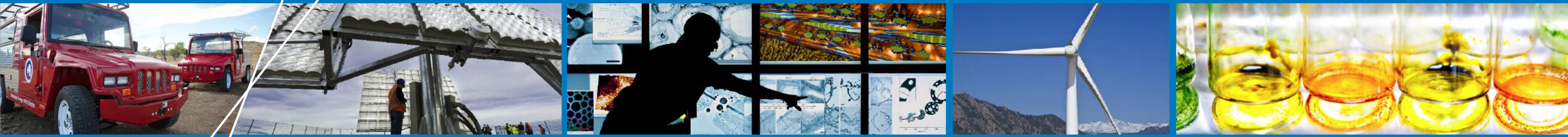
Introduction to the OC5 Project,

an IEA Task Focused on Validating Offshore Wind Modeling Tools



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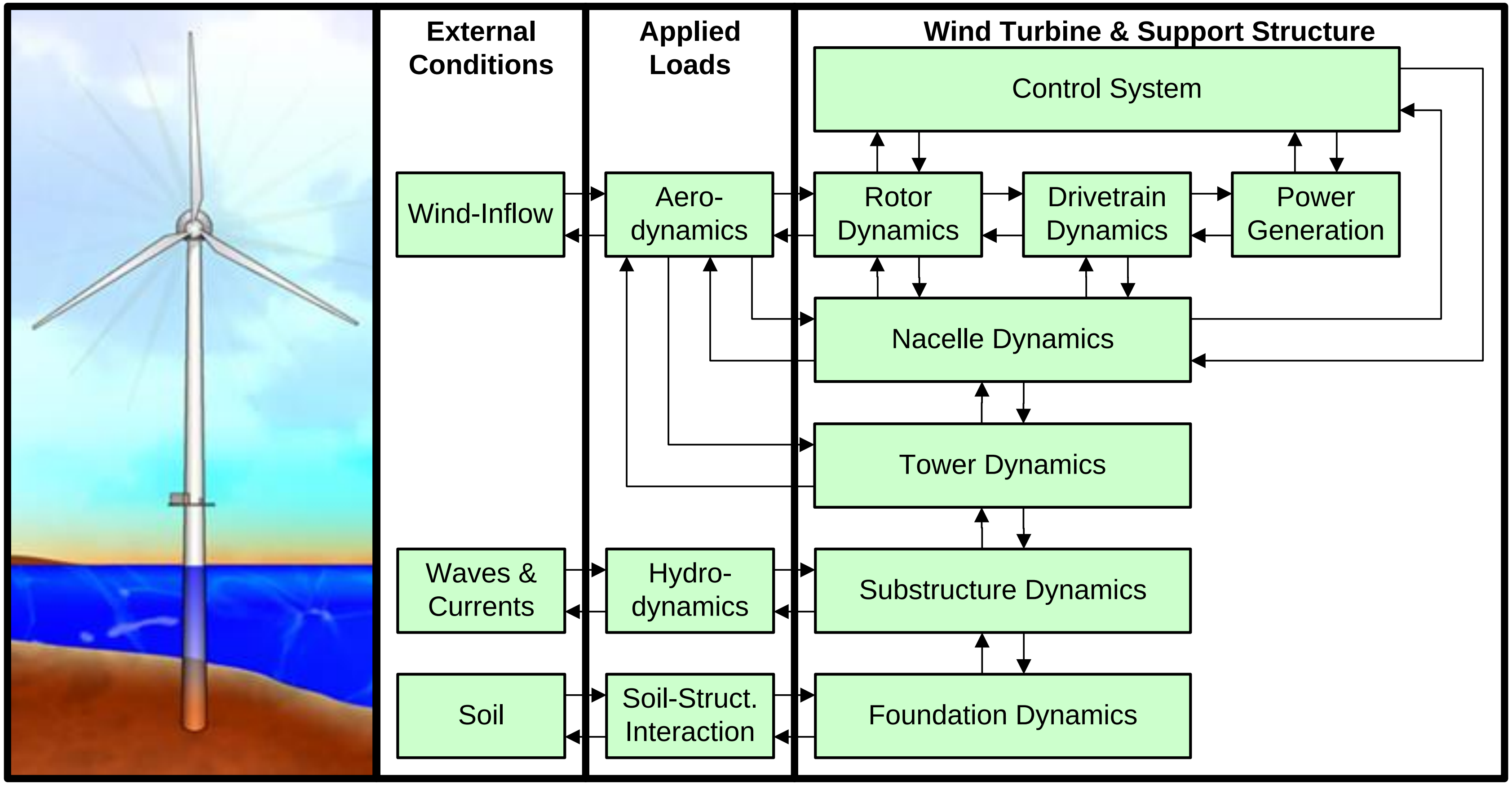
Trondheim, Norway

February 5, 2015

Offshore Wind Modeling Tools

- **OWTs are designed using aero-hydro-servo-elastic tools**
- **The tools must be verified and validated to assess their accuracy**



The OC3 & OC4 Projects

- **Two research tasks were initiated under IEA Wind to address this issue:**
  - OC3 (IEA Task 23, Subtask 3): 2005 - 2009
  - OC4 (IEA Task 30): 2010 - 2013
- **Focus was on OWT tool verification & benchmarking, with emphasis on the support structure**

