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MULTI-PURPOSE FLOATING STRUCTURES

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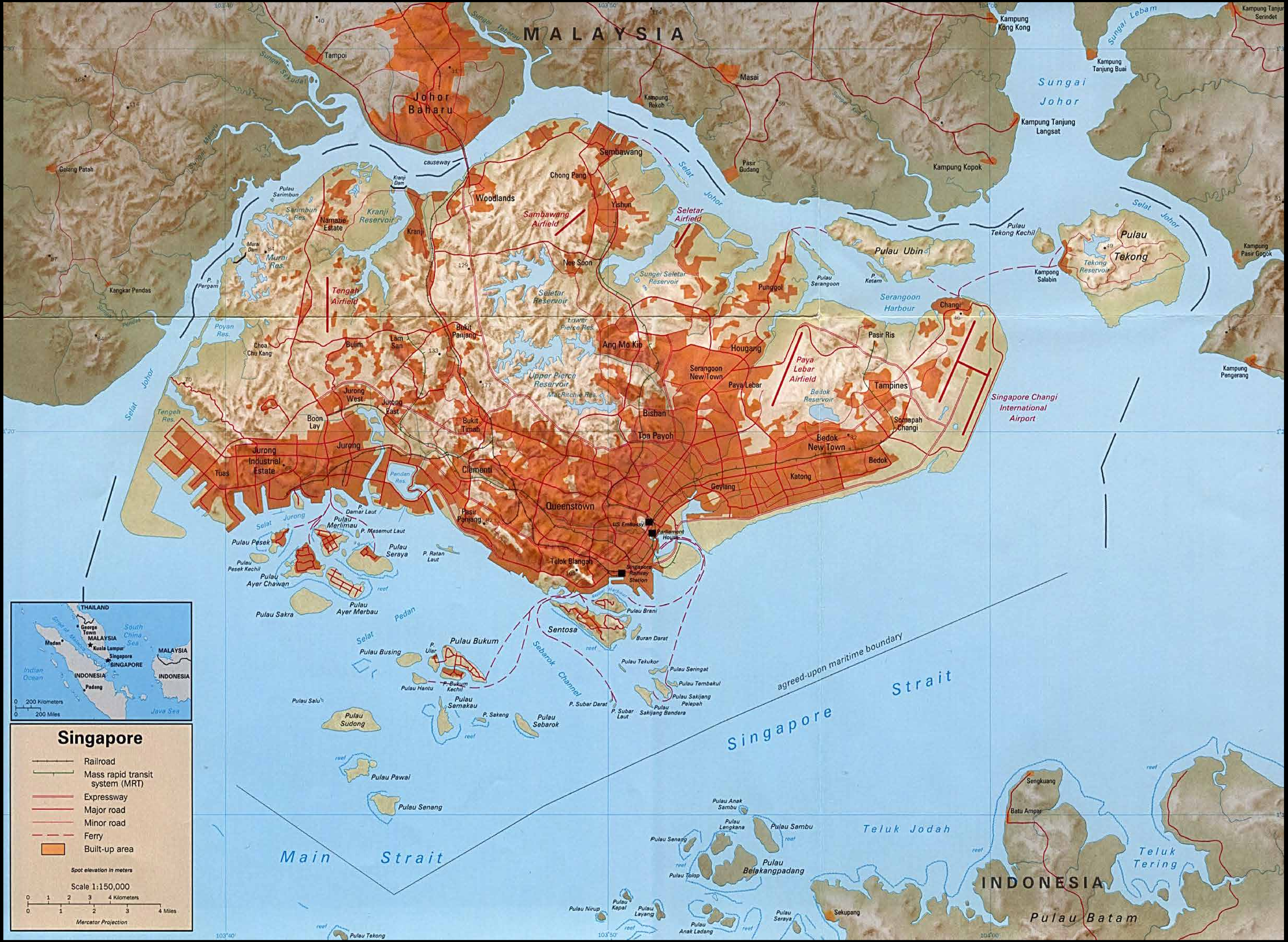
Vice President Research, SINTEF Ocean


MALAYSIA
INDONESIA
Singapore
Johor Baharu
Woodlands
Sembawang
Yishun
Ang Mo Kio
Hougang
Serangoon New Town
Paya Lebar
Tampines
Bedok New Town
Bedok
Katong
Geylang
Toa Payoh
Bishan
Queenstown
Clementi
Jurong
Jurong West
Jurong East
Boon Lay
Tuas
Jurong Industrial Estate
Bukit Timah
Bukit Panjang
Choa Chu Kang
Bulim
Lam San
Kranji
Nee Soon
Chong Pang
Punggol
Pasir Ris
Changi
Somapah Changi
Pasir Panjang
Telok Blangah
Sentosa
Pulau Ubin
Pulau Tekong
Singapore Changi International Airport
Paya Lebar Airfield
Tengah Airfield
Sembawang Airfield
Seletar Airfield
Selat Johor
Sungai Johor
Singapore Strait
Main Strait
Teluk Jodah
Teluk Tering
Pulau Batam
agreed-upon maritime boundary
causeway
Pulau Bukom
Pulau Semakau
Pulau Sudong
Pulau Pawai
Pulau Senang
Pulau Sakra
Pulau Seraya
Pulau Brani
Sebarok Channel
Singapore Railway Station
Parliament House
US Embassy
Tampoi
Masai
Kampung Kong Kong
Kampung Tanjung Langsat
Kampung Kopok
Pasir Gudang
Gelang Patah
Kangkar Pendas
Kampung Pengerang
Sekupang
Batu Ampar
Sengkuang
Railroad
Mass rapid transit system (MRT)
Expressway
Major road
Minor road
Ferry
Built-up area
Spot elevation in meters
Scale 1:150,000
Mercator Projection
THAILAND
MALAYSIA
INDONESIA
SINGAPORE
Kuala Lumpur
Medan
Padang
South China Sea
Indian Ocean
Java Sea

Singapore

- Land area: 722 km^2
- Population: 5.5 + 1 million
- 7796 persons per km^2

Norway

- **Total land area: 385 180 km2**
- **Total population: 5.2 millions**
- **13.7 persons per km^2**

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Oslo + Bærum + Asker

- Total land area: 750 km2
- Total population: 850 000
- 1 130 persons per km^2

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Singapore

Need for space!

Ambitions development plans:

