

Offshore Wind Accelerator (OWA) DONISIS Interim Workshop

Design of Offshore Monopiles Including Seismic Interaction with Soil

4 June 2026
Yokohama, Japan

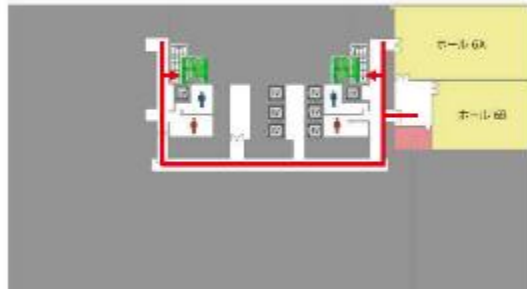
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TKP Emergency and safety briefing



■ 5F&6F非常避難経路 Emergency exits



■ 広域避難場所 (グランモール公園) Emergency evacuation site (Gran Mall Park)



諸注意

基本的に防災センターよりアナウンスの指示に従います。
有事の際「避難誘導等は会場スタッフ」が行います。
各部屋毎にTKPスタッフが参りますので、その場でお待ちください。

In case of emergency, please follow instructions from the **venue staff**.

OWA DONISIS Interim Workshop

Raise awareness, build confidence, and accelerate the adoption of advanced seismic design methods for monopile supported offshore wind turbines.



Time (JST)	Topic
08:30 – 09:00	Registration
09:00 – 09:30	Opening Remarks
09:30 – 10:30	Setting the Scene: Why DONISIS Is Needed and Current Practice
10:30 – 10:45	Coffee break
10:45 – 12:30	DONISIS Technical Work: Project Overview & Applicability Centrifuge test results and numerical modelling
12:30 – 13:30	Lunch break
13:30 – 15:30	Panel Session 1: Certification Roundtable Translating DONISIS Research into Standards & Guidance
15:30 – 15:45	Coffee break
15:45 – 17:15	Panel Session 2: Bridging The Gap Between Industry & Academia Current Gaps, Industry Needs & Future Direction

OWA DONISIS INTERIM WORKSHOP

Carbon Trust



Christina Starost

Associate, Offshore Renewables

Carbon Trust

Our mission is to accelerate the move to a decarbonised future



7

offices supporting clients across 5 continents

400+

experts and consultants

20

years of experience in sustainability consultancy



Carbon Trust's Offshore Wind Team (UK, Netherlands, Mexico and Singapore)

Our Expertise

Focus Industries

Offshore Wind - Fixed

Offshore Wind - Floating

Offshore Energy Integration

Maritime Decarbonisation

Marine Energy

Hydrogen

Collaboration

We are global leading experts in delivering large scale RD&D and collaboration programmes, with a track record of delivering real cost reductions.

- Programme Design & Set up
- Programme Management
- Stakeholder Mapping & Engagement
- Capacity Building and Knowledge Management

Research & Insight

Over a decade of experience delivering market insights to international organisations to aid in their market & industry knowledge, analysis and feed into strategic expansion plans.

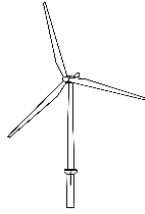
- Market Insight
- Policy, Technology, Strategy & Innovation Review
- Energy Systems & Future Energy Analysis
- Environmental & Social Analysis
- LCOE Modelling for Innovation
- Infrastructure and Logistical Reviews

Strategic Advice

We provide strategic policy and market support, cost reduction and economic development, and deliver insights into technology and industry progress to help understand market gaps and evaluate solutions.

- Innovation Needs Assessment
- Technology Guidance
- Policy Design & Recommendations
- Supply Chain Enablement
- Skills & Workforce Development
- Site Selection, Auction and Subsidy Support
- Scenario Planning

Carbon Trust's Programmes



The Offshore Wind Accelerator (OWA)

Carbon Trust's flagship collaborative RD&D programme for bottom-fixed offshore wind.

2008



The Offshore Renewables JIP (ORJIP)

Offshore Renewables JIP aims to reduce consenting and environmental risks for offshore projects.

2011



The Floating Wind JIP (FLW JIP)

The Floating Wind JIP Overcomes challenges and advance opportunities for commercial scale floating wind

2016



The Integrator

The Integrator is designed to examine the interplay between offshore wind, existing infrastructure, and other technologies to highlight opportunities for innovation investment.

2020



Sustainability JIP (SUS JIP)

The Sustainability JIP mission is to decarbonise future fixed and floating offshore wind farms, to support the transition to a net-zero OSW industry.

2023

Partners we work with:



Carbon Trust's Large-Scale Joint Industry Projects (JIPs)

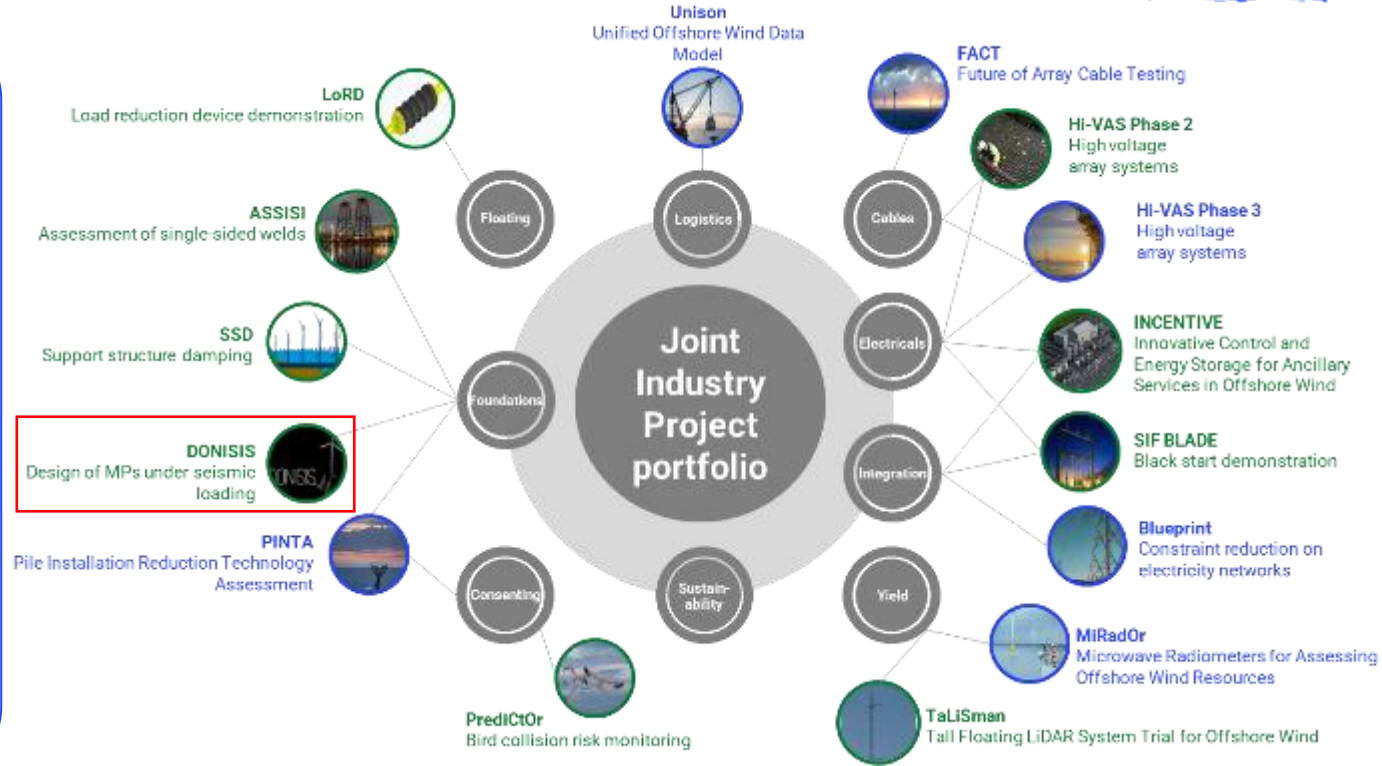


Some projects “spin out” of our core programmes, because:

- Require larger investments.
- Only a subset of programme partners may be interested.
- They involve external partners and/or public funding.

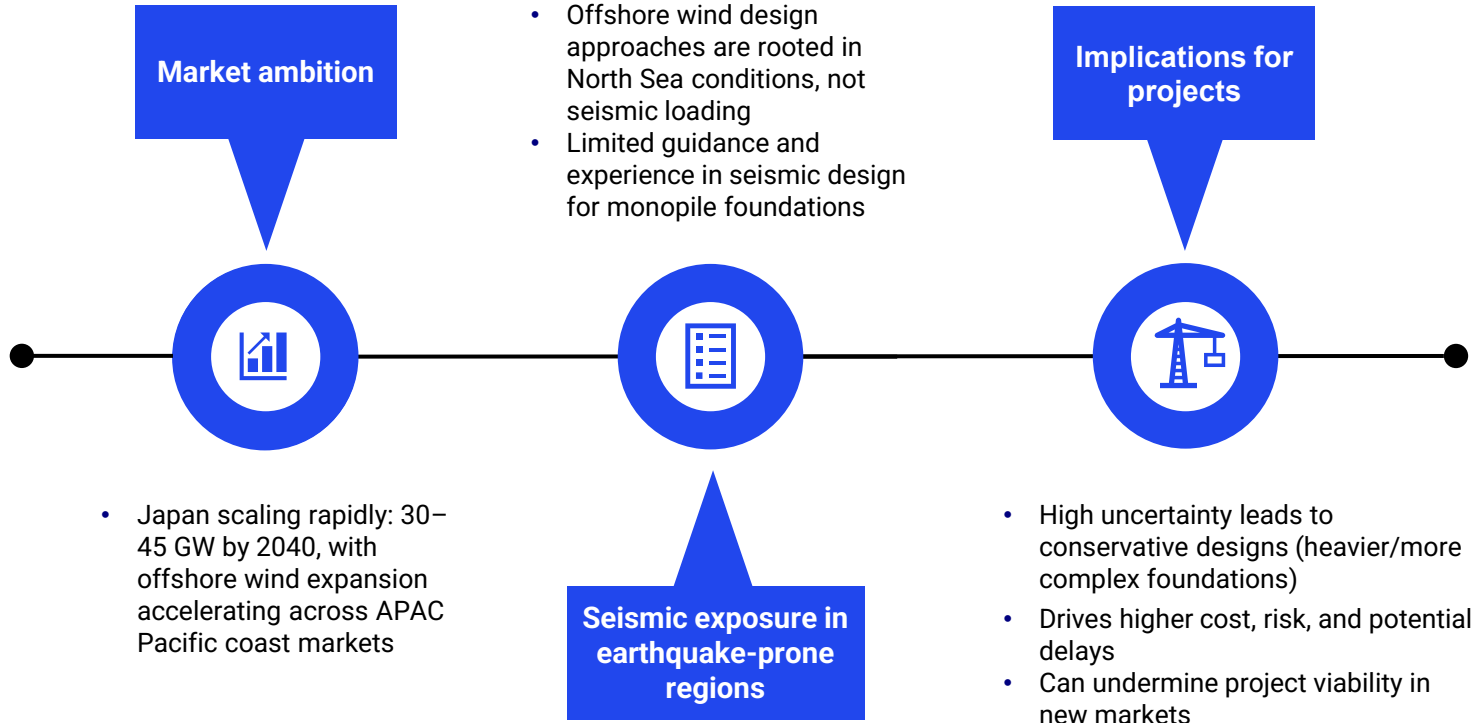
The programme partners (and third parties) can join these at their **discretion**. We therefore refer to them as “**Discretionary Projects**”.

- Carbon Trust has set up and run **25 DPs**.
- Total budget: **>£43million**
- Public funding: **>£11million**



Scaling offshore wind in seismic markets

Rapid growth is concentrated in earthquake-prone regions, creating new design and cost challenges



Offshore wind development in APAC

Challenges for developers

- Seismic uncertainty is driving **conservative and costly foundation design**.
- Lack of proven methods for monopiles in seismic and liquefiable soil conditions **increases project risk**.
- Excessive conservatism can **undermine project viability** in new offshore wind markets.

Collaboration is essential to tackle complex uncertainties, reduce risk, and accelerate cost-effective innovation to meet ambitions offshore wind targets.



Why DONISIS matters

Unlocking offshore wind development in seismic active regions

De-risking design

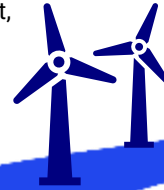
Better understanding of seismic soil-monopile behaviour reduces uncertainty and improves design confidence.

Optimising cost & efficiency

Minimises overdesign, steel use and damage risk through advanced analysis and testing.

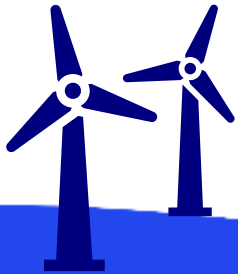
Unlocking value

Supports expansion into seismic regions with resilient, durable and cost-effective offshore wind turbines.



Enabling industry adoption

Delivers best practice, design guidance and alignment with certification and standards.



Project timeline



Set-up phase

- Consortium set-up and stakeholder engagement
- Identifying public funding sources
- Development of technical scope
- Identifying independent technical reviewers and certification bodies

2021

Project kick-off

- Successfully secured funding from Dutch NOW
- Kick-off with 19 parties
- Research activities start at TU Delft and ETHZ Zurich

2023

Half-way point

- Interim workshop with presentation of initial findings
- Collating feedback from industry and academia to further calibrate guidelines
- Starting discussions around follow-on work, e.g., floating-specific case

2026

Project end

- Final summary report and design guidelines to be published
- Close-out workshop in Delft, Netherlands

2028

INTERNATIONAL COLLABORATION



PUBLIC & PRIVATE FUNDING



Industry match funding leading to a project value of over €2m

CERTIFICATION BODIES GROUP

Engagement with certification bodies to increase the acceptance and support the dissemination of results



TIMEFRAME: 5 years



Tangible intermediate results in 2.0 years

The Netherlands and TU Delft

オランダとデルフト工科大学

Offshore Engineering
オフショア工学

Evangelos Kementzetzidis



The Netherlands

オランダ



こちらがオランダです。北西ヨーロッパに位置する、北海に面した小さな国です。

デルフトは、ロッテルダムとハーグの間に位置しています。

その地理的条件により、オランダは常に水と密接に関わってきました。この関係は、オランダの工学の伝統を強く形づくり、ある意味ではそれを必然的なものにしてきました。

Delft デルフト



デルフトは、オランダの小さな歴史都市であり、運河、デルフトブルー陶器、フェルメール、そしてデルフト工科大学で知られています。
工学と水に深く関わるこの街は、洋上風力発電や地盤工学の研究に適した場所でもあります。

Delft University of Technology

デルフト工科大学



since 1842

こちらが私たちのキャンパスです！

デルフト工科大学は、オランダを代表する工科大学であり、美しく機能的なキャンパスと、先進的な研究施設を備えています。

Civil Engineering and Geosciences

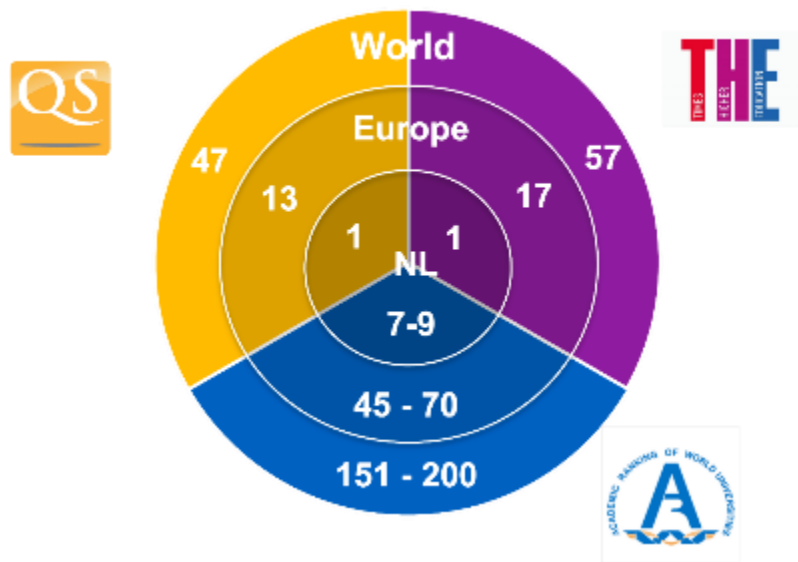
土木工学・地球科学部



デルフト工科大学では、私たちは土木工学・地球科学部、水工学科、海洋工学セクションに所属しています。

A Leading University in Engineering

工学分野をリードする大学



Facts and Figures	
Faculties	8
Students	~ 26,500
Employees	~7,500
Professors	~1,400
PhD researchers	~2,300

デルフト工科大学は国際性の高い大学であり、世界の工学分野で高く評価され、多様な学生・研究者・教員が集まる大きなコミュニティを形成しています。

From Windmills to Offshore Wind 風車から洋上風力へ

Enabled by Dutch leadership in hydraulic, geotechnical and offshore engineering

水工学・地盤工学・海洋工学におけるオランダのリーダーシップが支える発展

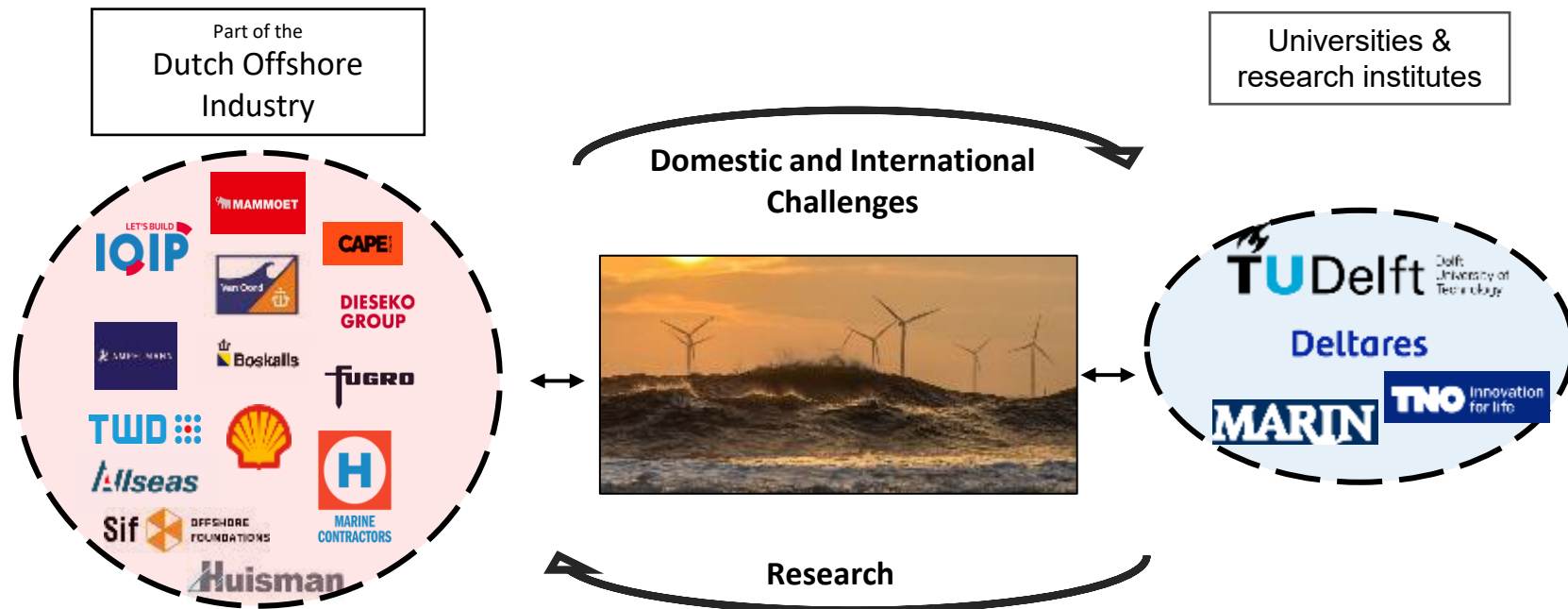


オランダには、風力エネルギーを活用してきた長い歴史があります。

13世紀の製粉用風車から、15世紀以降のポルダー排水・干拓、そして現代の洋上風力発電へと、その役割は進化してきました。

A mature industry-academia ecosystem

産学連携が進んだエコシステム








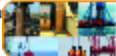
























オランダには、強い産学連携エコシステムがあります。
海洋施工会社、開発事業者、エンジニアリング会社が、デルフト工科大学、Deltares、MARIN、TNOなどの大学・研究機関と密接に連携しています。
これにより、実務上の海洋工学の課題が研究に反映され、その成果が再び実務へ還元されています。

Research on Offshore Monopiles

洋上風力モノパイプに関する研究

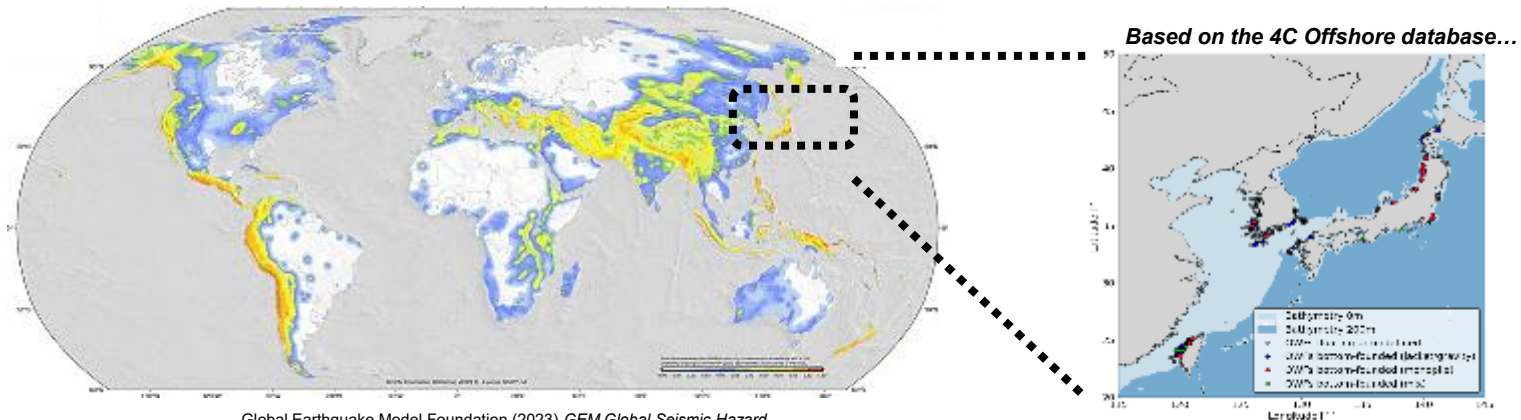


GROW: Growth through Research, development & demonstration in Offshore Wind

	Cost-effective Lifecycle Ending for Asset Removal in Offshore Wind (CLEARWind)		Vibratory-based Installation: Extended duration (VINEK) Additional data collection for the SIMDX project		Silent Installation of MonoPILES IIB (SIMPLE IIB)
	Pile-Run Risk Assessment (PIRRA)		Monopile Improved Design through Advanced cyclic Soil modelling (MIDASclay)		Sustainable Installation of XXL Monopiles (SIMDX)
	Silent Installation of MonoPILES in pre-vailing Clay and Sand (SIMPLECS)		Runwave		Gentle Driving of Piles 1.2 (GDP1.2) COMPLETED
	Silent and Circular Decommissioning of Monopiles (SICD)		Gentle Driving of Piles 2.0 (GDP2.0)		Wrapped Composite Joints for Next Generation Offshore wind support Structures - Phase 1 (WrapNode-I) COMPLETED
	Hydraulic Pile Extraction Scale Tests 1.1 (HyPE-ST 1.1)		Tubular Pile Pull-out Testing Program II (TPP)		Hydraulic Pile Extraction Scale Tests 1.2 (HyPE-ST 1.2) COMPLETED
	Improving Cable Protection for Offshore Wind (ICPS2)		Wrapped Composite Joints for Next generation Offshore wind support Structures - Phase 2 (WrapNode-II)		Monopile Improved Design through Advanced cyclic Soil modelling (MIDAS) COMPLETED
	Towards the Dynamic PressureMeter (T-DPM)		Silent Installation of MonoPILES III (SIMPLE III)		Corrosion Fatigue Life Optimisation (C-FLO) COMPLETED
	Avoiding Damage due to Piling Vibrations (AD-PVIB)		Collaboration to collect data for Integrated prediction modelling (COAX)		Hydraulic Pile Extraction Scale Tests (HyPE-ST) COMPLETED
	CompoSmart		Optimising Pile Installation through Scale Modelling (OSM)		Gentle Driving of Piles (GDP) COMPLETED
	SCALEWIND		Tubular Pile Pull-out Testing program (TPP)		Slip Joint Offshore Research project (SJOR) COMPLETED

Why DONISIS? なぜDONISISなのか？

- Offshore wind is expanding into seismically active regions.
- Countries such as Japan, Taiwan, South Korea and Vietnam combine major offshore wind potential with significant earthquake hazard.
- In the APAC region, monopiles are attractive foundation solutions, but their use requires reliable assessment of seismic soil–structure interaction (SSI).
- 洋上風力発電は、地震活動の活発な地域へと拡大しています。
日本、台湾、韓国、ベトナムなどの国々では、大きな洋上風力ポテンシャルと高い地震ハザードが共存しています。
比較的浅い沿岸海域では、モノパイル基礎が有力な基礎形式となりますが、その適用には、地震時の地盤–構造物相互作用（SSI）を信頼性高く評価することが不可欠です。



Setting the Scene: Why DONISIS Is Needed and Current Practice



Ranea Rafanan

Foundation Engineer
EDF Power Solutions Japan K.K



Yiorgos Perikleous

Principal Geotechnical Engineer
DNV



Dr. Cheng-Hsien Chung

Director
Marine Industrial Department, Ship and
Ocean Industries R&D Centre Taiwan



Dr. Federico Pisanò

Manager, Energy Transition & Emerging
Markets
NGI

Setting the Scene: Current Practice and Why DONISIS is Needed

Ma. Ranea Rafanan (Raffy)
Foundation Engineer

2026 June 4th

Minato Mirai Yokohama, Japan



EDF Group : world's leading producer of low-carbon electricity

EDF Group in 2025



197 000

Employees worldwide



41 M

Customers worldwide

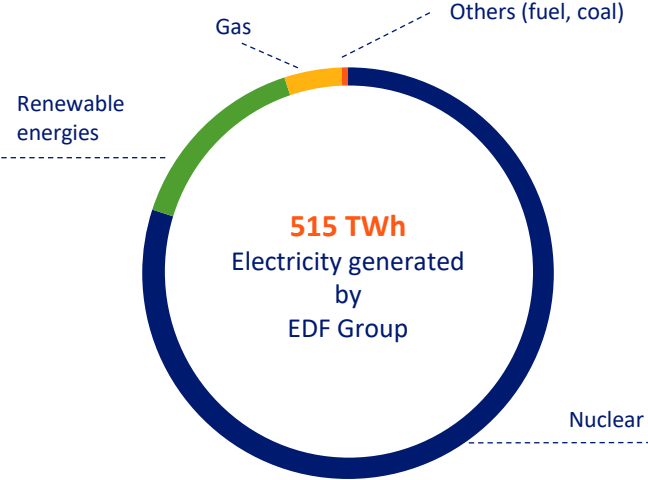


95%

Production free from CO₂ emissions

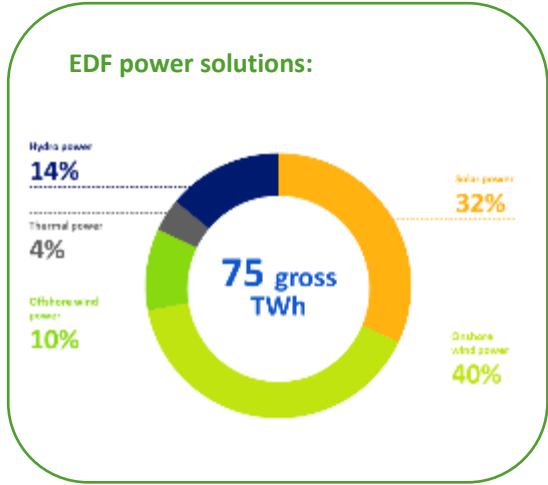


26.5 g CO₂/kWh
Carbon footprint



Nuclear : 80%, Renewable energies : 15%, Gas : 4.5%, Others (fuel, coal) : 0.5%

EDF power solutions:

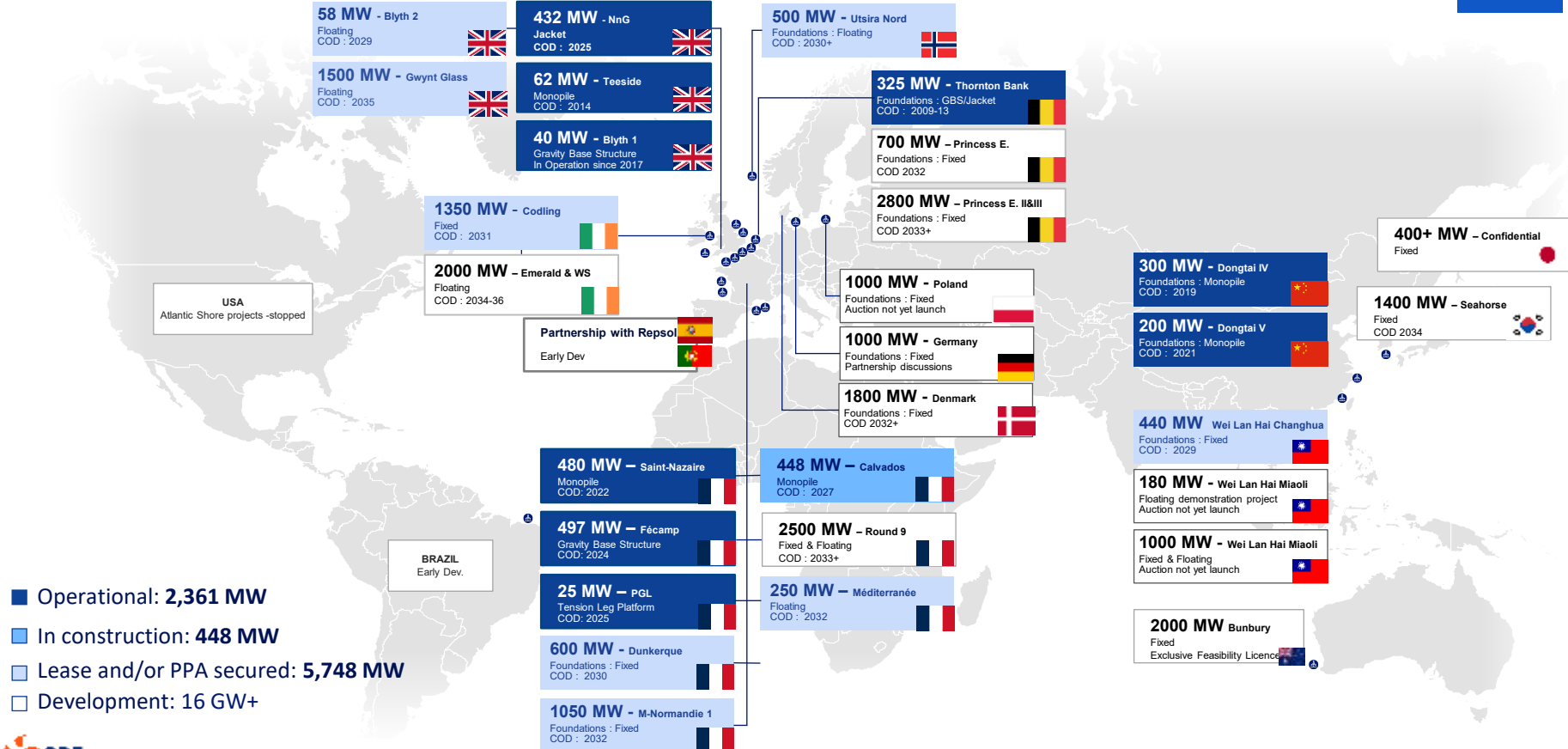


Our "raison d'être" : build a net zero energy future with electricity and innovative solutions and services, to help save the planet and drive wellbeing and economic development



EDF power solutions Offshore Wind Project portfolio (25GW+)

A large and diversified pipeline worldwide



- Operational: **2,361 MW**
- In construction: **448 MW**
- Lease and/or PPA secured: **5,748 MW**
- Development: **16 GW+**



Why DONISIS is Needed?

Seismicity in APAC and Americas is different from Europe

- › The offshore wind industry is expanding from Europe to new geographies in APAC and Americas



Figure 1. Global Seismic Hazard Map



Figure 2. Europe Seismic Hazard Map

This region consists of:
90 % of Global Earthquakes
75 % of World's volcanoes

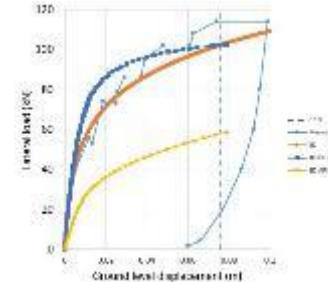


Why DONISIS is Needed?

Seismic design of Monopiles must evolve with monopile-specific frameworks

Early Monopile seismic design methods are primarily adapted from:

- ✓ Building standards
- ✓ Bridge piles
- ✓ Port piles
- ✓ Small-diameter offshore oil & gas piles



Merits of monopile-specific frameworks as demonstrated by PISA.

Figure 3. Displacement – load curve of pile on clay ($L/D=5.2$)

Key areas of **uncertainty**:

- Monopile-soil system's dynamic response to high-frequency transient dynamic loading
- Complex soil layering effects
- Pore water pressure build-up
- Liquefaction
- Soil non-linearity
- Soil damping contributions

Current researches are looking at 1D modelling that can reproduce detailed response in 3D finite-element without losing significant accuracy.

DONISIS is not meant to be a “**revolutionary**” change to seismic design of Monopiles, rather an “**evolutionary**” one.



Why DONISIS is Needed from Developer's perspective?

Uncertainty = Bankability impact

- **Uncertainty matters because it drives more conservative design choices.**
- In practice, uncertainty can translate to:
 - Higher safety factors and heavier foundations
 - Fabrication, storage, transport, and installation constraints
 - Higher project cost therefore higher LCoE and weaker bankability

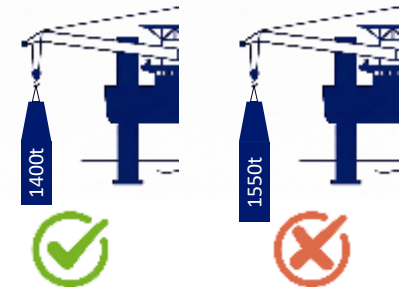
Rough scenario:

- 450MW project, 15MW class, 30 units
- Foundation accounts for 30% of CAPEX
- 10% of foundation weight is set as uncertainty buffer. It is equivalent to 100-150 ton of steel per MP-TP set.

**For the uncertainty buffer alone ,
Δ3% Total project CAPEX (Total Delta: €38 Million EUR / ¥7 Billion JPY)
Due to extra tons of steel, upgrading vessel assumption, extra charter days for
reduced MP-TP set/trip due to deck limits etc.**

only

Hypothetical figures



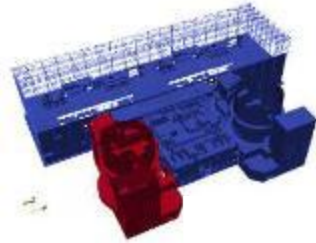
If no vessel available in Japan,
procuring vessel abroad
(cabotage / reflagging risk)

- To minimize conservatism, **unique methods for each project** can be developed.
⇒ **Extra development cost, Schedule impact, and Certification risk !**

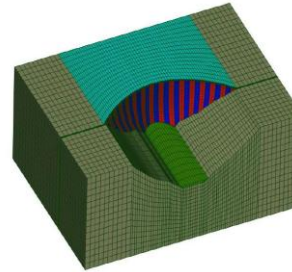


EDF R&D and seismic analysis

EDF R&D has historically a lot of experience in seismic analysis, in particular in traditional power plants, nuclear power plants, and dams



Assessment of **seismic relative displacements between structures** by considering soil-structure interaction of the whole **nuclear site**



FEM model of **arch dam**, foundation and reservoir for seismic studies.

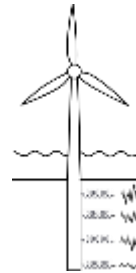
CODE aster is an open-source finite-element software developed by EDF.

EDF R&D's in-kind Contribution to DONISIS

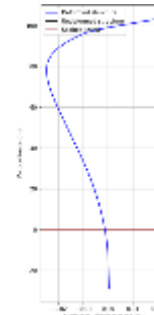
- The in-kind contribution focuses on modelling and benchmarking the ETH Zurich centrifuge tests.
- EDF is involved in the review, independent model validation, and contribution to specification of centrifuge test.

OpenSees

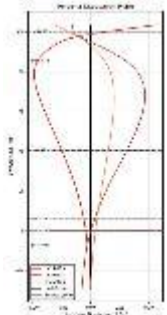
+
GR8GEO
tool for
DONISIS



Engineering model



Second eigenmode



Mode shape diagram



References

[Global Seismic Hazard Map | Global Earthquake Model Foundation](#)

[GeoStudio | PLAXIS - Comparison of PISA and API methods for monopile under lateral loads – Communities](#)

[Assessment of capital expenditure for fixed-bottom offshore wind farms using probabilistic engineering cost model](#)

OWA DONISIS Interim Workshop

Typhoon and Seismic Documentation Review for Offshore Wind Projects in Taiwan

Cheng-Hsien Chung

Director, Marine Industrial Department
Ship and Ocean Industries R&D Center (SOIC) Taiwan

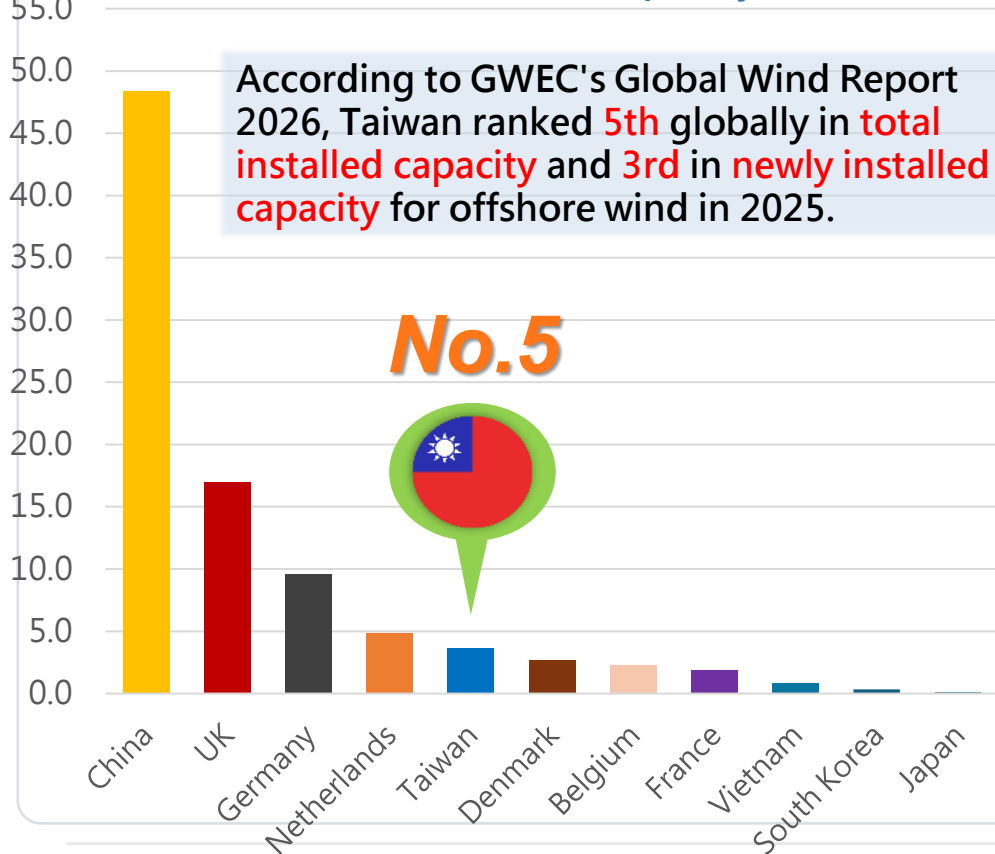


SOIC

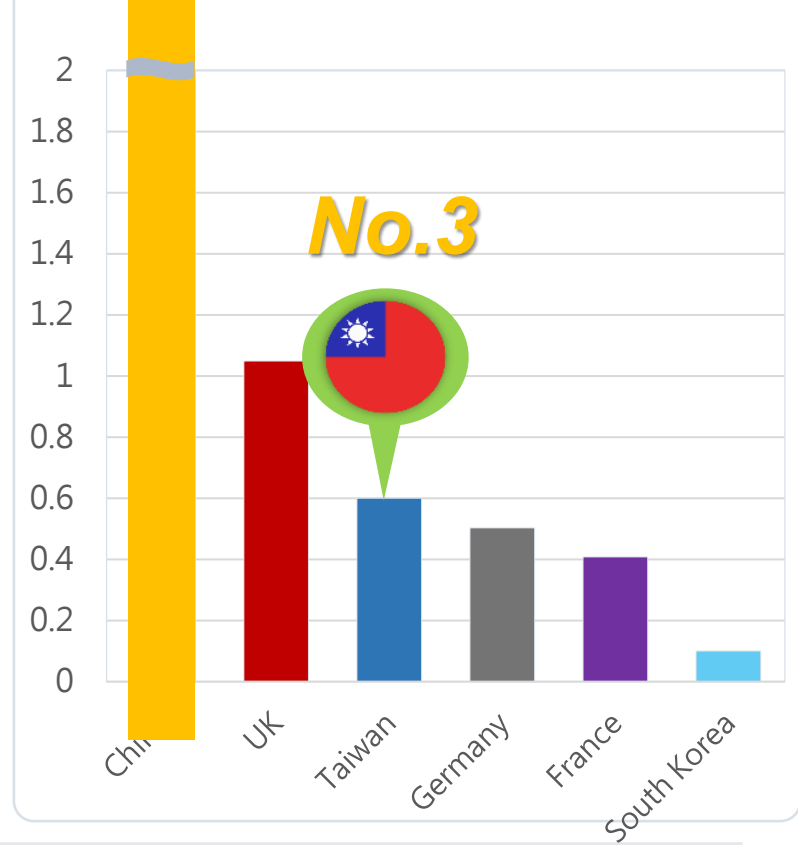
Yokohama, Japan | 2026



Total Installed Capacity

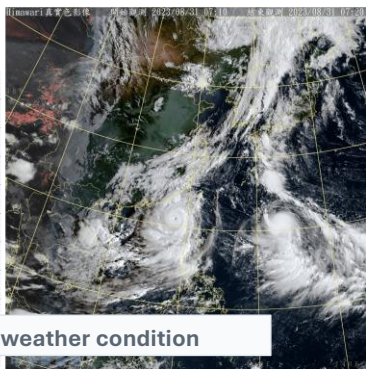
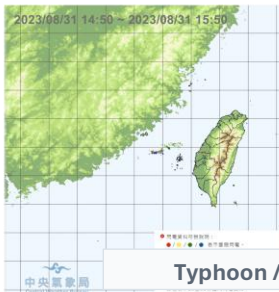


Newly Installed Capacity



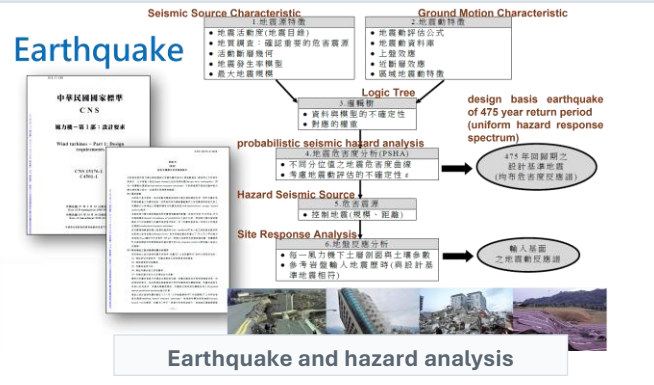
Taiwan-Specific Environmental Conditions

Weather Condition



Typhoon / weather condition

Earthquake



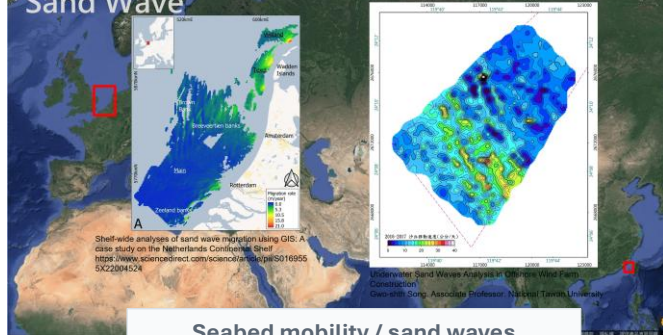
Earthquake and hazard analysis

Geological Condition



Geological condition and pile interaction

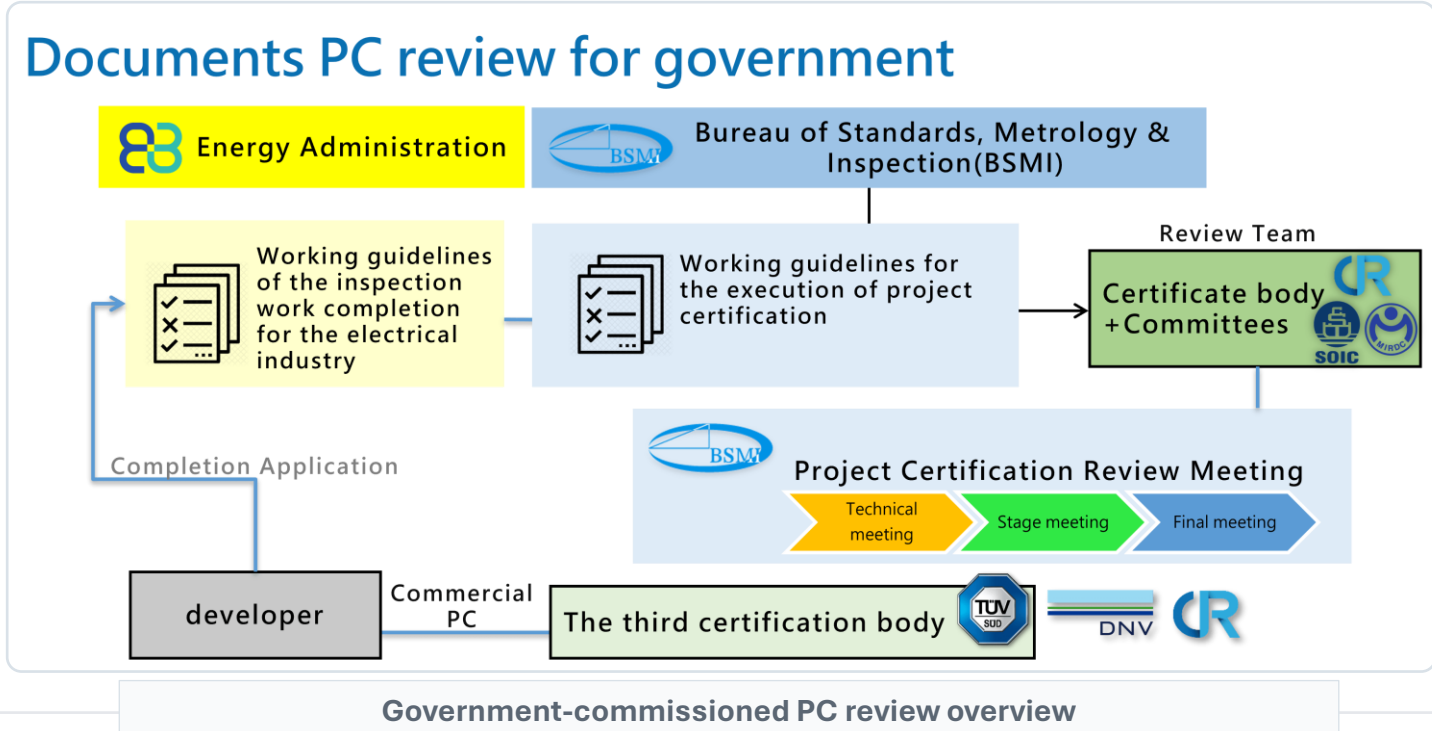
Sand Wave



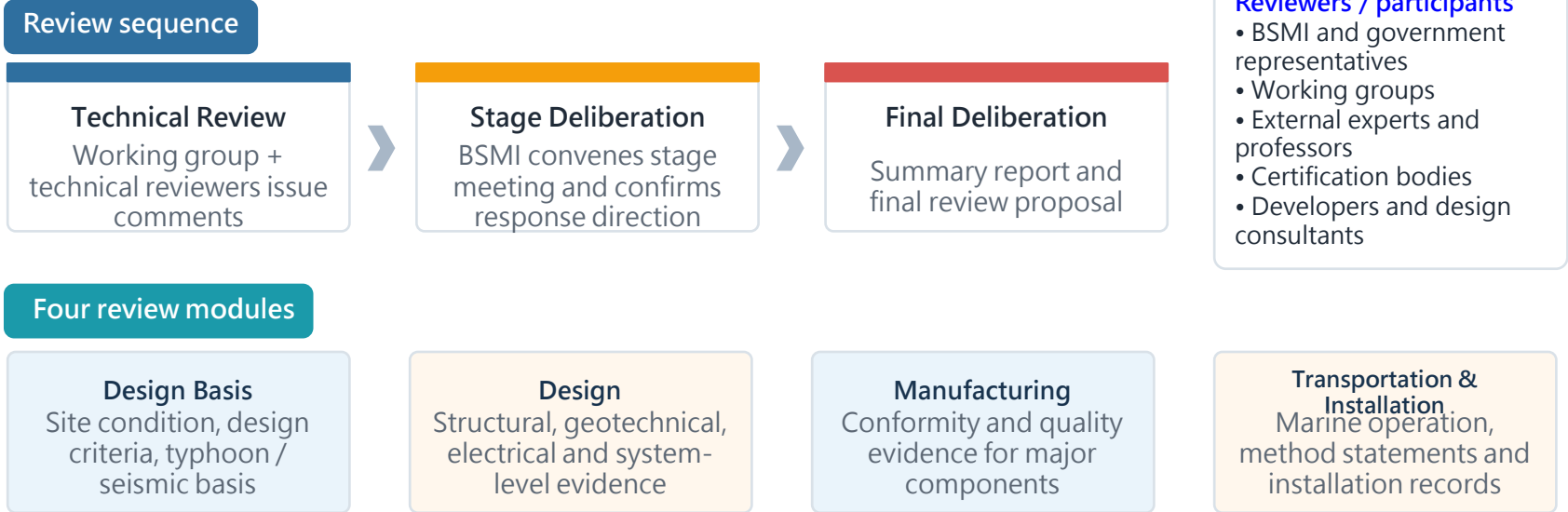
Seabed mobility / sand waves

Current Seismic Design Framework in Taiwan

Taiwan extends its general seismic design practice into offshore wind through national standards, project certification and government review.