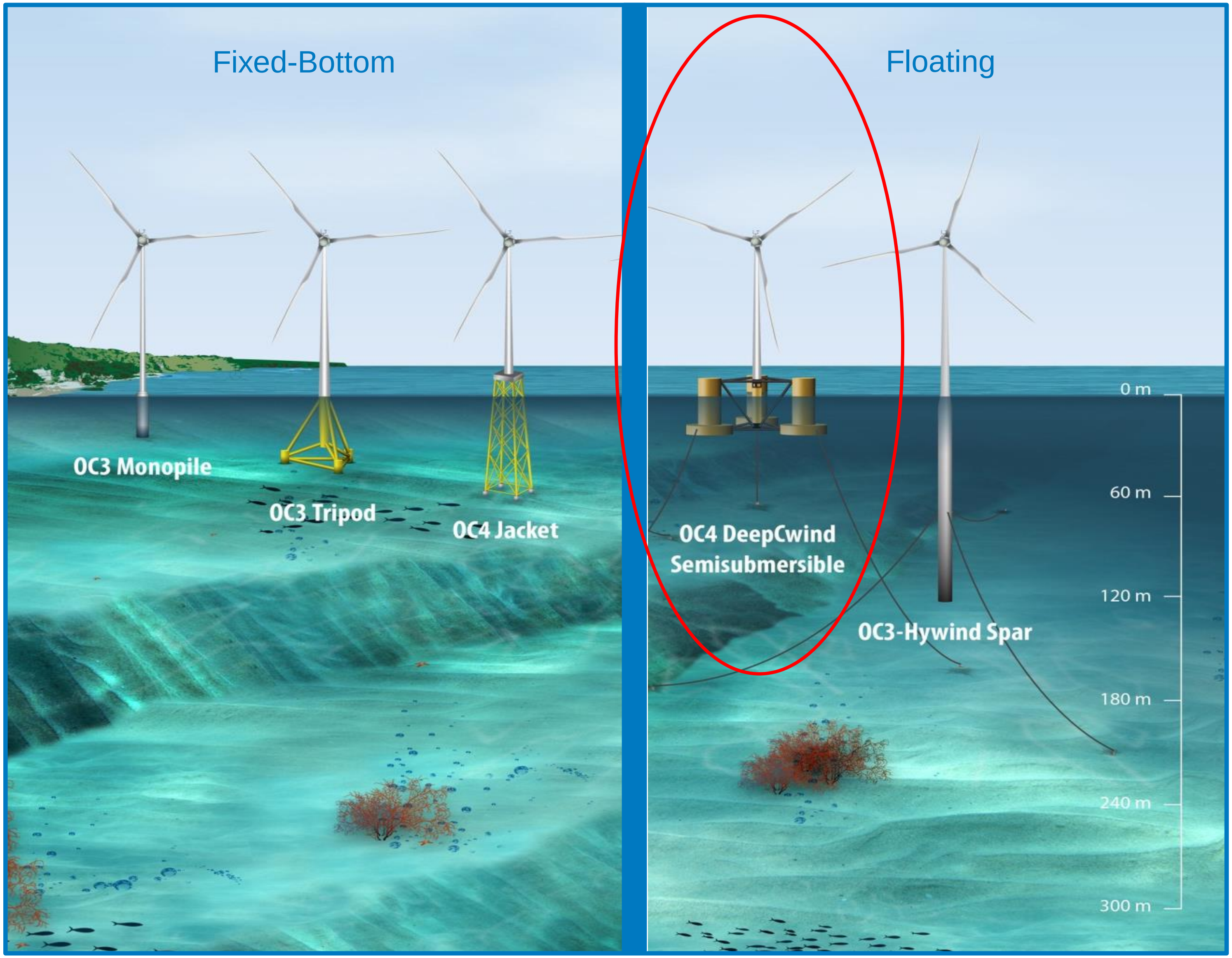
OC3 = Offshore Code Comparison Collaboration

OC4 = Offshore Code Comparison Collaboration, Continued

OC3/OC4 Verification Process

STEP 1: Create a model of the system	○ Obtain system design information ○ Develop a specification document of the design for participants (participants will help modify/improve this document) ○ Participants will then develop a model of the structure based on the specification document within their modeling tool of choice
STEP 2: Choose load cases	○ Develop a list of load cases to be run to examine model accuracy ○ Cases are developed to first examine components of model, then full system response ○ Select measurement channels to be used for comparisons
STEP 3: Simulate model	○ Simulate model for a variety of cases with increasing complexity (if available): wind-only, wave-only, and then wind/wave
STEP 4: Verify tools through code-to-code comparisons	○ Process results ○ Compare simulated response between tools ○ Repeat simulations until general agreement found ○ Discuss reasons for differences between participant results – modeling approach, user error, different approach
STEP 5: Publicize Work	○ After project is complete, make results available to public ○ Publish papers summarizing the findings from the work

