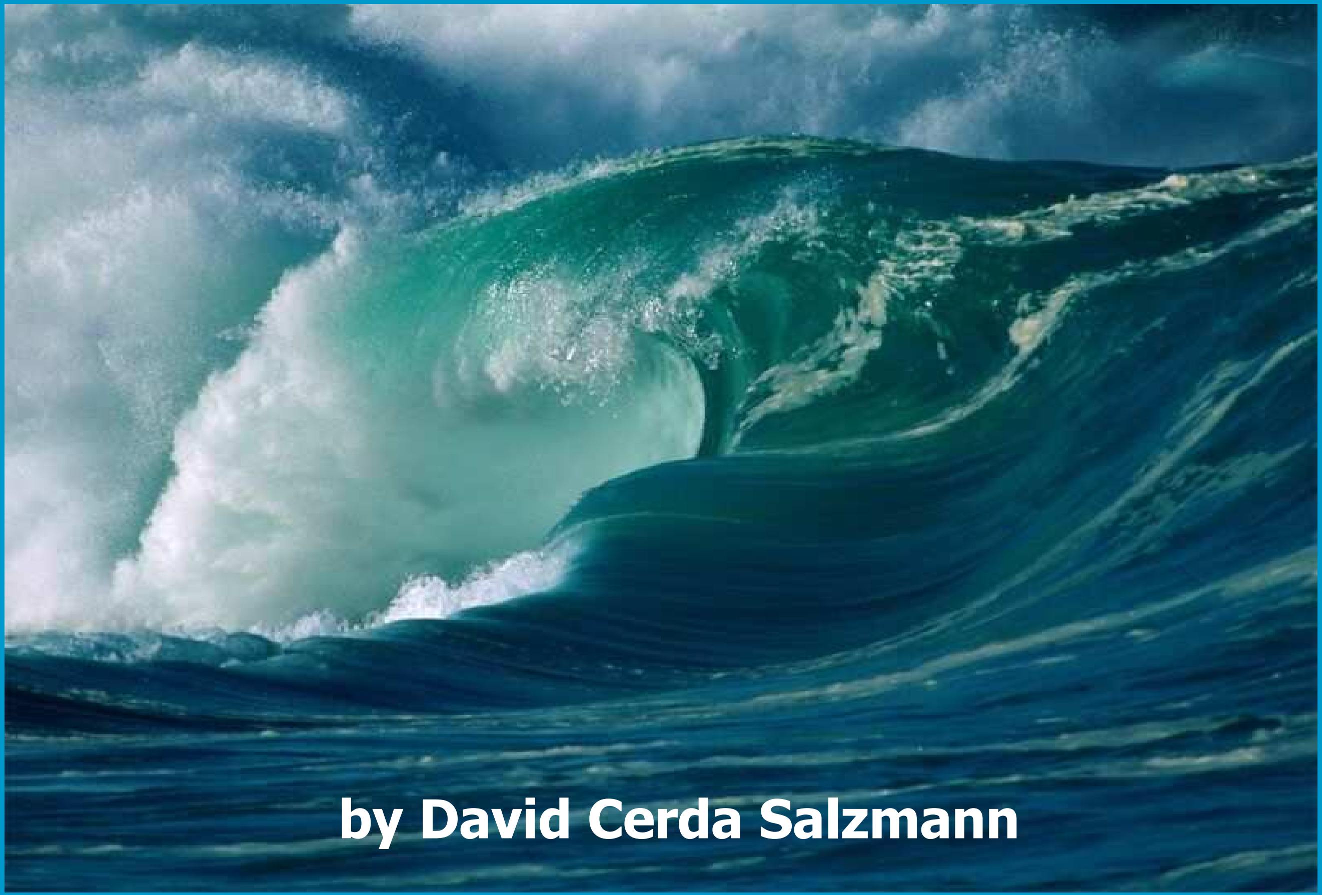
Waves & Current



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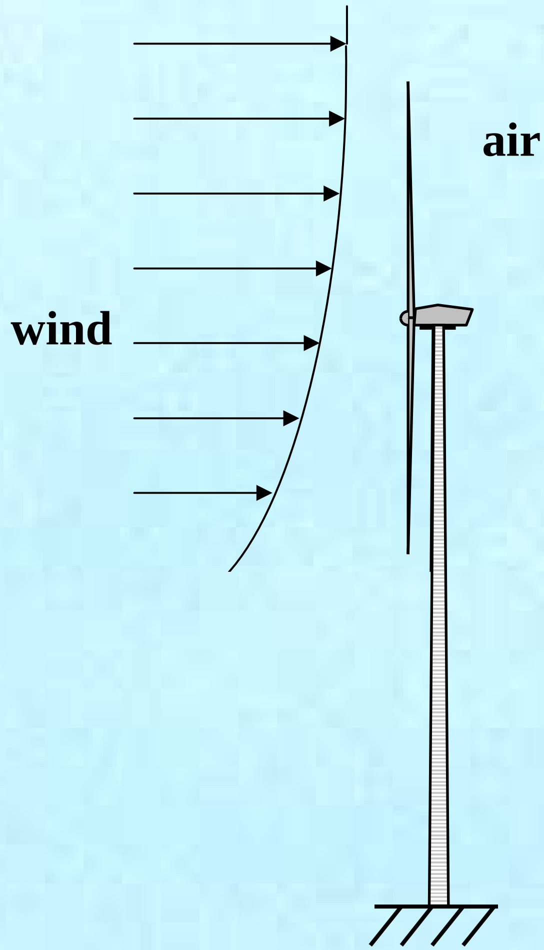
Environmental Loads: Onshore



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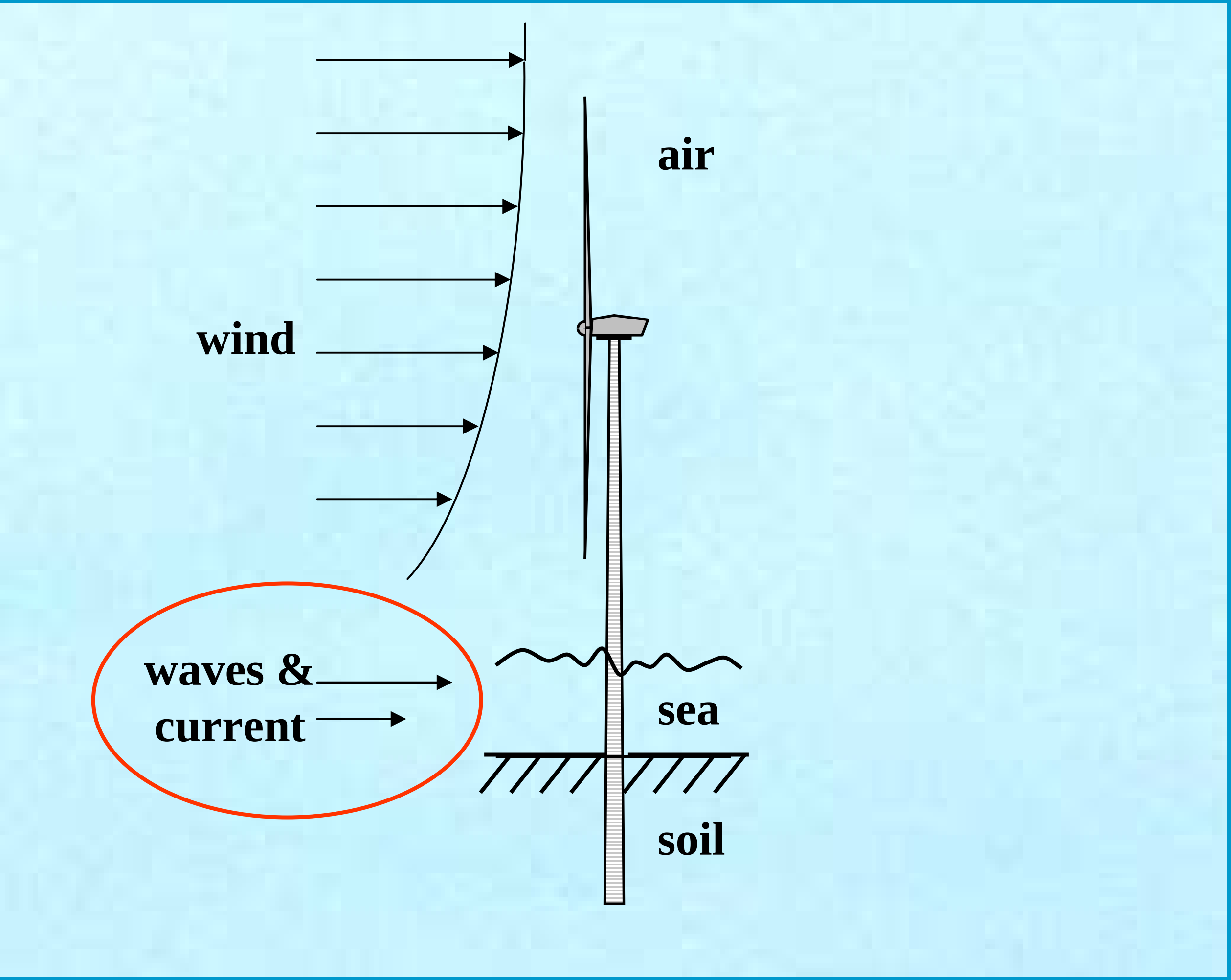
Environmental Loads: Offshore



Waves

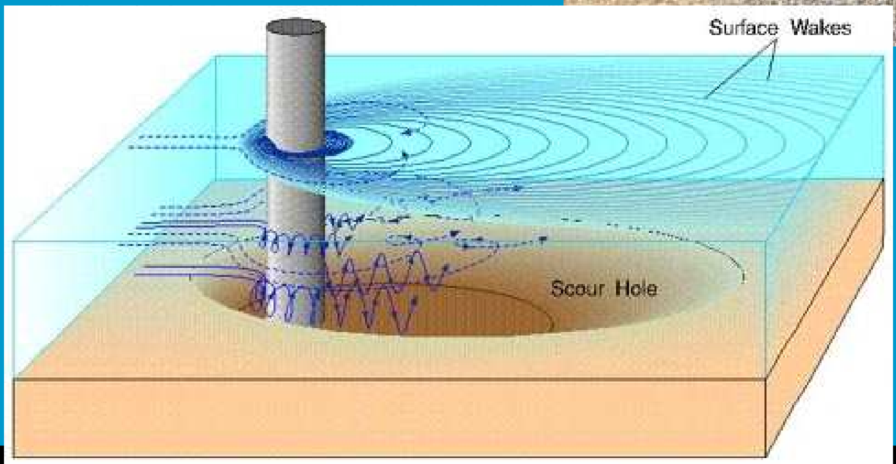
Consider waves for:

- Extremes
- Fatigue
- Installation & Maintenance

Current

Consider current for:

- Extremes
- Fatigue
- Installation & Maintenance
- Scour



In this lecture...