How the government review is organized



Government-Commissioned Project Certification Review Service

The review covers four modules: Design Basis, Design, Manufacturing, and Transport & Installation, applied to WTG & FOU, Cable, and Offshore OSS. Some modules require certification body involvement; The required documents according to “**Working Guidelines For The Execution Of Project Certification**”

Grid-connected year	On or before 2021.12.31			2022.01.01–2025.12.31		
	WTG & FOU	Cable	Offshore OSS	WTG & FOU	Cable	Offshore OSS
Design Basis	●	○	○	●	○	○
Design	●	○	○	●	●	●
Manufacturing	○	○	○	●	○	●
Transport & Installation	○	○	○	●	○	●

Completed / operating wind farms

Wind farm / cluster	Public status	Note
Formosa 1	Completed / operating	Demonstration-phase reference
Taipower Phase 1	Completed / operating	Public-sector demonstration case
Formosa 2	Completed / operating	Zone-development project case
Greater Changhua 1 & 2a	Completed / operating	Large commercial-scale case
Changfang & Xidao	Operating / commercial stage	Large commercial-scale case
Yunlin / Zhong Neng	Operating or staged progress	Large commercial-scale case

- Project certification of the module must be conducted by an accredited certification body.
- Project certification of the module is not mandatory by a certification body; however, related documents must still be submitted and reviewed by the government review team.

Offshore Wind Support Structures and Seismic Design

Seismic Design Requirement

- Scope
 - Rotor-Nacelle Assembly (RNA)
 - Support structure: tower, substructure and foundation
- Performance Objectives
 - EQ1: return period of 475 years
 - RNA: allowable damage
 - Support structure: almost elasticity
 - EQ2: return period of 95 years
 - Foundation:
 - Allowable permanent deformation
 - Inclination angle of foundation shall meet the performance requirements of SLS.
- Analysis Essentials
 - ULS: stress and strength of structural components, bearing capacity of foundation piles
 - SLS: permanent deformation of foundation

EQ1 & EQ2: according to
Appendix H of CNS 15176-1

Common Seismic Issues during Technical Review

Typical review focus for typhoon / seismic and site-condition related documents

Review intent

These issues usually require the developer to demonstrate traceability between site investigation, design basis, numerical analysis, and certification evidence.

The key review question is whether local Taiwan conditions are properly reflected in the design and not only referenced as generic standard compliance.

Focus: consistency + traceability

1

CPT execution vs. CNS 15176-1

Check whether CPT locations, depth, cone parameters, calibration records and reporting format are consistent with required site investigation practice.

2

PSHA / SRA and liquefaction depth

Confirm the return period, input motions, soil profile, nonlinear soil parameters and liquefaction assessment; identify the maximum liquefaction depth used for design.

3

Shear velocity of bedrock

Review the engineering bedrock definition, Vs profile and Vs30 assumption. Sensitivity checks may be needed when reference depth or bedrock stiffness is uncertain.

4

Maximum seabed level change

Assess seabed mobility, sand-wave migration, scour and possible exposure. The result should be reflected in cable burial and foundation design assumptions.

5

Corrosion protection strategy

Clarify coating durability, cathodic protection design life, inspection plan, and microbial corrosion (MIC) consideration for long-term offshore exposure.

Suggested review comment: request clear acceptance criteria, supporting references, and consistency among design documents. The identified issues should also be continuously monitored and followed up during the operation and maintenance phase.

Conclusion and Feedback

Current review system and suggested improvements for typhoon / seismic design evidence

Conclusion

Taiwan has established a project certification review framework for offshore wind development, and the review process has been applied to multiple offshore wind farm projects. Through these accumulated project cases, the regulatory and technical review practices for typhoon and seismic design have become more structured and experience-based.

Feedback / Suggested Improvements

1

Clarify review interfaces

Define clearer links among Energy Administration, BSMI, certification bodies and developers at each permitting milestone.

2

Strengthen criteria

Provide more explicit acceptance criteria for PSHA / SRA, liquefaction depth, bedrock velocity, seabed change and typhoon assumptions.

3

Link to O&M follow-up

Carry critical typhoon / seismic assumptions into O&M plans, monitoring, post-event inspection and periodic reassessment.

Earthquake

Seismic Source Characteristic

- Seismicity Assessment (Earthquake Catalog)
- Geological Investigation: Identification of Significant Seismic Sources
- Active Fault Geometry
- Earthquake Recurrence Model
- Maximum Magnitude (Mmax)

Ground Motion Characteristic

- Ground Motion Prediction Equations (GMPEs)
- Ground Motion Database
- Hanging Wall Effect
- Near-Fault Effect
- Regional Ground Motion Characteristics

Logic Tree

- Data and Model Uncertainties
- Logic Tree Weighting Factors

Probabilistic Seismic Hazard Analysis

- Seismic Hazard Curves for Different Fractile Levels
- Incorporation of Ground Motion Prediction Uncertainty (ϵ)

Hazard Seismic Source

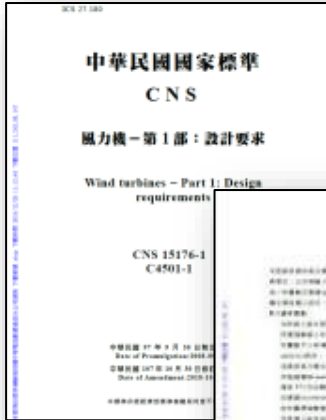
- Controlling Earthquake Scenarios (Magnitude and Distance)

Site Response Analysis

- Soil Profiles and Geotechnical Parameters at Each Wind Turbine Location
- Reference Rock Input Ground Motion Time Histories (Consistent with Design Basis Earthquake)

design basis earthquake of 475 year return period (uniform hazard response spectrum)

ground motion response spectrum





WHEN TRUST MATTERS

The ♠ CE Joint Industry Projects Key insights

Alleviating Challenges from Earthquakes for Wind Farms

Yiorgos Perikleous

Content



Introduction

The ACE 1&2 JIPs

Key takeaways for Donisis JIP

Q&A

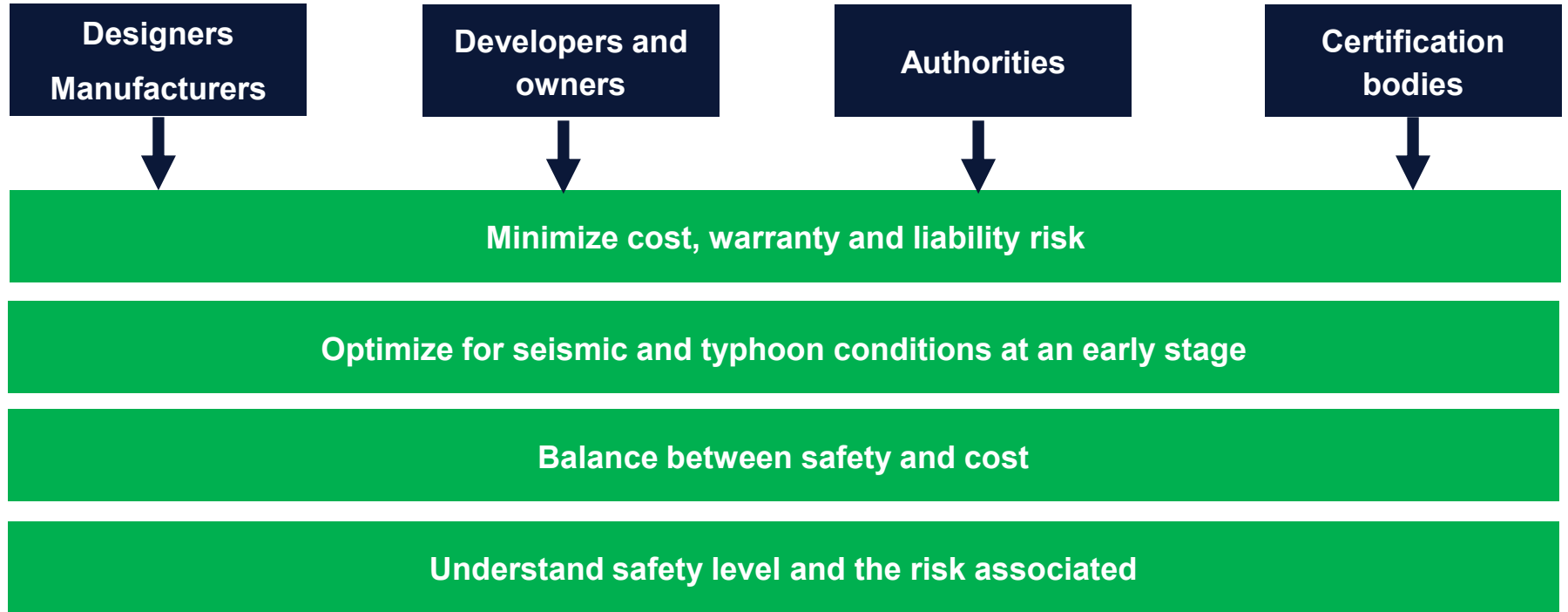
The ♠CE Joint Industry Project

Challenge:

Agree on industry approach how wind turbine structures should be designed for Cyclones and Earthquakes



Why a JIP?



ACE 1 (2019-2021)

♠CE 2 - Members



Industry Partners

- Calibration and validation, limitations of simplified methods
- Development of DNV-RP-0585

Remaining challenges



ITRP members

- "term sign loading"
- ...

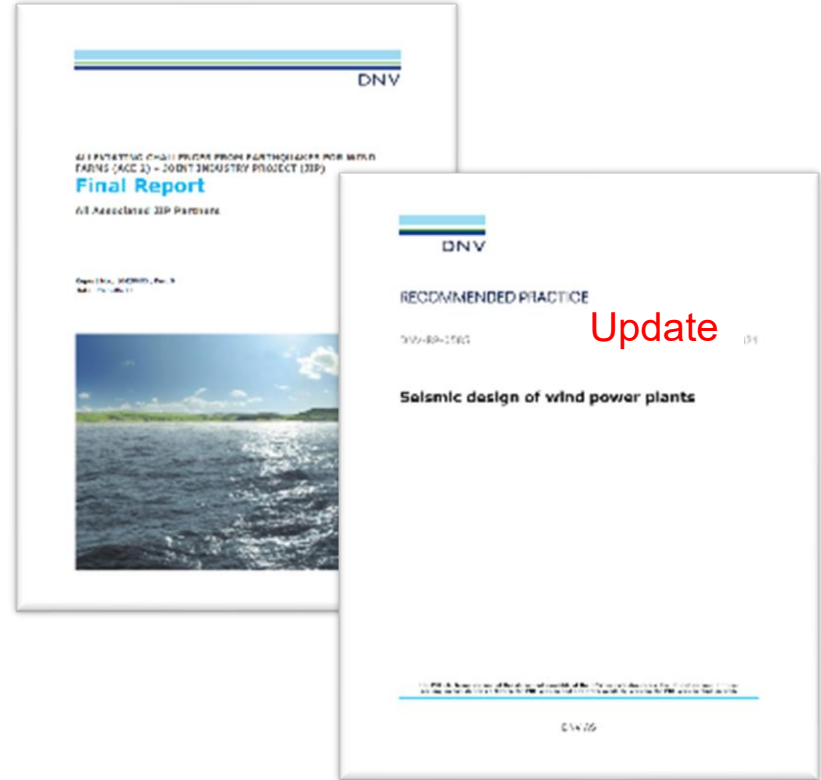
♠CE 2 (2023-2025)



ACE 1 – (2019-2021)



♠CE 2 – (2023-2025)



Key takeaways for Donisis JIP

Design Principles

Wind Turbines

- Following IEC 61400 and DNV standards
- 475-yr return period
- ULS check, reduced material safety factor for steel support structures allowed
- Reduction of ULS return period possible for RNA
- ALS check should only be performed in case of increased safety demand
- 95-y SLS check for geotechnical aspects

Substations

- Follow ISO 19901-2 and ISO 19902 process
- L1 structure, ALE typically around 3,000-yr
- ELE typically at 300-yr if $C_r = 2.8$
- $C_r = 2.8$ represents a ductile jacket with X-braces
- ULS check at ELE level; nonlinear check at ALE level

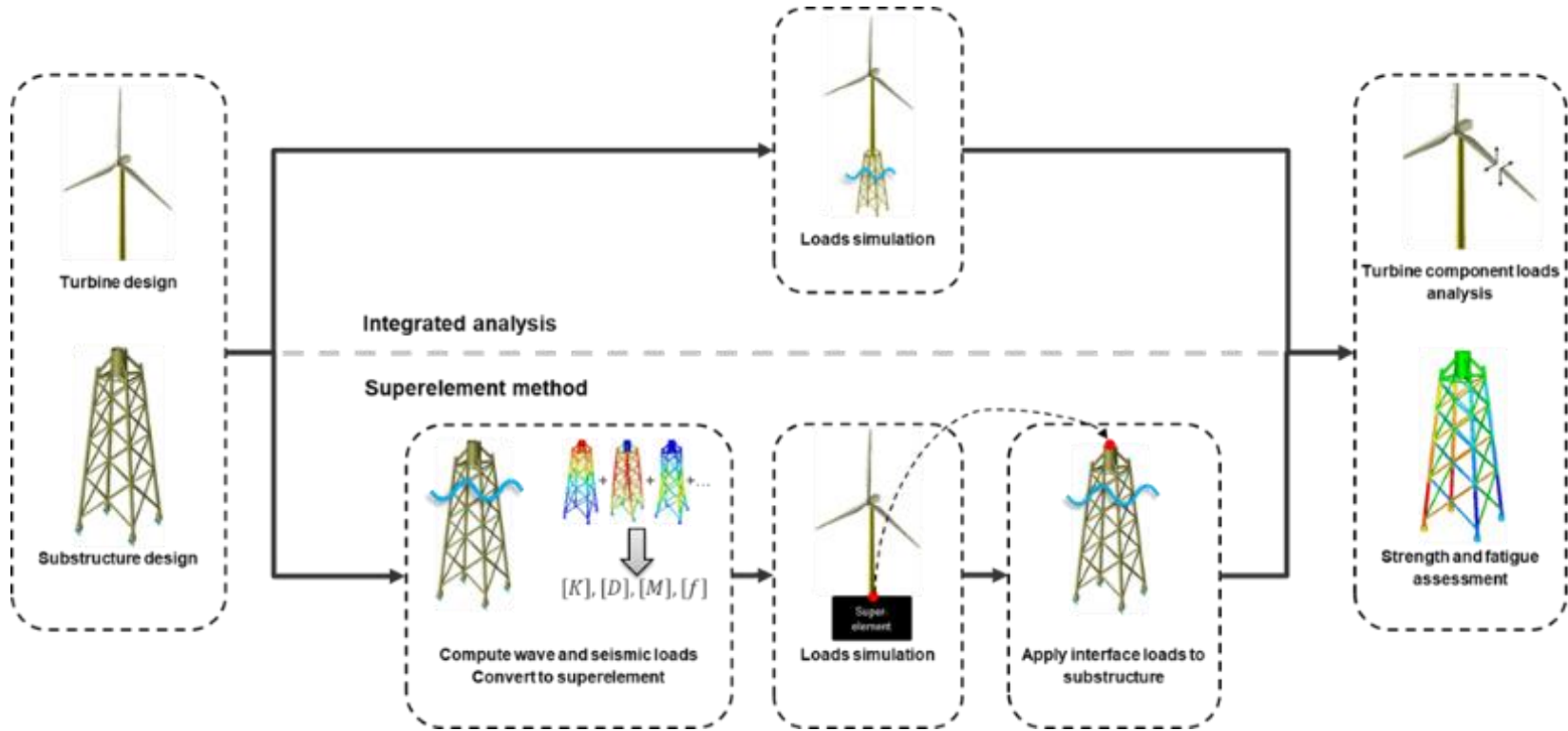
Response spectrum method

- Allowed for onshore WTG
- As stated in IEC 61400-1
- Low damping when compared to ordinary onshore structures, this should be adjusted according to IEC 61400-1 process

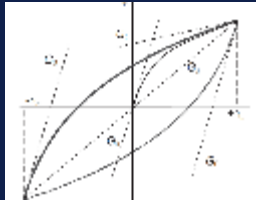
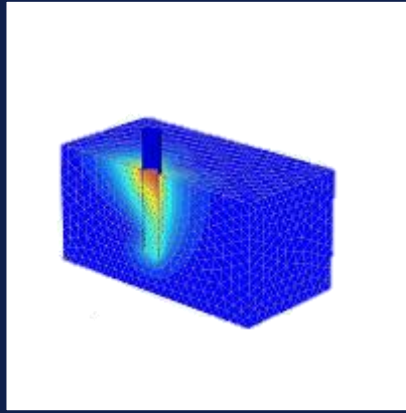
Time history method

- Offshore WTG and WTG foundations must use time history method
- As required in IEC 61400-3-1
- A minimum of 4 sets of earthquakes should be used
- Preferably 7 sets of earthquakes are used to cover seismic variability

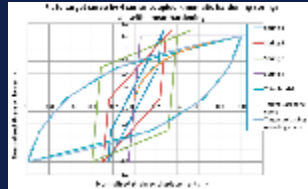
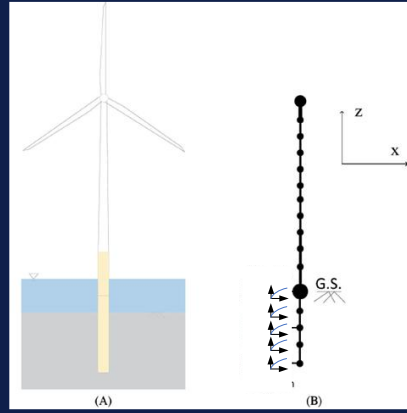
Modelling approaches in seismic design



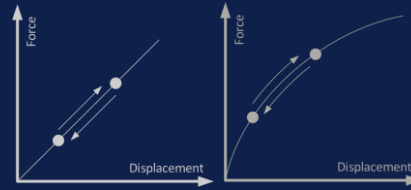
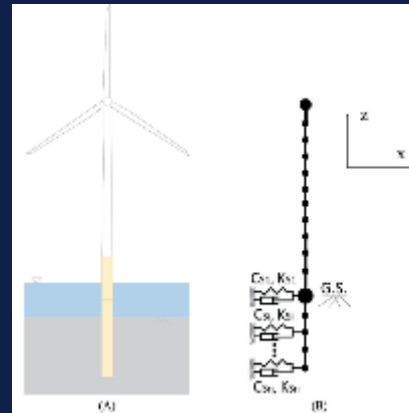
WP1 Damping – How can it be modelled



1. FEA-based

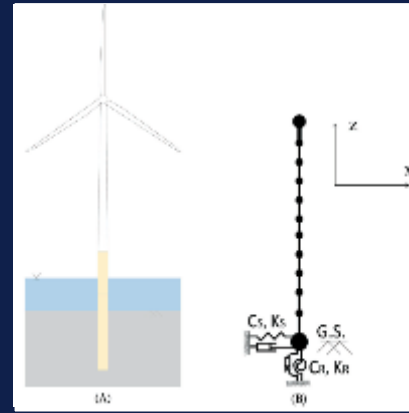


2. Nonlinear Hysteretic springs



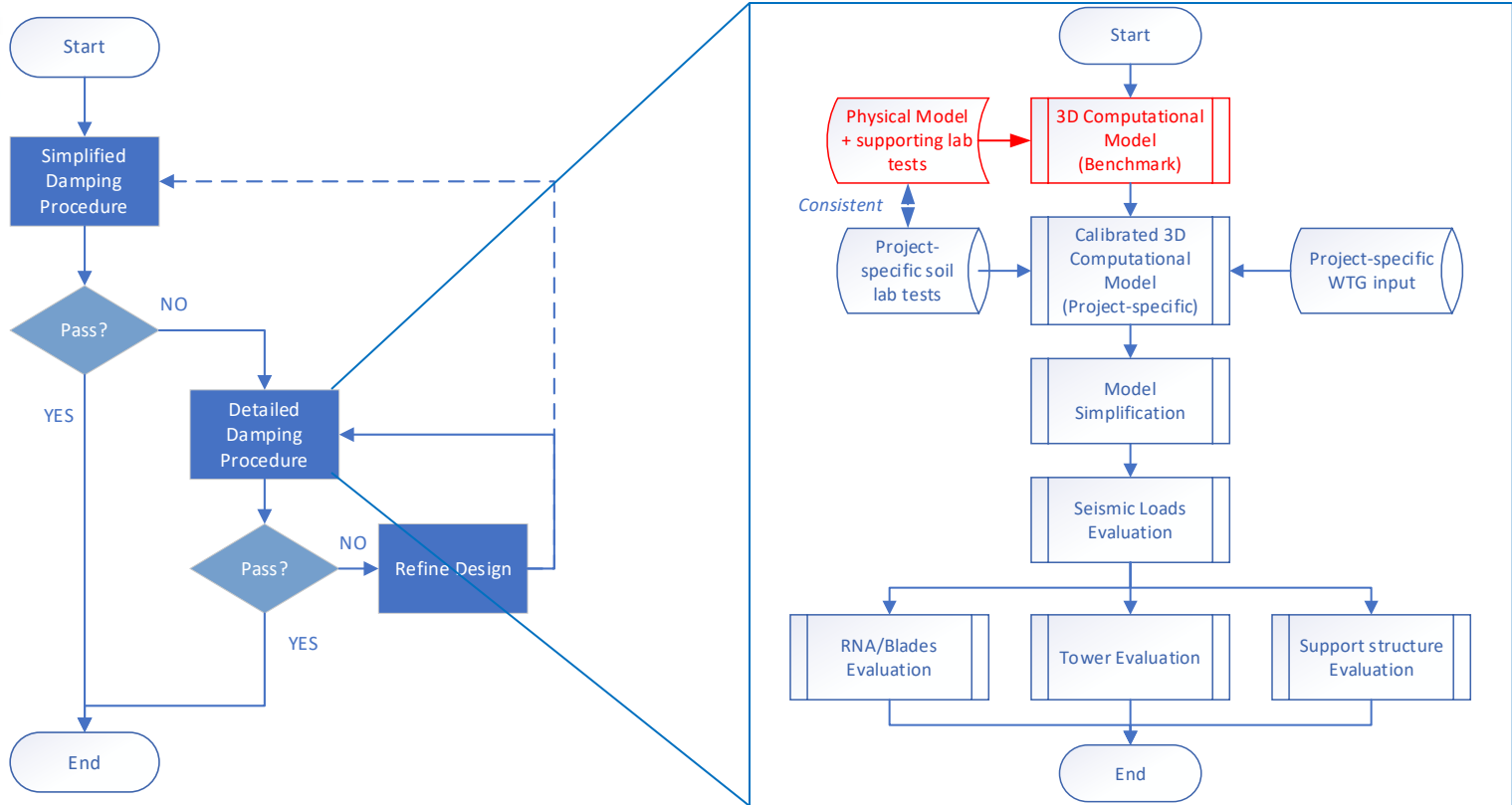
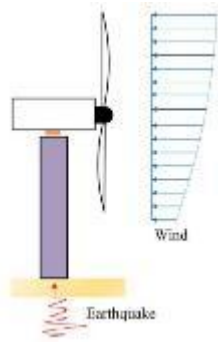
a. Linear b. Non-Linear

3. Spring & Dashpot

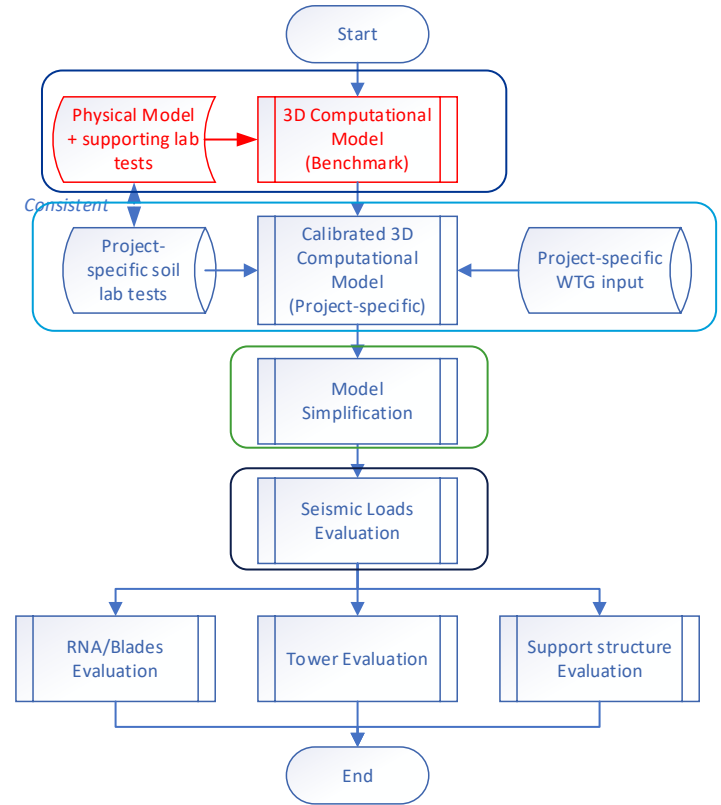
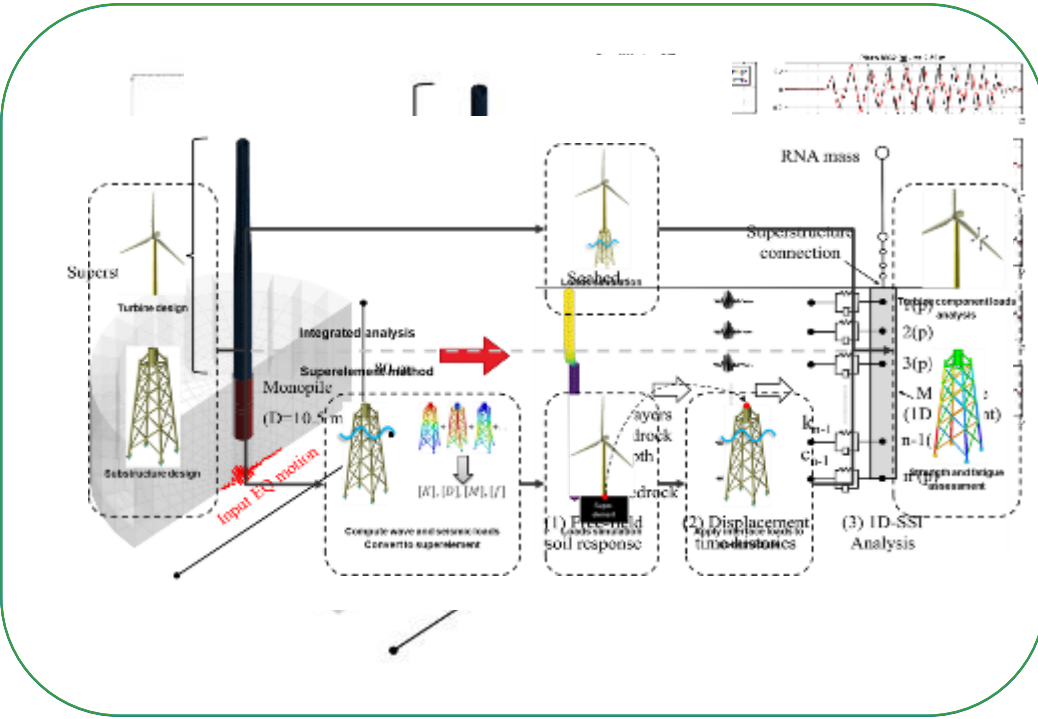


4. Linearised Super-element with Rayleigh damping

Framework for including soil damping in WTG seismic design



Framework for including soil damping in WTG seismic design





How it all began

Federico Pisanò

NGI Boston (formerly TU Delft)



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Outline

- An enabling research environment
- A research journey on monopiles
- The MIDAS framework
- Towards DONISIS and future challenges

An enabling research environment

Cross-faculty research capabilities



- Faculty of Aerospace Engineering
- Faculty of Mechanical, Maritime and Materials Engineering
- Faculty of Civil Engineering and Geosciences
 - structural analysis & design
 - material behaviour & testing
 - soils & foundations
 - hydraulics & coastal engineering
 - strong links to offshore industry
 - software development



An enabling research environment

The GROW consortium (Growth through Research, development & demonstration in Offshore Wind)



GROW is a joint research programme in offshore wind that initiates research and accelerates innovations. GROW's strength lies in its ability to run focused, sequential and complementary RD&D activities. The consortium includes over 20 leading and committed partners that cooperate closely to conduct joint research. Short lines of communication, trust and exchange of experience and knowledge are all significant contributions to the success of GROW.

source: <https://grow-offshorewind.nl/>

Projects

- Show all
- Project status
- Completed
- Theme Partners
- End-of-life
 - Energy system
 - Environment
 - Foundation
 - Installation
 - O&M
 - Turbine
 - Wind farm optimisation

Theme	Partners
Ampelmann	MARIN
Boskalis	RWE Renewables
Deltares	Seaway T
DDT	Shell
Enerco	Siemens Energy
Fugro	Sif
G&M Works	TNO
Heerema Marine Contractors	TotalEnergies
Huisman	Tree Composites
IOIP	TU Delft
IERA Nex	Van Dord
KD	Vattenfall

An enabling research environment

A Dutch R&D portfolio on offshore wind foundations



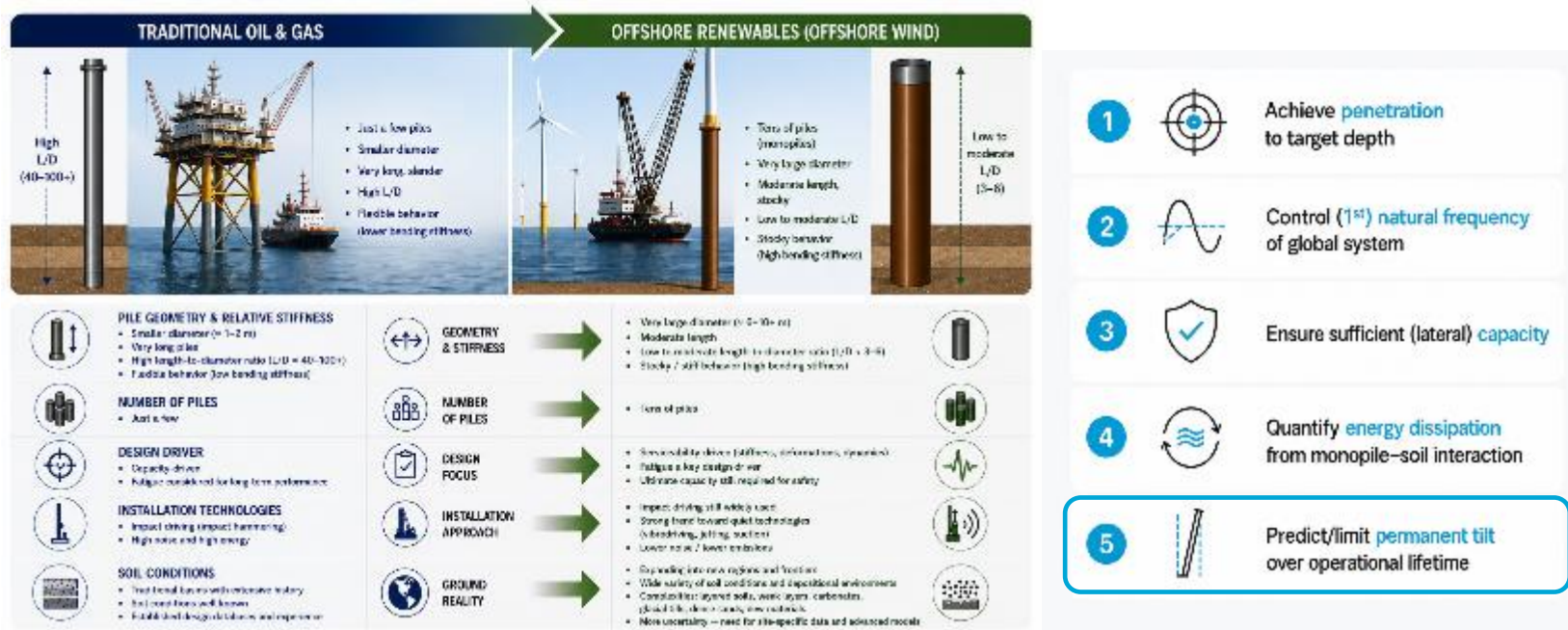
- Slip Joint Offshore Research project (SJOR) OWP/PS
- Gentle driving of Piles (GDPI) OWP/PS
- Hydraulic Pile Extraction Scale Tests (HyPC-ST) OWP/PS
- Corrosion Fatigue Life Optimisation (C-FLO) OWP/PS
- Monopile Improved Design through Advanced cyclic Soil modelling (MIDAS) OWP/PS
- Hydraulic Pile Extraction Scale tests 1.2 (HyPC-ST 1.2) OWP/PS
- Wrapped Composite Joints for Next generation offshore wind support structures - Phase 1 (WnapNode-1) OWP/PS
- Sustainable Installation of XXL Monopiles (SIMOX) OWP/PS
- Gentle Driving of Piles 1.2 (GDPI.2) OWP/PS
- Silent installation of Monopiles IIR (SIMPLE IIR) OWP/PS
- Optimising Pile Installation through Scour protection (OPIS) OWP/PS
- Tubular Pile Pull out testing program (TPPT) OWP/PS

- Collaboration to collect data for Integrated offshore drivability and noise prediction modelling (COAX) OWP/PS
- Silent installation of Monopiles III (SIMPLE III) OWP/PS
- Wrapped Composite Joints for Next generation offshore wind support structures - Phase 2 (WnapNode-II) OWP/PS
- Tubular Pile Pull-out Testing Program II (TPPT-II) OWP/PS
- Gentle Driving of Piles 2.0 (GDPI.0) OWP/PS
- Runwave OWP/PS
- Monopile Improved Design through Advanced cyclic Soil modelling in clay (MIDASclay) OWP/PS
- Vibratory-based Installation: Extended data collection for XXL monopiles (VINDEX) OWP/PS
- SCALEWIND OWP/PS
- CompoSmart OWP/PS
- Avoiding Damage due to Piling vibrations (AD-PVIB) OWP/PS
- Improving Cable Protection for Offshore Wind (ICP52) OWP/PS

- Towards the Dynamic PressureMeter (T-DPM) OWP/PS
- Hydraulic Pile Extraction Scale Tests 1.3 (HyPC-ST 1.3) OWP/PS
- Pile Run Risk Assessment (PRRA) OWP/PS
- Silent installation of Monopiles in prevailing Clay and Sand soils (SIMPLECS) OWP/PS
- Silent and Circular Decommissioning of Monopiles (SIDE-WP) OWP/PS
- Cost-effective lifecycle: Ending for Asset Removal in offshore WIND (CLEARWIND) OWP/PS

A research journey on monopiles

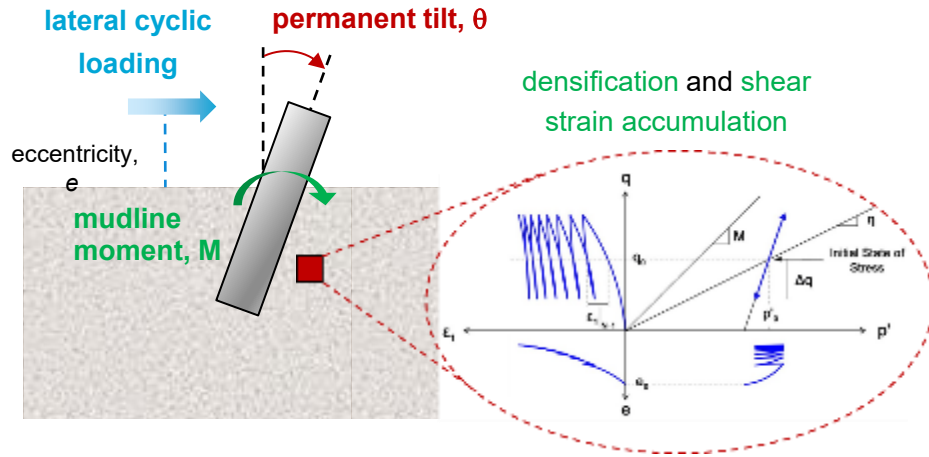
Evolution of (mono)pile engineering across offshore energy markets/regions



AI-generated image

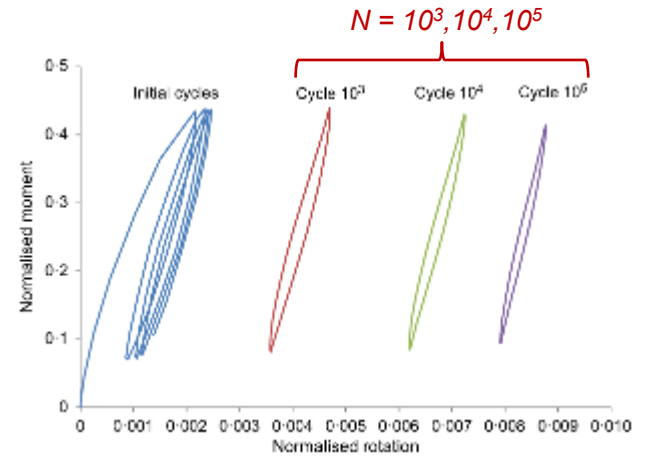
A research journey on monopiles

3D analysis of monopile tilt using the SANISAND-MS model



Pasten et al. (2014)

measured tilting response at pile head

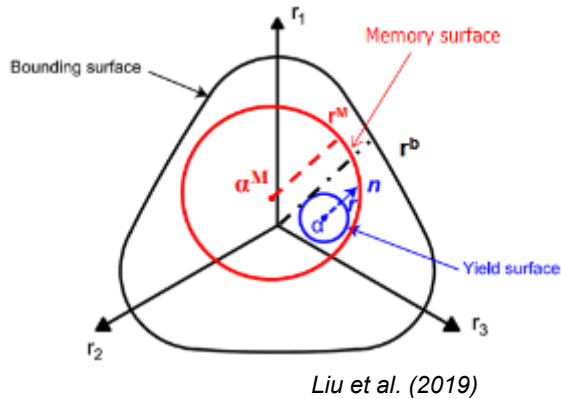


Houlsby (2016)

