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Analysis of biofouling effect on the fatigue life and energy performance of wave energy converter system

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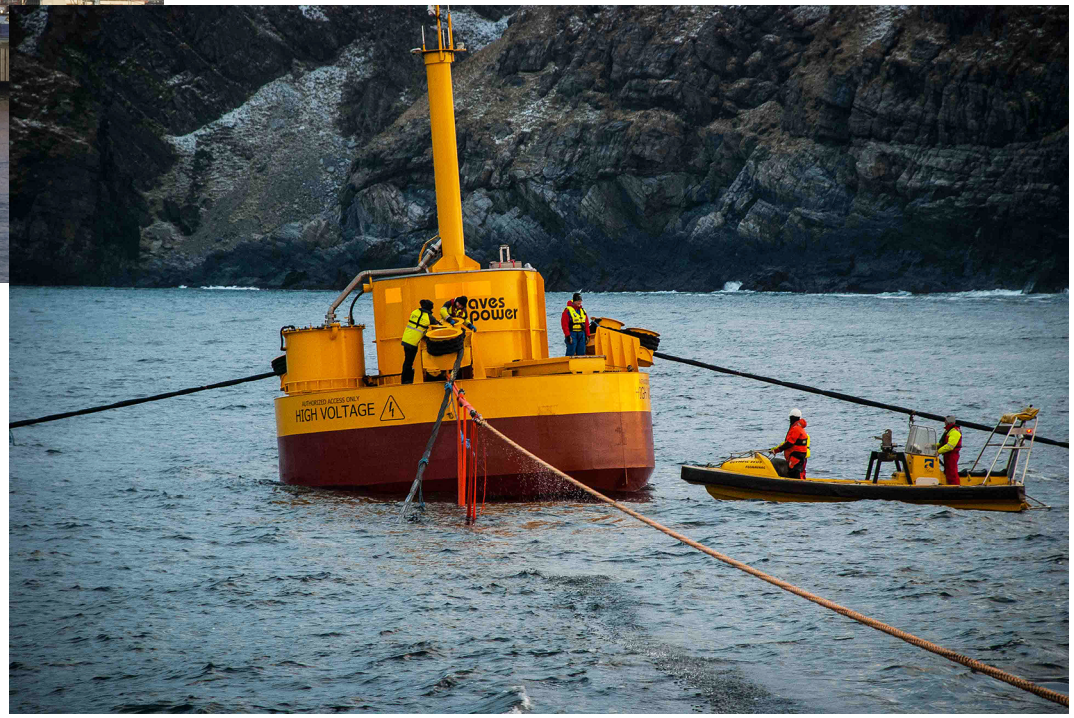
Point absorbing wave energy converter

(Courtesy of Jonas W. Ringsberg)

waves 4power



(Source: http://www.waves4power.com/waveel/)

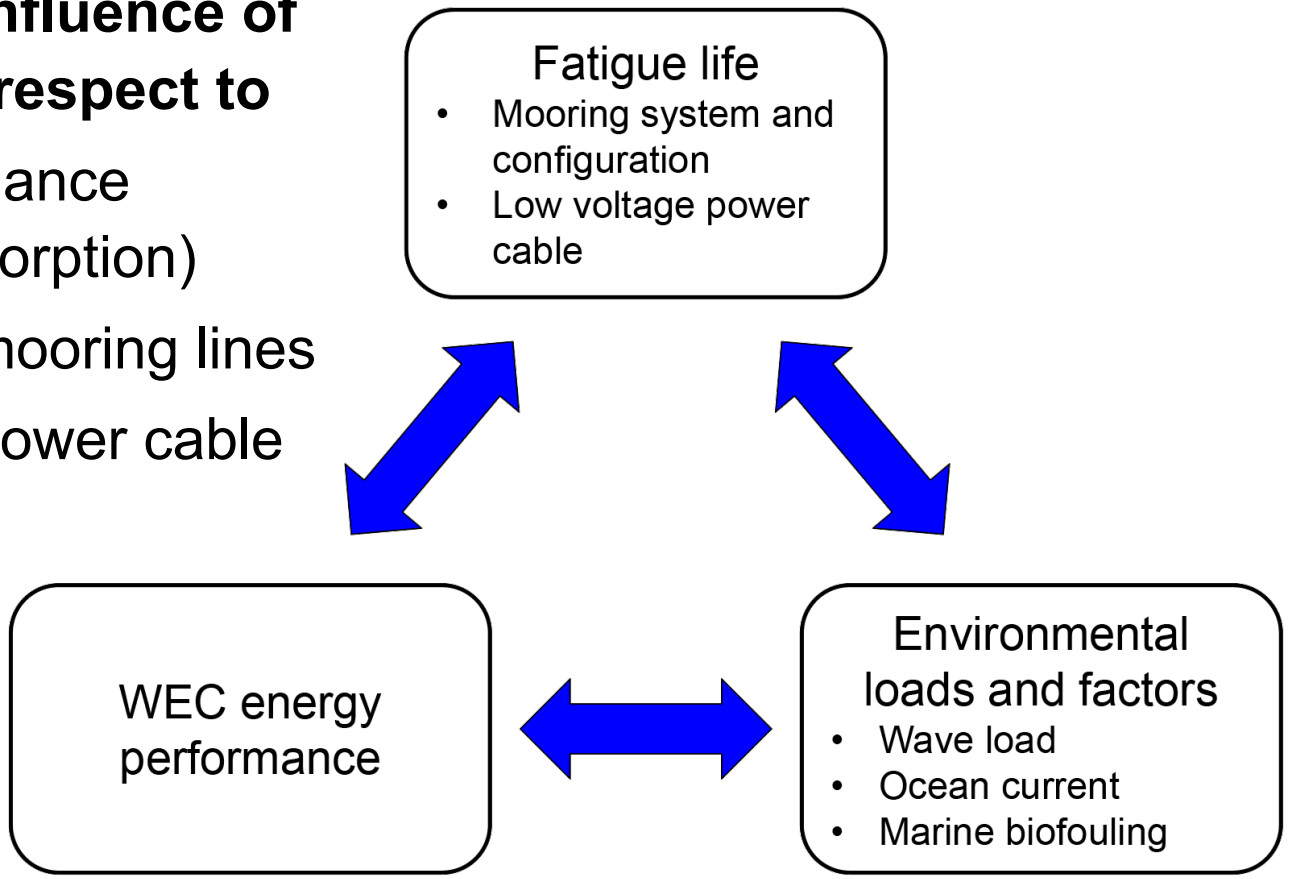
Marine biofouling

(Source: M. Salta, 2014, Biomimetic strategies in antifouling coatings)

(Source: http://www.channelcoast.org/gallery/viewphoto/equipment/oceanographic_instruments/directional_waverider/2004)