The OC3/OC4 Systems Examined



OC4 Phase II Participants & Tools

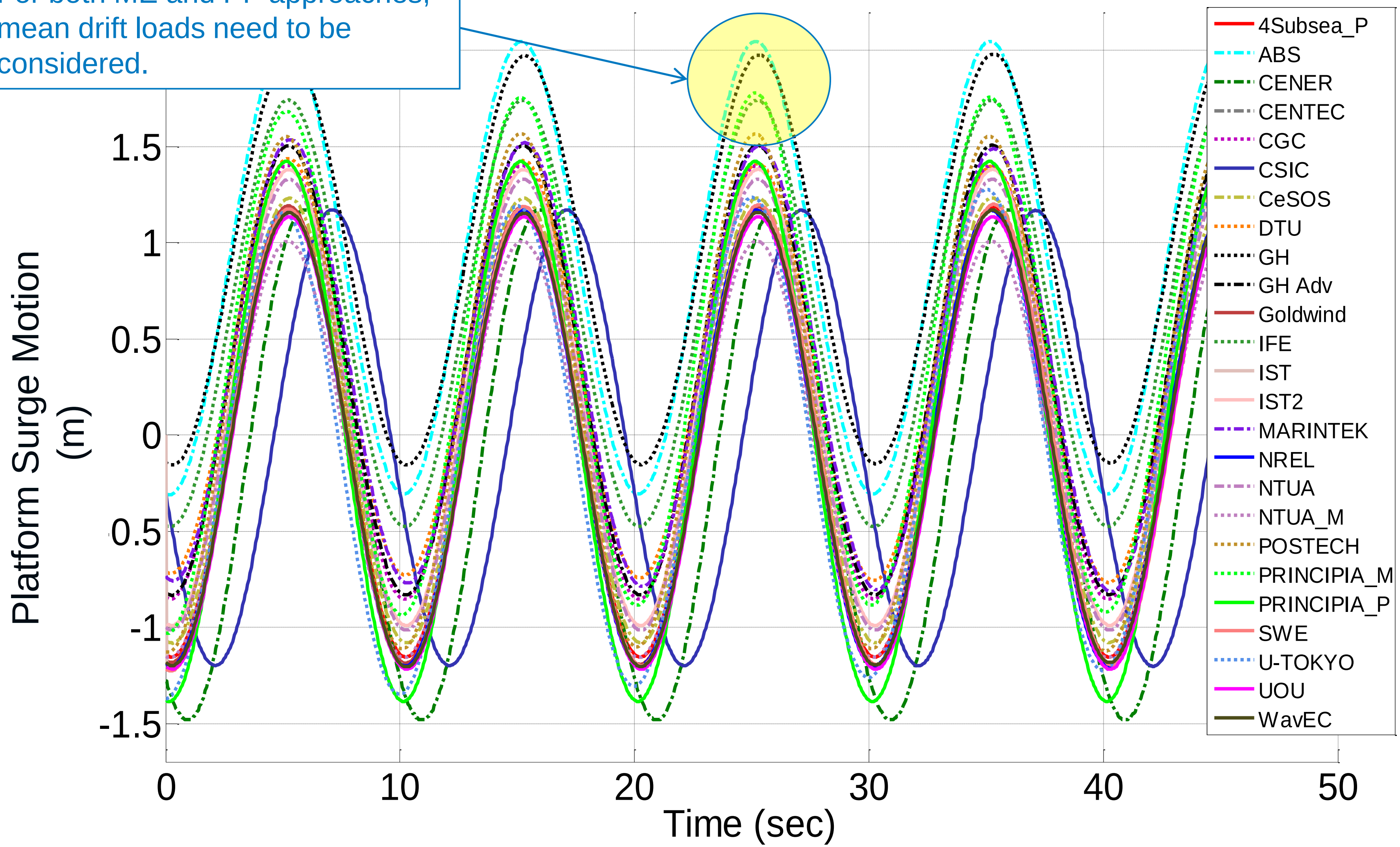
Company	Simulation Tool
4Subsea	OrcaFlex
ABS	CHARM3D + FAST
CENER	OPASS + FAST
CENTEC	FAST
CeSOS (NTNU)	Simo+Riflex+Aerodyn
CGC	Bladed 4.3
DHI	WAMSIM
DTU	HAWC2
GH	Bladed 4.4 /Bladed Advanced Hydro Beta
Goldwind	FAST
IFE	3DFLOAT
IST	FAST
LMS-IREC	SWT
MARINTEK	RIFLEX-Coupled
NTUA	hydro-GAST
NREL	FAST
POSTECH	GH Bladed
PRINCIPIA	DeepLinesWT
SWE	SIMPACK +HydroDyn
Univ. of Tokyo	CAST
Univ. of Ulsan	UOU + FAST
WaveEC	Wavec2Wire

OC3/OC4 Summary

- **Verification:**
  - Code-to-code comparisons have agreed well
  - Differences caused by variations in:
    - Model fidelity
    - Aero-, hydro-, & structural-dynamic theories
    - Model discretization
    - Numerical problems
    - User error
- **Modeling tool improvements:**
  - Many errors have been identified and resolved
  - Analysis methods have been refined
  - Future R&D needs identified
- **Benchmark development:**
  - Benchmark model/data available to public
  - Provided useful modeling experience to many engineers
- **Expert Meeting on Code-to-Data Validation showed interest for the group to work on this topic**