A research journey on monopiles

3D analysis of monopile tilt using the SANISAND-MS model

memory-enhanced bounding surface plasticity



Yield surface (YS)

determines onset of irreversible strains

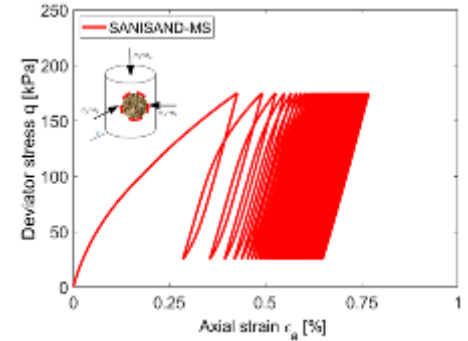
Bounding surface (BS)

encloses admissible stress states

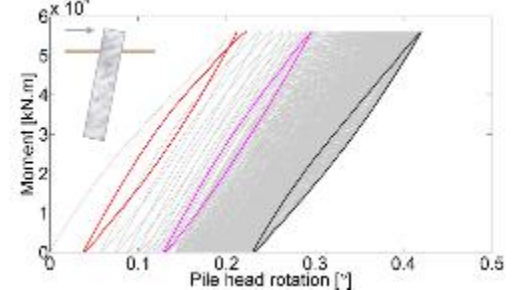
Memory surface (MS)

defines *virgin loading* (deletion of *fabric memory*)

sample response to triaxial loading



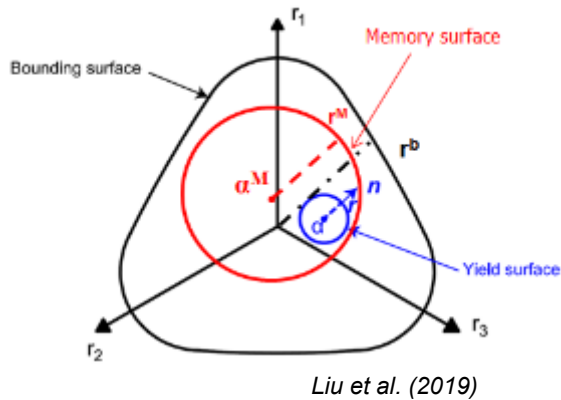
3D FE monopile response simulation



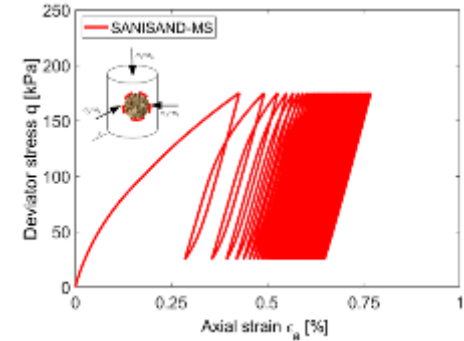
A research journey on monopiles

3D analysis of monopile tilt using the SANISAND-MS model

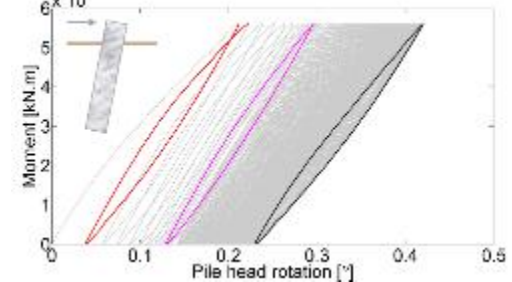
memory-enhanced bounding surface plasticity



sample response to triaxial loading

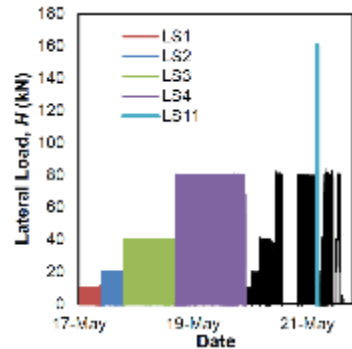


3D FE monopile response simulation



A research journey on monopiles

Application of SANISAND-MS 3D FE modelling to PISA field tests in Dunkirk

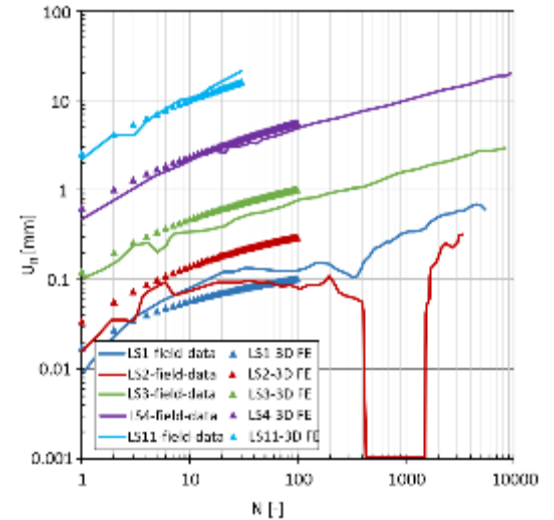
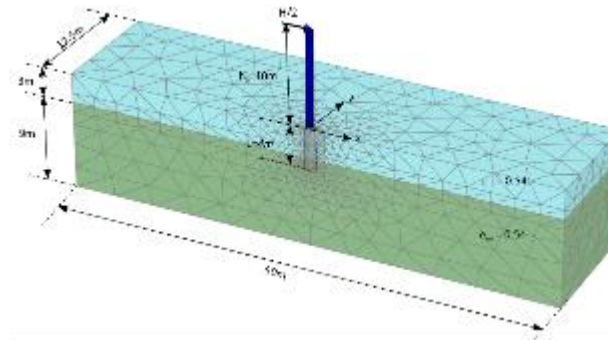


Byrne et al. (2020)

Pisanò, F. et al. (2024) *Geotechnique Letters* 14, 1-11, <https://doi.org/10.1680/jgeol.23.00075>

3D FE simulation of PISA monopile field tests at Dunkirk using SANISAND-MS

F. PISANÒ (1), L. DEL BROCCO (2), H. M. HÖG (3) and S. SPASILE (1)



Pisanò et al. (2024)

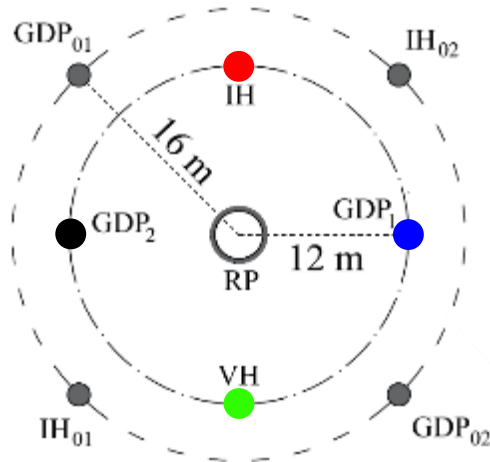
A research journey on monopiles

Improving efficiency and applicability: 1D cyclic modelling with CPT-based calibration

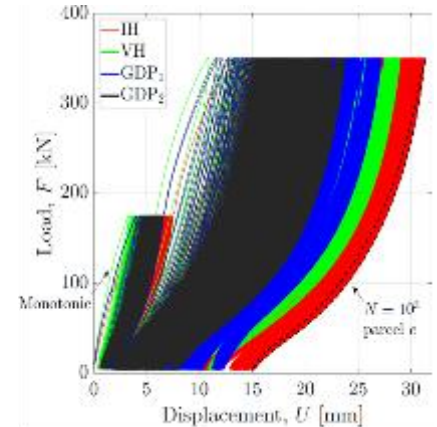
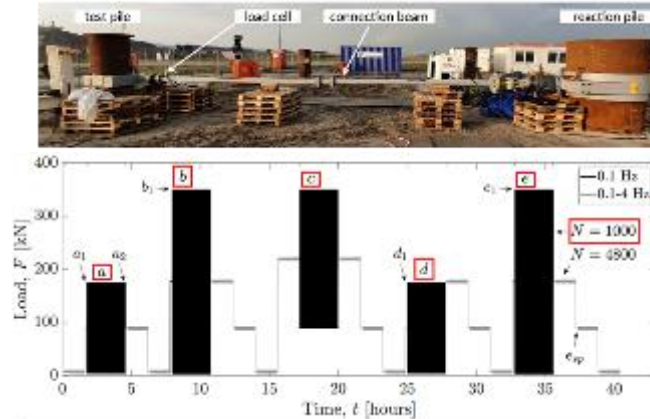
PROJECT:

Gentle Driving of Piles (GDP) COMPLETED

Making the pile installation process as efficient as possible by means of testing a novel pile installation method based on simultaneous application of low-frequency and high-frequency vibrators.



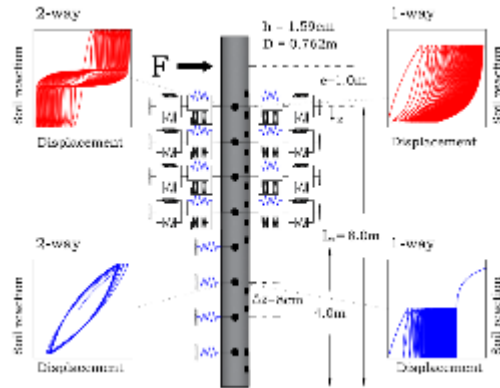
3 piling methods: Impact Hammering (IH), Vibro-Hammering (VH), GDP method (GDP₁, GDP₂)



Kementzetzidis et al. (2023)

A research journey on monopiles

Improving efficiency and applicability: 1D cyclic modelling with CPT-based calibration



elastic stiffness
 $k_{el} \approx 7G_0$

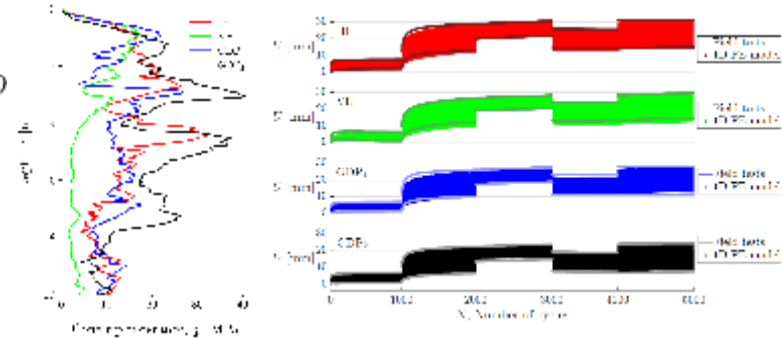
ultimate local resistance

$$p_u = C_{pu} \sigma'_{v0} D \left(\frac{q_c}{\sigma'_{v0}} \right)^{0.67} \left(\frac{z}{D} \right)^{0.75} \leq q_c D$$

ratcheting-control parameter

$$\mu_0 = C_{p0} \cdot \left(\frac{q_c}{\sigma'_{v0}} \right)^{0.1} \left(\frac{\sigma'_{v0}}{\sigma'_{v,ref}} \right)^{0.75}$$

Parameter	GDP ₁	GDP ₂	IH	VH
q_{car} (MPa)	12.4	21.3	14.9	6.4
C_{pu}	0.417	0.411	0.365	0.674
C_{p0}	310	181	282	165



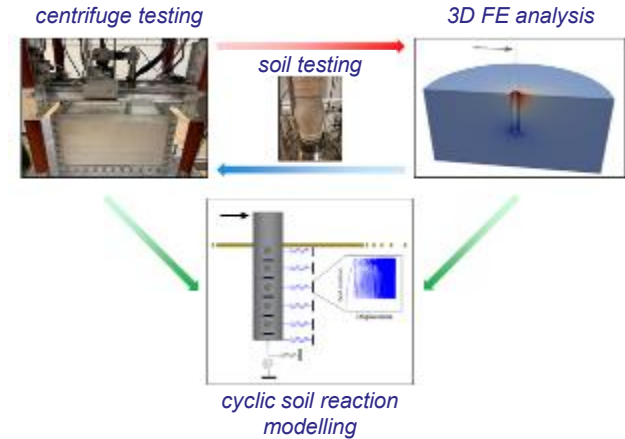
Kementzetidis et al. (2023)

The MIDAS framework

Addressing gaps about monopile cyclic analysis/design in sand



courtesy of Per Sparrevik (NGI)

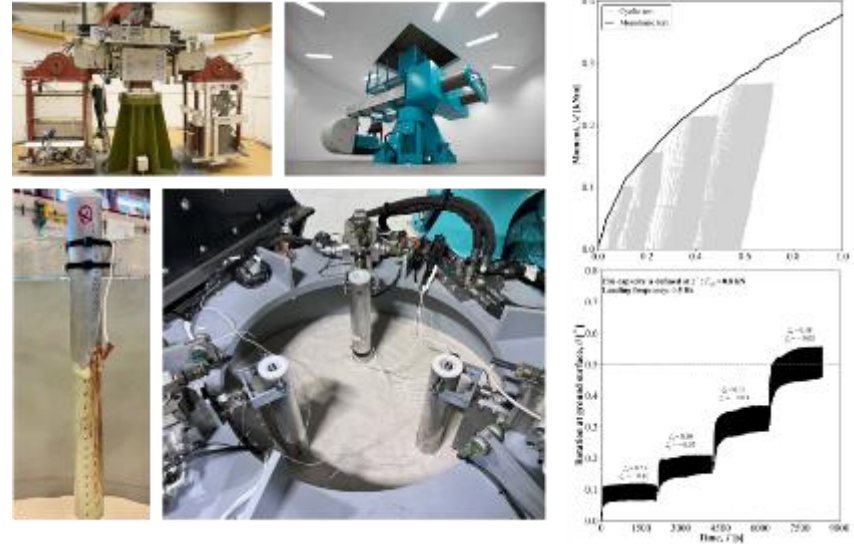


Develop and calibrate a 1D cyclic soil reaction model for monopiles in sand building on advanced numerical & physical modelling

The MIDAS framework

Project activities (2020-2024)

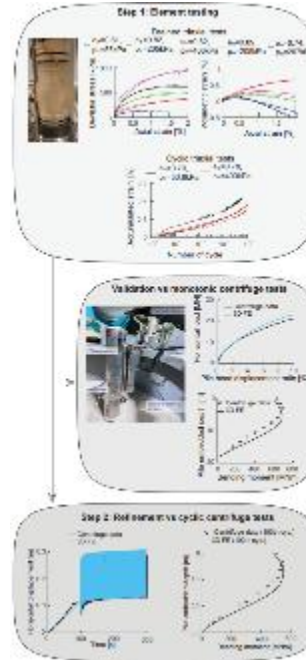
- WP1: centrifuge tests at TU Delft & Deltares
- WP2: 3D FE studies using SANISAND-MS
- WP3: formulation, calibration, & validation of MIDAS cyclic soil reaction model
- WP4: towards Technology Qualification



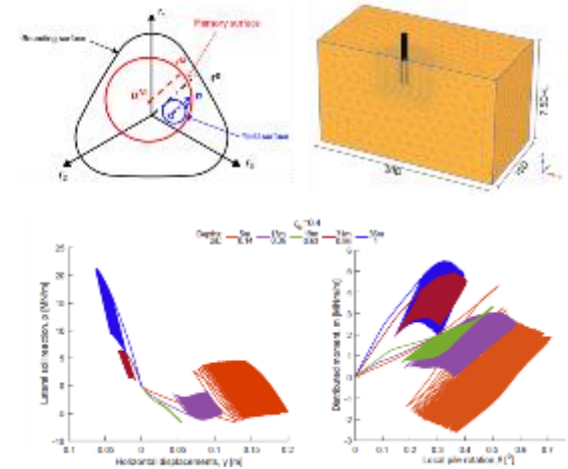
The MIDAS framework

Project activities (2020-2024)

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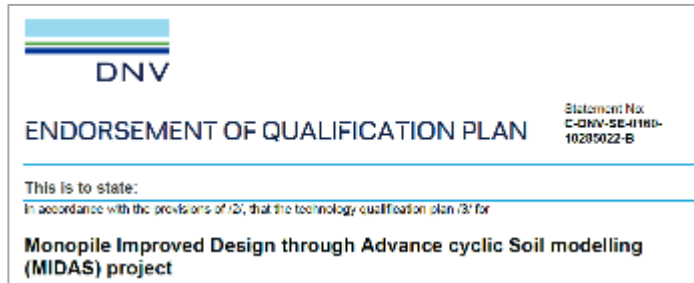
- calibration vs soil element & centrifuge tests
- parametric studies using Plaxis 3D
- informing formulation of cyclic soil reaction model



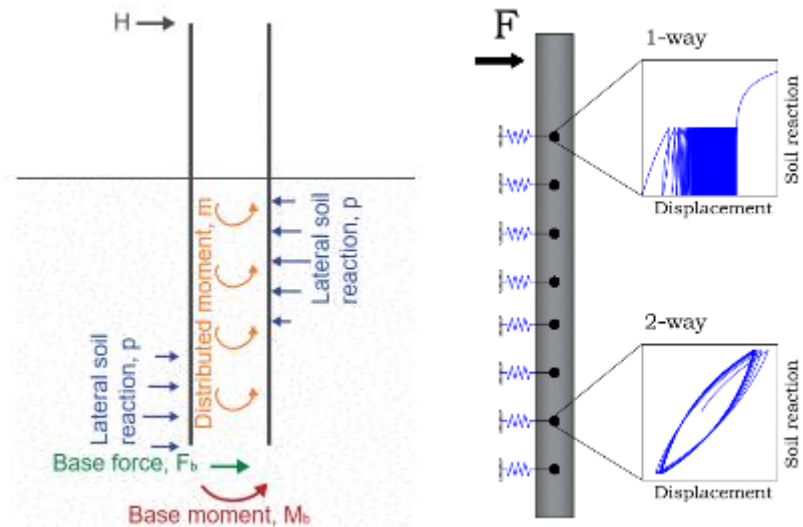
The MIDAS framework

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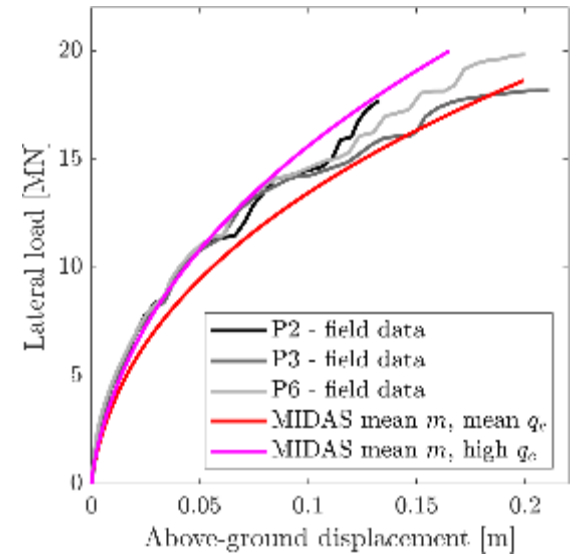
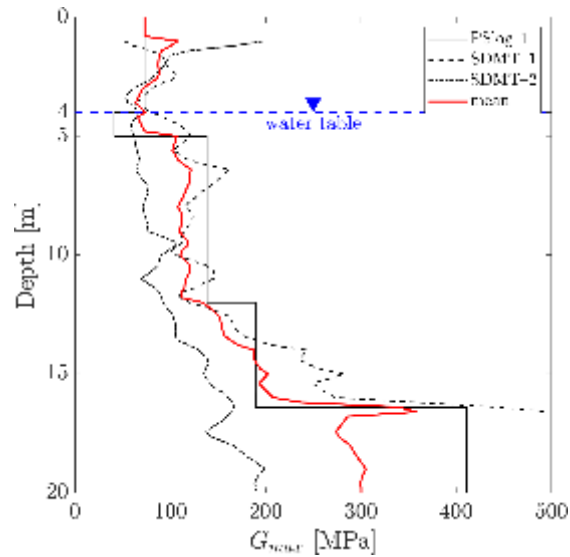
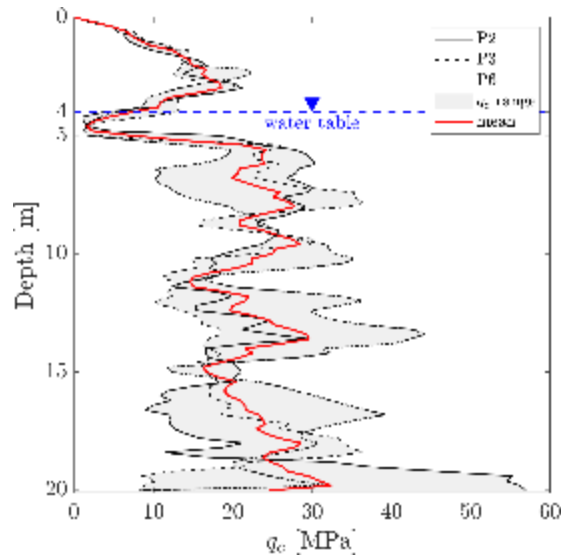


memory-enhanced bounding surface plasticity
with multiple soil reaction components



The MIDAS framework

SCPT-based calibration + comparison to VIBRO field tests



	MIDAS	VIBRO
INST.	WIP	Impact
Dr [%]	93 – 100	medium to very dense
D [m]	1.8 – 8	4.3
L/D [-]	3.75 – 7.5	4.2 – 4.3

The MIDAS framework

Current and upcoming publications

WP1

- Peccin da Silva, A., Wang, H., Zwaan, R., Askarinejad, A., & Pisanò, F. (2026). Cyclic lateral behaviour of monopiles in very dense sand: a centrifuge study on pile geometry and loading sequence effects. *International Journal of Physical Modelling in Geotechnics (Special Issue)*, *Accepted for publication*. + database (Deltares centrifuge tests)
- Wang, H. (2026). (2026). Physical modelling of monopiles in sand: A generalized scaling law and long-term cyclic response. *International Journal of Physical Modelling in Geotechnics (Special Issue – Bright Spark Lecture)*, *Under review*.
- Wang, H., Askarinejad, A., & Pisanò, F. (2026). A centrifuge dataset on a cyclically loaded monopile in sand. *In preparation*. + database (TU Delft centrifuge tests)

WP2

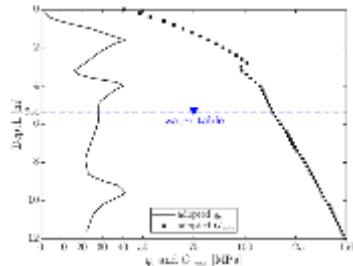
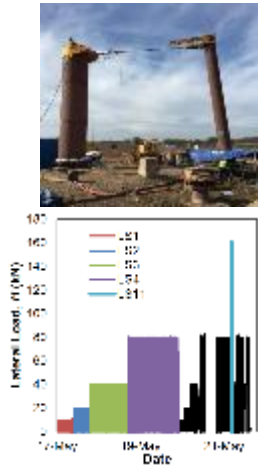
- Liu, H., Konstadinou, M., Wang, H., Jostad, H. P., & Pisanò, F. (2026). 3D FE cyclic modelling of monopiles in sand using SANISAND-MS: Calibration and validation from soil element to pile-interaction scale. *Soil Dynamics and Earthquake Engineering*, *204*, 110177.
- Flessati, L., Habib, F., Wu, K. W., Liu, H., & Pisanò, F. (2026). Conceptualising the lateral response of monopiles in sand to monotonic and cyclic loading: A SANISAND-MS 3D FE investigation. *Computers and Geotechnics*, *195*, 108069.

WP3

- Pisanò, F., Kementzetzidis, E., Wang, H., Marino, M., Wu, K.-W., Habib, F., & Peccin da Silva, A. (2026). An SCPT-based monotonic soil reaction model for monopiles in sand: calibration with centrifuge tests and assessment against field data. *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, *Accepted for publication*.
- **Kementzetzidis et al. (2027). MIDAS cyclic method paper – In preparation.**

The MIDAS framework

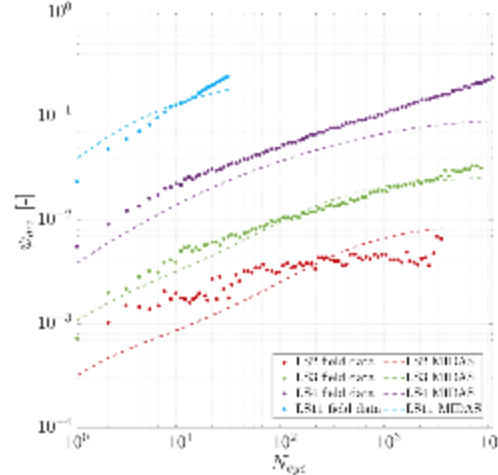
A sneak peek at the closing act... (Dunkirk PISA test simulation – DM2 pile)



LS	H_{max}	ζ_0	N
[#]	[kN]	[-]	[-]
1	10	0.046	5100
2	20	0.093	3300
3	40	0.19	8100
4	80	0.37	11110
11	160	0.74	31

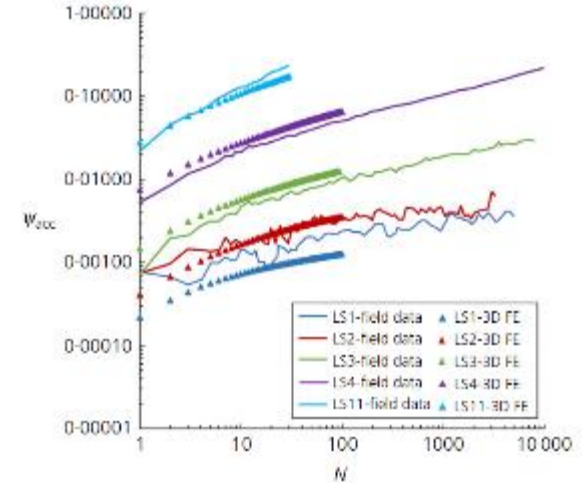
Byrne et al. (2020)

in-situ data + centrifuge-calibrated MIDAS 1D model parameters



Kementzetzidis et al. (in preparation)

3D FE SANISAND-MS simulation using in-situ + laboratory data



Pisanò et al. (2024)

Towards DONISIS and future challenges

Main achievements and limitations

- Joint efforts of industry and academia to advance cyclic monopile design
- New experimental datasets, cyclic pile load tests at different scales
- Enhancement of cyclic modelling capabilities and their validation
- Development of industry-oriented model calibration approaches
- MIDAS limited to sandy soils under low-frequency/quasi-static cycling
- Ongoing research for monopiles in clay and seismic loading conditions



Saint-Nazaire OWF
France



Federico Pisano
*Manager, Energy
Transition & Emerging
Markets*
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DONISIS Overview and Applicability

Centrifuge test results and numerical modelling



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Staff of Professorship for Geotechnical
Engineering
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PhD Researcher, TU Delft
Senior Geotechnical Engineer, Siemens
Energy

The DONISIS project

DONISIS (ギリシャ語で「振動」)

Engineering of

Monopile-Supported Offshore Wind Turbines

モノパイル支持式洋上風力タービンの工学

Evangelos Kementzetzidis



TU Delft

ETH zürich

NTML

NGI

Durham University

CARBON TRUST

Bentley

DNV

EDF

SSE Renewables

GLOBAL WIND ENERGY

Ørsted

五洋建設

RWE

SIEMENS Gamesa

TEPCO



The offshore monopile 洋上風力モノパイル



Smith, A., Stehly, T., & Musial, W. (2015).
2014-2015 Offshore wind technologies market report.
National Renewable Energy Lab.

the success of monopiles:
simple fabrication and robust design



Source: Sif Group

Monopile engineering challenges

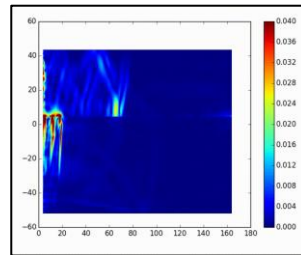
モノパイル工学上の課題

- Driveability
- Safety
- Noise
- New Technologies



shallow waters – monopile
浅海域におけるモノパイル

Installation
モノパイルの施工



Monopile engineering challenges

モノパイル工学上の課題

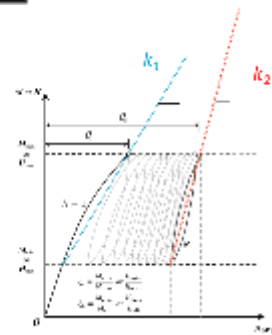
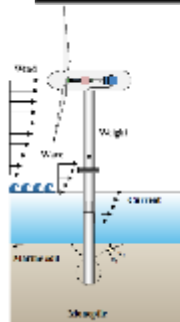
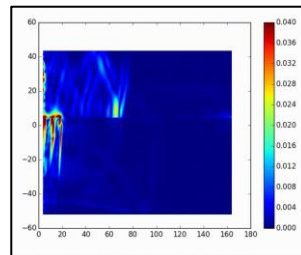
- Cyclic loading
- Diverse soil conditions
- Earthquakes
- Design optimisation



shallow waters – monopile
浅海域におけるモノパイル

Installation
モノパイルの施工

Operation
運用時性能



Monopile engineering challenges

モノパイル工学上の課題

- Feasibility
- Environmental concerns
- Technology/method
- Operational protocols

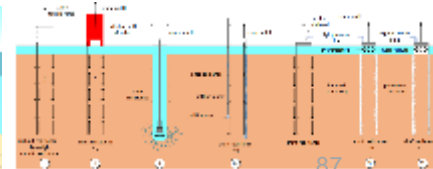
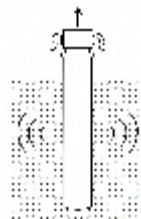
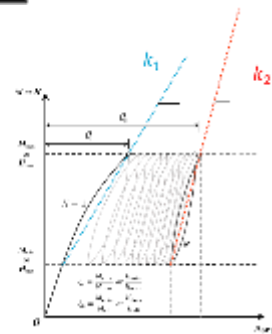
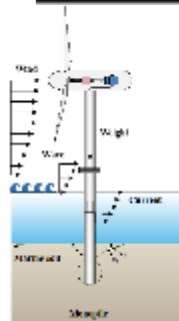
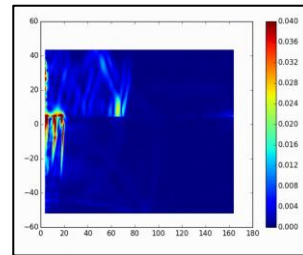


shallow waters – monopile
浅海域におけるモノパイル

Installation
モノパイルの施工

Operation
運用時性能

Decommissioning
モノパイル基礎の撤去



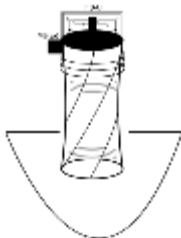
Knowledge, Tool Transfer and Continuity Across Projects

プロジェクト間での知識・ツールの共有と継続的发展

RESEARCH PROJECTS

産学連携研究プロジェクト

GENTLE
DRIVING OF
PILES (GDP)



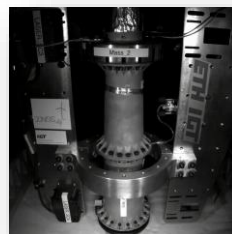
MIDAS
OFFSHORE WIND

MIDAS clay
OFFSHORE WIND



FIELD & CENTRIFUGE TESTING

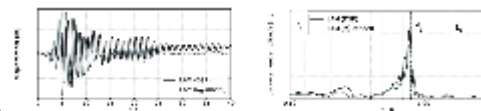
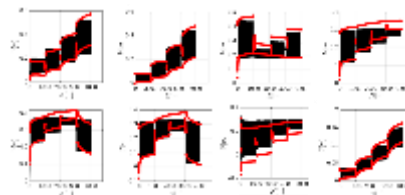
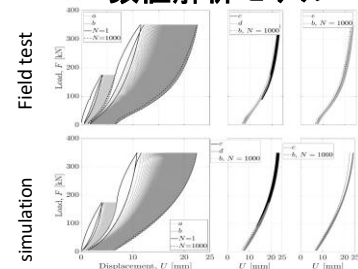
現場試験と遠心模型実験



ETH zürich

NUMERICAL MODELS

数値解析モデル



The DONISIS project

DONISIS (ギリシャ語で「振動」) プロジェクト

Project goals

プロジェクトの目標

- Understand the seismic response of offshore wind turbines, including pore pressure effects

液状化を含む洋上風力タービンの地震応答を理解する

- Develop design guidelines for OWTs and monopile foundations in seismic regions

地震地域における洋上風力タービンおよびモノパイル基礎の設計指針を策定する

- Establish engineering models for reliable seismic soil–foundation–OWT simulations

信頼性の高い地震時の地盤–基礎–洋上風力タービン連成解析のための工学モデルを構築する

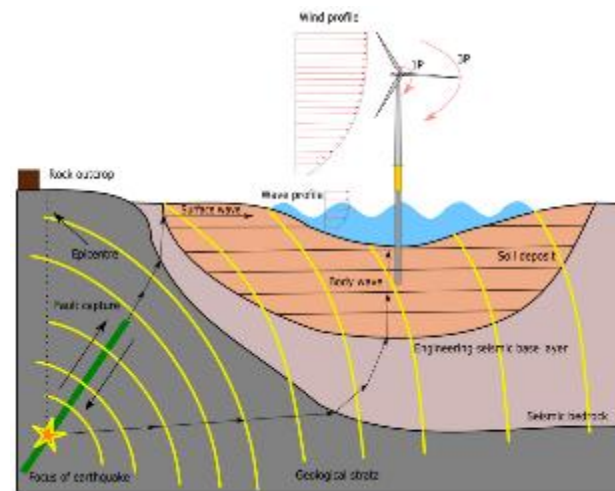


Figure from Bhattacharya et al. (2021)

The DONISIS project

DONISIS (ギリシャ語で「振動」) プロジェクト



Project Steering Committee

Research Group



Industry Partners



Certification Bodies Group



Independent Technical Review Panel

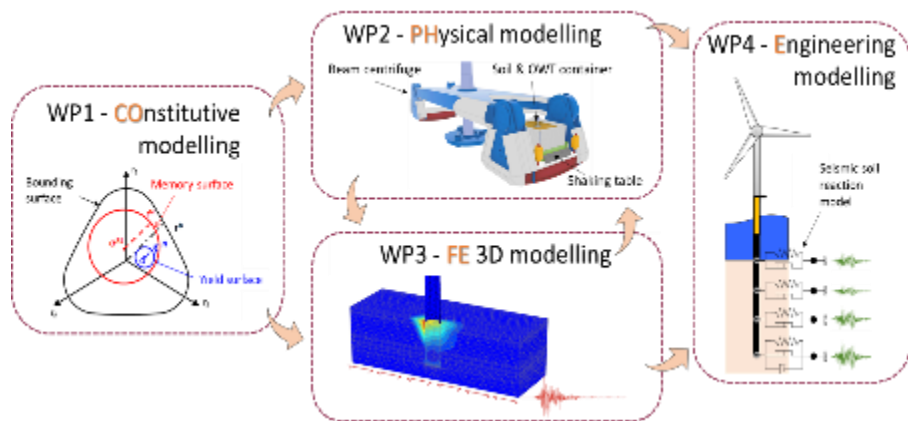


- Universities & research institutes
- Offshore wind developers
- Energy companies
- Engineering and modelling specialists
- Offshore contractors
- OEMs
- Geotechnical consultants and international experts
- Certification bodies

研究・産業・認証分野の
パートナーに支えられたプロジェクト

The DONISIS project

DONISIS (ギリシャ語で「振動」) プロジェクト



4つの技術ワークパッケージ:

- 砂の繰返し構成モデル化
- モノパイル支持式洋上風力タービンの地震遠心模型実験
- 遠心模型実験の3次元有限要素解析
- 工学的な1次元地震時モノパイル-洋上風力タービンモデルの開発

Project Technical Coordination: TU Delft

WP1: Cyclic sand constitutive modelling

Led by TU Delft & Durham University

with support: NGI, PLAXIS, ITRP

WP2: Seismic centrifuge testing

Led by ETHz

with support: TU Delft, SGRE, Ørsted, EDFR, Industry Partners, ITRP, CBG

WP3: 3D FE modelling

Led by TU Delft

with support: ETHz, NTNU, Durham University, SGRE, Plaxis, ITRP

WP4: 1D FE modelling

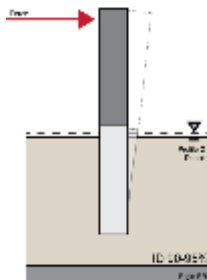
Led by TU Delft

with support: NTNU, NGI, SGRE, Geotechnical Consultant, Carbon Trust, ITRP, CBG, Industry Partners

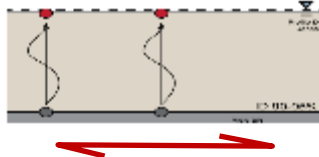
The DONISIS project

DONISIS（ギリシャ語で「振動」）プロジェクト

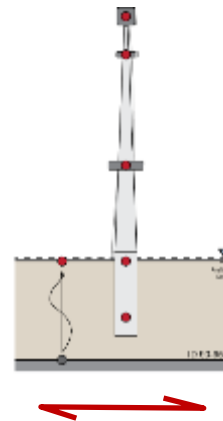
Monotonic + cyclic loading



Site Response Analysis



Dynamic System Response



実験・数値解析手法

すべての段階を、実験と数値解析の両面から検討：

- モノパイルの準静的な単調載荷および繰返し載荷
- 地震時における地盤柱の動的応答
- サイト応答解析
- 地盤-基礎-洋上風力構造物系の統合的な地震応答

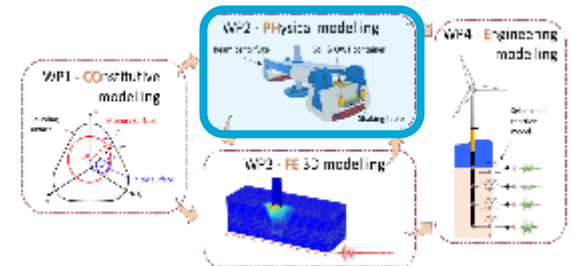
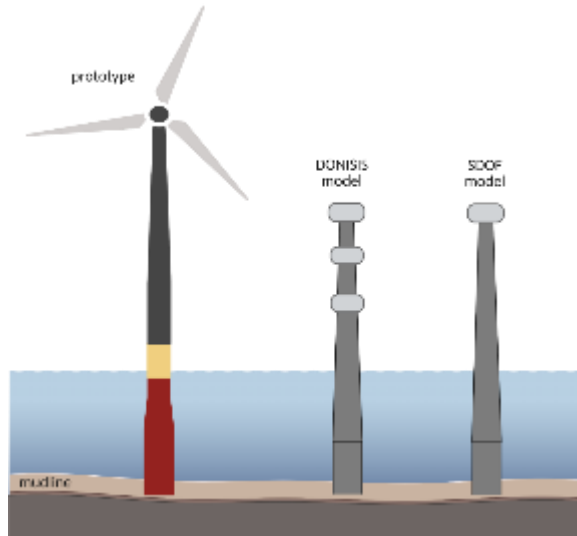
What follows? この後の内容



Stavros Panagoulas
(PhD student)
TU Delft

- Mr Stavros Panagoulas will present the novel DONISIS prototype dynamic scaling method

Stavros Panagoulas氏：DONISISにおける新しいプロトタイプ動的スケーリング手法について





Liam Jones
ETHZ

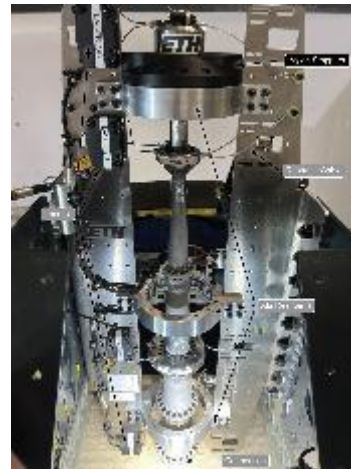
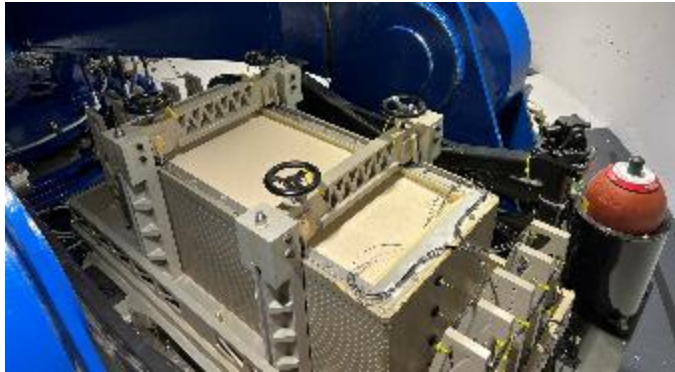
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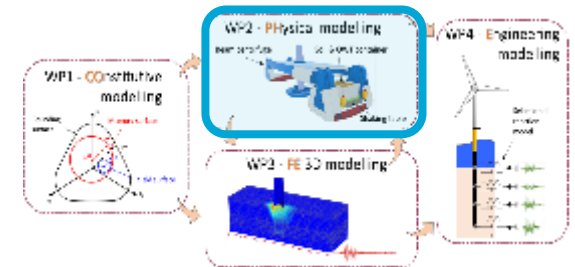
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Liam Jones博士：ETH Zürichで実施された遠心模型実験の設計と実施について



Courtesy of ETH Zurich



DONISIS Workshop | Yokohama, Japan



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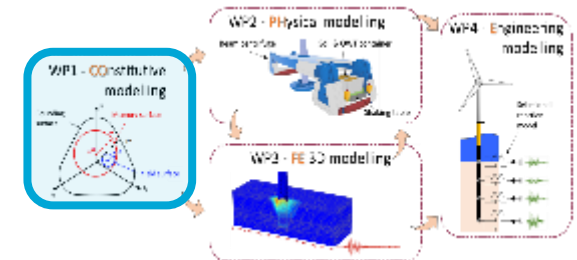
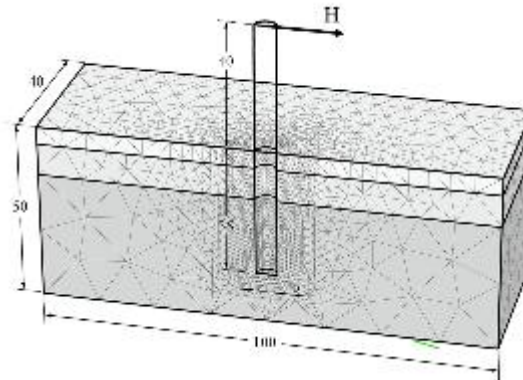
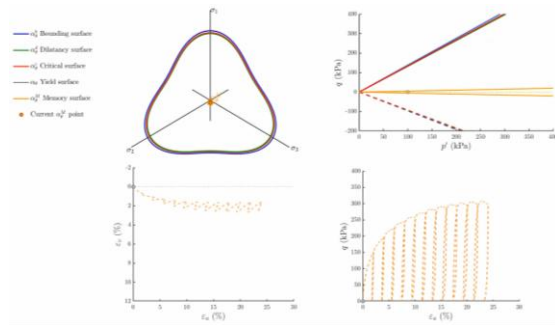
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Iman Moghadam氏：地震時の地盤–構造物相互作用問題の解析における構成モデル化の役割について



What follows? この後の内容



Stavros Panagoulas
(PhD student)
TU Delft

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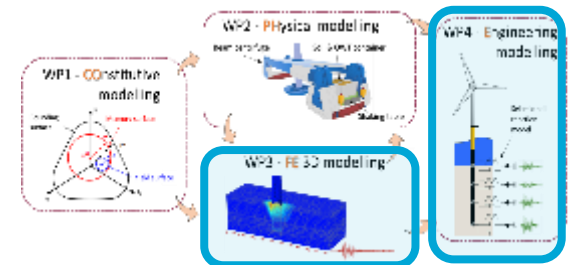
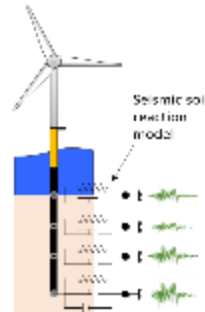
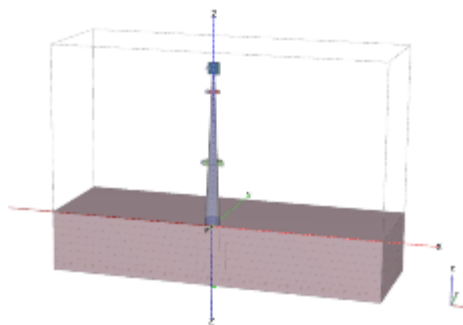
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- Mr Stavros Panagoulas will present the 3D FE and 1D FE modelling activities within DONISIS

Stavros Panagoulas氏：DONISISにおける3D有限要素解析および1D有限要素解析のモデル化活動について



DONISIS Workshop | Yokohama, Japan

DONISIS team | Acknowledgments



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TU Delft – Project
Coordination



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NGI



Sandro Brasile
Bentley Systems



Tuan-Anh Bui
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Pim Versteijlen
Siemens Gamesa



Tobias Verfuss
Carbon Trust



Marcela Betancur Diaz
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Alicia Stammers
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Christina Starost
Carbon Trust

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Federico Pisanò
TU Delft → NGI



Tobias Verfuss
Carbon Trust



Stavros Panagoulas
Siemens Gamesa / TU Delft



Christina Starost
Carbon Trust



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Project Funding



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本研究成果は、DONISISプロジェクト（プロジェクト番号：19882）の一部であり、オランダ研究評議会（NWO）のOpen Technology Programmeにより一部助成を受けています

o





Dynamic scaling 動的相似則

Stavros Panagoulas

DONISIS Workshop, Yokohama, Japan

June 4, 2026



Presentation outline

発表概要

- Why seismic centrifuge testing is needed for offshore wind turbines
洋上風力発電設備における地震時遠心模型実験の必要性
- Selected prototype: key dynamic and foundation characteristics
対象プロトタイプ：主要な動的特性および基礎特性
- Dynamic scaling methodology for centrifuge model design
遠心模型設計のための動的相似手法
- Performance of the optimised downscaled model
最適化縮尺模型の性能評価

Seismic centrifuge testing considerations for OWTs

- **Full-scale** seismic testing of OWTs is impossible - only monitoring of built structures.
- **Centrifuge testing** provides a controlled test environment to study **seismic soil-structure interaction**.
- **Seismic centrifuge testing** requires **dynamic similitude** between the complex prototype OWT structure and the centrifuge test model – **not trivial**.



