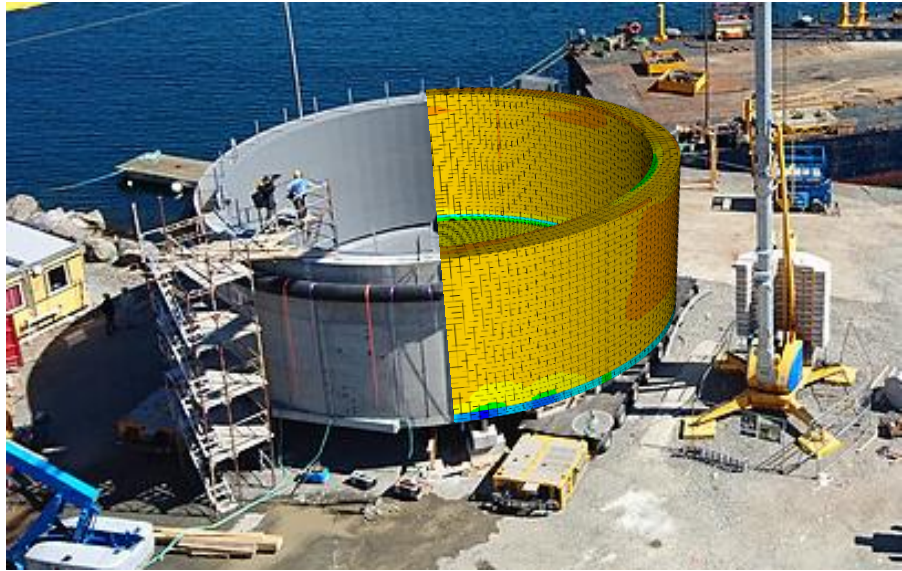
Contours



Sesam Xtract D5.1-10 2016-06-06 15:24  
Model: Elements  
Sektor  
Model Deformed (1152.75)  
Result case BAS301 ULS design combination loadcase  
Design section Sectional Forces N1  
Min: -649.204 Max: 31.4207

# FishFarming Innovation





07,08/06/2018



Technology and experience create possibilities:

«Salmon home #1» prototype  
The worlds first closed concrete bucket for fish farming