- Land reclamation
- Up in the air
- Under ground
- Into the sea

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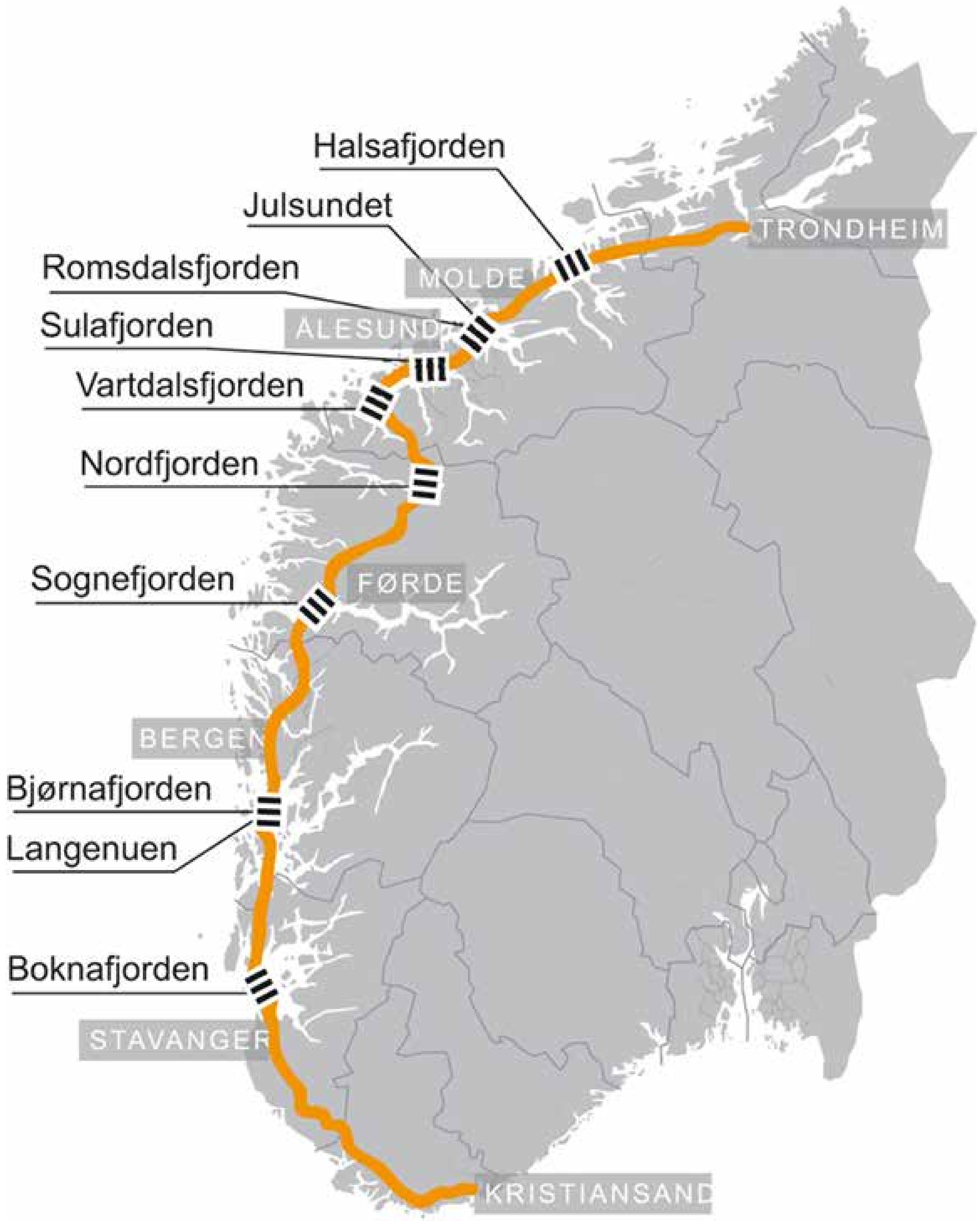
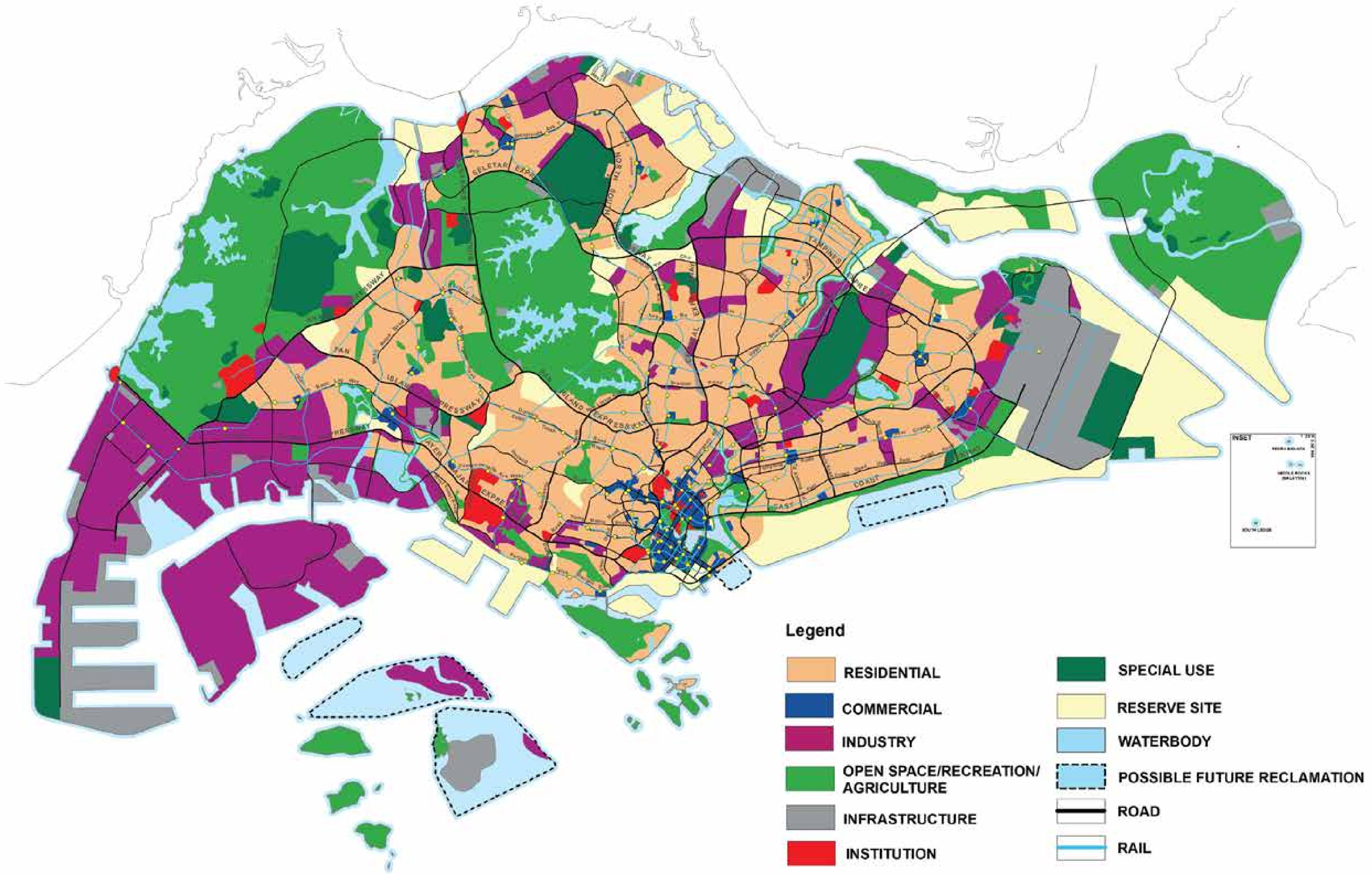

Halsafjorden
Julsundet
Romsdalsfjorden
Sulafjorden
Vartdalsfjorden
Nordfjorden
Sognefjorden
Bjørnafjorden
Langenuen
Boknafjorden
TRONDHEIM
MOLDE
ÅLESUND
FØRDE
BERGEN
STAVANGER
KRISTIANSAND


Legend
RESIDENTIAL
COMMERCIAL
INDUSTRY
OPEN SPACE/RECREATION/ AGRICULTURE
INFRASTRUCTURE
INSTITUTION
SPECIAL USE
RESERVE SITE
WATERBODY
POSSIBLE FUTURE RECLAMATION
ROAD
RAIL

Wide apart - yet common interests

Norway

- Support growth and national development
- Connecting people and businesses
- New coastal highway E39:
  - Floating bridges,
  - Submerged bridges
- Port development
- Coastal development

Singapore

- Support growth and national development
- Creating space: Moving infrastructure from land to sea
- Oil & Gas Storage
- Strategic storage
- LNG terminals
- Port development
- Industrial lands
- Housing and residential areas
- Recreational areas

