Introduction to Offshore Structures - Focus on Marine Aspects

Note Title 05.04.2016

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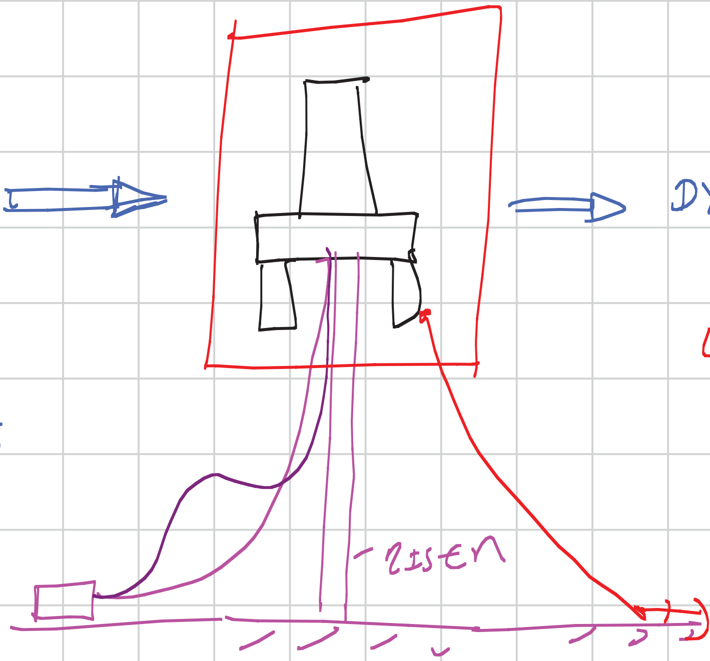
Hydrodynamic loads ⟹
- ↳ waves
- ↳ current
- ↳ wind



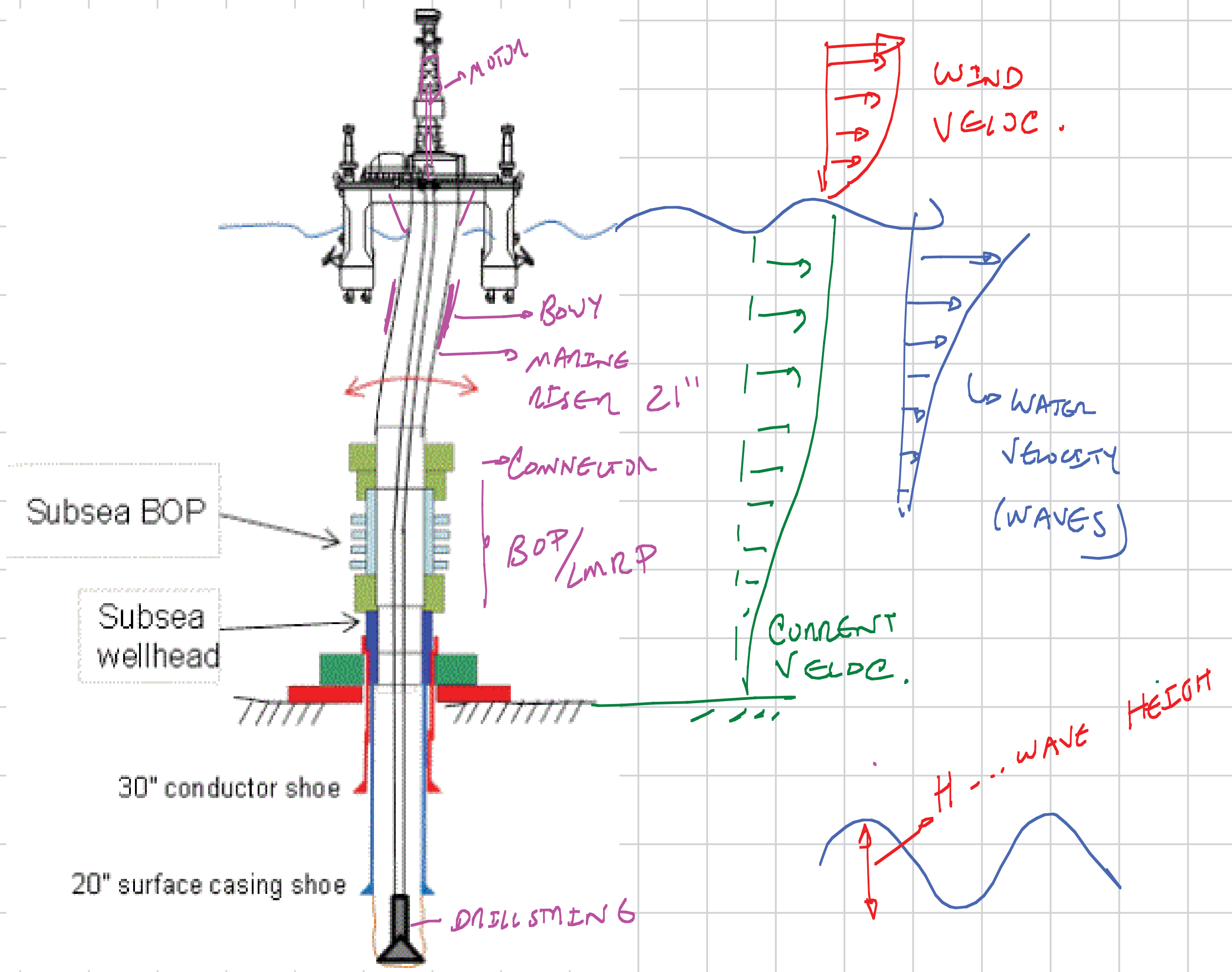
⟹ Dynamic response
- ↳ marine structure
- ↳ connection to the seabed
  - ↳ risers
  - ↳ mooring system

Cases that show how not to do it

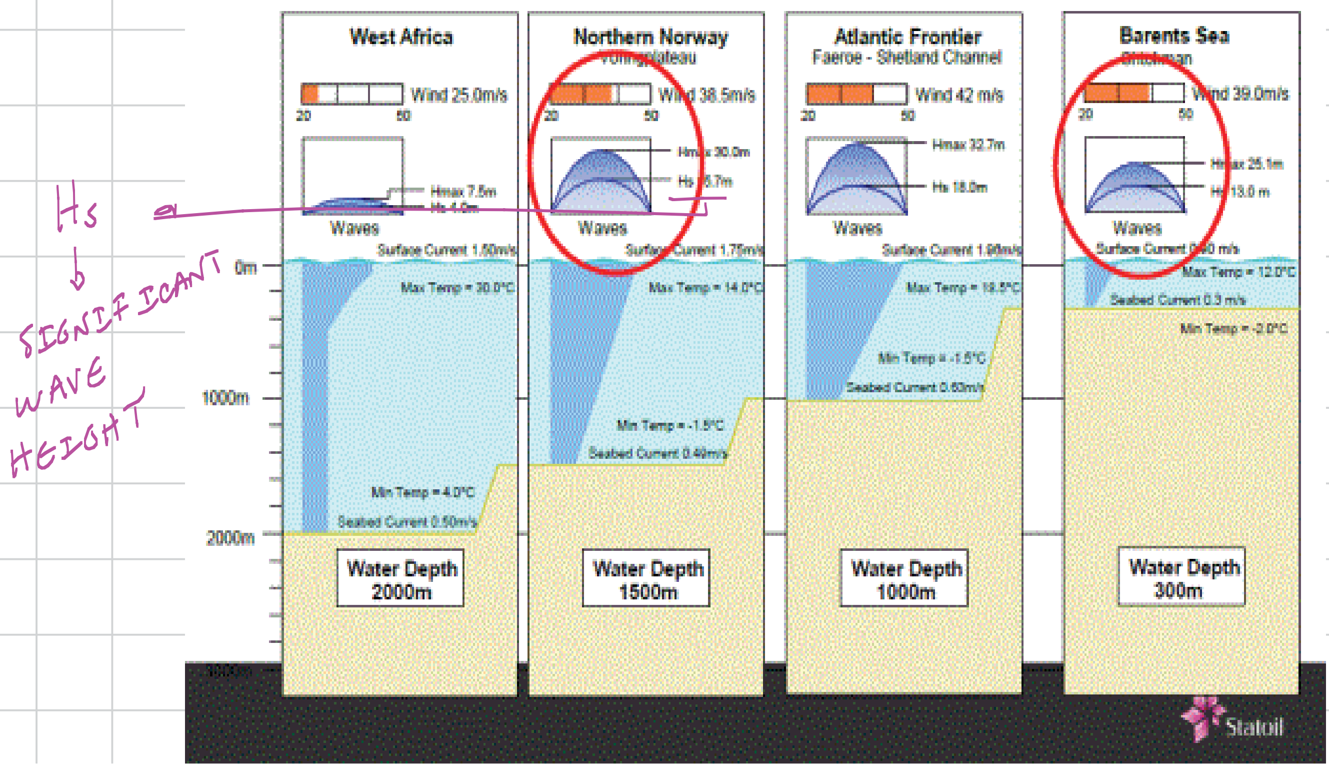
The Mars TLP after the hurricane Katrina

Typhoon upside down after hurricane Rita

ENVIRONMENTAL LOADS



Waves, wind and current comparable with Norway



- CURRENT ≈ 1 m/s CONSTAT ⇒ "NCS" DESIGN
  - ↳ 2 m/s COULD BE REACHED.

- WAVES:
  - ↳ $H_{max} \approx 30$ mts
  - ↳ $H_S \approx 18$ mts ⇒ DESIGN
    - SIGNIFICANT WAVE HEIGHT
    - ↳ MEAN VALUE OF THE HIGHEST 1/3 OF THE WAVES

  TIME - SCALE
  - AVERAGE CHARACT (1 TO 4 hr)
  - RAPID FLUCTUATION (4 TO 24 s)

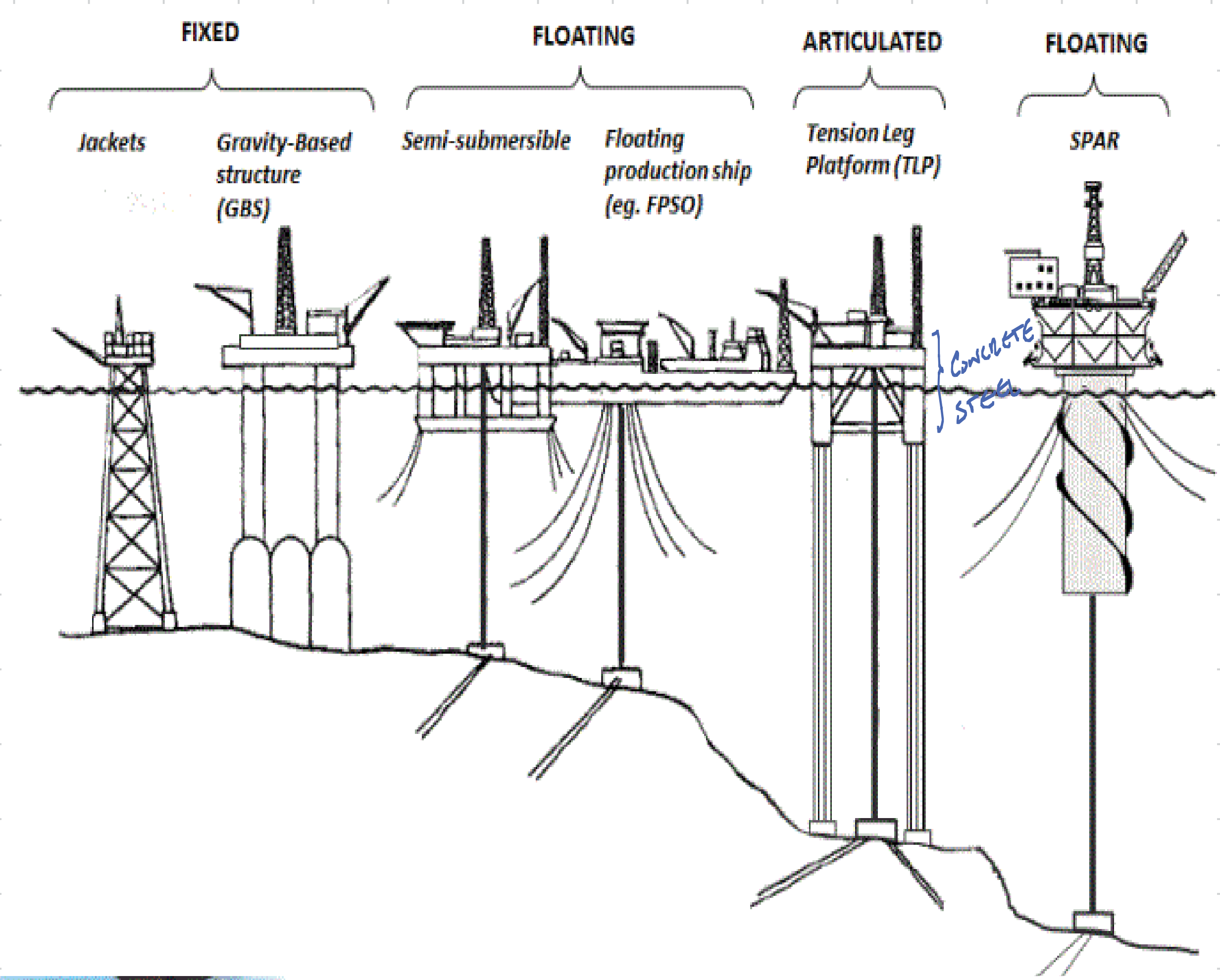
- WIND | TWO SCALES
  - SLOW-VARYING MEAN CHARACTERISTICS (1 TO 3 min)
  - RAPID FLUCTUATIONS,

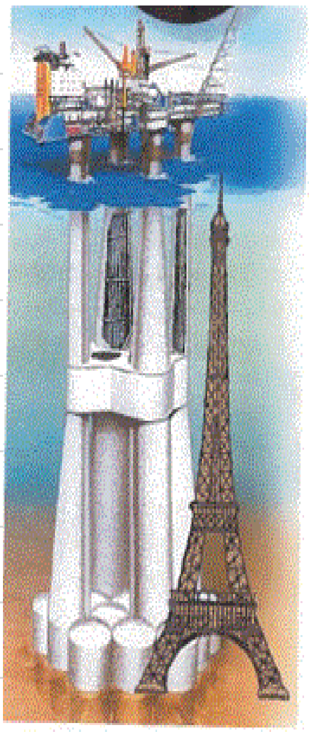
  ↳ 150 km/hr IN NCS MAY BE REACHED.

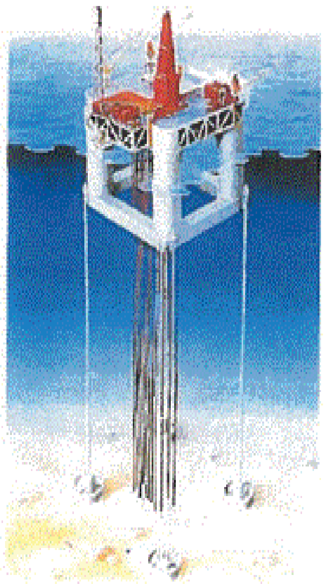
CONVENTIONALLY DIFFERENT STRUCTURES ← WATER DEPTH.

↳ MOVE VERY DIFFERENT

↳ HORIZONTAL AND VERT. MOTION







MARINE STRUCTURES

- WATER DEPTH
- HYDRODYNAMIC LOADS,
- FOUNDATION SUPPORT (SEA BED)
- DYNAMIC RESPONSE OF THE STRUCTURE

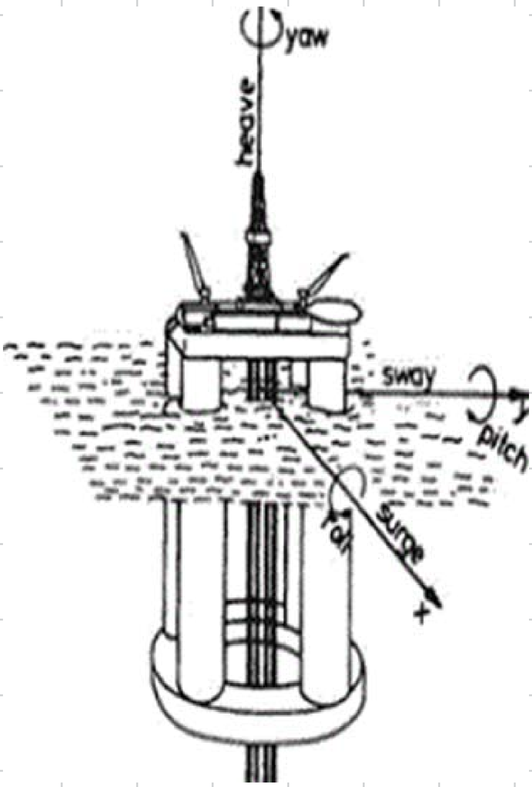
(
- RESERVOIR
- SUBSEA TECH.
)

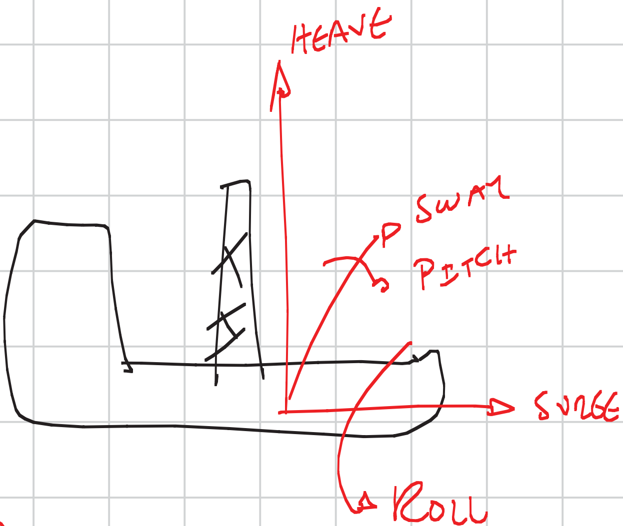
Table 1. Examples of offshore structures in the NCS for different water depths.