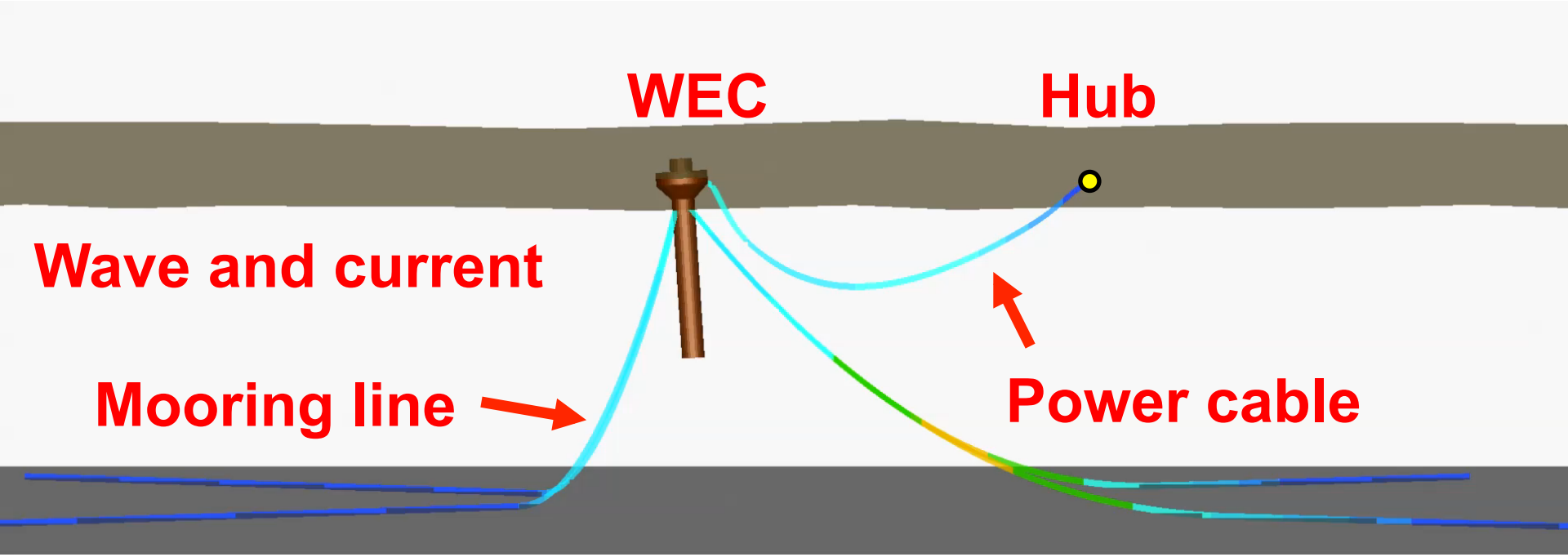
Objective

- **Investigate the influence of biofouling, with respect to**
  - Energy performance (i.e., power absorption)
  - Fatigue life of mooring lines
  - Fatigue life of power cable



Methodology

Numerical model of WEC system

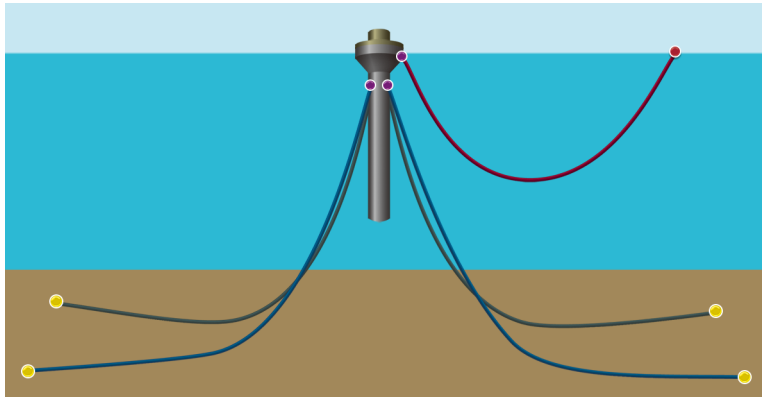


- Heave motion of WEC → velocity → energy performance analysis
- Force response of moorings and cable → stress response → fatigue damage analysis

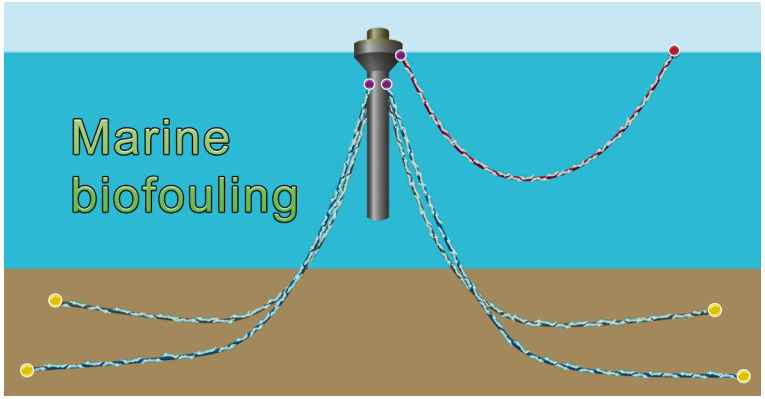
Biofouling cases

- **Modelled by an increase in the masses and drag coefficients of the moorings and the cable**

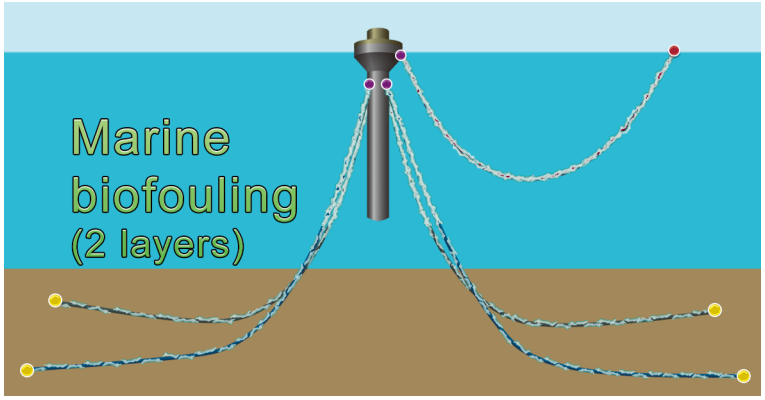
- **Three cases**
  - F1: no fouling



  - F2: Tiron et al. (2012)

