Assessment of operational limits for offshore wind turbine installation activities

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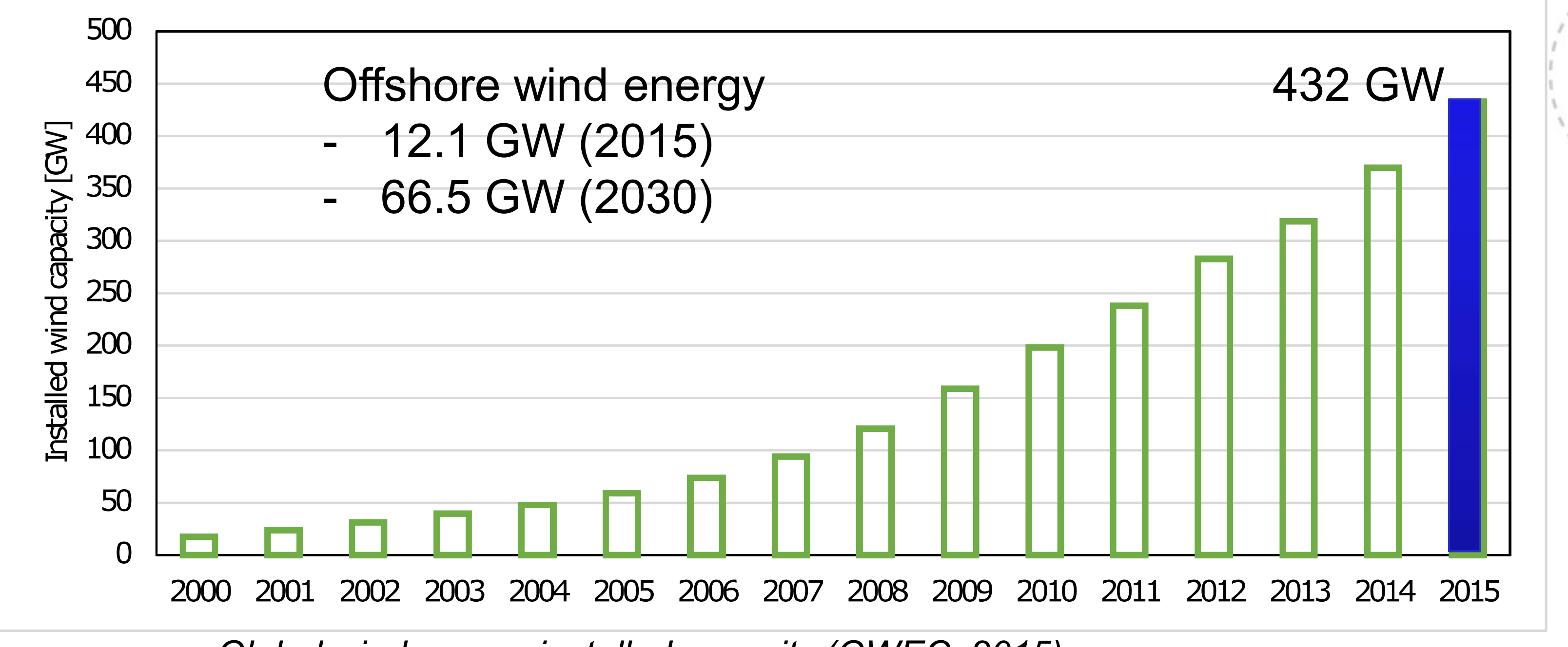
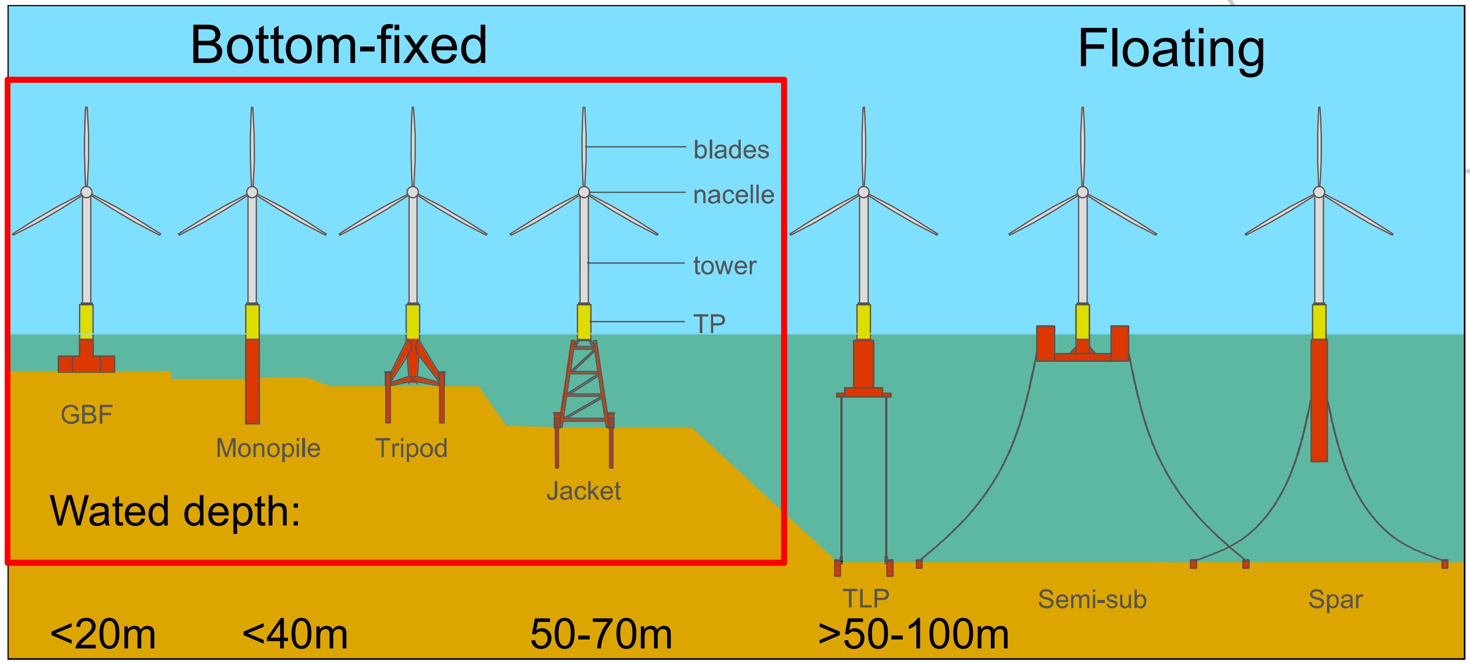
Background

- Transition from O&G to renewable energy.
- Wind energy is an alternative.