Courtesy of ETH Zurich

Seismic centrifuge testing considerations for OWTs

Prototype

Representative of a **multi-MW** offshore wind turbine with a **realistic** support-structure design.

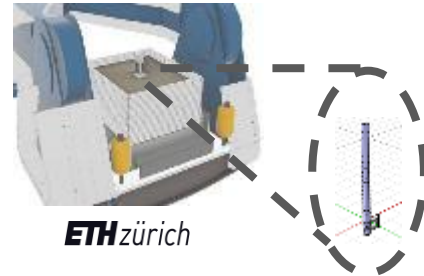


*courtesy of
SGRE | SG
14-236 DD
prototype in
Brande,
Denmark*



Downscaled Model

The downscaled model must satisfy the **geometrical constraints** imposed by the centrifuge environment.



The 14MW Siemens Gamesa 14-236 DD prototype

Prototype

Representative of a **multi-MW** offshore wind turbine with a **realistic** support-structure design.



*courtesy of
SGRE | SG
14-236 DD
prototype in
Brande,
Denmark*

Selected offshore wind turbine generator:
Siemens Gamesa 14-236 DD

Estimated natural frequencies
(fore-aft, side-side range):

$$f_1 \sim 0.15 \text{ Hz}$$

$$f_2 \sim 0.8 - 0.9 \text{ Hz}$$

$$f_3 \sim 1.5 - 1.7 \text{ Hz}$$

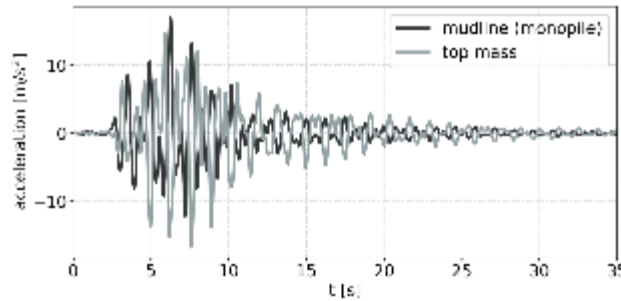
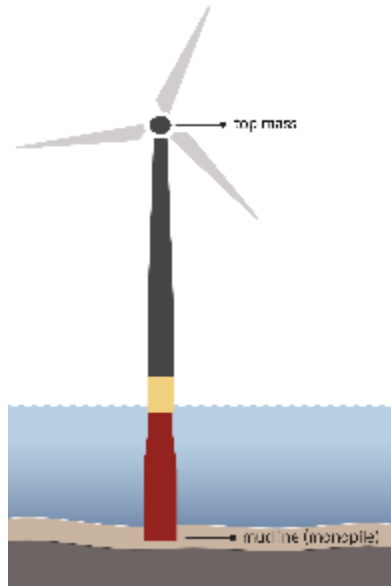
$$f_4 \sim 2.8 - 3.0 \text{ Hz}$$

Main support structure & offshore site properties:

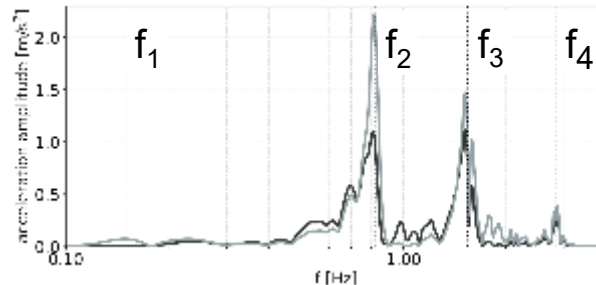
- Water depth: ~30 m
- Sand-dominated site
- Hub height (above mudline): ~170 m
- Monopile diameter: 9.0 m
- Monopile embedment: 29.0 m
- Length-to-diameter ratio (L/D): 3.2

Dynamic complexity of OWT motion under seismic shaking

- Under earthquake loading **multiple modes** may be mobilised which influence **foundation loading** and as a result **soil reaction** and **pore-pressure** response.
- An **indicative** numerical study with the **Kobe JMA (1995)** motion highlights the role of **higher bending modes** in the coupled system response of the **selected prototype**.



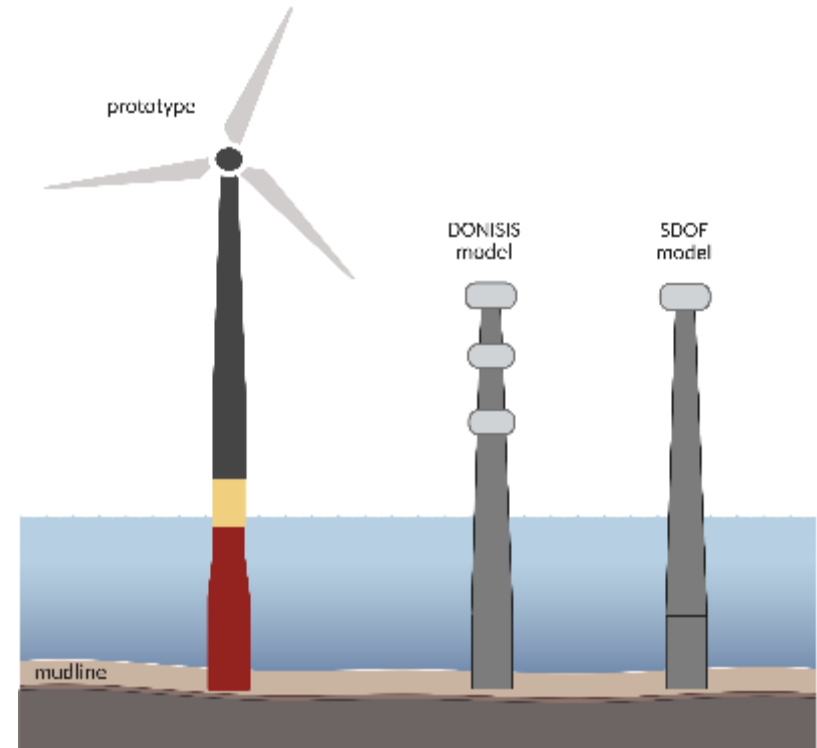
*Panagoulas et al.
(under review)*



Note
 f_n denotes the n^{th}
natural frequency

DONISIS introduces a novel dynamic scaling approach

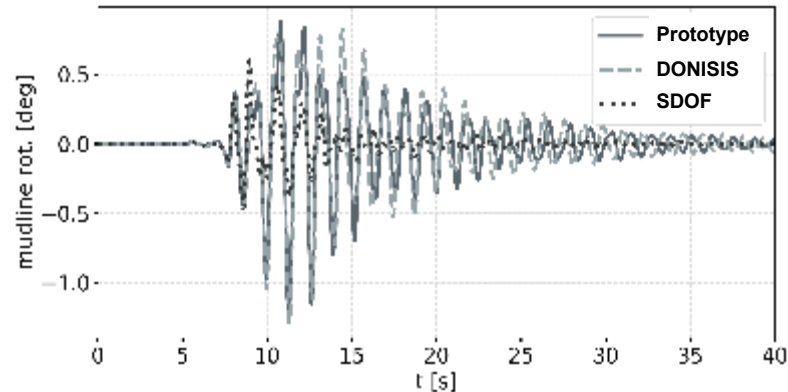
- OWT centrifuge models *often* use simplified single-degree-of-freedom (**SDOF** model) representations tuned only to the prototype's **first natural frequency**.
- DONISIS proposes a **dynamic scaling framework** that preserves the prototype's **multimodal** behaviour within centrifuge constraints (Panagoulas et al., under review).
- The **optimised “DONISIS model”** preserves key **dynamic characteristics** of the prototype, including natural frequencies and bending mode shapes.
- **Dynamic similitude** is achieved through geometry optimisation and auxiliary masses along the superstructure.



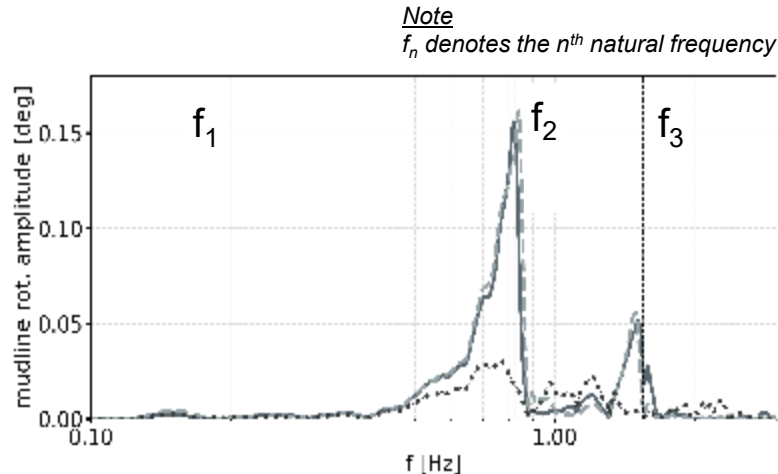
Panagoulas et al.
(under review)

Improved fidelity under seismic loading

- The **optimised DONISIS model** reproduces the prototype response more accurately than the SDOF simplification.
- Improved agreement is observed for **key response indicators**: displacement, acceleration, rotation and monopile bending moments.
- An indicative numerical study using the **Kobe JMA (1995)** motion highlights the **improved fidelity** of the optimised DONISIS model.

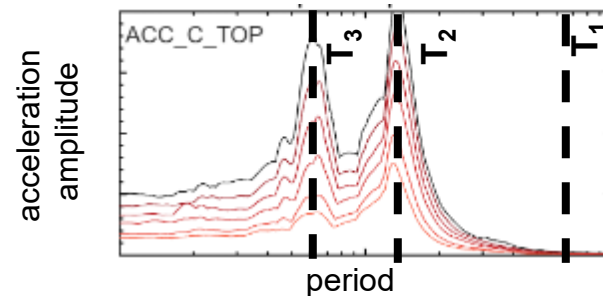
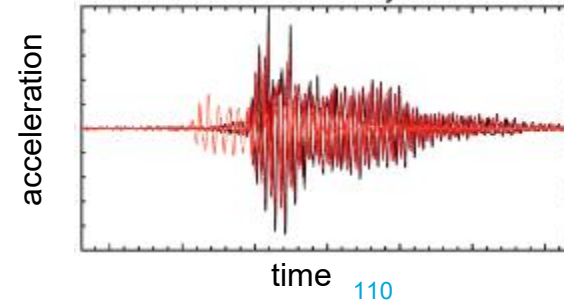


Panagoulas et al. (under review)



Experimental evidence for higher-mode effects

- The optimised DONISIS model **was manufactured and tested at 100g** at the **ETH Zurich Geotechnical Centrifuge Centre**.
- A first glimpse of **experimental evidence** on the importance of higher modes - to be presented next by Dr. Liam Jones (ETH Zurich).



Note
 T_n denotes the n^{th} natural period

Physical validation of the multimodal OWT seismic response

- The experiment was designed to reproduce the **coupled soil–monopile–superstructure** response of the prototype under seismic loading.
- By preserving the prototype's **multimodal characteristics**, the test setup enables physically consistent investigation of:
 - **structural response**
 - **foundation loading**
 - **pore-pressure buildup**
- The centrifuge test data provide a **controlled benchmark** for **developing** and **validating seismic soil reaction models** for monopile-supported OWTs.

Points for discussion

ディスカッション項目

- How important is it to capture **higher-mode effects** in experimental and numerical studies of seismic OWT response?

洋上風力発電設備の地震応答に関する実験的・数値的研究において、高次モードの影響を捉えることはどの程度重要でしょうか。

- Do optimised multimodal centrifuge models provide a valuable **benchmark** for calibrating and validating soil reaction models?

最適化されたマルチモーダル遠心模型は、地盤反力モデルのキャリブレーションおよび検証のための有用なベンチマークとなるでしょうか。

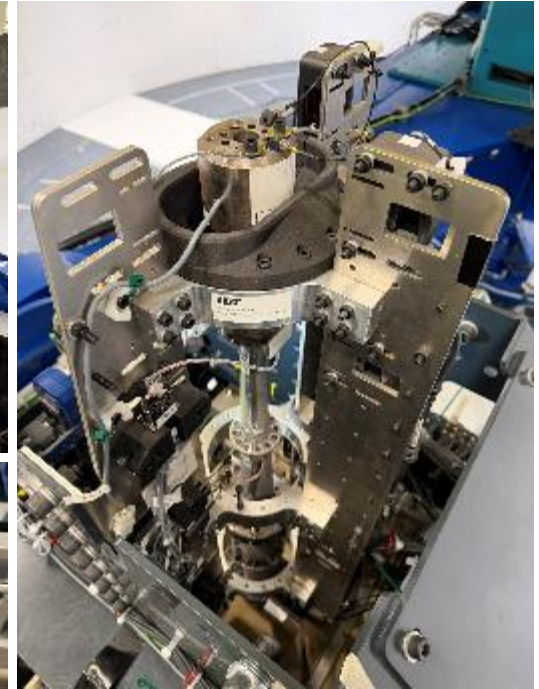
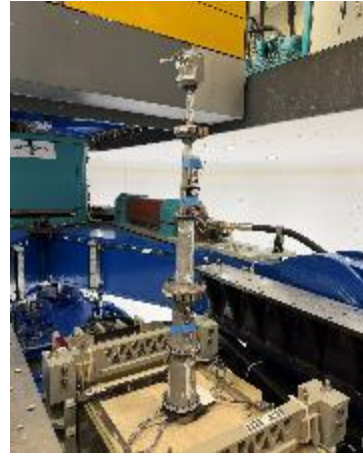


DONISIS WP2 Centrifuge Modelling

**Dr. Liam Jones, Eva Brunschweiler,
Ioannis Anastasopoulos**
ETH Geotechnical Centrifuge Centre

Outline

1. DONISIS Project (WP2)
 - Problem Statement
 - Objectives
 - Description of tests
2. Progress and results
 - Approximate order of execution
 - Technical Challenges
 - Initial Results
 - Outlook



1. DONISIS WP2

Problem Statement, Objectives



DONISIS Project – Key Objectives

Monopile Supported OWTs in Seismic Environments



What Happens During Earthquake Loading?

System Response:

What is the role of higher modes?
Seismic Soil Structure Interaction?

Pore Pressures:

Liquefaction?
Permanent Deformation?

How to Design?

Reliable Design Tools *needs* →

Rigorous benchmark Data

That's us!

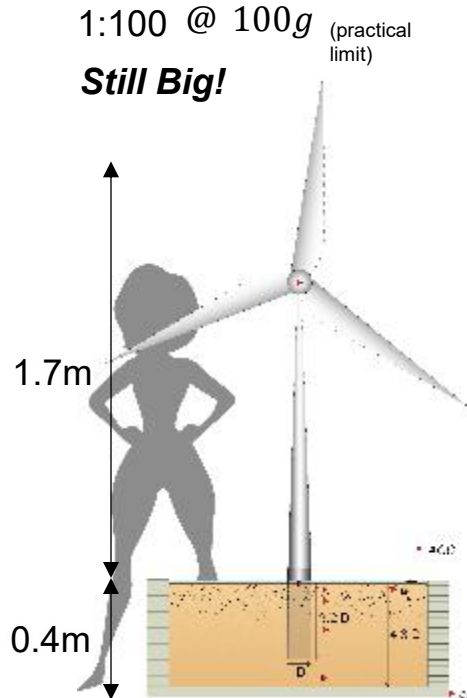
Reduced scale modelling of large OWT subject to seismic loading

DONISIS Project – Key Challenges

Prototype

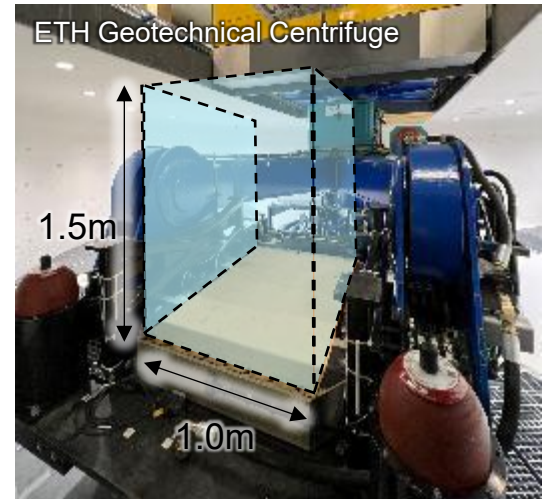


Reduced Scale



Centrifuge

Too Big!



Additional Downscaling req.
(Panagoulas et al. 2026...)

DONISIS Project – Key Challenges

What Role does structural response play?

How to Produce the correct structural response?

- *Downscaling Method*
- *Realisation of complex geometry*



Mode 2

1D Model



3D FEM



3D Metal Print

What is the effect of pore pressure buildup?

How to monitor and reproduce pore pressure buildup?

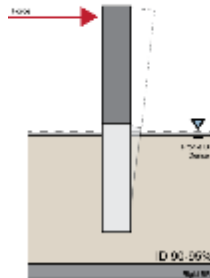
- *Isolate EPWP effects*
- *Develop tools*



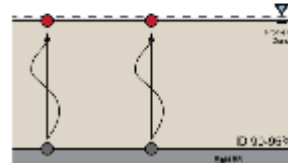
Outline of tests

3 Unique Setups

Monotonic/Forced Excitation
MONO/CYC

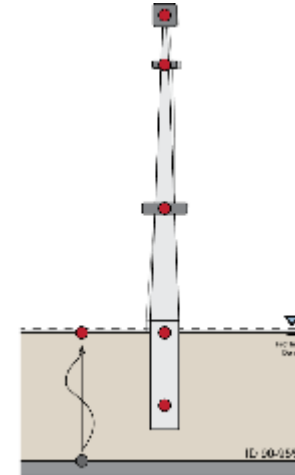


Site Response Analysis
SRA



← Shaking →

Dynamic System Response
DSR



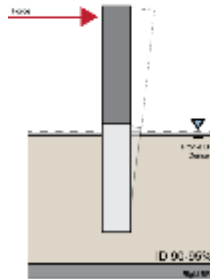
← Shaking →

Unique to this project: multi-setup test for same model structure

Outline of tests

3 Unique Setups

Monotonic/Forced Excitation
MONO/CYC

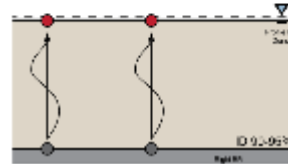


Typical Design Workflow:

Pushover



Site Response Analysis
SRA

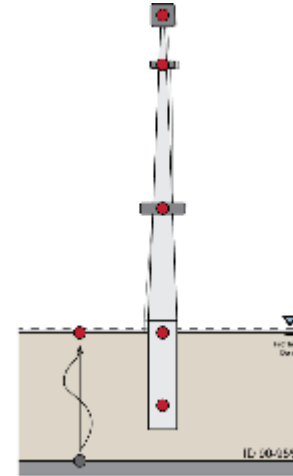


Shaking

Site Response
(Seismic Hazard)



Dynamic System Response
DSR

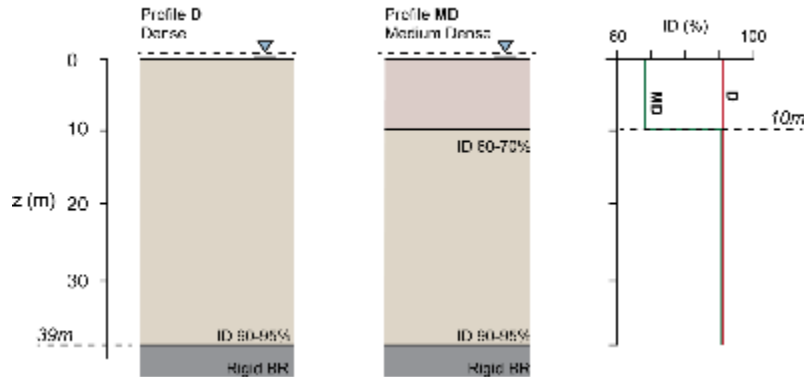


Shaking

SSI: Combination of interactions

Boundary Conditions

Soil



D - Dense

Low excess pore pressures

MD Medium Dense (Layered)

Limited Liquefaction

Drainage

High Permeability Tests

- Saturated **with water**.
- Behaves as **very porous** soil
- Correct stresses
- Very **rapid dissipation** – limited liquefaction

LP - Low Permeability Tests

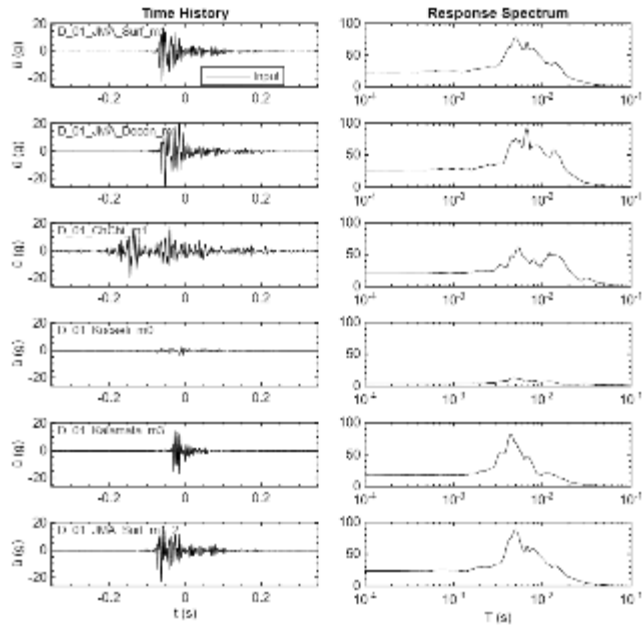
- Saturated **with Viscous Fluid**.
- **“Correct” permeability**.
- Correct stresses
- **Scaled dissipation** – significant liquefaction potential

Hostun HN31 – Clean Sand, Very well documented, Easy Availability in EU

Boundary Conditions

Excitation/Load

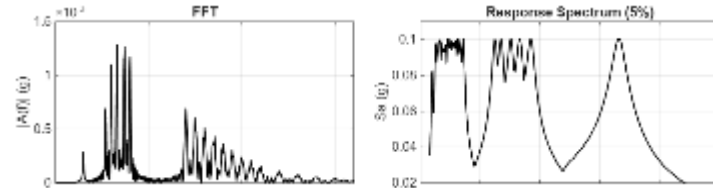
Earthquakes



Shock response

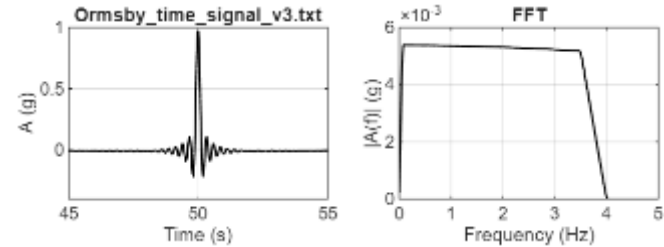
Artificial Signals

F-Sweeps



Steady-State Response

Wavelets



Impulse Response

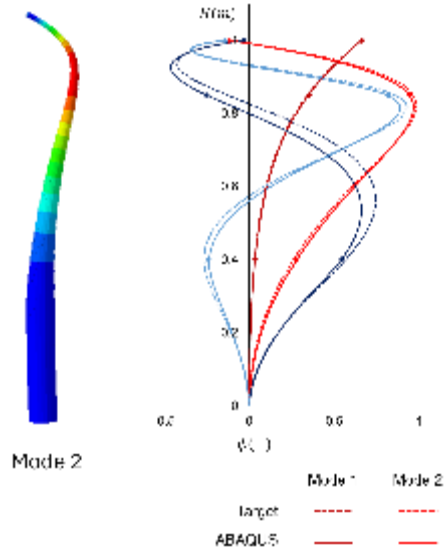
2. Progress and Experiments

What has been done, in approximate
chronological order.



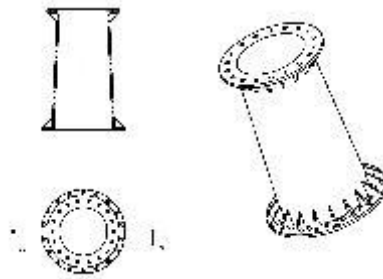
Realisation of Model Superstructure

Concept

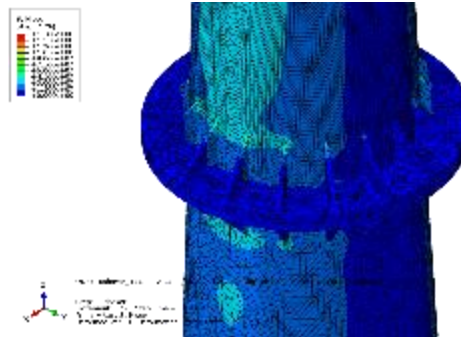


Simple 1-D Beam Model

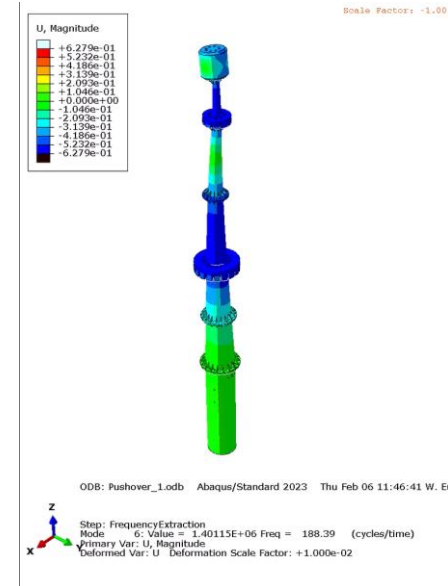
Mechanical Design



Full 3D FEM



Detailed Design



- Check Still Behaves Correctly
- Check Stability

Realisation of Model Superstructure



Printing + Assembly



Instrumentation



Installation

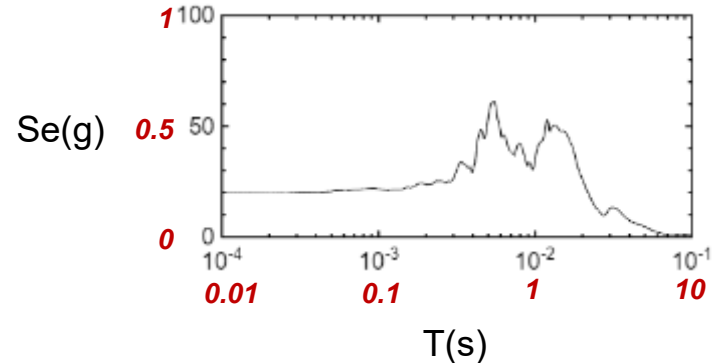
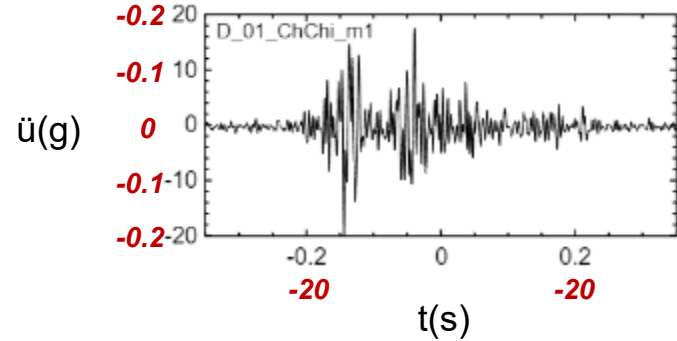


Quick Note – Scaling

Everything from this point is in **Model Scale!**

Quick Rule:

	Model		Proto.
<u>Acceleration</u>	1g	$\div 100$	0.01g
<u>Time</u>	1s	$\times 100$	100s
<u>Freq.</u>	1Hz	$\div 100$	0.01Hz
<u>Displacement</u>	1mm	$\times 100$	10cm
<u>Pressure</u>	1Bar	$\times 1$	1Bar
<u>Force</u>	1kN	$\times 10k$	0.1MN



Model Creation

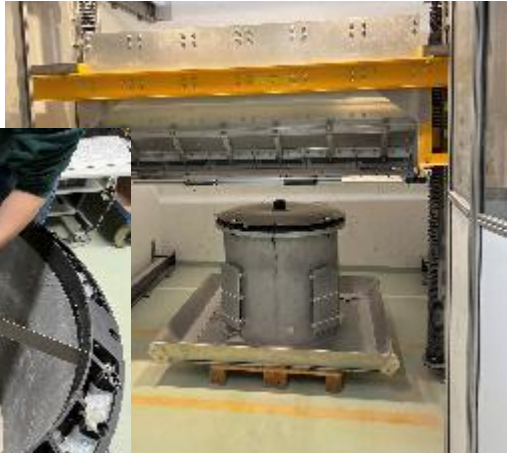
Create proposed density in multiple setups, *identically*

Problem!

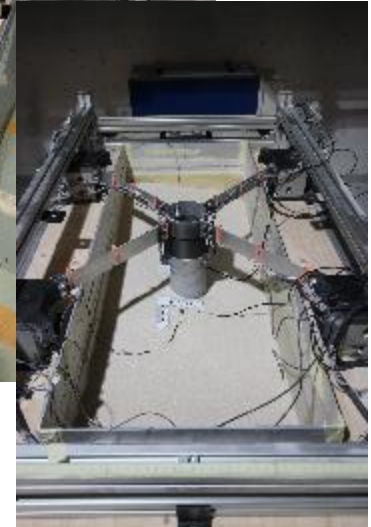
- Very Different Boundary effects
- Try to eliminate effects of pile presence

MONO

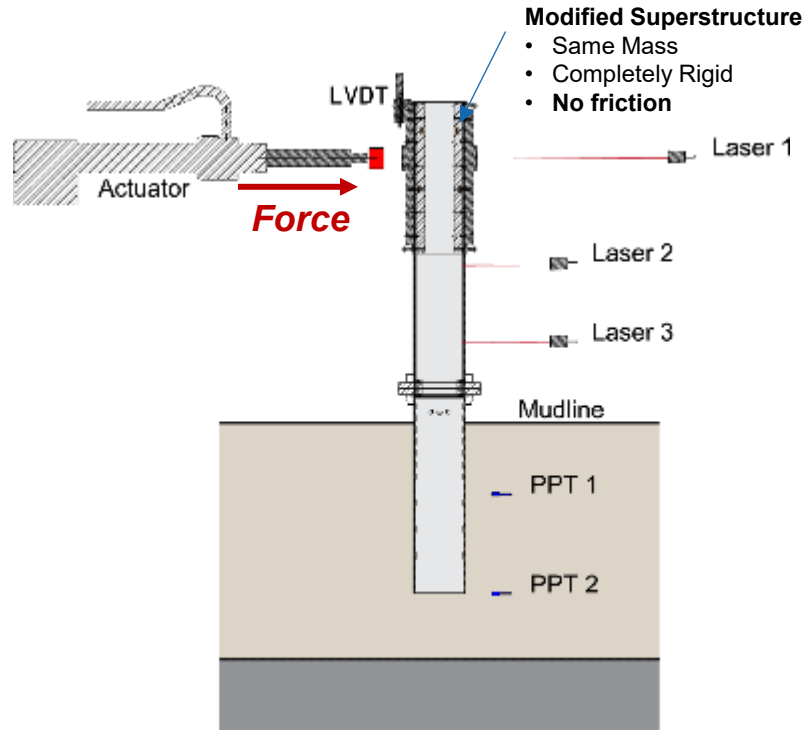
Round-box



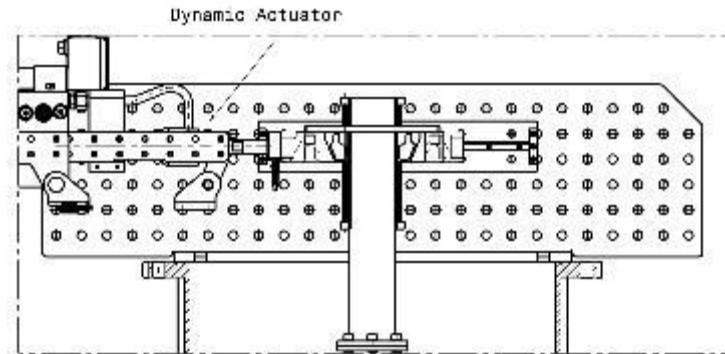
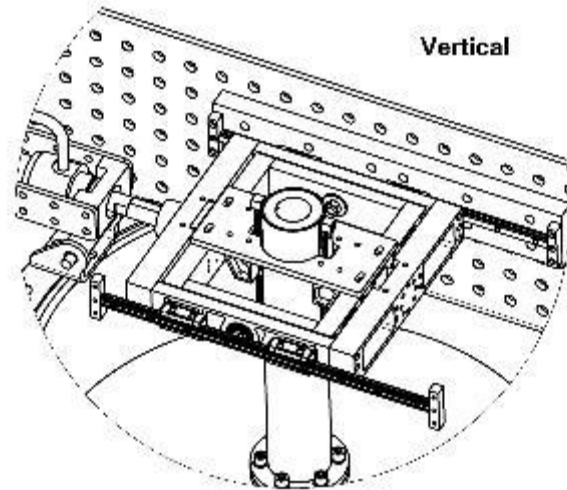
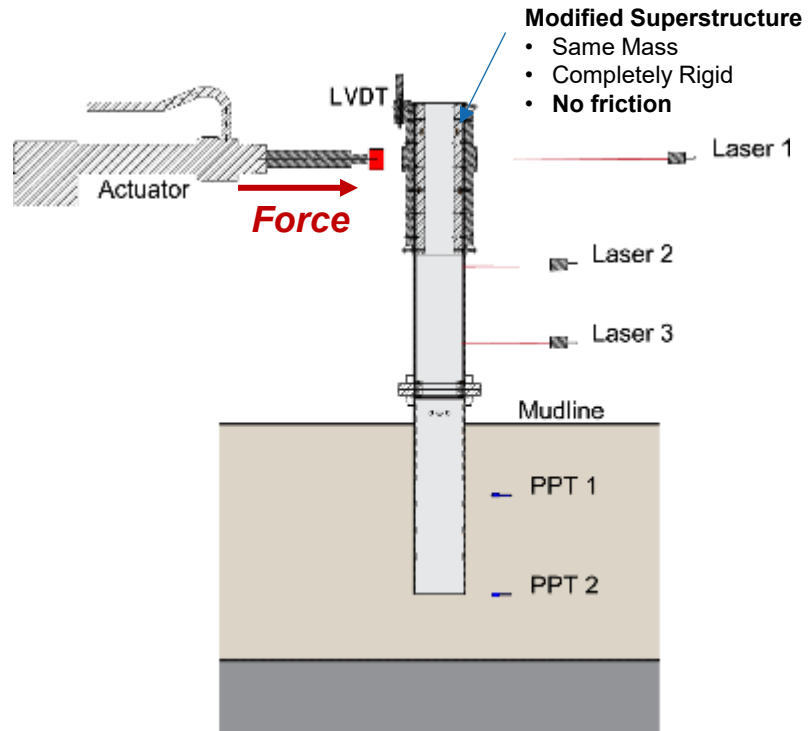
DSR/SRA
Laminar-box



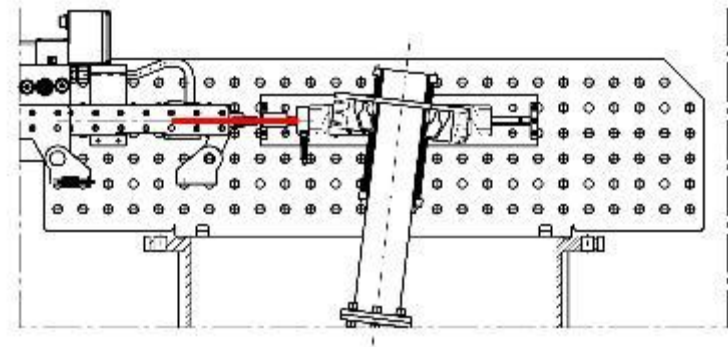
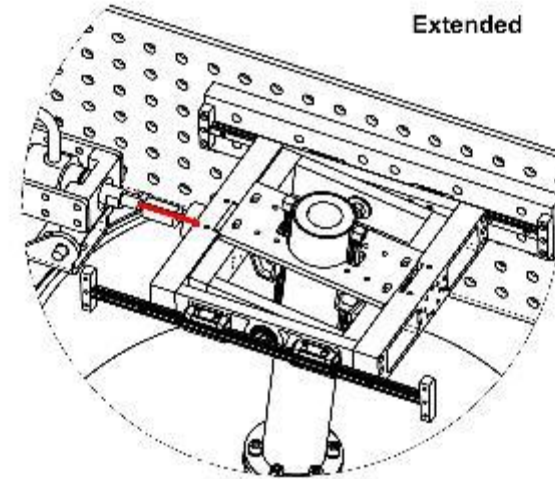
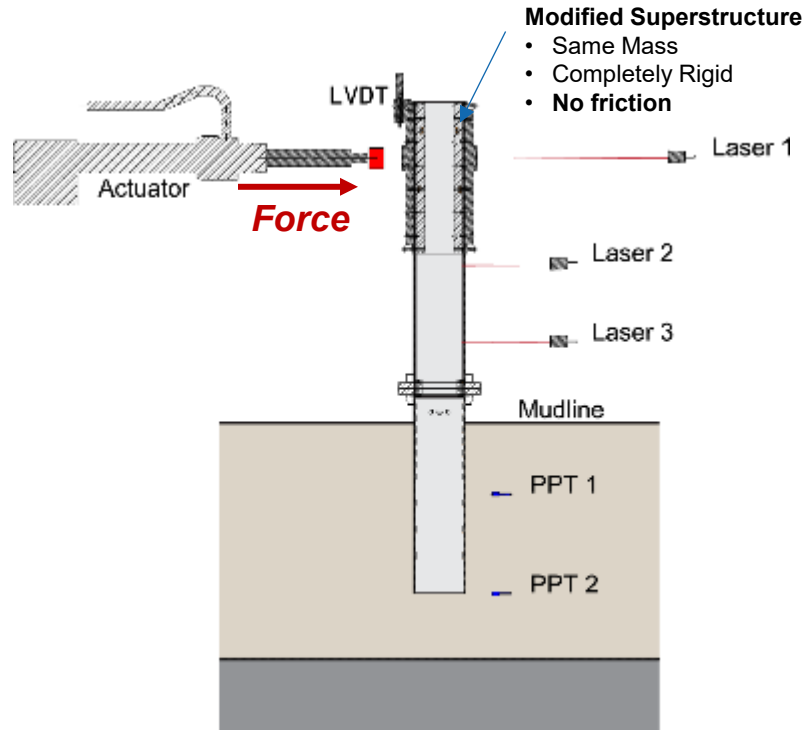
Monotonic Testing



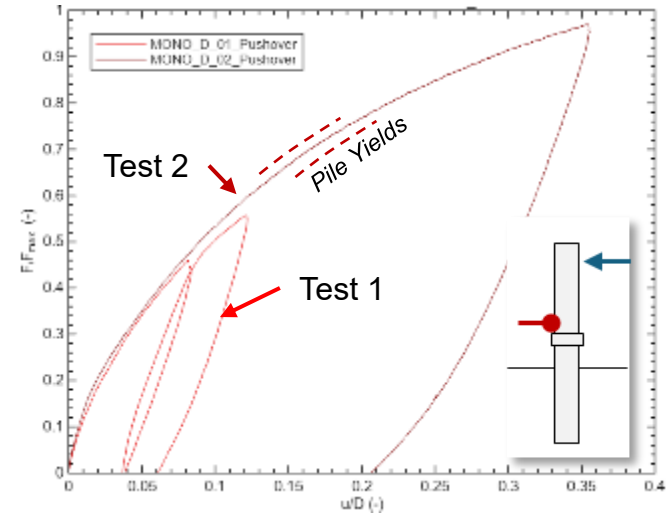
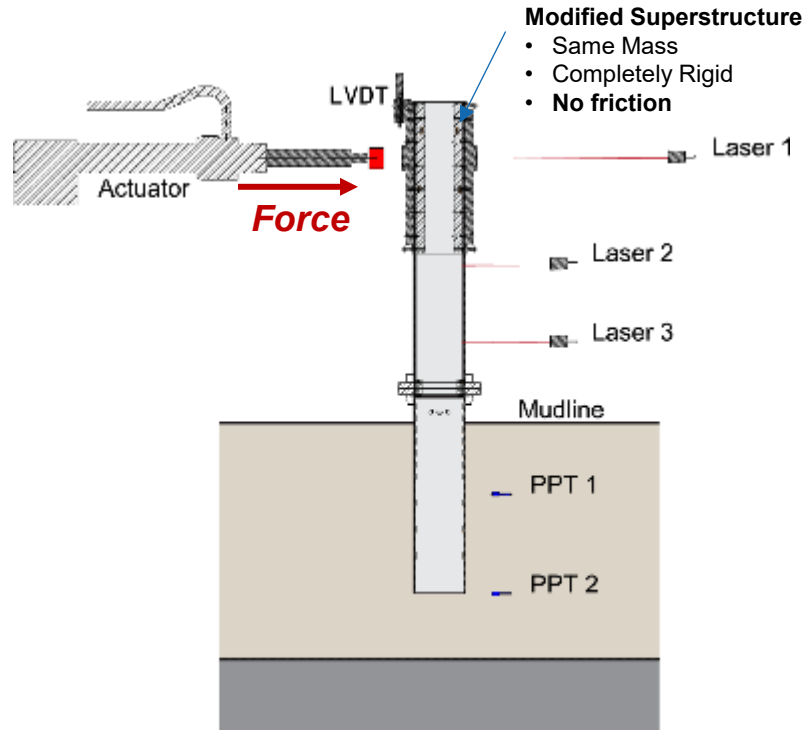
Monotonic Testing



Monotonic Testing



Monotonic Testing



Identical Pushover results in 2 models:

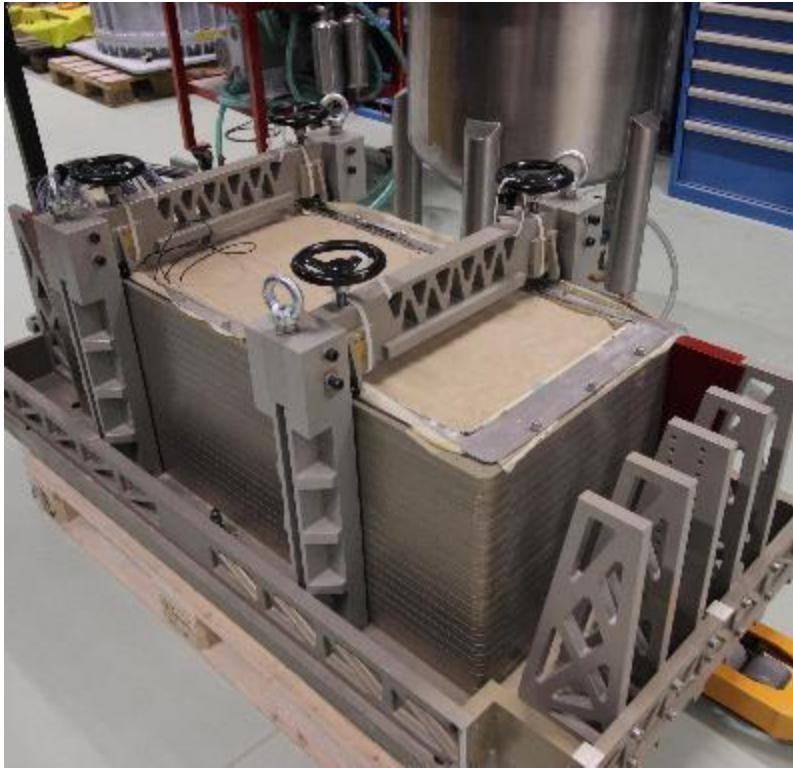
Test 1: Load – Unload – Reload

Test 2: Load to pile failure – Unload

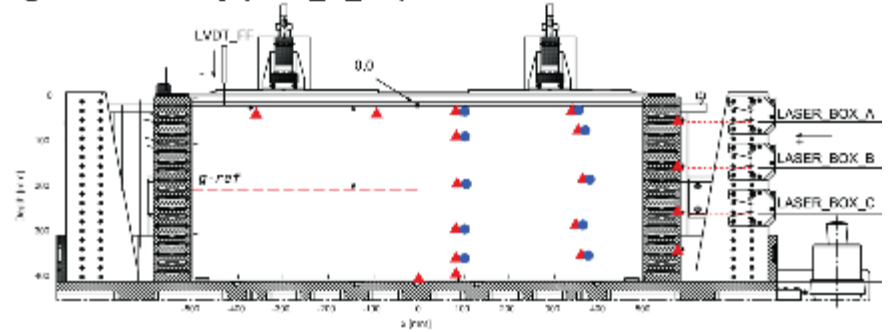
Backbone ✓ **ULS** ✓

Site Response

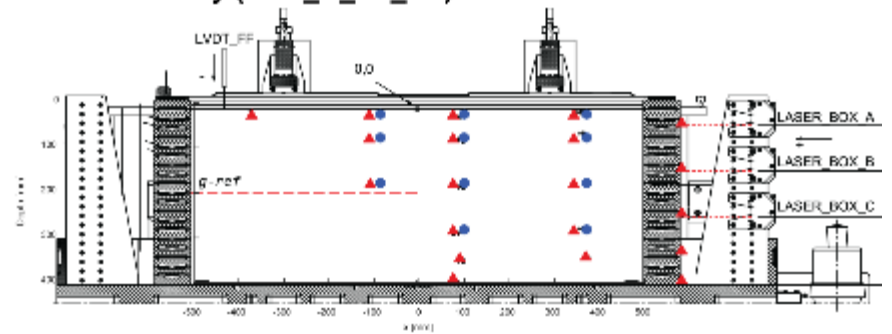
Define Site Response



High-Permeability (SRA_D_XX)