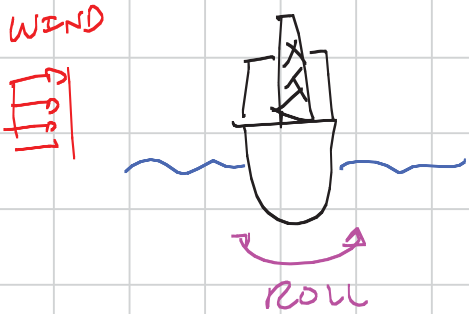
Water depth	Field	Offshore structure
70-75 mts	Ekofisk	Jackets
120-130 mts	Balder	FPSO
130-250 mts	Gullfaks	Concrete fixed facilities and steel topside
300 mts	Troll	Concrete fixed facilities and steel topside
300 mts	Åsgard B	Semi-submersible platform
300-350 mts	Snorre	TLP steel platform
370 mts	Kristin	Semi-submersible platform
1300 mts	Luva*	Spar platform

**Future field development*

- MOTION UNDER OCEAN WAVES LOADS:





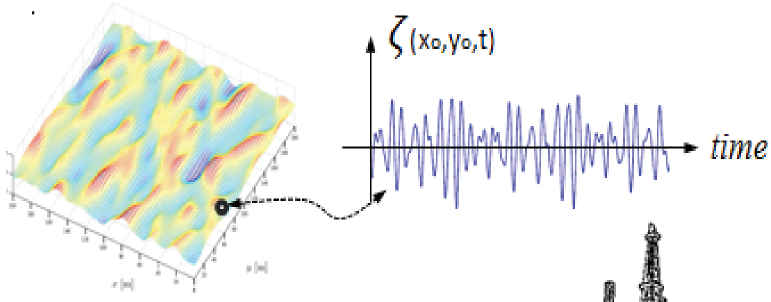


- STOCHASTIC ANALYSIS OF OFFSHORE STRUCTURES (WAVE LOADS)

WAVES ARE VERY RANDOM → (STATISTICAL APPROACH)

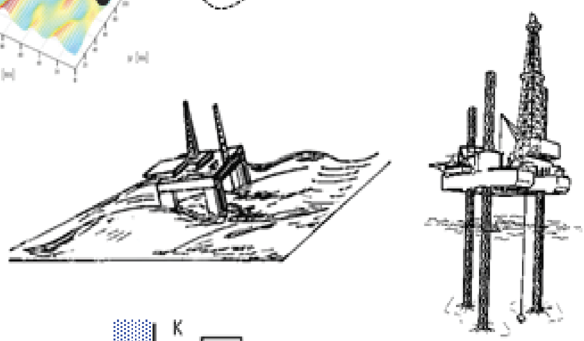
Statistics of waves

Wave surface elevation
Wave spectrum (Hs, Tp)



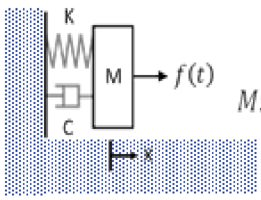
Calculation of hydrodynamic loads

Fluid-structure interaction



Dynamic analysis response

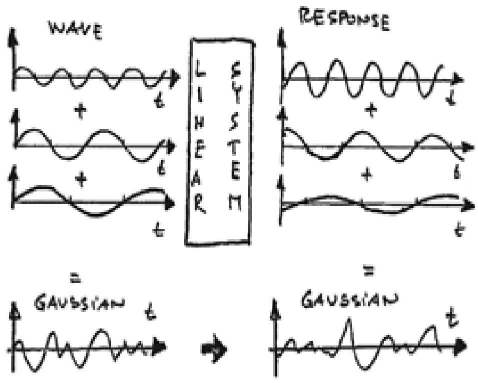
For practical purposes considered linear



$$M\ddot{x}_{(t)} + C\dot{x}_{(t)} + Kx_{(t)} = f(t)$$

Statistics of the response

Verification of design and operation according to rules
Ordinary gravity wave-wind usually of interest (period 4-24s)

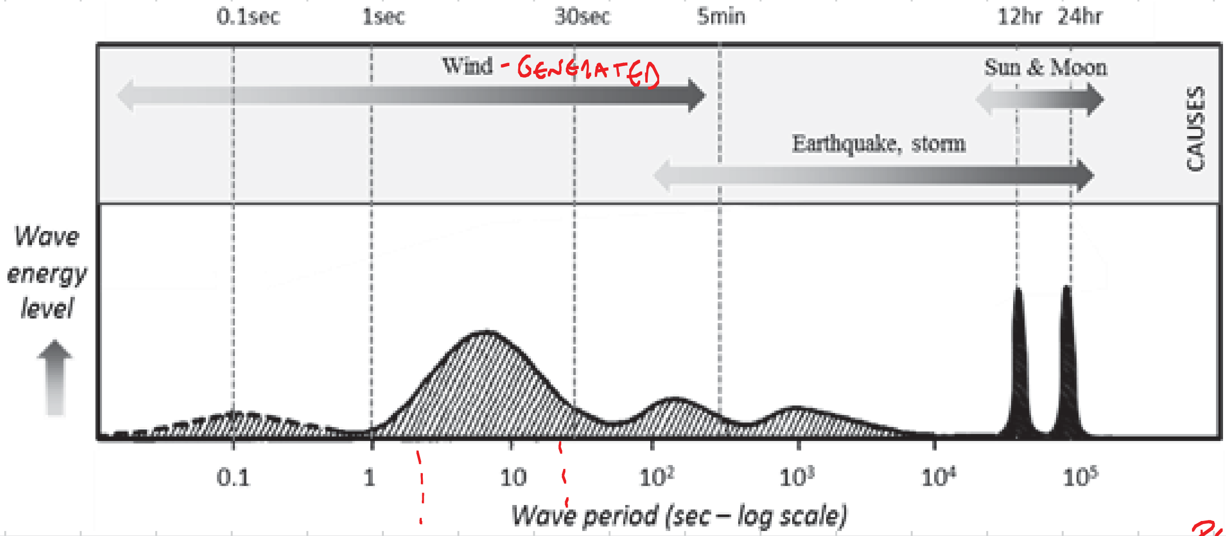


⇓

WHAT'S GOING TO HAPPEN AFTER 100 YEARS?

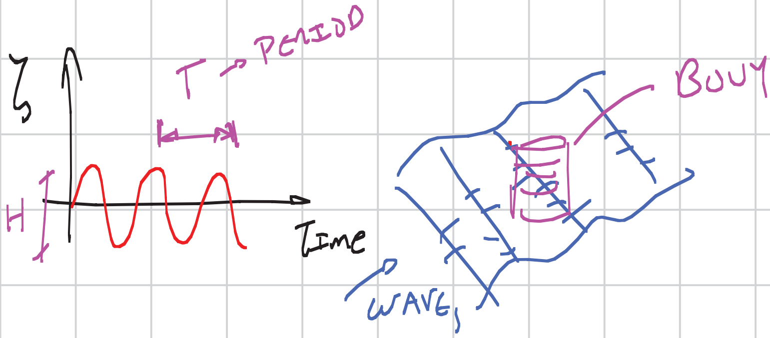
WAVES AND WAVES STATISTICS

- GENERATION OF WAVES — DEPENDENT ON SITE AND WATER DEPTH



OIL AND GAS
↳ OFFSHORE STRUC.
4-24s

PERIOD:
NCS → 13
(SEVERE) TO 15s



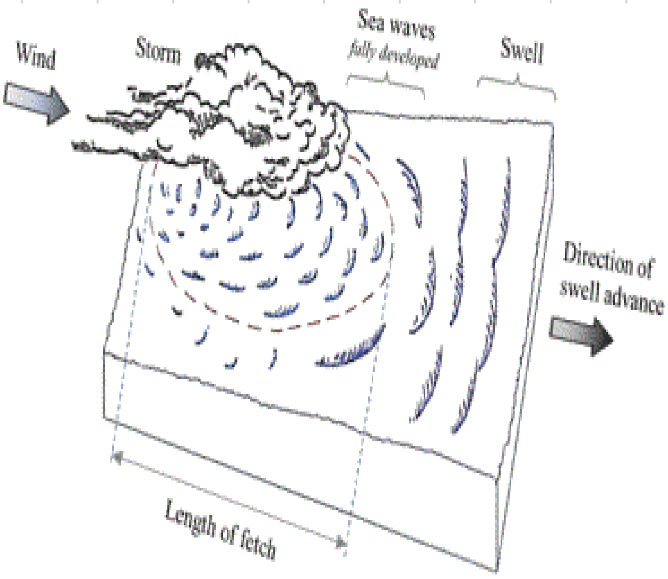
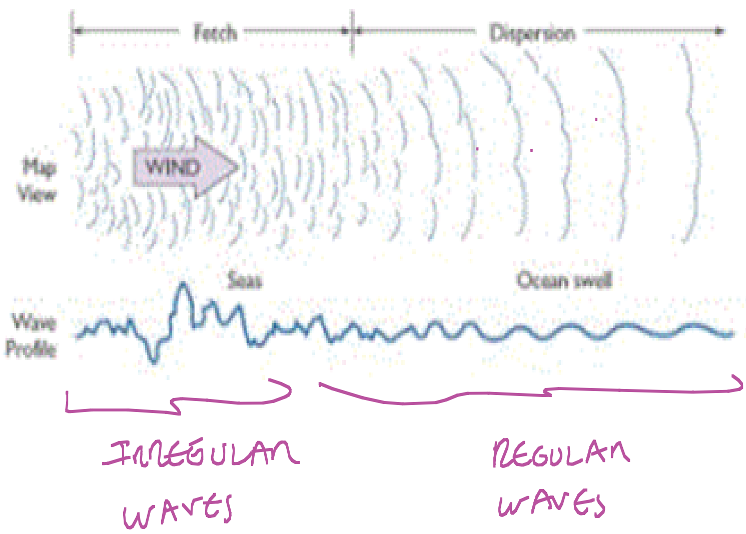
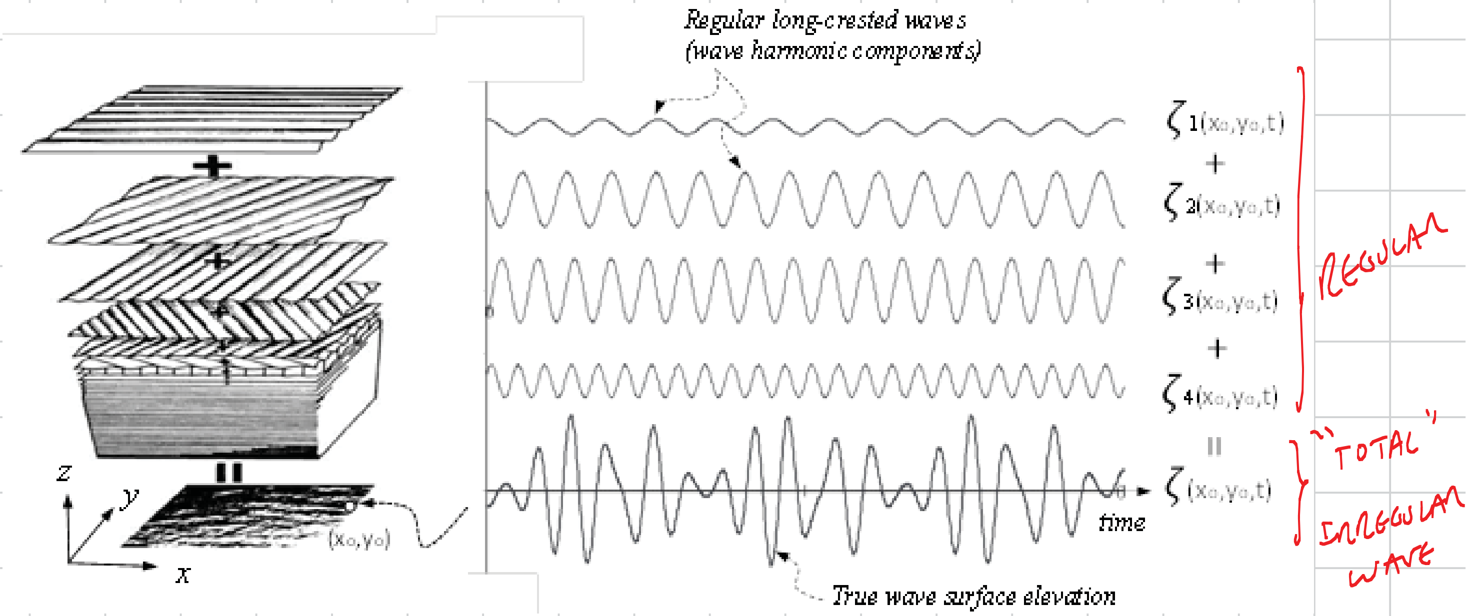
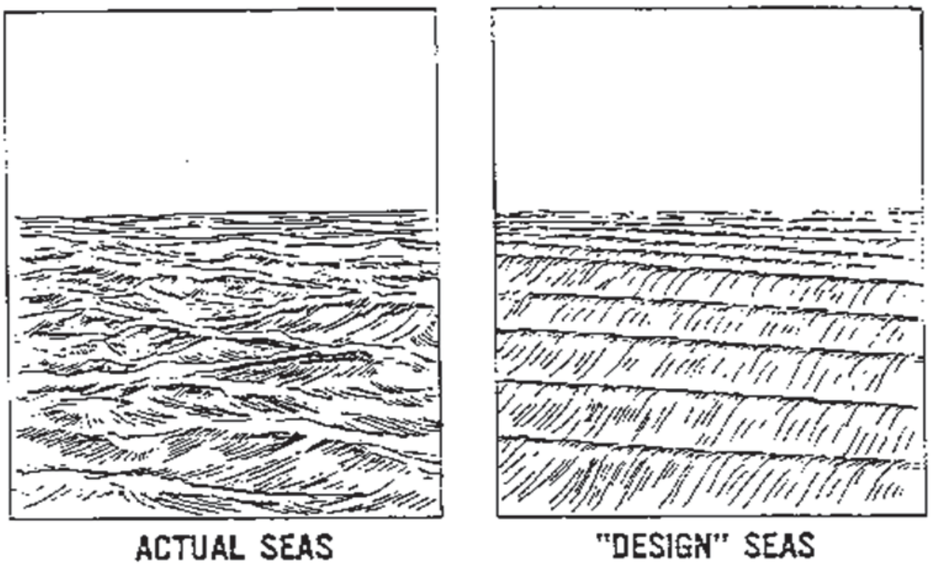


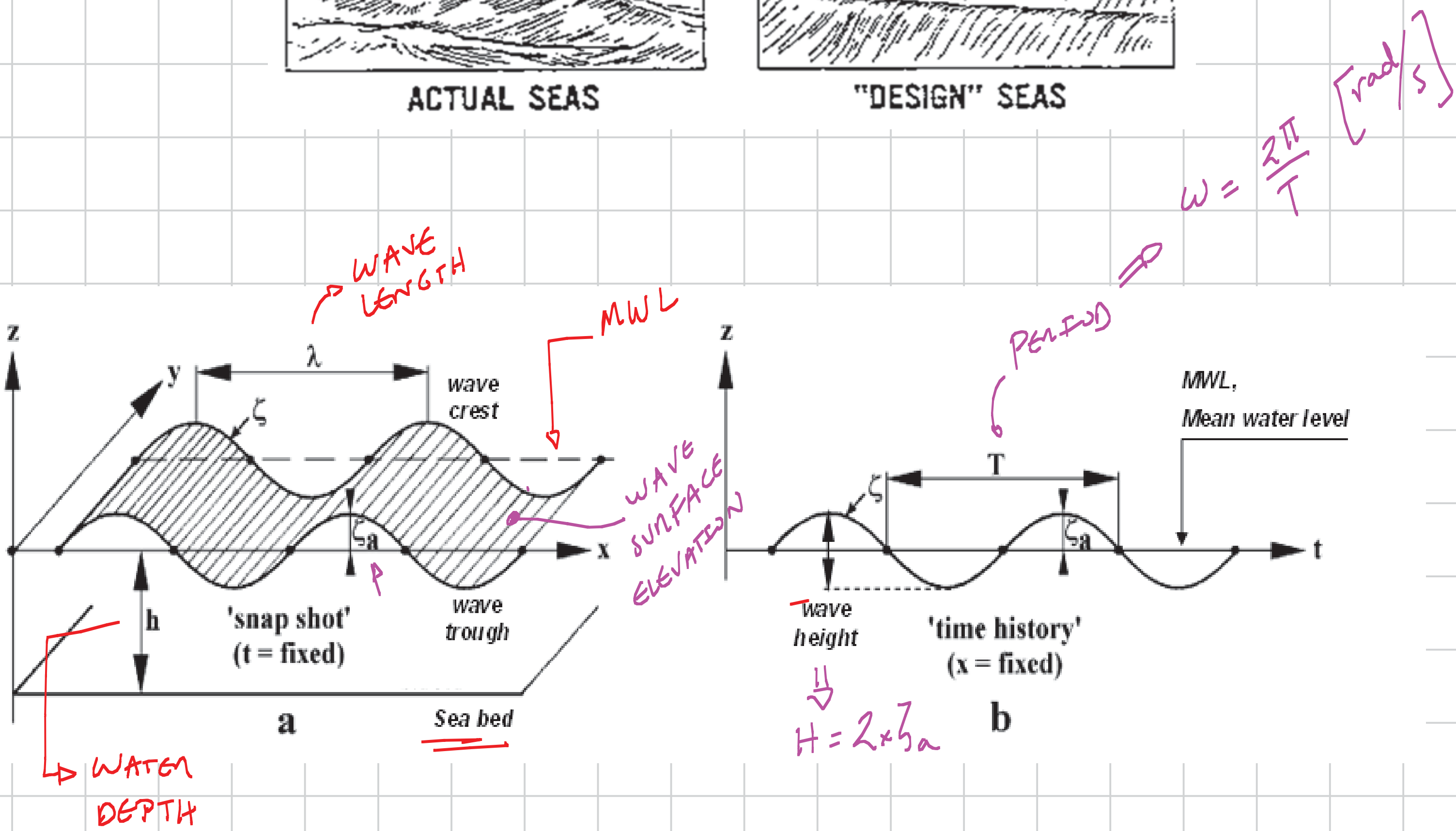
Fig. 4. Illustration of sea waves and swell generation.