Global wind energy installed capacity (GWEC, 2015)

Offshore wind turbine (OWT) concepts



- **3230** botom-fixed OWT's installed in total.
- **419** OWT's installed in 2015 with average capacity 4.2 MW.
- **Average 8 MW** OWT capacity by 2018 (EWEA 2015).
- Monopile (**MP**) mostly used (**80%**).
- **More and larger OWT's will be installed in future.**

Installation methods - foundations

Tripod installation using a jack-up vessel (http://worldmartimenews.com)

Jacket installation using a floating vessel (https://www.boskalis.com)

- Similar procedures as for the O&G industry.
- Huge crane vessels are needed (2-3 MW OWT).
- Operational limits are based on experience (normally Hs, crane tip motions).
- Weather restricted operations (T_R<72 hours).

Installation methods – turbine tower, nacelle and blades

Blade installation using a jack-up vessel (https://media.licdn.com)

Single lift installation using a floating vessel (http://www.scaldis-smc.com)

- New procedures with respect to the O&G industry.
- Huge crane vessels are needed (single lift).
- Operational limits are nor clearly provided.

Operational limits

Operation	Parameter	Limit	Ref.
Heavy lifts	Crane block heave 2xrms	0.9 m	Rawstron and Blight (1978) OTC3150
Moderate lifts	Crane block heave 2xrms	1.2 m	
Hammer installation	Crane block heave 2xrms	1.8 m	
Heavy lift	Roll 2xrms	6 deg	Nojiri and Sasaki (1983) OTC4603
Float-over	Hs, Tp, Vwi (based on design of mating components)	1 m, <6 s, 15 knot	Peace D. et al (1985) OTC5048

- Operational limits based on experience.
- Given in terms of significant values.
- Their origin is not clear.

Offshore standards – marine operations (MO)

DNV GL, LOC, ISO Rules and **standards**

- Design & Fabrication (ULS, FLS, ALS). Ensure structural integrity $Pf<10^{-4}$, D<1, P(Sc >Sallow)= 0.1

DNV OS H102, DNV OS H206 part 2-6

- Numerical modeling and assessment of dynamic responses (planning phase)

DNV RP-C205, DNV CN 30.5, ISO 19901-1 environmental conditions; DNV RP-H103, Modeling and analysis of MO

- Modeling of marine operations (exec. phase). Operational limits in terms of Hs. Alpha factors (α) to reduce Hs for weather-restricted MO. Ensure $Pf<10^{-4}$

- DNV OS H101
- GL Noble Denton, General guidelines for MO
- LOC, Guidelines for MO
- ISO 19901-6 Marine operations O&G
- ISO 29400 Ships & Marine Tech. Offshore wind energy-Port and MO
- NORSOK (before J now M) Marine Operations

- Specific requirements. Preparations, monitoring responses, etc.

- DNV OS H201 Load-out, mating
- DNV OS H205 part 2-5 Lifting oprations
- DNV OS H206 Load-out, transport, installation of subsea objects

Weather restricted marine operations (MO)

Alpha factor

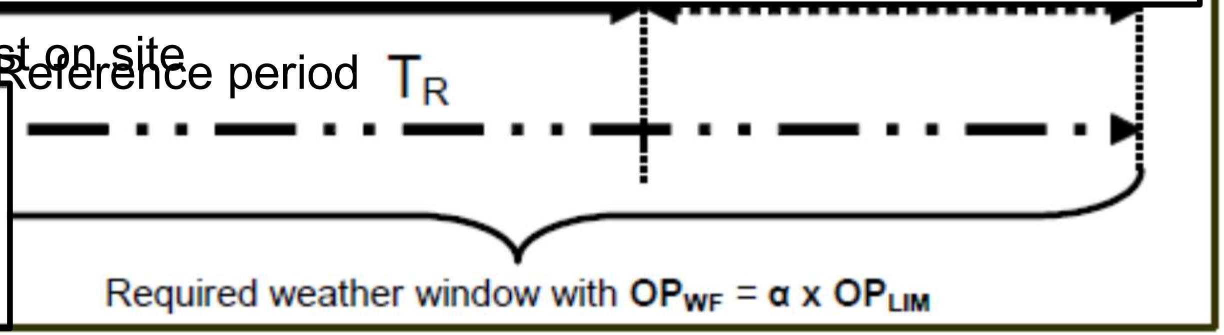
Reference period T_R

Table 4-1 α-factor for waves, base case

Operational Period [h]	*Design Wave Height [m]*						
	$H_s = 1$	$1 < H_s < 2$	H_s =2= 2	$2 < H_s < 4$	$H_s = 4$	$4 < H_s < 6$	$H_s \geq 6$
$T_{POP} \leq 12$	0.65	Linear Interpolation	0.76	Linear Interpolation	0.79	Linear Interpolation	0.80
$T_{POP} \leq 24$	0.63		0.73		0.76		0.78
$T_{POP} \leq 36$	0.62		0.71		0.73		0.76
$T_{POP} \leq 48$	0.60		0.68		0.71		0.74
$T_{POP} \leq 72$	0.55		0.63		0.68		0.72

With metheorologist on site

$T_{POP} \leq 12$	0.72
$T_{POP} \leq 24$	0.69
$T_{POP} \leq 36$	0.68
$T_{POP} \leq 48$	0.66
$T_{POP} \leq 72$	0.61



What about Tp?

- Duration < 72 hours, forecasts can be used.
- α factors (<1) need to be applied to the *design limit* of Hs.
- α factors depend on the duration, forecast method and Hs level.

Methodology for assessment of operational limits

- Operational limits: Hs_lim.
- Uncertainty in forecasted weather data: alpha_factor (for Hs).
- Target Pf 10^-4 per operation.

(Guachamin A. et al., 2016b)

- Proposed general methodology, main steps:
  - Identification of critical events of a given operation system and procedure.
  - Numerical analysis for dynamic responses considering stochastic sea states (models and numerical methods).
  - Comparison of the characteristic responses with their allowable limits (response-based criteria). ID limiting parameters.
  - A backward derivation of the corresponding allowable limits of sea states (Hs, Tp, Uw, directions) for lim. parameters .
  - Using hindcast and forecasted wave data, weather window analysis to obtain the operability and workable weather windows WOWWs.

Methodology for assessment of operational limits

ID crit. activities & events → Num. modeling → ID lim. param. → Assess charac. value → Assess oper. limits