Results – LC 2.1 – Regular Waves

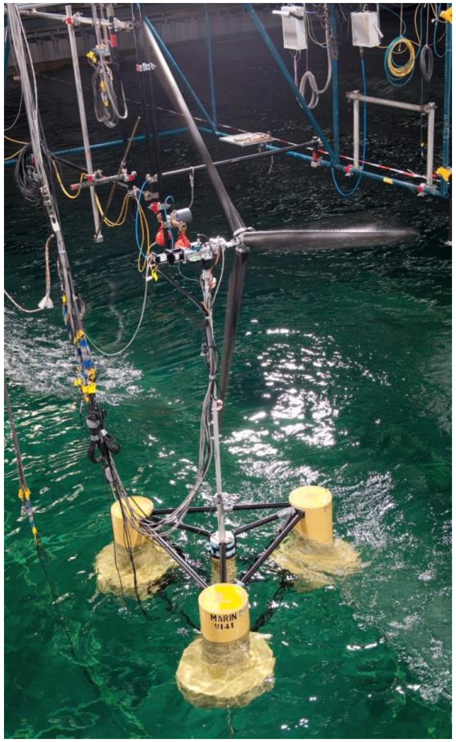
For both ME and PF approaches, mean drift loads need to be considered.



OC5 – Simulation Tool *Validation*

- **OC5 = Offshore Code Comparison Collaboration, Continued, with Correlation**
  - Code-to-data validation of offshore wind modeling tools
  - Extension of IEA Wind Task 30: 2014-2018
  - Three phases – examining three different systems

Monopile - Tank Testing



Semi - Tank Testing

Jacket/Tripod – Open Ocean

Timeline

Phase	Description	Timeline
Phase Ia	MARINTEK Cylinder	June 2014 – Feb. 2015
Phase 1b	DTU/DHI Cylinder	Feb. 2015 – June 2015
Phase II	DeepCwind Semisubmersible	June 2015 – June 2016
Phase III	Open Ocean System	June 2016 – June 2017

Participating Countries

Country	Status
China	Active
Denmark	Active
France	Considering
Germany	Active
Italy	Active
Japan	Active
Korea	Active
Netherlands	Active
Norway	Active
Portugal	Active
Spain	Active
United Kingdom	Considering
United States	Active

OC5 Validation Project Process

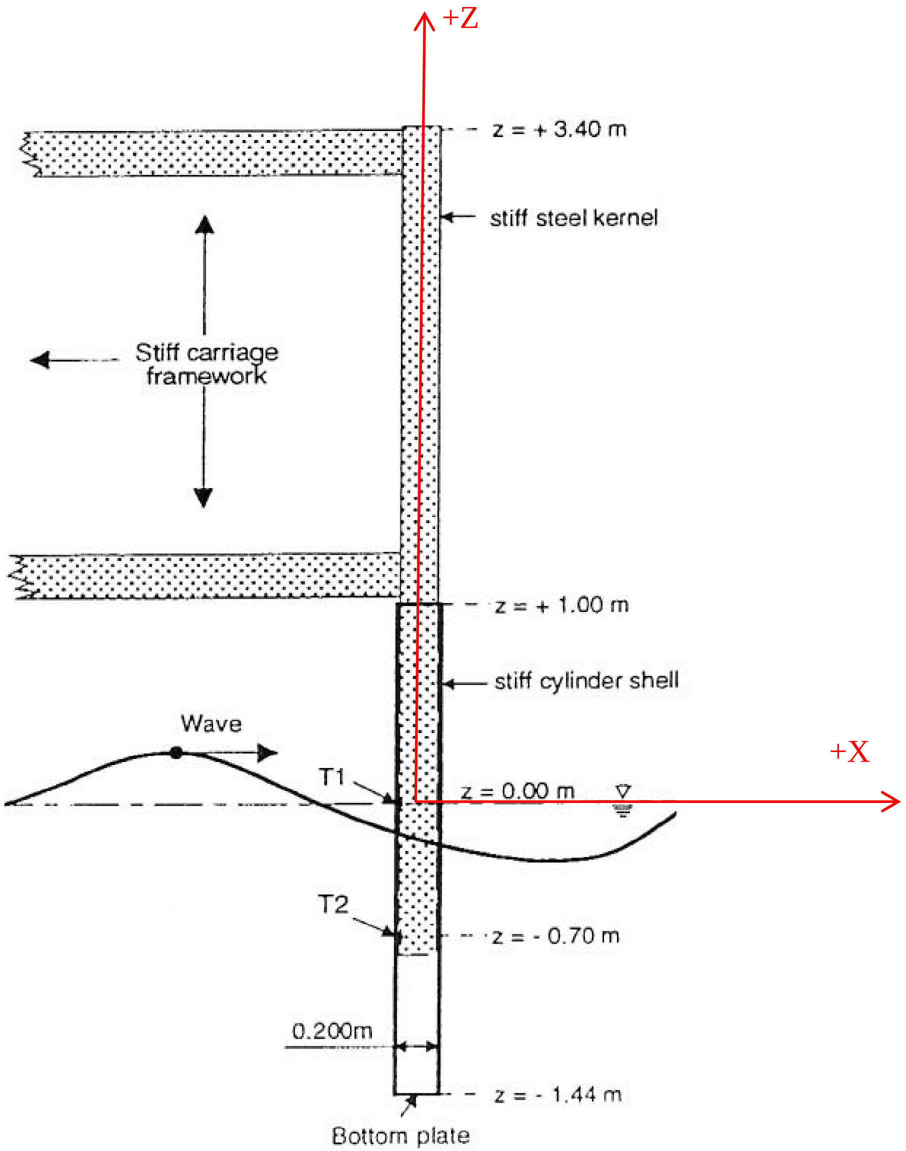
STEP 1: Create a model of the system	○ Obtain system design information ○ Develop a specification document of the design for participants (participants will help modify/improve this document) ○ Participants will then develop a model of the structure based on the specification document within their modeling tool of choice
STEP 2: Choose data sets for comparison	○ Create a list of available datasets, including specifics on wind/waves ○ Group will down-select data sets to be used for calibration and validation ○ Select measurement channels to be used for comparisons
STEP 3: Calibrate the model	○ Calibration will be done as a group. ○ Run structural-only cases, and calibrate model properties (mass/stiffness) using natural frequencies, structural damping rations, mooring force-disp. ○ Run steady wind-only cases, and calibrate airfoil coefficients using rotor performance (power, torque, thrust) ○ Run wave-only cases, and calibrate hydrodynamic coefficients using free-decay tests, current-only tests, and wave-only tests
STEP 4: Validate the model	○ Simulate model for a variety of cases with increasing complexity (if available): wind-only, wave-only, and then wind/wave ○ Do not use datasets used for calibration ○ Compare simulated response to that of the measurements ○ Discuss differences between participant results and tests