Background – Norwegian Underground Technology


Sub-sea tunnels


R&D partner: Nanyang University

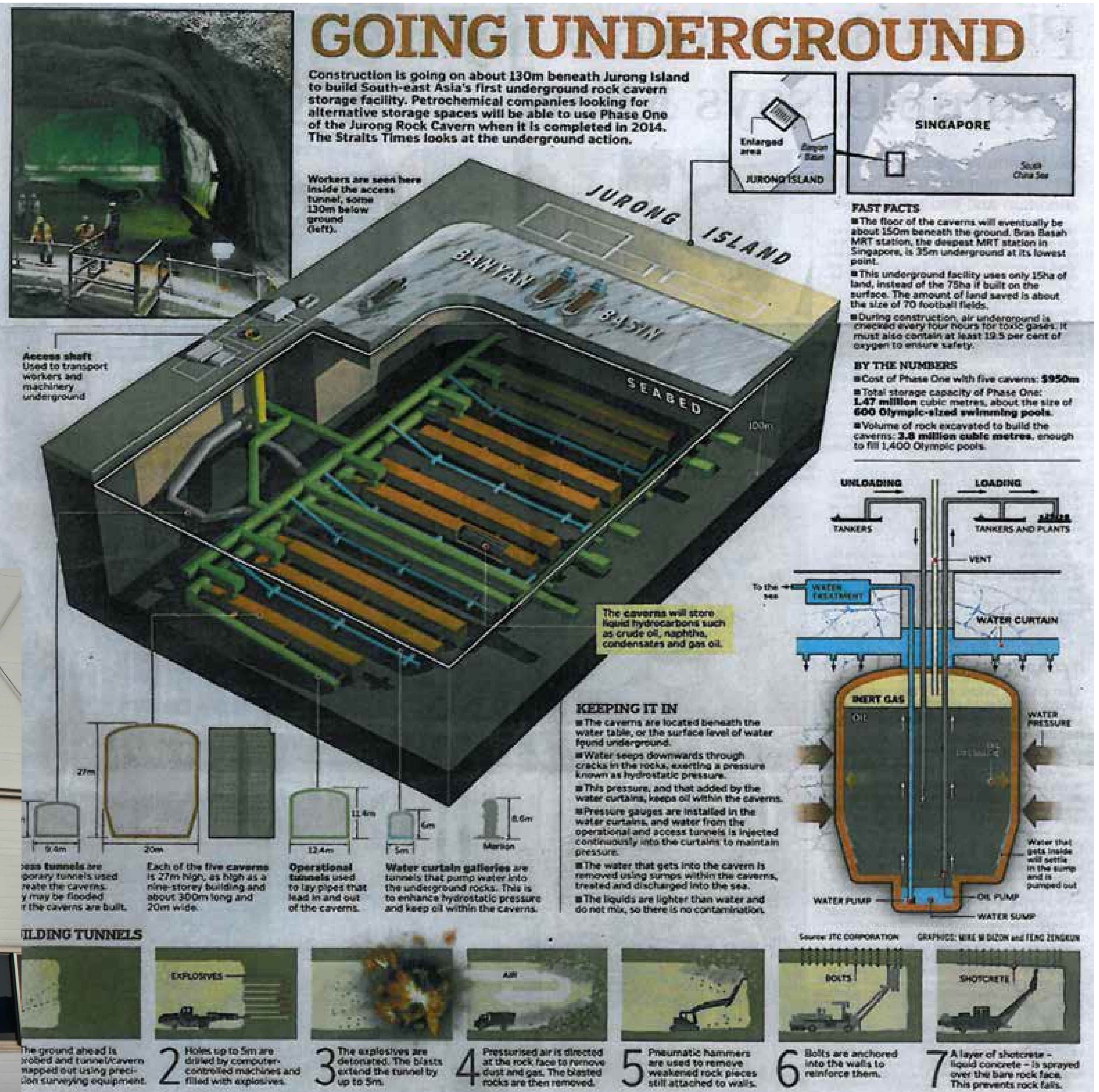

Large rock caverns –Gjøvik hall


Partnership
SINTEF – Tritech – Multiconsult
10 years > 100 mill NOK
Project Management and Technical review

Jurong Rock Caverns

– Underground subsea hydrocarbon storage

From research to completed project



GOING UNDERGROUND

Construction is going on about 130m beneath Jurong Island to build South-east Asia's first underground rock cavern storage facility. Petrochemical companies looking for alternative storage spaces will be able to use Phase One of the Jurong Rock Cavern when it is completed in 2014. The Straits Times looks at the underground action.

Workers are seen here inside the access tunnel, some 130m below ground (left).

JURONG ISLAND
BANYAN BASIN
SEABED
Enlarged area
JURONG ISLAND
SINGAPORE
South China Sea
Access shaft
Used to transport workers and machinery underground

FAST FACTS

- The floor of the caverns will eventually be about 150m beneath the ground. Bras Basah MRT station, the deepest MRT station in Singapore, is 35m underground at its lowest point.
- This underground facility uses only 15ha of land, instead of the 75ha if built on the surface. The amount of land saved is about the size of 70 football fields.
- During construction, air underground is checked every four hours for toxic gases. It must also contain at least 19.5 per cent of oxygen to ensure safety.

BY THE NUMBERS

- Cost of Phase One with five caverns: **$950m**
- Total storage capacity of Phase One: **1.47 million** cubic metres, about the size of **600 Olympic-sized swimming pools**.
- Volume of rock excavated to build the caverns: **3.8 million cubic metres**, enough to fill 1,400 Olympic pools.

UNLOADING
LOADING
TANKERS
TANKERS AND PLANTS
VENT
WATER TREATMENT
WATER CURTAIN
INERT GAS
OIL
WATER PRESSURE
Water that gets inside will settle in the sump and is pumped out
WATER PUMP
OIL PUMP
WATER SUMP

The caverns will store liquid hydrocarbons such as crude oil, naphtha, condensates and gas oil.

...ess tunnels are ...porary tunnels used ...reate the caverns. ...y may be flooded ...r the caverns are built.

Each of the five caverns is 27m high, as high as a nine-storey building and about 300m long and 20m wide.

Operational tunnels used to lay pipes that lead in and out of the caverns.

Water curtain galleries are tunnels that pump water into the underground rocks. This is to enhance hydrostatic pressure and keep oil within the caverns.

KEEPING IT IN

- The caverns are located beneath the water table, or the surface level of water found underground.
- Water seeps downwards through cracks in the rocks, exerting a pressure known as hydrostatic pressure.
- This pressure, and that added by the water curtains, keeps oil within the caverns.
- Pressure gauges are installed in the water curtains, and water from the operational and access tunnels is injected continuously into the curtains to maintain pressure.
- The water that gets into the cavern is removed using sumps within the caverns, treated and discharged into the sea.
- The liquids are lighter than water and do not mix, so there is no contamination.

Source: JTC CORPORATION   GRAPHICS: MIKE M DIZON and FENG ZENGKUN

...ILDING TUNNELS

...The ground ahead is ...robed and tunnel/cavern ...mapped out using preci-...sion surveying equipment.

2 Holes up to 5m are drilled by computer-controlled machines and filled with explosives.

3 The explosives are detonated. The blasts extend the tunnel by up to 5m.

4 Pressurised air is directed at the rock face to remove dust and gas. The blasted rocks are then removed.

5 Pneumatic hammers are used to remove weakened rock pieces still attached to walls.

6 Bolts are anchored into the walls to reinforce them.

7 A layer of shotcrete – liquid concrete – is sprayed over the bare rock face. This prevents rock falls.

Client: JTC – Breaking New Ground

Consortium:

- SINTEF, Tritech and Multiconsult

Assignment

- Project management
- Design review and approval
- Technical advisor to JTC

Progress:

- 2003 NTNU-NTU-SINTEF initial discussions
- 2004 SINTEF and Tritech site investigations
- 2006 STM contract awarded
- 2008 Basic Engineering Design completed
- 2009 Access shafts completed
- 2015 Caverns opened
- 2019 Project completed

