Pushing Offshore Wind Energy Regions (POWER)

POWER Offshore Summer School 2006

SUPPORT STRUCTURES and FOUNDATIONS for OFFSHORE WIND TURBINES

Gerard van Bussel

Pushing Offshore Wind Energy Regions (POWER)

Overview

Support structures and foundations

- Offshore experience and examples
- Various options for offshore wind
- Foundation modelling
- Installation

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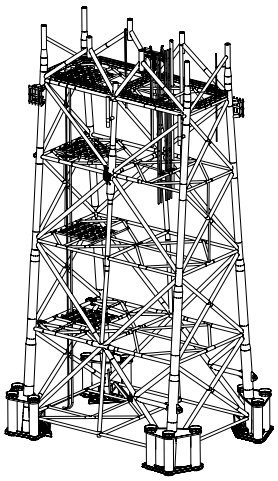

Tower Structure steel

Gravity Base concrete

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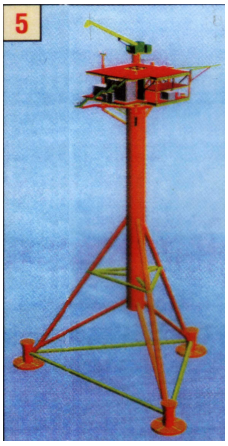
Steel hybrids



Tripod

Quadpod

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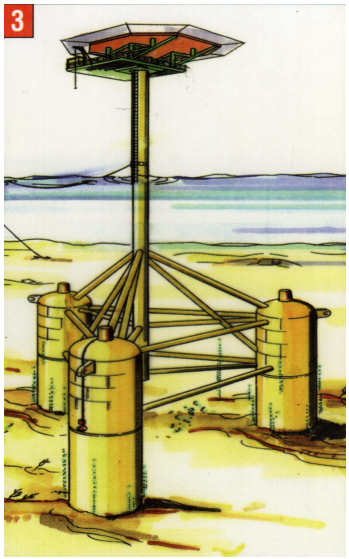
Suction Piles



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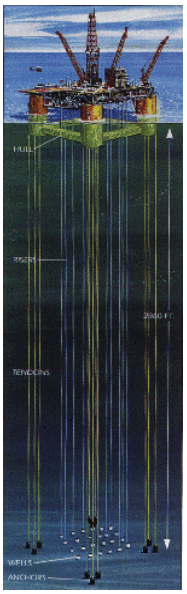
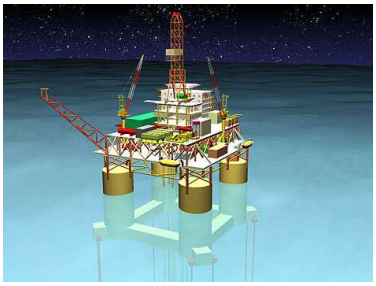
Tension Leg Platforms TLP's





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Approximate numbers of permanent structures

Permanent installations

Platforms

Structure type	Fixed Structure	Compliant Tower	Guyed Tower	Tension Leg Platform	Anchored Floater	Total
USA – Gulf of Mexico	4000	2	1	5		4000
USA – West Coast	45					45
Central/South America	340				8	360
Europe – North Sea	400			3	20	425
Europe/Africa – Medit.	100				3	100
Africa – West Coast	380				9	390
Middle East	700					700
Asia	950				19	975
Australia/New Zealand	30				7	40
Total	~ 7000	2	1	8	66	**~ 7000**

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Approximate numbers of concrete structures

- Fixed concrete structures 33
  - North Sea 27
  - Baltic 2
  - Australia 4
- Floating concrete structures 4

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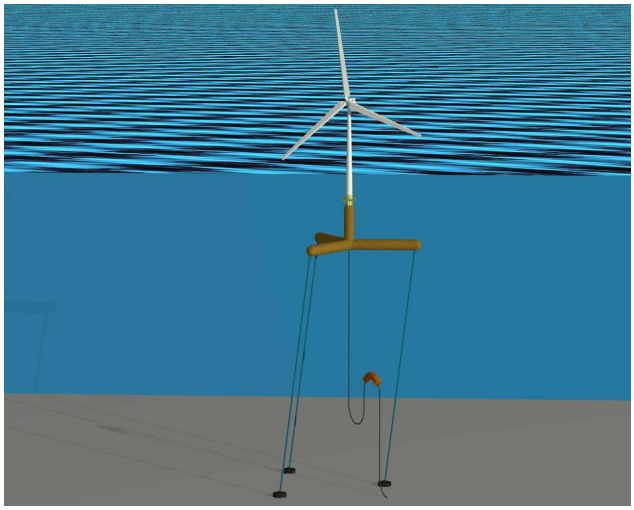
TLP offshore wind turbine