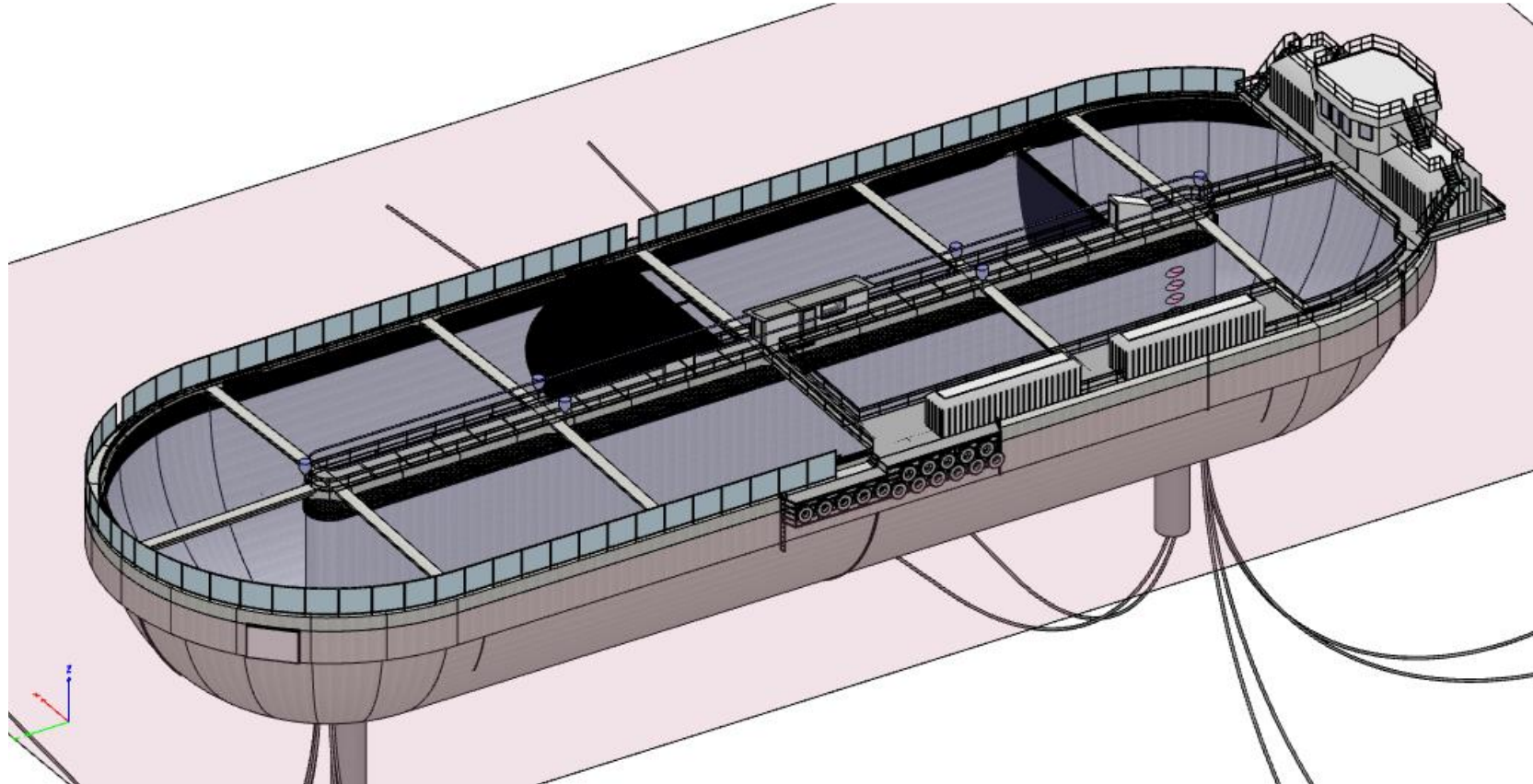
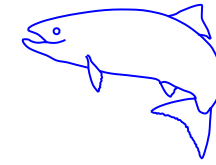