Wind-generated waves present irregularity motion that in time and space cannot be exactly predicted. Therefore, it is a common practice to represent the elevation of the sea surface with sum of many sinusoidal waves with different direction, amplitudes, frequencies, and phases





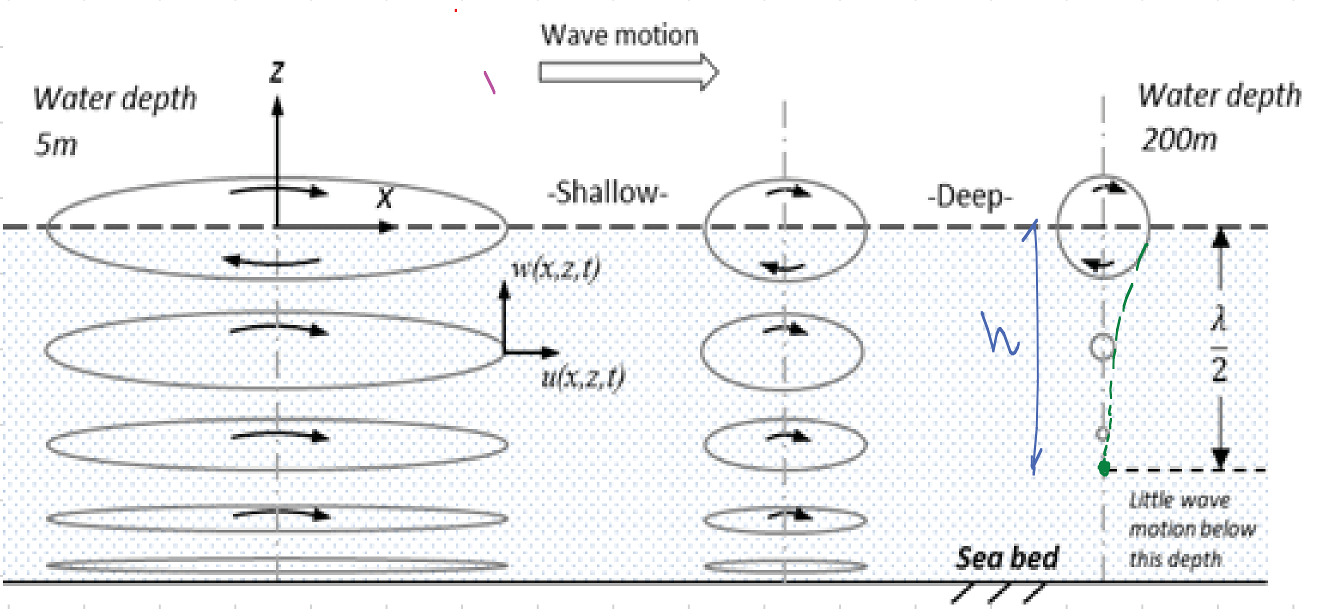


EQ. FOR THE IRREGULAR WAVE:

$$\zeta(x,t) = \sum_{i=1}^{N} \zeta_{a_i} \cdot \sin(\omega_i \cdot t - k_i \cdot t - \varepsilon_i)$$

- ω_i → FREQ.
- k_i → WAVE NUMBER: $k_i = \frac{2\pi}{\lambda_i}$
- ζ_{a_i} → WAVE "i" ELEVATION AMPLITUDE
- ε_i → PHASE AMONG WAVES ($0 - 2\pi$)

• SHALLOW VS DEEP WATER:



• FOR DEEP WATER (EX.)

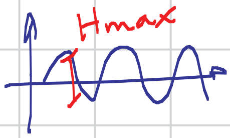
• T = 12 sec. → WAVE LENGTH ⇒ $\lambda = \frac{g \cdot T^2}{2\pi}$

↑ PERIOD IN NCS

$$\lambda = \frac{(10\ m/s^2) \times (12\ s)^2}{2\pi} = 229\ mts$$

• WATER DEPTH → $h = \frac{\lambda}{2} = 115\ m$

• MAX. WAVE HEIGHT



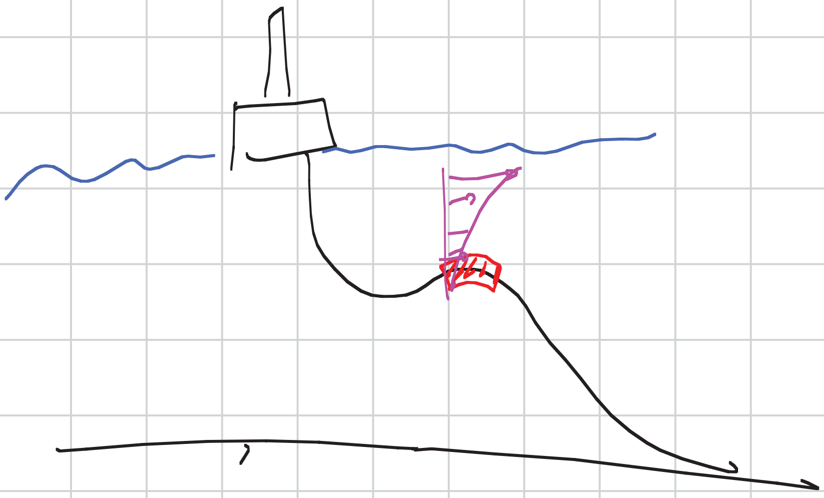
NCS → $H_{max} = 30m$ ←

SIMPLE THEORY (CONSERVATIVE)

$H_{max} = \lambda/7 = 229/7 = 32m$

- HORIZONTAL VELOC OF THE WAVE

$$u = \omega \cdot \zeta_a \cdot e^{kz}$$



$$u_{z(z=-150)} = \frac{2\pi}{T} \times \frac{H_{max}}{2} \times e^{\left(\frac{2\pi}{\lambda}\right)(z)}$$

(T: 120; H_{max}: 32 m; z: −150; λ: 229)

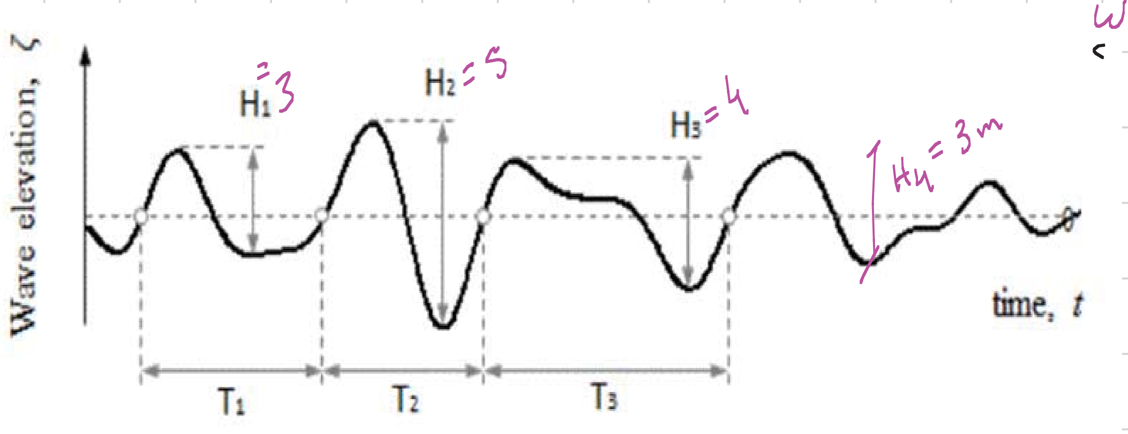
$$u(z=-150) = 0.14\ m/s$$

$$u(z=-15m) = 5.6\ m/s$$

SIGNIFICANT WAVE HEIGHT: (H_s)

→ THE AVE. OF THE HIGHEST 1/3 WAVES PRESENT

↳ GOOD INDICATOR FOR POTENTIAL DAMAGE DUE TO THE WAVE



○ Zero-upcrossings

H1, H2, H3 ...individual wave heights

T1, T2, T3 ...corresponding zero-upcrossings periods

$$T_z = \frac{1}{N}(T_1 + T_2 + T_3 + \cdots + T_N) \qquad (9)$$

$$H_{mean} = \frac{1}{N}(H_1 + H_2 + H_3 + \cdots + H_N) \qquad (10)$$

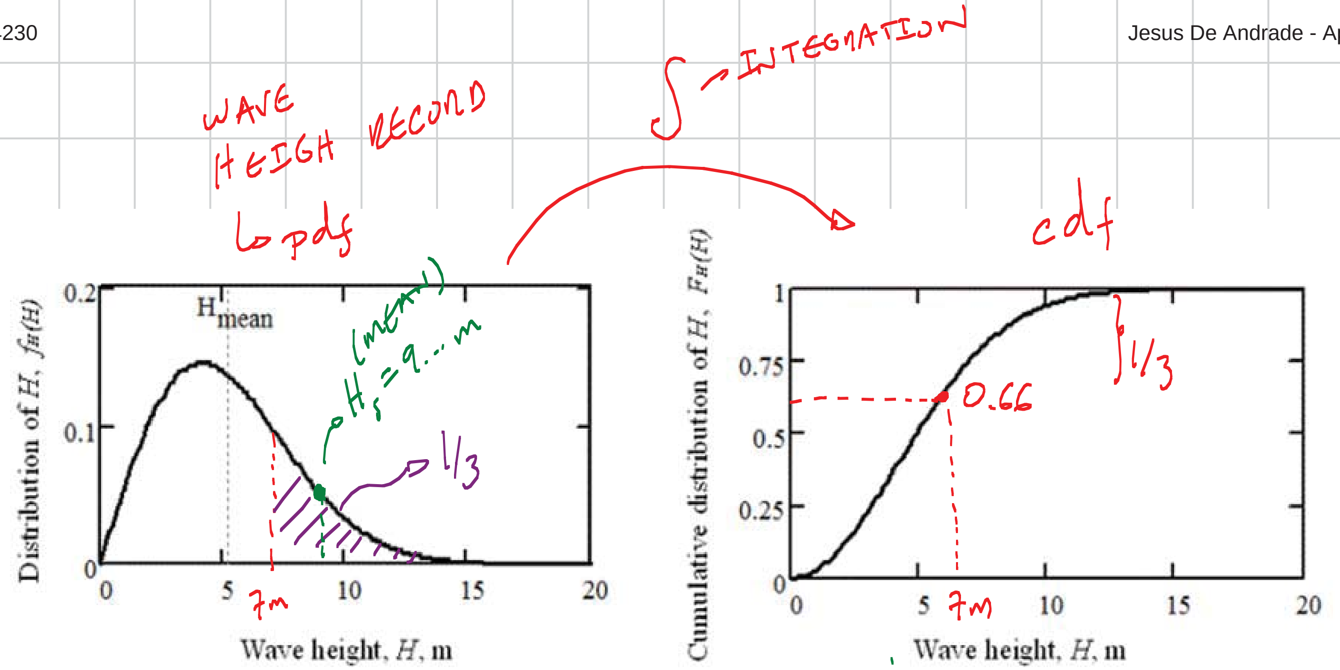
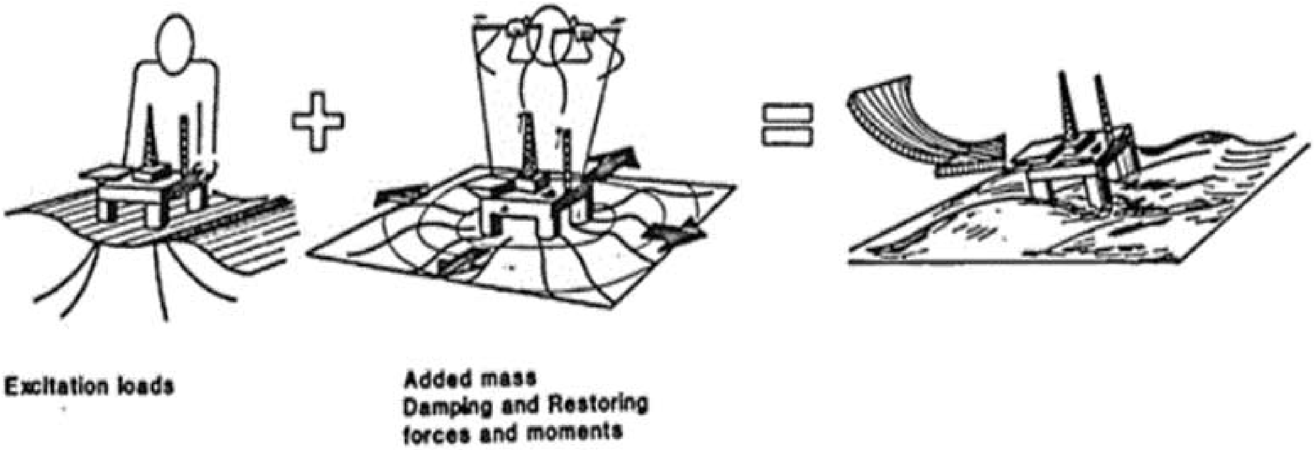


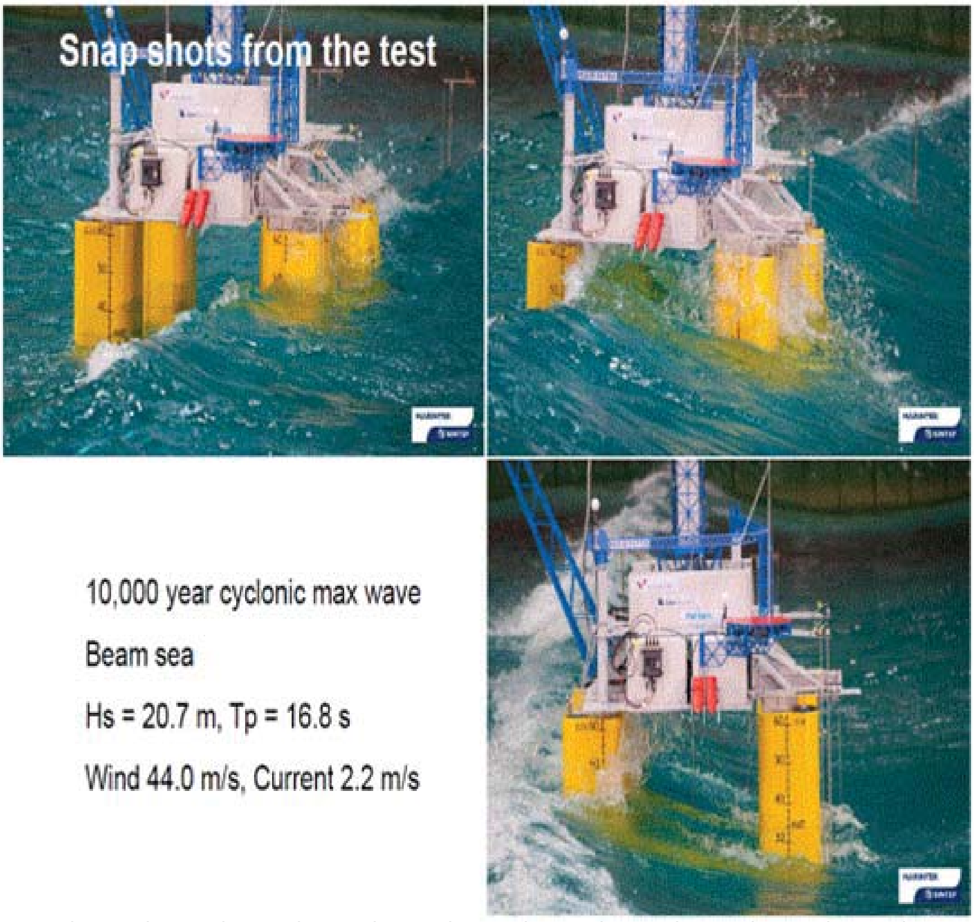
Fig. 10. Probability density function f_H (Rayleigh distribution) and cumulative distribution function F_H for the wave height of certain sea state.

Motion of marine structures



Superposition of wave excitation, added mass, damping and restoring loads.

