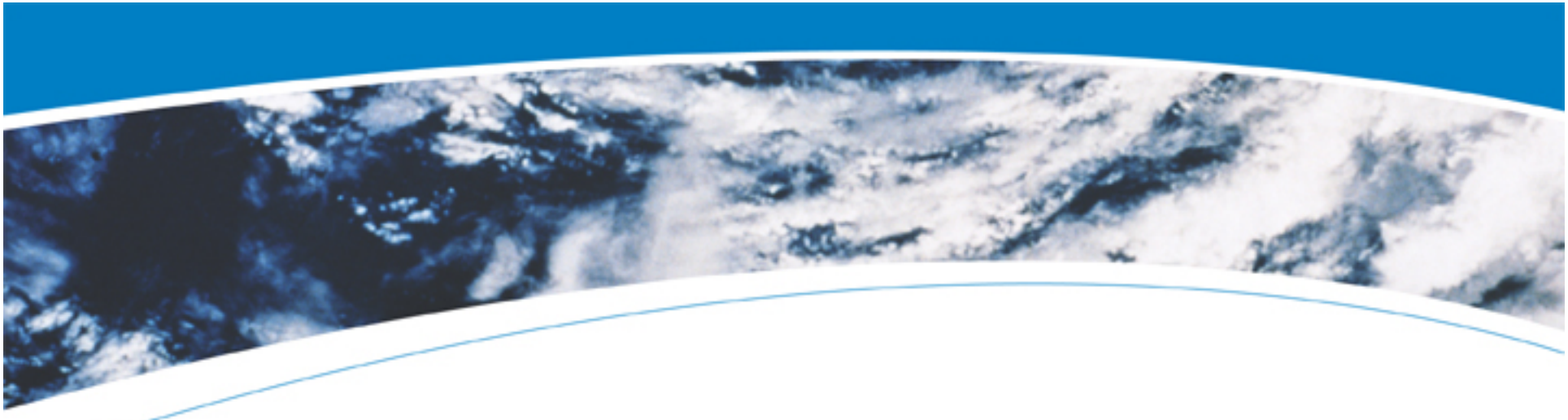

An International Design Standard for Offshore Wind Turbines: IEC 61400-3

David Quarton, Garrad Hassan and Partners Ltd

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The need for an international offshore wind turbine standard

- Offshore wind turbines are not onshore wind turbines!
  - Hydrodynamic loads, sea ice, long periods at standby
- Offshore wind turbines are not oil rigs!
  - Wind loads, shallow water, dynamics, unmanned
- Marriage of expertise from wind power and offshore engineering industries
- International consensus
  - Improve confidence with which offshore wind farms can be financed and implemented

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What standards already exist?

- Onshore wind turbines
  - IEC 61400-1, Edition 3
- Offshore wind turbines
  - GL Regulations for Offshore WECS, 1995
  - Danish Recommendation for Technical Approval of Offshore Wind Turbines, 2001
  - DNV, Design of Offshore Wind Turbine Structures, OS-J101, 2004
  - GL Wind, Guideline for the Certification of Offshore Wind Turbines, 2005
- Offshore structures – petroleum and natural gas industries
  - ISO 19900, General Requirements for Offshore Structures, 2002
  - ISO 19901, Specific Requirements for Offshore Structures, 2003
  - ISO 19902, Fixed Steel Offshore Structures, 2004 (DIS)
  - ISO 19903, Fixed Concrete Offshore Structures, 2004 (DIS)

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The history

- IEC TC88 MT1 tasked in 1999 with development of Ed. 3 of the onshore wind turbine standard: 61400-1
- Subgroup of MT1 dealing with offshore issues
- Proposal for separate WG to develop offshore standard, February 2000
- Proposal accepted, launch meeting of WG3 held in October 2000
- IEC TC88 WG3 tasked with developing offshore wind turbine standard: 61400-3

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WG3 participation

- Members appointed from:
  - Denmark
  - Germany
  - Greece
  - Japan
  - Netherlands
  - Norway
  - S. Korea
  - Spain
  - Sweden
  - UK
  - USA
- Convenor from UK
- Secretary from the Netherlands

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Objective of WG3

- To develop an international standard for the engineering and technical requirements which should be considered during design in order to ensure the safety of systems and components of offshore wind turbines, inclusive of their support structures."
- 61400-3 covers only those issues relevant to offshore wind turbines but remaining fully consistent with the onshore standard 61400-1