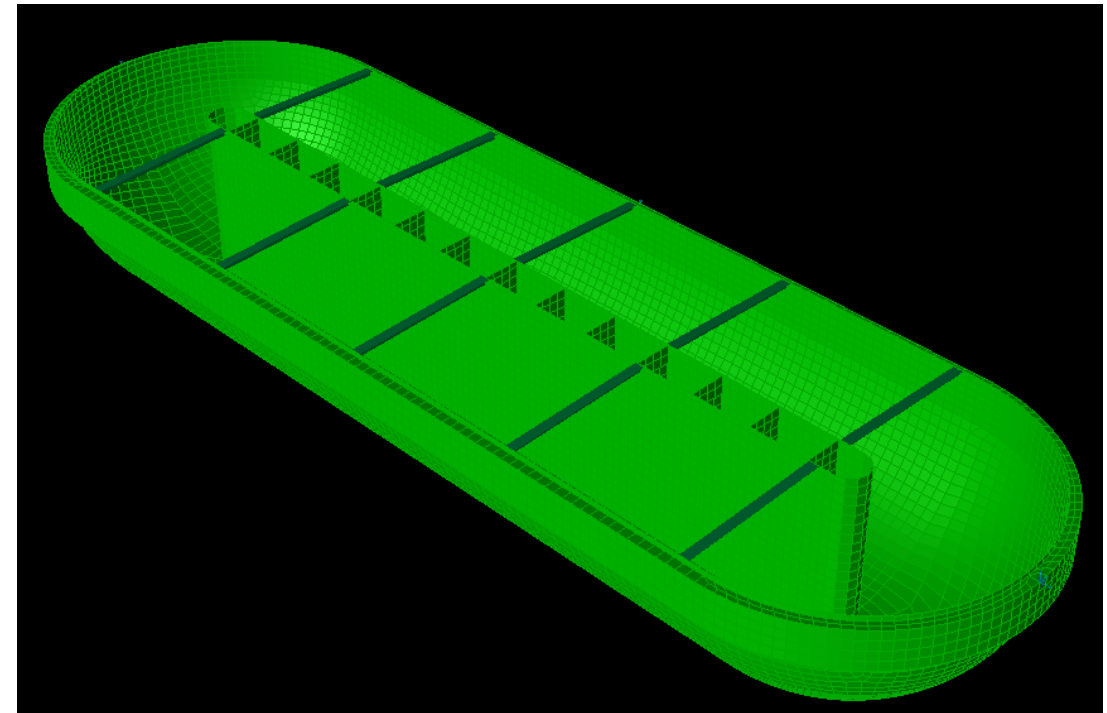
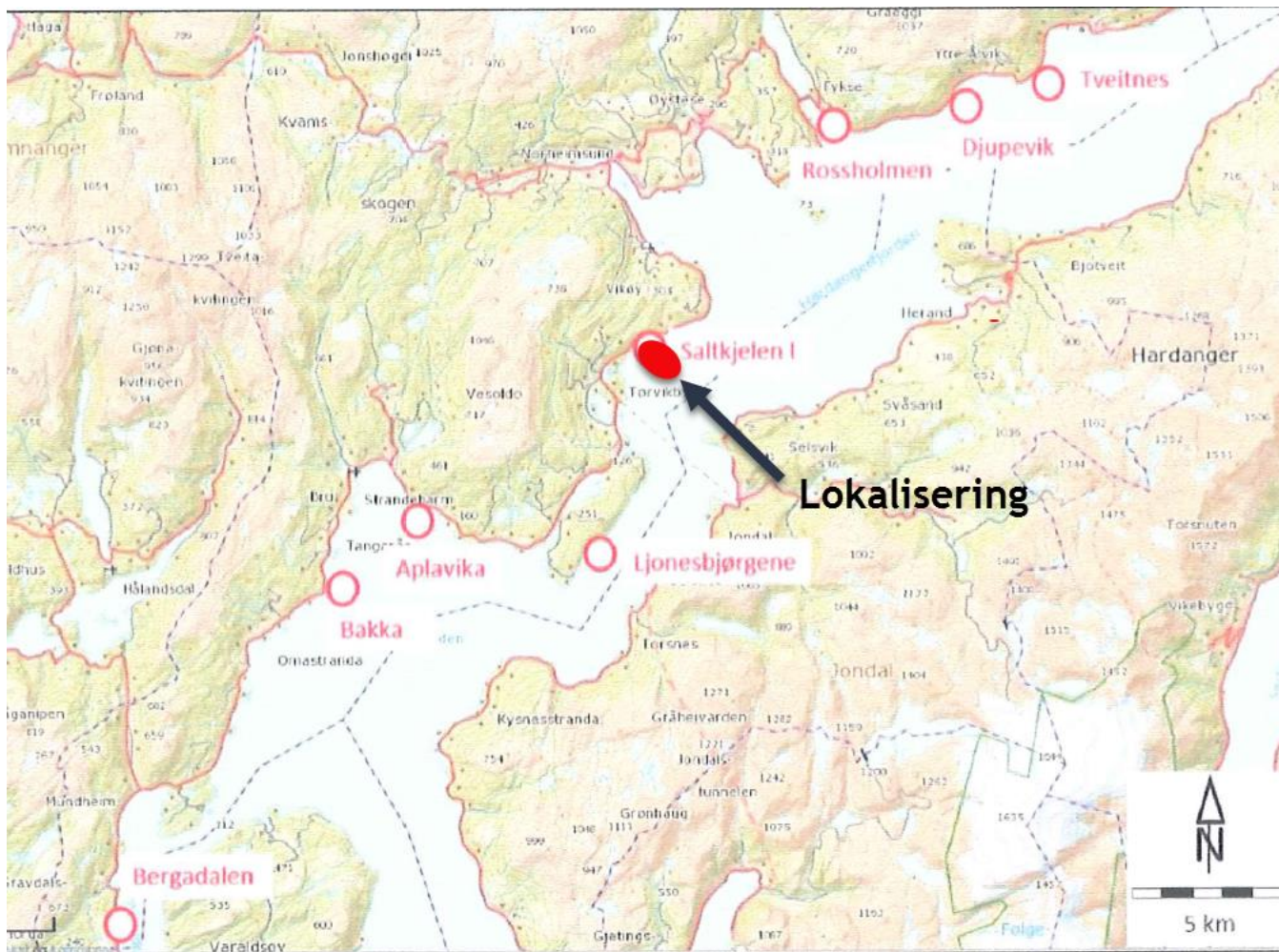