- Semi-analytical
- Numerical Model
- Experimental testing



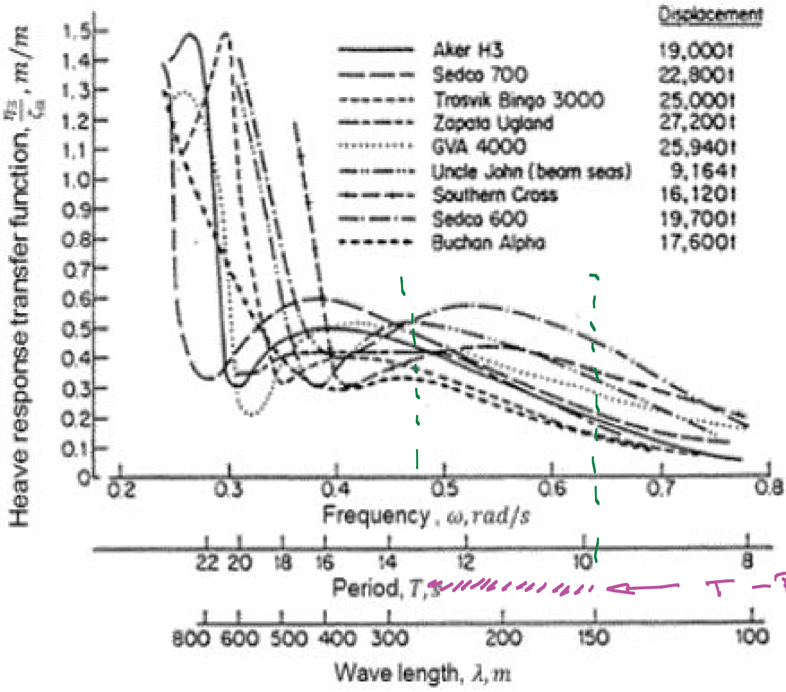
• PURPOSE
- VERIFICATION OF MOORING SYSTEM
- VERIFICATION OF DECK LEVEL
- GLOBAL MOTIONS
⋮

Response amplitude operator, RAO

it establishes a relation between the motion and wave amplitude in the frequency domain

heave motion of semi-submersible platforms

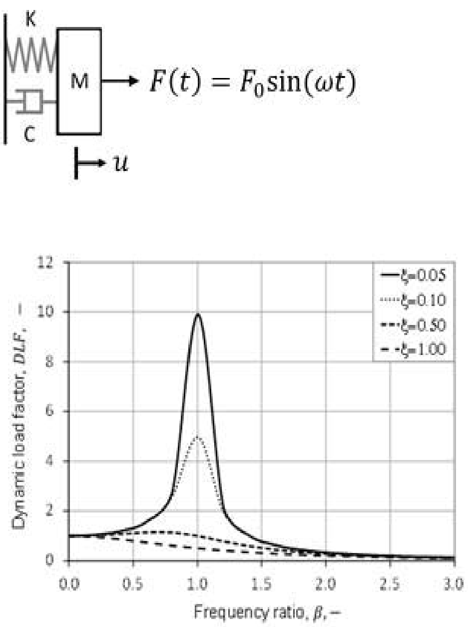
HEAVE AMPLITUDE → $\frac{\eta_3}{\zeta_a}$ ← WAVE AMPLITUDE



WAVE T - PERIOD

Fig. 24. Representative heave response transfer functions for different semi-submersibles.

IF T= 12s → SEMIS WILL MOVE UP AND DOWN (HEAVE) 20 TO 50% OF THE WAVE AMPLITUDE



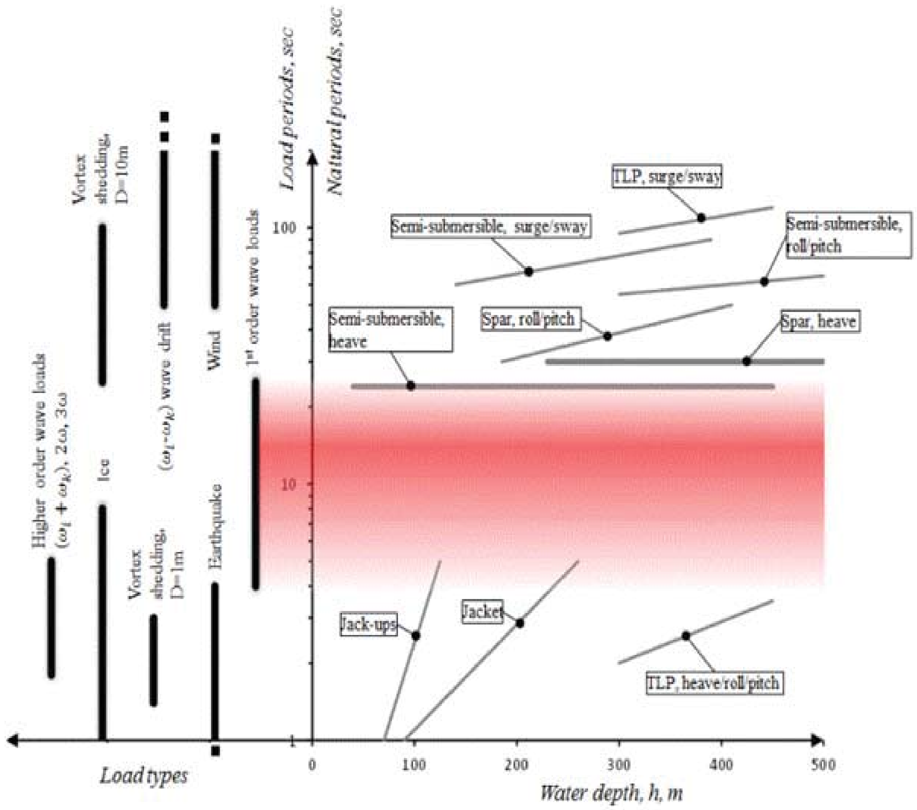


Illustration of largest natural period versus depth for some platform concepts, and periods for important environmental loads.

- WAVE SPECTRUM:

$$\frac{E}{\rho g} = \sum_{i=1}^{N} \frac{1}{2} \zeta_{a_i}^2(\omega_i)$$

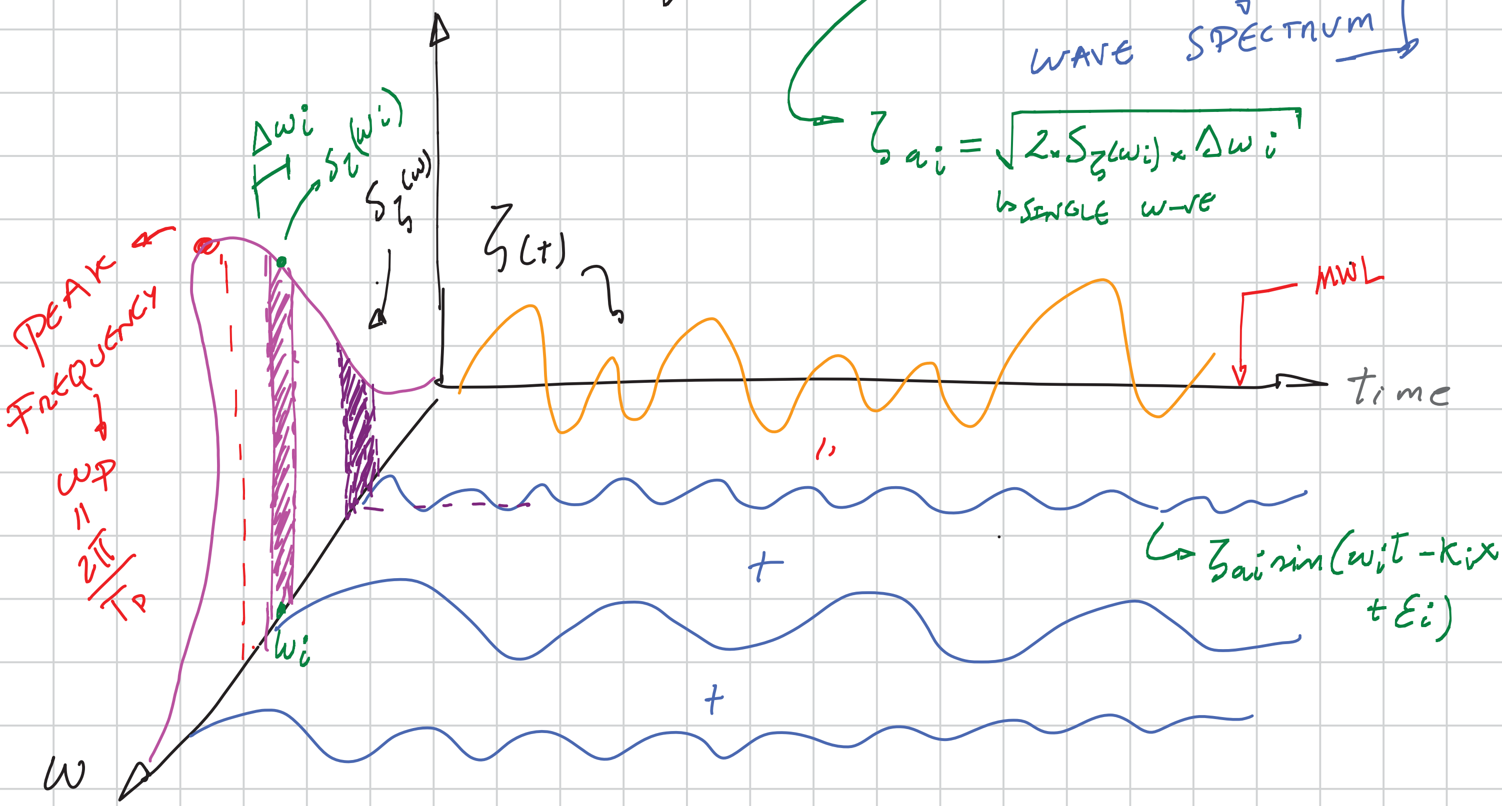
SPECTRUM OF ENERGY:

$$\text{Energy}\ \frac{E}{\rho g} = \sum_{i=1}^{N} \frac{1}{2} \zeta_{a_i}^2(\omega_i) \triangleq \sum_{i=1}^{N} S_\zeta(\omega_i) \times \Delta\omega_i$$

$S_\zeta(\omega_i)$ → WAVE SPECTRUM

$$\zeta_{a_i} = \sqrt{2 \times S_\zeta(\omega_i) \times \Delta\omega_i}$$

↳ SINGLE WAVE



SPECTRUM ⟹ STATISTICAL INFORMATION

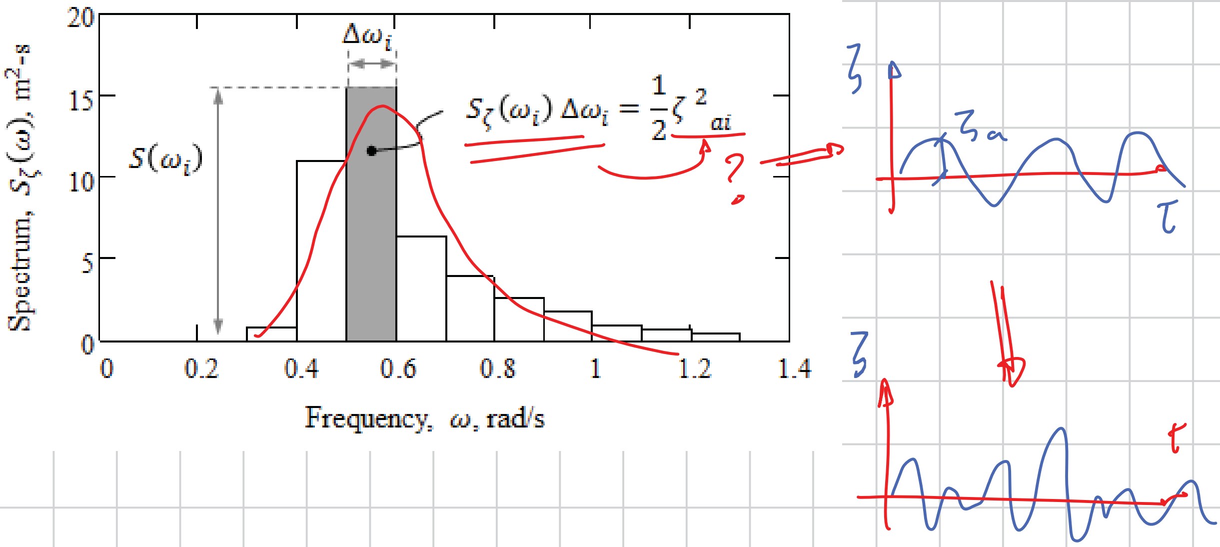
↳ PERIOD

↳ H_s (SIGNIFICANT WAVE HEIGHT)

$$T_p \text{ (PEAK PERIOD)} = 2\pi / \omega_p$$

$$\int_0^\infty S_\zeta(\omega)\, d\omega = \sigma_\zeta^2 \Rightarrow \sigma_\zeta \to \text{STD. DEVIATION OF THE WAVE SURF. ELEVATION}$$

$$H_s = 4\sigma_\zeta$$



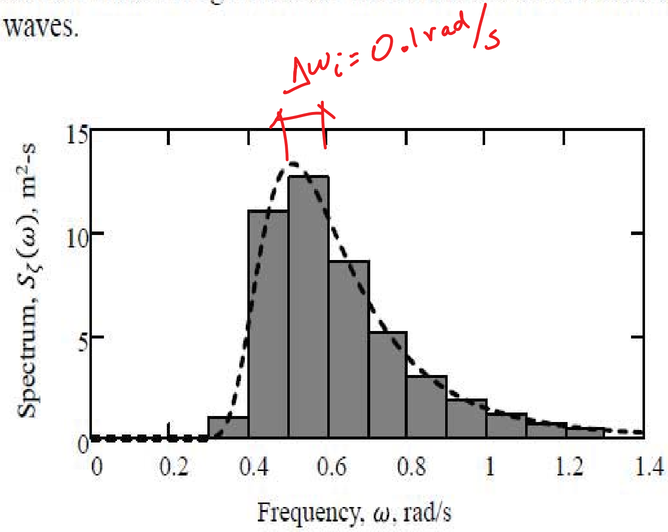
USUALLY, THERE ARE CORRELATIONS.

T_{WAVES}, H_S ⇒ SPECTRUM

↳ HOW THE WAVES LOOK LIKE

Ex. 1 Wave energy spectrum and time domain wave record

A wave energy spectrum obtained from 20 min sample of instrumentally recorded wave data in the Troll field (position 60° 45' 21.12" N 3° 38' 22.98" E) is given in the figure below. The spectrum has been simplified to a column type diagram with frequency steps of $\Delta\omega_i$=0.1 rad/s, and the values are given in the table. This sea state is formed by long crested deep-water waves.



ω	S_ζ
rad/s	m^2-s
0.35	1.1
0.45	11.1
0.55	12.6
0.65	8.6
0.75	5.2
0.85	3.1
0.95	1.9
1.05	1.2
1.15	0.8
1.25	0.5

Tasks:

1. Find the wave surface elevation amplitude for each wave component
2. Find and plot the wave elevation function corresponding to the first, fourth and eighth wave component (0.35, 0.65 and1.05 rad/s).
3. Then, find and plot the resulting wave surface elevation by adding the contribution of all the harmonic wave components for time steps such as: 0,1,2 … 300s.
   - Generate random values for the phase angle ε_i among all wave components. To do so, it is possible to use excel functions as follow: =RAND()*2*Pi()

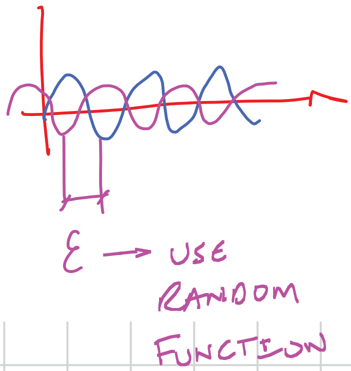
Useful equations:

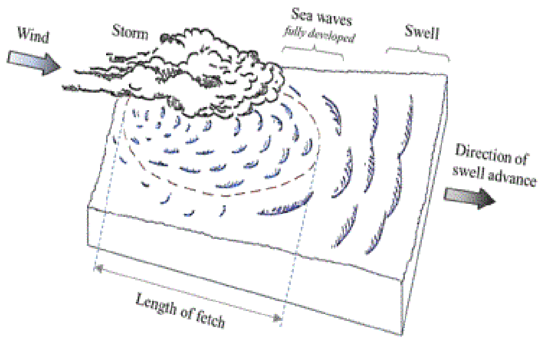
Wave surface elevation for an "*i*" harmonic component: $\zeta_i(x,t) = \zeta_{ai}\, sin(\omega_i * t + \varepsilon_i)$

Total wave surface elevation: $\zeta(x,t) = \sum_{i=1}^{N} \zeta_{ai}\, sin(\omega_i * t + \varepsilon_i)$

Wave energy spectrum: $\frac{1}{2}\zeta^2{}_{ai}(\omega_i) \triangleq S_\zeta(\omega_i)\,\Delta\omega_i$