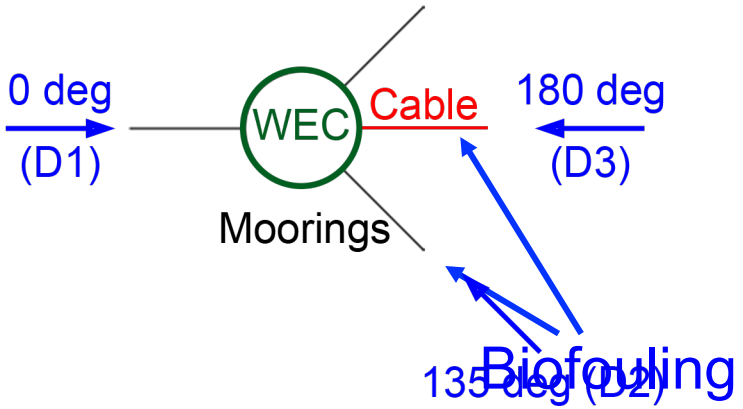


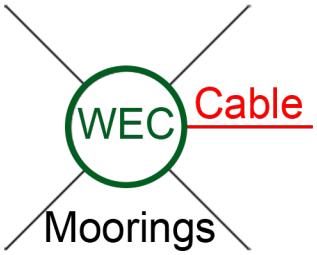
  - F3: NORSOK (2007)



Parametric analysis

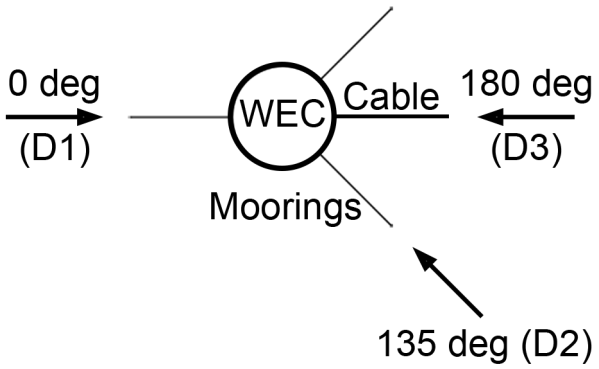
- **Mooring configuration**
  - Three-mooring and four-mooring configuration
- **Biofouling cases**
  - No fouling case and another two cases of fouling
- **Sea states**
  - Four sea states with various wave heights and wave periods
- **Wave and current direction**
  - Three directions of incoming waves and currents