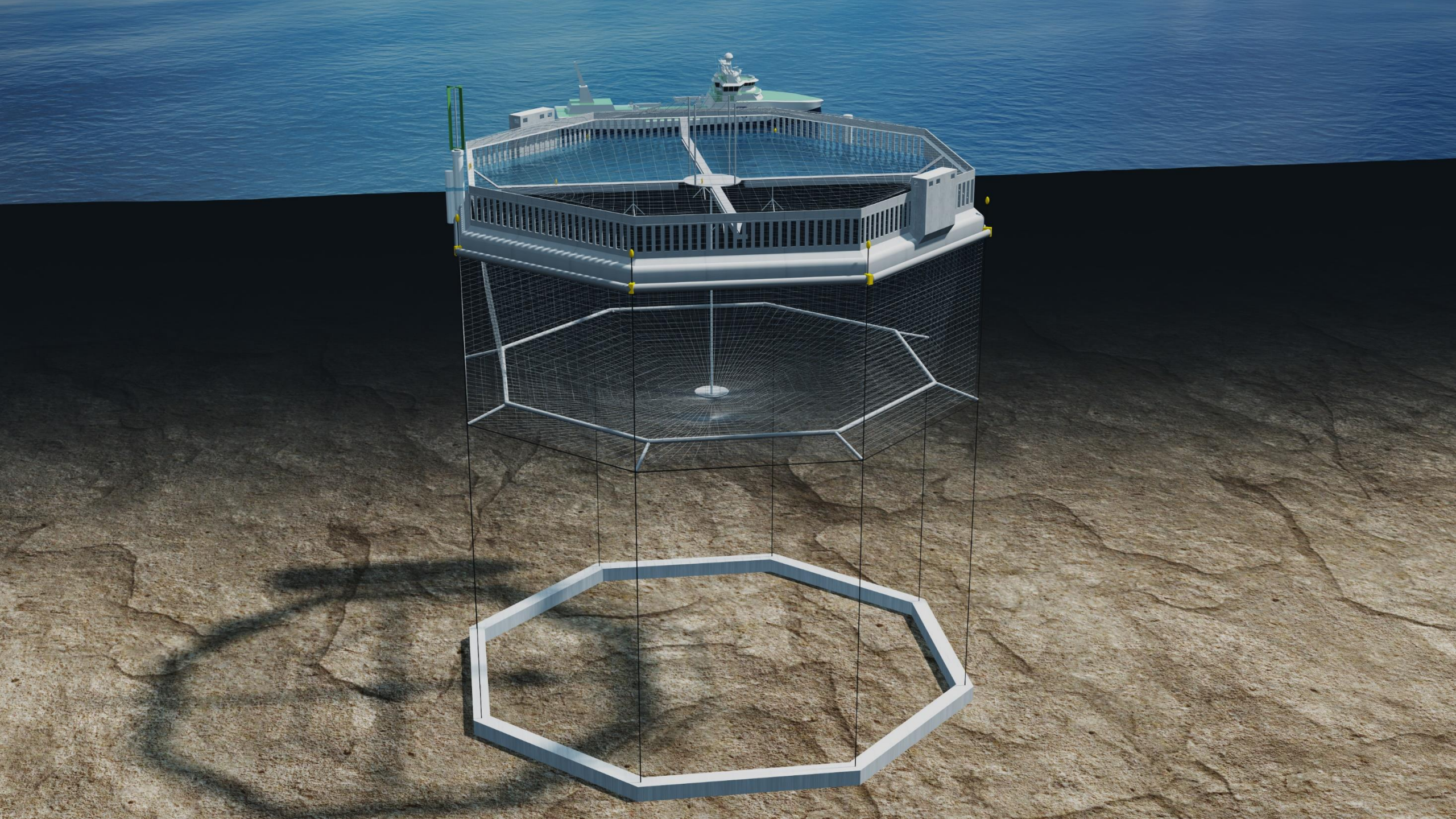


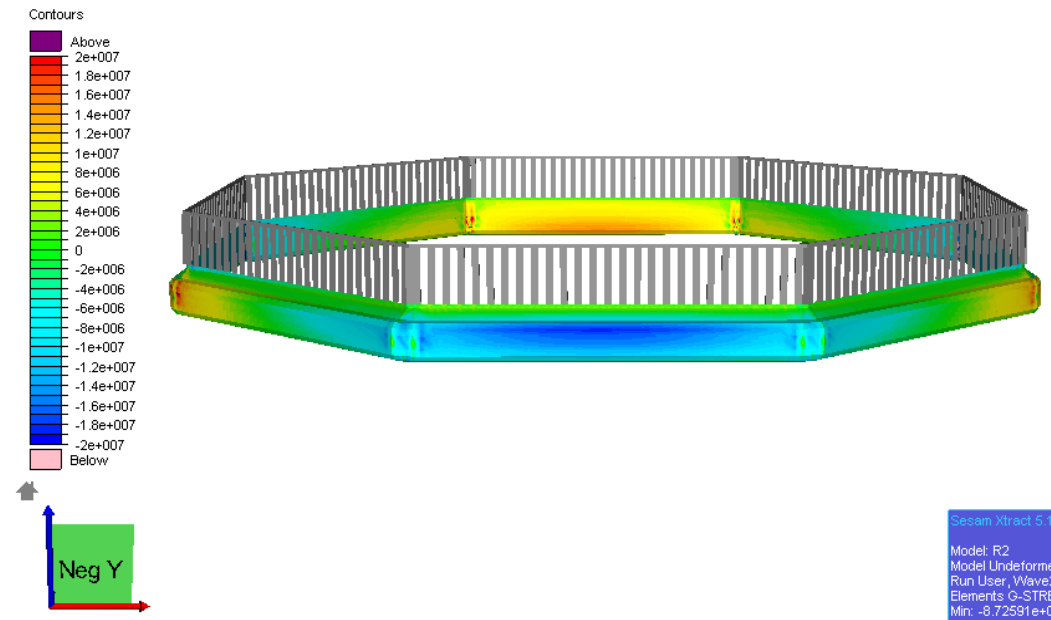