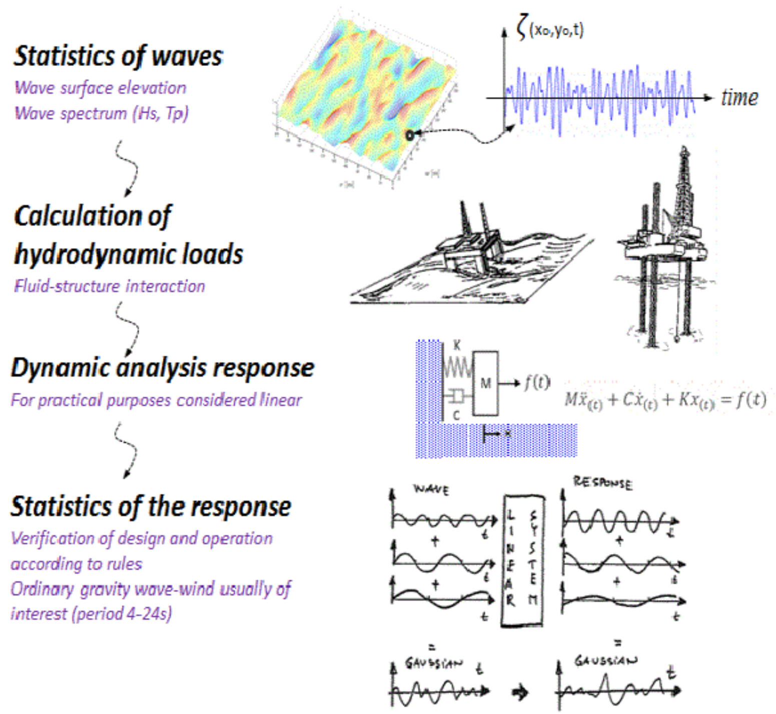
$$\frac{E}{\rho g} = \sum_{i=1}^{N} \frac{1}{2}\zeta^2{}_{ai}(\omega_i) \triangleq \sum_{i=1}^{N} S_\zeta(\omega_i)\,\Delta\omega_i$$





Introduction to Offshore Structures with focus on Marine Dynamics

Jesus De Andrade
April, 2016

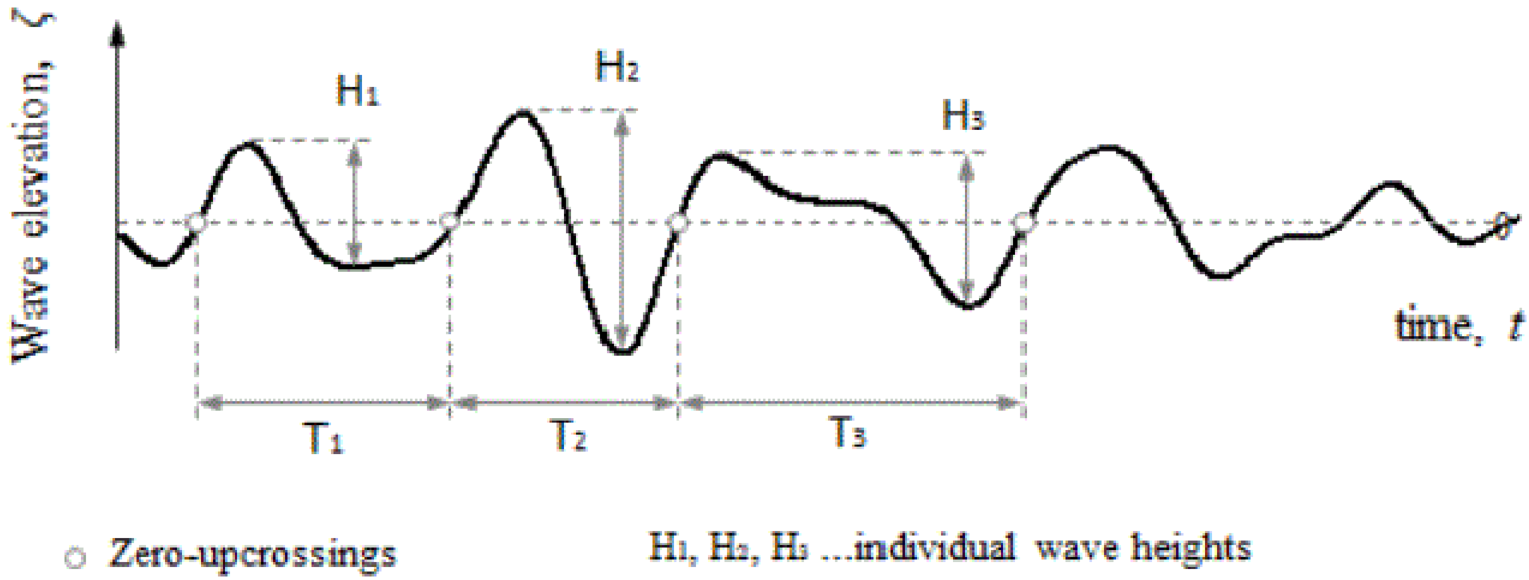


Cases that show how not to do it

The Mars TLP after the hurricane Katrina

Typhoon upside down after hurricane Rita

Waves statistics / Short-term



$$T_z = \frac{1}{N}\,(T_1 + T_2 + T_3 + \cdots + T_N) \tag{9}$$

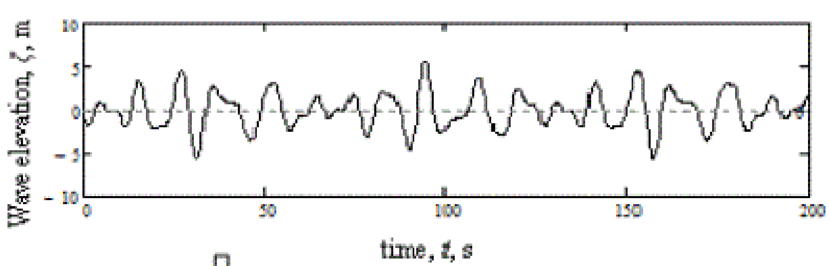
$$H_{mean} = \frac{1}{N}\,(H_1 + H_2 + H_3 + \cdots + H_N) \tag{10}$$

Waves statistics / Short-term

- Distribution of wave surface elevation

$$T_z = \frac{1}{N}\left(T_1 + T_2 + T_3 + \cdots + T_N\right) \quad (9)$$

$$H_{mean} = \frac{1}{N}\left(H_1 + H_2 + H_3 + \cdots + H_N\right) \quad (10)$$

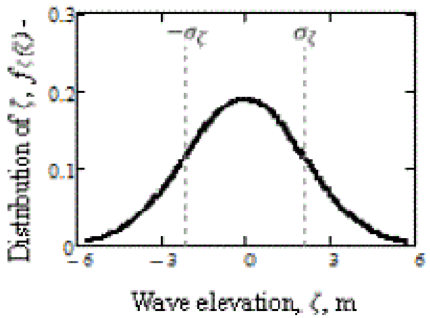


$$\zeta(t) = \sum_{i=1}^{N} \zeta_{ai} \sin(\omega_i t + \varepsilon_i)$$

Mean: $\mu = \frac{\int_0^{t_{final}} \zeta(t)dt}{t_{final}} = \frac{1}{N}\sum_{i=1}^{N} \zeta_i \approx 0$

Variance: $\sigma_\zeta{}^2 = \frac{1}{N}\sum_{i=1}^{N}(\zeta_i - \mu)^2 = \frac{1}{2}\sum_{i=1}^{N}(\zeta_{ai})^2$

σ_ζ… standard deviation



Probability density function of wave elevation (Gaussian):

$$f_\zeta(\zeta) = \frac{1}{\sigma_\zeta\sqrt{2\pi}} exp\left[-\left(\frac{\zeta}{\sigma_\zeta\sqrt{2}}\right)^2\right]$$

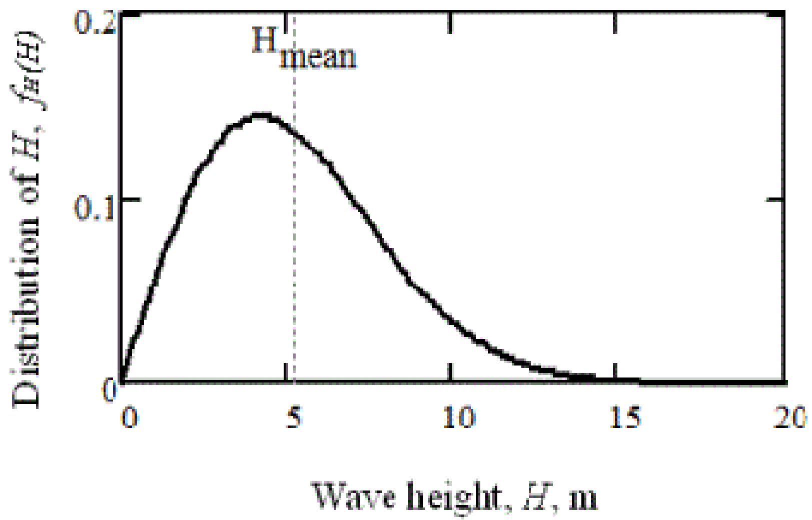
Fig. 8. Wave surface elevation normally distributed (Gaussian).

Waves statistics / Short-term

- Distribution of Wave Height

Rayleigh distribution, which can be written as:

$$f_H(H) = \frac{H}{4\sigma_\zeta^2} exp\left[-\left(\frac{H}{\sigma_\zeta\sqrt{8}}\right)^2\right] \qquad (11)$$



The mean and variance of wave height can now be expressed as follow:

$$H_{mean} = \frac{\int_0^\infty H f_H(H)\, dH}{\int_0^\infty f_H(H)\, dH} = \int_0^\infty H f_H(H)\, dH$$

$$\sigma_H^2 = \int_0^\infty (H - H_{mean})\, f_H(H)\, dH$$

Waves statistics / Short-term

- Distribution of Wave Height

From statistics, the probability for the stochastic variable wave height H is lower that certain value H' is given by:

$$P(H < H') = \int_0^{H'} f_H(H)\,dH = F_H(H') = 1 - exp\left[-\left(\frac{H'}{\sigma_\zeta\sqrt{8}}\right)^2\right] \qquad (14)$$

Where $F_H(H)$ is the **cumulative distribution function** (cdf) for the wave height. Fig. 10 provides an example of probability density function f_H and cumulative distribution function F_H for the wave height of the wave record in Fig. 8. For example, in the figure it can be seen that less than 75% of the waves will have wave heights lower than approximately 7m, or one could say that the probability of exceeding 7m wave height is 25%.

Waves statistics / Short-term

- Distribution of Wave Height

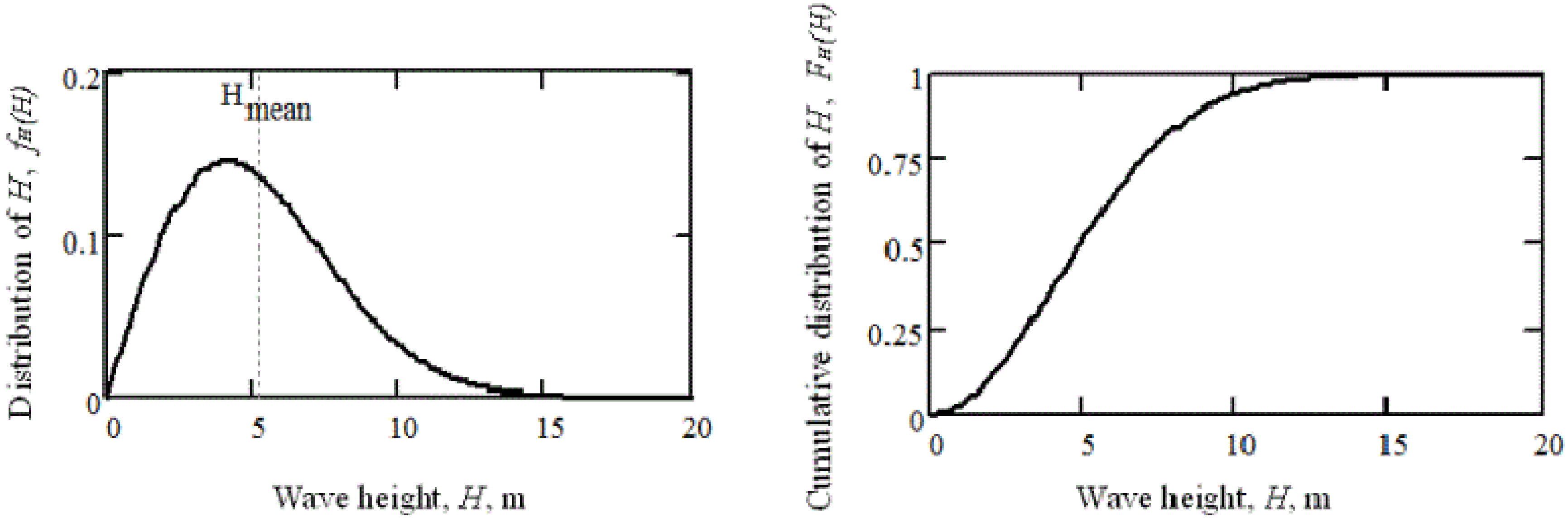


Fig. 10. Probability density function f_H (Rayleigh distribution) and cumulative distribution function F_H for the wave height of certain sea state.

Waves statistics / Short-term

- Distribution of Wave Height

At this instant, it is also convenient to bring up the definition of **significant wave height**, H_s, H_{m0} or $H_{1/3}$, which is defined as the average of the highest 1/3 of the waves in the record. Hence, according to Fig. 11, the H_s is provided by:

$$H_s = \frac{\int_{h_{1/3}}^{\infty} H\, f_H\,(H)\; dH}{\int_{h_{1/3}}^{\infty} f_H\,(H)\; dH} = \frac{\int_{h_{1/3}}^{\infty} H\, \frac{H}{4\sigma_\zeta^2}\, exp\left[-\left(\frac{H}{\sigma_\zeta\sqrt{8}}\right)^2\right] dH}{1/3} \qquad (15)$$

$$h_{1/3} = 4\,\sigma_\zeta \sqrt{\frac{\ln(3)}{2}} \qquad (16)$$

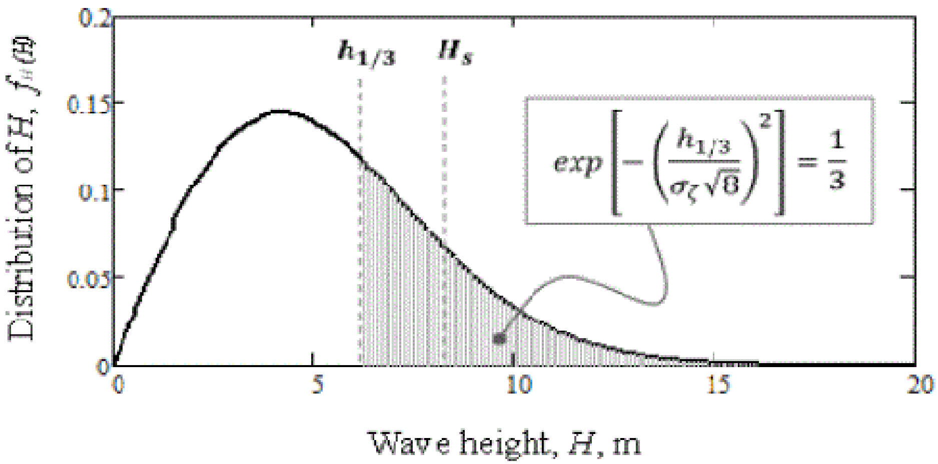


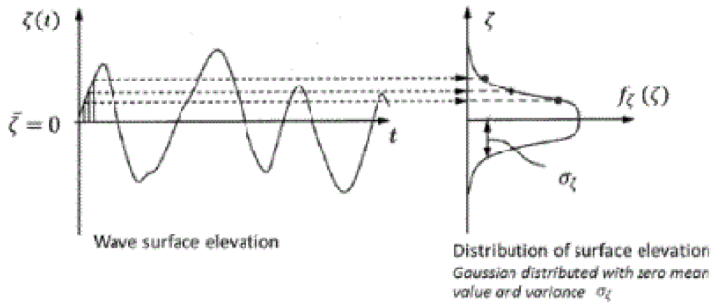
Fig. 11. Probability density function f_H (Rayleigh distribution) and significant wave height of a certain sea state.

- **Exercise**

Short-term statistics

Ex. 2 Wave energy spectrum and time domain wave record

The total surface elevations in the previous Ex 1 is assumed to be Gaussian distributed, which means that the expected mean value will be zero and the variance equal to ${\sigma_\zeta}^2$, and they are considered to be constant during the whole time interval. This is illustrated in the figure below.