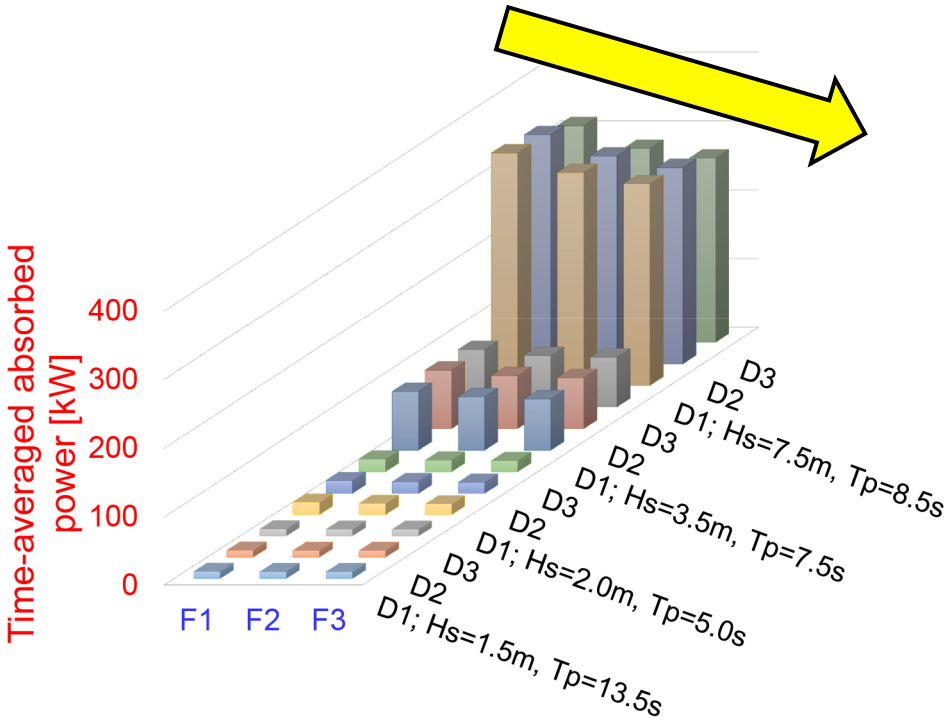


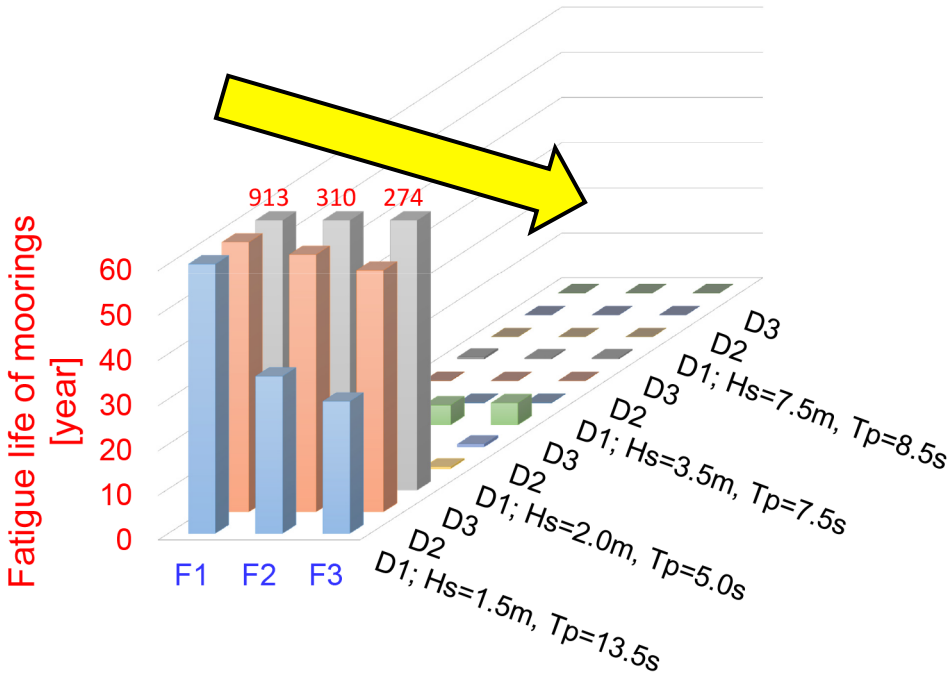


Results

Effect of biofouling on the moorings and cable

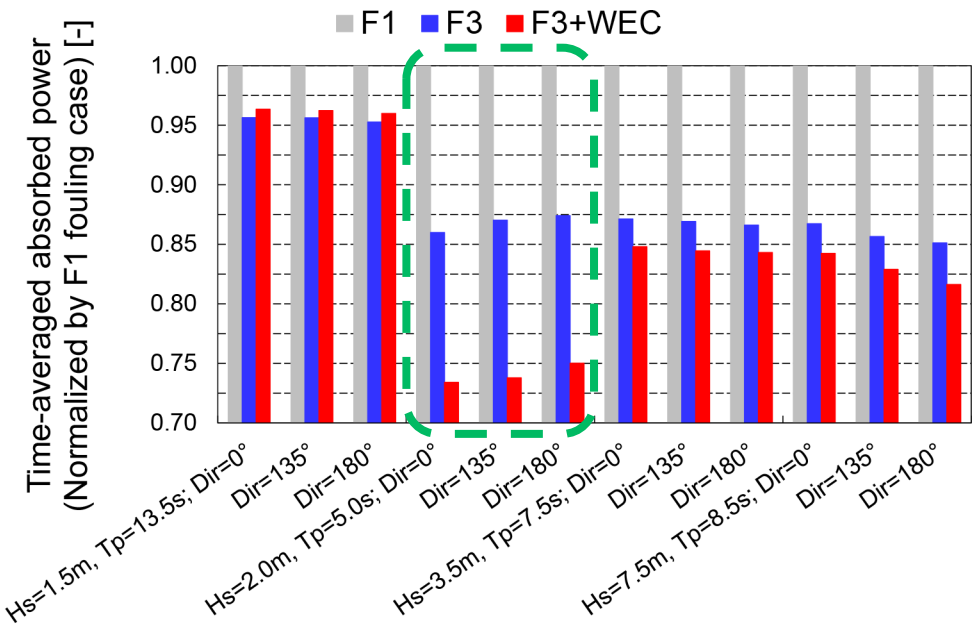


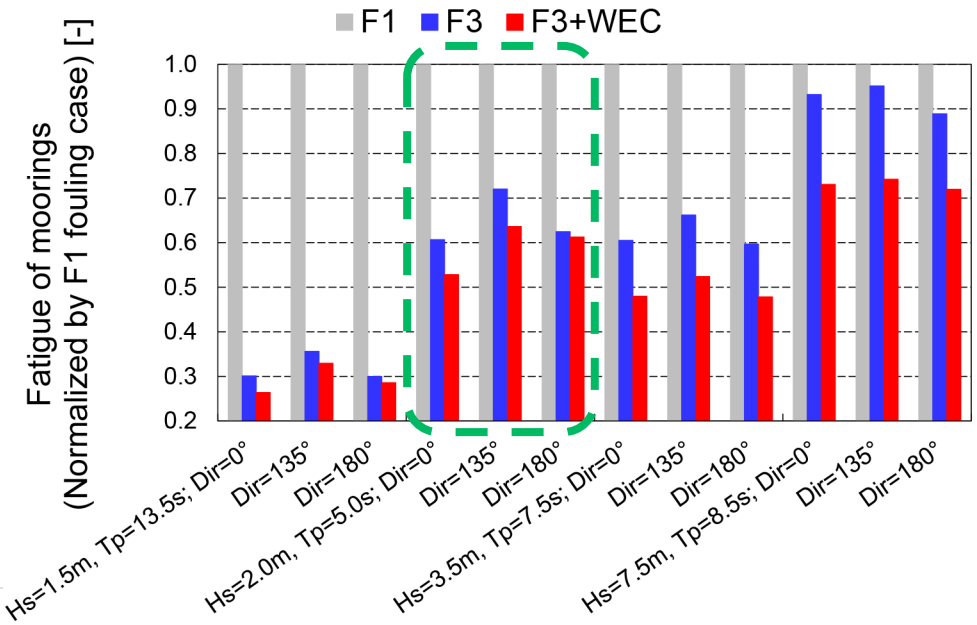




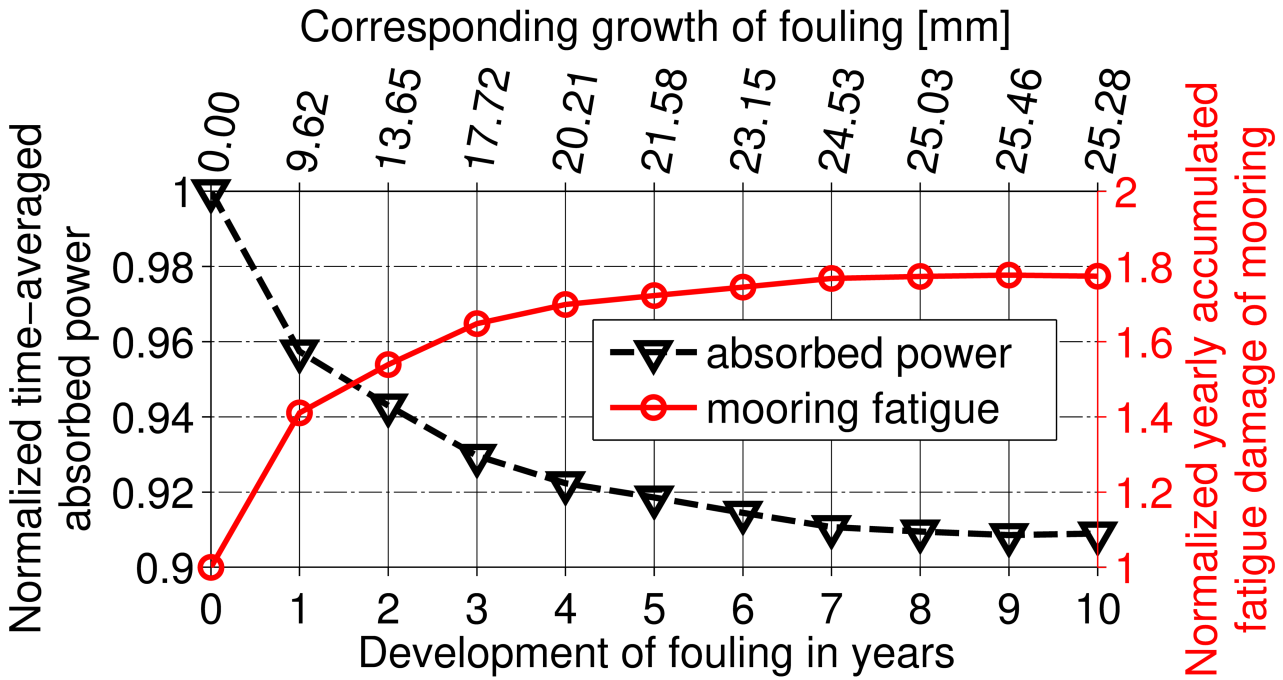
Effect of biofouling on the WEC device

- **Fouling condition**
  - F1: no fouling on the entire WEC system
  - F3: fouling accumulated only on the cable and moorings
  - F3+WEC: fouling accumulated on the entire WEC system





Effect of biofouling over different time durations



- **If the WEC system is assumed to operate during 25 years, the presence of biofouling (F2 case) can lead to:**
  - a 10% reduction of absorbed power, and
  - a 20% decrease in fatigue life of the most “fatigued” mooring line

Summary and conclusions

- **This investigation studied various factors on the operation of WEC systems: mooring configuration, biofouling accumulation, and environmental load.**
- **Biofouling has a negative effect on both fatigue life of the mooring lines and power cable, and energy performance of the WEC.**
  - a 10% reduction of absorbed power, and
  - a 20% decrease in fatigue life of the mooring line
- **Future work**
  - Validation of numerical models (experiment completed in October 2016)
  - Development of a local model for the power cable
  - Investigation of different mooring materials

Thank you.