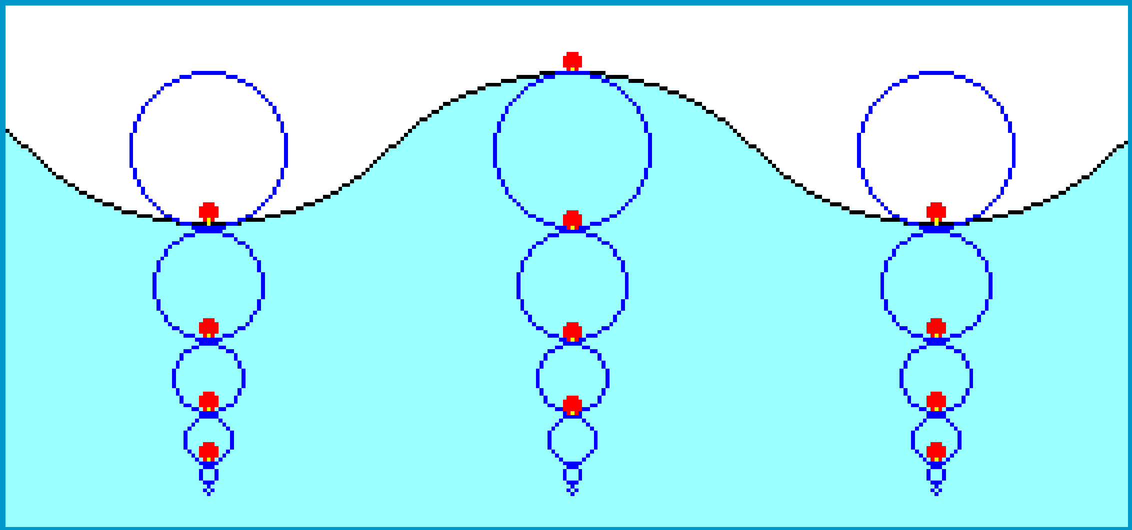
- What data do you need
- What do you use it for

- Next hour: where to get data from

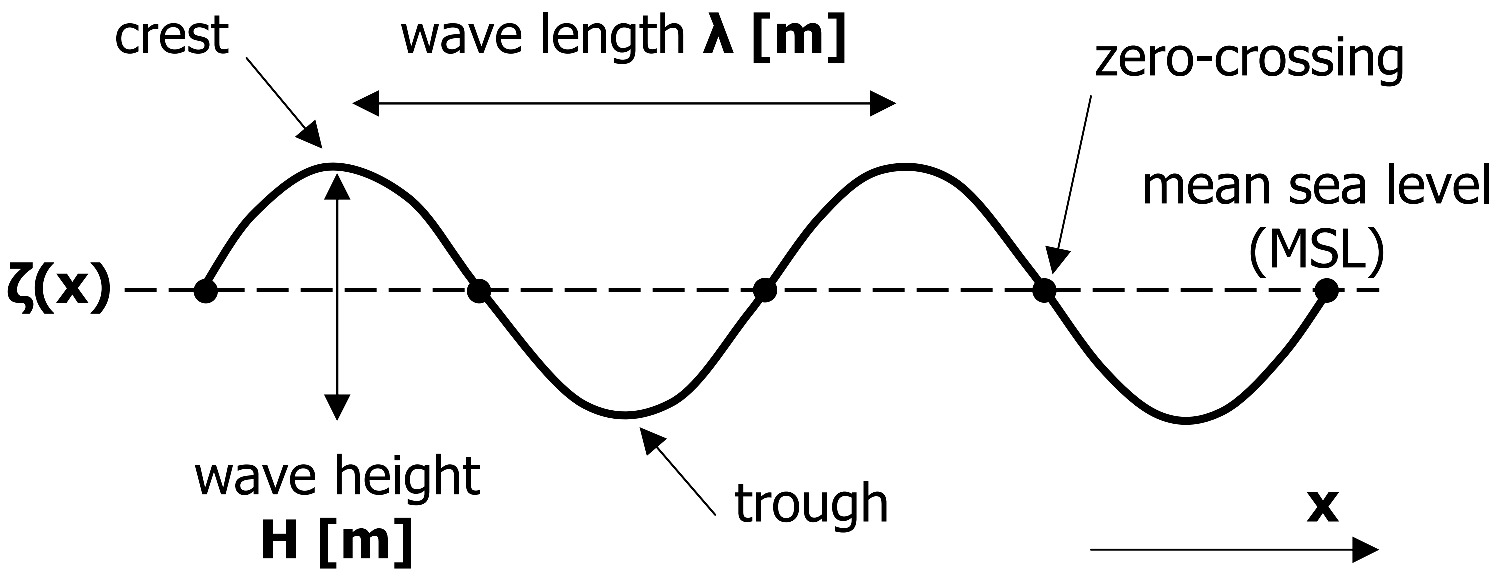
Ocean Surface Waves

Definition:

"Perturbations that propagate through water"



Regular Waves



snap shot: t = fixed

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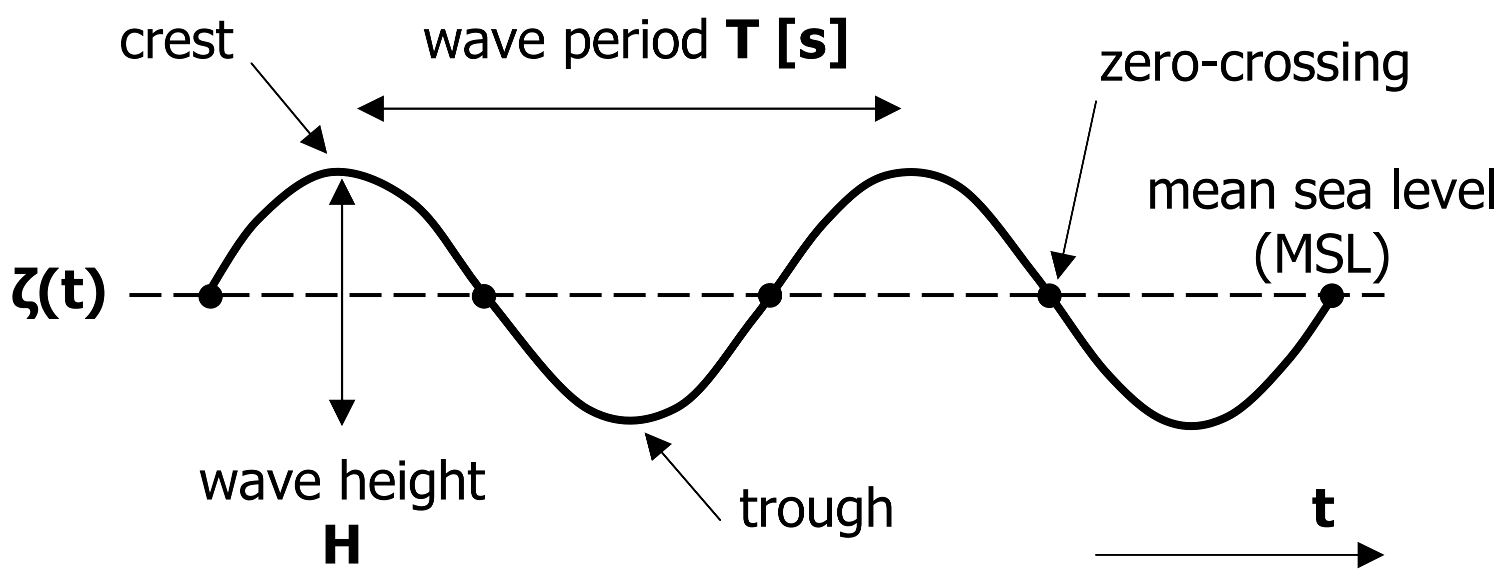
Regular Waves



time history: x=fixed

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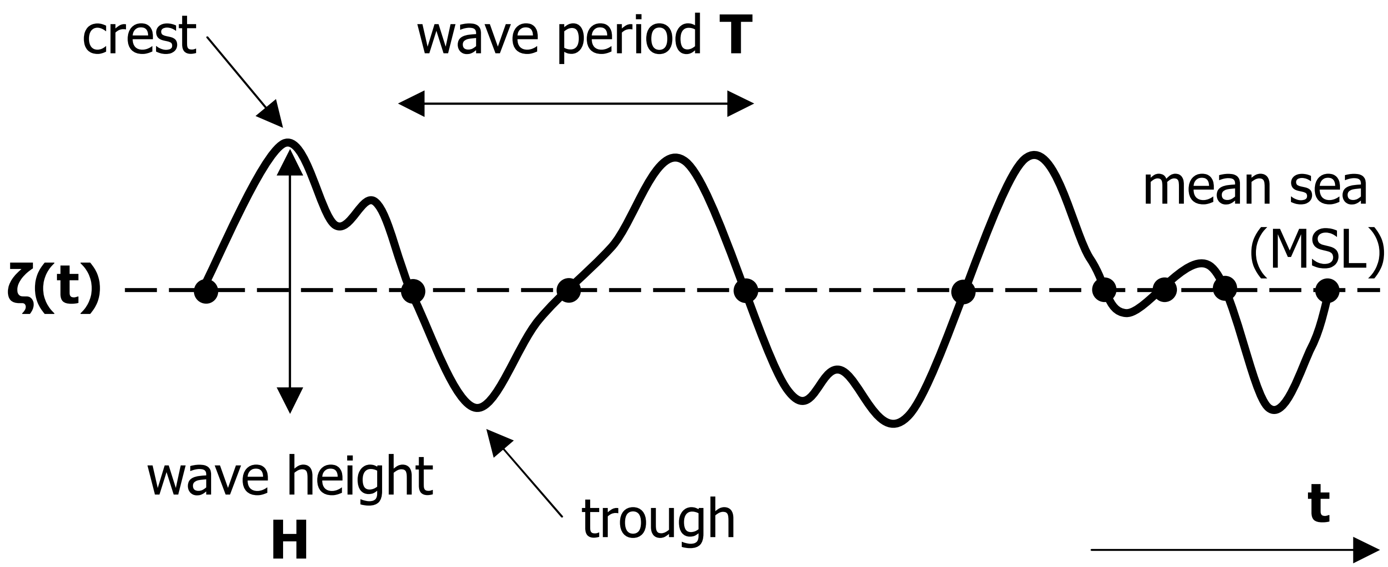
Irregular Waves



time history: x=fixed

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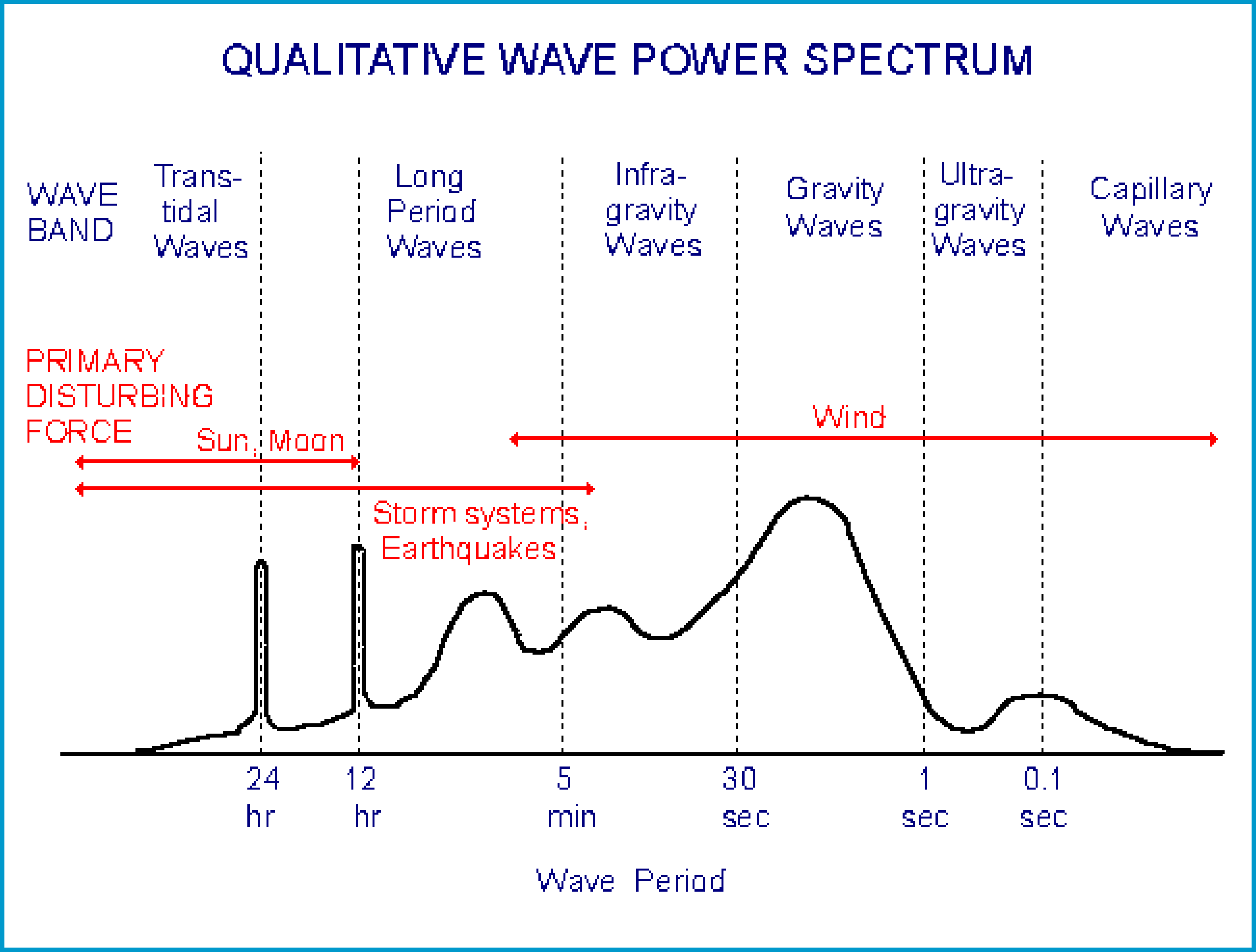
Irregular Waves