Tasks:
Using the data of wave surface elevation for time steps from 0,1,2…300s, find:

- Statistical calculations:
1. The mean value of wave surface elevation, $\bar{\zeta}$
2. The variance of the surface elevation, σ^2_ζ
3. The limit of the highest 1/3 of wave heights, $h_{1/3}$
4. The significant wave height, H_s

- Distributions:
1. Probability density function of wave elevations, $f_\zeta(\zeta)$ (Gaussian distribution)
2. Probability density function of wave heights, $f_H(H)$ (Rayleigh distribution)
3. Cumulative distribution function of wave heights, $F_H(H)$

Useful equations:

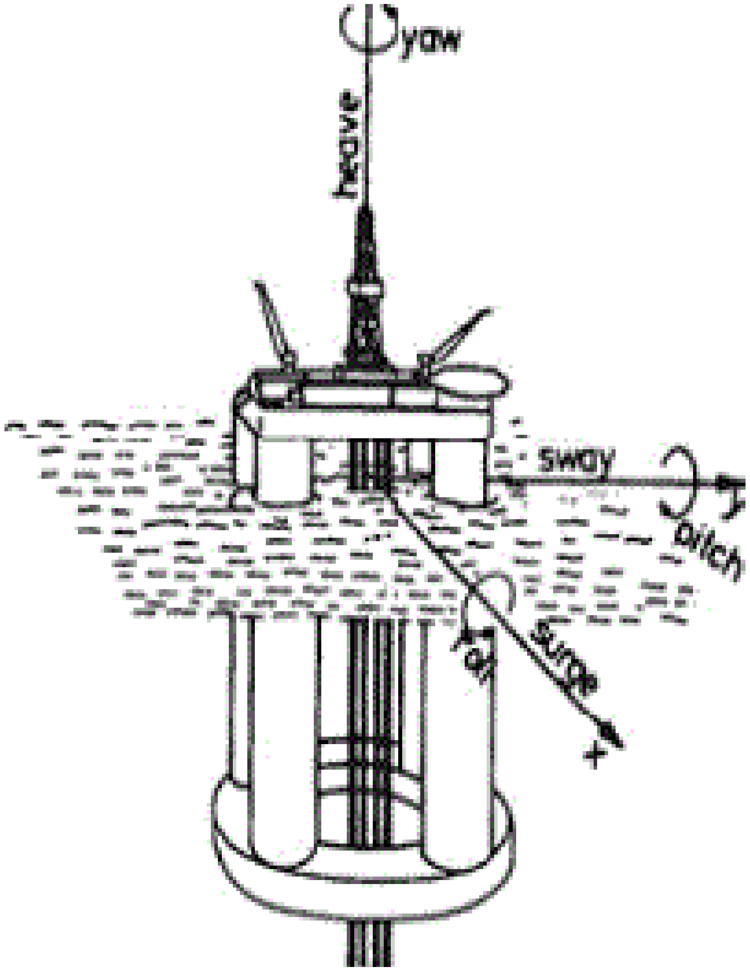
$$H_s = 4\,\sigma_\zeta \qquad h_{1/3} = 4\,\sigma_\zeta\sqrt{\frac{\ln(3)}{2}}$$

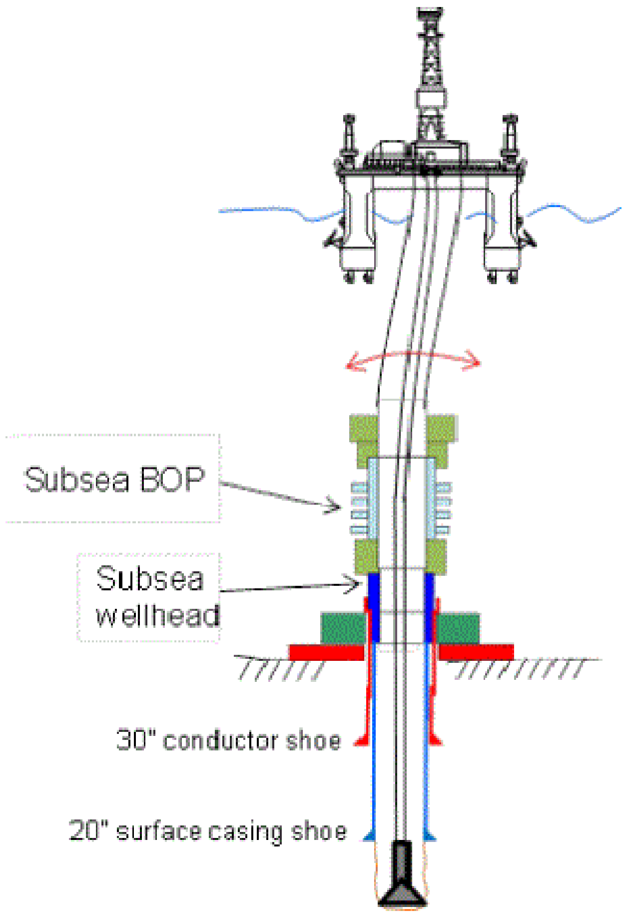
$$f_\zeta(\zeta) = \frac{1}{\sigma_\zeta\sqrt{2\pi}} exp\left[-\left(\frac{\zeta}{\sigma_\zeta\sqrt{2}}\right)^2\right]$$

$$f_H(H) = \frac{H}{4{\sigma_\zeta}^2} exp\left[-\left(\frac{H}{\sigma_\zeta\sqrt{8}}\right)^2\right]$$

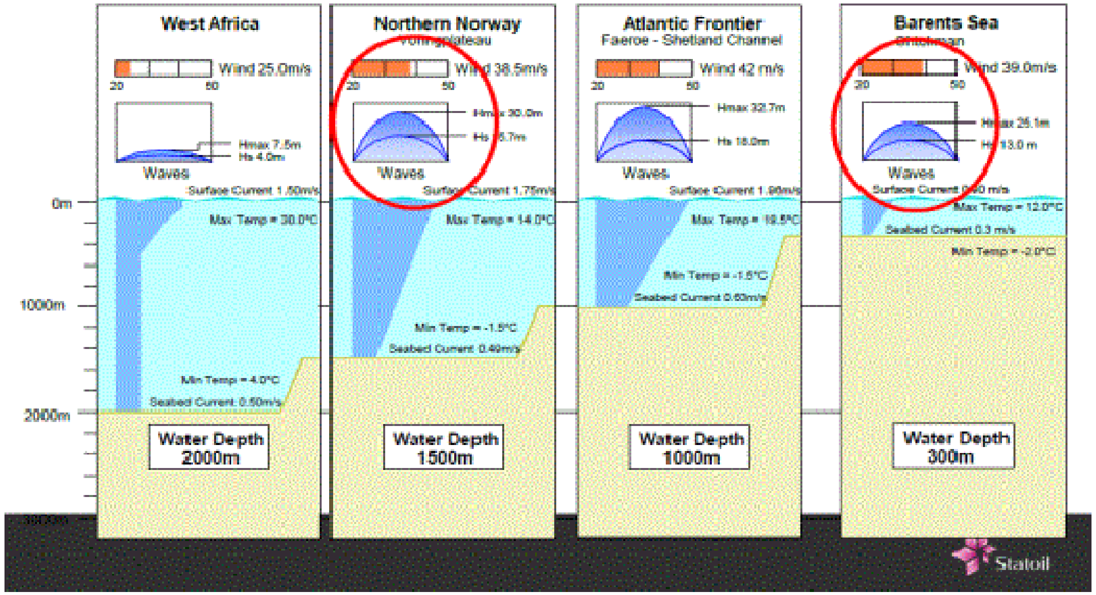
$$F_H(H) = 1 - exp\left[-\left(\frac{H}{\sigma_\zeta\sqrt{8}}\right)^2\right]$$

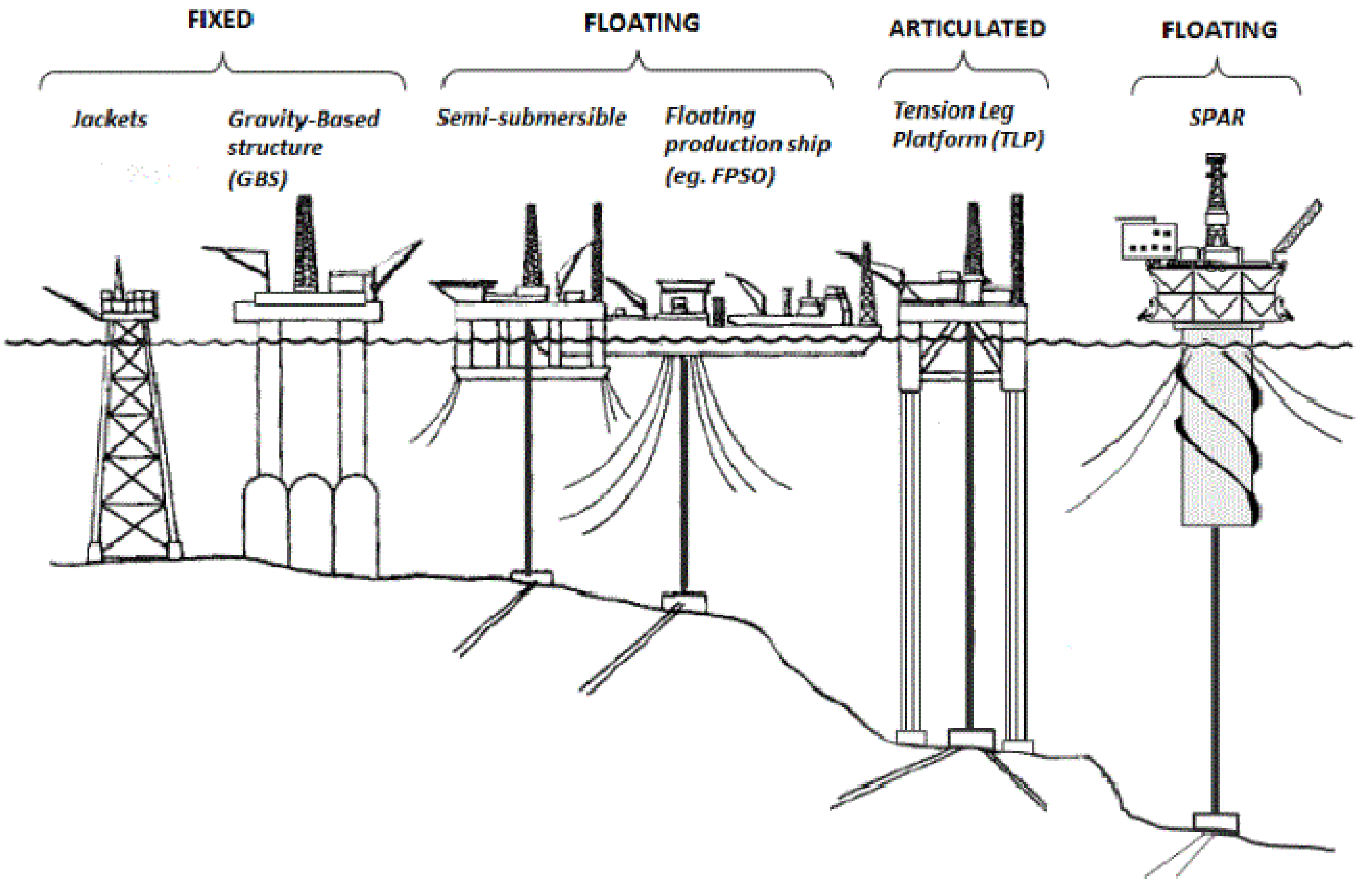
Motion of marine structures





Waves, wind and current comparable with Norway




FIXED
FLOATING
ARTICULATED
FLOATING
Jackets
Gravity-Based structure (GBS)
Semi-submersible
Floating production ship (eg. FPSO)
Tension Leg Platform (TLP)
SPAR

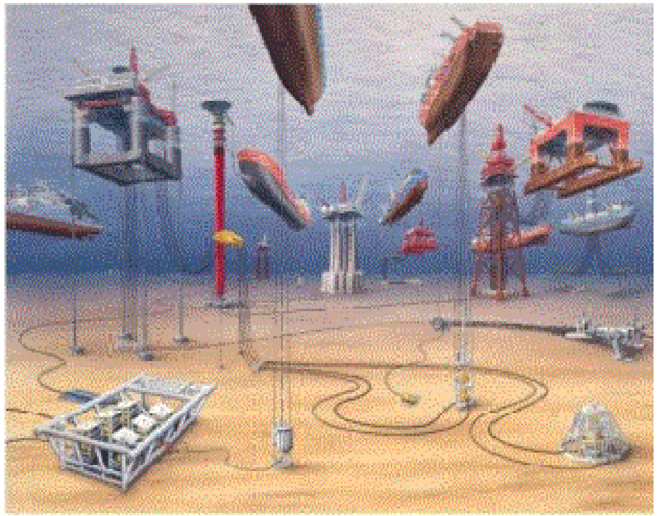
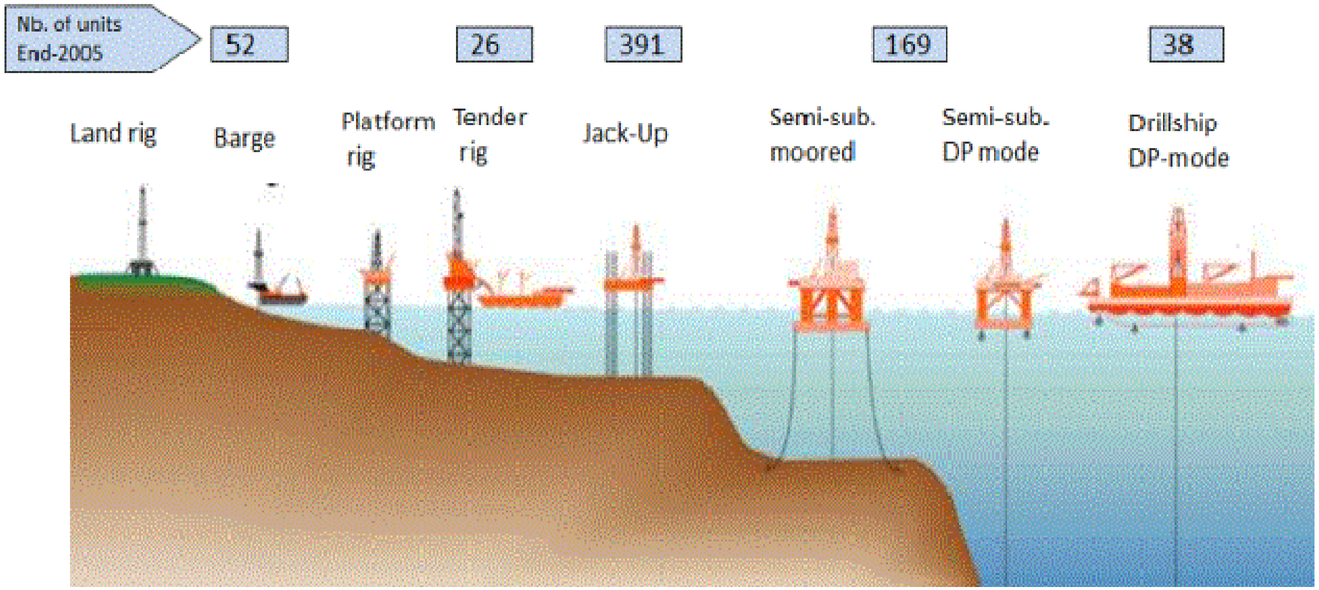



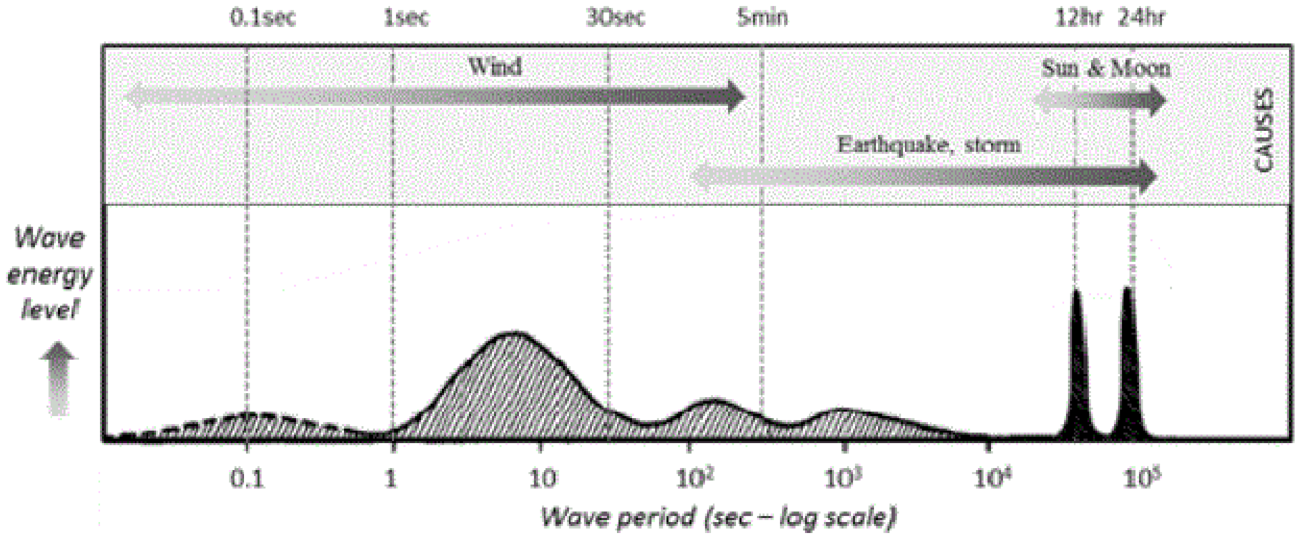

Table 1. Examples of offshore structures in the NCS for different water depths.