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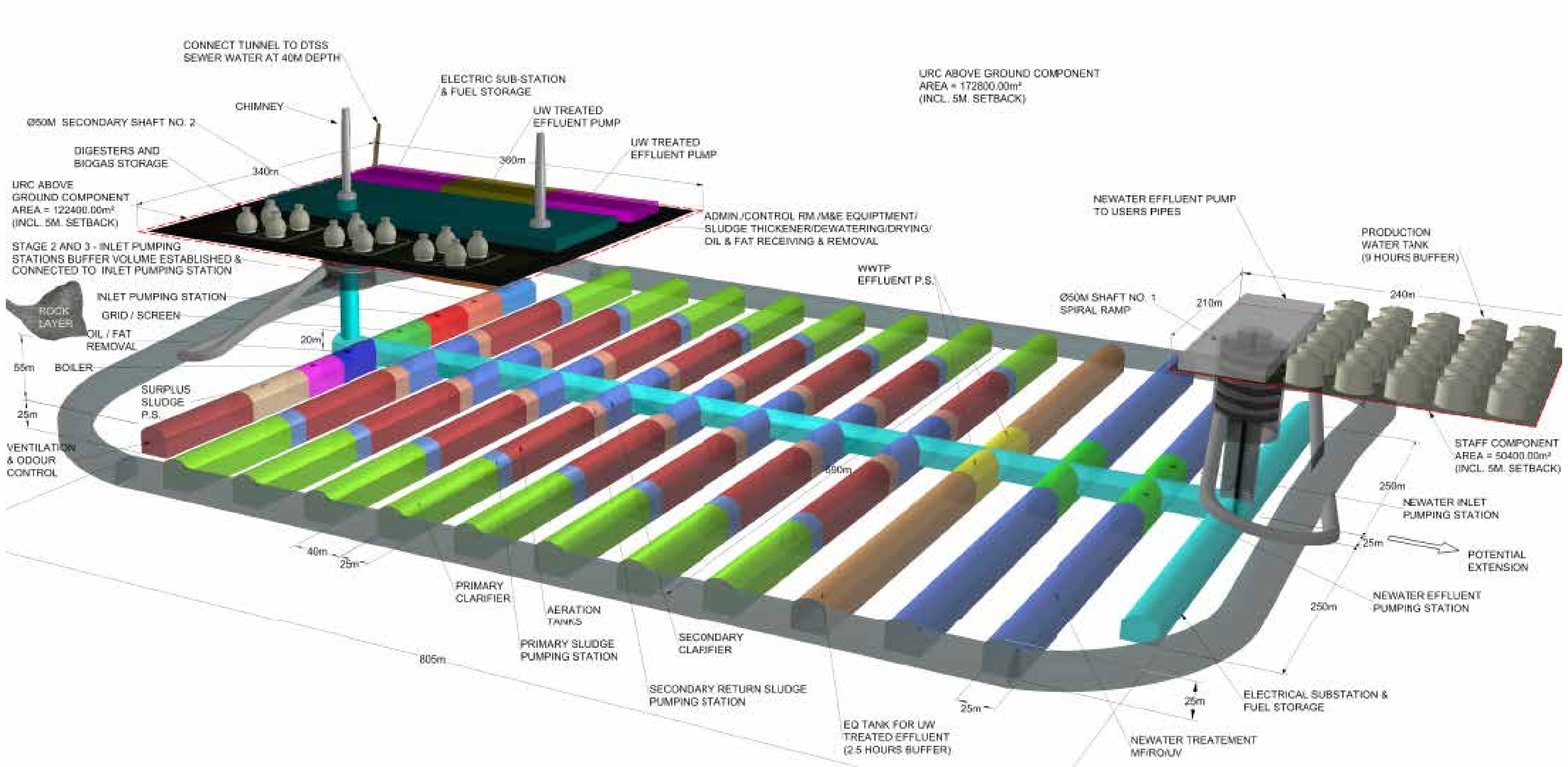
URC- Underground Rock Cavern Usage Feasibility Study, Singapore

Water Reclamation Plant



Total Vol. : 7,844,690 m^3
Cavern Vol. : 5,937,500 m^3 (76%)
Shaft +Tunnel Vol. : 1,907,190 m^3 (24%)

Production Capacity: 800,000 m^3 per day
NEWater Plant at 556,000 m^3 per day

10 specified usages in underground rock cavern

- Technical and operational feasibility
- September 2008 – June 2009

SINTEF – Tritech - Multiconsult

Awarded best strategic planning project 2009

Underground science city

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MULTI-PURPOSE FLOATING STRUCTURES

Multi-purpose Floating Structures

Collaborative R&D project to investigate use of sea area

- JTC (Jurong Town Corporation)
- NUS (National Universty of Singapore)
- SINTEF
- NTNU (advisory role)
- National Research Foundation Singapore

Four main tracks

- **Floating hydrocarbon storage**
- **Floating bridges | coastal structures**
- **Floating modular multi-purpose structures**
- **Design guidance**