Phase I - Monopile

- **Phase I examines monopile**
  - No wind turbine
  - Fixed structure
  - Tank tests
- **Two data sources:**
  - MARINTEK testing
  - DTU/DHI testing

MARINTEK Tests

- Single steel cylinders with varying diameter
  - Draft = 1.44 m
  - Water depth = 10 m
- Cylinders attached to a steel framework
  - Attachment through two force transducers (T1 and T2)
  - Vertical and transverse motion restricted by stiffener rods
  - Eigenfrequencies > 10 Hz
  - Consider framework as rigid
  - Free surface on bottom, pierces water line



Datasets simulated in OC5 project

OC5 Test No.	Original Test No.	Condition	Diameter (m)	H/Hs (m)	T/Tp (s)	Gamma*
1	441	Regular	0.2	0.15	1.533	
2	444	Regular	0.2	0.23	1.533	
3	442	Regular	0.2	0.28	1.533	
4	445	Regular	0.2	0.37	1.533	
5	341	Regular	0.327	0.15	1.533	
6	344	Regular	0.327	0.23	1.533	
7	342	Regular	0.327	0.28	1.533	
8	345	Regular	0.327	0.37	1.533	
9	431	Regular	0.2	0.282	2.114	
10	433	Regular	0.2	0.45	2.114	
11	432	Regular	0.2	0.522	2.114	
12	434	Regular	0.2	0.6	2.114	
13	1331	Regular	0.327	0.282	2.114	
14	333	Regular	0.327	0.450	2.114	
15	332	Regular	0.327	0.522	2.114	
16	334	Regular	0.327	0.6	2.114	
17	401	Irregular	0.2	0.279	2.4	1.7
18	4301	Irregular	0.327	0.279	2.4	1.7
19	402	Irregular	0.2	0.357	2.76	1.7
20	4302	Irregular	0.327	0.357	2.76	1.7