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Semi submersible floating offshore wind farm

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Floating offshore wind

- Technically feasible
- Too expensive

- Not an option, yet

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Fixed support structures for wind turbines

monotower	monopile foundation bearing foundation
tripod/ quadpot	piled foundation bearing foundation
space frame/ jacket	pile foundation bearing foundation

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Fixed support structures for wind turbines

Location	Country	Online	MW	No	tripod	GBS	Monopile
Norgersund	Sweden	1990	0.22	1	X		
Vindeby	Denmark	1991	4.95	11		X	
Lely (Ijsselmeer)	Holland	1994	2.0	4			X
Tunø Knob	Denmark	1995	5.0	10		X	
Dronten (Ijsselmeer)	Holland	1996	16.8	28			X
Gotland (Bockstigen)	Sweden	1997	2.75	5			X
Blyth Offshore	UK	2000	3.8	2			X
Middelgrunden, Copenhagen	Denmark	2001	40	20		X	
Uttgrunden, Kalmar Sound	Sweden	2001	10.5	7			X
Yttre Stengrund	Sweden	2001	10	5			X
Horns Rev	Denmark	2002	160	80			X
		Totals	**256**	**173**	**1**	**41**	**132**

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Fixed support structures for wind turbines

Is monopile the winner?

NO!

Choice of support structure is fully location dependent !!

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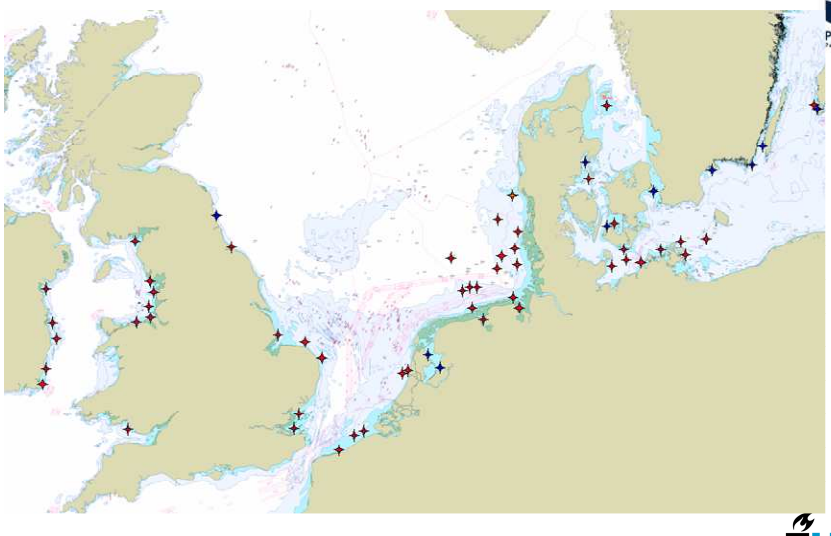
Offshore wind projects in NW Europe



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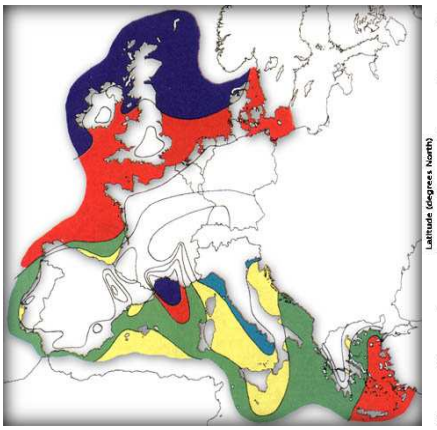
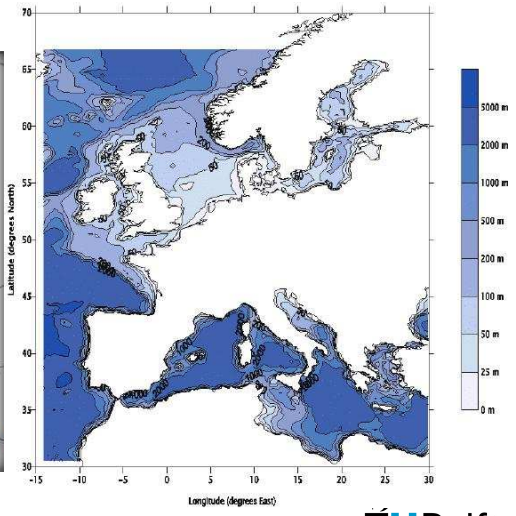
Wind resource and water depth