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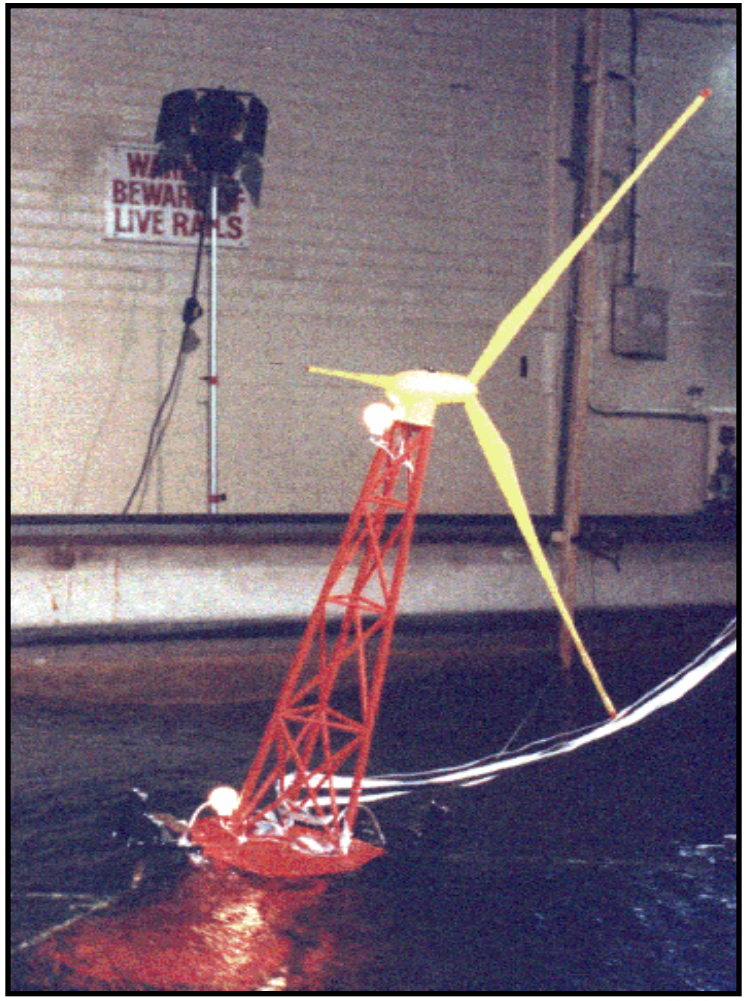
Scope of 61400-3

- A wind turbine is considered “offshore” if the support structure is subject to hydrodynamic loading.

Scope of 61400-3



- Although relevant to both “bottom-mounted” and floating offshore wind turbines, the design requirements specified in the standard are not sufficient to ensure the engineering integrity of floating wind turbines