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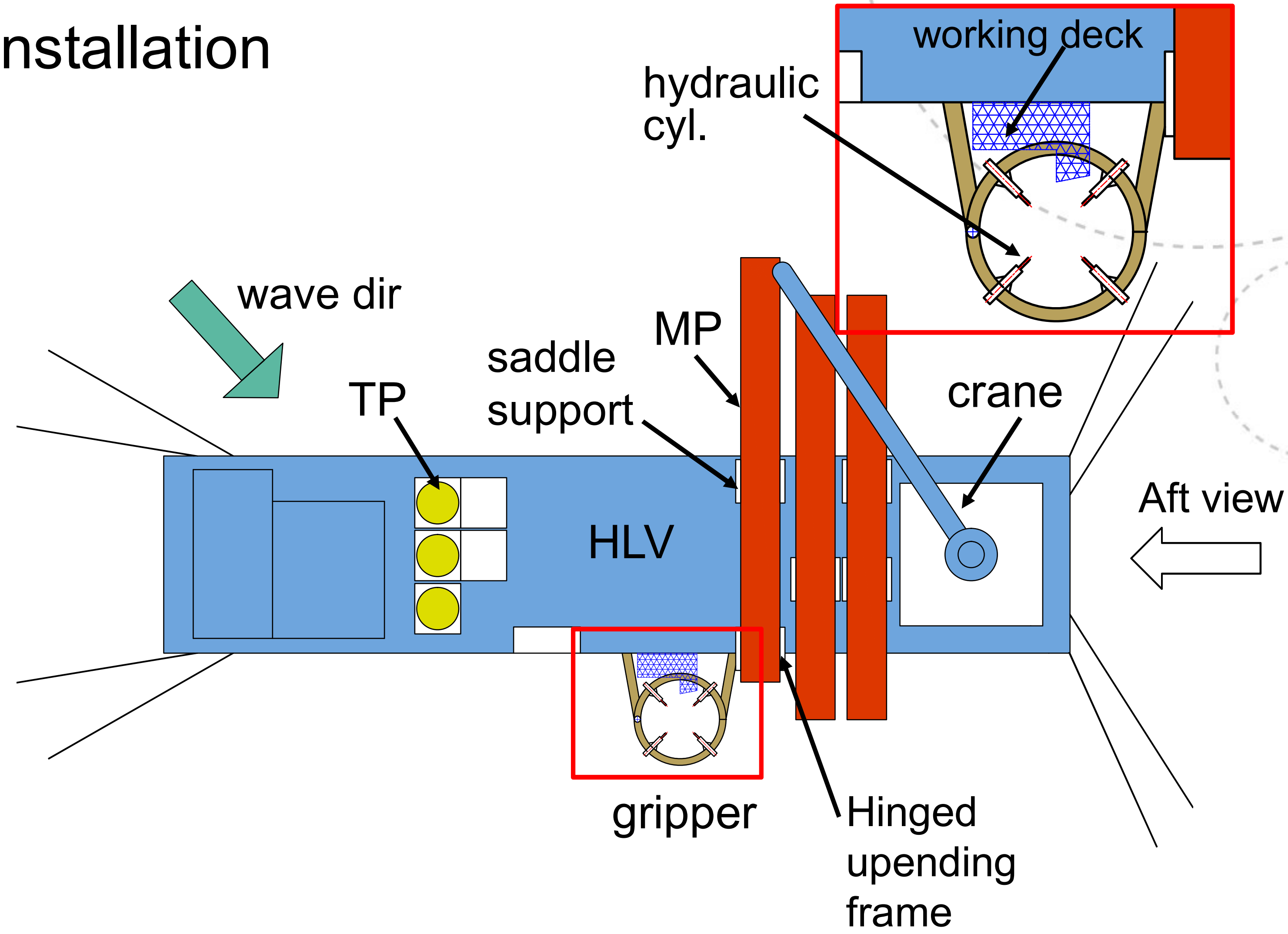