*Gamma = peak enhancement factor for a JONSWAP spectrum

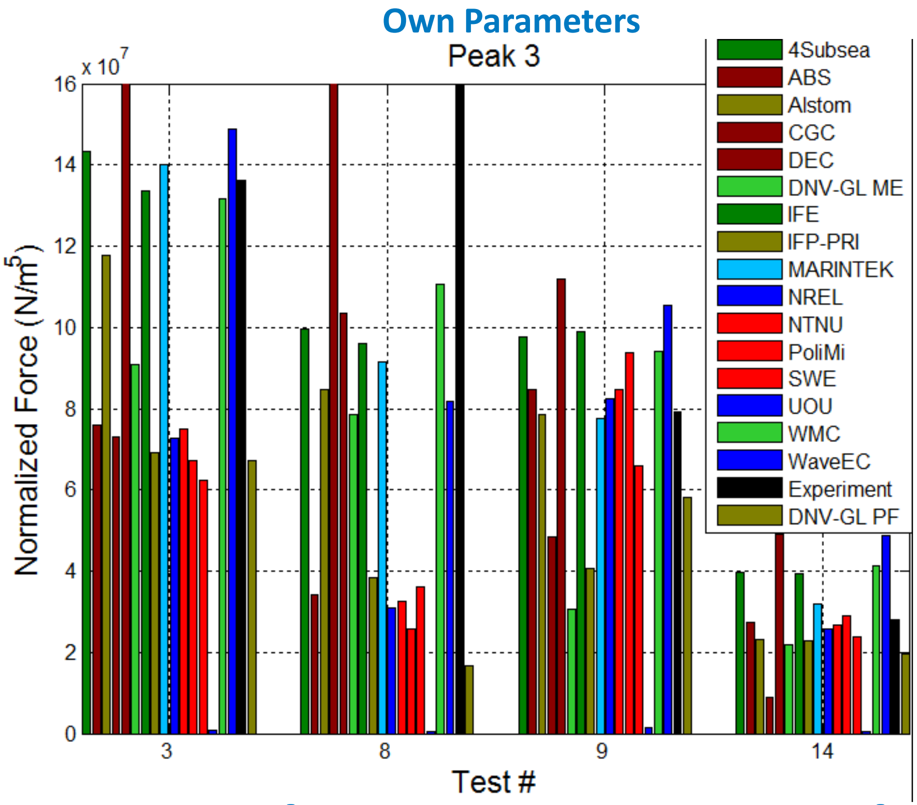
Modeling Participants/Tools/Approach

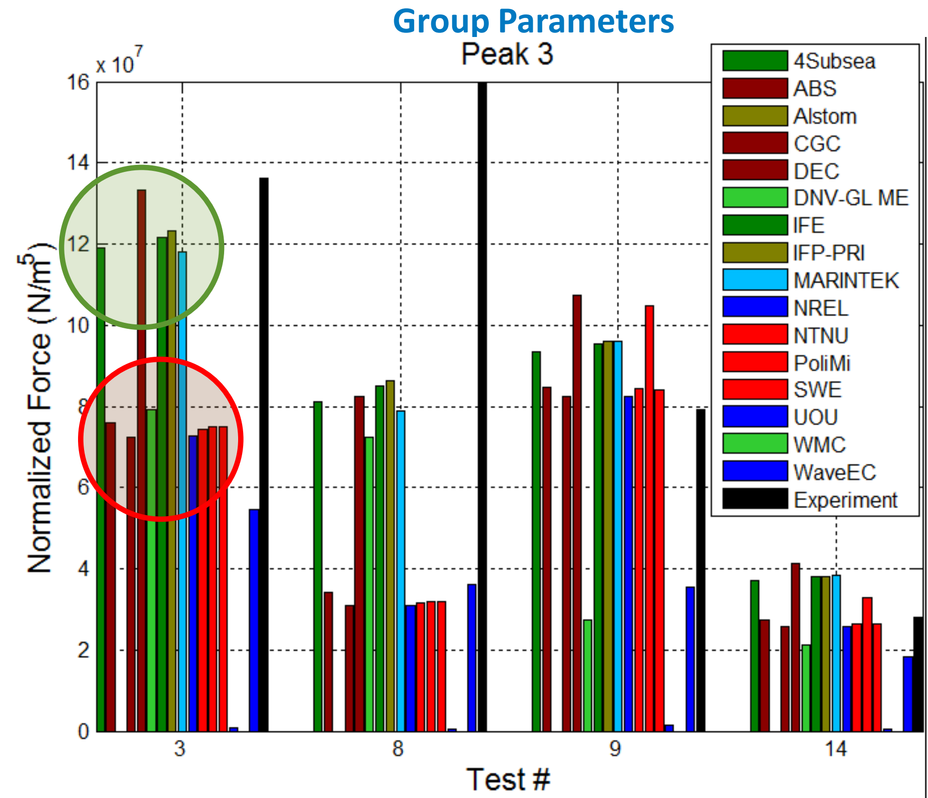
Participant	Code	Wave Model	Hydro Model	Wave Surface Treatment
4Subsea	ORCAFLEX	3^{RD} ORDER DEAN	ME	IW
ABS	CHARM3D+ FAST	LINEAR AIRY	ME	IWV
Alstom	S4WT	5^{TH} ORDER STOKES/L.AIRY	ME	IW/IWW
CGC	BLADED 4.3	LINEAR AIRY	ME	IWW
Dec	MORISON'S EQ.	LINEAR AIRY	ME	IWW
DNV GL	BLADED 4.6	6^{TH} AND 8^{TH} ORDER SF/L. AIRY	ME	IW/IWW
GOLDWIND	FAST	2^{ND} ORDER STOKES	PF	NO
IFE	3DFLOAT	6^{TH} ORDER SF/L. AIRY	ME	IW/IWE
IFPEN/PRI	DEEPLINESTMWIND	3^{RD} ORD. SF (ACTUAL)/L. AIRY	ME	IW
MARINTEK	RIFLEX	2^{ND} ORDER STOKES (ACTUAL)	ME	IWE
NREL	FAST	2^{ND} ORDER S+D/ACTUAL	ME	NO
NTNU	MORISON'S EQ.	LINEAR AIRY	ME	NO
POLIMI	ILMAS	LINEAR AIRY	ME	NO
SWE	SIMPACK +HYDRODYN	LINEAR AIRY	ME	NO
UTOKYO	CAST	LINEAR AIRY	ME	NO
UOU	UOU + FAST	2^{ND} ORDER STOKES	ME	NO
WAVEC	WAVEC2WIRE	2^{ND} ORDER STOKES	PF	NO
WMC	FOCUS6 (PHATAS)	3^{RD} ORDER SF/L. AIRY	ME	IW/IWW