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Support structure solutions

P·O·W·E·R

Suitable solutions

- Gravity based
- Monopile
- Piled tripods / jackets
- Suction piled tripods (?)

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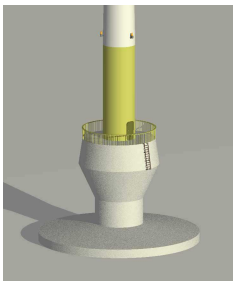
Gravity Base Structures



- Shallow water (2-10m)
- Little wave current action
- Good resistance to ice loading
- Effective separation between foundation and tower/turbine

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Monopile

- Shallow-intermediate water (2-30m)
- Heavy response to wave loads
- Dynamic response and fatigue are critical design parameters
- Integrated design is essential

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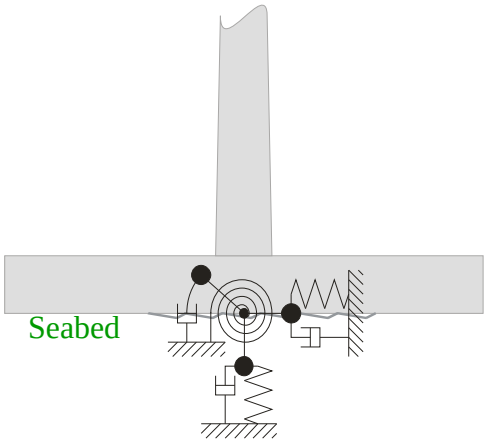
GBS foundation model (principle)



Lumped springs and dampers for:
- Horizontal
- Vertical
- Rocking

movements

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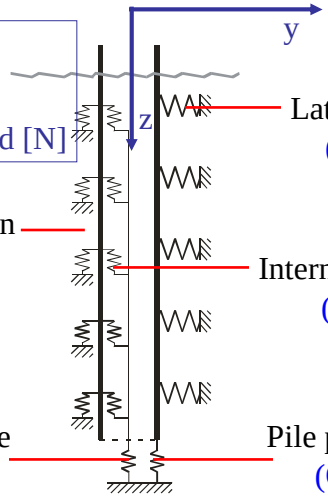
Pile foundation load model

p horizontal load [N/m^2]
t vertical load [N/m^2]
Q remaining vertical load [N]



Lateral resistance (p-y curves)

External shaft friction (t-z curves)

Internal shaft friction (t-z curves)

Pile plug resistance (Q-z curves)

Pile point resistance (Q-z curves)

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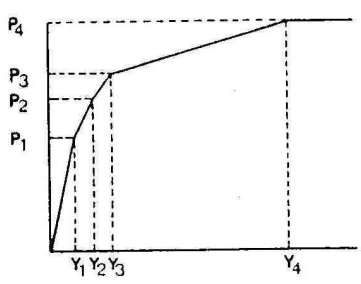
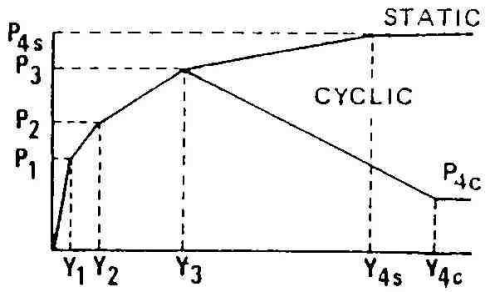
Pile-soil interaction (horizontal)

p-y curves



Sands
Reese/Cox/Koop (1974)



Soft clay
Matlock (1970)