T_z = Mean zero (up/down)-crossing period [s]

H_s = Significant wave height [m]

"Average of highest 1/3 of the waves in the record."

Wind Waves



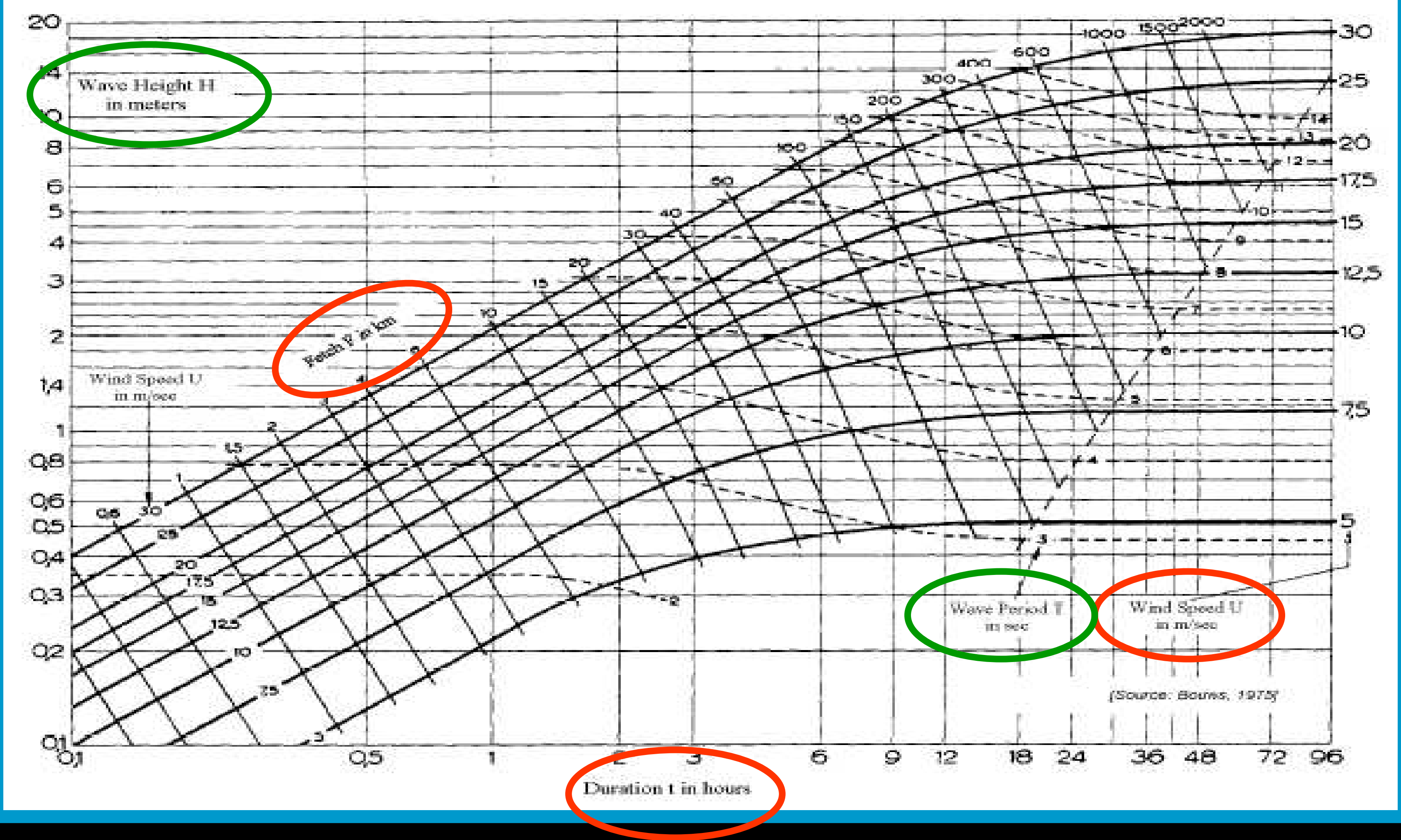
QUALITATIVE WAVE POWER SPECTRUM
WAVE BAND
Trans-tidal Waves
Long Period Waves
Infra-gravity Waves
Gravity Waves
Ultra-gravity Waves
Capillary Waves
PRIMARY DISTURBING FORCE
Sun, Moon
Wind
Storm systems, Earthquakes
24 hr
12 hr
5 min
30 sec
1 sec
0.1 sec
Wave Period

Wind Waves

Wave generation influenced by:

- Wind speed
- Fetch: distance over which the waves have travelled under that wind field
- Duration of the wind speed

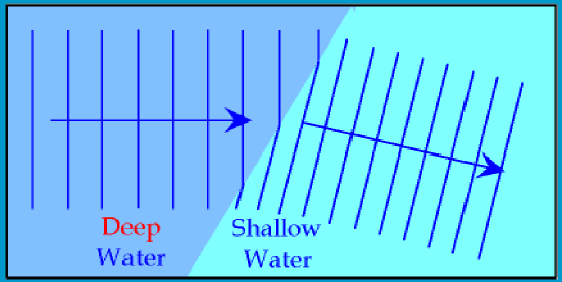
Wind Waves


Wave Height H in meters
Wind Speed U in m/sec
Fetch F in km
Wave Period T in sec
Wind Speed U in m/sec
Duration t in hours
(Source: Bouws, 1975)

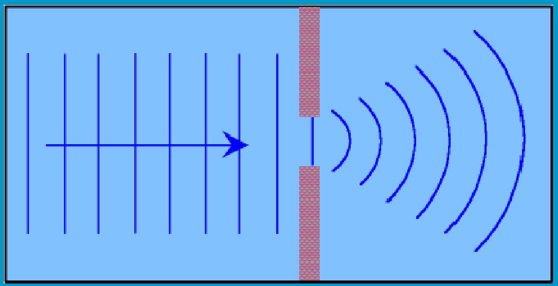
Wind Waves

Wave characteristics influenced by:

- Refraction



- Diffraction



- Breaking Waves

$$H \leq 0.78 * d$$

Wind Waves

SO:

Look at the map and use common sense!

Wind Waves

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Wind Waves Resuming

The development of wind waves requires:

- Wind speed
- Fetch
- Time

- Water Depth

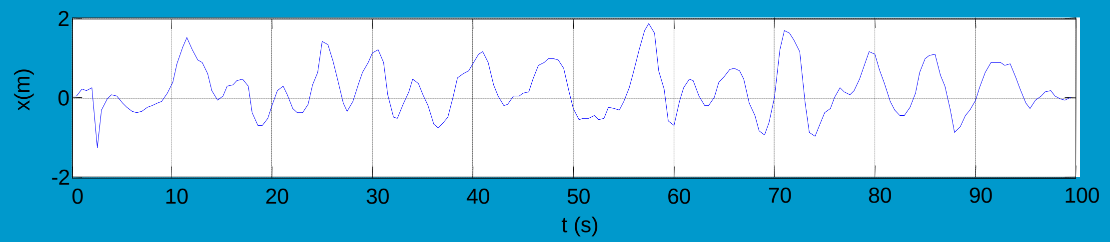
Wave Statistics

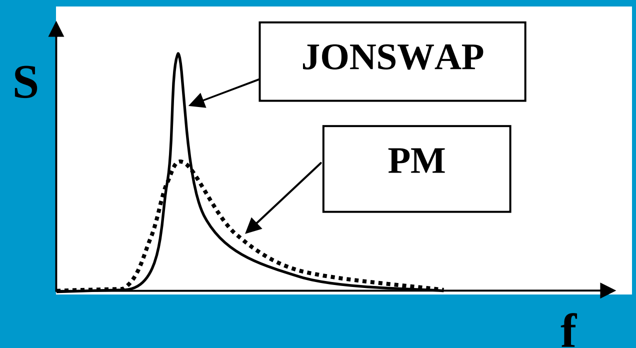
Required for Simulations & Calculations

- Short term 3 hours
- Long term year(s)

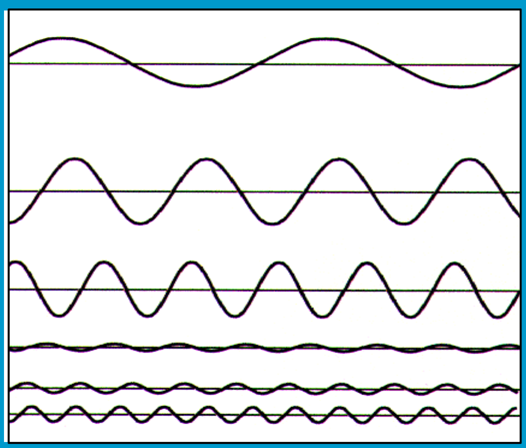
Short term statistics

Wave Time Series:
Irregular!