jtc Breaking New Ground

NUS National University of Singapore

SINTEF

NTNU

Singapore Government Integrity · Service · Excellence

Multi-purpose Floating Structures

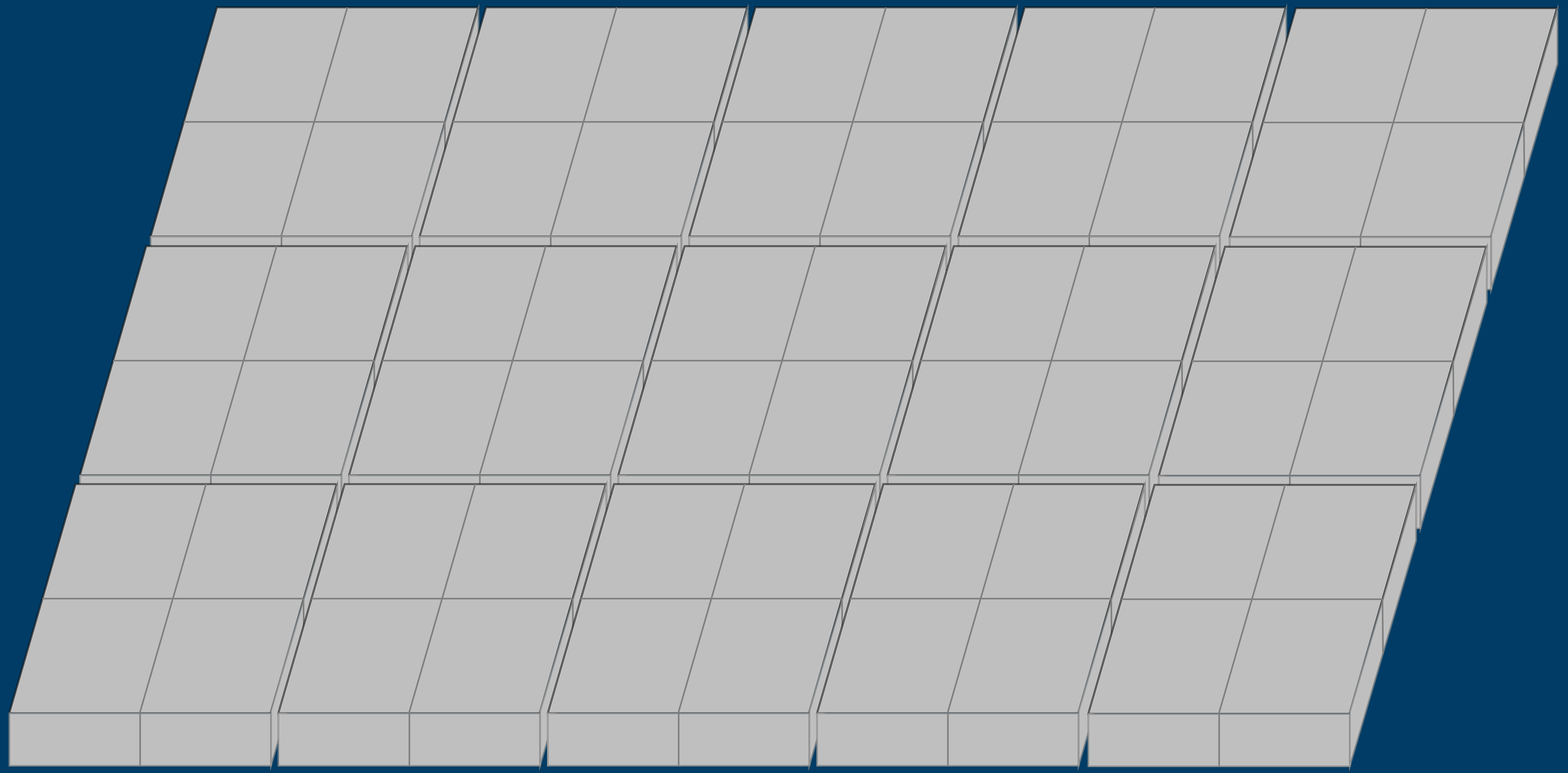
Phase A: Concept Study

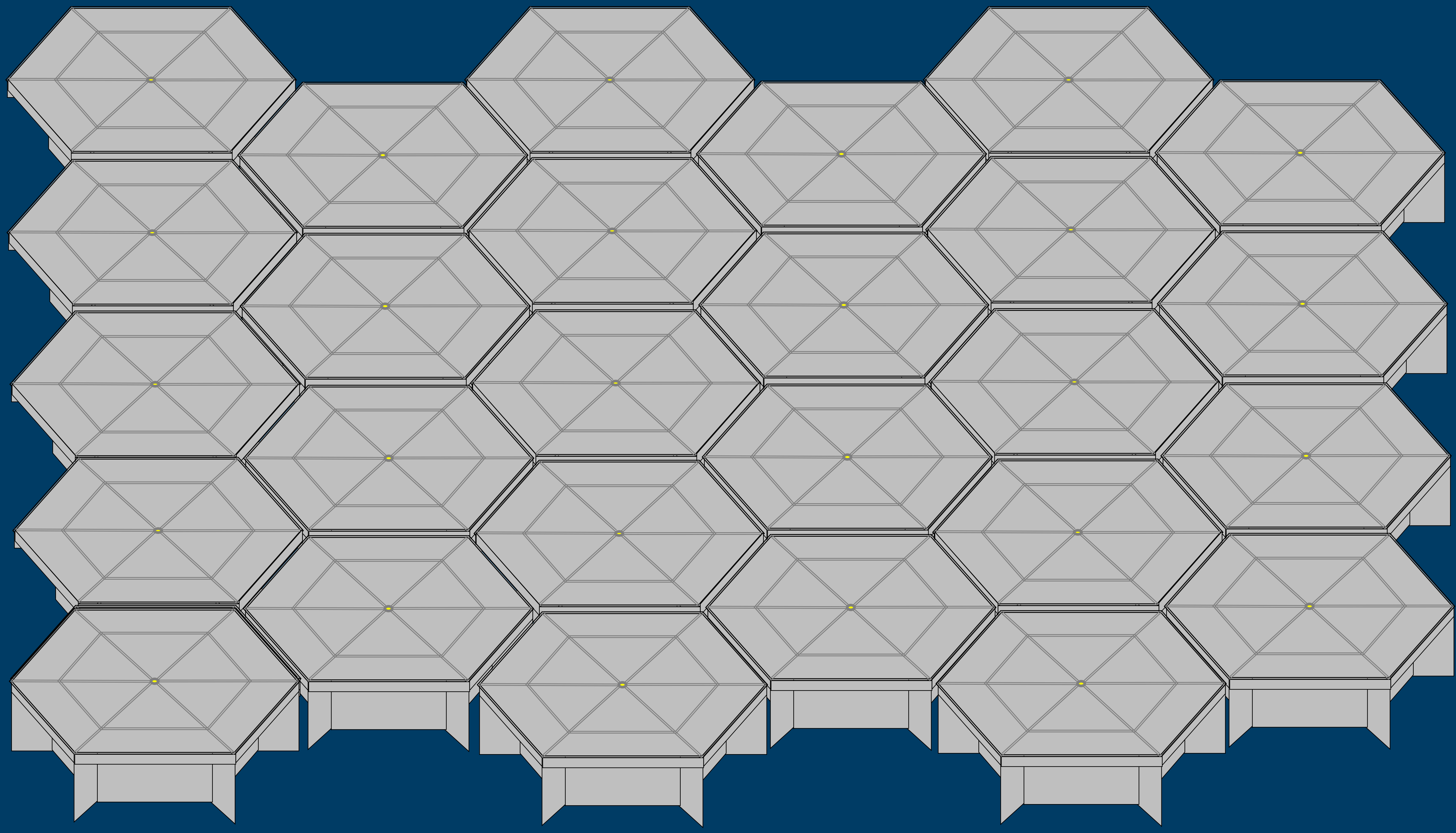
- A1 Concept evaluation and development
- A2 Foundation and Mooring systems
- A3 Structural Solutions
- A4 Materials selection, development and testing
- A5 Construction, installation and marine operations
- A6 Model testing and concept qualification

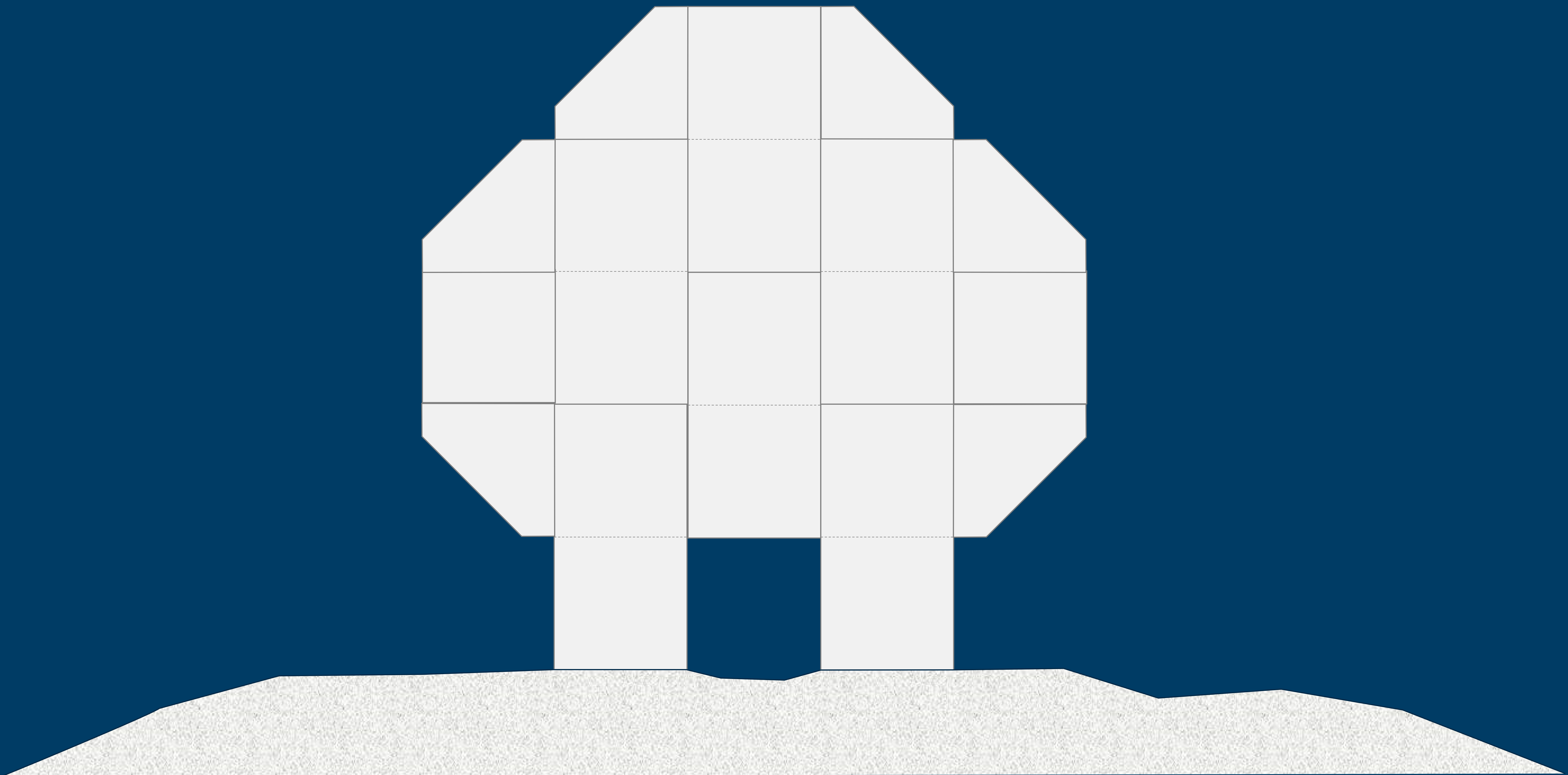
Phase B: Development and verification

- B1 Structural design for prototyping
- B2 Concept verification and prototyping (test-bedding in real environment)