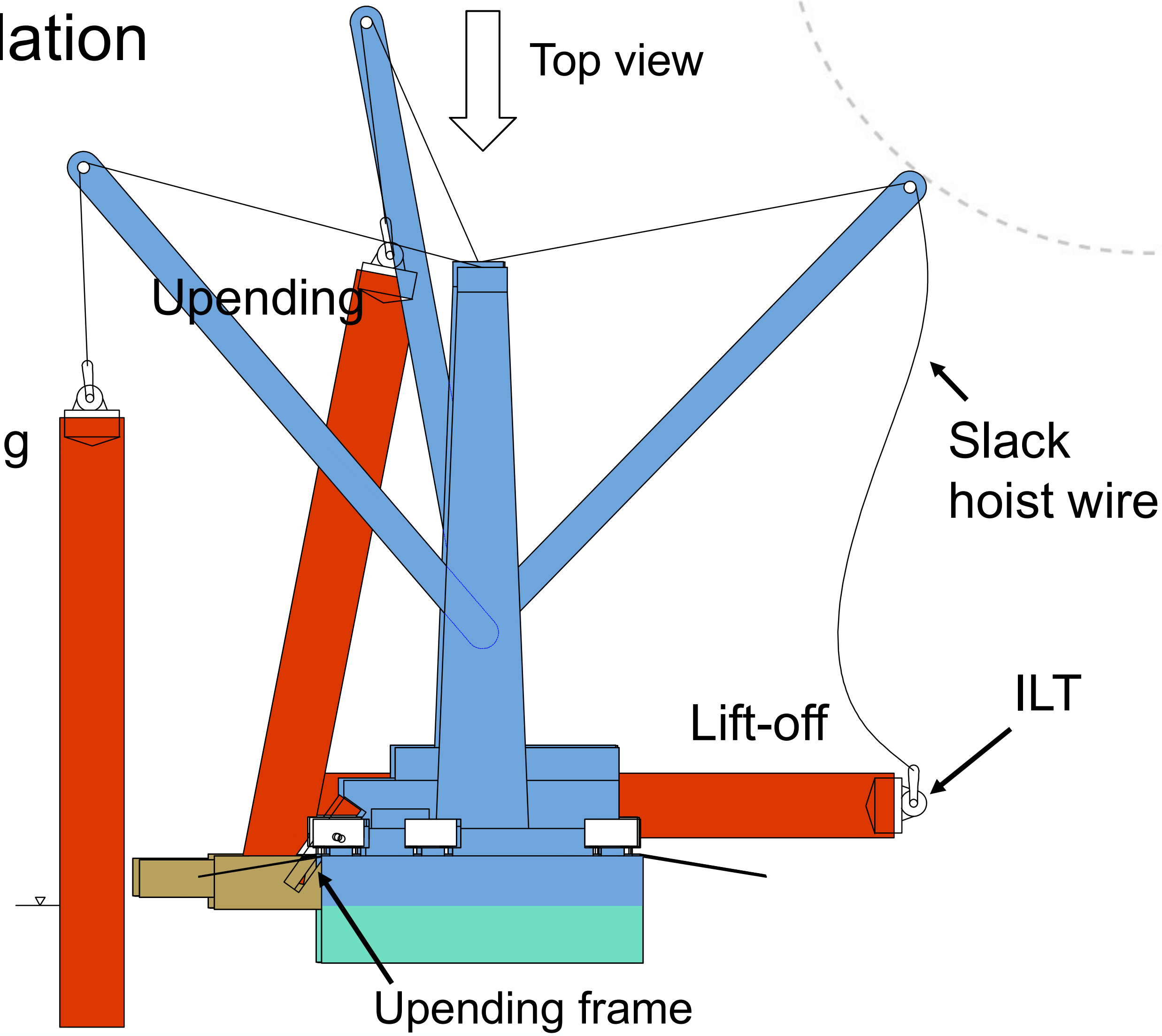
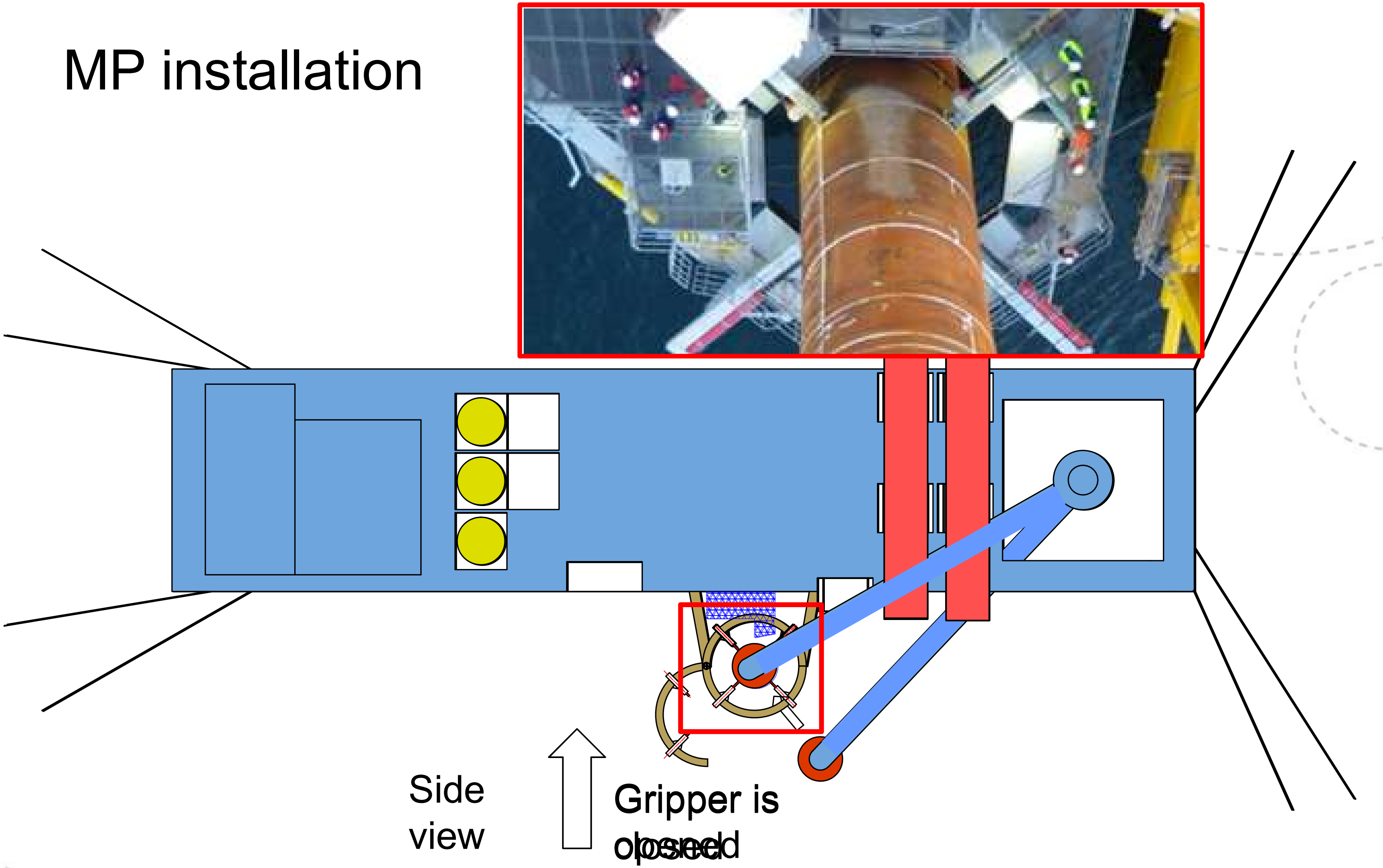
MP installation