Wave Spectrum:
Statistical representation of
3-hour sea state



Series of regular waves

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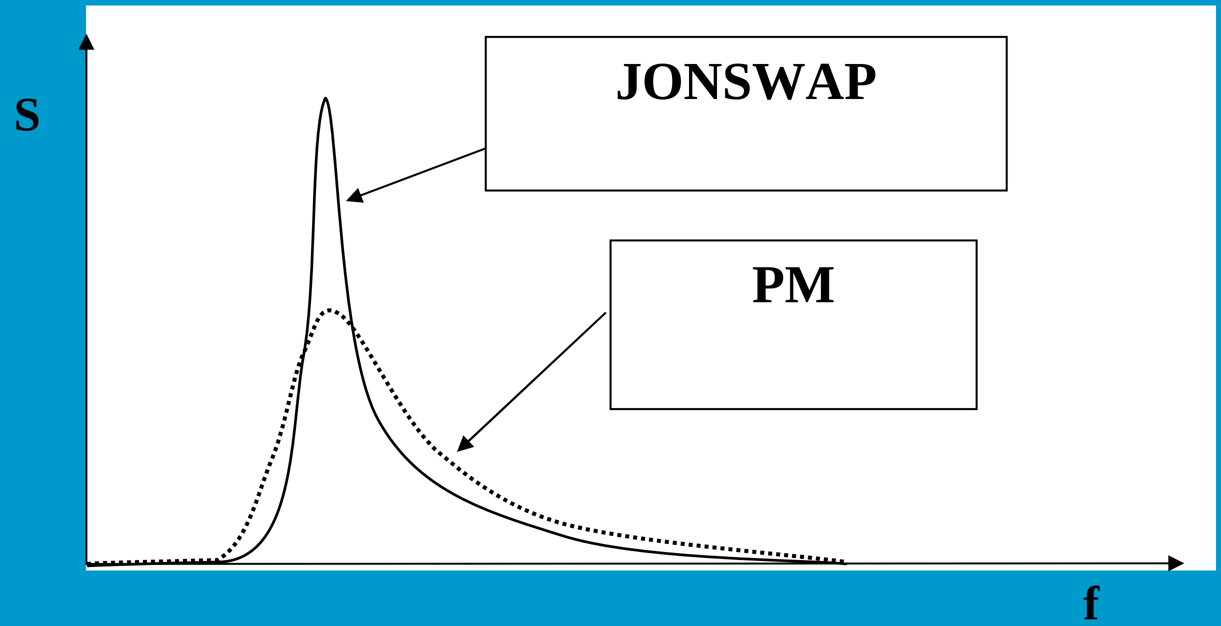
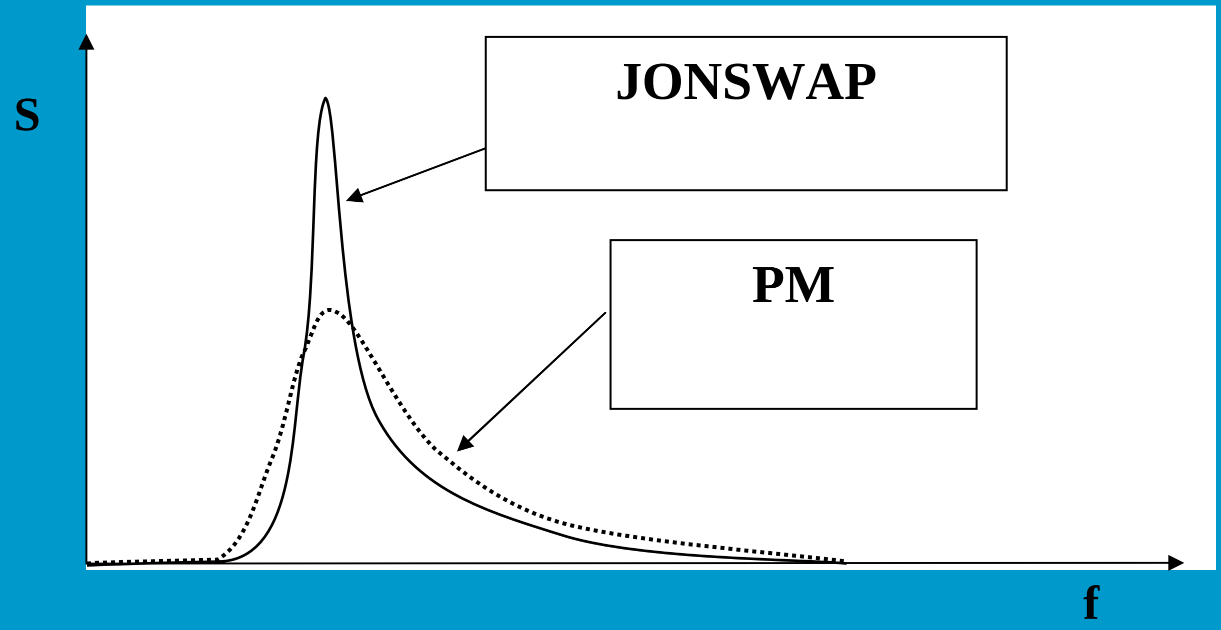
Short term statistics

JONSWAP: Fetch limited
Pierson-Moskowitz: Fully developed sea

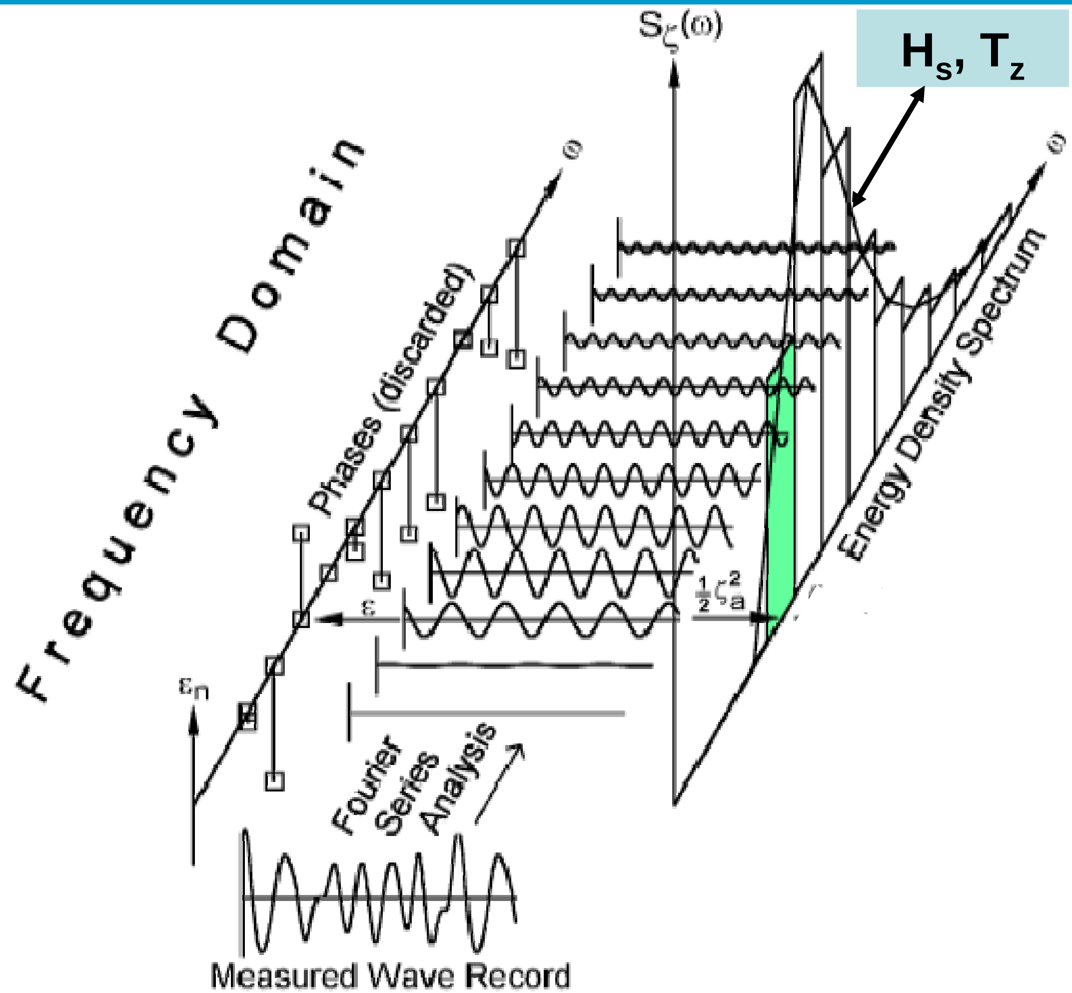


Short term statistics

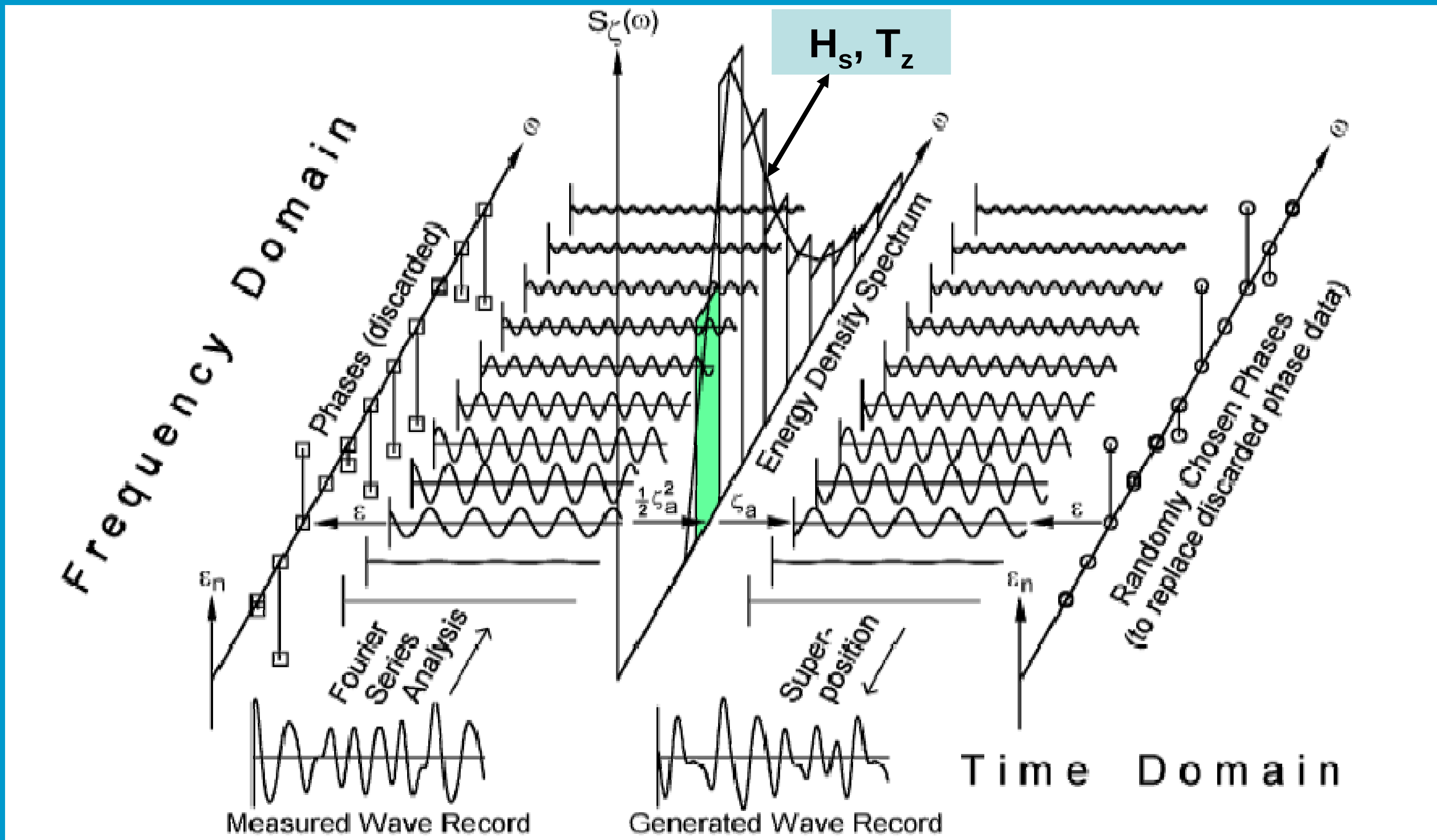
H_S = Significant Wave Height [m]
T_Z = Mean Zero Crossing Period [s]