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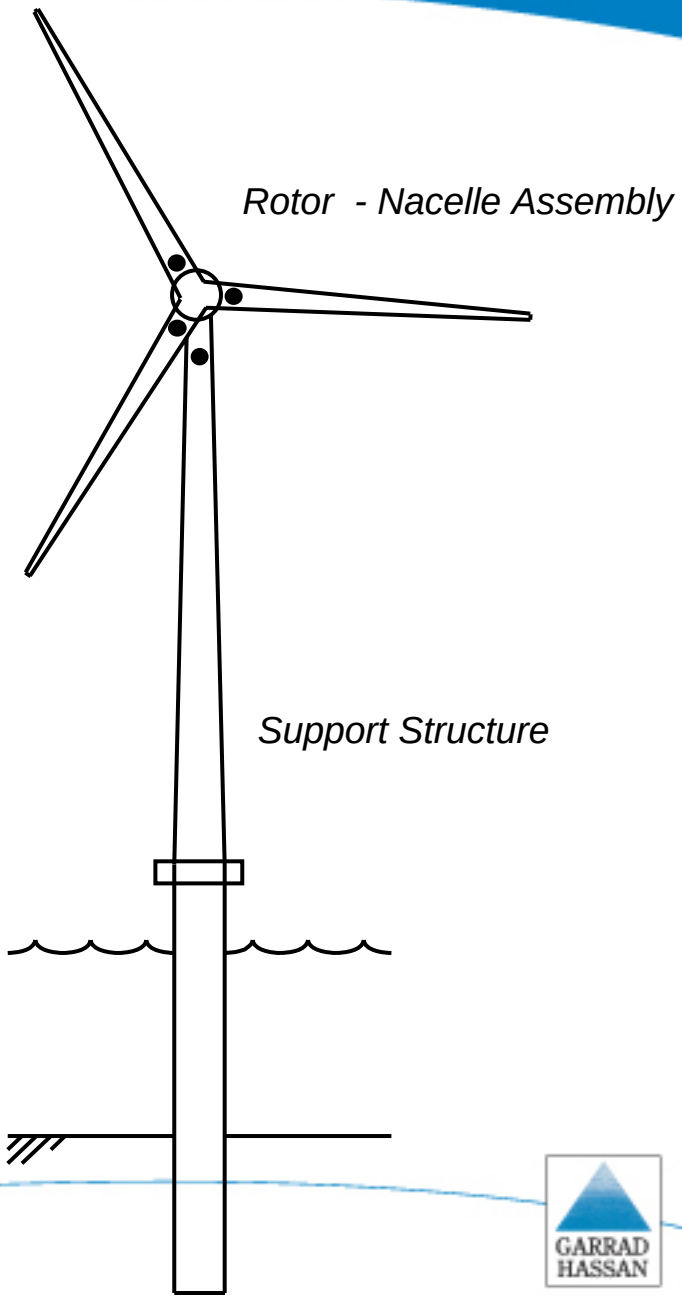
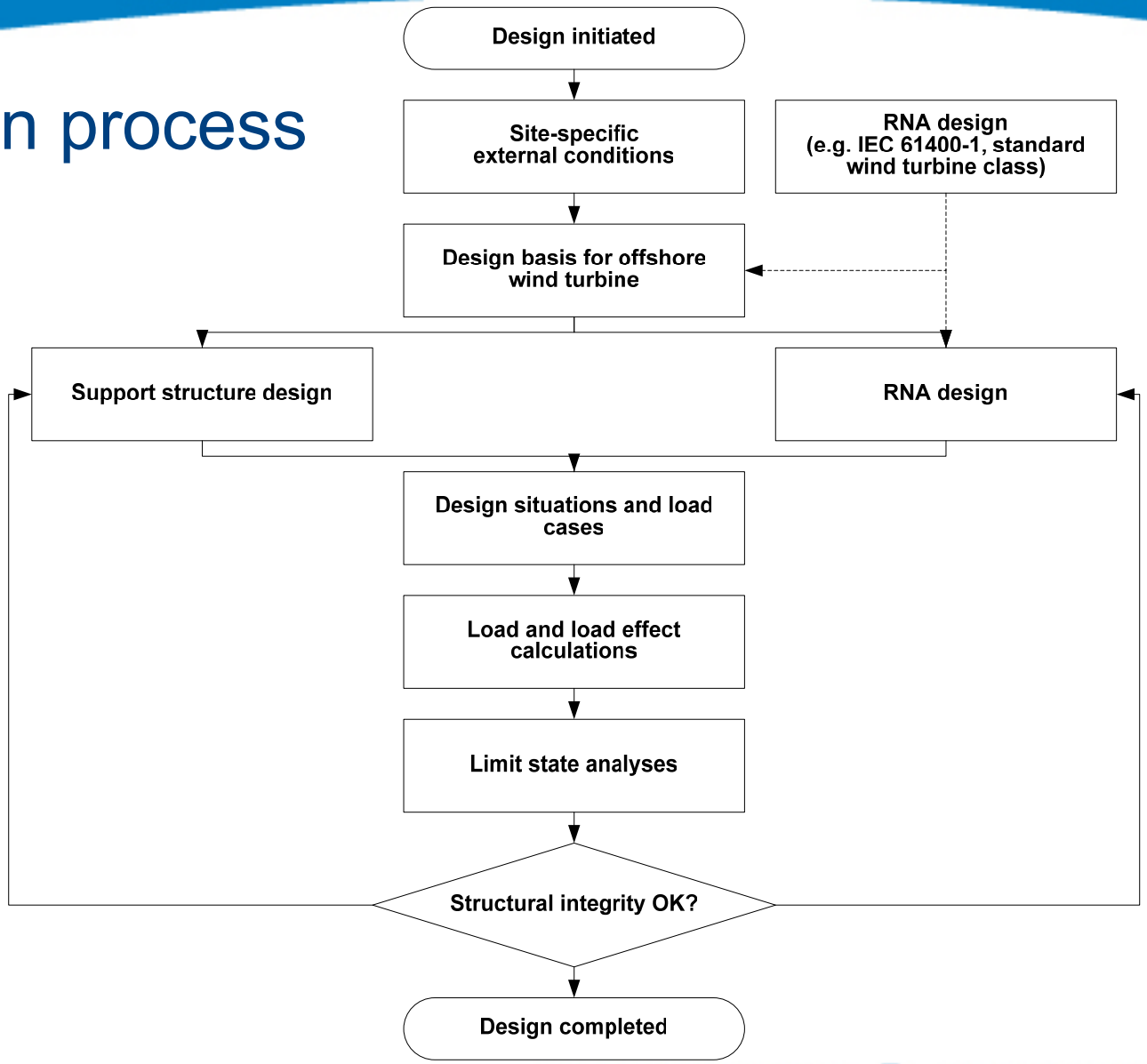
Design basis