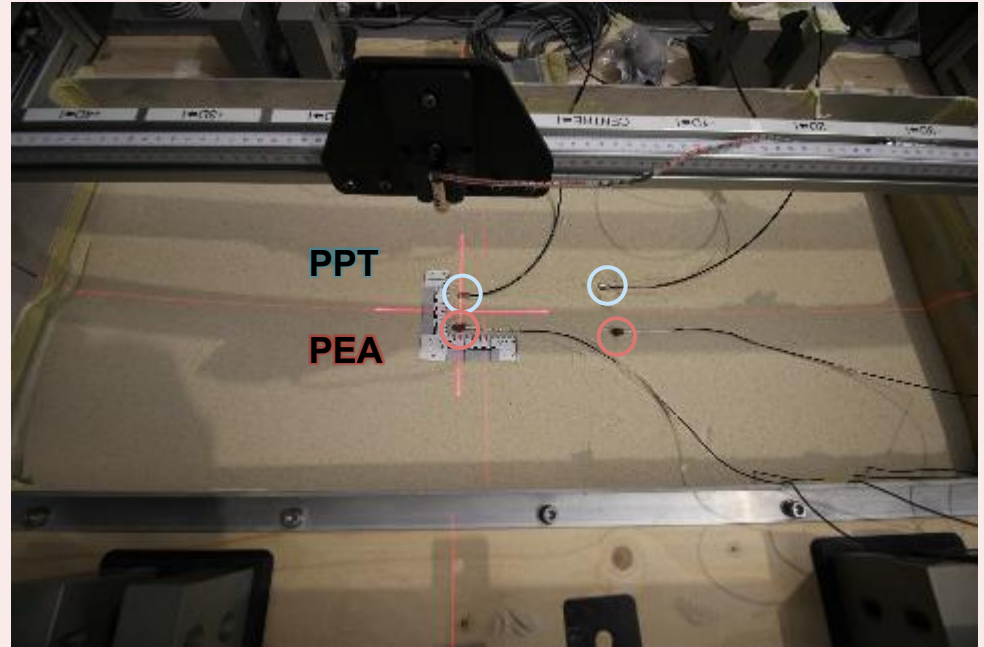
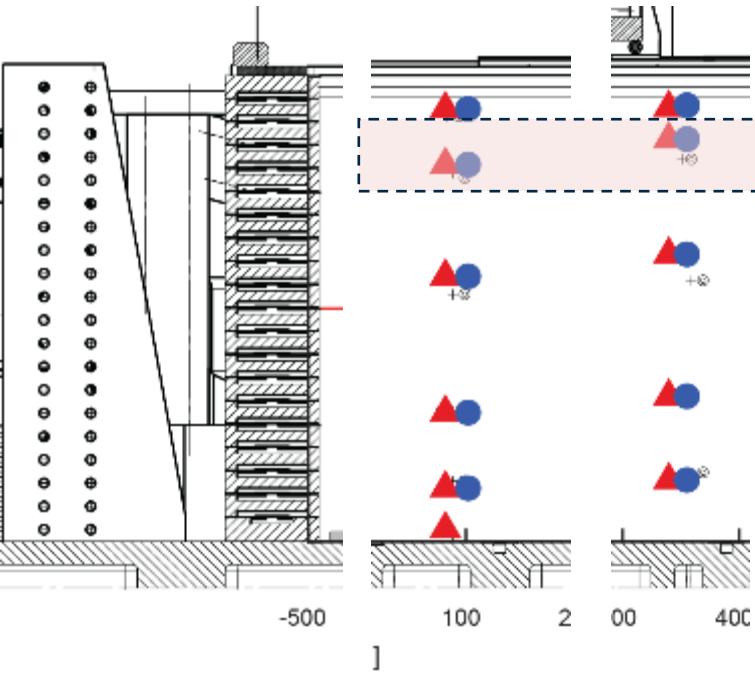
Low-Permeability (SRA_D_LP_XX)



Model Creation

Saturation/Instrumentation

Very Dense sensor scheme



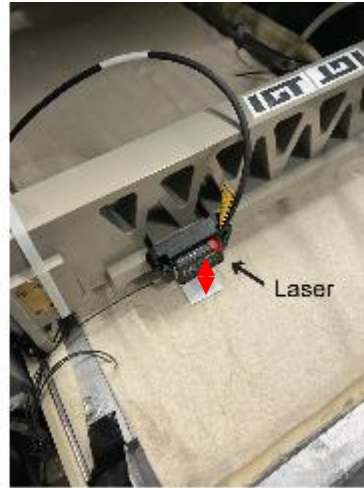
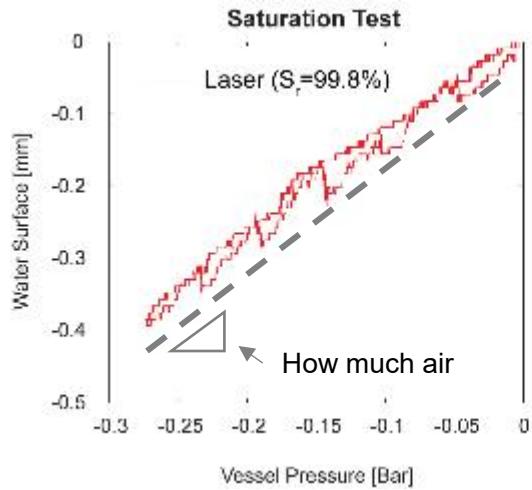
PPT: *Pore Pressure Transducer*

PEA: *Piezo-Electric Accelerometer*

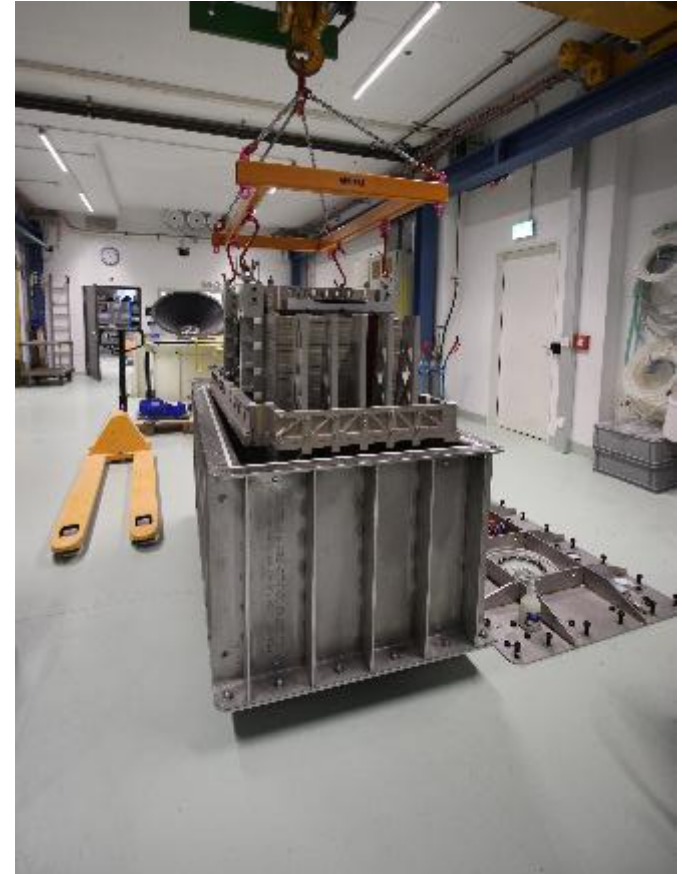
Model Creation

Saturation/Instrumentation

1. Saturation for high g-level

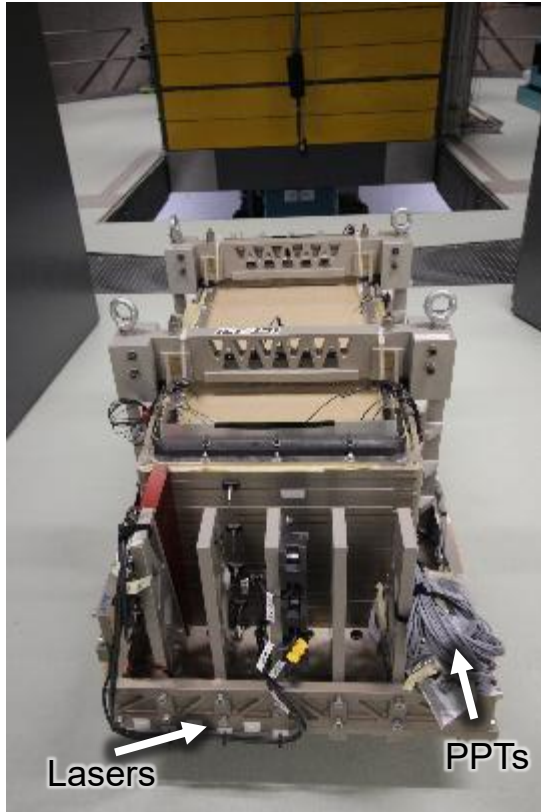


(Jones et al. ICPMG-2026)



New Saturation Chamber

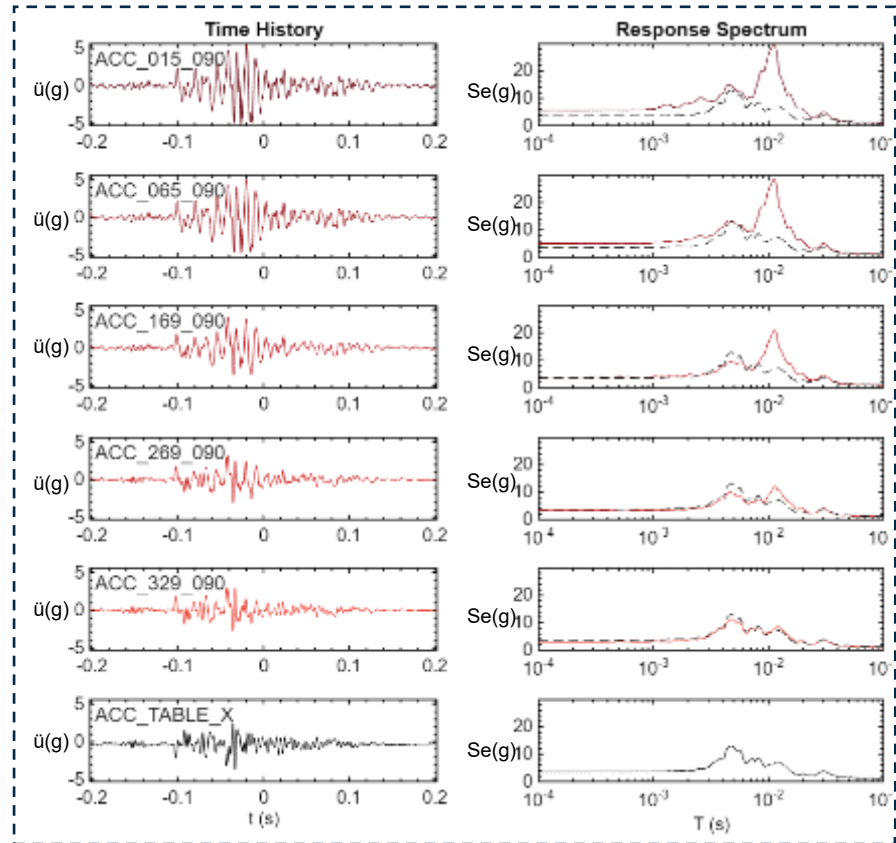
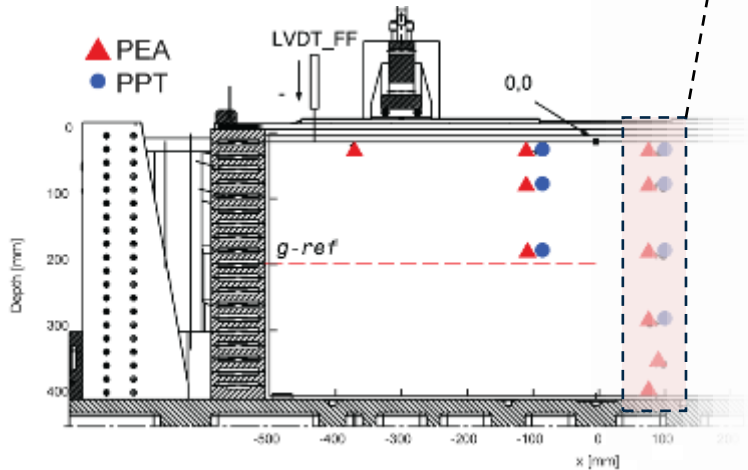
Mounting and Testing



Data Processing

Identify Site Periods

Response Spectrum at depths (d)



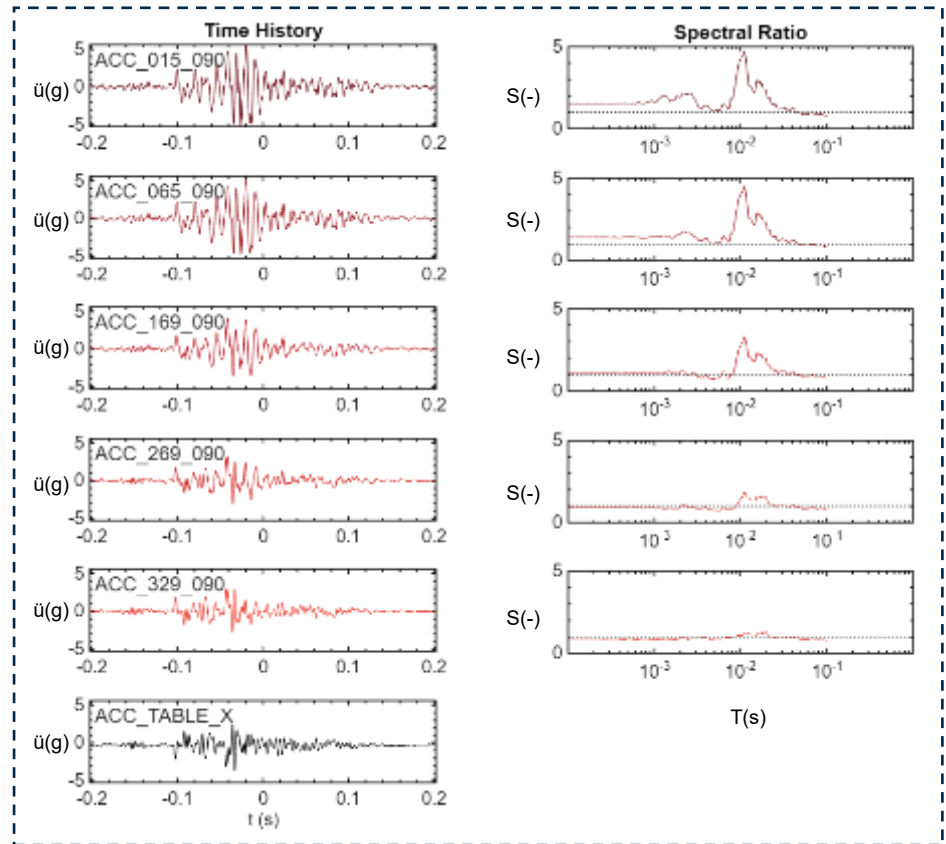
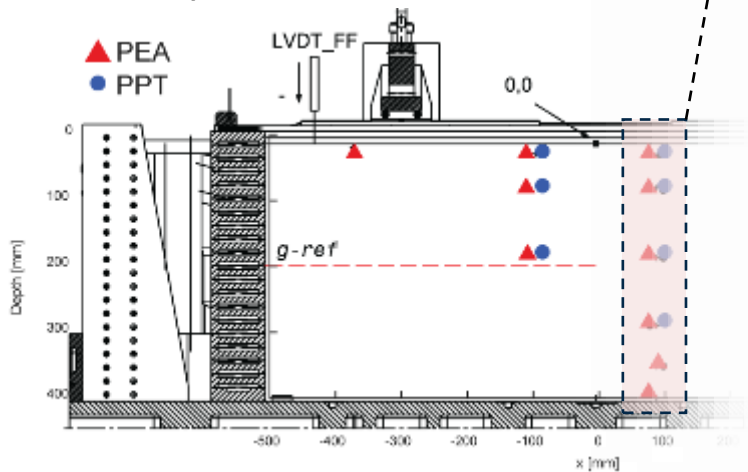
Data Processing

Identify Site Periods

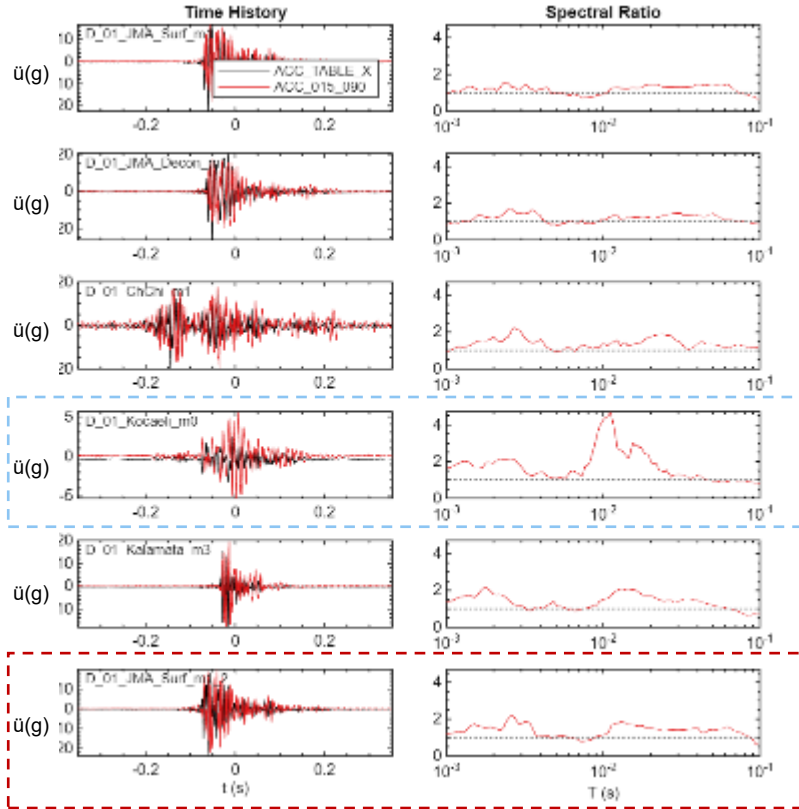
Response Spectrum at depths (d)

Ratio of response spectrums:

Spectral Ratio



SRA

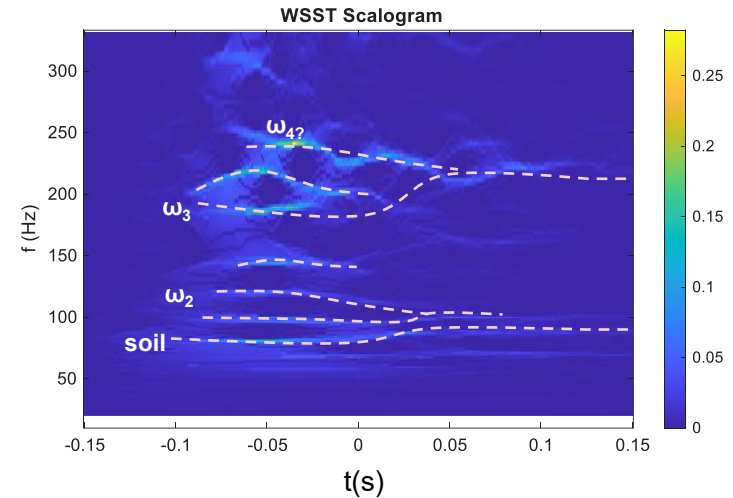


Low Amplitude

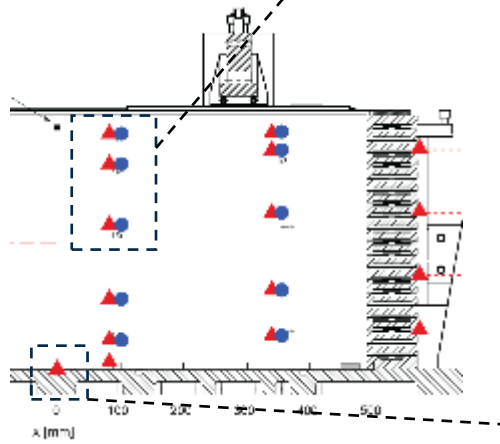
Freq Response clear; matches expectations

High Amplitude

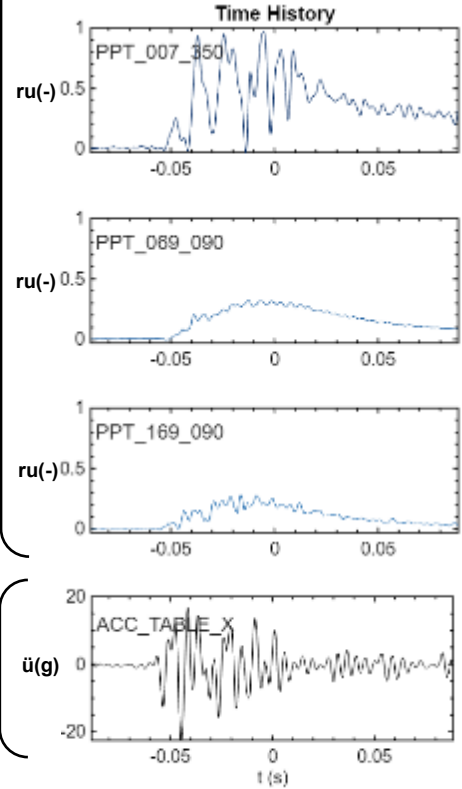
Much more non-linear: need to develop special tools:



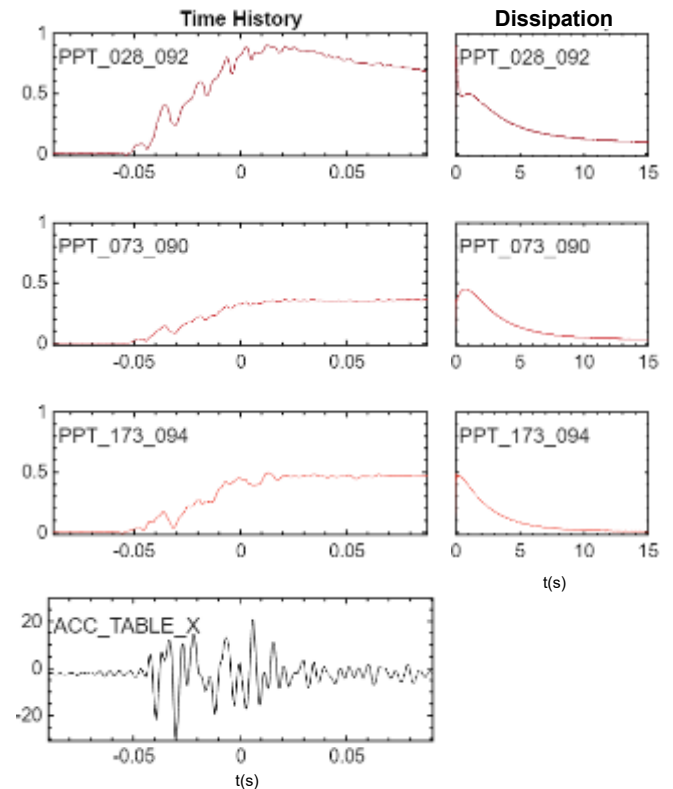
Pore Pressures



High Permeability



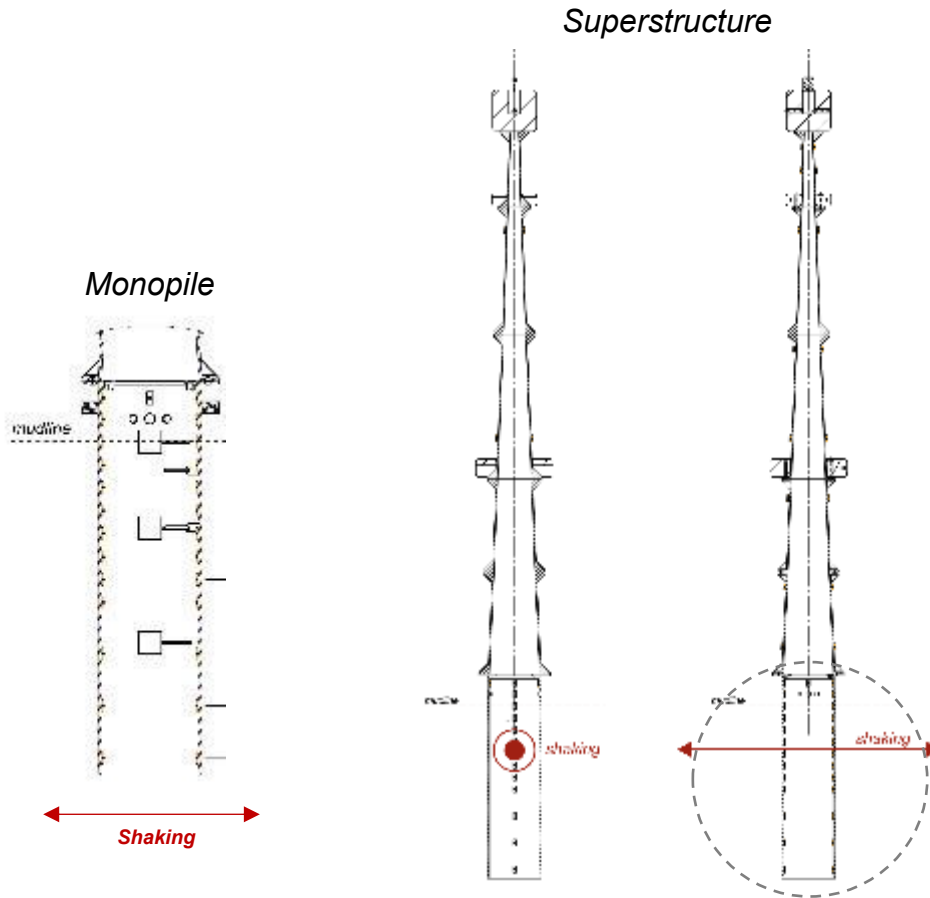
Low Permeability



Dynamic System Response

Overview

1. Very complex structure
2. Very high Instrumentation

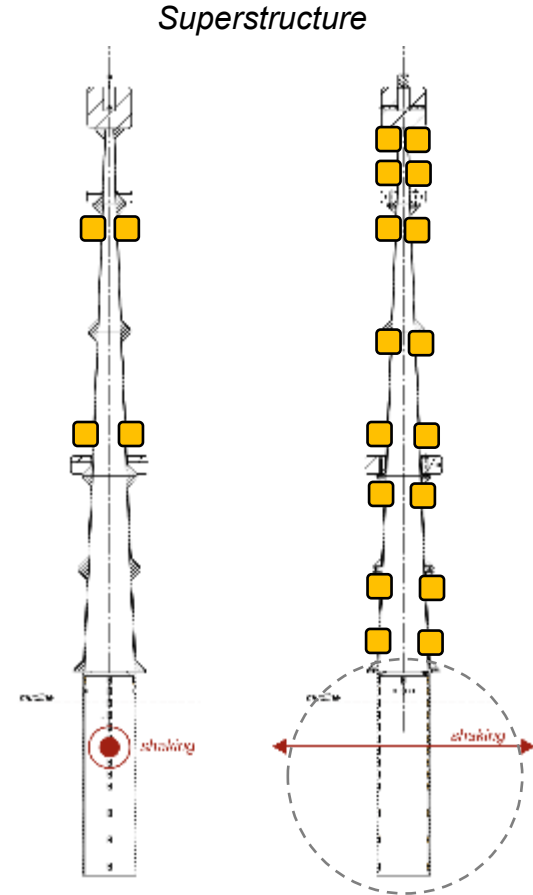
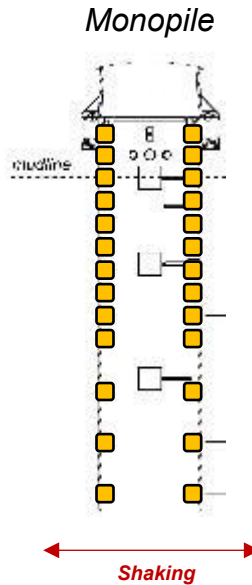


Dynamic System Response

Overview

1. Very complex structure
2. Very high Instrumentation

■ Strain Gauges (x48)



Dynamic System Response

Overview

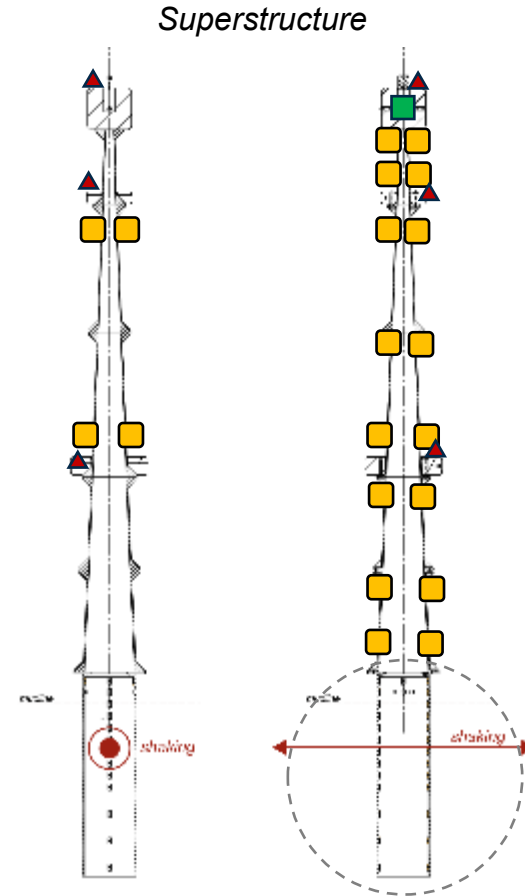
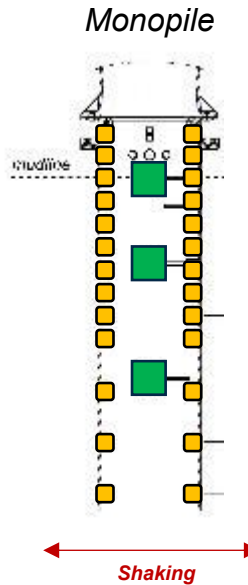
1. Very complex structure
2. Very high Instrumentation

■ Strain Gauges (x48)

Accelerometers

▲ PEA

■ MEM



Dynamic System Response

Overview

1. Very complex structure
2. Very high Instrumentation

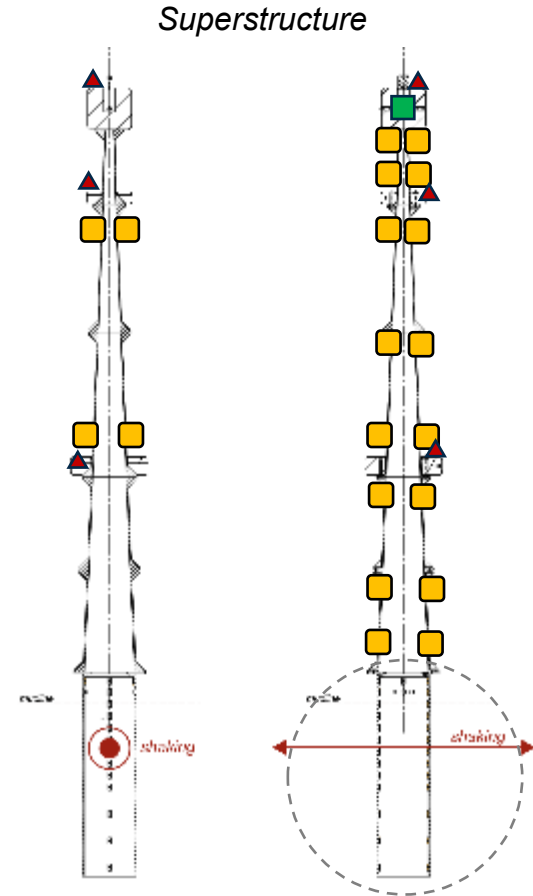
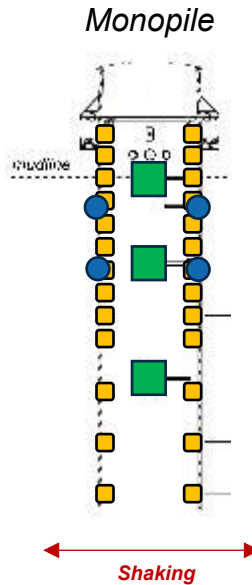
■ Strain Gauges (x48)

Accelerometers

▲ PEA

■ MEM

● Pore Pressure Transducers (PPT)

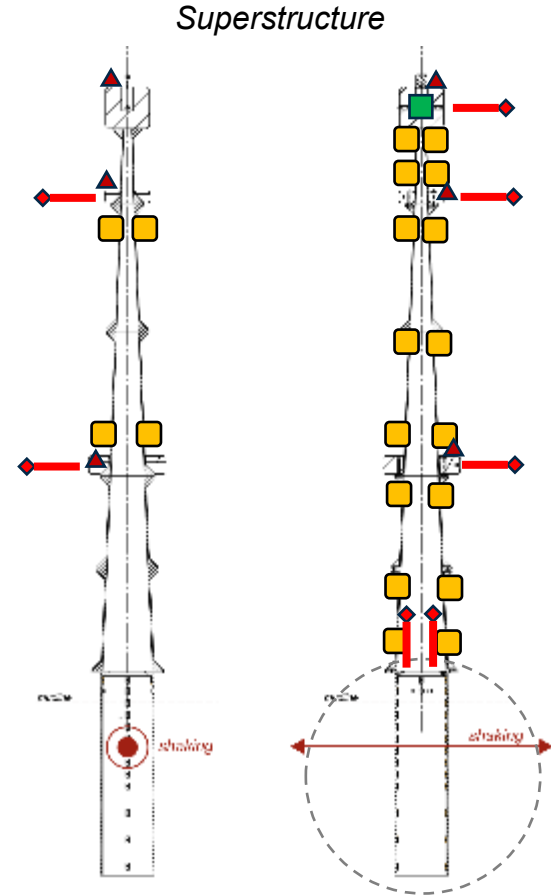
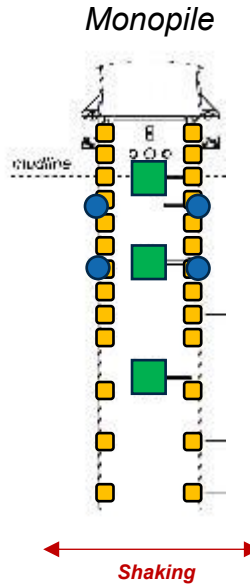


Dynamic System Response

Overview

1. Very complex structure
2. Very high Instrumentation

- Strain Gauges (x48)
- Accelerometers
 - ▲ PEA
 - MEM
- Pore Pressure Transducers (PPT)
- ◆ Displacement Transducers (Laser)



Dynamic System Response

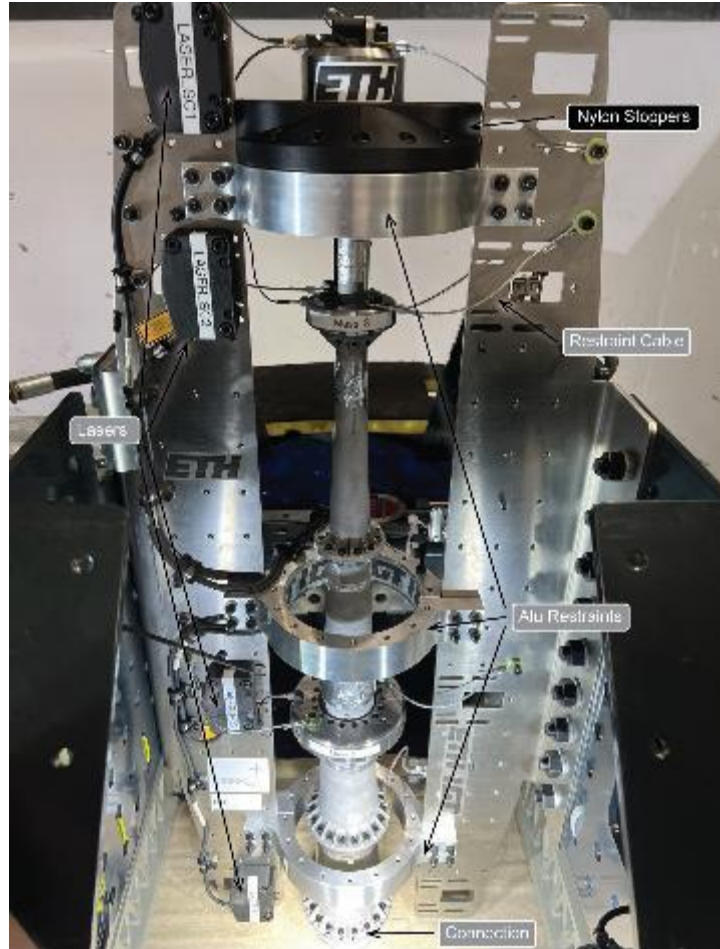
In-Flight Handling

Problem

- Don't Lose Superstructure
- Don't interfere with dynamic response!

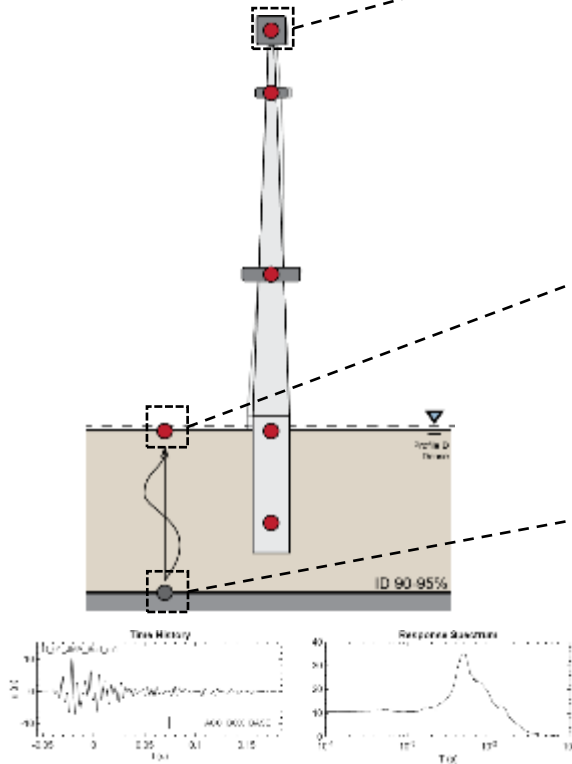
Solution

- Set acceptable limit on rotation and displacement
- Build in redundancy



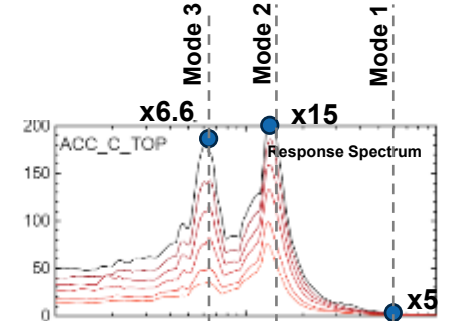
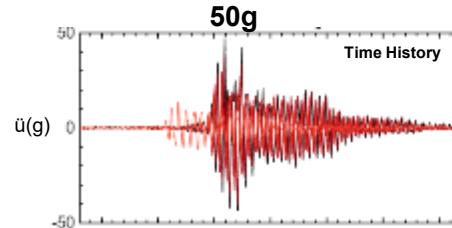
Dynamic System Response

Some initial Results

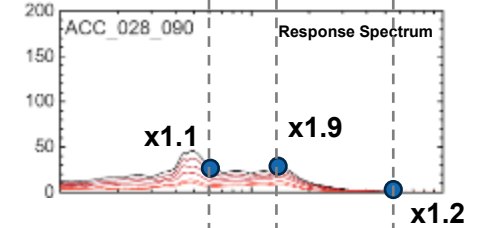
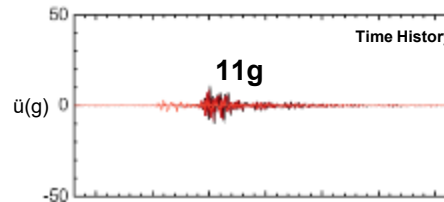


x7 Increasing Amplitude

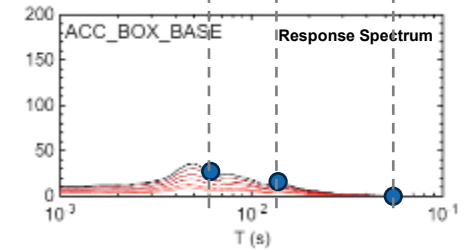
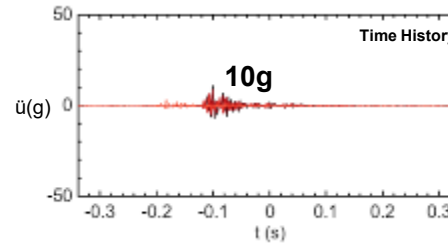
Structure



Surface Motion



Input



Dynamic System Response

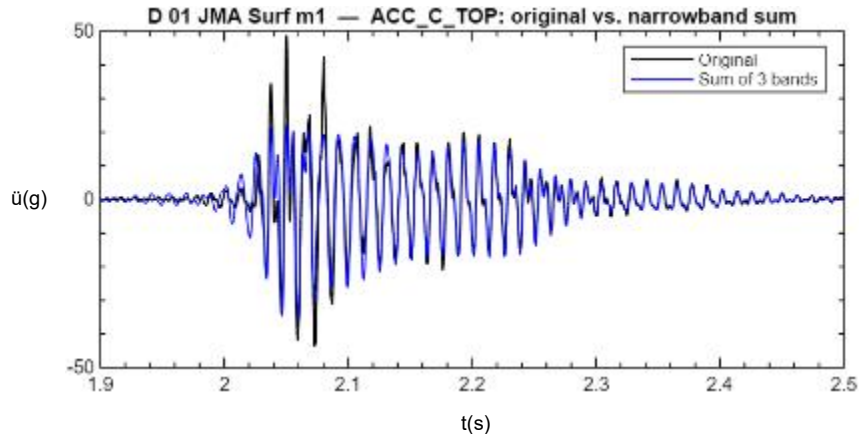
Some initial Results

We asked:

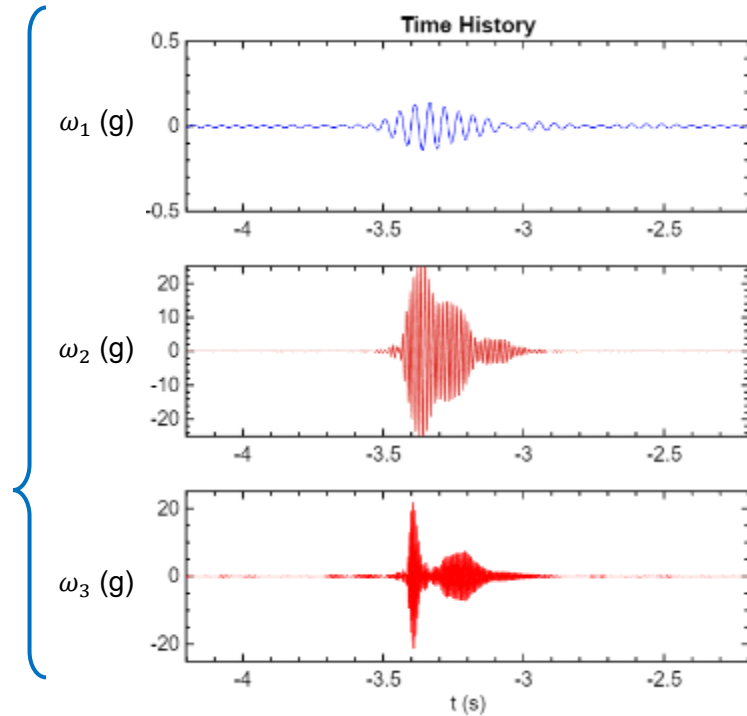
What role does the modal response play?