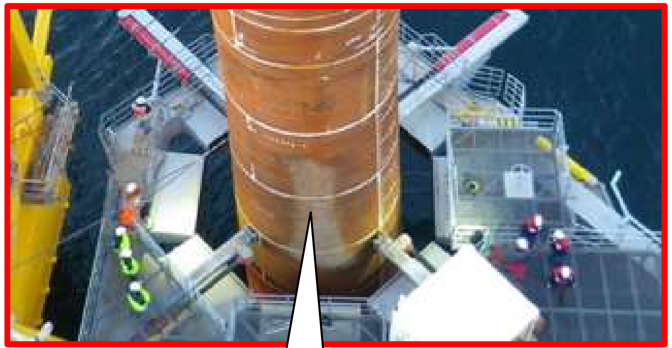
MP installation

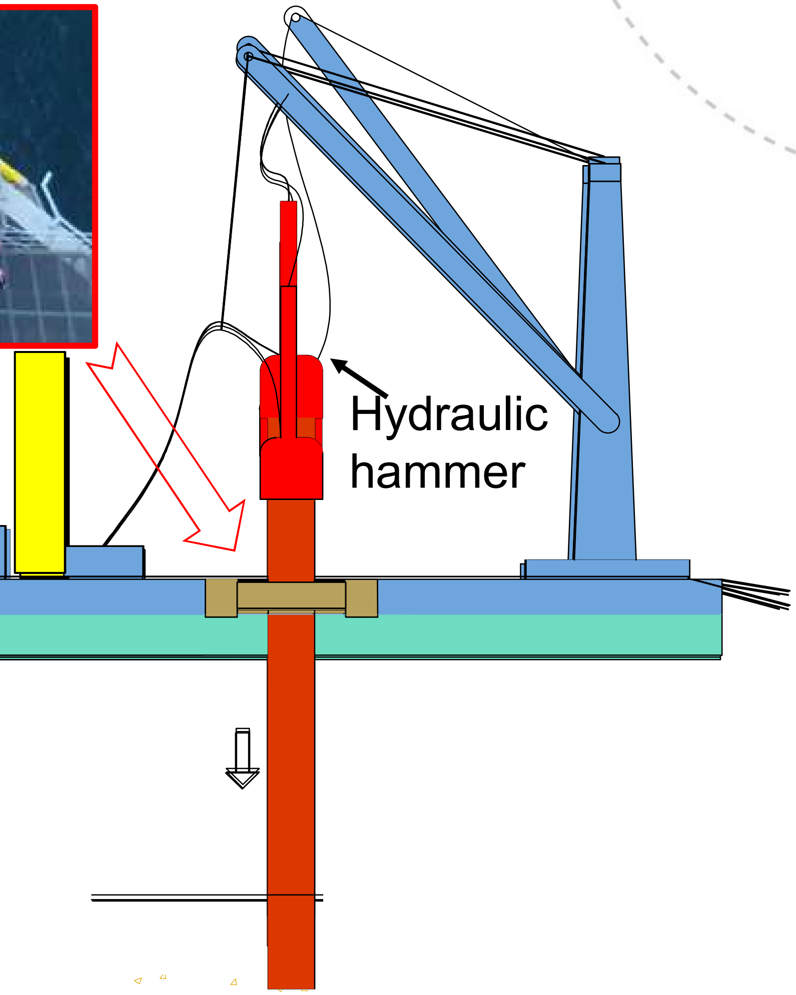


MP installation



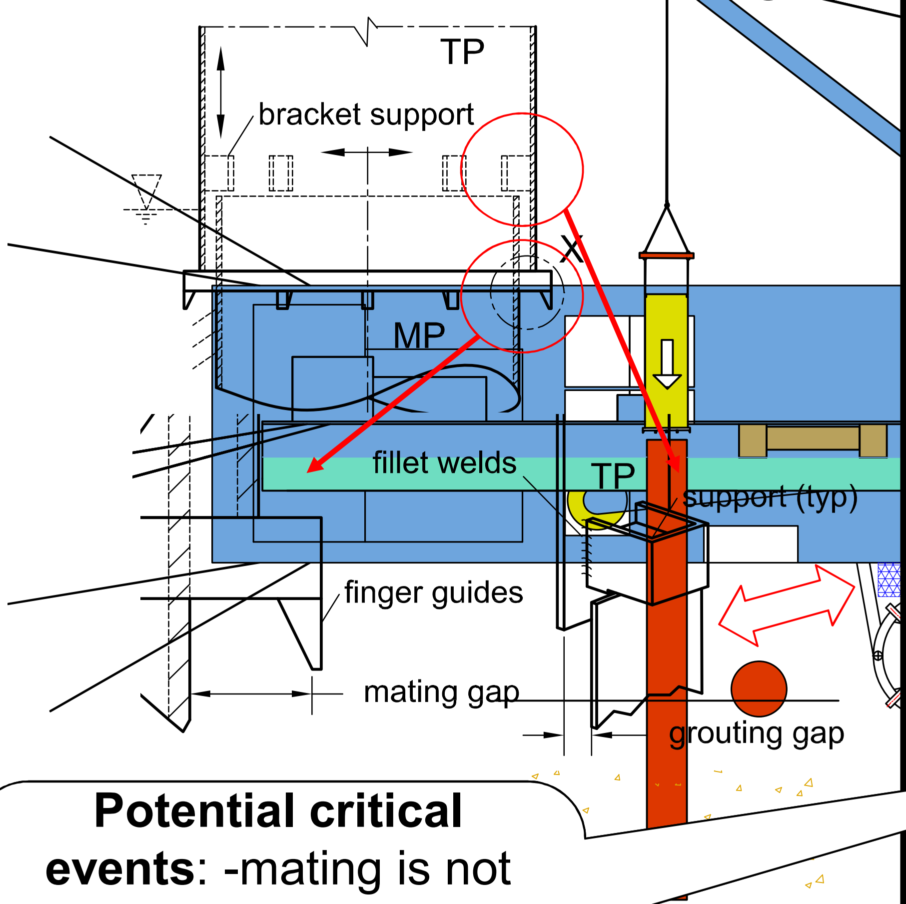
MP installation – initial hammering process





Potential critical events: Structural failure of hyd. System and out of tolerance MP inclination

TP installation - mating



Potential critical events: -mating is not possible, structural failure of rigging system, structural damage of the brackets

http://dantysk.vattenfall.com

MP and TP installation

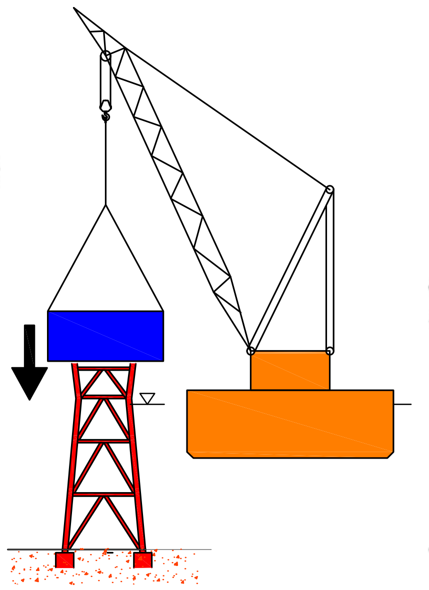
ID crit. activities & events → Num. modeling → ID lim. param. → Assess charac. value → Assess oper. limits

Potential critical events and parameters that limit the operation

No.	Activity	Critical event	Parameter limiting operation
1	MP lowering/ initial hammering	Structural failure of the hydraulic system	Gripper contact force
2	MP initial hammering	Insufficient MP inclination correction force	Thruster, mooring line force
3	MP initial hammering	Unacceptable MP inclination	MP inclination
4	TP bottom tip motion monitoring	Failed mating attempt	Horizontal motions
5	TP-MP mating	Structural damage (finger guides)	Impact velocity
6	TP lowering	Structural failure (rigging system)	Wire tension
7	TP landing	Structural failure of the brackets	Impact velocity

Numerical methods

ID crit. activities & events → Num. modeling

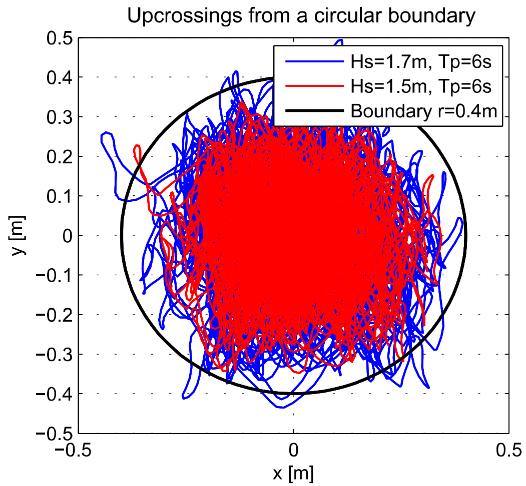


Frequency domain method (FD)

- Weakly non-linear models
- Stationary process
- Examples: free hanging condition, pre-lift

Time domain method (TD)

- Non-linear models
- Non-stationary process
- Examples: float-over, lowering, lift-off, etc



Rate of crossing out of a circular boundary *(Guachamin A. et al., 2015, 2016a)*

Numerical methodology

ID crit. activities & events → Num. modeling

Equations of motion (12DOF):

$$(\mathbf{M}+\mathbf{A}(\infty))\cdot\ddot{\mathbf{x}}+\mathbf{D}_1\dot{\mathbf{x}}+\mathbf{D}_2 f(\dot{\mathbf{x}})+\mathbf{K}\mathbf{x}+\int_0^t \mathbf{h}(t-\tau)\dot{\mathbf{x}}(\tau)d\tau=\mathbf{q}(t,\mathbf{x},\dot{\mathbf{x}})$$

Step by step integration method

SIMO numerical model:

Vessel model: (6 DOF)
- 1st and 2nd order wave forces (potential flow theory)
- Catenary mooring lines

Monopile model: (6 DOF)
- Gravity and buoyancy forces
- Wave forces (Morison)