- Support structure design <u>must</u> be based on “site-specific” conditions

- Design of rotor - nacelle assembly <u>may</u> be based on:
  - site-specific conditions, or,
  - generic conditions, e.g. from 61400-1. In this case the structural integrity of RNA <u>must</u> be demonstrated based on site-specific conditions



Design process



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Wind turbine classes

- Wind turbine classes defined in 61400-1 Ed.3 remain appropriate as basis of design of RNA of offshore wind turbine
- No justification for change to wind speed or turbulence parameter values

Wind turbine class		**I**	**II**	**III**	**S**
V_{ref}	(m/s)	50	42,5	37.5	Values specified by the designer
A	I_{ref} (-)	0,16			
B	I_{ref} (-)	0,14			
C	I_{ref} (-)	0,12			

Marine environmental conditions

- Marine conditions
  - Waves
  - Currents
  - Water level
  - Sea ice
  - Marine growth
  - Scour and seabed movement
- Normal conditions – occur frequently during normal operation of wind turbine
- Extreme conditions – 1 year and 50 year recurrence period

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Waves

- Stochastic sea state model
  - Wave spectrum (Pierson-Moskowitz, JONSWAP)
  - Significant wave height
  - Peak spectral period
  - Mean wave direction
  - Normal sea state (NSS), Extreme sea state (ESS), Severe sea state (SSS)
- Deterministic design wave
  - Height, period and direction
  - Normal wave height (NWH), Extreme wave height (EWH), Reduced wave height (RWH), Severe wave height (SWH)

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Correlation of wind and waves

- Normal conditions
  - Joint probability distribution of mean wind speed, significant wave height and peak spectral period from site specific data (“scatter diagram”)
  - Common averaging period
  - Wind and wave directions may be considered
    - Importance of directionality depends on symmetry of support structure
    - Designer may demonstrate in some cases that it is conservative and acceptable to assume wind and waves are “co-directional” and “uni-directional”