How Important is it?

Sum of modes **1 2 and 3**:



Modal Contributions



Dynamic System Response

Modal Contributions

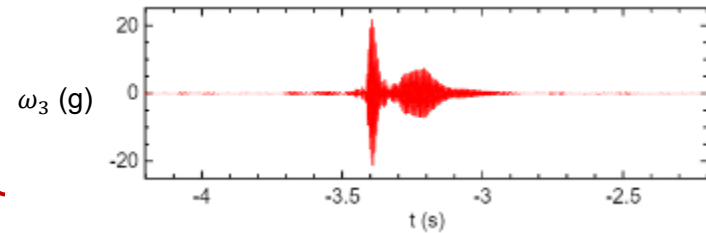
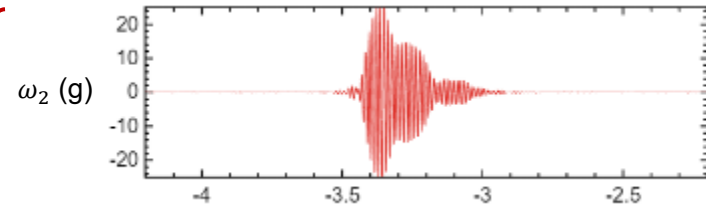
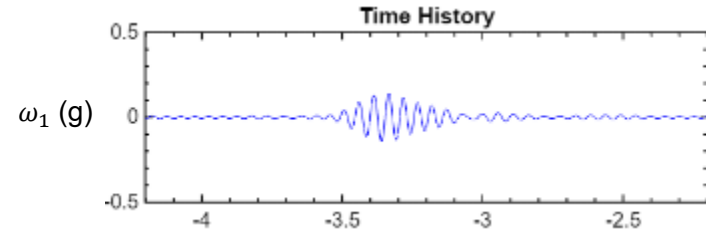
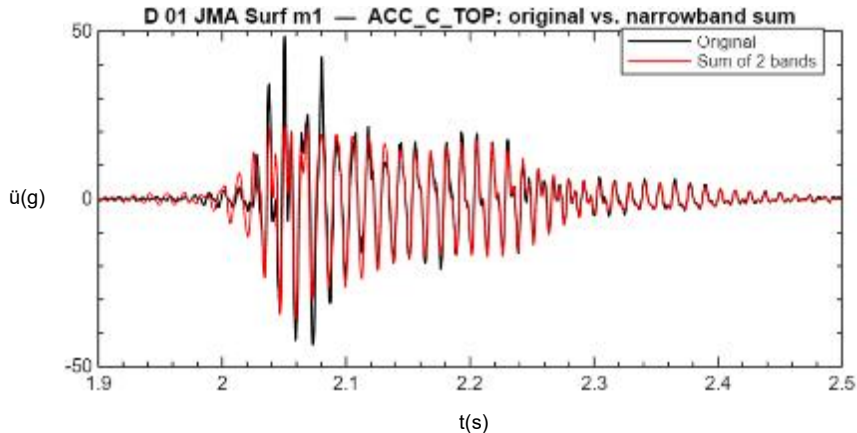
Some initial Results

We asked:

What role does the modal response play?

How Important is it?

Only considering modes **2** and **3**:

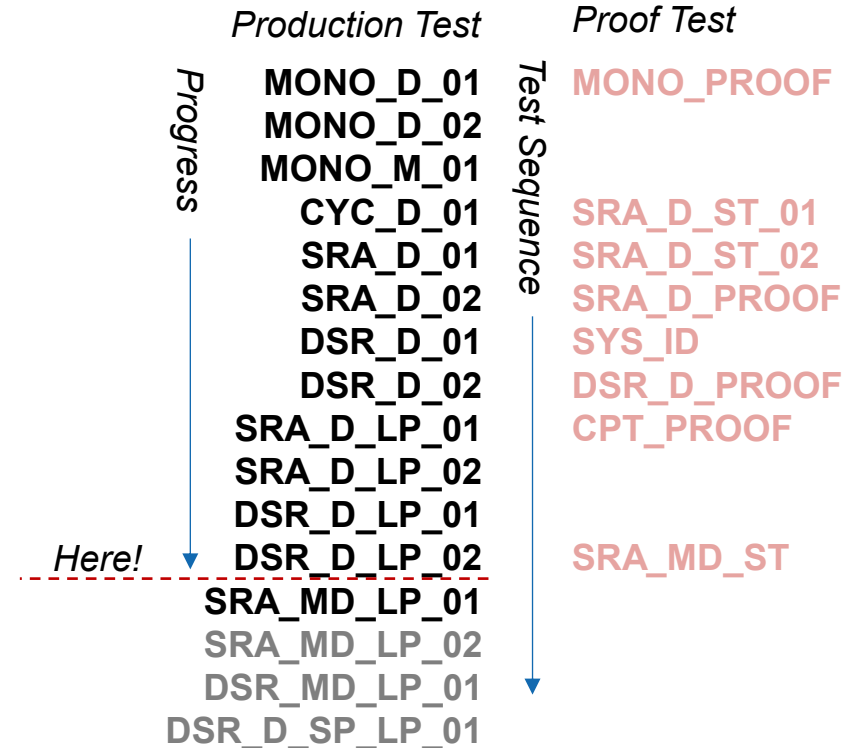


Contribution of higher modes dominates response!

Outlook

Very complex and comprehensive set of tests:

- Unique combination of
 - Multiple Setups with single prototype (MONO –SRA –DSR)
 - Direct comparison with/without EPWP
 - Very detailed instrumentation
- Technical Achievements
 - Proper full dynamic scaling – structure and soil.
 - Realistic input motions with large structures.



DONISIS

WP1: Soil constitutive modelling for seismic loading applications

Iman Moghadam

DONISIS Workshop, Yokohama, Japan

June 4, 2026



Who Am I?



Iman Moghadam

Education

- M.Sc. - Tarbiat Modares University



- PhD Researcher - TU Delft (2024-present)



Research Focus

- Constitutive modelling

WP1 DONISIS – Supervisory Team

PhD Project: *Soil constitutive modelling for seismic loading applications*



A. Petalas
(Durham University)



E. Kementzetzidis
(TU Delft)



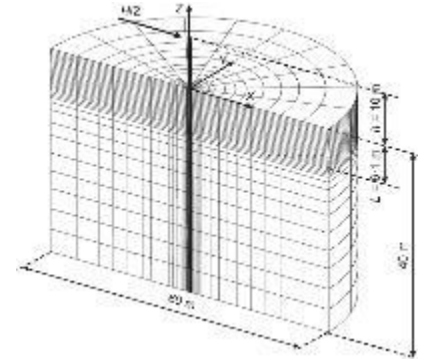
F. Pisanò
(NGI)

Role of Constitutive Models in Geotechnical Engineering

- ✓ FE Analysis
 - Geometry
 - Boundary conditions
- ✓ Constitutive Model
 - Hydromechanical behaviour
 - Pore pressure build-up
 - Sand liquefaction



Field Test (Dunkirk site)



3D FE model

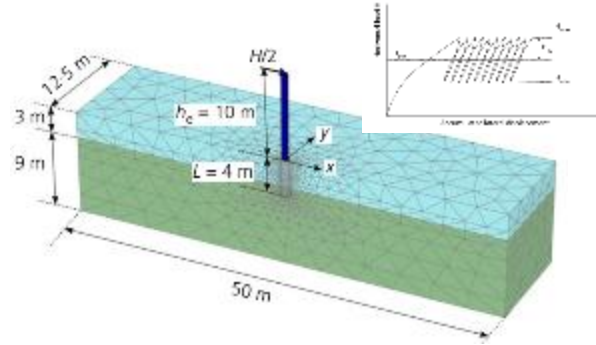
Complex geotechnical problems can be accurately simulated and interpreted through the combination of **advanced constitutive soil models** and **finite element analysis**

Role of Constitutive Models in Geotechnical Engineering



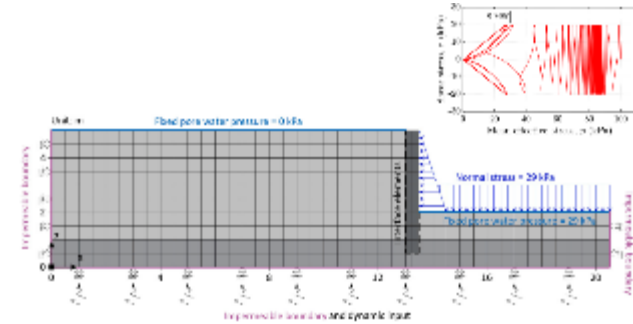
Ross A. McAdam et al. 2020

Monotonic monopile capacity and stiffness



F. Pisanò et al. 2024

Drained ratcheting and cyclic stiffness

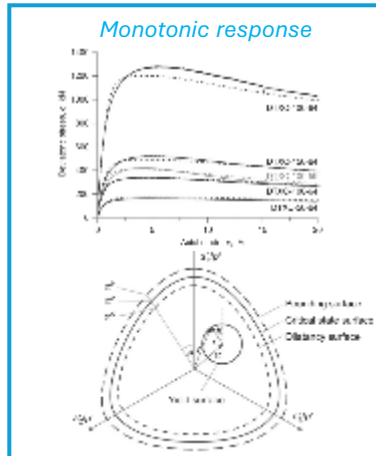


K. Perez et al. 2023

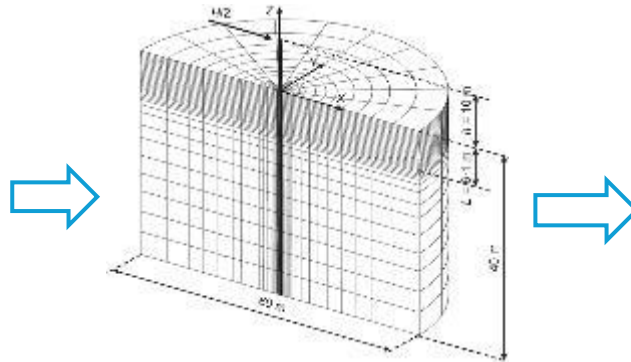
Cyclic undrained seismic response

Role of Constitutive Models in Geotechnical Engineering

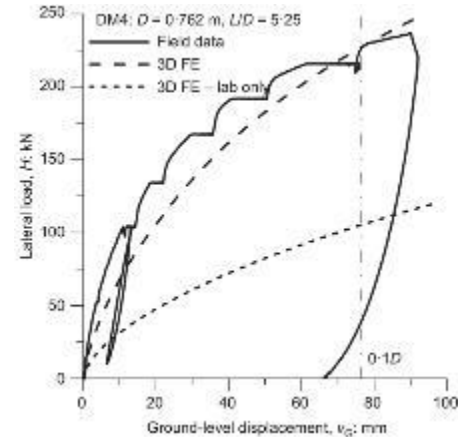
- ✓ FE Analysis
 - Monotonic monopile analysis
 - Constitutive model: Bounding surface plasticity model
- ✓ Outcome
 - 3D FE analyses validated by/the Dunkirk field test measurements and enabled the development of the monotonic monopile analysis PISA method



Constitutive Model



3D FE model



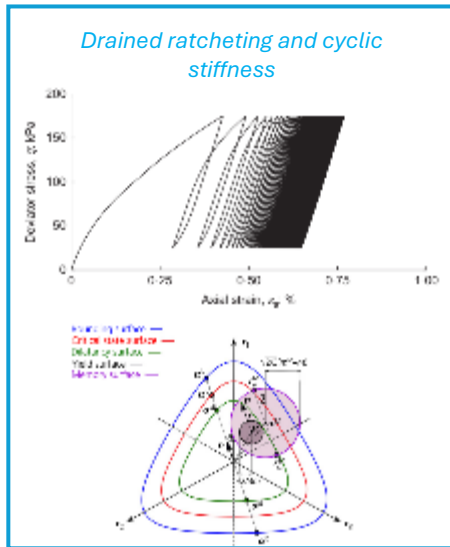
David M. Taborda et al.

2020

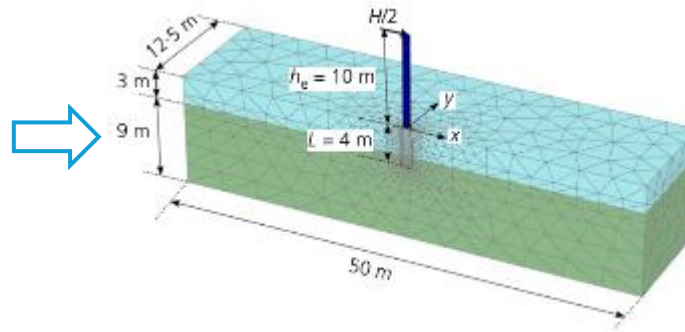
Role of Constitutive Models in Geotechnical Engineering

- ✓ FE Analysis
 - Cyclic ratcheting analysis
 - Constitutive model: SANISAND-MS

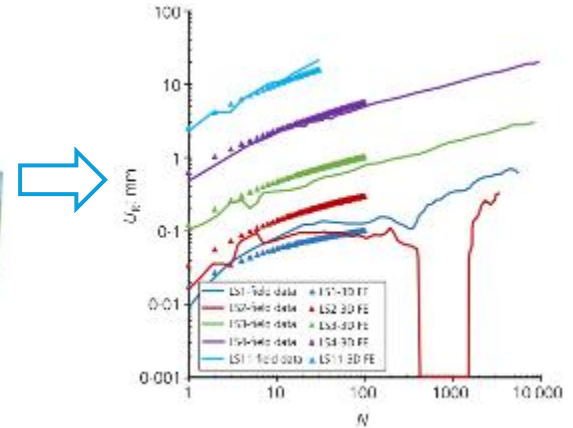
- ✓ Outcome
 - 3D FE cyclic analysis results validated against Dunkink field test measurements



Constitutive Model



3D FE model

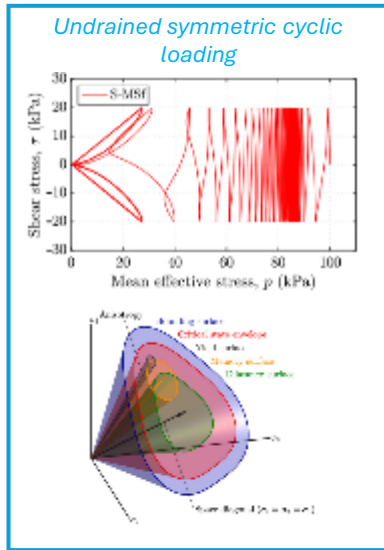


F. Pisanò et al. 2024

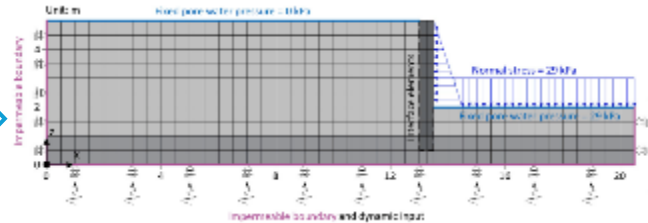
Advanced Constitutive Models in Centrifuge Simulations

- ✓ FE Analysis
 - SANISAND-MSf in coupled FE analysis
 - Undrained cyclic loading and liquefaction

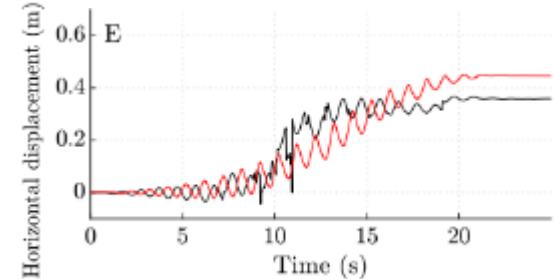
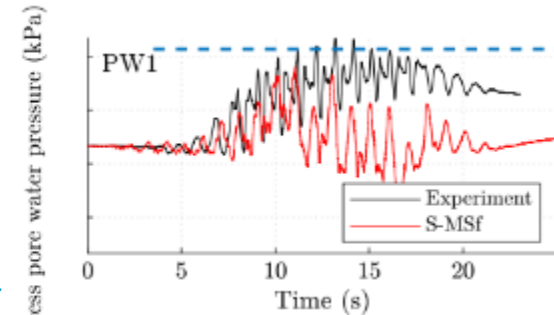
- ✓ Outcome
 - Good agreement with centrifuge measurements
 - Reproduces pore pressure build-up and liquefaction triggering



Constitutive Model



2D FE model



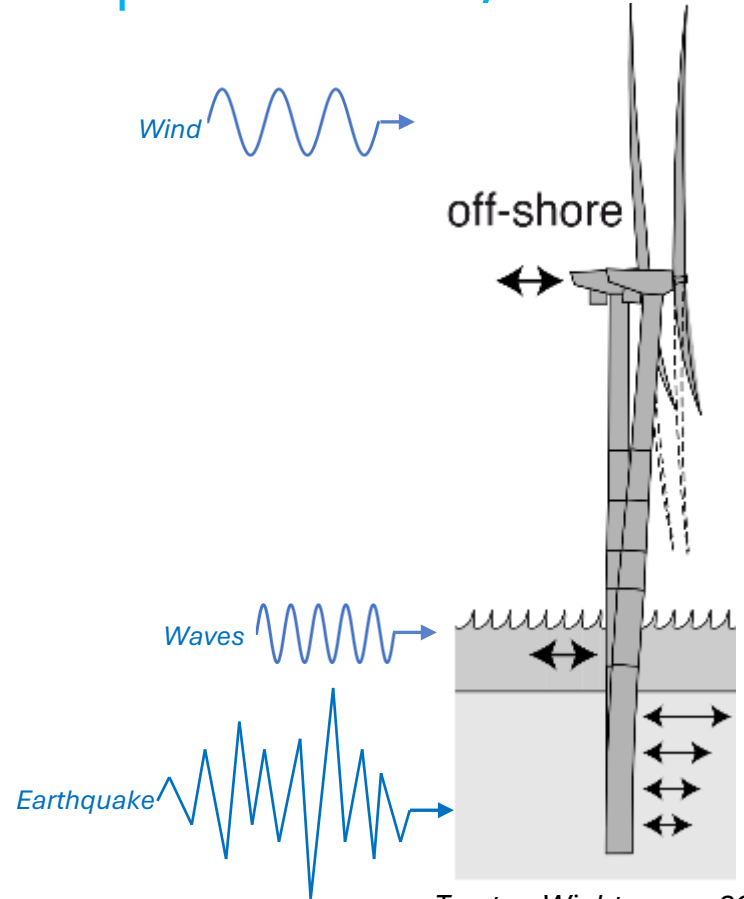
The DONISIS challenge: Seismic OWT response in sandy soils

During a seismic event, foundation soil may undergo:

- Variable amplitude, 1&2 – way cyclic loading
- Under undrained or partially drained hydraulic conditions

The constitutive model should be able to reproduce:

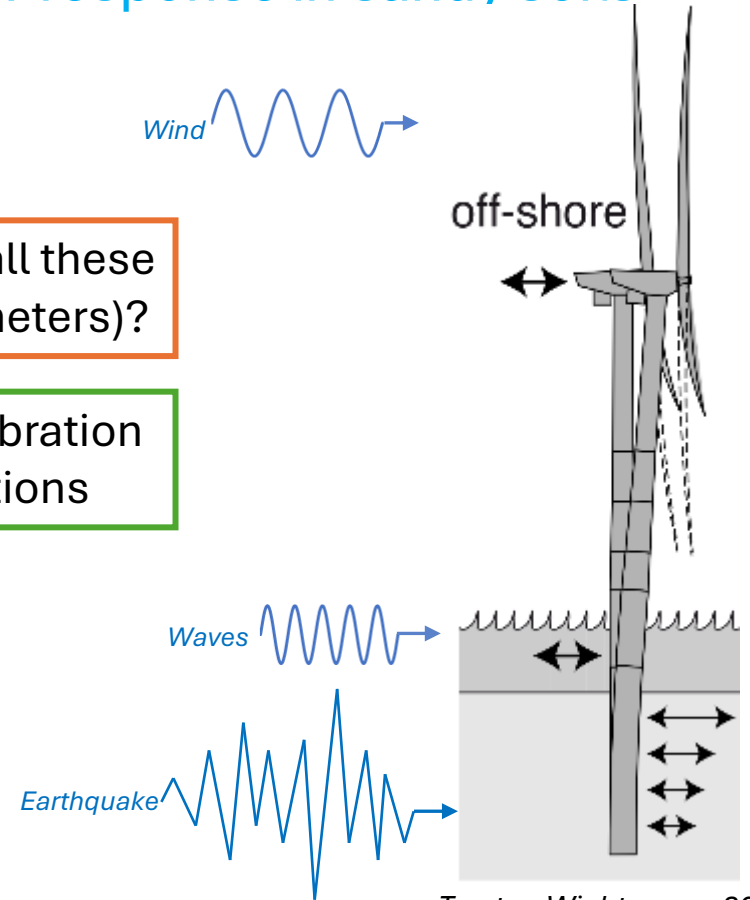
- Drained-undrained soil behaviour
- Cyclic stiffness
- Pore pressure buildup
- Complex loading input
- Energy dissipation - hysteresis



The DONISIS challenge: Seismic OWT response in sandy soils

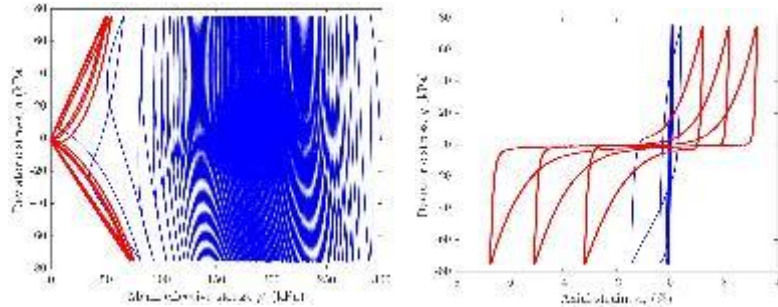
Can one constitutive model reliably capture all these response features (and with one set of parameters)?

Need for robust constitutive models and calibration procedures across realistic loading conditions

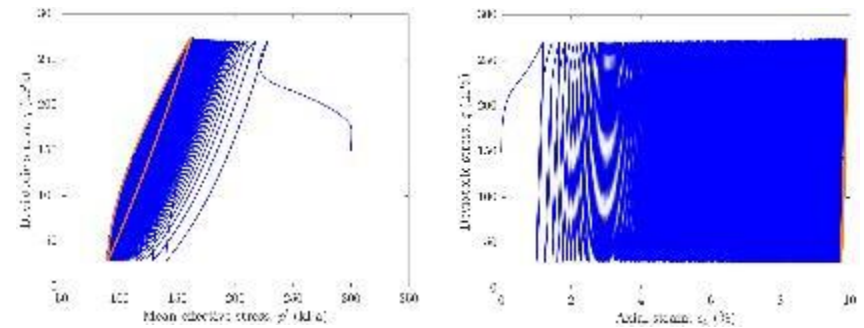


Sand, Different Loading Conditions, Different Responses

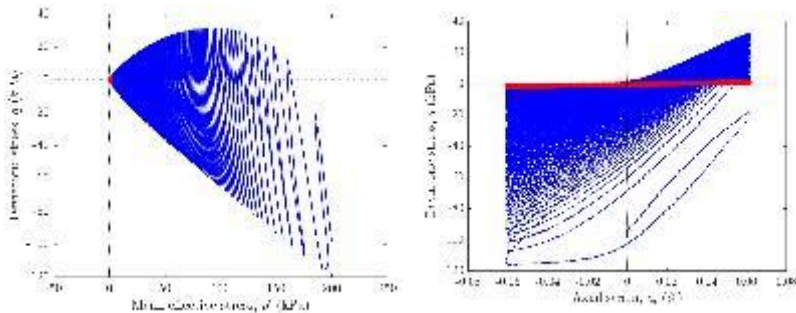
Symmetric stress-controlled loading



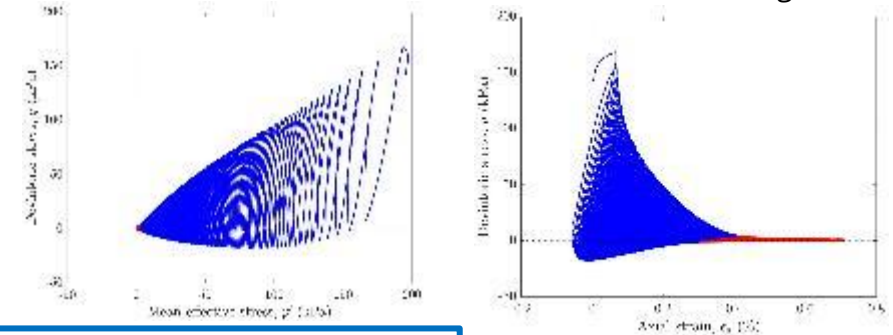
Non-zero shear stress stress-controlled loading



Symmetric strain-controlled loading

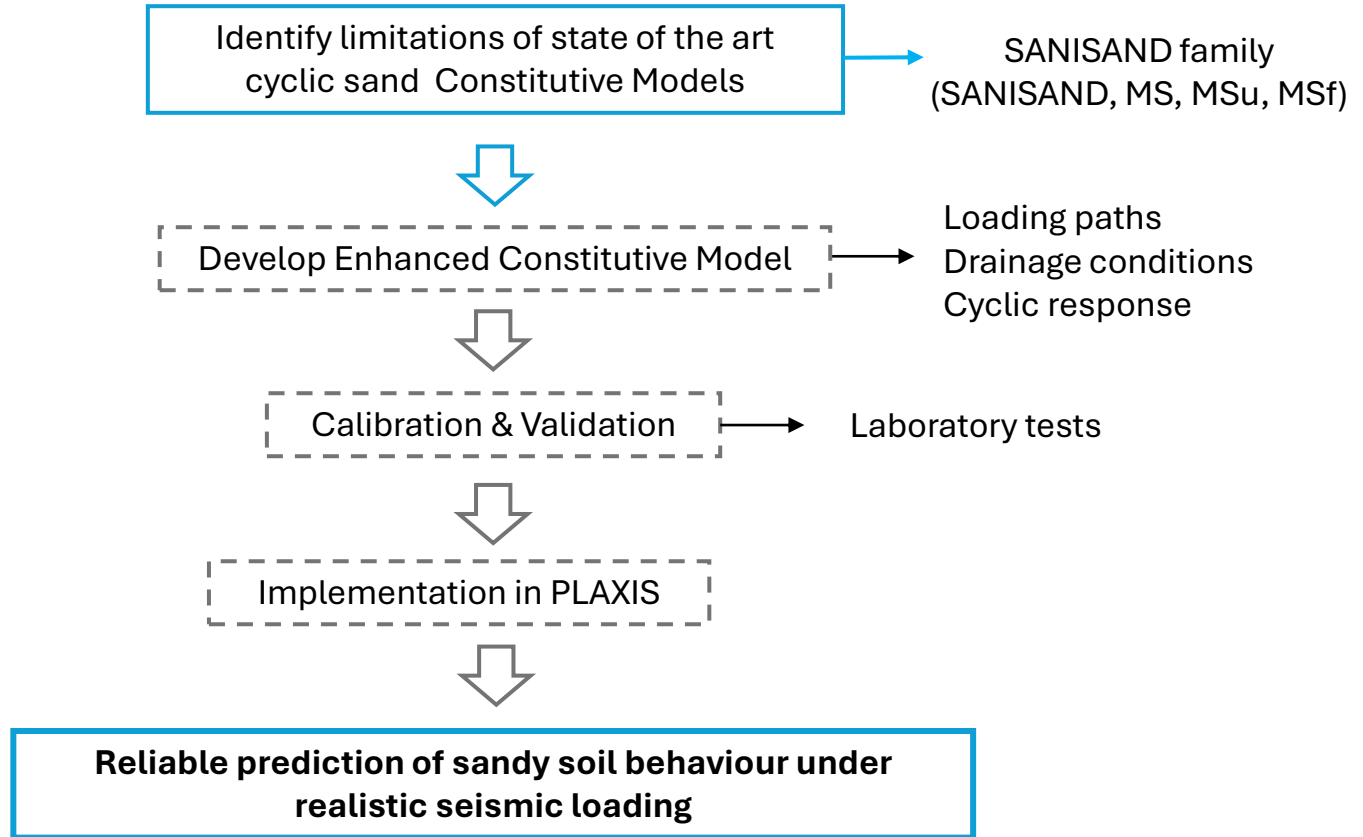


Non-zero shear stress strain-controlled loading



Different loading conditions → Different soil response

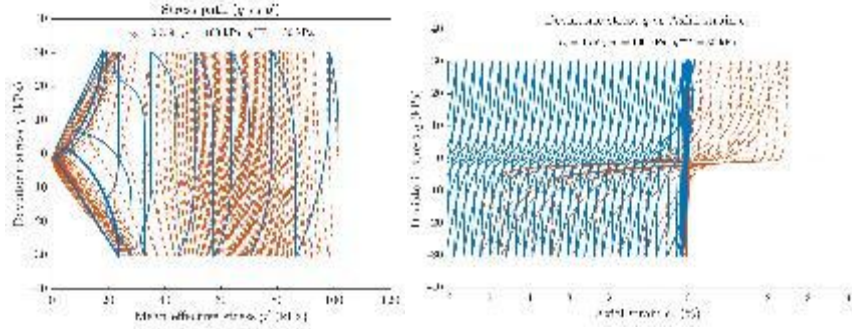
PhD Research Framework



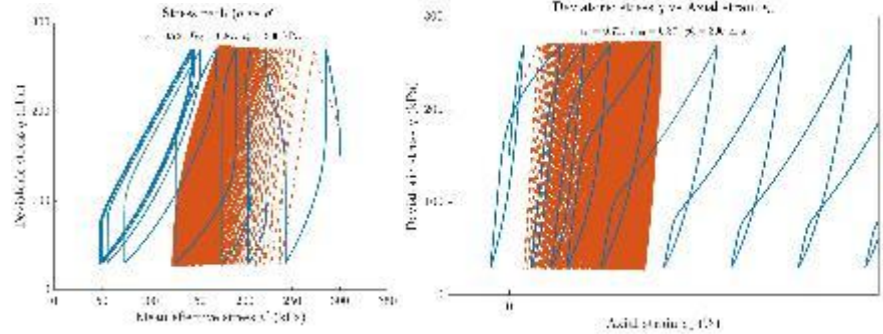
Identified Limitation: Undrained Cyclic Loading

Assessment of constitutive model performance in capturing liquefaction, cyclic mobility, ratcheting and stiffness degradation.

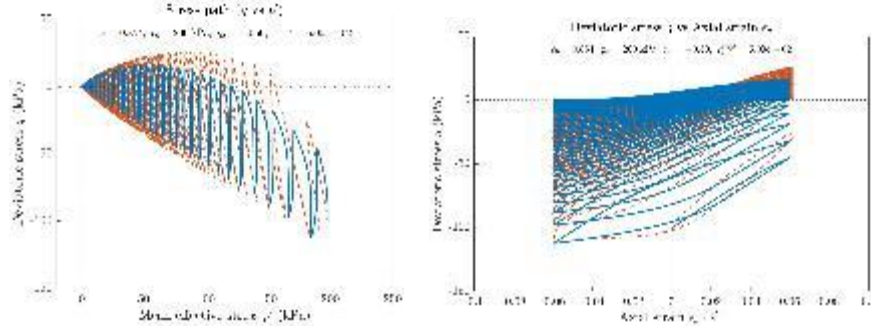
Symmetric stress-controlled loading



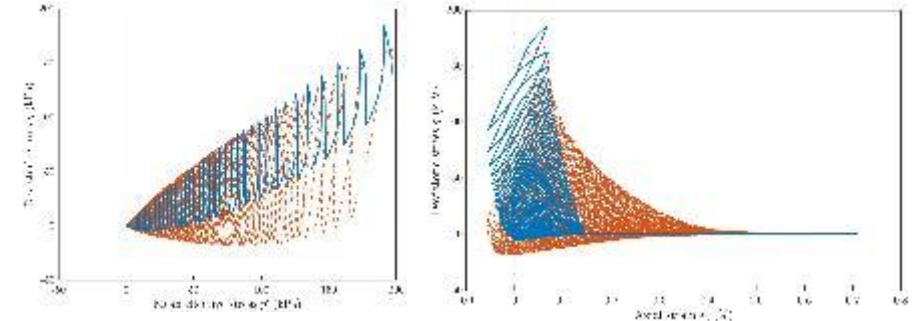
Non-zero shear stress stress-controlled loading



Symmetric strain-controlled loading

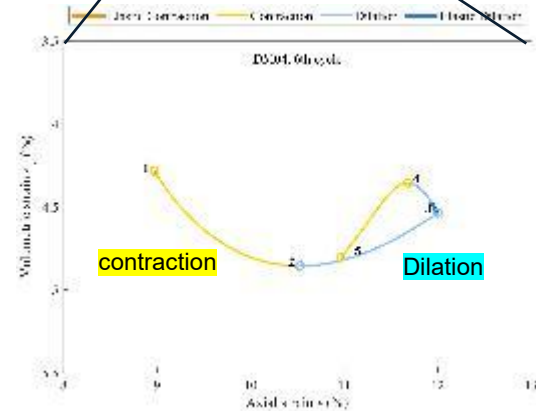
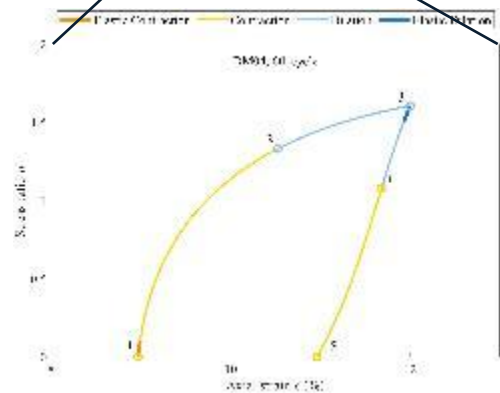
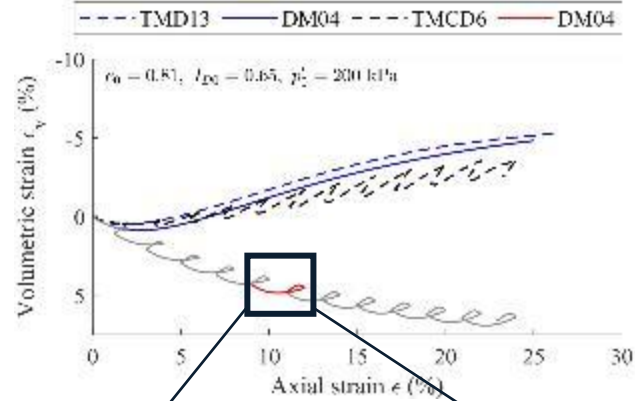
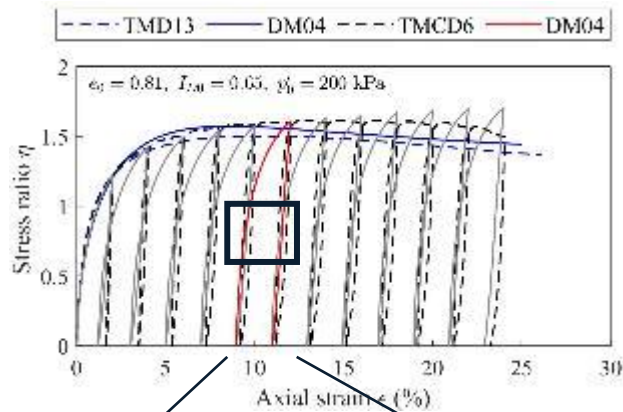


Non-zero shear stress strain-controlled loading



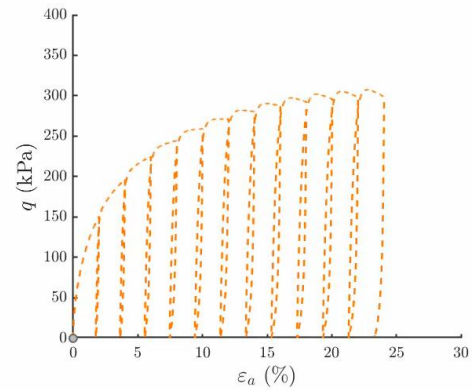
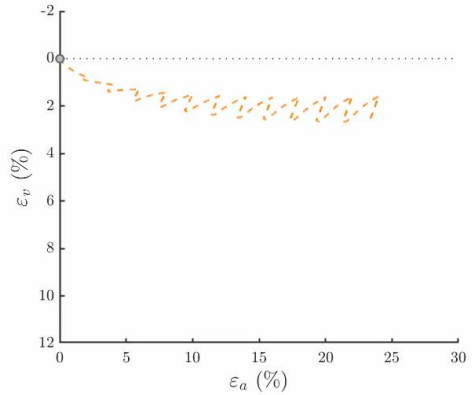
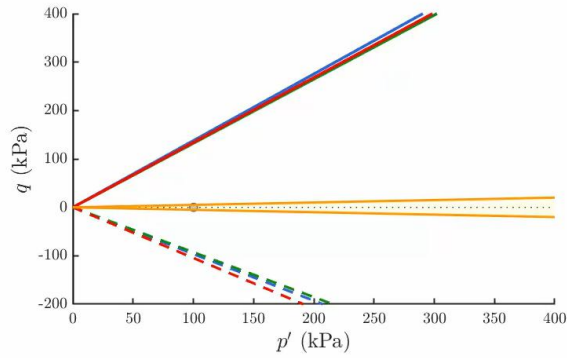
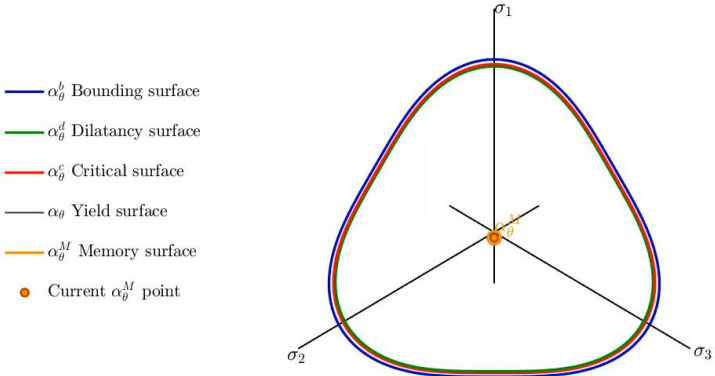
Identified Limitation: Drained Cyclic Loading

Evaluation of volumetric response during unloading–reloading cycles



Identified Limitation: Drained Cyclic Loading

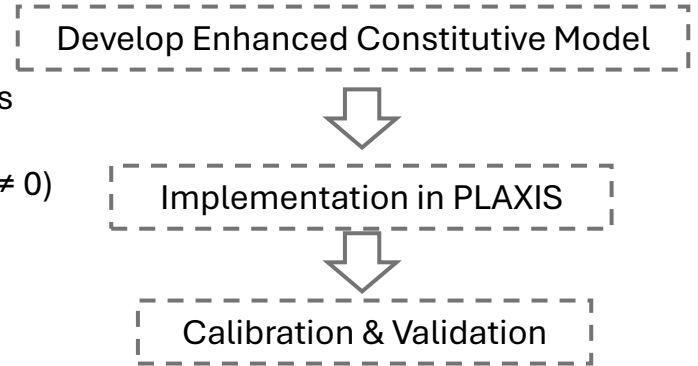
Memory Surface Evolution during Drained Cyclic Loading



Towards an Enhanced Constitutive Model

Based on the identified limitations:

- ✓ Improve memory effects during dilative deformation phases
- ✓ Enhance prediction under anisotropic stress conditions ($q \neq 0$)
- ✓ Span drained, partially drained and undrained conditions
- ✓ Plaxis implementation and validation



Goal : A constitutive model capable of reproducing realistic seismic sand behaviour across a wide range of loading conditions

Conclusion

1. Advanced constitutive models play a key role in seismic FE analyses and centrifuge data simulations.
2. Existing models can successfully reproduce specific loading conditions.
3. Important limitations remain with regard to:
 - ✓ Cyclic loading around anisotropic stress states
 - ✓ Cyclic dilatancy under (relatively) large cyclic stress amplitudes
 - ✓ Response to irregular/random cyclic load histories with varying drainage conditions
4. An enhanced constitutive model is being developed within DONISIS to address these limitations.



WP3 | 3D FEA 3次元有限要素解析

Stavros Panagoulas

DONISIS Workshop, Yokohama, Japan

June 4, 2026



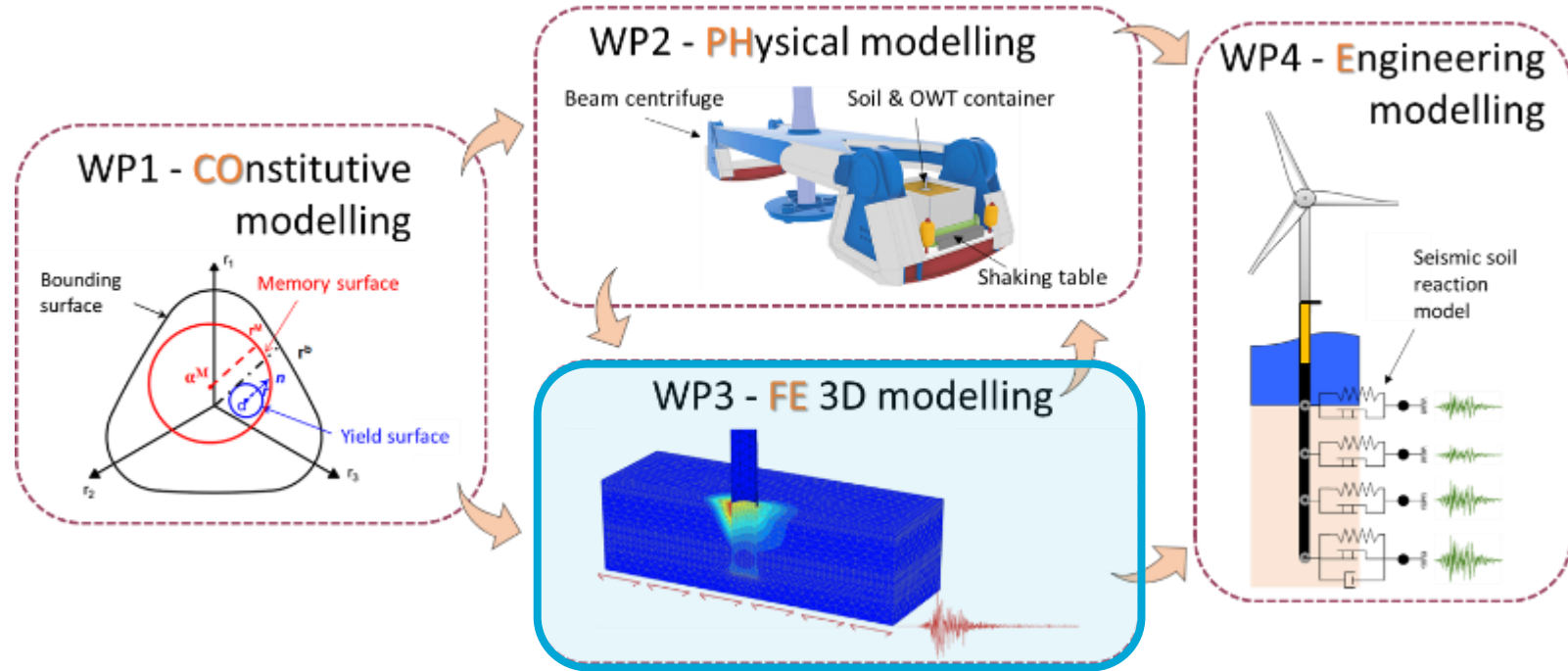
Presentation outline

発表概要

- Motivation: the role of 3D FE in seismic OWT design
動機：洋上風力発電設備の耐震設計における3次元FEの役割
- Numerical strategy: PLAXIS 3D and advanced constitutive modelling
数値解析戦略：PLAXIS 3Dと高度な構成モデル
- Preliminary results: soil response and centrifuge-test simulation
予備解析結果：地盤応答と遠心模型実験のシミュレーション
- Next steps: validation, calibration and simplified engineering models
今後の展開：検証、キャリブレーション、簡易工学モデル

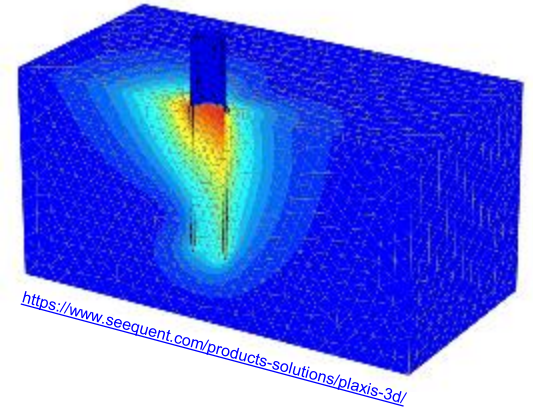
DONISIS work packages overview

The **CO.PH.FE.E.** modelling approach



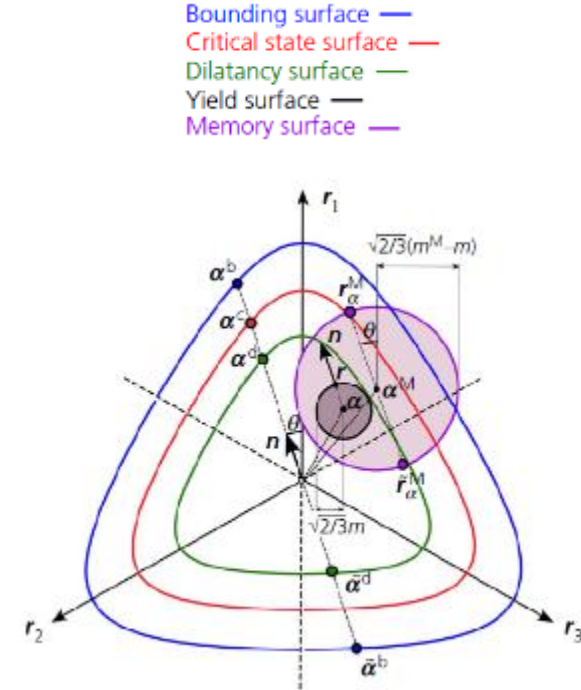
3D FE modelling: from centrifuge tests to predictive insight

- **PLAXIS 3D** is used within DONISIS to model the centrifuge experiments performed at ETH Zurich.
- The **3D FE models** support the experimental campaign by:
 - **informing** test design through preliminary desk studies;
 - **reproducing** the coupled soil–monopile–superstructure response observed in the centrifuge tests;
 - **supporting interpretation** of structural response, foundation loading and pore-pressure evolution;
 - **enabling parametric studies** beyond the tested configurations.