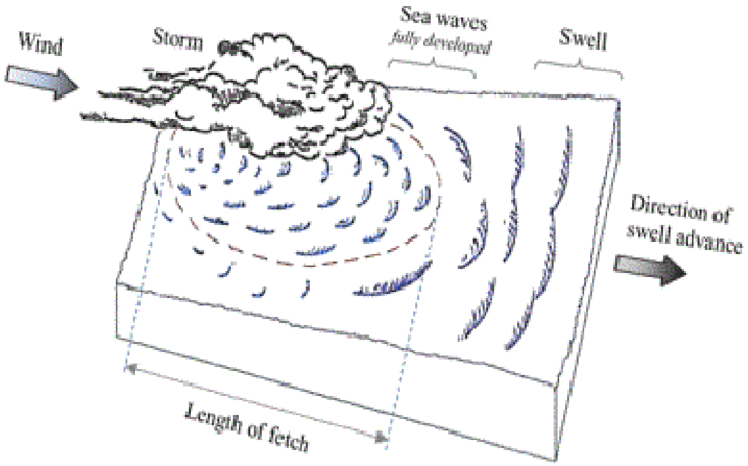
Water depth	Field	Offshore structure
70-75 mts	Ekofisk	Jackets
120-130 mts	Balder	FPSO
130-250 mts	Gullfaks	Concrete fixed facilities and steel topside
300 mts	Troll	Concrete fixed facilities and steel topside
300 mts	Åsgard B	Semi-submersible platform
300-350 mts	Snorre	TLP steel platform
370 mts	Kristin	Semi-submersible platform
1300 mts	Luva*	Spar platform

**Future field development*

RIG TYPES


Nb. of units
End-2005
52
26
391
169
38
Land rig
Barge
Platform
rig
Tender
rig
Jack-Up
Semi-sub.
moored
Semi-sub.
DP mode
Drillship
DP-mode





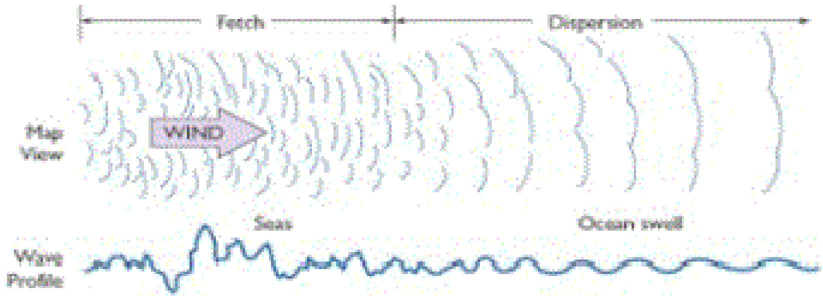
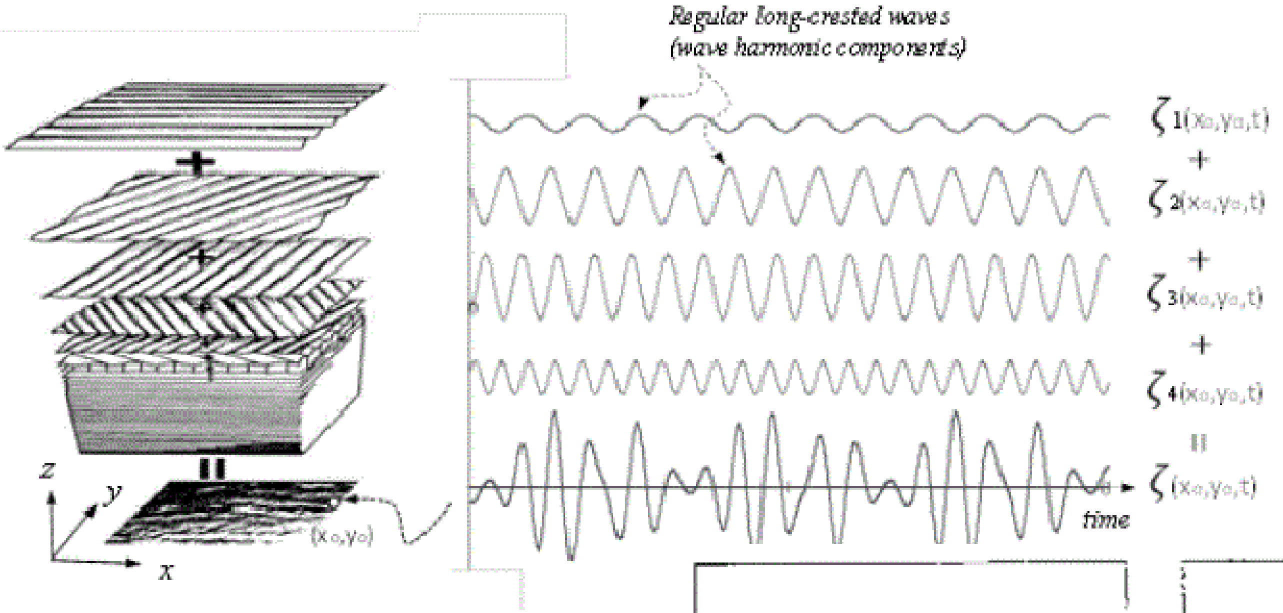
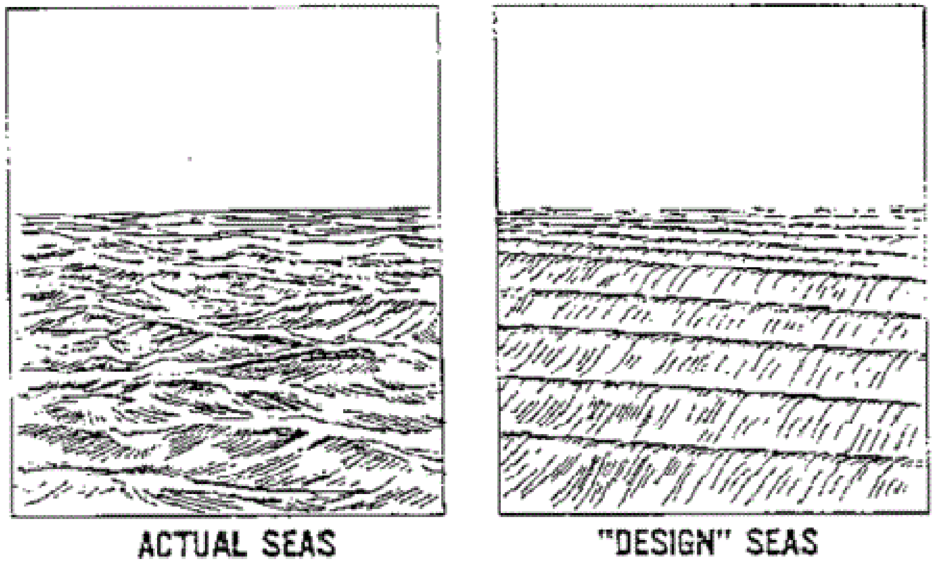
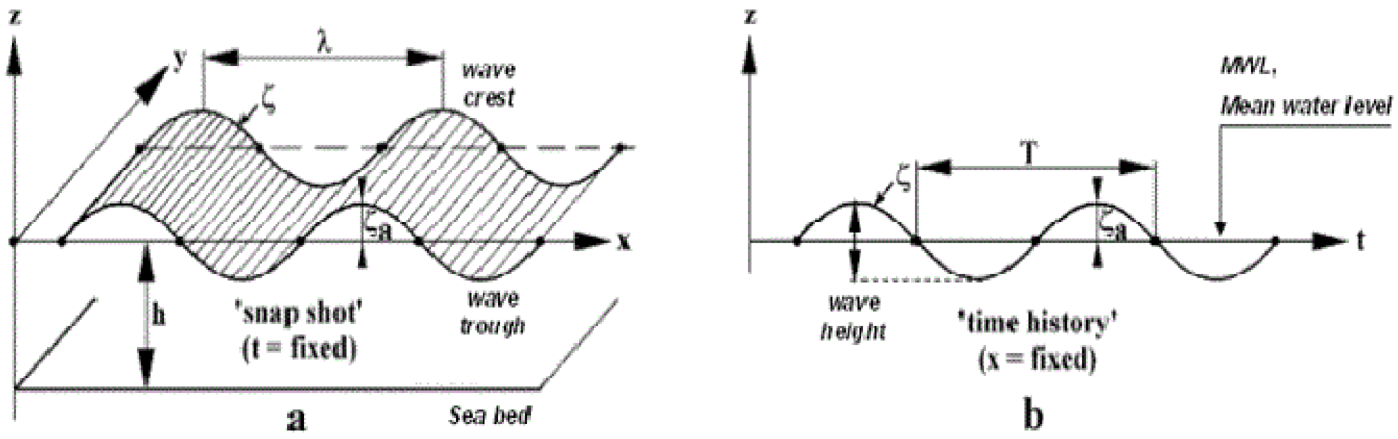
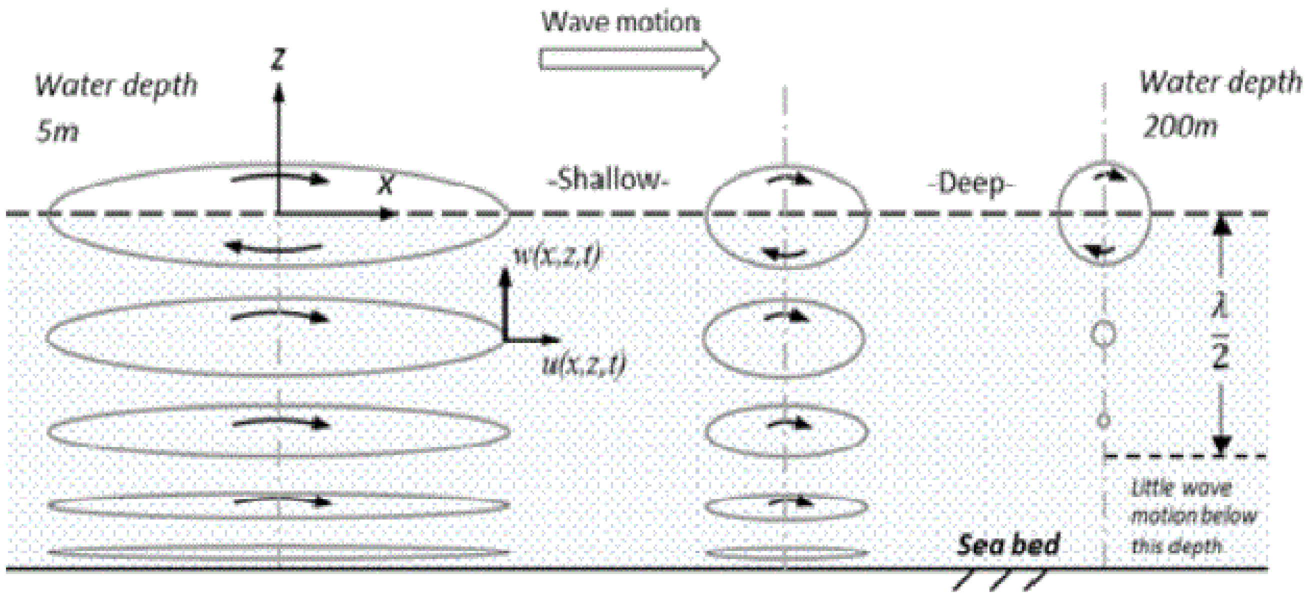


Fig. 4. Illustration of sea waves and swell generation.


Regular long-crested waves
(wave harmonic components)
ζ1(xo,yo,t)
+
ζ2(xo,yo,t)
+
ζ3(xo,yo,t)
+
ζ4(xo,yo,t)
=
ζ(xo,yo,t)
time
z
y
x
(xo,yo)


ACTUAL SEAS
"DESIGN" SEAS


z
y
λ
wave
crest
ζ
ζa
x
h
'snap shot'
(t = fixed)
wave
trough
Sea bed
a
z
MWL,
Mean water level
T
ζ
ζa
t
wave
height
'time history'
(x = fixed)
b

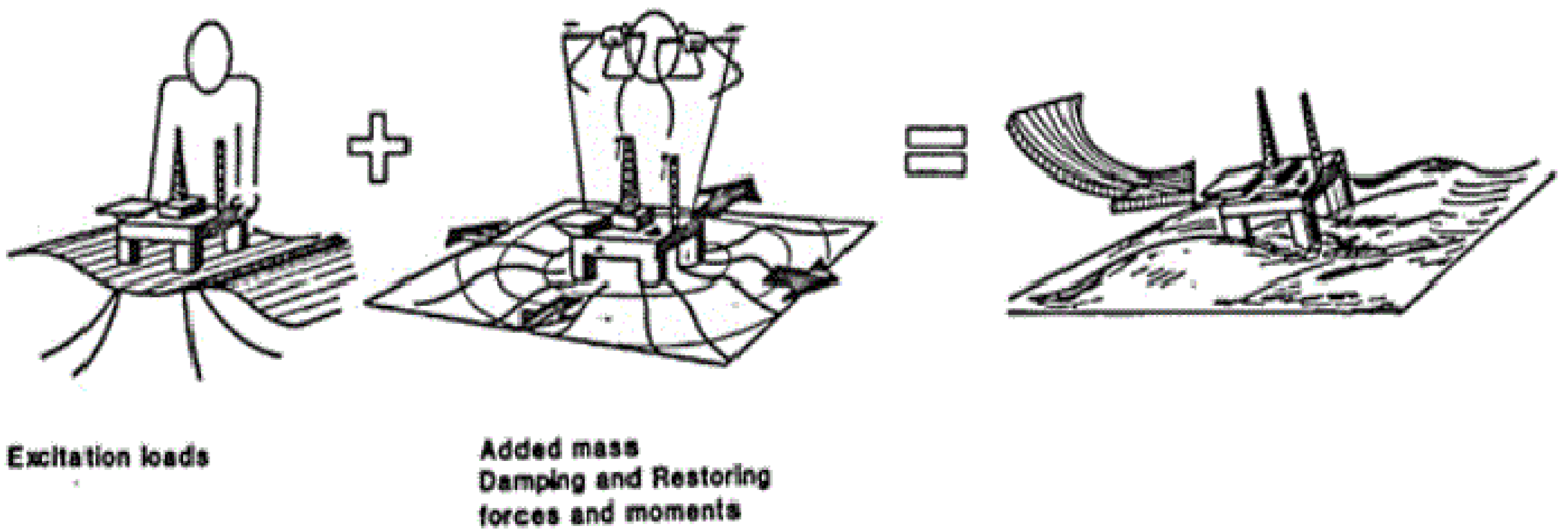

Wave motion
z
Water depth
5m
x
-Shallow-
-Deep-
Water depth
200m
w(x,z,t)
u(x,z,t)
λ
2
Little wave
motion below
this depth
Sea bed

Properties of Ocean Waves

- A fully developed sea is a sea state where the waves generated by the wind are as large as they can be under current conditions of wind velocity.

- Significant wave height is the average of the highest 1/3 of the waves present.
  - Good indicator of potential for wave damage to marine structures

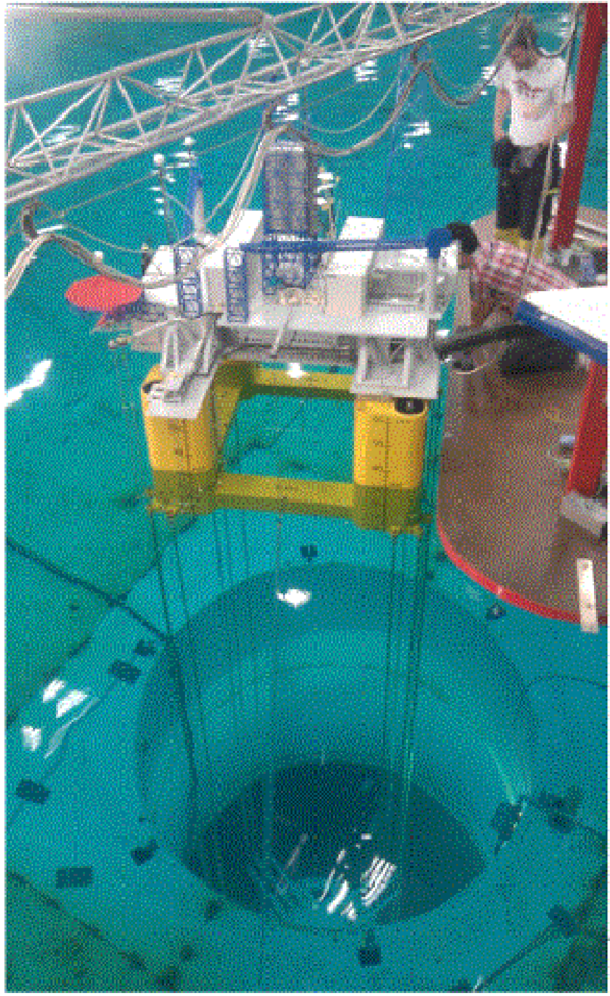
Motion of marine structures

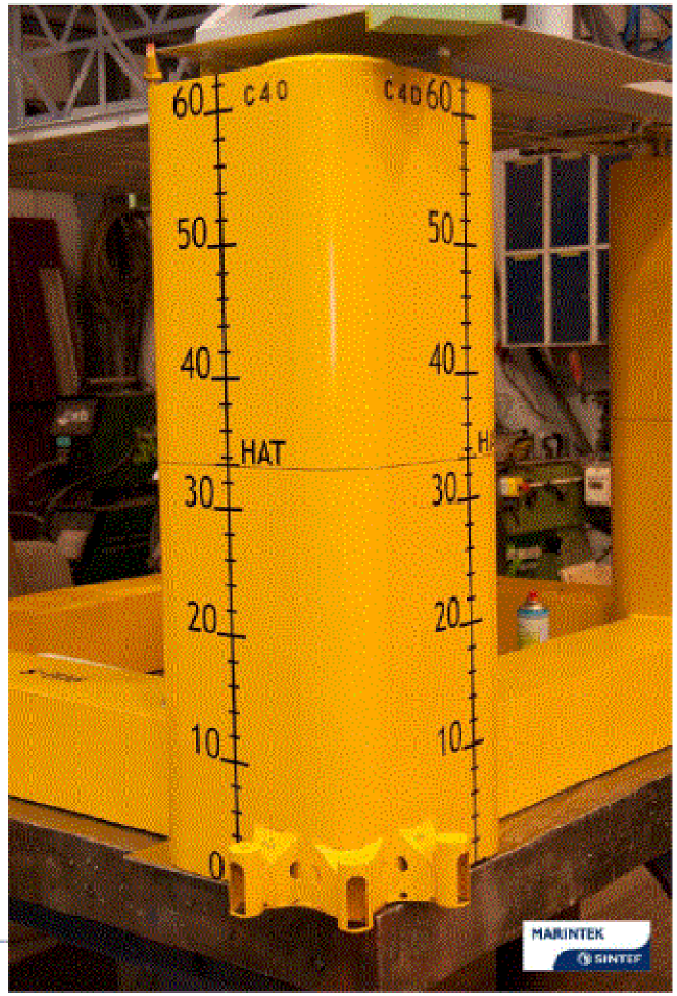


Superposition of wave excitation, added mass, damping and restoring loads.