We look forward to fruitful cooperation with both national and international partners.

For detailed project information, please contact:

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Adjunct Professor Erland Johnson (Erland.Johnson@sp.se)

Coupled hydrodynamic and structural response analyses of the WEC system

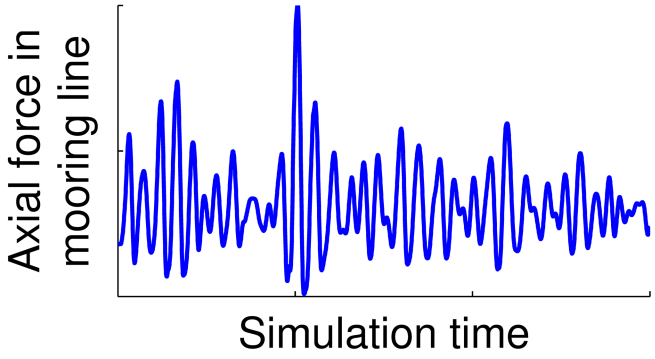
- **Hydrodynamic response of the WEC buoy**
  - Radiation-diffraction panel method and drag effect from Morison equation
  - 6 DOFs rigid body motion
  - DNV Sesam package, including HydroD and SIMO in DeepC
- **Hydrodynamic and structural response of the mooring lines and power cable**
  - Nonlinear time-domain
  - Nonlinear finite element method
  - Axial force and bending moment
  - DNV DeepC (Riflex)

Nonlinearity in numerical simulation

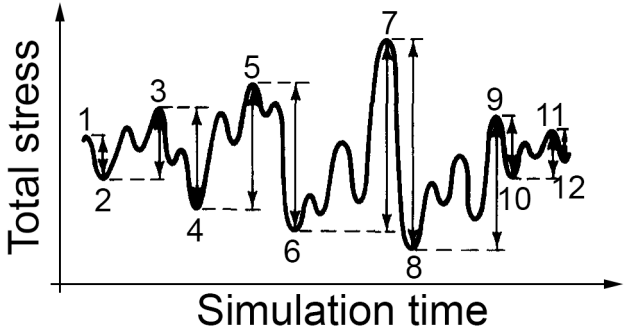
- **Nonlinear finite element method**
  - Geometric stiffness (i.e. contribution from axial force to transverse stiffness)
  - Hydrodynamic loading according to the generalized Morison equation expressed by relative velocities
  - Contact problem (i.e. seafloor contact)
- **Nonlinear time-domain analysis**
  - Step by step numerical integration of the incremental dynamic equilibrium equations, with a Newton-Raphson type of equilibrium iteration at each time step.

Stress and fatigue damage analyses of the mooring lines and power cable

- **First-principle design**
- **Stress analysis**
  - Mooring: axial stress
  - Power cable: axial and bending stresses

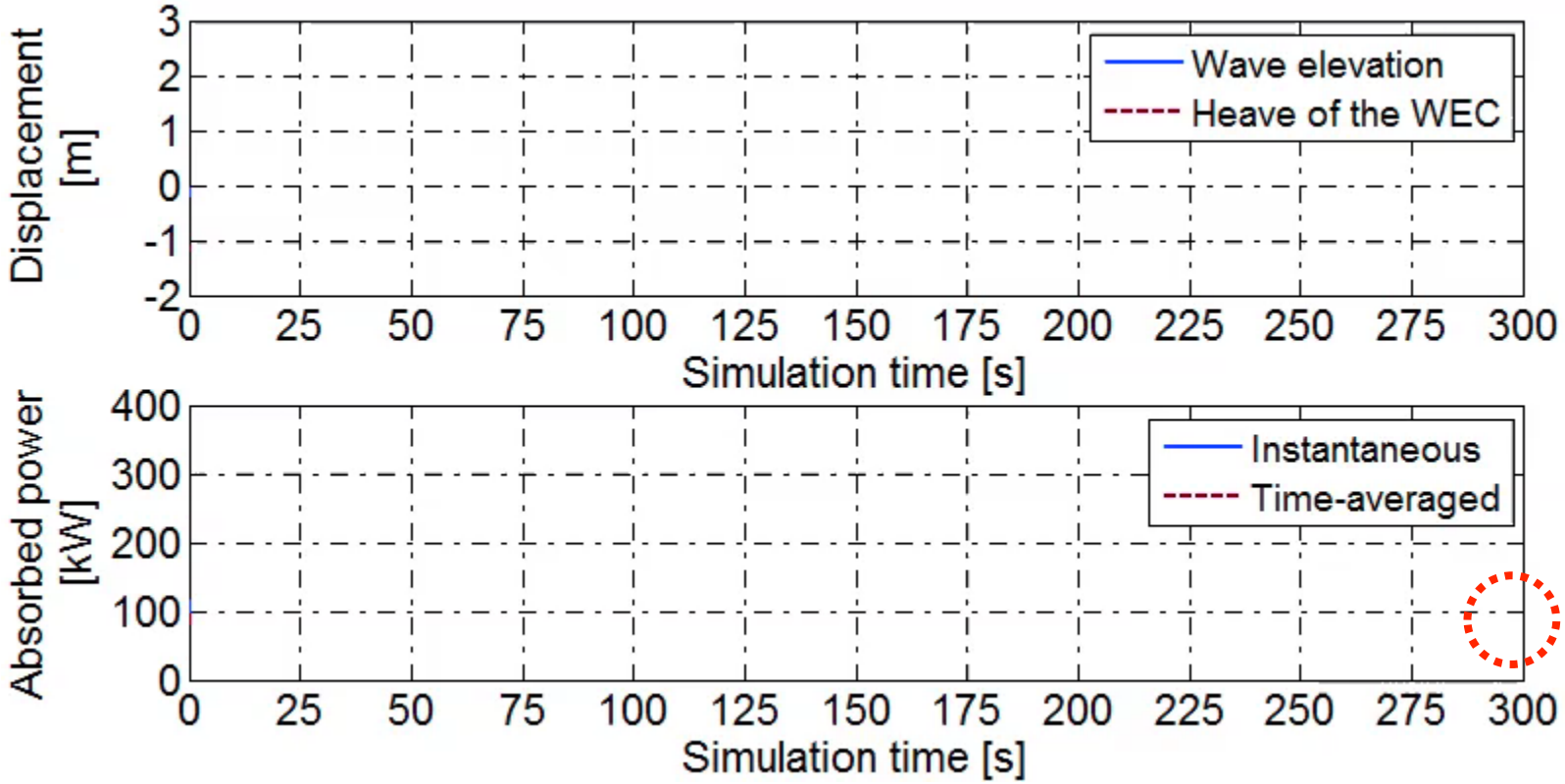


- **Material property: S-N curve**
  - Mooring: DNV (2010)
  - Power cable: Nasution et al. (2013)
- **Fatigue damage evaluation**
  - Stress-based approach
  - Basquin's equation
  - Palmgren-Miner rule
  - Rainflow cycle counting method