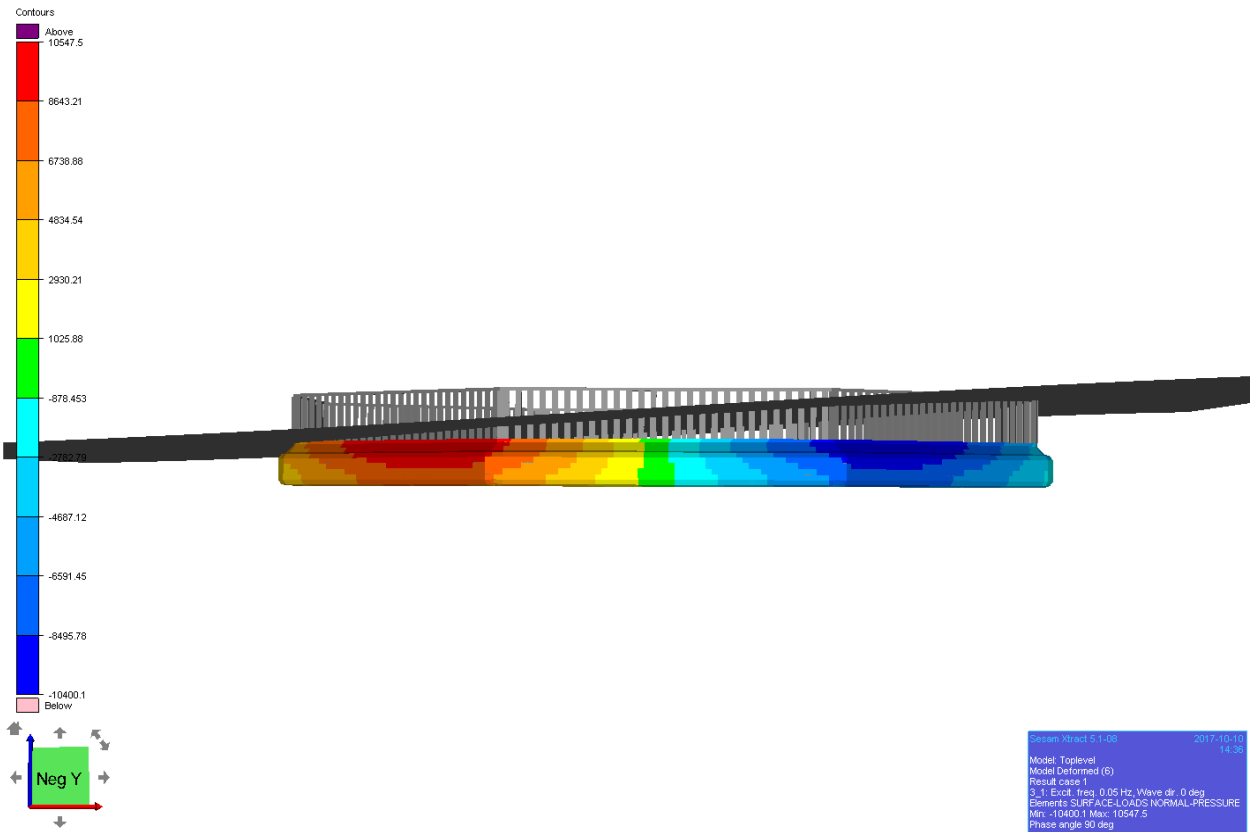