Short term statistics



Short term statistics



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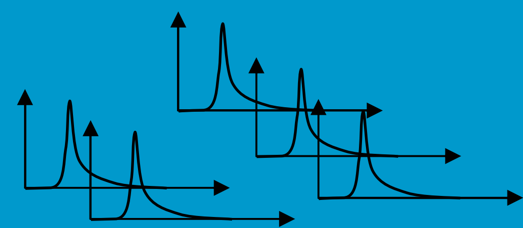
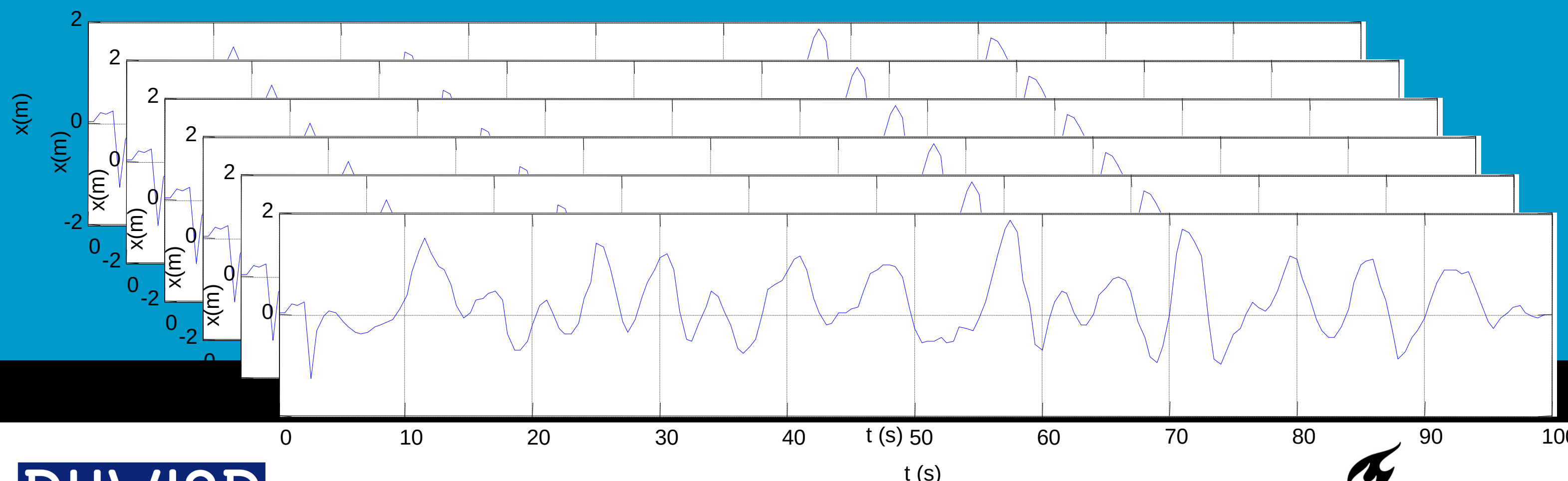
Long term statistics

So: Wave scatter diagram is the long-term statistical representation of sea states

H_s [m] \ T_z [s]	0 - 1	1 - 2	2 – 3	3 – 4	4 – 5	5 - 6	6 - 7	7 - 8	Sum:
6.5 - 7.0									**0**
6.0 - 6.5								0.1	**0.1**
5.5 - 6.0							0.1	0.1	**0.2**
5.0 - 5.5							0.1	0.1	**0.2**
4.5 - 5.0							1		**1**
4.0 - 4.5							4		**4**
3.5 - 4.0						4	5		**9**
3.0 - 3.5						19	0.1		**19.1**
2.5 - 3.0					0.1	38			**38.1**
2.0 - 2.5					27	43			**70**
1.5 - 2.0				0.1	115	5			**120.1**
1.0 - 1.5				6	220	1			**227**
0.5 - 1.0				236	145	1			**382**
0.0 - 0.5	1		1	113	14	0.1	0.1		**129.2**
sum:	**1**	**0**	**1**	**355.1**	**521.1**	**111.1**	**10.4**	**0.3**	**1000**





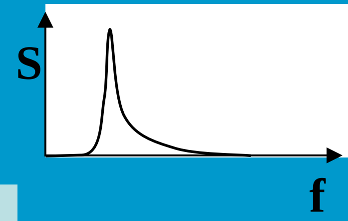
Environmental Data

Scatter diagram gives the wave data:

- Over a certain period
- For a certain location

Long term statistics

Wave scatter diagram



H_s [m]	T_z [s] 0 - 1	1 - 2	2 – 3	3 – 4	4 – 5	5 - 6	6 - 7	7 - 8	Sum:
6.5 - 7.0									**0**
6.0 - 6.5								0.1	**0.1**
5.5 - 6.0							0.1	0.1	**0.2**
5.0 - 5.5							0.1	0.1	**0.2**
4.5 - 5.0							1		**1**
4.0 - 4.5							4		**4**
3.5 - 4.0						4	5		**9**
3.0 - 3.5						19	0.1		**19.1**
2.5 - 3.0					0.1	38			**38.1**
2.0 - 2.5					27	43			**70**
1.5 - 2.0				0.1	115	5			**120.1**
1.0 - 1.5				6	220	1			**227**
0.5 - 1.0				236	145	1			**382**
0.0 - 0.5	1		1	113	14	0.1	0.1		**129.2**
sum:	**1**	**0**	**1**	**355.1**	**521.1**	**111.1**	**10.4**	**0.3**	**1000**

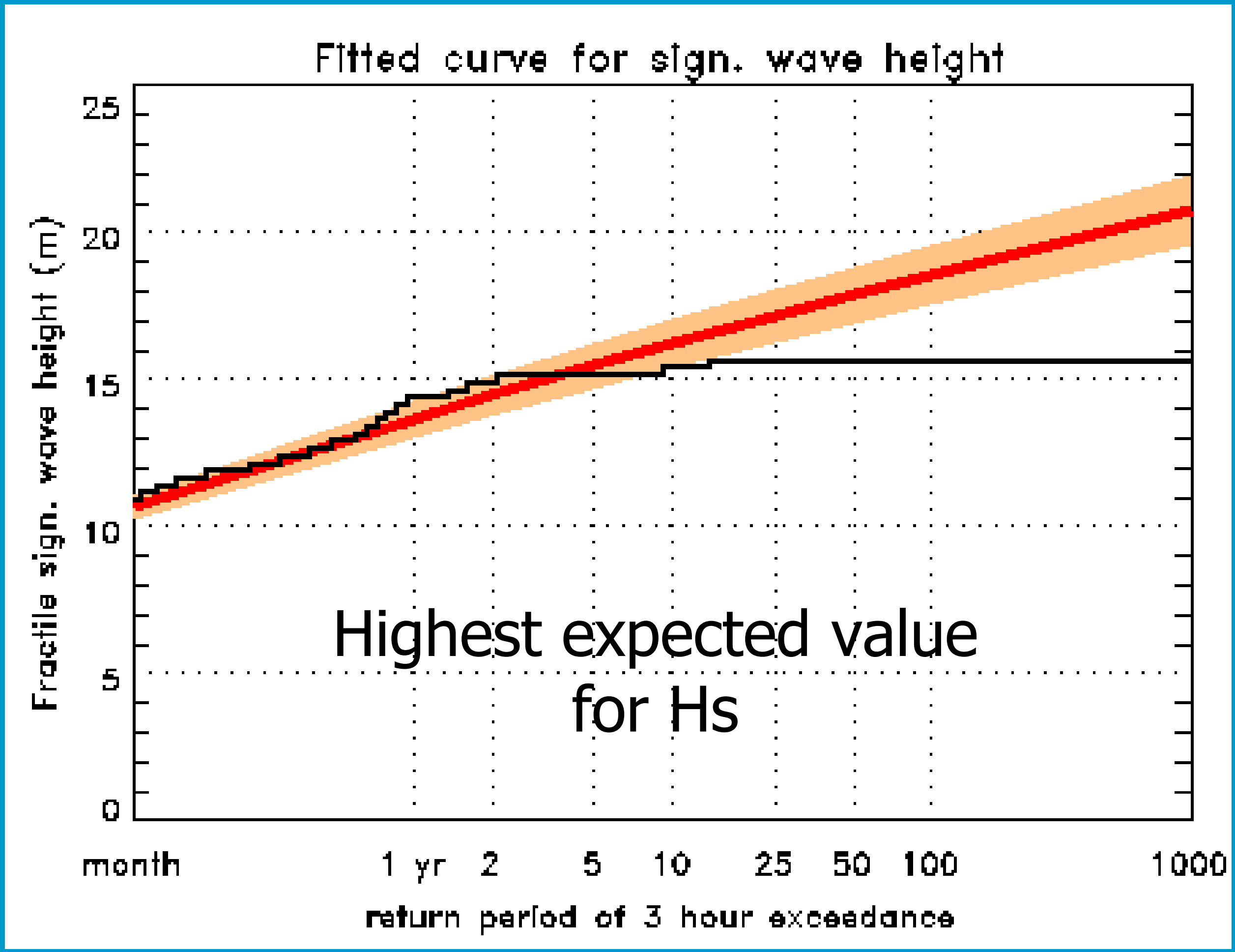
Extreme wave height

Wave scatter diagram

H_s [m] \ T_z [s]	0 - 1	1 - 2	2 – 3	3 – 4	4 – 5	5 - 6	6 - 7	7 - 8	Sum:
6.5 - 7.0									**0**
6.0 - 6.5								0.1	**0.1**
5.5 - 6.0							0.1	0.1	**0.2**
5.0 - 5.5							0.1	0.1	**0.2**
4.5 - 5.0							1		**1**
4.0 - 4.5							4		**4**
3.5 - 4.0						4	5		**9**
3.0 - 3.5						19	0.1		**19.1**
2.5 - 3.0					0.1	38			**38.1**
2.0 - 2.5					27	43			**70**
1.5 - 2.0				0.1	115	5			**120.1**
1.0 - 1.5				6	220	1			**227**
0.5 - 1.0				236	145	1			**382**
0.0 - 0.5	1		1	113	14	0.1	0.1		**129.2**
sum:	**1**	**0**	**1**	**355.1**	**521.1**	**111.1**	**10.4**	**0.3**	**1000**

Chance of occurrence

Extreme wave height



Extreme wave height

Largest wave during lifetime:

From Rayleigh probability density function

or

$$H_{max} \approx 1.86 * H_s$$

or

$$H_{max} = 0.78 * d$$

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Extreme wave height

Extreme wave height known
add period to wave height:

steepness

$$T_{\min} = 2.46\sqrt{H_{\max}} \qquad (1{:}9.5)$$

$$T_{\max} = 3.70\sqrt{H_{\max}} \qquad (1{:}21)$$

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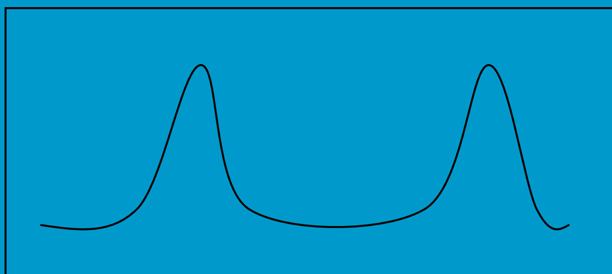
Extreme wave height