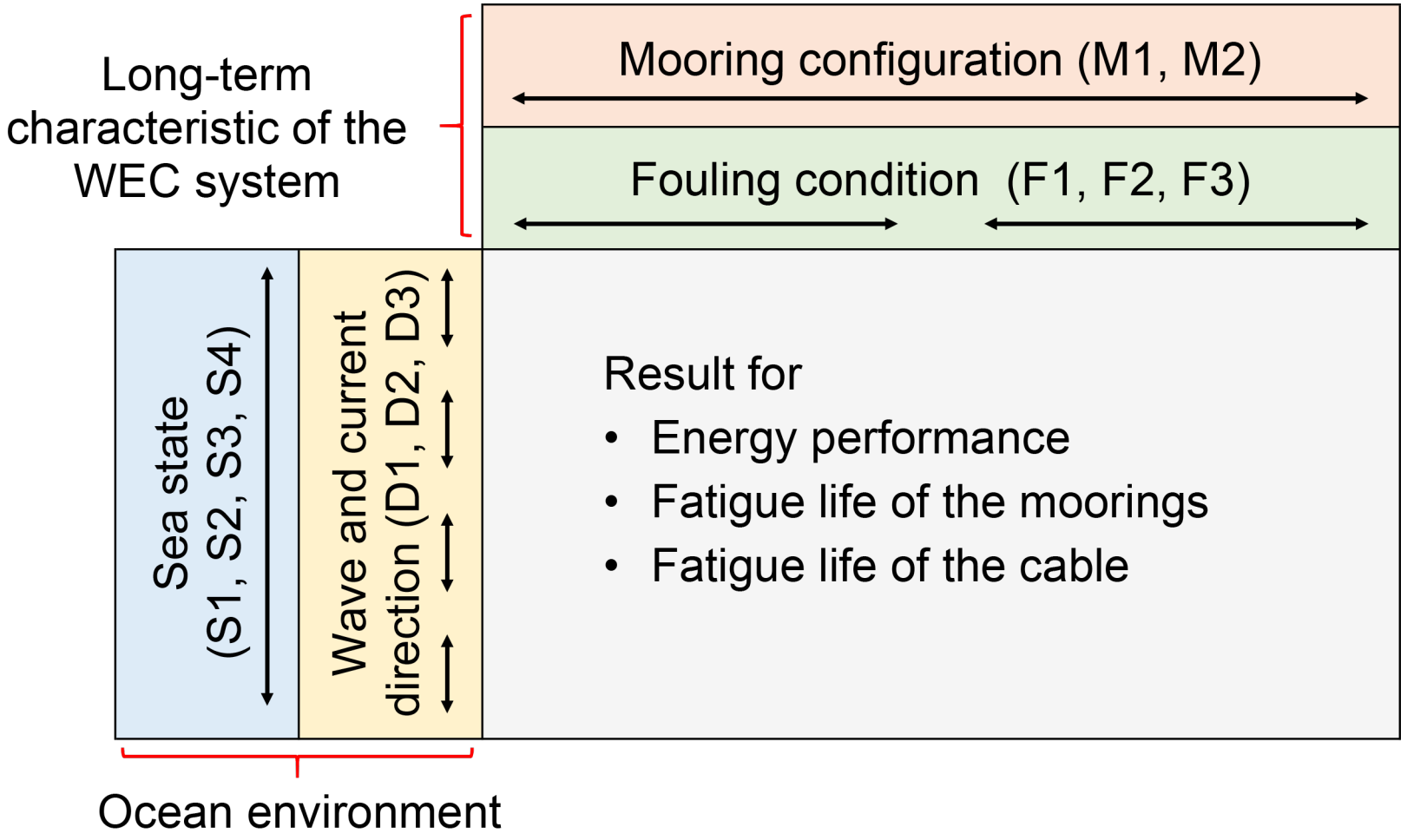


Energy performance analysis of the WEC

- Instantaneous absorbed power
  = PTO linear damping coeff.×(velocity in heave direction)^2