Modular multi-purpose floating structures







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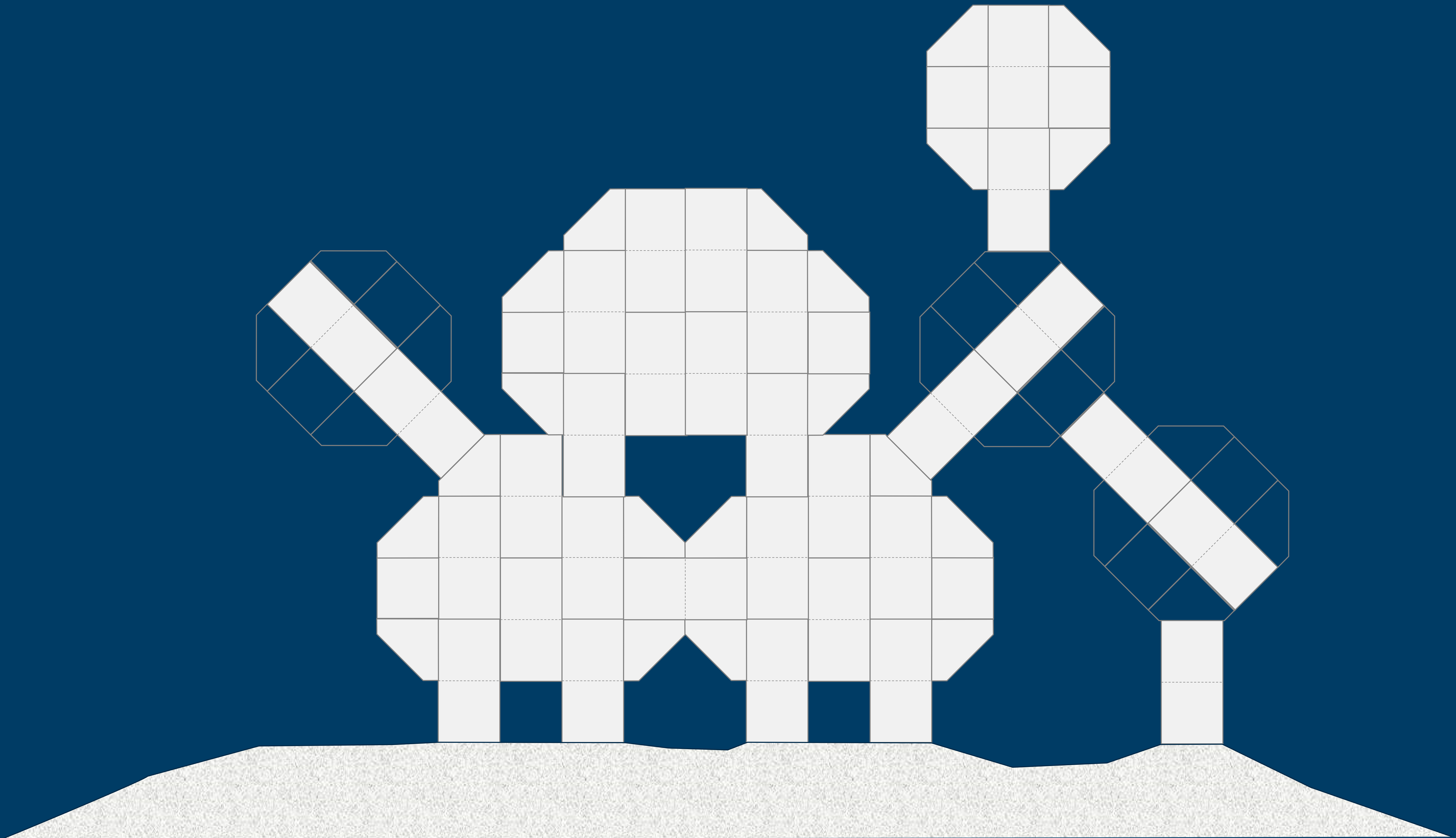


Design issues

- Modular, inter-connected structure
- Articulated, w/rigid and flexible joints
- Long service lifetime
- High tidal variations
- Moderate waves

- Large structure compared to wave length
- Non-uniform bathymetry
- Non-uniform environmental actions across the structure
- Possible hydro-elastic effects

Large Floating Coastal Structures

Norwegian R&D project on design and verification of large floating coastal structures

- Recommendations to design guidelines
- Methods and numerical tools
  - Hydro-elastic effects
  - In-homogeneous environmental conditions
  - In-homogeneous bathymetry