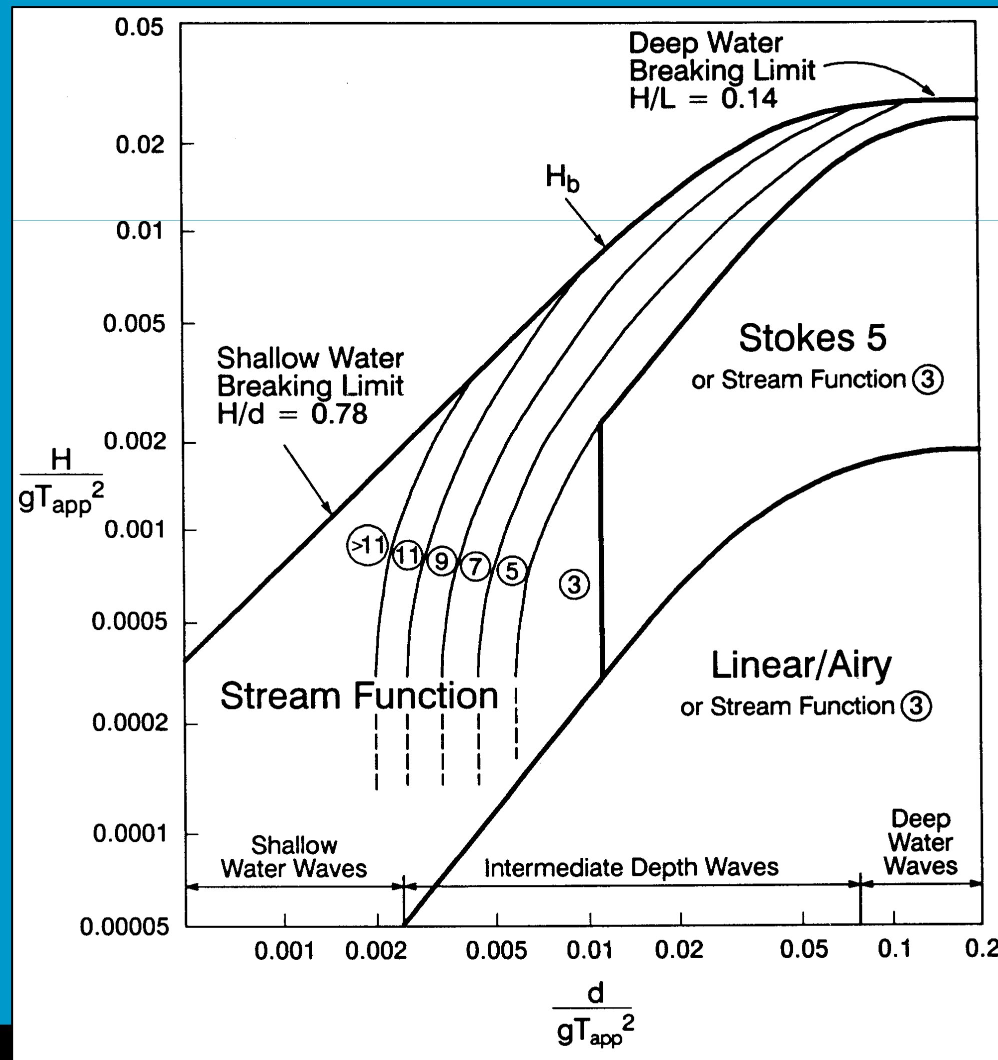
Wave form:



Wave theory

↓

Water particle velocities and accelerations



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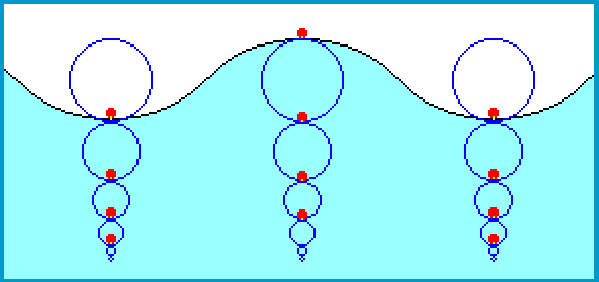
Extreme wave height

For Example:



Linear/Airy Wave theory:

$$u_n(z,t) = \zeta_{a,n} \cdot \omega_n \cdot \frac{\cosh k_n(z+d)}{\sinh k_n d} \cdot \sin(\omega_n t + \varepsilon_n)$$

$$\dot{u}_n(z,t) = \zeta_{a,n} \cdot \omega_n^2 \cdot \frac{\cosh k_n(z+d)}{\sinh k_n d} \cdot \cos(\omega_n t + \varepsilon_n)$$

Extreme wave height

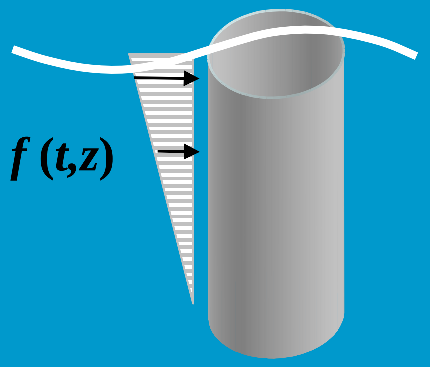
Finally determine loads:

the Morison Equation

$$f(t,z) = C_m \cdot \tfrac{1}{4}\rho\pi D^2 \cdot \dot{u} + C_d \cdot \tfrac{1}{2}\rho D \cdot |u|u$$

acceleration   velocity

- Unit: [N/m]
- Vertically distributed load along pile



Resuming

- Extreme Wave Load
- From Extreme Maximum Wave Height H_{max}
- From Extreme Significant Wave Height H_s
- From Scatter Diagram

Fatigue

Scatter diagrams: waves and wind

↓

Environmental conditions during entire lifetime

↓

All loads during entire lifetime

↓

All stress variations during entire lifetime

Fatigue

H_s-V_w

	lower	00	02	04	06	08	10	12	14	16	18	20	22	24	
lower	upper	02	04	06	08	10	12	14	16	18	20	22	24		total
00	01	0.1	0.1	0.3	0.1	0.0	0	0	0	0	0	0	0	0	0.6
01	02	1.0	2.0	4.6	4.5	2.0	0.3	0.0	0	0	0	0	0	0	14.4
02	03	0.6	1.5	3.7	7.1	8.7	4.7	1.3	0.1	0.0	0.0	0	0	0	27.7
03	04	0.1	0.4	1.2	3.2	5.1	6.2	4.1	1.0	0.3	0.0	0	0	0	21.6
04	05	0.0	0.1	0.4	1.0	2.9	3.7	4.1	2.3	0.7	0.1	0.0	0.0	0	15.3
05	06	0	0.0	0.0	0.2	0.9	1.6	2.5	2.7	1.4	0.2	0.0	0	0	9.5
06	07	0	0	0.0	0.0	0.2	0.4	0.8	1.3	1.2	0.4	0.0	0	0	4.3
07	08	0	0	0	0.0	0.0	0.2	0.3	0.6	1.1	0.6	0.1	0	0	2.9
08	09	0	0	0	0	0.0	0.0	0.1	0.2	0.8	0.6	0.1	0	0	1.8
09	10	0	0	0	0	0	0.0	0.0	0.1	0.3	0.3	0.1	0	0	0.8
10	11	0	0	0	0	0	0	0.0	0.0	0.1	0.1	0.0	0	0	0.2
11	12	0	0	0	0	0	0	0.0	0.0	0.0	0.1	0.1	0.0	0	0.2
12	13	0	0	0	0	0	0	0.0	0.0	0.0	0.1	0.0	0.0	0	0.1
13	14	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0	0.0
14	15	0	0	0	0	0	0	0	0	0	0.0	0.0	0	0	0.0
15	16	0	0	0	0	0	0	0	0	0	0	0.0	0	0	0.0
16		0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
total		1.8	4.1	10.2	16.1	19.8	17.1	13.2	8.3	5.9	2.5	0.4	0.0	0.0	

H_s-T_z

	lower	00	04	05	06	07	08	0							
lower	upper	04	05	06	07	08	09	1							
00	01	0	0.2	0	0.5	0	0	0							
01	02	0	2.0	6.0	6.4	1.8	0.7	0							
02	03	0	0	9.1	9.1	3.6	3.1	0.							
03	04	0	0	0.5	12.2	8.6	1.8	1.							
04	05	0	0	0	1.1	6.6	2.0	0.							
05	06	0	0	0	0	4.2	3.1	1.3	0.4	0	0.2	0	0	0	9.2
06	07	0	0	0	0	0.2	3.5	2.2	0	0	0	0	0	0	5.9
07	08	0	0	0	0	0	1.8	1.3	0.2	0	0	0	0	0	3.3
08	09	0	0	0	0	0	0	1.6	0	0	0	0	0	0	1.6
09	10	0	0	0	0	0	0	0.2	0.2	0	0	0	0	0	0.4
10	11	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0.4
11	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
12	13	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0.2
13		0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
total		0.0	2.2	15.6	29.3	25.0	16.0	9.3	1.4	0.8	0.2	0.0	0.2	0.0	

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Fatigue

H_s-T_z-V_w

93 states

Hs	Tz	< 3.0	3.0 - 4.0	4.0 - 5.0	5.0 - 6.0	6.0 - 7.0	7.0 - 8.0	8.0 - 9.0	9.0 - 10.0	10.0-11.0	
	17.5					0.2	0.7		0.4		1.3
	15					0.3	0.6				0.9
>4.0	12.5					0.4	0.4				0.8
	17.5					0.7	0.4				1.1
	15					0.9					0.9
3.5 - 4.0	12.5					1.0					1.0
	17.5				0.2	1.4					1.6
	15				0.3	1.2					1.5
3.0 - 3.5	12.5				0.4	0.9					1.3
	17.5				1.1		0.9				2.0
	15				2.0	0.2					2.2
	12.5				3.0						3.0
2.5 - 3.0	10				0.3						0.3
	17.5				2.5	0.5					3.0
	15				3.0	0.4					3.4
	12.5				4.0	0.2					4.2
	10				1.1						1.1
	7.5				0.2						0.2
2.0 - 2.5	2.5				0.2						0.2
	17.5						0.1	0.3	0.4	0.5	1.3
	15			1.4	1.4	0.2	0.4	0.3	0.3	0.2	4.2
	12.5			3.0	2.8	0.2	0.1				6.1
	10			3.9	0.6						4.5
	7.5			1.6							1.6
	5			0.5							0.5
1.5 - 2.0	2.5			0.4							0.4
	15				0.1	0.1	0.3	0.2	0.4	0.5	1.6
	12.5				0.6	0.2	0.7	0.4	0.2	0.1	2.2
	10			4.4	1.8	0.5					6.7
	7.5			4.5							4.5
	5			1.9							1.9
1.0 - 1.5	2.5		0.4	1.0							1.4
	12.5					0.2				0.2	0.4
	10				3.0						3.0
	7.5		2.4	3.0	1.7						7.1
	5		2.8	2.0	0.1						4.9
0.5 - 1.0	2.5		4.3								4.3
	10					0.2				0.1	0.3
	7.5				2.2	0.3					2.5
	5		0.7	2.2	1.6	0.1					4.6
0.0 - 0.5	2.5	0.8	3.6	1.4	0.2						6.0
		0.8	14.2	31.2	34.4	10.3	4.6	1.2	1.7	1.6	100.0

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Fatigue

H_s-T_z-V_w

Reduce to

16 states

	Hs	Tz	Vw	%
1	0.25	3.82	3.30	8.7
2	0.25	5.63	6.47	4.6
3	0.75	3.84	5.19	14.5
4	0.75	5.54	9.15	5.0
5	0.58	10.5	11.67	0.3
6	1.25	4.44	6.00	7.8
7	1.25	4.86	10.29	6.9
8	1.25	8.28	13.19	3.6
9	1.75	4.59	8.64	7.0
10	1.75	4.99	13.31	8.6
11	1.75	8.73	15.83	3.0
12	2.25	5.59	13.97	12.1
13	2.75	5.77	14.47	7.5
14	3.25	6.3	15.17	4.4
15	3.75	6.63	15.08	3.0
16	4.25	7.47	15.42	3.0
				100.0