Simulation matrix



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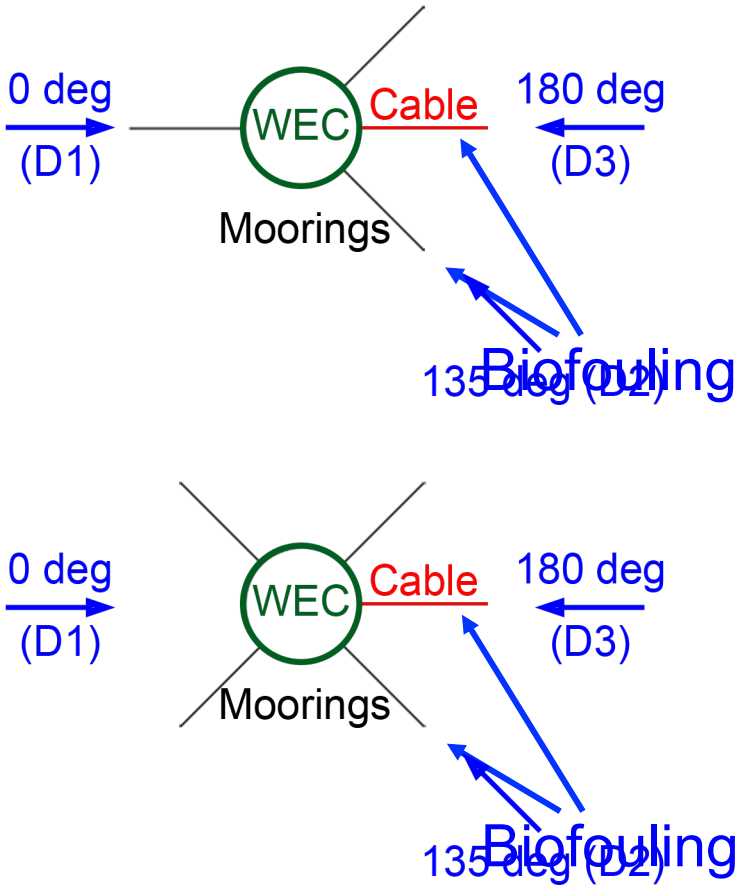
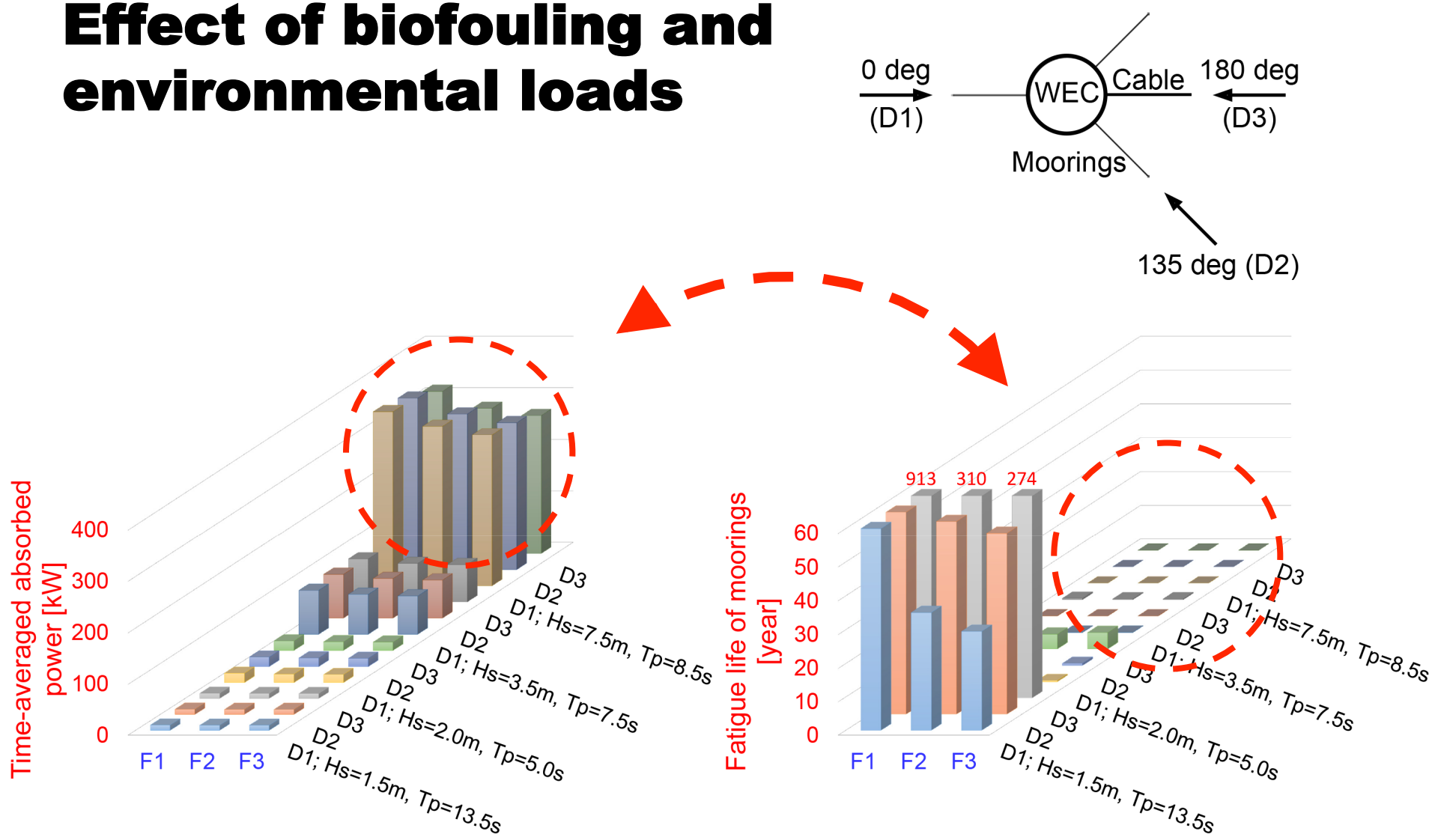


Effect of biofouling and environmental loads



Assessment of marine biofouling

Marine biofouling accumulation

- **Wave energy converter**

	Mass [metric tonnes]	Draft [m]	Centre of gravity (x, y, z) [m]
1. no fouling	353.8	27.8	(0, 0, -11.8)
2. NORSOK (2007)	382.1	28.3	(0, 0, -11.9)

- **Mooring line and power cable**

	Mooring line			**Power cable**		
	Mass [kg/m]	Drag coefficient [-]		Mass [kg/m]	Drag coefficient [-]	
		C_{dx}	C_{dy}		C_{dx}	C_{dy}
F1: no fouling	45	0.50	2.50	2	0	1.20
F2: Tiron et al. (2012)	60	1.03	5.13	9	0	2.72
F3: NORSOK (2007) (water depth: 0~40 m & >40 m)	99 & 64	1.75 & 1.13	8.75 & 5.63	27	0	3.80

Effect of biofouling

- **Static analysis**

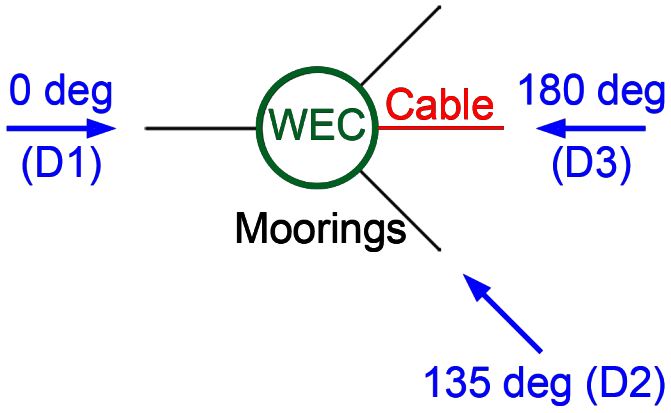
Case	Surge [m]	Heave [m]	Pitch [deg]	Force in mooring [kN]
F1: No fouling	-7.273	-0.030	-0.971	64.270
F2: Tiron et al (2012)	-5.418	-0.100	-0.718	74.877
F3: NORSOK (2007)	-4.225	-0.214	-0.287	90.082