# Stadionbasseng B

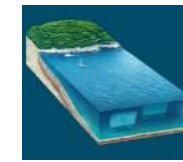




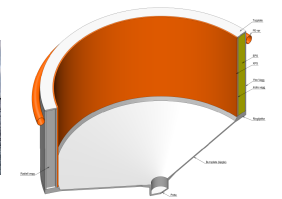
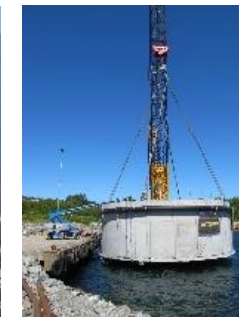
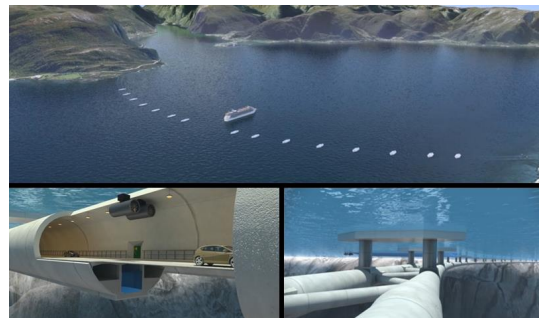
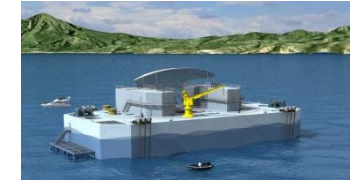
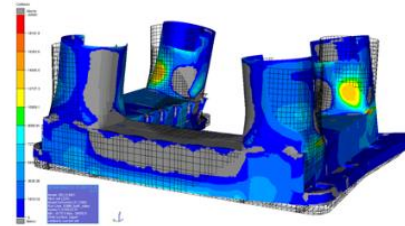




Sesam Xtract 5.1.08 2017-10-12 18:54  
 Model: R2  
 Model Undeformed  
 Run User: Wave20sP350  
 Elements: G-STRESS SIGXX  
 Min: -8.72591e+007 Max: 3.49249e+007  
 Shell surface: Upper



Marine concrete structures:





**THANK YOU  
FOR YOUR ATTENTION!**

**[too@olavolsen.no](mailto:too@olavolsen.no)**