Statens vegvesen

Multiconsult

SWECO

LMG MARIN

SINTEF

NTNU

NUS National University of Singapore

The Research Council of Norway

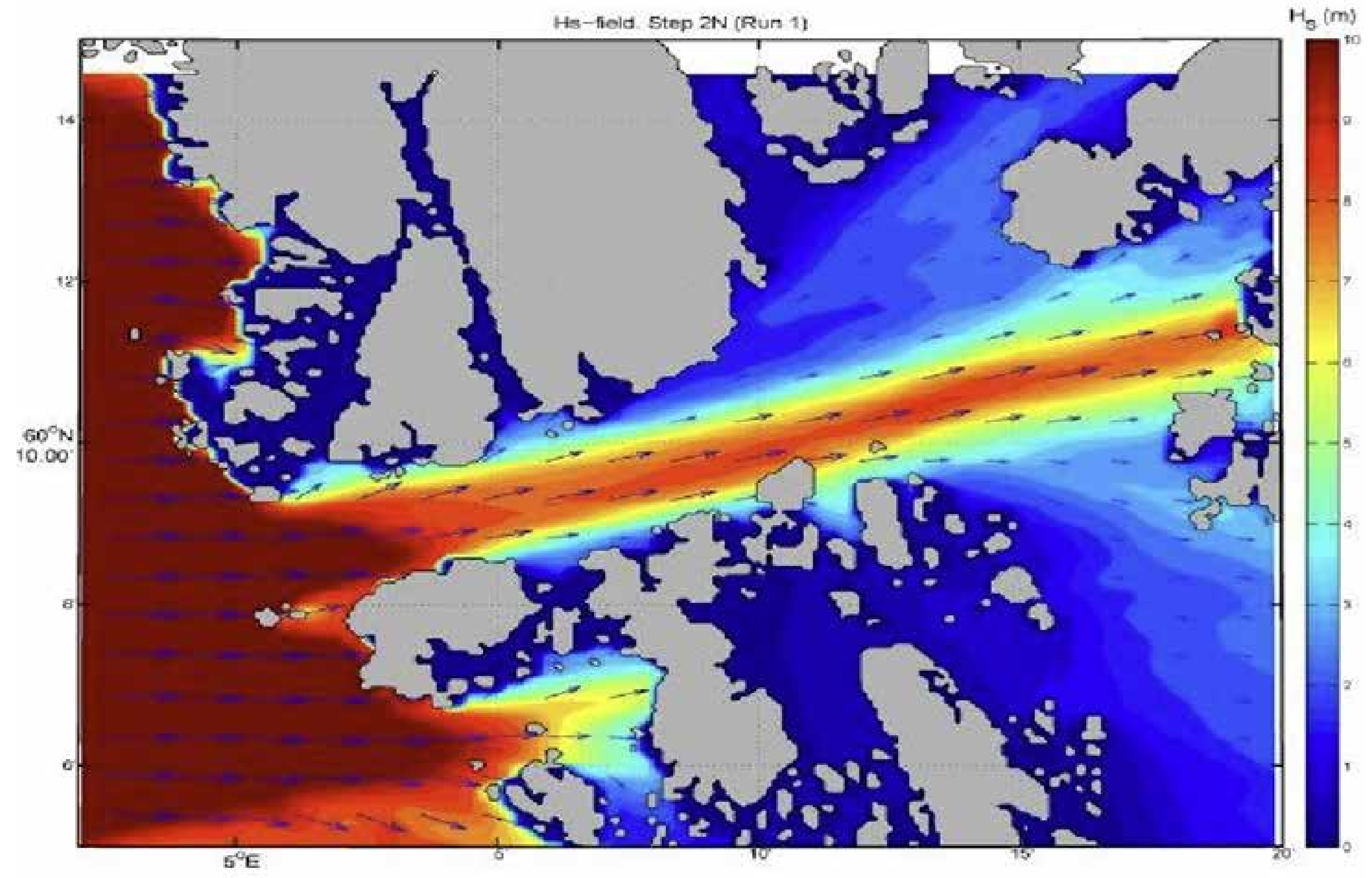
Large Floating Coastal Structures

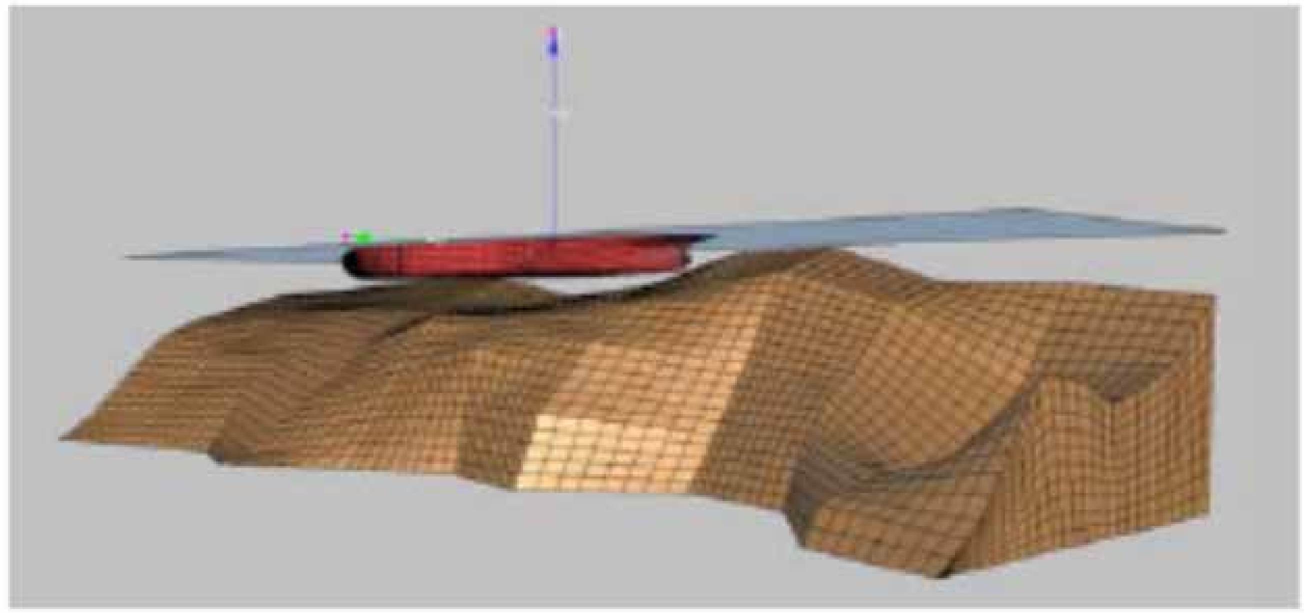
Rational *description model* of
inhomogeneous environmental conditions

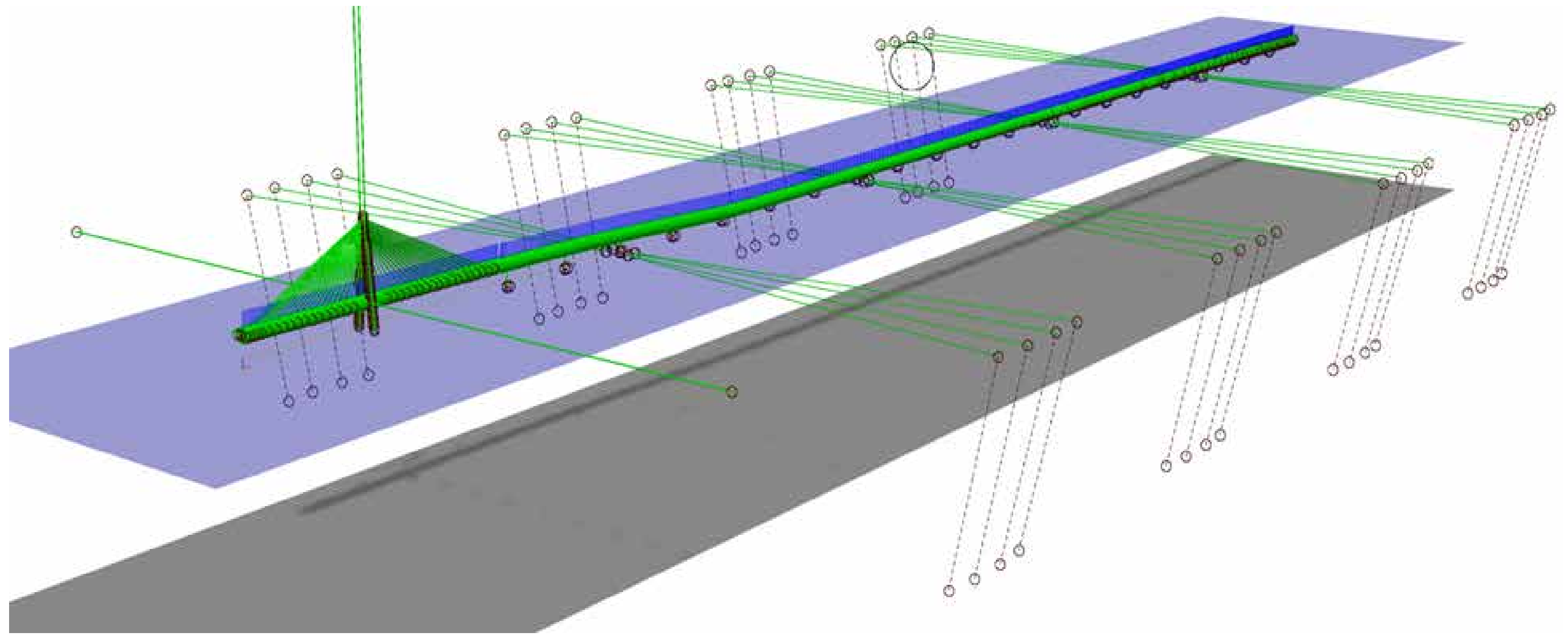
Rational *evaluation models* of
wave/wind/current loads
under inhomogeneous environments

Improved *methods* for hydro-elastic response,
applicable to combined rigid, elastic and/or
articulated structures.