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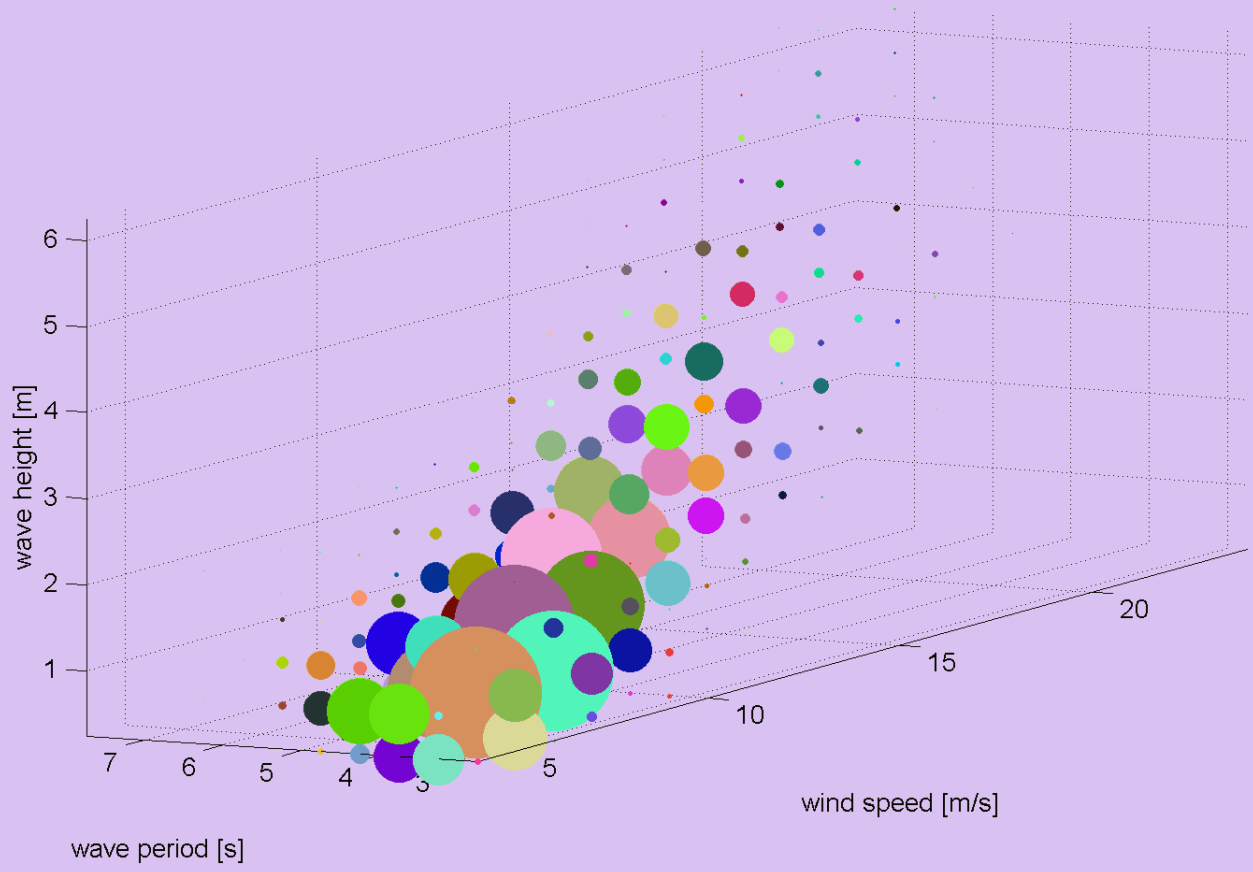
Scatter diagram – North Sea site



Correlation of wind and waves

- Extreme conditions
  - Combinations of mean wind speed and sea state corresponding to 50 year recurrence period
  - Relevant to turbine in power production and at standby
  - Assume that 50 year recurrence 10 min. wind speed (V_{ref}) and 50 year recurrence sea state (H_{s50}) are correlated
  - No correlation of 50 year recurrence 3s gust and 50 year recurrence extreme wave height
    - Assume 50 year recurrence extreme wave height is correlated with 50 year recurrence reduced wind speed ($V_{r50} = 1.1 * V_{ref}$)
    - Assume 50 year recurrence 3s gust is correlated with 50 year recurrence "reduced wave height" ($H_{r50} = 1.1 * H_{s50}$)

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Breaking waves (spilling, plunging)

- Great uncertainty
- Guidance on site assessment to determine nature of breakers
  - Water depth, sea bed slope, wave period etc
- Guidance on load calculation

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Sea currents

- Sub surface currents generated by tides, storm surge and atmospheric pressure variations
- Wind generated, near surface currents
- Near shore, breaking wave induced surf currents

- Normal current model (NCM)
  - Combination of wind generated and surf induced currents
  - NCM assumed for load cases involving normal and severe waves

- Extreme current model (ECM)
  - Combination of sub surface, wind generated and surf induced currents
  - ECM assumed for load cases involving extreme waves