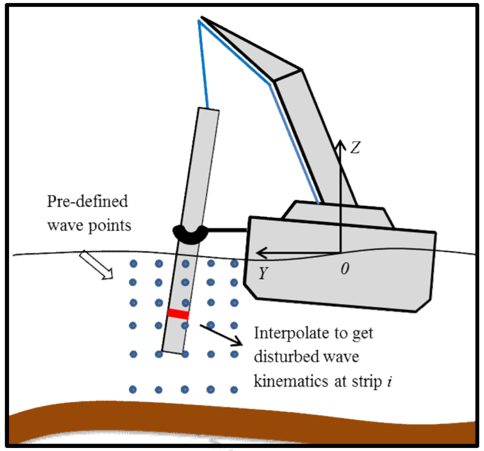
Couplings:
- Lift wire coupling
- Gripper device coupling

Interpolation method for MP non-stationary lowering

SIMO (Marintek)
Establish coupled equations of motion; solve the equations

OUTPUT
Positions, velocities and accelerations of each body, etc

EXTERNAL DLL
Calculate wave forces on monopile considering vessel shielding effects



Vessel shielding effect

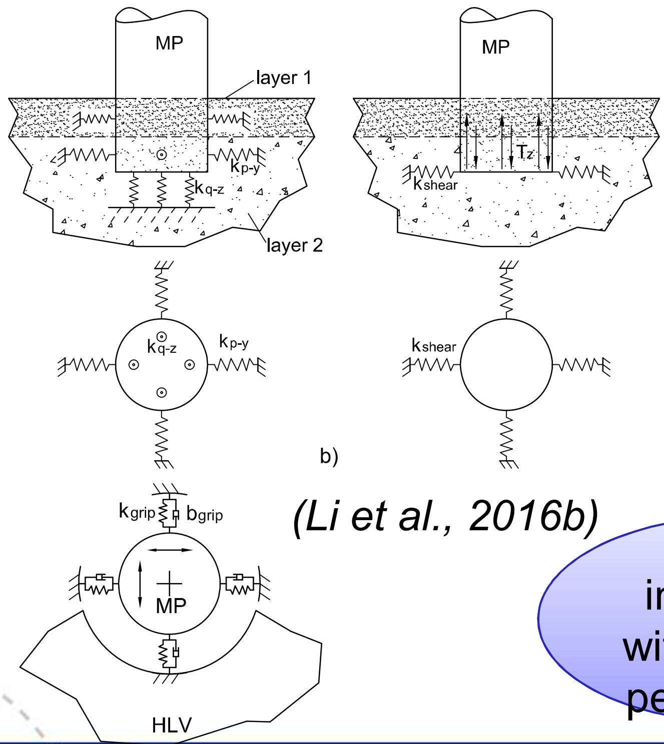
Monopile radiation damping effect (interpolation of the submergence-dependent retardation function)

(Li et al., 2014)

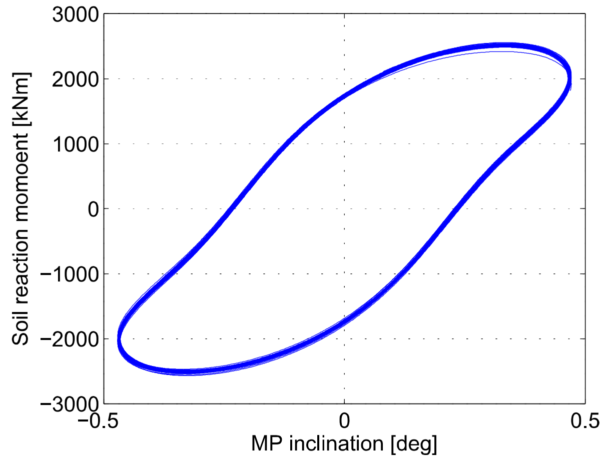
Numerical models - Monopile initial hammering process

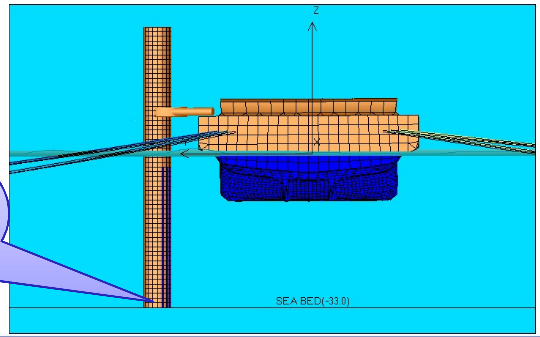
ID crit. activities & events → Num. modeling → ID lim. param. → Assess charac. value → Assess oper. limits

Numerical models for dynamic analysis (MP initial hammering process)



(Li et al., 2016b)