Calibration Methods

Participant	Wave Ht Tuning	Cd/Ca Calibration	Cd/Ca Extrapolation
4SUBSEA	Manual tuning	1.0/Manual	1.0/KC-based
ABS	Ave. peaks/troughs	1.0/Least squares	1.0/Re and KC-based
ALSTOM	Ave. peaks/troughs	Weighted least squares	DNV
CGC	Ave. peaks/troughs	Least squares	Re and KC-based
DEC	Least squares	Least squares	Re-based
DNV GL	Ave. peaks/troughs	0.0/Least squares	0.0/Re-based
Goldwind	Ave. peaks/troughs	N/A	N/A
IFE	Ave. peaks/troughs	1.0/Match amplitudes	1.0/Re, KC, and DP-based
IFPEN/PRI	Ave. peaks/troughs	DNV	DNV
MARINTEK	Exp., filtered to 1^{st} order	Least squares	D and Tp-based, MF
NREL	Least squares	1.0/Least squares	1.0/D and Tp-based
NTNU	Frequency peak	1.0/Least squares	1.0/D and Tp-based
PolyMilano	Frequency peak	DNV/KC-based	DNV/Manual
SWE	Frequency peak	Least squares	DNV with correction
UTOKYO	Least squares	Least squares	N/A
UOU	Frequency peak	1.0/Morison method	KC-based with correction
WAVEC	Frequency peak	Morison method	DNV/KC-based
WMC	Manual tuning	1.0/KC-based	1.0/KC-based

Example of Results - 3rd Order Forces





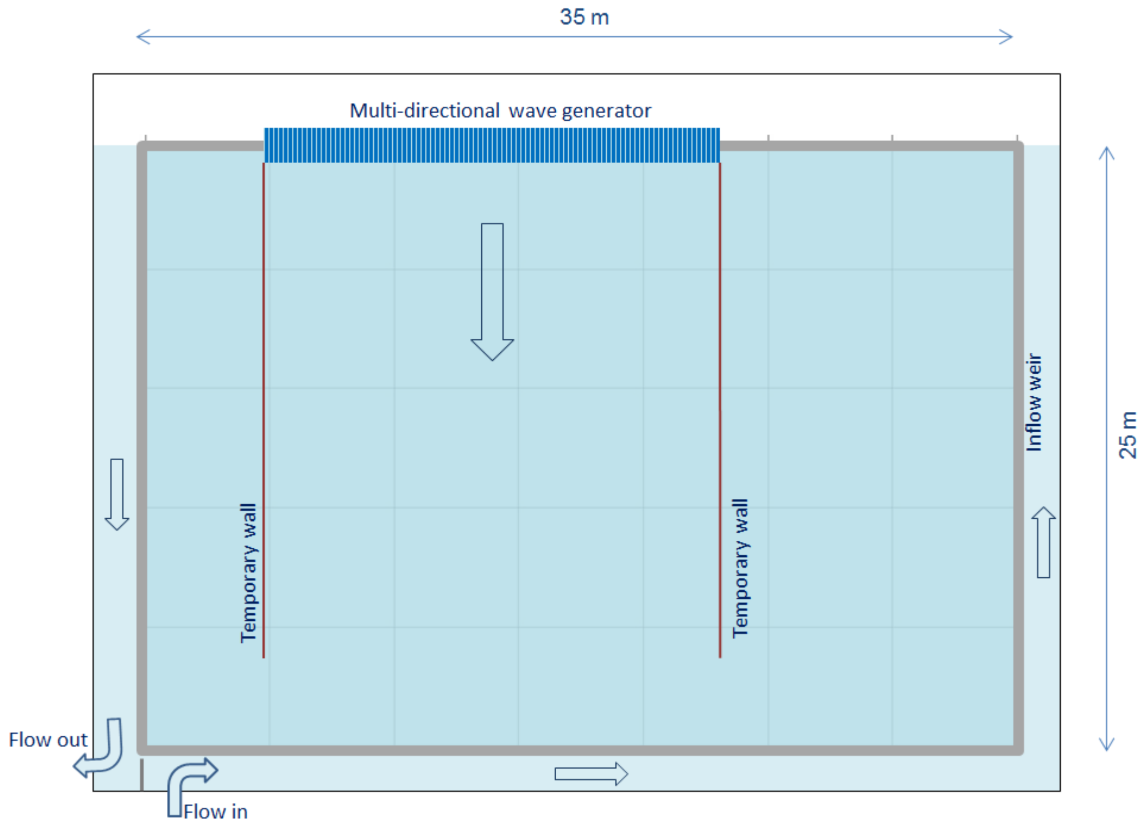
- **Results more consistent when using group parameters**
  - Those using 1st or 2nd order and no wave stretching show similar values, but lower than the rest
  - Those using higher-order waves and stretching not as similar
- **Under-prediction of experimental forces for case 8, but similar for 3, 9, and 14**