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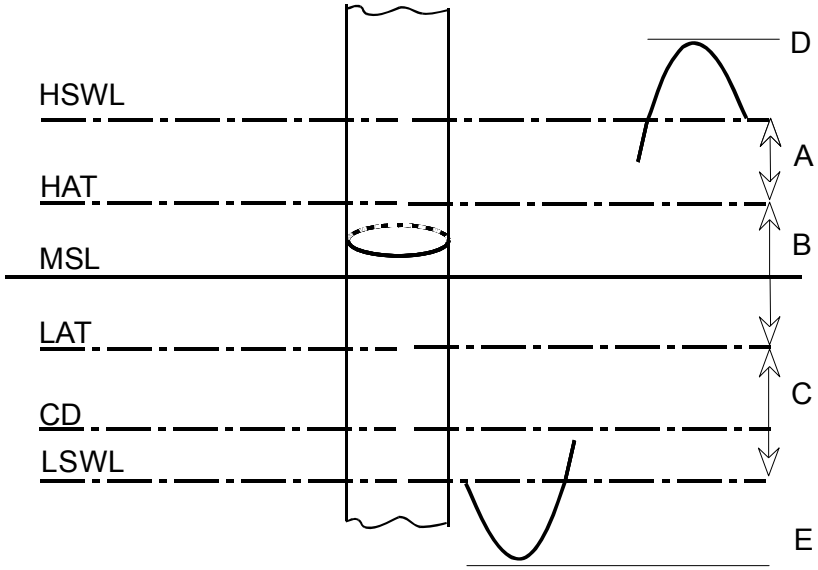
Water level

- Variation in water level important for load calculations
- Normal water level range (NWLR)
  - Variation in water level with 1 year recurrence period
  - In absence of site-specific data, assume between HAT and LAT
- Extreme water level range (EWLR)
  - Variation between HSWL (combination of HAT and positive storm surge) and LSWL (combination of LAT and negative storm surge), 50 year recurrence period



HSWL	highest still water level
HAT	highest astronomical tide
MSL	mean sea level
LAT	lowest astronomical tide
CD	chart datum (often equal to LAT)
LSWL	lowest still water level
A	positive storm surge
B	tidal range
C	negative storm surge
D	maximum crest elevation
E	minimum trough elevation

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Sea ice

- Loads from rigid ice cover
  - Thermal ice pressure
  - Sea level fluctuation
- Loads from moving ice floes
- Dynamic loading
- Standard provides:
  - Definition of load cases
  - Guidance on site assessment
  - Guidance on load calculation methods

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Loads

- Sources of load as for onshore turbines +
  - Hydrodynamic loads
  - Sea ice loads
  - Boat (+helicopter) impact
- Hydrodynamic loads affect RNA indirectly through vibration of support structure
  - Weak effect

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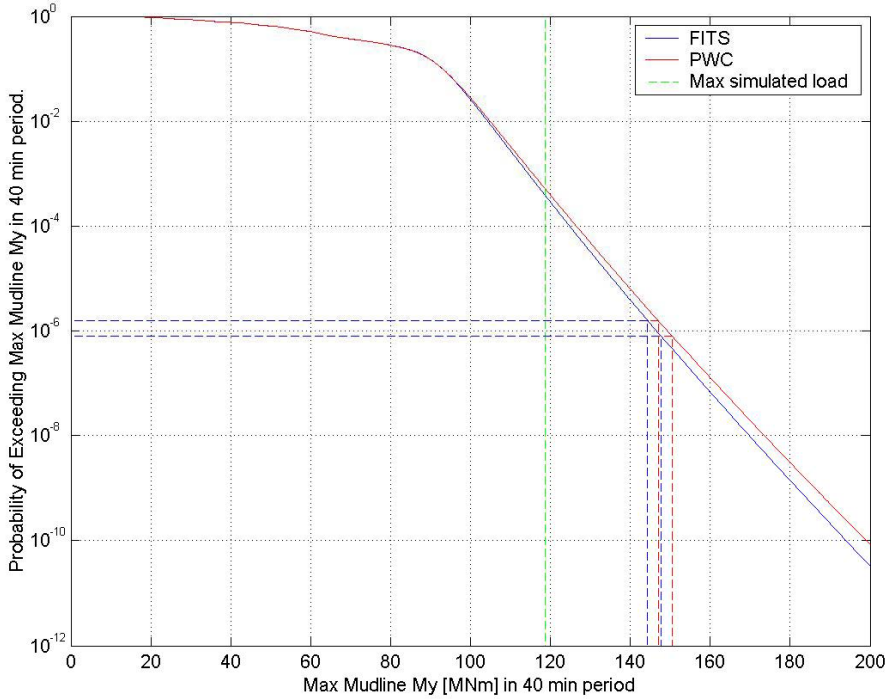
Load calculation methods