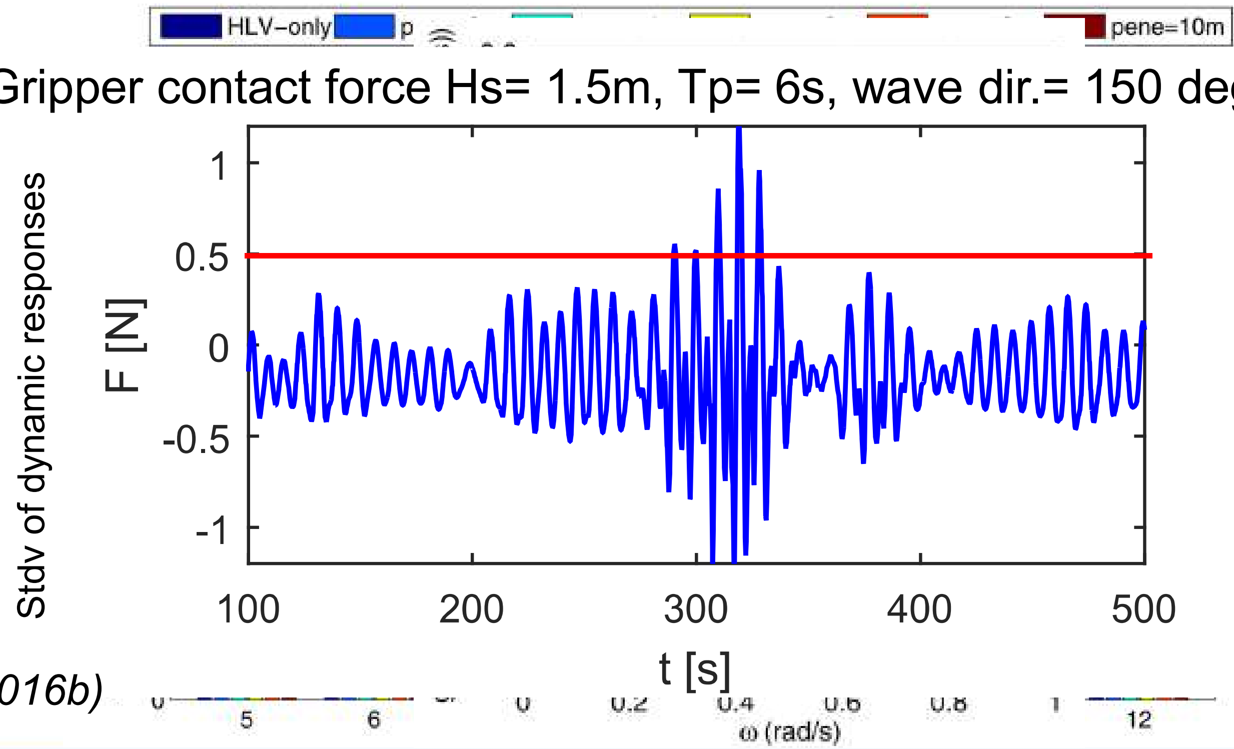


Soil-pile interaction with different penetrations

Monopile initial hammering process

Dynamic responses

Example of surge response spectra

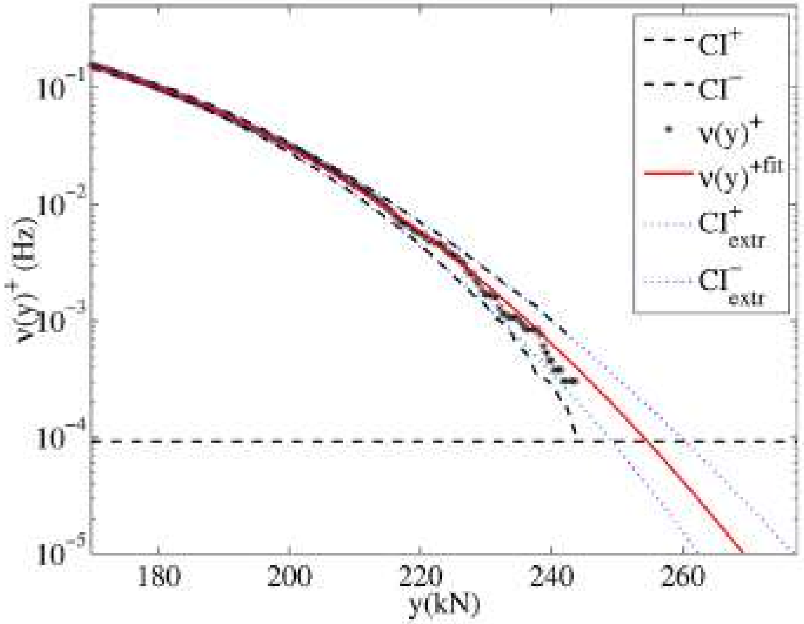


(Li et al., 2016b)

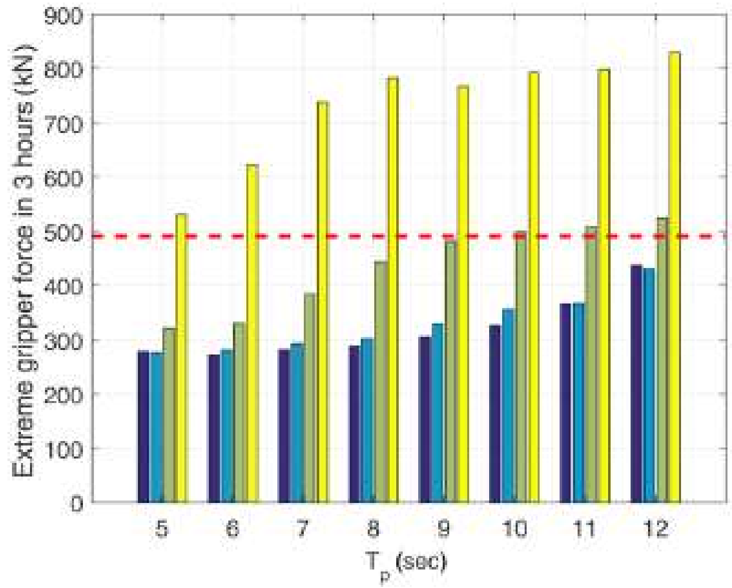
Monopile initial hammering process

ID crit. activities & events → Num. modeling → ID lim. param. → Assess charac. value → Assess oper. limits

Gripper contact force, Hs= 1.5m, Tp= 6s, wave dir= 150 deg



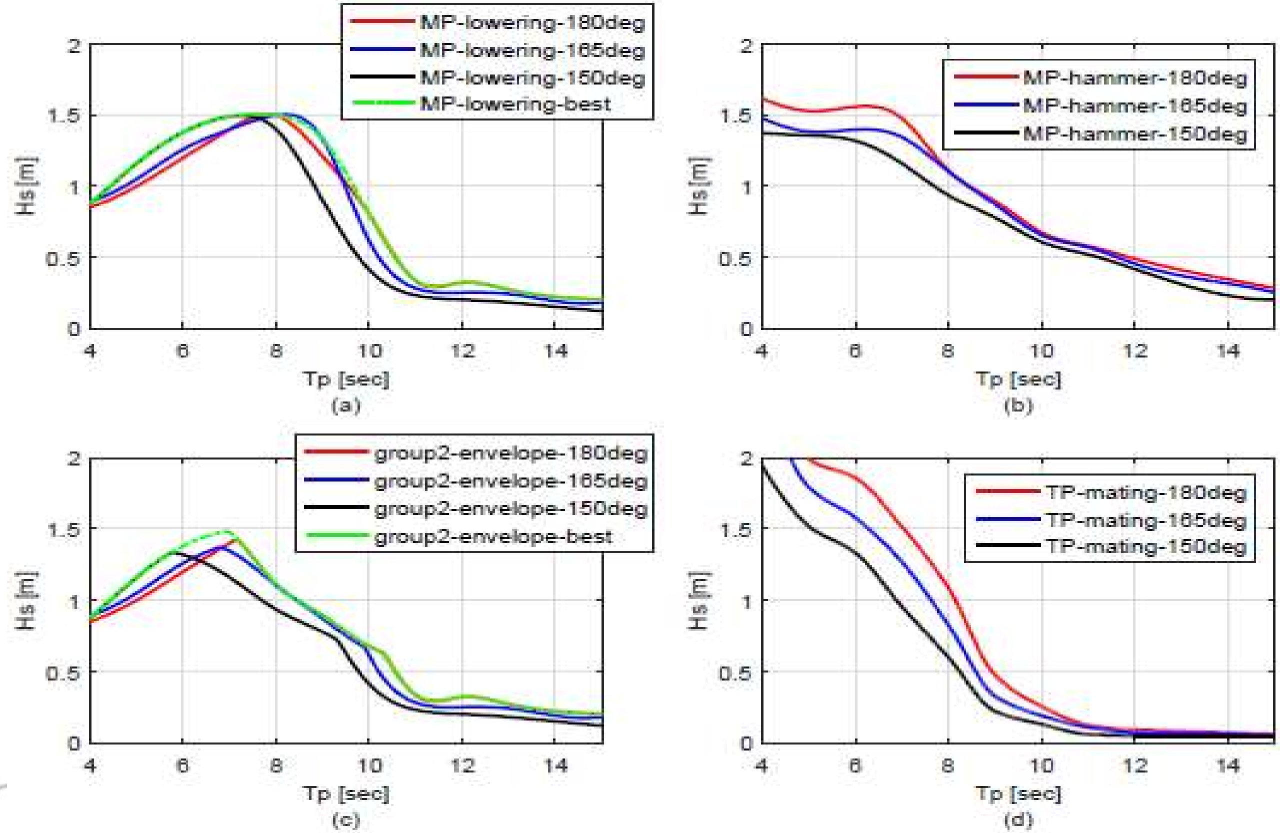
Characteristic gripper dynamic contact forces