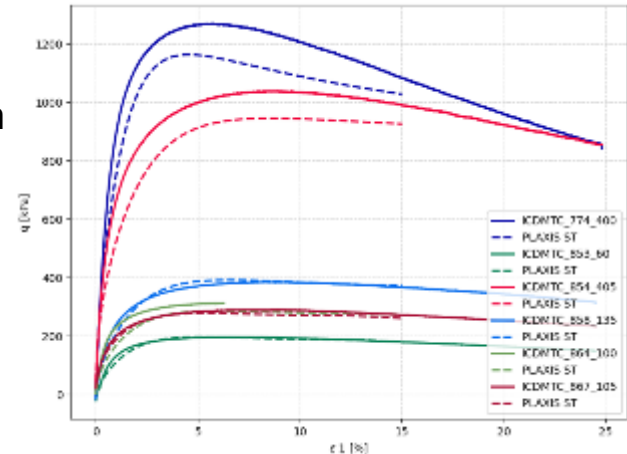
SANISAND: current capability and WP1 developments

- **Advanced constitutive modelling** is used to capture key **sand** behaviour under seismic loading, including stiffness degradation and pore-pressure generation.
- The current modelling strategy uses **SANISAND-MS**, developed by Liu et al. (2019, 2020) and implemented in PLAXIS 3D (Pisanò et al., 2024).
- The existing formulation is considered suitable for the **high-permeability DONISIS tests**, where excess pore-water pressures remain relatively low.
- **DONISIS WP1** will further develop SANISAND-type models for seismic monopile–soil interaction problems.
- The enhanced formulation aims to improve the representation of **partially drained response**, where pore pressure effects become more prominent.



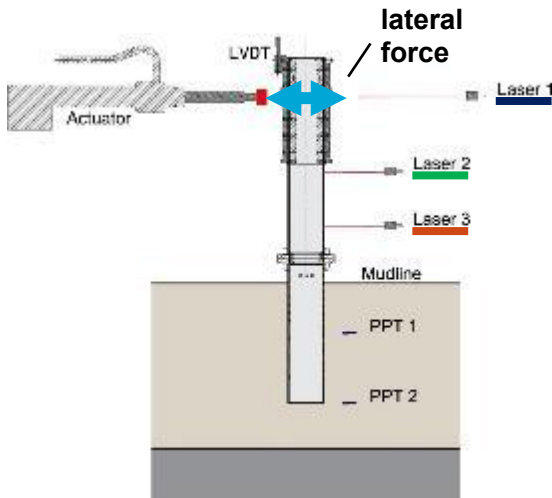
SANISAND-MS calibration for Hostun sand

- **Hostun sand** is a well-characterised soil material, with extensive experimental data available from ETH Zurich and the wider literature.
- The **SANISAND-MS** model is calibrated against available laboratory test data for Hostun sand.
- The calibration includes comparison with **various drained and undrained lab tests** to assess the stress–strain response.
- Indicative results from **drained triaxial tests** show that SANISAND-MS captures the measured laboratory response with good accuracy, particularly the evolution of deviatoric stress (q) with axial strain (ϵ_1).

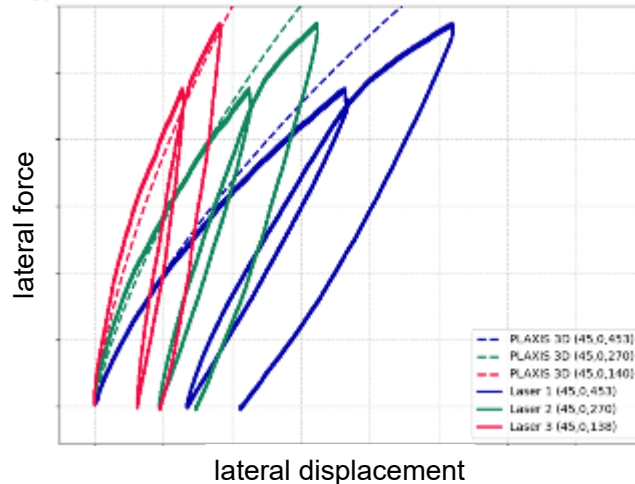


Validation against high-permeability centrifuge tests

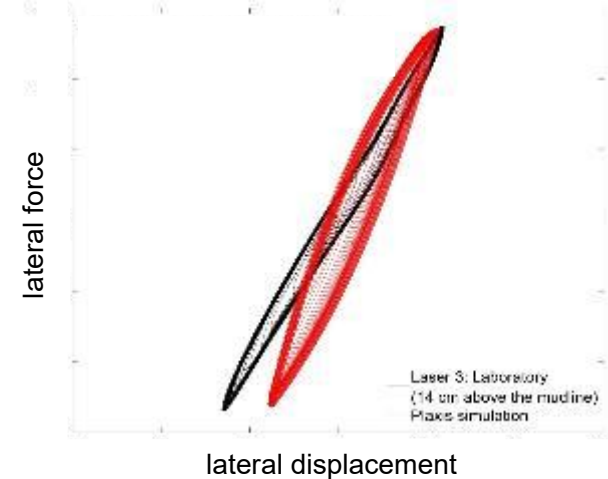
- The **calibrated SANISAND-MS** model is used to simulate the first DONISIS centrifuge tests at ETH Zurich under **high-permeability** conditions.
- Comparisons with experimental data show reasonably good agreement under both **monotonic** and **cyclic** pile-head loading.



monotonic loading with un/re-loading cycles

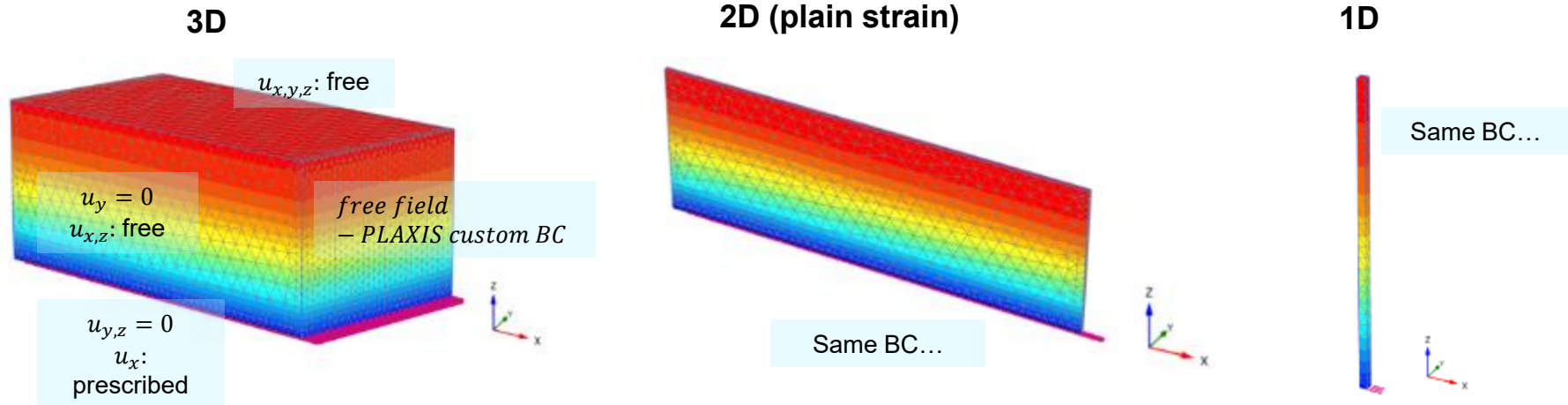


cyclic loading at 0.2 Hz



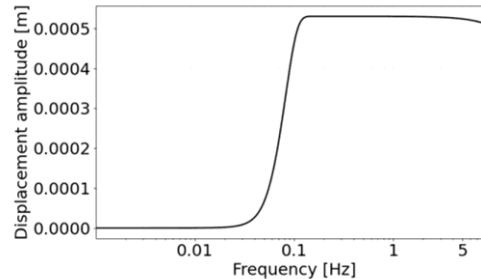
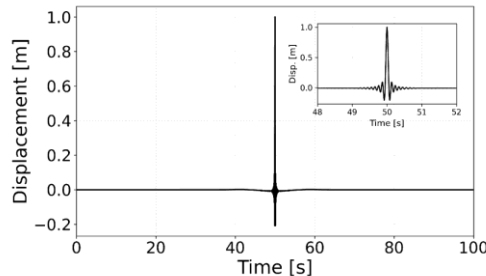
Soil-only model: domain and boundary-condition checks

- The influence of **domain geometry** and **dynamic boundary conditions** (BC) is assessed using a soil-only model.
- The objective is to ensure that the numerical domain can reproduce a realistic **free-field** soil response before introducing the monopile and superstructure.
- A **uniform horizontal excitation** is applied at the base of the model in the x-direction.



Frequency-response of the soil-only model

- A **small-amplitude Ormsby wavelet** is applied at the base of the 3D FE soil-only model in the time domain.
- The wavelet provides approximately uniform excitation over a selected frequency band (0.1 – 6.0 Hz), enabling identification of the soil deposit's **resonance frequencies**.

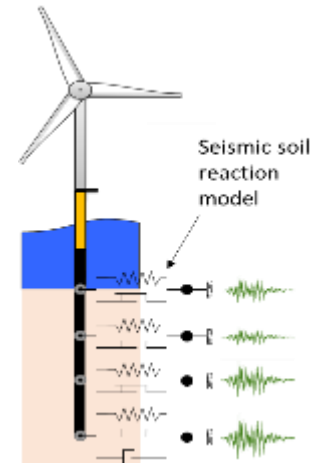
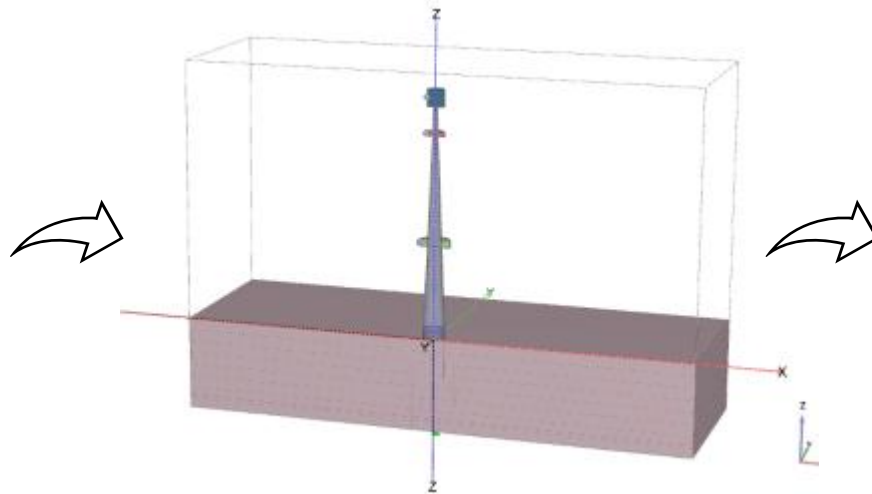


- The 3D FE results show very good **agreement** with:
 - 1D site-response analysis tools (RSSeismic / DEEPSOIL)
 - analytical estimates based on Gazetas (1991).

Method	$f_{1,soil}$ [Hz]
PLAXIS 3D	1.47
RSSeismic	1.51
Gazetas	1.48

Next steps in DONISIS 3D FE numerical modelling

- **Validate** the 3D FE models against the centrifuge test data.
- Employ the “**DONISIS WP1 constitutive model**” to simulate the low-permeability tests, where pore-pressure build-up and liquefaction effects are more pronounced.
- Establish a **calibration workflow**:
experimental data → 3D FE models → 1D FE engineering models.



Points for discussion

ディスカッション項目

- Do you consider **3D FE modelling** essential for the seismic design of offshore wind turbine foundations?
- Should it be used in **concept** design, **detailed** design, or mainly for **validation** of simplified models?
- What are the **key practical barriers**?
 - **constitutive model** formulations and calibration;
 - computational **cost**;
 - **translation** from 3D FE results to 1D engineering models;
 - **validation** against experimental data;
 - other?
- 洋上風力発電設備の基礎の耐震設計において、3次元FE解析は不可欠だと考えますか。
- 3次元FE解析は、概念設計、詳細設計、あるいは主に簡易モデルの検証に用いるべきでしょうか。
- 実務上の主な課題は何でしょうか。
 - 構成モデルの定式化とキャリブレーション
 - 計算コスト
 - 3次元FE解析結果の1次元工学モデルへの反映
 - 実験データによる検証
 - その他？

References

- Gazetas G. (1991). *Foundation Vibrations*, pages 553–593. Springer US, Boston, MA.
- Liu, H. Y., Abell, J. A., Diambra, A., & Pisanò, F. (2019). Modelling the cyclic ratcheting of sands through memory-enhanced bounding surface plasticity. *Géotechnique*, 69(9), 783-800. <https://doi.org/10.1680/jgeot.17.P.307>
- Liu, H., Diambra, A., Abell, J. A., & Pisanò, F. (2020). Memory-enhanced plasticity modeling of sand behavior under undrained cyclic loading. *Journal of Geotechnical and Geoenvironmental Engineering*, 146(11), 04020122. [https://doi.org/10.1061/\(ASCE\)GT.1943-5606.0002362](https://doi.org/10.1061/(ASCE)GT.1943-5606.0002362)
- Pisanò, F., Del Brocco, I., Ho, H. M., & Brasile, S. (2024). 3D FE simulation of PISA monopile field tests at Dunkirk using SANISAND-MS. *Géotechnique Letters*, 14(2), 35-45. <https://doi.org/10.1680/jgele.23.00073>



WP4 | 1D FEA 1次元有限要素解析

Stavros Panagoulas

DONISIS Workshop, Yokohama, Japan

June 4, 2026



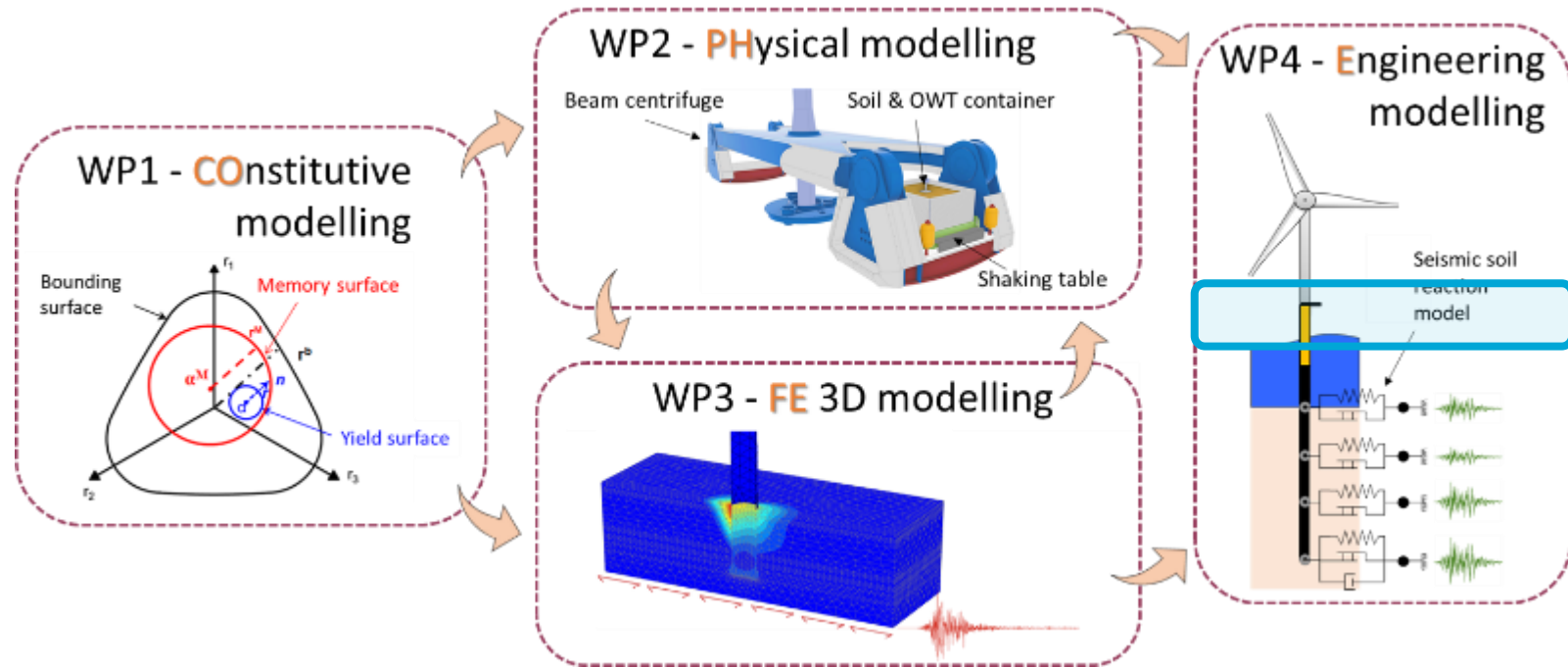
Presentation outline

発表概要

- Motivation and role of 1D engineering models
1次元工学モデルの動機と役割
- Towards the DONISIS soil reaction model
DONISIS地盤反力モデルに向けて
- Preliminary results and next steps
予備解析結果と今後の展開

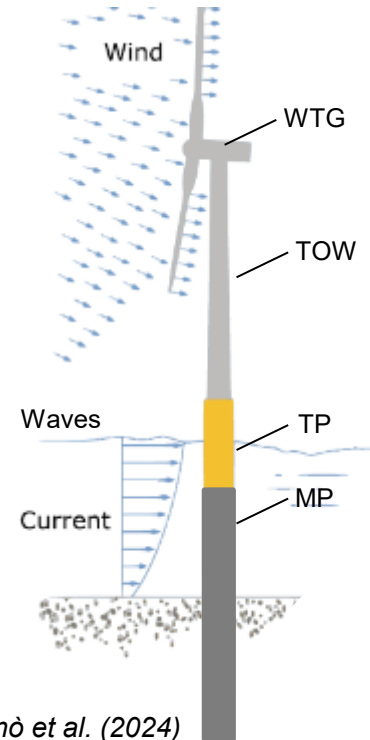
DONISIS work packages overview

The **CO.PH.FE.E.** modelling approach



1D Engineering design models are essential to offshore wind

- The offshore wind industry relies heavily on “**1D**” **engineering design** models → **fast, robust** design iterations.
- An offshore wind farm typically includes a large number of wind turbines, each assessed across multiple soil conditions, load cases and design updates → **efficient calculations** across many **design iterations**.
- Support structure design often involves a **split scope** between foundation designers and OEMs → clear **exchange** of “soil reaction inputs” and “structural response outputs”.



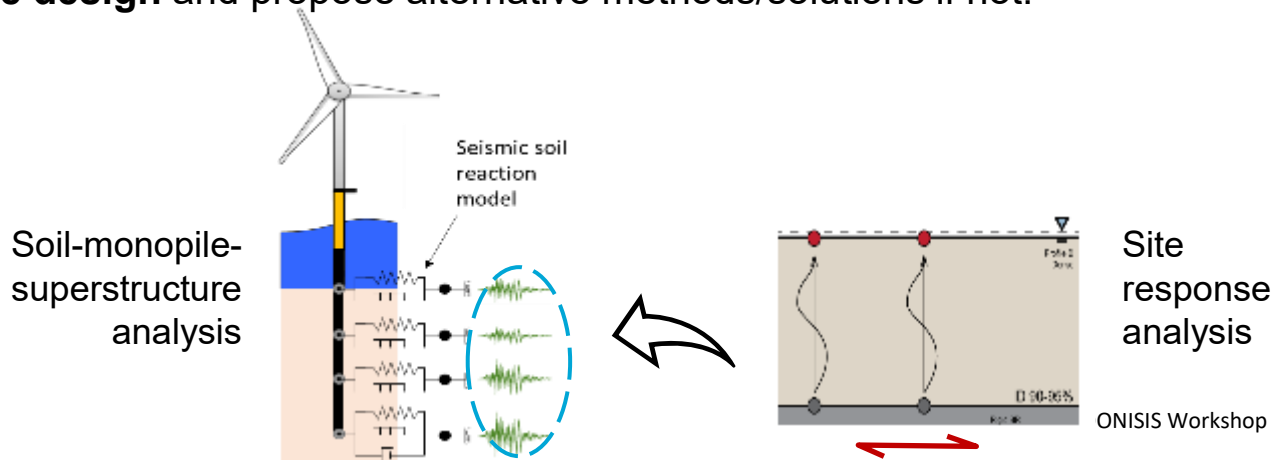
Pisanò et al. (2024)

Why seismic 1D soil reaction models need further development

- **Existing seismic soil reaction models** were mainly developed for **conventional slender piles**, typically employed in pile groups.
- **Monopile-supported OWTs** exhibit fundamentally different soil–structure interaction behaviour.
- Several **monopile-specific soil reaction models** exist, but most have been developed and validated for **slow quasi-static** or **cyclic loading**, representative of wind- and wave-dominated conditions.
- **Key seismic response mechanisms** remain insufficiently represented in existing models, including:
 - rate effects
 - cyclic degradation
 - pore-pressure build-up
- **Practical adoption** is limited by:
 - **complex calibration** and **parameter selection**;
 - **lack of standardised data-exchange formats** between foundation designers and OEMs.

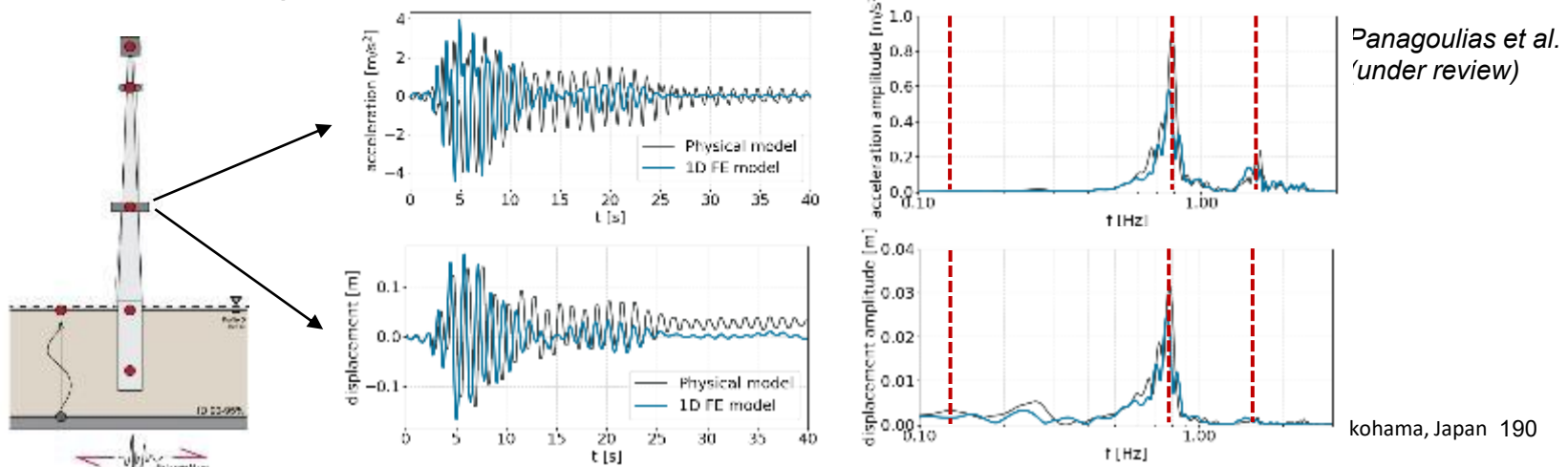
Assessing the two-step seismic design framework

- Seismic foundation design commonly relies on a **two-step design framework** (Boulanger, 1999):
site response analysis → **soil-monopile-superstructure interaction analysis**.
- DONISIS evaluates this framework through **centrifuge experiments** (WP2) and **advanced 3D FE modelling** (WP1 & WP3).
- The objective is to assess if simplified engineering workflows remain **valid** for **seismic monopile design** and propose alternative methods/solutions if not.



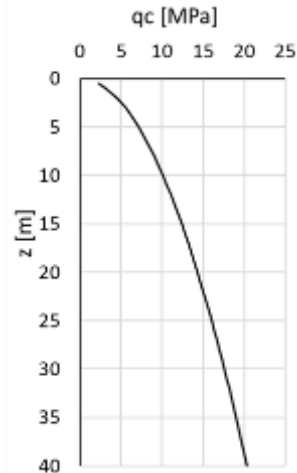
Step 1: linear(ised) soil reaction models

- For **low seismic demand** and **moderate soil non-linearity**, **linearised** soil reaction models *may* provide an efficient and defensible engineering approximation.
- DONISIS investigates **the conditions under which** such simplified models can reproduce the key features of soil–monopile–superstructure interaction.
- Preliminary comparisons with the high-permeability centrifuge test series show **promising agreement** and help define the **applicability range** of linear soil reaction models.



Step 2: non-linear seismic modelling framework

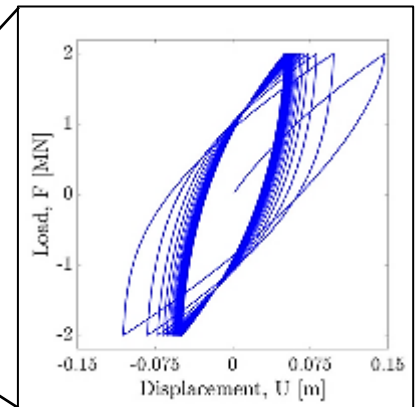
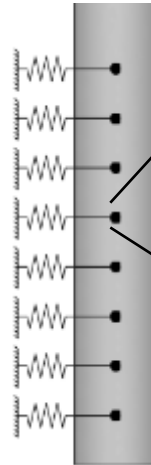
- Builds on the existing **(S)CPT-based nonlinear soil reaction elements** developed within the **GDP** and **MIDAS** projects (Kementzetzidis et al., 2022; Pisanò et al., 2026)
- The framework is extended within **DONISIS** to include **seismic-related mechanisms** such as **pore-pressure** and **dynamic effects**.
- Model parameters are linked to **(S)CPT** data via the cone resistance q_c .



— CPT-based (q_c) calibration —>

4 calibration
parameters

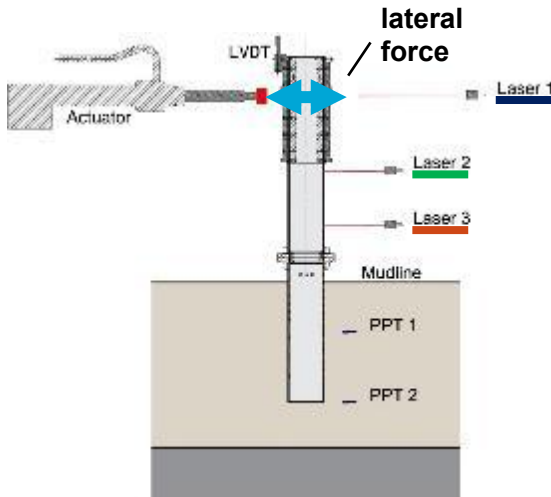
1D soil reaction
elements



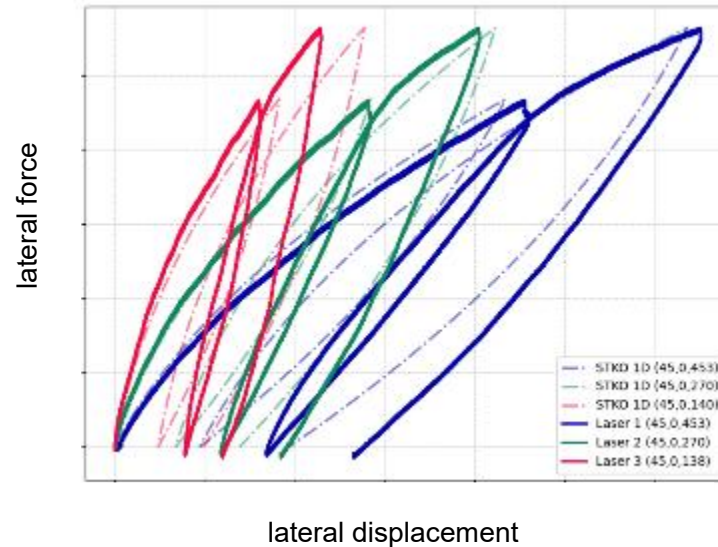
Kementzetzidis et al.
(2022)

Validation against high-permeability centrifuge tests

- The **1D soil reaction model** is used to simulate the first DONISIS centrifuge tests at ETH Zurich under **high-permeability** conditions.
- Comparisons with experimental data show good agreement under both **monotonic** and **cyclic** pile-head loading.



monotonic loading with un/re-loading cycles



Next steps in DONISIS 1D engineering modelling

- Develop **non-linear soil reaction elements** supported by a **practical calibration framework**.
- Improve the representation of **key seismic** monopile–soil interaction mechanisms:
 - dynamic loading effects;
 - cyclic degradation;
 - soil damping;
 - pore-pressure build-up.
- Use **evidence** from:
 - DONISIS centrifuge experiments (WP2);
 - 3D FE numerical simulations (WP1, WP3).

Points for discussion

ディスカッション項目

- Would an **(S)CPT-based soil reaction model** be attractive for the seismic design practice?
 - Do you believe that a **conventional p-y formulation** is sufficient, **or** is a **multi-spring framework** needed to capture seismic monopile response?
 - What are the **key design uncertainties** in relation to **seismic soil-structure interaction**?
 - soil non-linearity;
 - soil damping;
 - pore-pressure build-up and liquefaction;
 - translation from 3D FE results to 1D engineering models;
 - validation against centrifuge and field data;
 - other?
 - How would a practical **data-exchange format** between foundation designers and OEMs look like?
- 地震設計実務において、(S) CPTに基づく地盤反力モデルは有用だと思いますか。
 - 従来の p-y モデルで十分だと思いますか。それとも、地震時のモノパイル応答を捉えるにはマルチスプリング・フレームワークが必要でしょうか。
 - 地震時の土-構造物相互作用に関する主な設計上の不確実性は何でしょうか。
 - 地盤の非線形性
 - 地盤減衰
 - 過剰間隙水圧の蓄積と液状化
 - 3次元FE解析結果の1次元工学モデルへの反映
 - 遠心模型実験および実測データによる検証
 - その他
 - 基礎設計者とOEMの間で実用的なデータ交換フォーマットを構築するとしたら、どのような形が望ましいでしょうか。

References

Boulanger, R.W., Christina J.C., Bruce L.K., Daniel W.W., and Abbas A. (1999). “Seismic Soil-Pile-Structure Interaction Experiments and Analyses.” *Journal of Geotechnical and Geoenvironmental Engineering* 125, no. 9: 750–59. [https://doi.org/10.1061/\(ASCE\)1090-0241\(1999\)125:9\(750\)](https://doi.org/10.1061/(ASCE)1090-0241(1999)125:9(750))

Kementzetzidis, E., Pisanò, F., Metrikine, A.V., 2022. *A memory-enhanced p-y model for piles in sand accounting for cyclic ratcheting and gapping effects*. *Computers and Geotechnics* 148, 104810. <https://doi.org/10.1016/j.compgeo.2022.104810>

Pisanò, F., Panagoulas, S., Anastasopoulos, I., Kaynia, A. M., Petalas, A. L., Brasile, S., Page, A. M., Kementzetzidis, E. and Metrikine, A. V. (2024). DONISIS: Design of offshore monopiles including seismic interaction with soil. *Japanese Geotechnical Society Special Publication*, 10(36): 1530--1535. <https://doi.org/10.3208/jgssp.v10.OS-25-05>

Pisanò, F., Kementzetzidis, E., Wang, H., Marino, M., Wu, K.-W., Habib, F., & Peccin da Silva, A. (2026). An SCPT-based monotonic soil reaction model for monopiles in sand: calibration with centrifuge tests and assessment against field data. *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Accepted for publication.

Certification Roundtable

Translating DONISIS Research into Standards and Guidance



Moderator: Noel Boylan
Managing Director, Perth
NGI



Yiorgos Perikleus
Principal Geotechnical Engineer
DNV



Ignacio Romero-Sanz
Global Technical Lead, Wind
Bureau Veritas



Yu-Wei Hwang
Assistant Professor
NTU



Gerry Murphy
Associate Director, Japan Country
Manager
Wood Thilsted



Ayumu Naito
Foundation Design Manager
RWE



WHEN TRUST MATTERS

Donisis Workshop

Certification Round Table

Yiorgos Perikleous

28 May 2026

DNV's impact in Offshore wind

No. 1

We are the leading certification body in the wind industry for type and project certification

80%

80% of certified offshore wind farm utilized our project certification services to manage risks

25+

We have worked in more than 25 projects requiring seismic design analysis

20

We have 20 research and innovation projects running ensuring today's standards are ready for tomorrow's challenges



What About Seismic Design?

ACE 1 – (2019-2021)



DNV-GL

VALUATING COSTS AND RISK INQUIRY SCENARIOS FOR WIND POWER (ACE 1) – JOINT INDUSTRY PROJECT (JIP)

Final Report Seismic Workstream

All Associated JIP Partners

Report No. DNV-GL-19-011
April 2021



DNV

RECOMMENDED PRACTICE

R-2160 Edition August 2021


Seismic design of wind power plants

DNV & the Association of the Owners of the Offshore Wind Power Industry

DNV

201 DNV © 28 MAY 2026

♠CE 2 – (2023-2025)



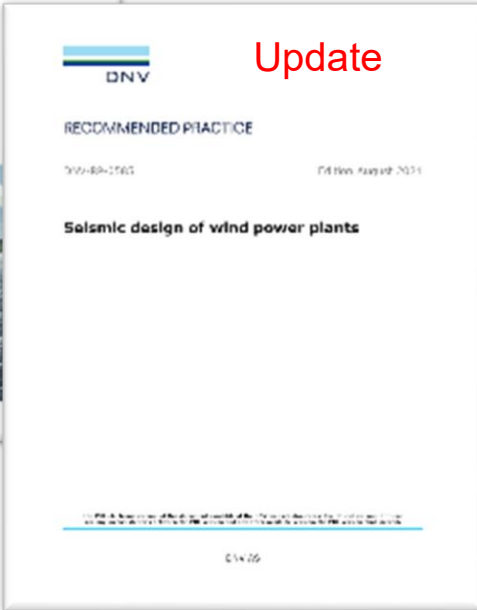
DNV

VALUATING COSTS AND RISK INQUIRY SCENARIOS FOR WIND POWER (ACE 2) – JOINT INDUSTRY PROJECT (JIP)

Final Report

All Associated JIP Partners

Report No. DNV-CE-23-001, Rev. 0
April 2023



DNV **Update**

RECOMMENDED PRACTICE

R-2160 Edition August 2021

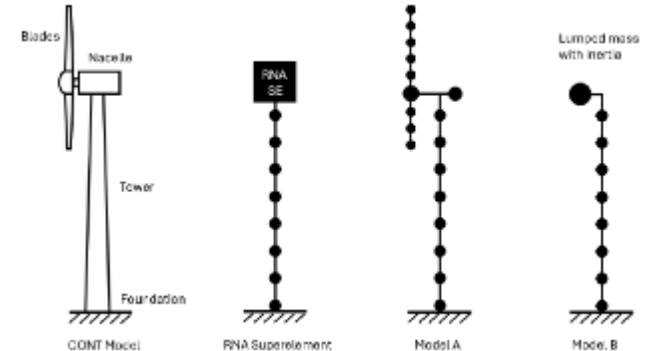
Seismic design of wind power plants

DNV & the Association of the Owners of the Offshore Wind Power Industry

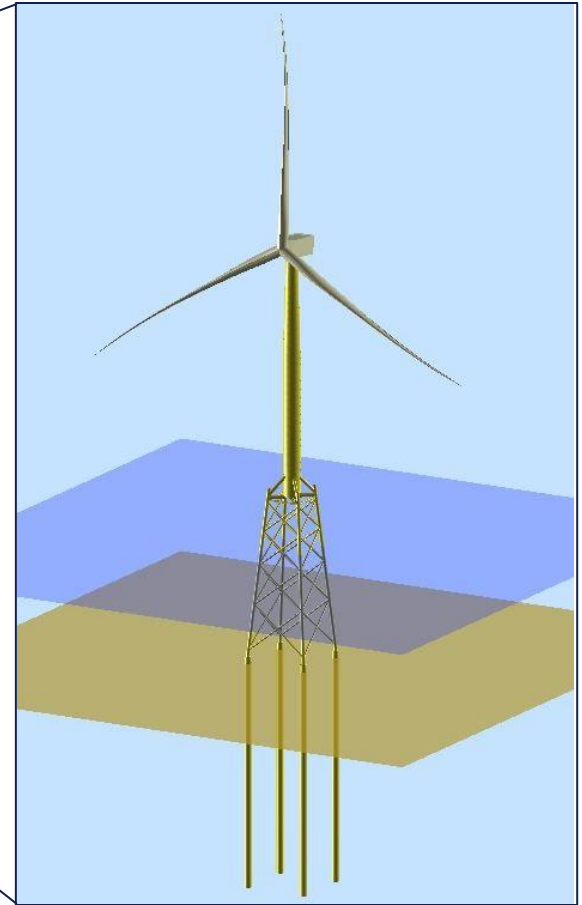
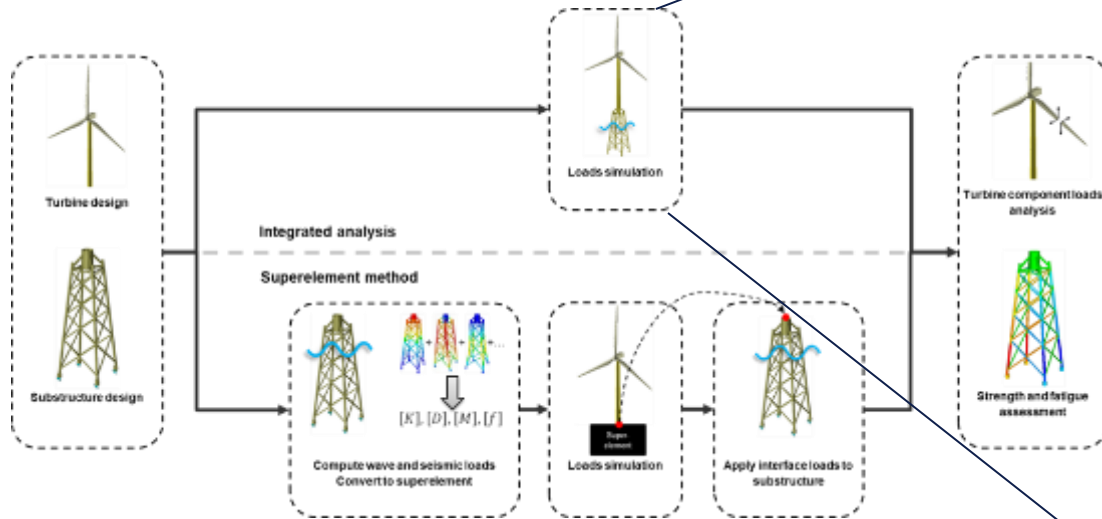
DNV

DNV-RP-0585 Update Japan related content

- No existing content specific for Japan
- Update 1: additional Annex for Japanese topics
- Update 2: Within the new Annex, permit simplified models for support structure design (incl. tower)
- Update 3: Within the new Annex, encourages CONT model (full aeroelastic) to be adopted wherever feasible
- Update 4: Within the new Annex, respect current Japanese local practice (code-based 1D horizontal seismic excitation)



What About Seismic Design?





BUREAU VERITAS RENEWABLES- WIND CERTIFICATION

JUNE
2026



**BUREAU
VERITAS**

BUREAU VERITAS: UNIQUE REACH, UNIQUE SCOPE

UNRIVALLED GLOBAL PRESENCE AND SERVICE PORTFOLIO



140+
Countries



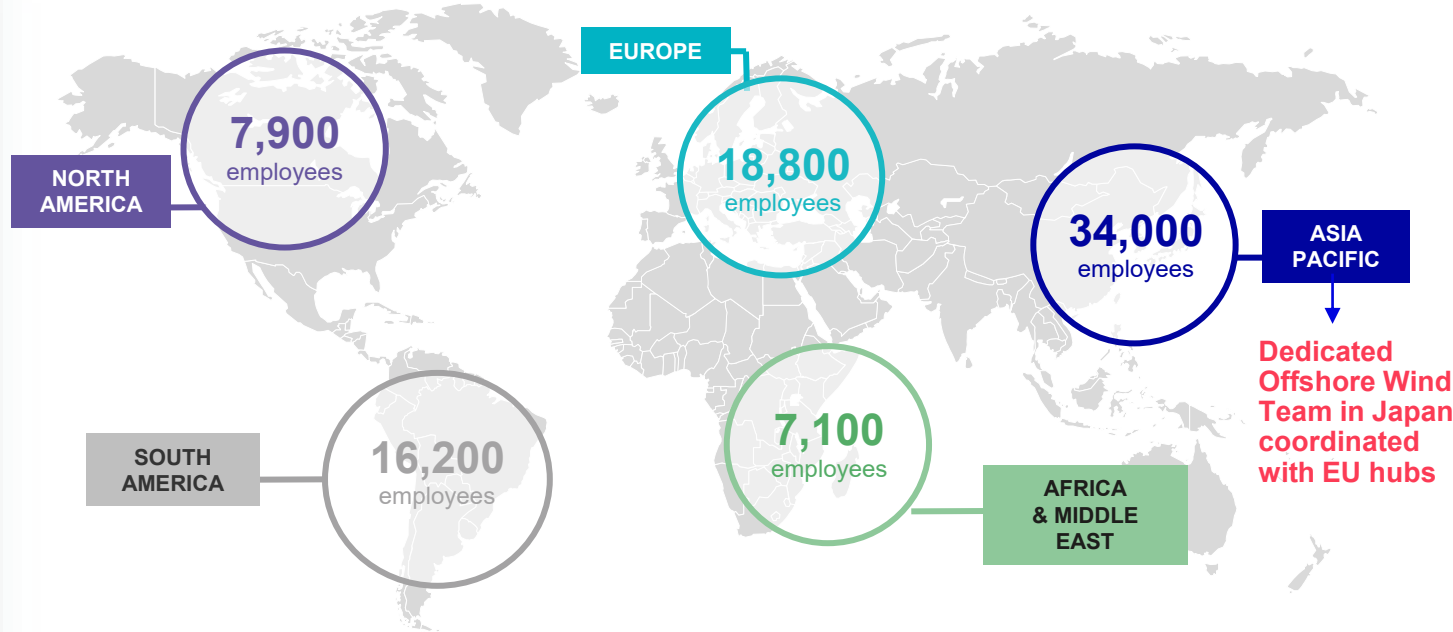
85,000+
Employees

› EXPERTISE

› INDEPENDENCE

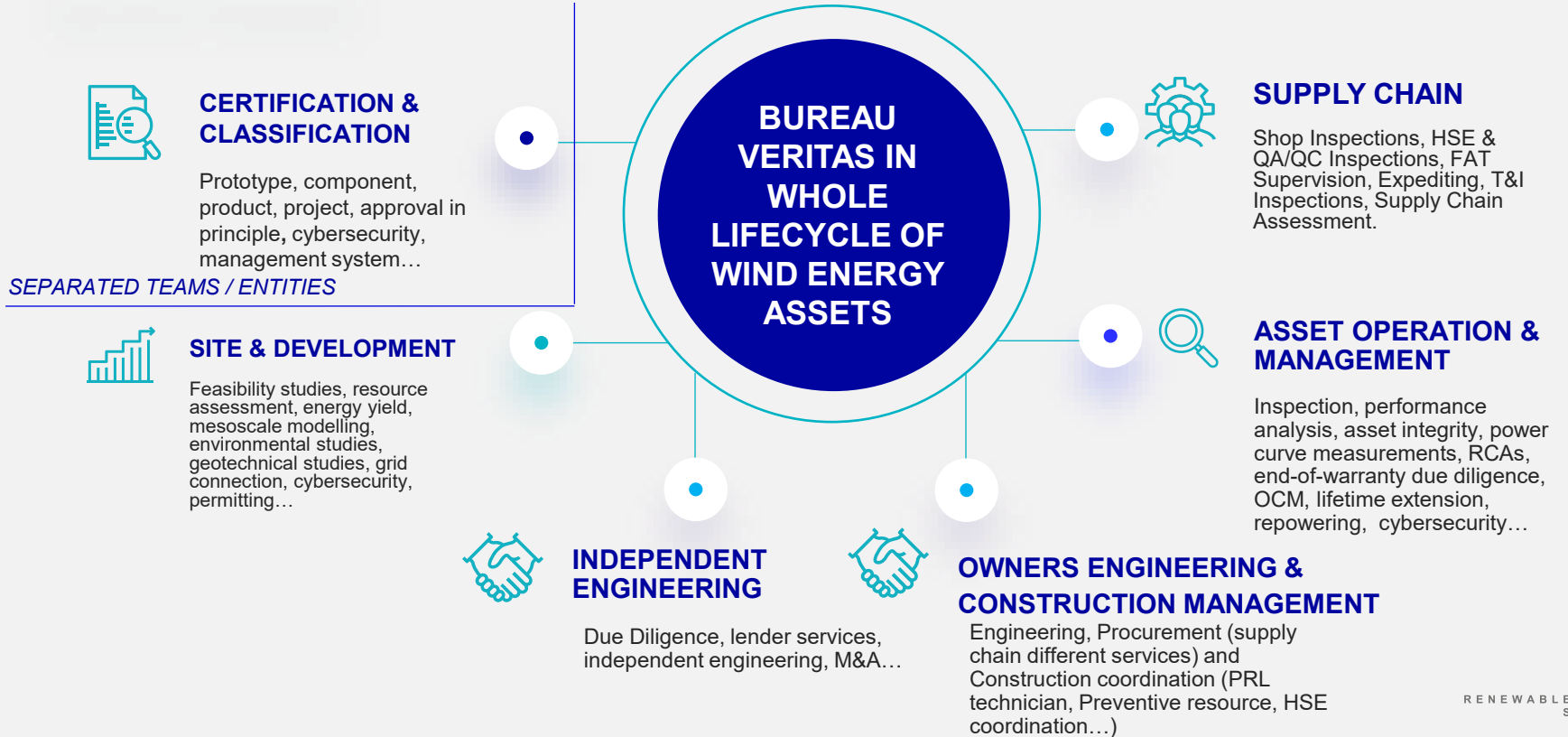
› IMPARTIALITY

› INTEGRITY



HOW CAN BUREAU VERITAS ASSIST?