Improved *methods* for mooring and position







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Large Floating Coastal Structures

Large Floating Coastal Structures

Review phase

Map and evaluate technology gaps

Planning phase

Defining and targeting R&D activities

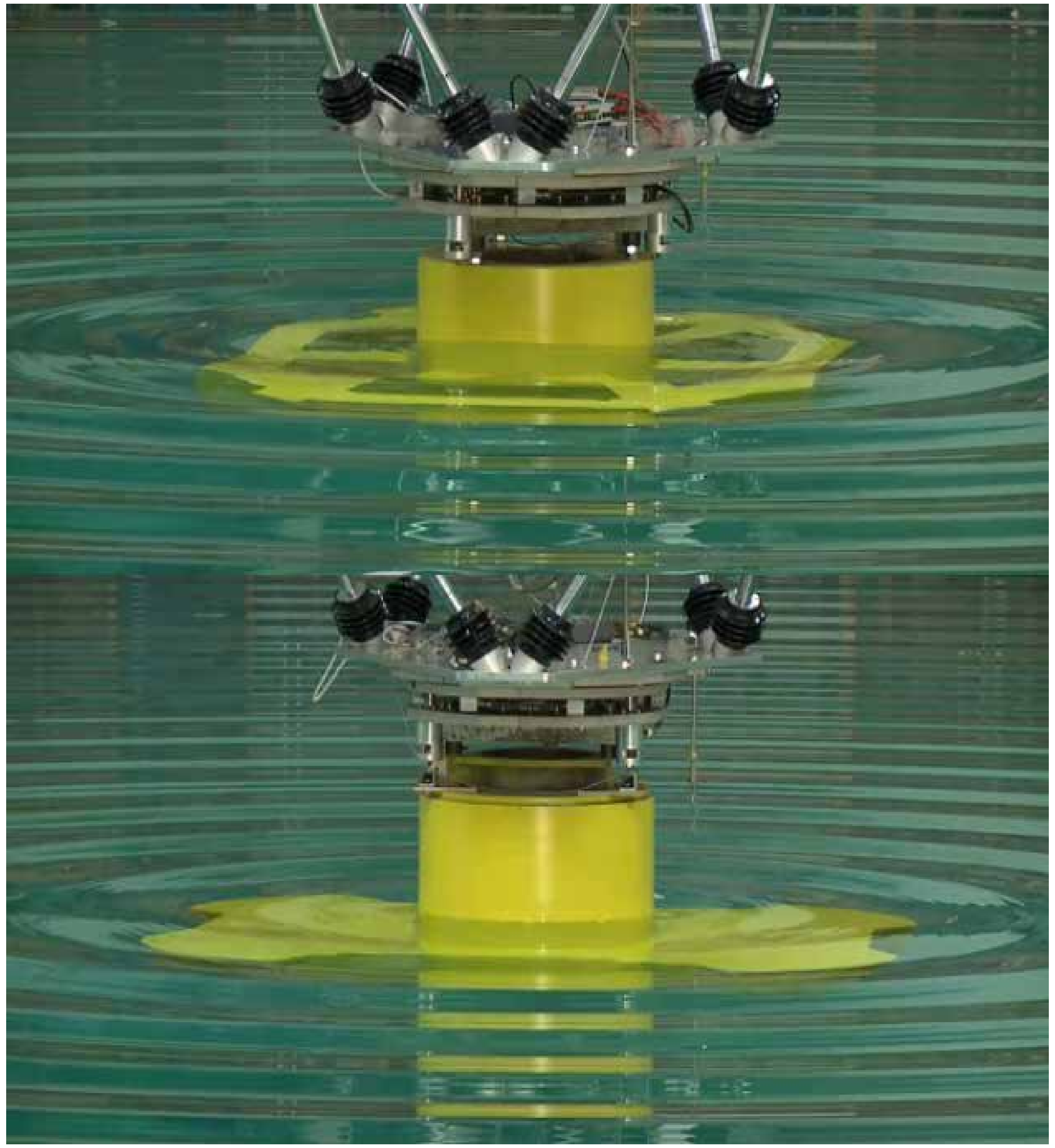
Development phase

Development of numerical models and tools
Case studies
Sensitivity studies

Verification phase

High-fidelity model tests

Model tests in SINTEF's Ocean Basin



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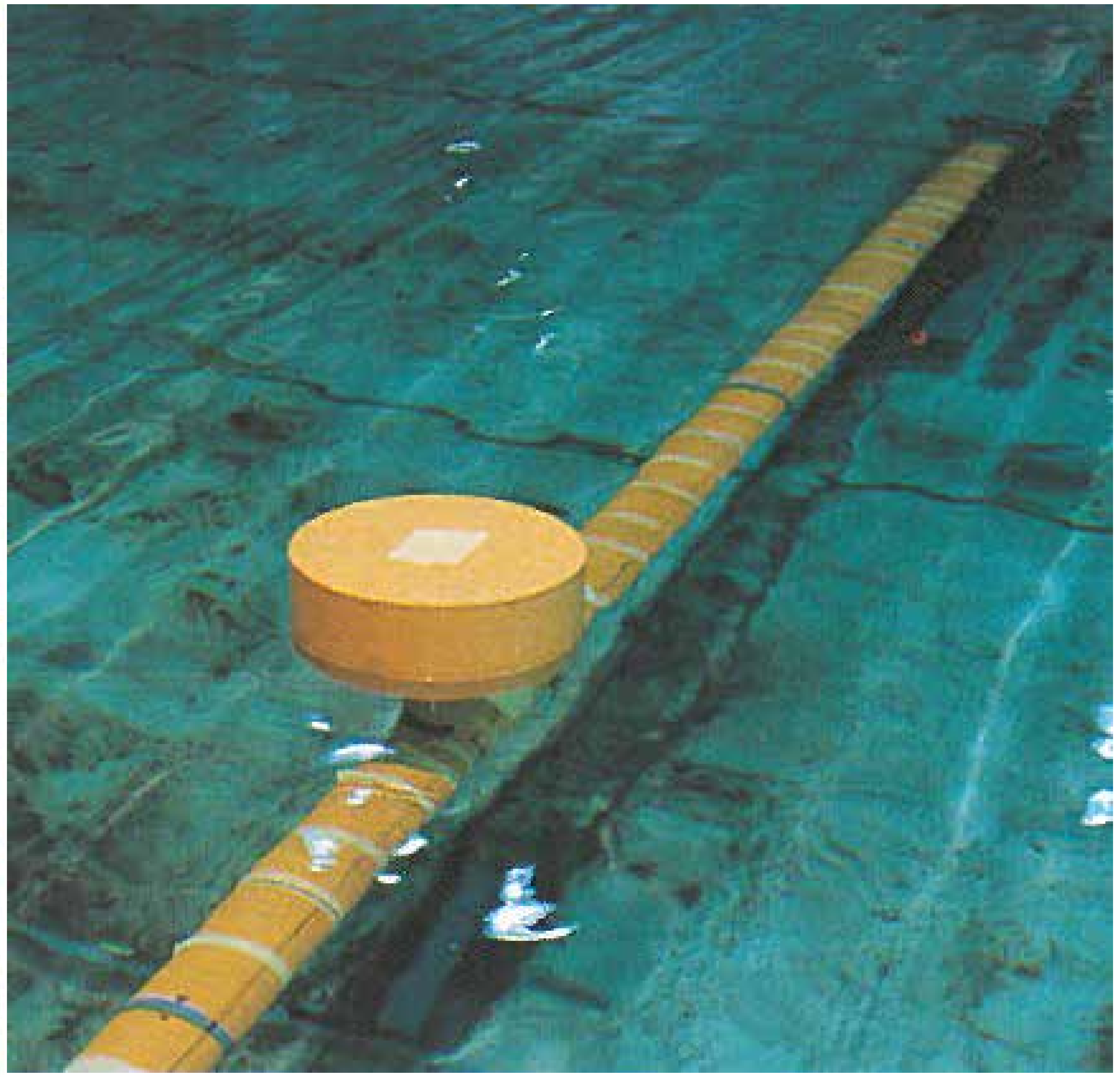
Model tests in SINTEF's Ocean Basin



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