Fatigue

Now lifetime loads can be simulated:

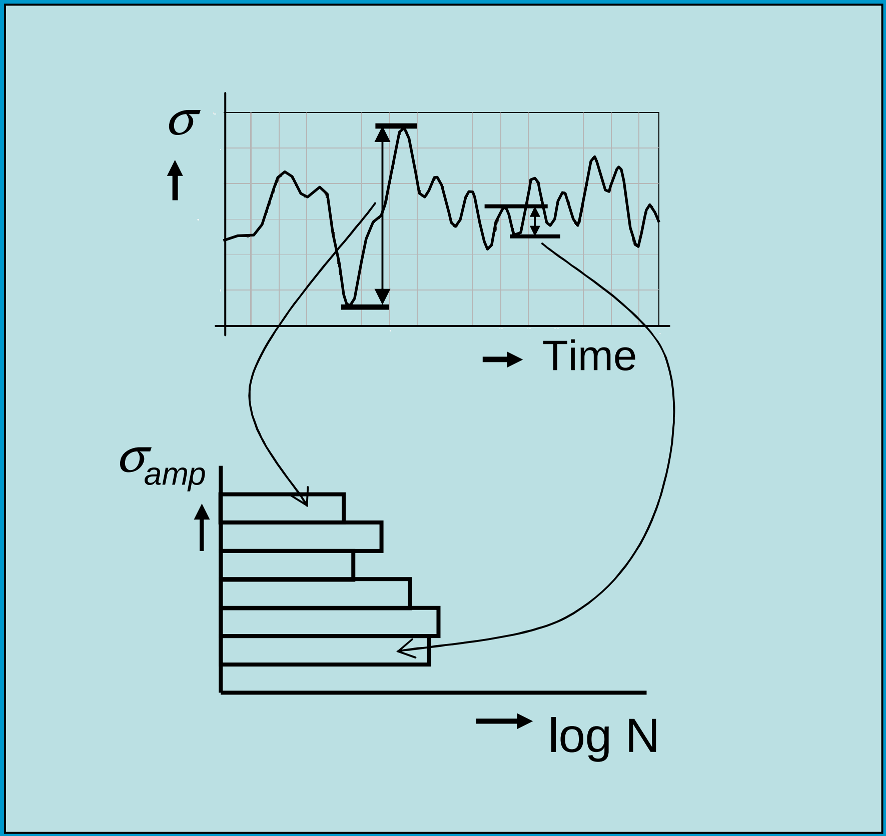
- Aerodynamic loads: BEM
- Hydrodynamic loads: Morison

Then stresses can be determined along structure

Fatigue

Stress Time Series

Stress Histogram

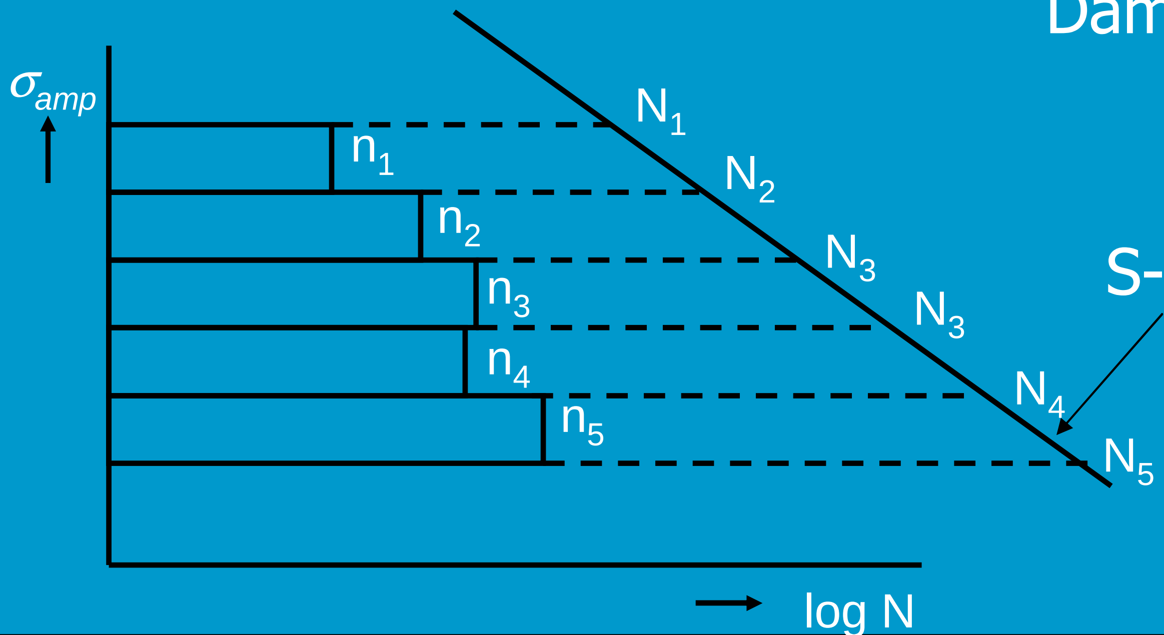


Fatigue

Miner's Damage Rule:

$$\sum \frac{n_i}{N_i} = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \frac{n_4}{N_4} + \frac{n_5}{N_5}$$

Damage < 1.0



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Installation & Maintenance

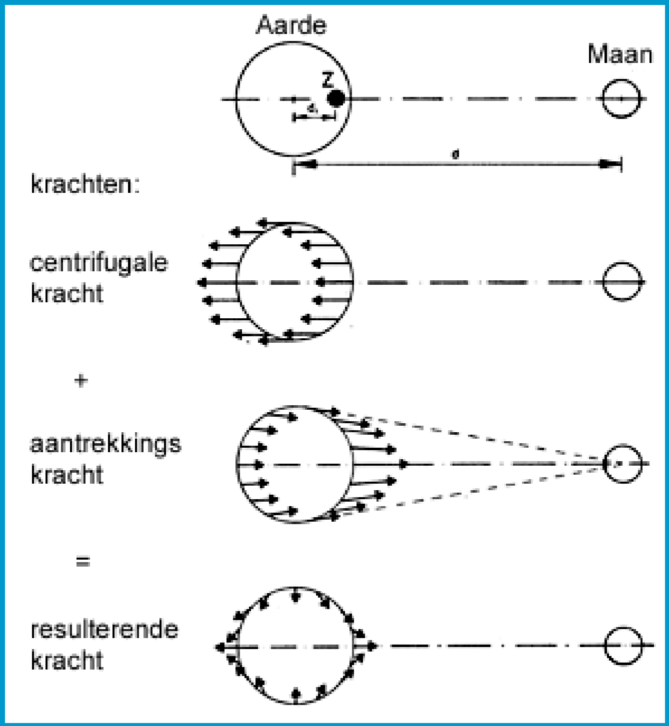
Workability:

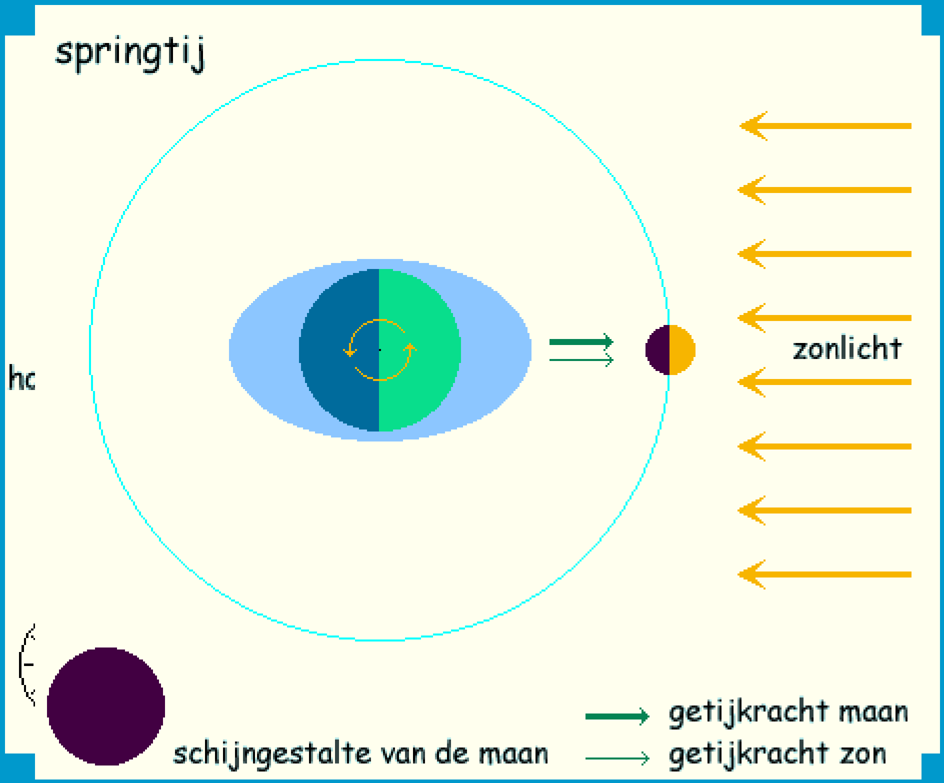
Different activities have different workability limits

Sailing	H_s = 4m
Transfer	H_s = 2m
Jacking up	H_s = 1m
Jack-up working	H_s = 3m

Current

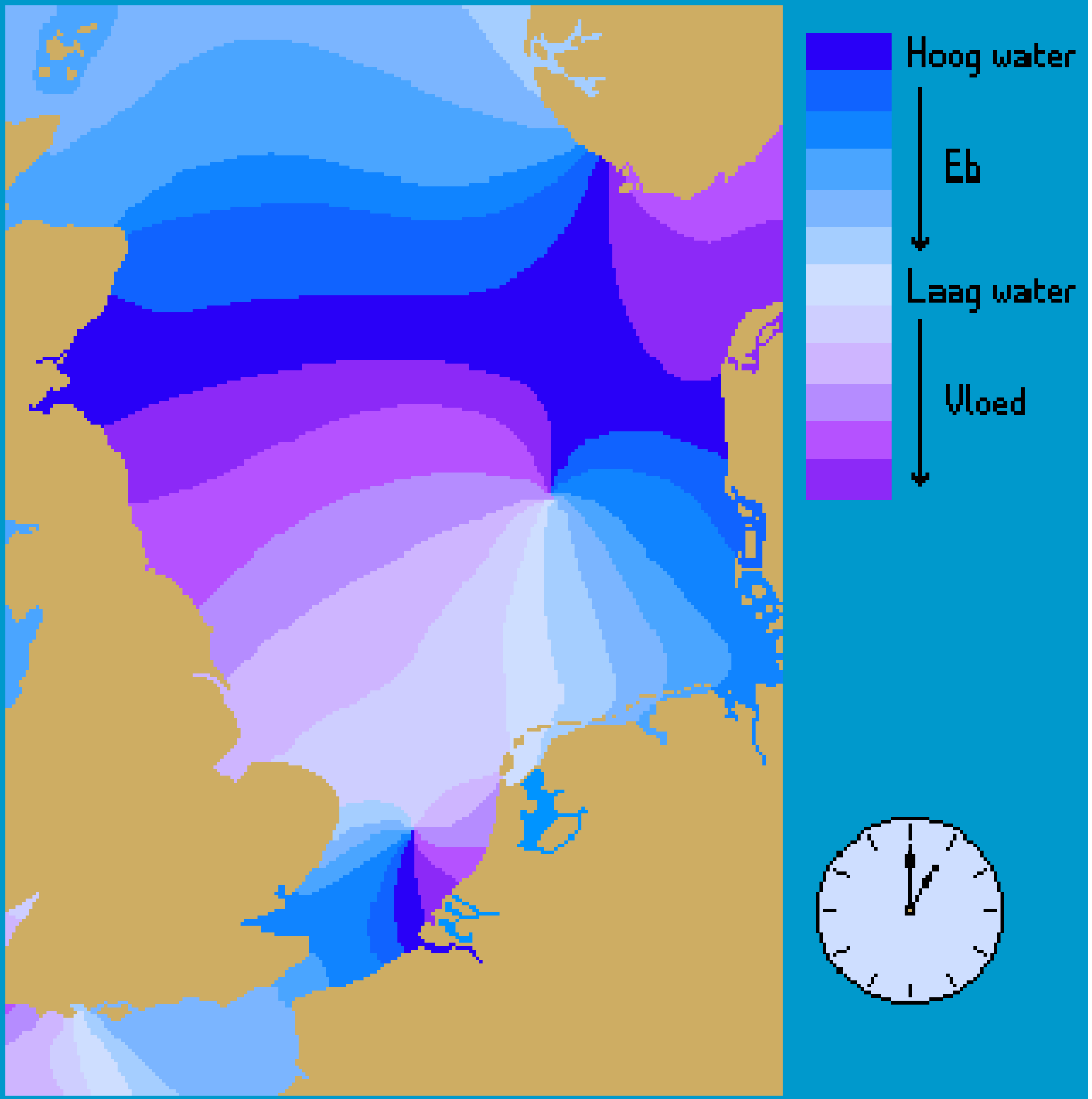
Horizontal movement of water, due to tidal waves