Services Portfolio



WIND CERTIFICATION

BUREAU VERITAS LICENSES TO OPERATE

ACCREDITATIONS & APPROVALS

- ISO/IEC 17065 accreditation:
 - Component, Type & Project Certification (IEC/EN 61400-22)
- IECRE approved:
 - Component & Type Certification (OD-501)
 - Project Certification (OD-502)
- Approval from national regulatory entities, some examples:
 - Germany - Bundesamt für Seeschifffahrt und Hydrographie (BSH)
 - USA - BOEM: 30 CFR Part 585
 - Denmark - Danish Energy Agency, BEK nr 648 & 1047 af 2023
 - **Japan - Japan Accreditation Board, JIS Q 17065:2012 and METI approval**



30+ PROJECT CERTIFICATION

(WTG, FIXED / FLOATING FOU, SUBSTATION, CABLES, including Germany, UK, France, Belgium, Netherlands, Poland, USA, S. Korea, Japan...)

20+ FLOATING CONCEPTS CERTIFICATION

(Approval in Principle / Prototype Certification for Floaters and Moorings)

50+ COMPONENT & TYPE CERTIFICATION

(onshore / offshore)

WIND CERTIFICATION

BUREAU VERITAS

CHALLENGES/OPPORTUNITIES DURING OW CERTIFICATION UNDER SEISMIC

- | Seismic characterization as part of Site Conditions Assessment
- | Requirements about how seismic action is represented (e.g. site spectra inputs, directionality, damping assumptions) and how it couples to support structure
- | Combination rules of existing DLCs with seismic conditions
- | Soil-Structure Interaction



From High-Fidelity Modeling to Design Guidance: Installation and decommissioning of OWT foundations



Yu-Wei Hwang, Ph.D.
 Assistant Professor, NTU
 Email: yuweihwang@ntu.edu.tw

Academic Background:

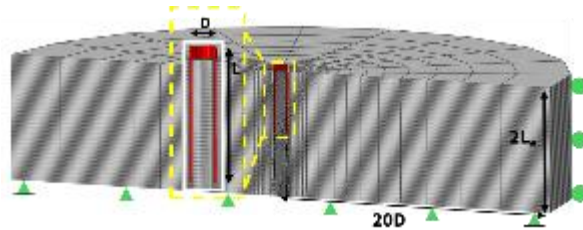
- Assistant Professor, NTU, 2024-present
- Assistant Professor, NYCU, 2022-2024
- *Ph. D.*, CU Boulder, 2018–2021

Specialties:

- Data-driven Engineering
- Geotechnical Engineering
- Performance design of geosystem
- Physical and numerical modelling
- Structure-Soil-Structure Interaction

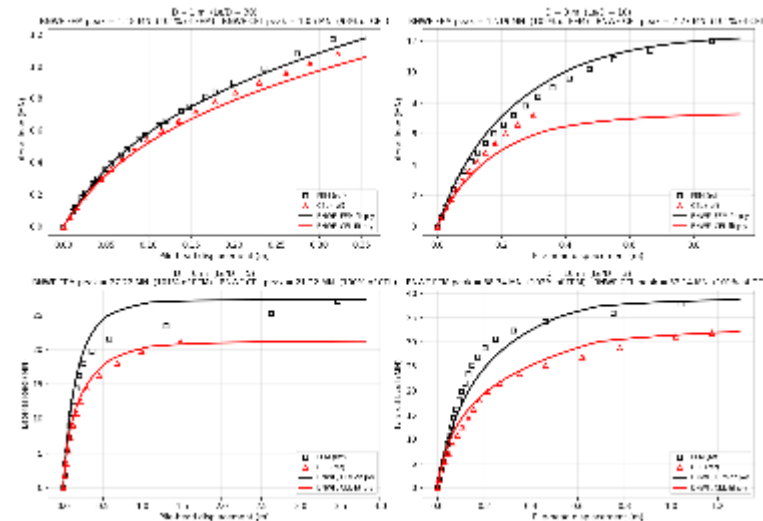
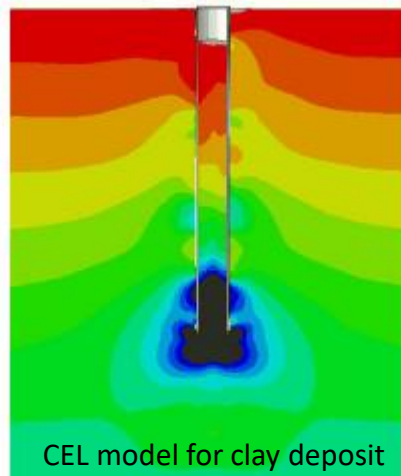
1. Large deformation simulation for offshore wind turbine foundation

- Simulate foundation installation and decommission.



$$\frac{p}{p_u} \left(\frac{y}{D} \right) = \begin{cases} \frac{y}{D} & \text{when } \frac{y}{D} < \frac{y_{cr}}{D} \\ \frac{1}{k_{ini}} + B^* \left(\frac{y}{D} \right)^n & \text{when } \frac{y}{D} \geq \frac{y_{cr}}{D} \end{cases}$$

$\frac{y_{cr}}{D}$: critical normalized displacement, solved by incrementally stepping $\frac{y}{D}$ until $\frac{p}{p_u}$ first = 1

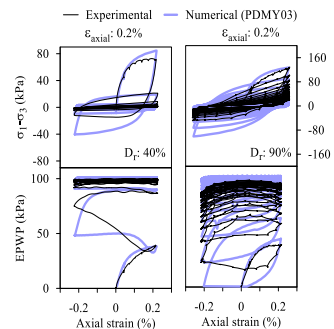


From High-Fidelity Modeling to Design Guidance: Seismic and Liquefaction Performance of Offshore Wind Foundations

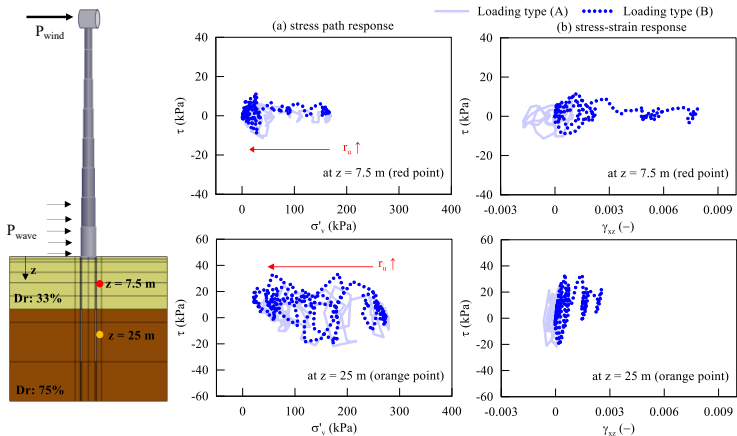
2. Evaluation of seismic performance of OWT monopile foundation on liquefiable soils

Type (A): EQ
Type (B): EQ+Env. Load

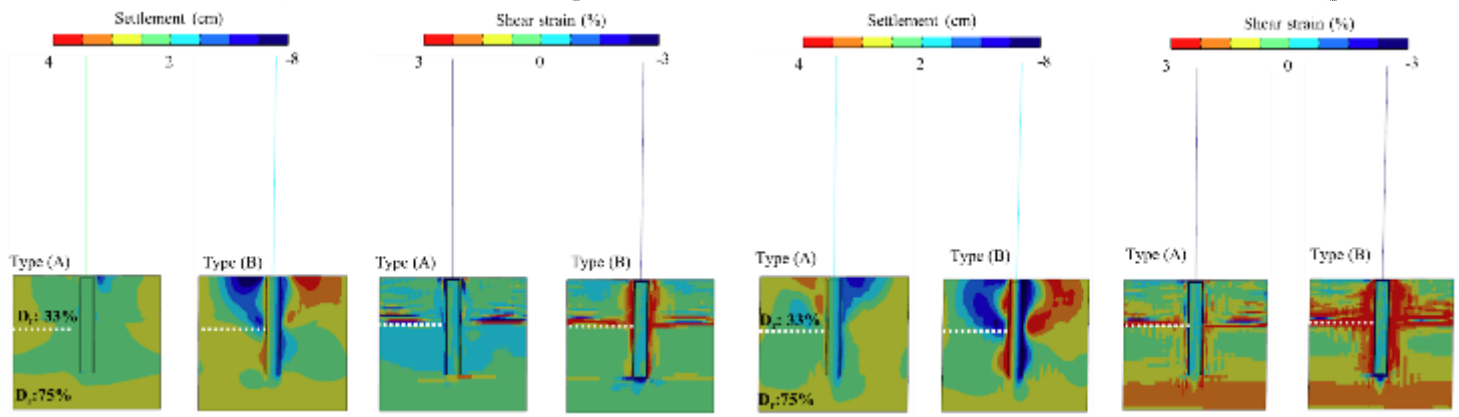
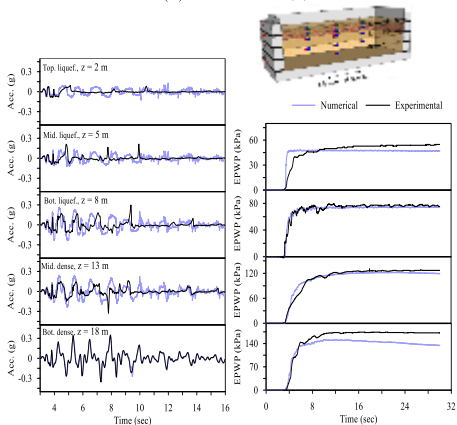
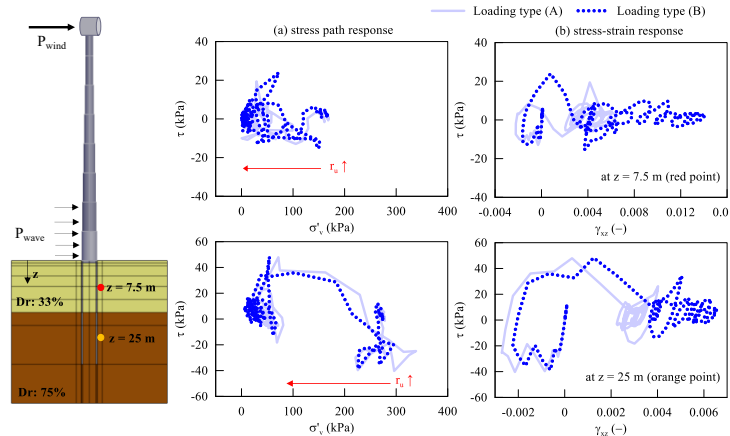
- OpenSeesMP
 - PDMY03 soil model
- Soil parameter calibration



System performance under NP motion



System performance under P motion



From High-Fidelity Modeling to Design Guidance: Seismic and Liquefaction Performance of Offshore Wind Foundations

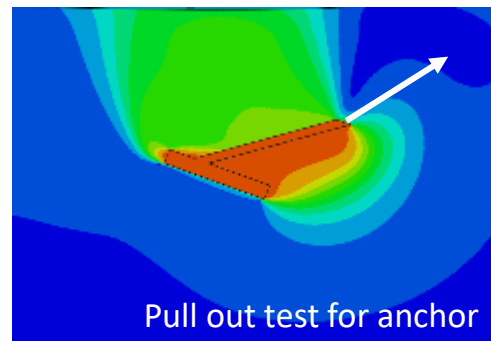
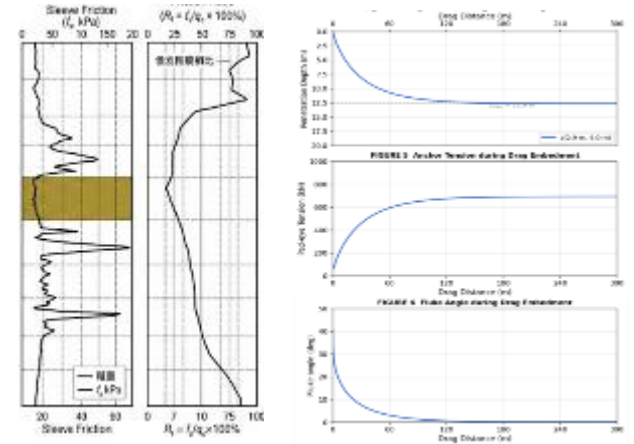
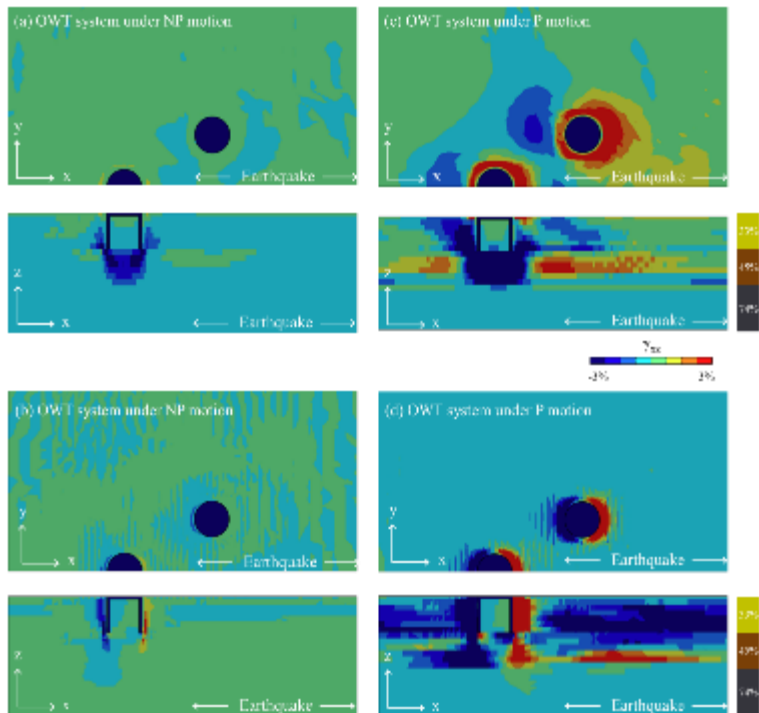
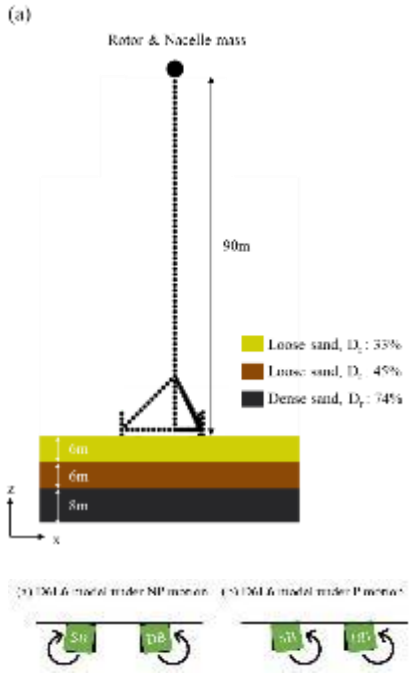
3. Evaluation of seismic performance of OWT tripod bucket foundations/anchor on liquefiable soils

- OpenSeesMP
- PDMY03 soil model

System performance under NP&P motion

Anchor foundation

Tripod bucket foundation





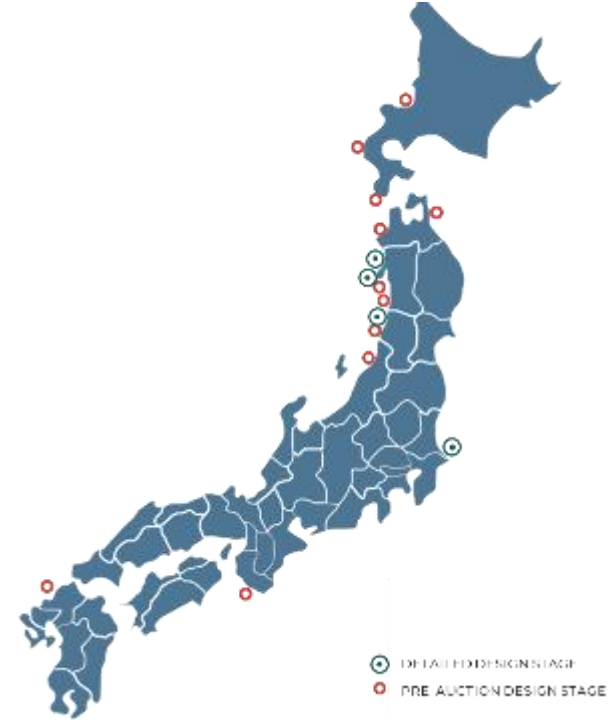
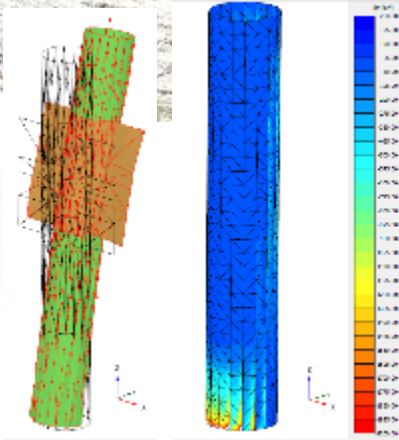
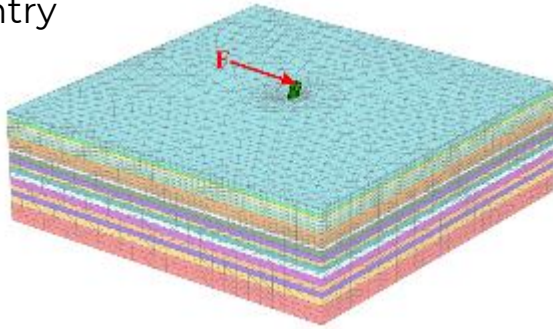
SEISMIC DESIGN IN JAPAN – CONSULTANTS PERSPECTIVE



INTRODUCTION



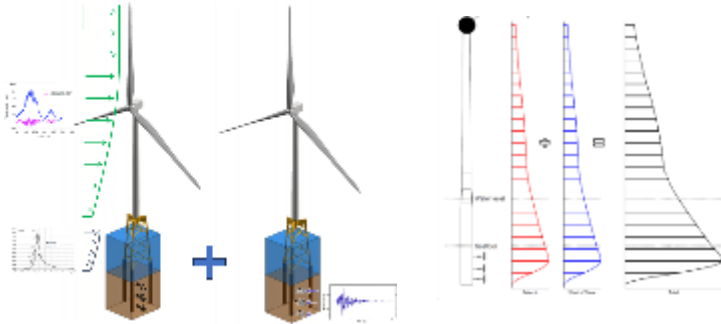
Gerry Murphy
Wood Thilsted
Japan Country
Manager



JAPANESE SEISMIC DESIGN: A DESIGN CONSULTANTS PERSPECTIVE

Loads Analysis Approach

- ▶ Seismic loads must be derived at every WTG position
- ▶ 1D, 2D & 3D approaches are accepted
 - ▶ 1D: JSCE F&G springs/dashpots – fast but generally very high loads
 - ▶ 2D/3D: Thin Layer methods is standard approach to derive non-linear springs for more challenging positions
 - ▶ 3D/FEA: Present in recent publications but no fully certified projects at this time
- ▶ De-coupled Loads Analysis approach:



Overall Approach & Requirements

- ▶ Industry practice is for local specialists to carry out the seismic load analysis and subcontract the wind/wave design to international consultants
- ▶ Overall approach
 - ▶ No single consistent approach outlined in guidance documents
 - ▶ Typically carried out using a combination of various software for SRA, derivation of soil springs and SSSI modelling
 - ▶ Several approaches often required for comparison
 - ▶ Local software and constitutive models recommended in guidance - but in practice are required – example: I-Y for non-linear spring
- ▶ Inputs
 - ▶ Inputs motions based on fixed motions with regional coefficient
 - ▶ Seismic motions based on regulations for tall buildings – very different behaviour than WTGs

LESSONS LEARNED FROM ADOPTION OF PISA IN JAPAN

Getting new or international approaches takes time in Japan – lessons from PISA

- ▶ Certification perceived as a key project delivery risk
 - ▶ Drives the post-auction to AfC schedule
 - ▶ Not a predictable or transparent process
 - ▶ What is certifiable > what is efficient
- ▶ PISA benefitted from across industry consensus & there was no established Japanese approaches
- ▶ Updates to design guidance
 - ▶ No update to the 2020 guidance documentation to clarify if PISA can be adopted or requirements around verification etc.
 - ▶ Limited industry input or clear mechanisms for innovation.
 - ▶ Numerical values or approaches stipulated in domestic standards must be adopted regardless of whether they are intended for offshore wind power generation facilities.
- ▶ Early adoption fear
- ▶ Recently PISA has been adopted in practice & several R2 projects very advanced in certification process



Consensus building

- Identify key local stakeholders
- Build relationships and trust

Localisation

- Demonstration that approach is appropriate for Japanese site conditions
- Examine impact of local constitutive models for 3DFEA?
- How can framework capture local requirements?

Precedence is key

- Need to benchmark against Japanese approaches (JSCE, TLM, SoilPlus etc.)
- Local publications to build awareness ahead of adoption on projects



Gerry Murphy

Japan Country Manager

gmu@woodthilsted.com



Ayumu NAITO

Foundation Design Manager, RWE

- Design and engineering of offshore wind foundation from early development to detailed design for various Japan and APAC projects.
- Lead foundation engineer for Murakami Tainai Offshore Wind project
- Managing overall design process of ILA and seismic analysis.
- Involved in DNV ACE 1&2 JIP
- Vast experience of Japanese seismic design practice and windfarm certification.

Career

2020-present RWE Renewables Japan

- Engineering of offshore wind turbine foundation and various activities of project development, bid, supply.

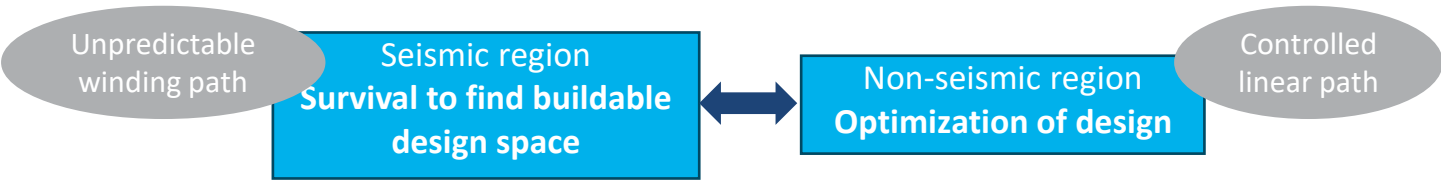
2013-2020 Kajima corporation

- Design and engineering of energy, coastal and various temporary structures
- Detailed design of the first commercial scale offshore wind project in Japan

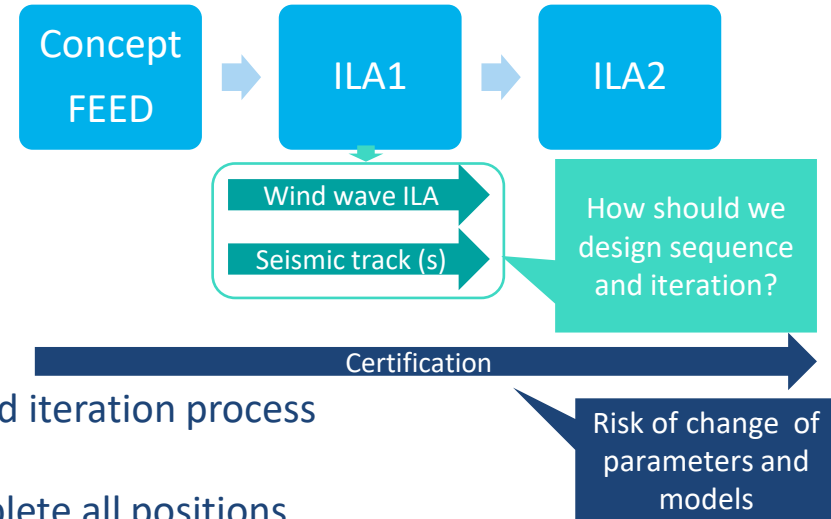
Academic and Qualification

- Professional Engineer Japan (Civil Engineering, Soil and Foundation)
- Concrete Engineer Japan
- MSc Civil Engineering, Univ. of Tokyo

Design



- Tower stiffness and geometry: Limited room for site specific geometry change, weight limit and bolt-flange size limitation due to Japanese building code
- Two tracks approach: Track 1 by WTG OEM tool and Track 2 by FOU designer
 - Either model has limitation of modelling.
 - Which load to take?
- Building code based regulation and practice:
 - Safety level of residential building
 - Limitation of bolt, flange and steel plate size
 - Maximum load, no averaging
 - Maximum load envelop of all WTG positions
- Difficult to predict and control load level through load iteration process
 - Small **damping** : Load is a kind of lottery
 - Maximum envelop : unable to confirm until complete all positions
 - This is nightmare for design management



Established soil spring and damping evaluation methodology (not too much computational effort)

Bridging The Gap Between Industry & Academia

Current Gaps, Industry Needs & Future Direction



Moderator: Prof Phil Watson

Professor, Director of ARC ITRH - TIDE
Research Hub

University of Western Australia



Prof Susumu Iai

Professor

Kyoto University/FLIP Consortium



Prof Jin-Hun Hwang

Professor

National Central University – Taiwan



Dr. Shambhu Sharma

Technical Expert & Site Characterisation
Lead, Perth

NGI



Hugo Portugal

Senior Engineer

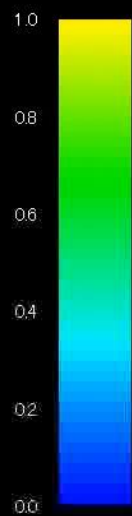
Ramboll



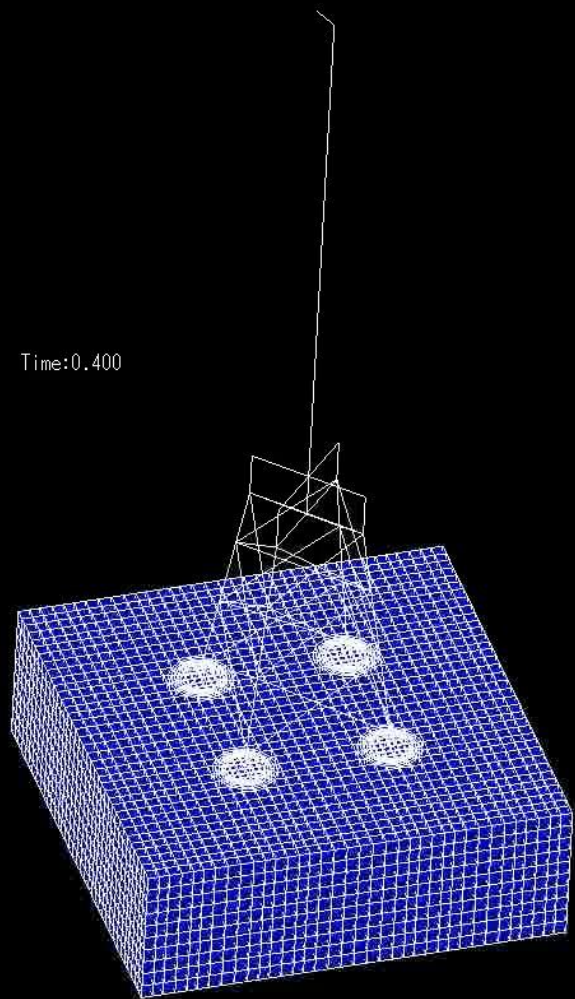
Dr. Martin Bjerre Nielsen

Technical Director

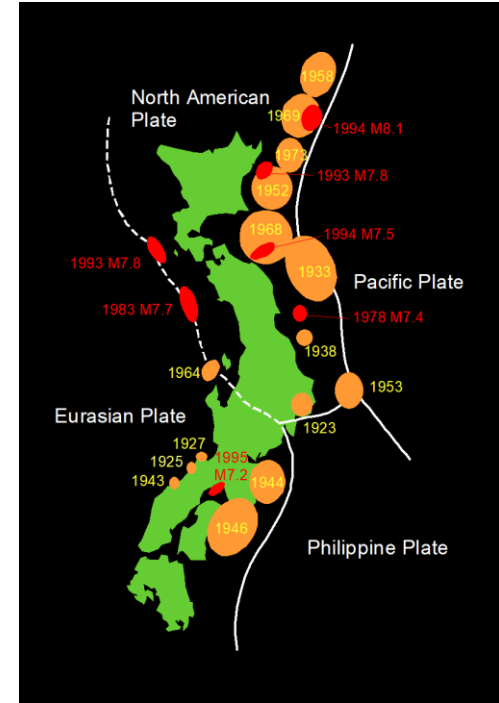
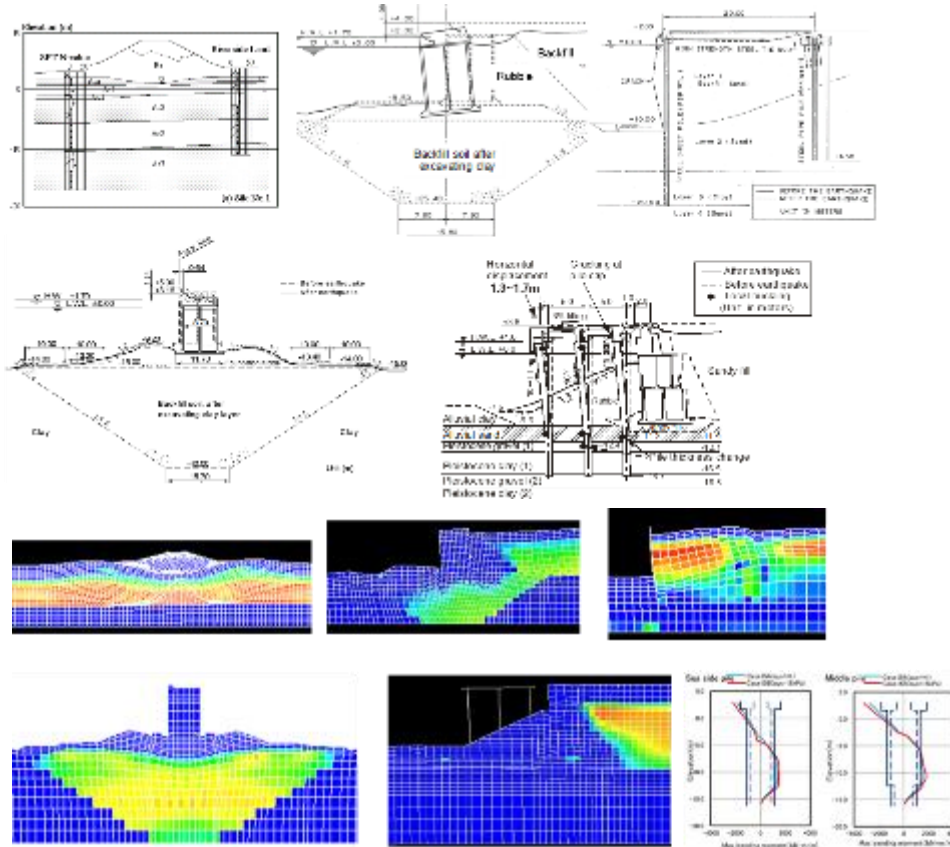
Wood Thilsted



Time:0.400



Case histories for validation



■ Prof., Civil Engineering Dept., National Central University (NCU), Taiwan. (2003~)

■ Chairperson, Earth Science and Geotechnical Engineering, National Center for research on Earthquake Engineering (NCREE). (2016~)

■ Expertise: Soil liquefaction, Piled foundation.

■ Relevant experiences on OWF

■ Member, Offshore Wind Farm Design & Construction Review Committee, Bureau of Energy, MOEA, Taiwan (2020~)

■ Technical Review Member, BSMI/MOEA OWF Design & Investigation Guideline in Taiwan. (2021~)

■ Plan and establish the new OWF geotechnical laboratory including large shaking table and laminar box in South NCREE. (2021~2024)

■ Researches on the following subjects:

- Centrifuge modelling and numerical analysis on the seismic behavior of OWT supported by mono-pile in liquefiable soil deposits.
- Model test and numerical simulation on the cyclic degradation behavior of pile.
- Size effect on the lateral bearing behavior of mono-pile.
- numerical simulation on the vertical bearing behavior of mono-pile due to soil plug.
- Soil liquefaction induced by sea wave.
- In-situ pile load test for the design of Taiwan's First Demonstration 5MW OWT.

JIN HUNG HWANG





Shambhu Sharma

Technical Expert &
Site characterisation Lead
NGI Perth, Australia



Academic Background

MEng: Asian Institute Technology, Thailand

PhD: Centre for Offshore Foundation Systems (COFS) UWA,
Australia



Geotechnical Research & Consulting Experience

25+ Years of Experience

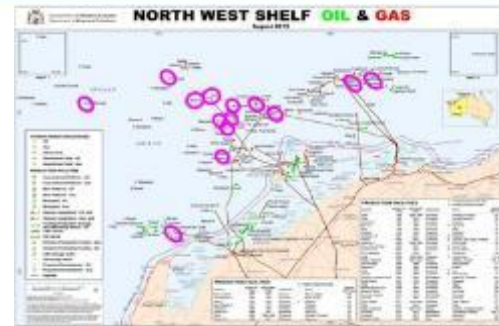
Global Offshore Project: Australia, Japan, Taiwan, and across Europe, SE
Asia, US, Middle East

Core expertise

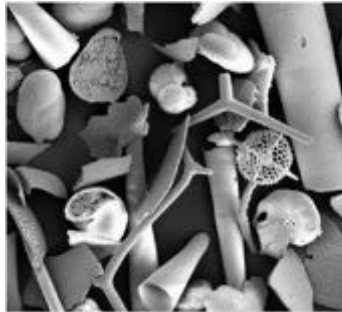
Site investigation & geotechnical characterisation
Advanced in situ & laboratory testing
Soil interpretation & parameterisation for design
Offshore foundations: piles, anchors, pipelines

Specialist Areas of expertise

Carbonate sediments
Problematic materials and ground conditions
Cyclic loading & soil degradation



Major Projects in Australia's North West Shelf



Micrograph of Carbonate sediments



Laboratory testing at NGIP



Relevance to DONISIS Workshop

Key Perspective: Site Characterisation → Reliable Foundation Design

Key Challenges

- Ground variability and data gap
- Sample/data quality and their representativeness
- Risk of data misinterpretation or over-simplification
- Limits in transferring knowledge across soils and regions

Reducing uncertainty

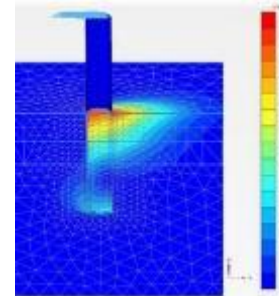
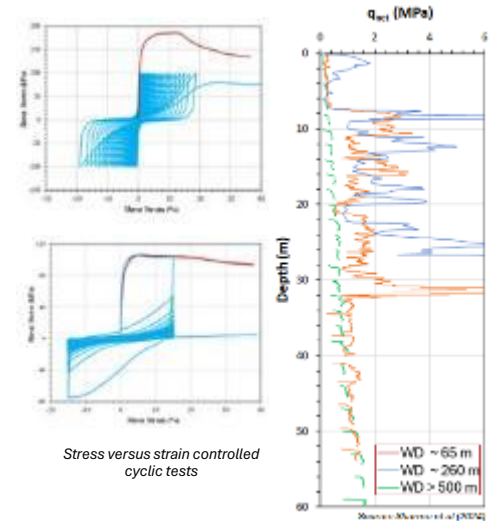
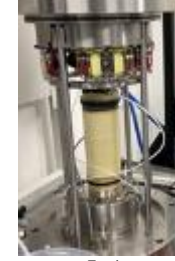
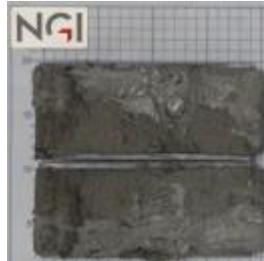
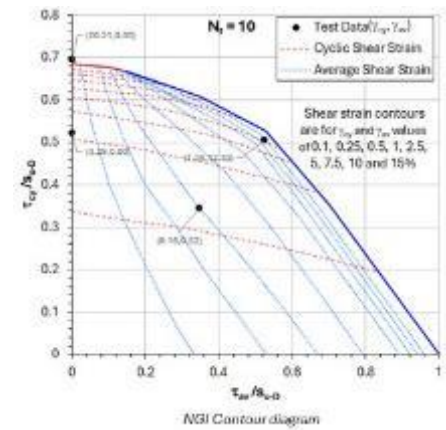
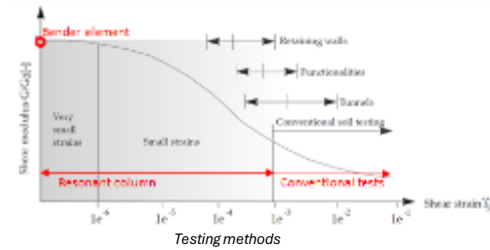
- Better interpretation (not just more data)
- Understanding soil behavior
- Holistic data interpretation while preserving local features
- Develop site-specific, soil behavior-based parameters
- Consistent testing and calibration with field (model) observations
- Data Integration (geotechnical, geophysical and geology)

Cyclic & seismic loading effects

- Strength & stiffness degradation
- Accumulated deformation
- Methods:
 - Advanced Testing (DSS, Triaxial, Resonant column)
 - Empirical Methods (S-N curves, NGI contour diagrams)
 - Constitutive modelling

Design Integration

- Translate data → reliable design parameters
- Bridge gap between soil behavior & design assumptions



Reliable foundation design starts with high-quality site characterisation and modelling realistic soil behavior

DONISIS workshop

04/06/2026

Yokohama, Japan

Slides from Ramboll

Panel participant: Hugo Portugal

Hugo Portugal

Senior geotechnical engineer

Key responsibilities in Ramboll

- ✓ Offshore wind monopile and jacket pile foundation design
- ✓ Development of geotechnical earthquake engineering design methodologies.
- ✓ Representative of the seismic workgroup

Educational background

- Civil engineer
- Peru, Netherlands, United Kingdom

About myself

- Peruvian
- Based in Hamburg, Germany
- With Ramboll since 2020



Ramboll's experience

Over the past 8+ years

- ❖ Dedicated Seismic Expert Workgroup
- ❖ Participation in the ACE-JIP 1
- ❖ 10+ projects executed in Asia
 - Seismic hazard (in-house)
 - Geotechnical design (in-house)
 - Structural design (in-house)
- ❖ International and local experience with certification processes - Relationships established.
 - Japan
 - Taiwan
 - South Korea



Ramboll's experience

What we want to share

- ❖ Key performance findings in our designs
- ❖ Limitations in state-of-the-art modelling in practice
- ❖ The risk and consequences of conservatism stacking
- ❖ Certification considerations



Martin Bjerre Nielsen

Technical Director, Wood Thilsted



18+ years bridging academia and industrial offshore wind foundation design — with a focus on integrated loads analysis for monopiles and jackets incl. seismic.

23+

Certified detailed designs

PhD

Structural Eng.
DTU, 2012

+35

Publications in scientific journals or conferences

Background

- **Academic:** PhD, Ass. Professor in Structural Engineering at DTU (2010–2015) — structural mechanics & dynamics, multibody dynamics, numerical methods and wind turbine modeling.
- **Industrial Experience:** Working with offshore wind since 2007 at ISC, Ramboll and Wood Thilsted.
- **Research projects and JIPs:** Industrial PhD supervisor (ICEWIND, TU Delft collaboration); Supervisor for numerous PhD, MSc or BSc projects; Close link with universities external examiner for 20+ theses.

Seismic Analysis — Methods, Tools and Projects

- **Integrated loads analysis:** Industry expert on ILA for bottom-fixed structures using both fully integrated and sequential approaches (superelements)
- **Seismic modeling:** Seismic superelements (COMPDYN2019) for monopiles and jackets, depth-varying seismic loads (SRA-coupled), and generation of artificial accelerograms.
- **Software development:** MORPHEUS (WT), ROSA (Ramboll), Interface automation and various stand-alone tools for frequency/time domain analysis of earthquakes

Industrial Experience — Detailed Designs

16 Monopile detailed designs

Dogger Bank A/B/C · Vineyard Wind 1 · East Anglia 1N/2/3 · Thor · BC Wind · Mermaid & Sea star · SPIC · Binhai South H3 · Hebei Laoting · Deutche Bucht · Horns Rev 3

Early phase in Japan: Ishikari, Yamagata Yuza + more.

Roles range from key seismic specialist and ILA lead to technical discipline lead

7 Jacket detailed designs

Changfang & Xidao, FM1-2 (seismic, TW) · Moray East · East Anglia 1 · Seagreen · Nissum Bredning Vind · Aberdeen Bay · Borkum Riffgrund 2

UPCOMING EVENTS

- **2nd JAPAN Workshop on Geotechnics for Offshore Wind**
5 June 2026
Yokohama, Japan
- **Offshore Wind Forum APAC Summit**
Key Challenges in the Japanese Market: Structural Design and Insurance Considerations
1- 2 July 2026
Tokyo Midtown Yaesu Conference

Registration open for Inter-Farm Wake Webinar in Japan held jointly by CT / WINC

Date / time	19 th June, 2026 15:00-17:30 (JST)	
Place	Online Zoom	
Registration fee	No fee	
Language	Japanese sessions, English sessions (w. Japanese subtitles)	
Organizers	Carbon Trust, WINC	
Programme	Session 1	Fundamental Understanding of Inter-Farm Wakes
	Session 2	Technical and Modelling Approaches
	Session 3	Financial Risk, Commercial and Legal Impact and Policy Implications
	Session 4	Panel Session: Next Steps and Priorities for Japan
How to attend	Registration required. Register from link below: 洋上風力発電におけるインターファームウェイクの影響 Eventbrite	