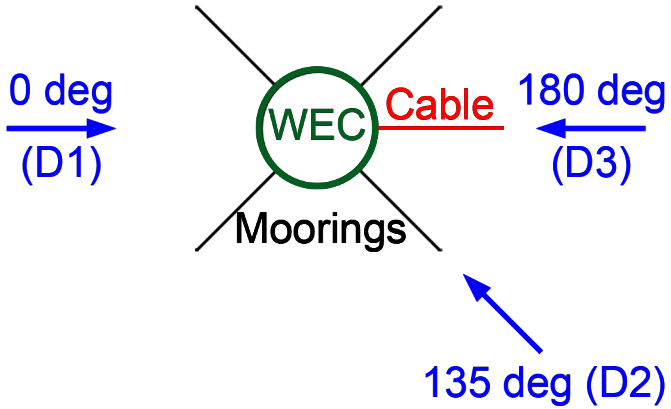
- **Final result**

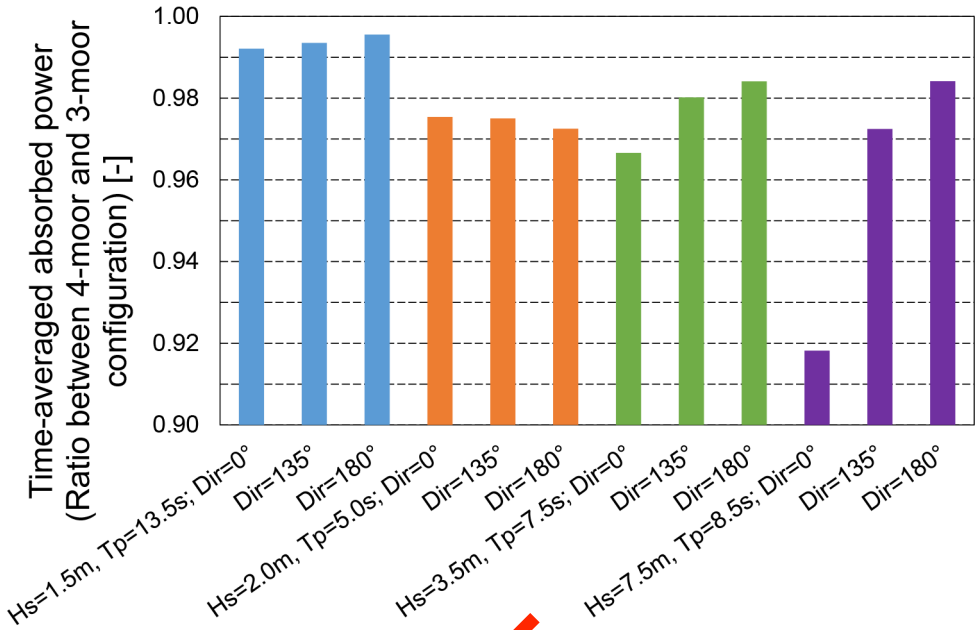
Case	Time-averaged absorbed power [kW]	Fatigue life of moorings [year]
F1: No fouling	18.4	7.8
F2: Tiron et al (2012)	16.8 (-9%)	4.4 (-44%)
F3: NORSOK (2007)	16.1 (-13%)	4.9 (-37%)

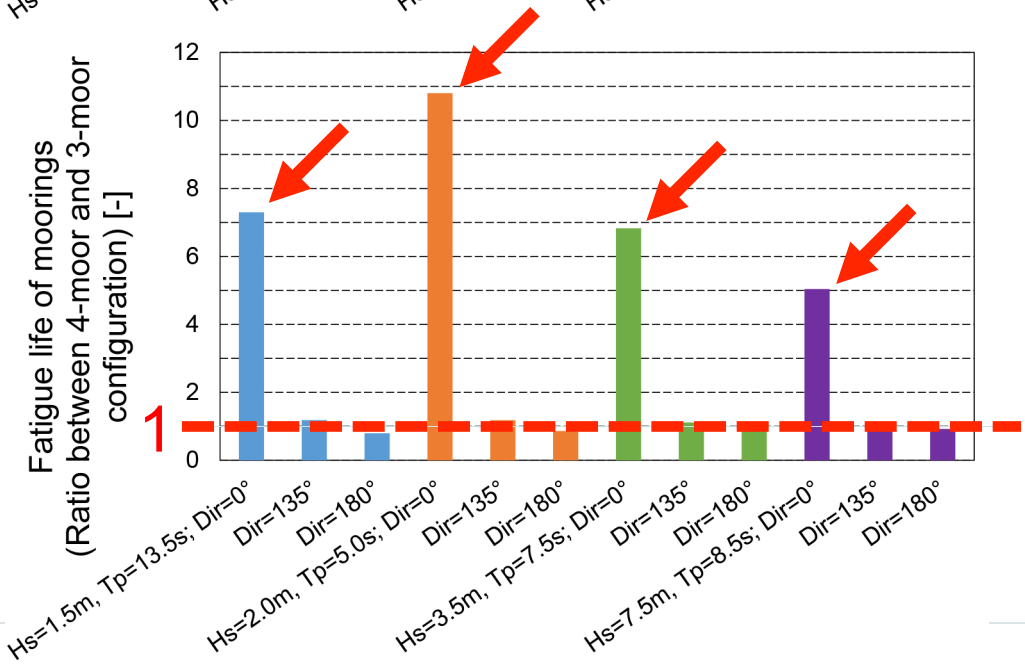
Effect of mooring configuration

Effect of mooring configuration









Effect of mooring configuration—static analysis

- Static analysis

Case	Surge [m]	Heave [m]	Pitch [deg]	Force in mooring [kN]
M1: 3-mooring	-7.273	-0.030	-0.971	64.270
M2: 4-mooring	-7.936	-0.026	-1.121	56.349

- Final result

Case	Time-averaged absorbed power [kW]	Fatigue life of moorings [year]
M1: 3-mooring	18.4	7.8
M2: 4-mooring	18.0 (-2%)	6.7 (-14%)

Effect of wind

Wind modelling

Spectrum	NPD
Speed	37.0 m/s
Reference height	10 m
Wind force area	$15m^2$
Exponent coeff.	0.12
Surface friction coeff.	0.002
Wind force coeff.	10.7 Ns^2/m^2

Case	Time-averaged absorbed power [kW]	Fatigue life of moorings [year]	Fatigue life of power cable [year]
No wind	18.4	7.8	2.0×10^4
With Wind	18.0 (-2%)	5.0 (-36%)	1.7×10^4 (-15%)

Modelling of marine biofouling

Modelling of biofouling

- **Static analysis**

Case	Surge [m]	Heave [m]	Pitch [deg]	Force in mooring [kN]
No fouling	-7.273	-0.030	-0.971	64.270
Change in mass	-5.339	-0.098	-0.737	74.127
Change in drag coeff.	-7.361	-0.031	-0.953	65.080
Change in mass and drag coeff.	-5.418	-0.100	-0.718	74.877
Change in mass, drag coeff., and diameter	-6.294	-0.075	-0.817	72.977

Modelling of biofouling

- **Energy performance and fatigue evaluation**

Case	Time-averaged absorbed power [kW]	Fatigue life of moorings [year]
No fouling	18.4	7.8
Change in mass	18.8 (2%)	15.2 (95 %)
Change in drag coeff.	16.2 (-12%)	2.1 (-73%)
Change in mass and drag coeff.	16.8 (-9%)	4.4 (-44%)
Change in mass, drag coeff., and diameter	13.2 (-28%)	0.9 (-88%)