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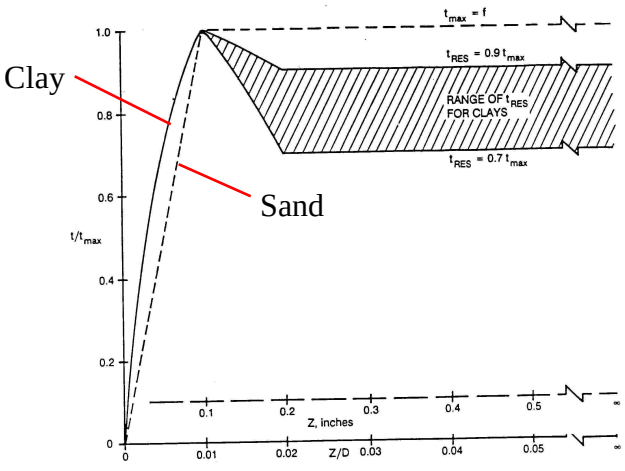
Pile-soil interaction (vertical)



t-z curves

(API 1993)

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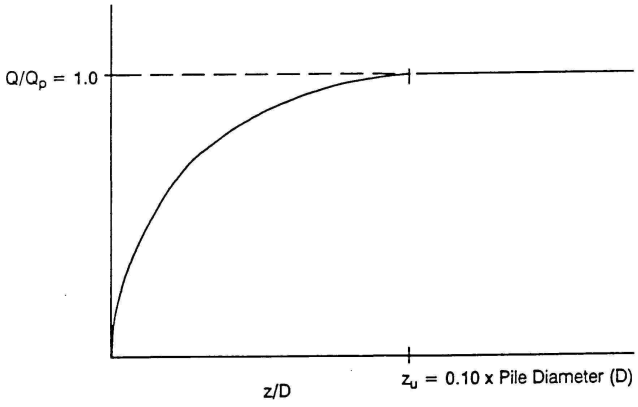
Pile-soil interaction (pile tip)



Q-z curves

(API 1993)

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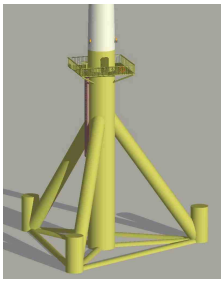
Tripod



- Increasing top mass
- Increasing water depth
- Higher stiffness at seabed level

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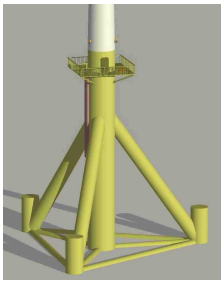
Tripod 2



- Installation of tripod in one lift
- Tripod is stable without foundation piles
- Connection piles with grout or swaging

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Jacket

- Alternative for tripod/quadropod
- Deeper water typically >30 m

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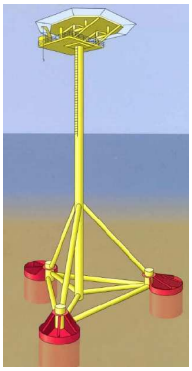
Suction piles



- Use structural weight and water pressure to penetrate the buckets
- No driving/drilling
- Variable loading not yet proven technology
- Watch out for scour!

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Suction piles 2

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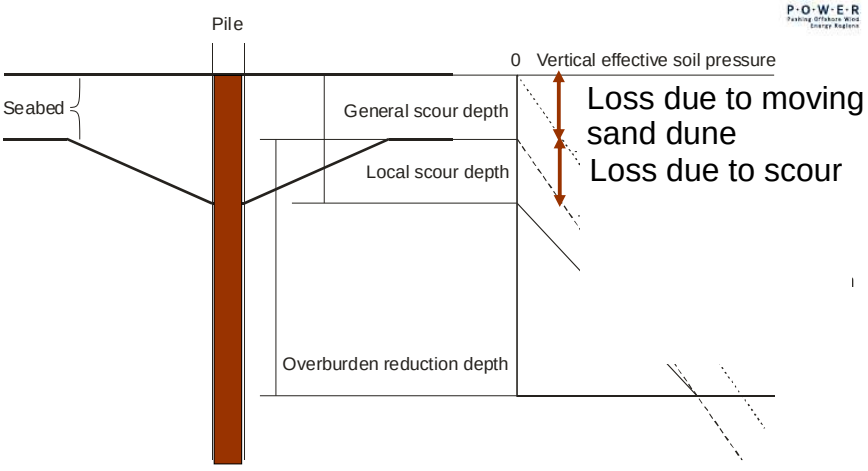
Sand dunes and scour uncertainty



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