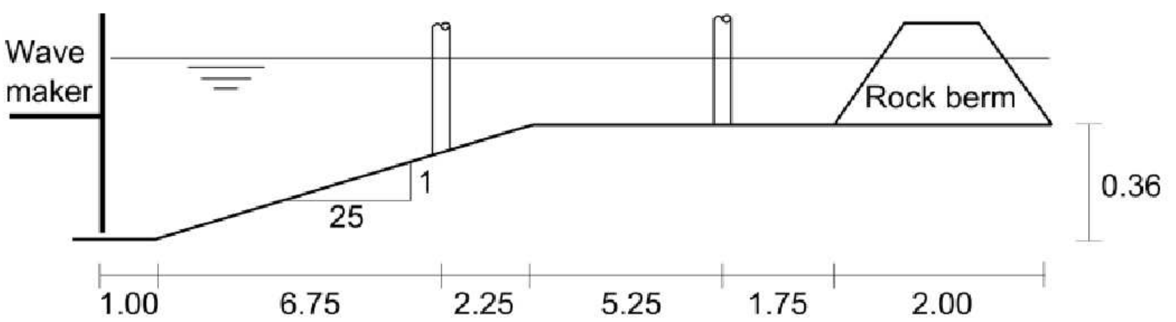
Findings from Phase Ia

- As waves become more nonlinear, higher-order wave theories better approximate shape of wave elevation and forces
- Most codes capture 1st-order force response very well, but only higher-order theories (or those using wave stretching) capture 2nd and 3rd-order components
    - 3rd order component important for capturing ringing phenomenon resulting from nonlinear wave passage
- Second-order wave kinematics do not have a significant effect on wave force
- For larger k*R values, non-slender diffraction effects reduce the 2nd order forces in the experiment – which are not captured by Morison's equation
- Influence of higher-order components not as evident in irregular wave results

Phase Ib - Wave Tank Testing by DHI/DTU

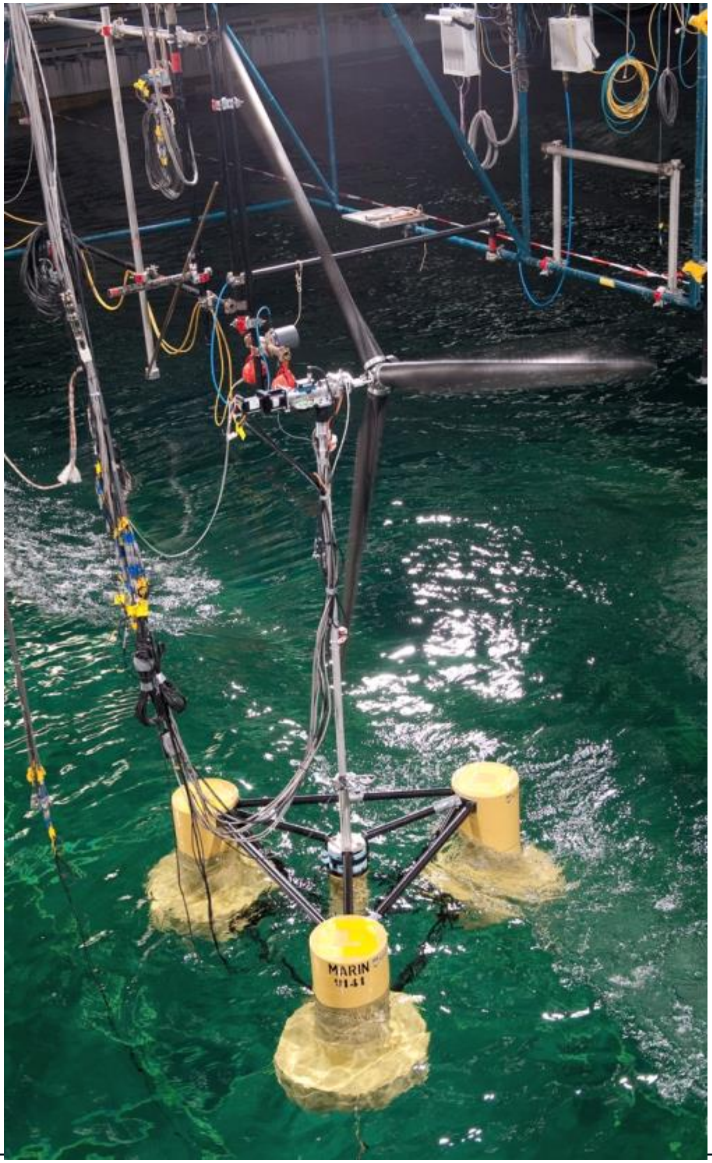
- Wave tests of cylinders performed in shallow water basin at DHI
- Examined steep and breaking waves using a slope of 1:25 built in front of the wave maker
- OC5 will model flexible cylinder at 1/80th scale
  - Focus on steeper waves
  - Examine influence of wave loads on structural response





Phase II

- Semisubmersible tested by DeepCwind in 2011 was re-tested at MARIN in 2013 with new, better performing turbine
- Turbine is MARIN stock turbine
    - NREL 5MW, performance-scaled at 1:50
- Will examine a series of wind/wave tests performed



Courtesy: Andy Goupee, University of Maine

Upcoming Meetings

- **Feb 6 – Trondheim, Norway (DeepWind conference)**
  - Review Phase Ia results – MARINTEK cylinder
  - Introduce work for Phase Ib – DTU/DHI cylinder
- **June 26 – Kona, Hawaii (ISOPE conference)**
  - Review Phase Ib results – DTU/DHI cylinder
  - Introduce work for Phase II – DeepCwind semisubmersible
  - Update status on Phase III – Open ocean test
- **Winter 2015 - ?**
- **Summer 2016 - ?**
  - Introduce work for Phase III – Open ocean test

NATIONAL RENEWABLE ENERGY LABORATORY

Thank You!

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