- Standard provides guidance on calculation methods
  - Combination of aerodynamic and hydrodynamic loads
  - Non-linear wave kinematics, diffraction
  - Misalignment between wind and wave directions
  - Extreme load calculations: deterministic simulation, stochastic simulation, probabilistic extrapolation



Design load cases

- Normal design situations with normal or extreme external conditions
- Fault design situations with appropriate external conditions
- Transportation, installation, maintenance situations with appropriate external conditions
- Offshore turbines may experience long periods of non-production time
  - Fault on the turbine, no access for repair
  - Non-connection / fault on electrical network

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Example design load cases

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
1) Power production	1.1a	NTM $V_{in} < V_{hub} < V_{out}$ RNA	NSS $H_s=E[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL	For extrapolation of extreme loads on the RNA	U	N (1,25)
	1.1b	NTM $V_{in} < V_{hub} < V_{out}$ Support structure	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, UNI	NCM	NWLR	For extrapolation of extreme loads on the support structure	U	N (1,25)
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ≥ MSL		F	*
	1.3	ETM $V_{in} < V_{hub} < V_{out}$	NSS $H_s=E[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.4	ECD $V_{hub} = V_r - 2$ m/s, V_r, $V_r + 2$ m/s	NSS (or NWH) $H_s=E[H_s \mid V_{hub}]$	MIS, wind direction change	NCM	MSL		U	N
	1.5	EWS $V_{in} < V_{hub} < V_{out}$	NSS (or NWH) $H_s=E[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.6a	NTM $V_{in} < V_{hub} < V_{out}$	SSS $H_s = H_{s,SSS}$	COD, UNI	NCM	NWLR		U	N
	1.6b	NTM $V_{in} < V_{hub} < V_{out}$	SWH $H = H_{SWH}$	COD, UNI	NCM	NWLR		U	N

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Partial safety factors

- Review of other standards
  - Onshore wind turbines
  - Offshore structures
- Assume same level of safety for offshore wind turbines as for onshore turbines (61400-1)
- Similar to safety level adopted in ISO 19902/3 for an unmanned offshore structure with low consequences of failure - “exposure level L3”
- Safety factor calibration studies
- For ultimate loading, PSFL = 1.35 (N)
- Structural design resistance (PSFM etc)
  - For RNA, follow IEC 61400-1
  - For support structure, follow ISO 19901/2/3 or other recognised offshore standards
  - If offshore standards other than ISO are used, same level of structural reliability must be demonstrated
  - Design resistance of tower may be determined from IEC 61400-1

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Site assessment

- Required as basis of design of support structure
- Required as basis of demonstration of structural integrity of RNA
- Standard specifies requirements for:
  - Establishment of the metocean database
  - Assessment of waves
  - Assessment of currents
  - Assessment of water levels, tides and storm surges
  - Assessment of sea ice
  - Assessment of marine growth
  - Assessment of scour and seabed movement
  - Assessment of weather windows and weather downtime
  - Assessment of seabed soil conditions
- Requirements of 61400-1 are followed for assessment of wind and other external conditions

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Other issues

- Reference to 61400-1 is made for:
  - Control and protection system
  - Mechanical systems
  - Electrical system
- Requirement for protection of all components against the effects of the marine environment
- Revision and supplement of requirements in 61400-1 for:
  - Assembly, installation, erection, commissioning, operation, maintenance and de-commissioning

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Informative annexes

- Standard provides substantial guidance and background information in annexes:
  - Key design parameters for offshore wind turbines
  - Wave spectrum formulations
  - Shallow water hydrodynamics and breaking waves
  - Guidance on calculation of hydrodynamic loads
  - Recommendations for design of support structures with respect to ice loads
  - Offshore wind turbine foundation design
  - Characteristic offshore wind turbine loads for ultimate strength analysis
  - Statistical extrapolation of operational metocean parameters for ultimate strength analysis
  - Corrosion protection
  - Bibliography

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Timetable

Status of 61400-3	**Target Date**
Availability of first WD (working draft)	December 2001
Circulation of first CD (committee draft)	December 2005
Submission of first CDV (committee draft for voting)	June 2006
Submission of FDIS (final draft international standard)	December 2006
Availability of IS (international standard)	2007

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