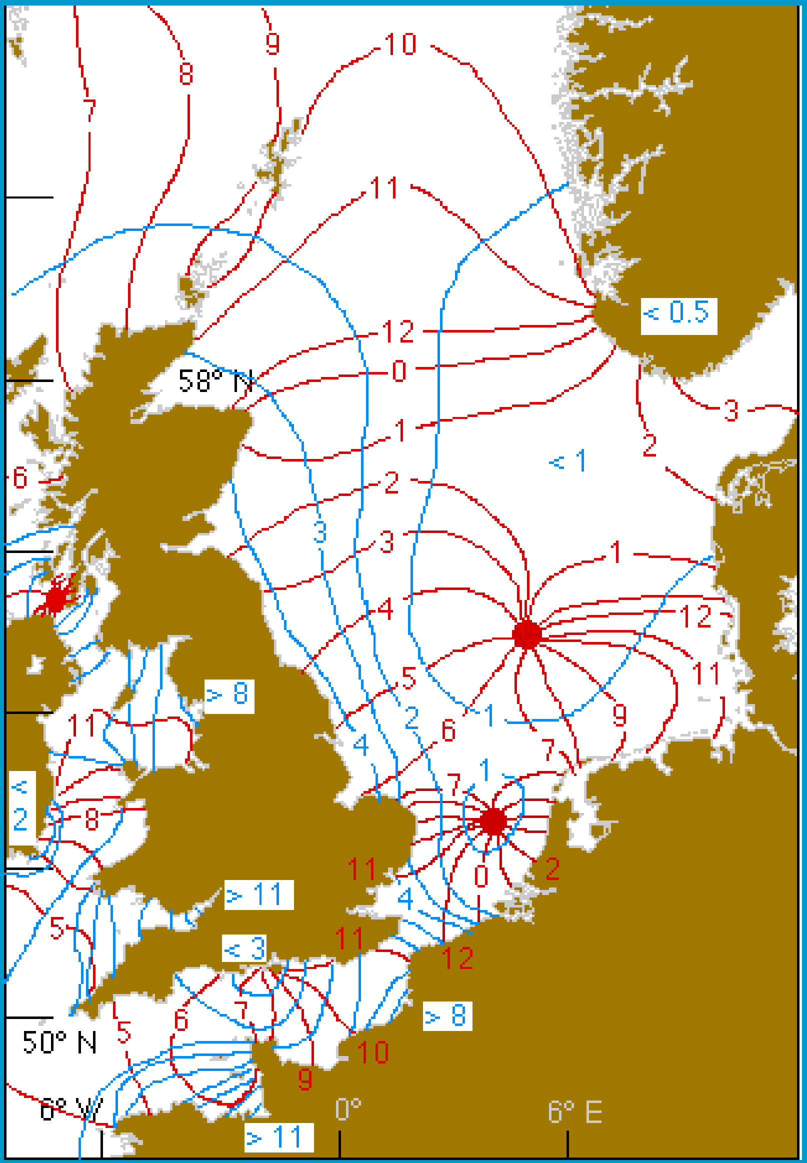


Current

Flow pattern North Sea



Current



Determine flow patterns and tidal differences

BIG DIFFERENCE

=

BIG CURRENT

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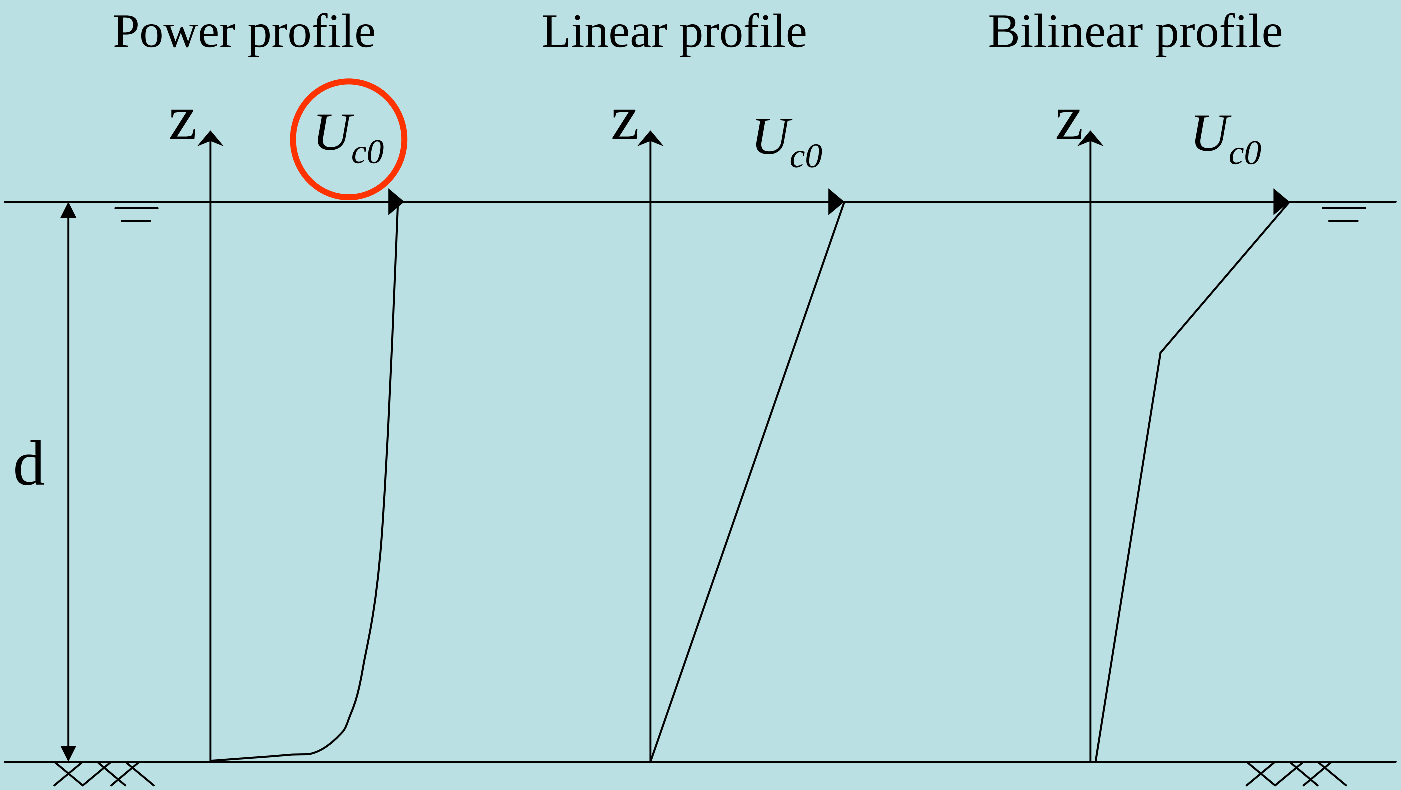
Current

- Length and time scale of tidal waves much larger than of wind waves
- Currents considered as flow of constant velocity
- Vertical variation: Current profile over depth

Current profiles



$$U_{current}(z) = U_{c0}\left(\frac{z+d}{d}\right)^{\alpha} = U_{c0}\left(\frac{z}{d}\right)$$

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Current effects

- Hydrodynamic loads on monopile

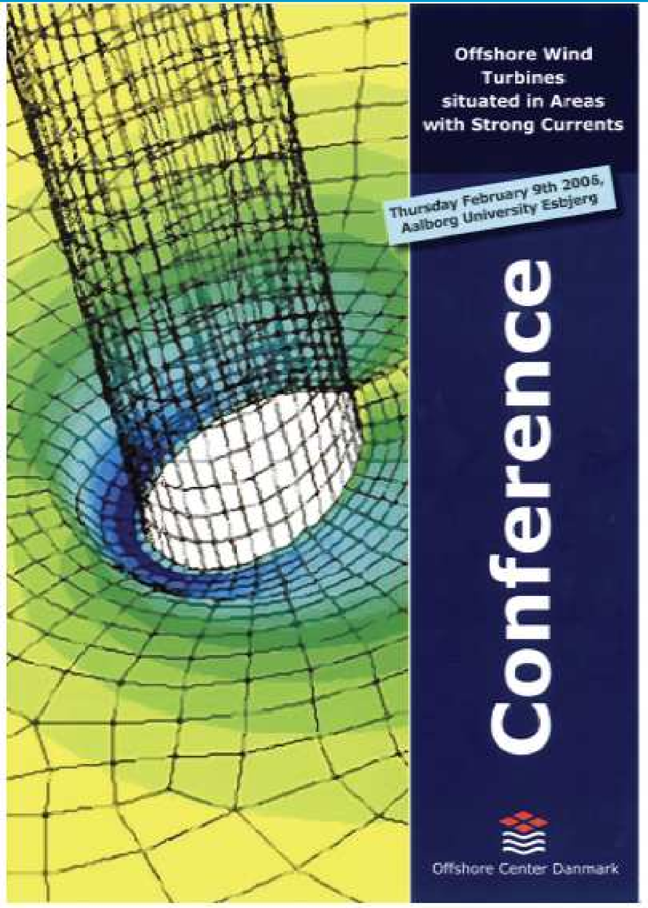
Morison Equation:

$$f(t) = C_m \cdot \frac{1}{4}\rho\pi D^2 \cdot \dot{u} + C_d \cdot \frac{1}{2}\rho D \cdot u|u|$$

velocity

Current effects

- Hydrodynamic loads on monopile
- Scour
  - Caused by current
  - Between 1.3*D and 2.5*D
  - Consider when designing



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Current effects

- Hydrodynamic loads on monopile
- Scour
- Installation & Maintenance: vessel manoeuvring

So.... Resuming:

- Long term: scatter diagrams
- Short term: wave spectra
- Hs and Tz
- Current velocity & profile

- Extremes
- Fatigue
- Installation & Maintenance
- Scour