(Li et al., 2016b)

Allowable limits of sea states MP and TP installation

ID crit. activities & events → Num. modeling → ID lim. param. → Assess charac. value → **Assess oper. limits**



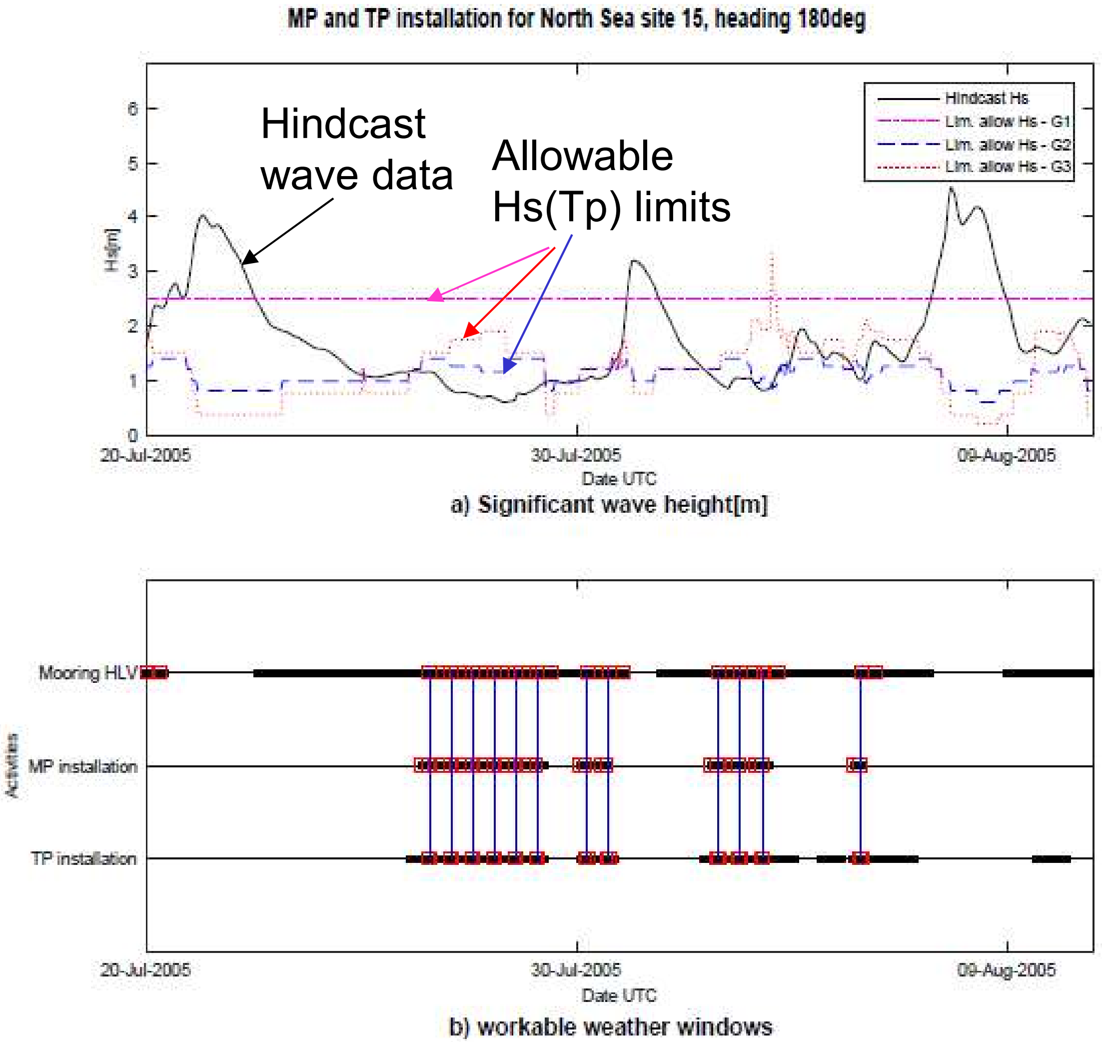
(Guachamin A. et al., 2016b; Li et al., 2016a)

Remember:

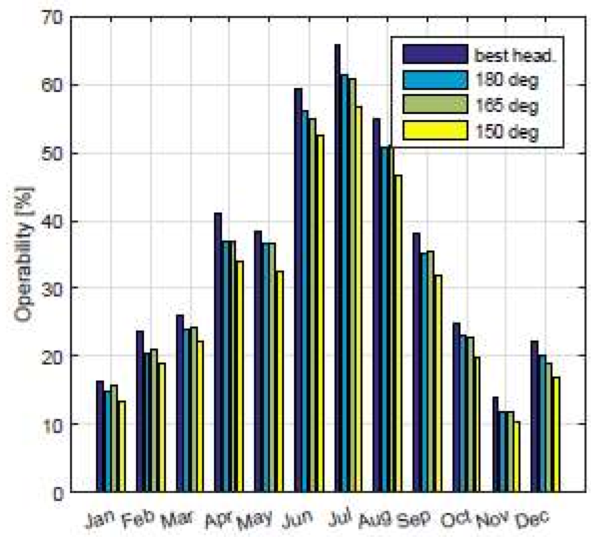
Decisions are made prior to execution of a MO (Another LC)!!

Courtesy of SHL

Assessment of the operability for MP and TP installation



Forecast can be used instead to make decision on-board vessels



(Guachamin A. et al., 2016b)

Conclusions and recommendations for future work

- A **generic and systematic methodology** for assessment of response-based operational limits was introduced.
- Operational limits can be given in terms of **Hs, Tp**, other **environmental parameter** of responses of vessels in a **monitoring condition prior to execution** of a MO.
- More **methodologies and tools** for numerical analysis of MO are needed.
- It is necessary to model the **real operations**, include duration.
- The operational limits should provide the **same safety levels** as the structural damage criteria.
- In future the operational limits should include various **sources of uncertainty and human decisions**.

Main references:

- Guachamin Acero, W., Gao, Z. & Moan, T. (2016a) Methodology for Assessment of the Allowable Sea States during Installation of an Offshore Wind Turbine Transition Piece Structure onto a Monopile Foundation. Journal of Offshore Mechanics and Arctic Engineering, under review.
- Guachamin Acero, W., Li, L., Gao, Z. & Moan, T. (2016b) Methodology for Assessment of the Operational Limits and Operability of Marine Operations. Ocean Engineering, 125: 308-327.
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- Li, L., Gao, Z., Moan, T. & Ormberg, H. (2014) Analysis of Lifting Operation of a Monopile for an Offshore Wind Turbine Considering Vessel Shielding Effects. Marine Structures, 39: 287-314.
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Thank you

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