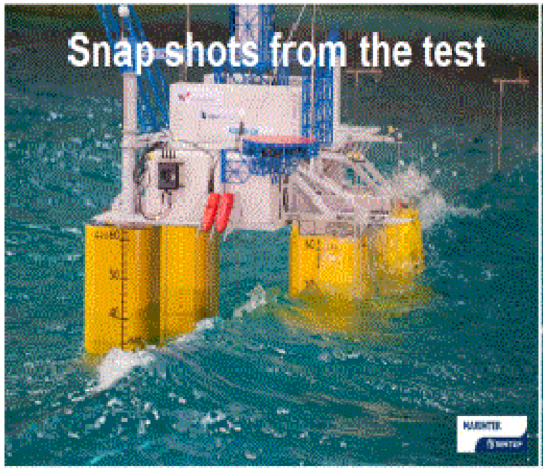
- Semi-analytical
- Numerical Model
- Experimental testing

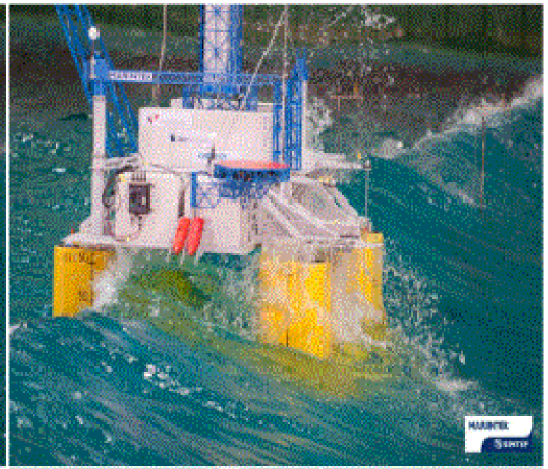
Scaled-down Exp. Tests





Scaled-down Exp. Tests



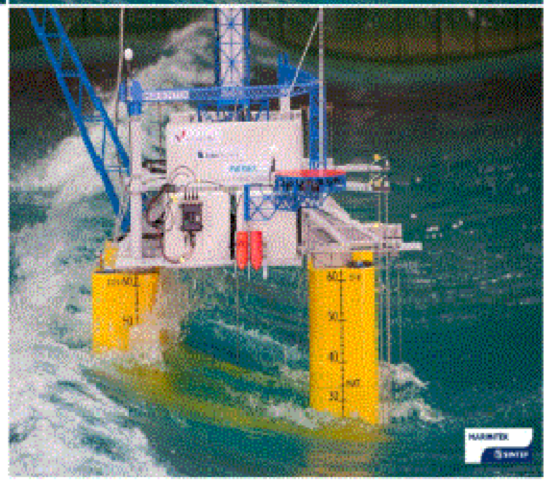


10,000 year cyclonic max wave

Beam sea

Hs = 20.7 m, Tp = 16.8 s

Wind 44.0 m/s, Current 2.2 m/s



Motion of marine structures

Response amplitude operator, RAO

it establishes a relation between the motion and wave amplitude in the frequency domain

heave motion of semi-submersible platforms

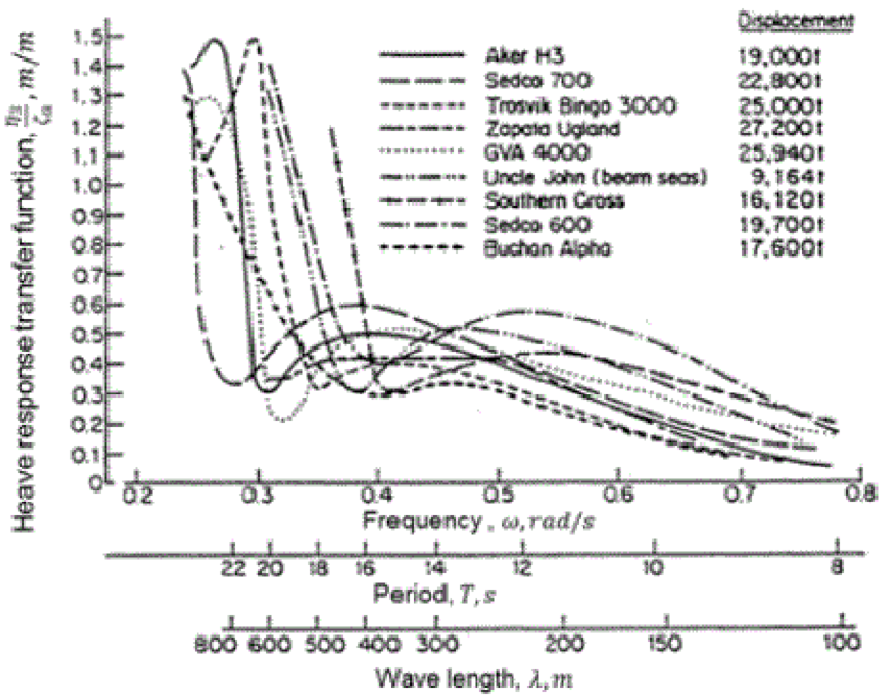


Fig. 24. Representative heave response transfer functions for different semi-submersibles.

Motion of marine structures

Surge (horizontal) motion of TLP platforms

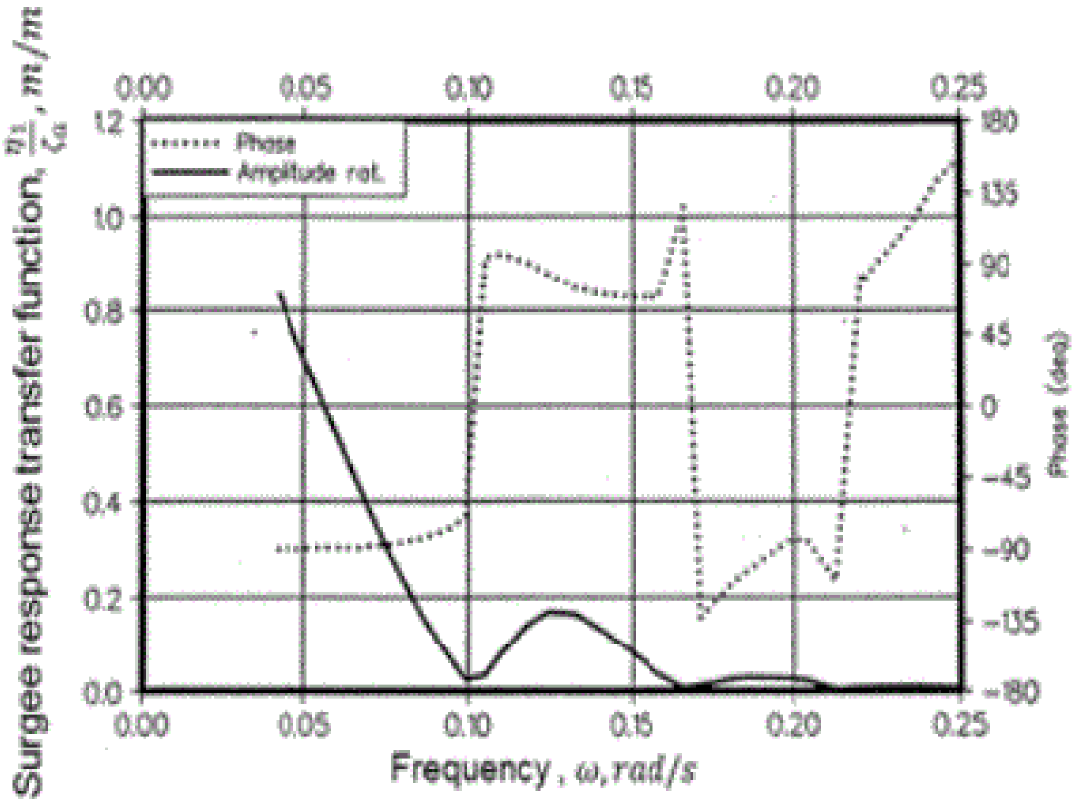
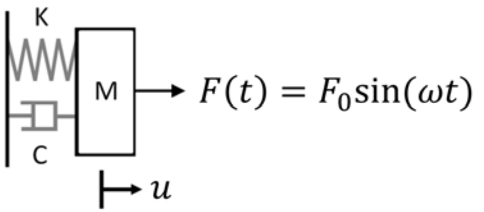
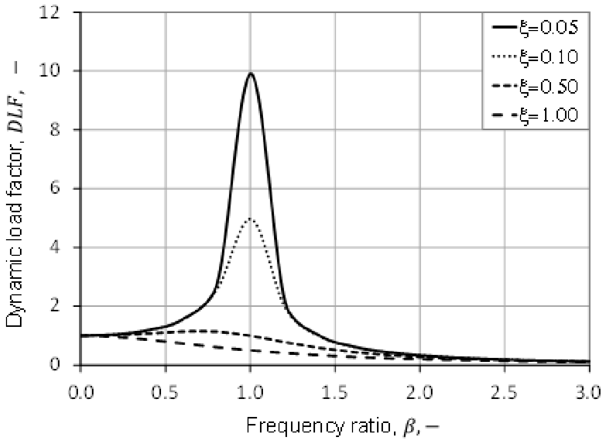


Fig. 25. Surge response transfer function of TLP.

Motion of marine structures





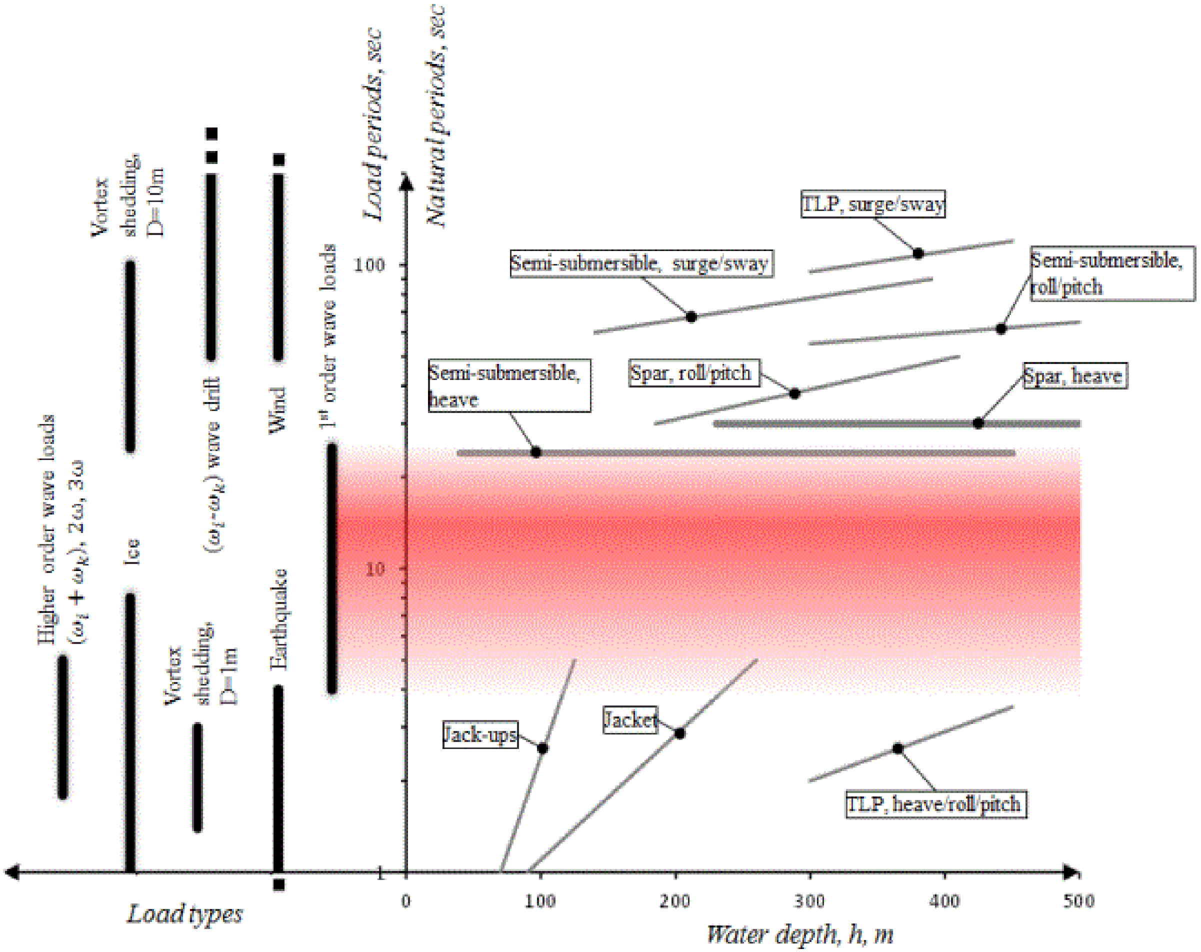


Illustration of largest natural period versus depth for some platform concepts, and periods for important environmental loads.

Motion of marine structures

Which natural periods ($=2\pi/\omega_0$) do we phase for offshore structures?

- **Fixed platforms:**
  Jackets and GBS's: About: 1s for depth < 100m, 3-5s for 200-250m depth

  Jack-ups: About: 4-5s for depth of about 90 150m (depending on foundation solution).

- **Floating platforms:**

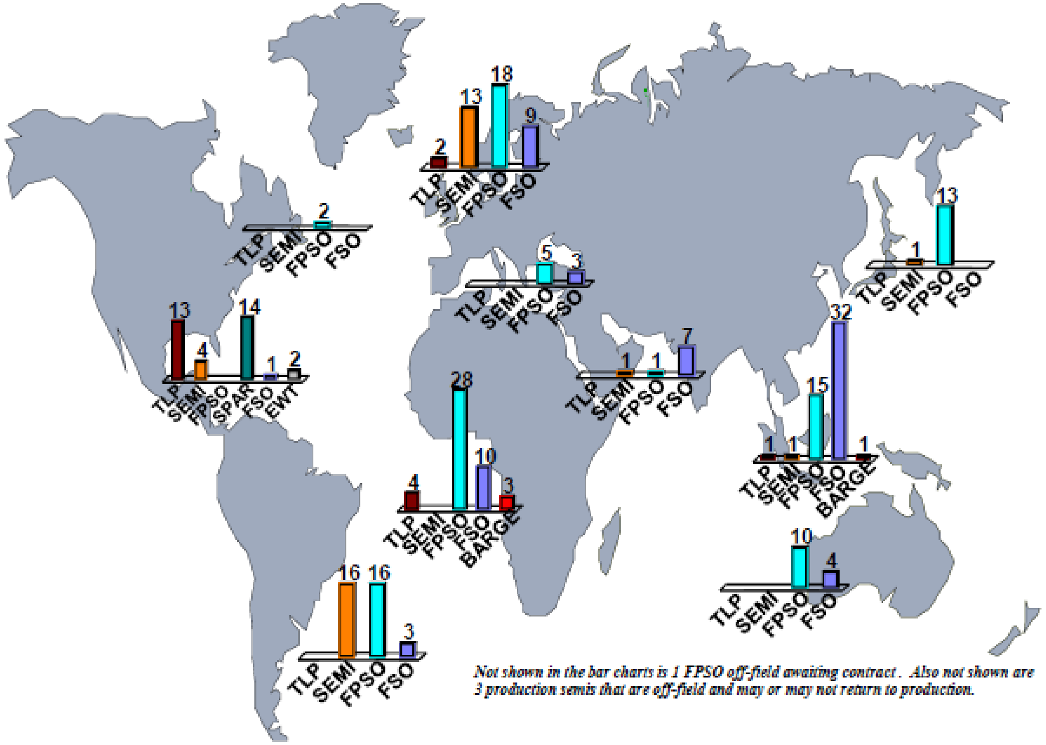
Heave semi-submersible:	23 – 26s
Surge/sway of catenary moored semi submerisble:	60 – 90s
Pitch/Roll of semi submersible:	30 – 50s
Heave of Cell spar platform (see next page):	25 – 35s
Surge/sway of taut moored spar:	2 – 3 min.
Roll – pitch of spar:	about 1 min

- **Articulated platforms**

Heave TLP	2 – 3s
Surge/sway of TLP (300 – 400m depth):	1 – 2 min.
Roll/Pitch of TLP:	2 – 3.5s

StatoilHydro

Current world fleet of floating systems



<u>256 Floating Production Units worldwide (Aug 2011, ref. Petroleum Insights)</u>

62% are floating production, storage, offloading (FPSO) vessels;

17% are production semisubmersibles (Semi);

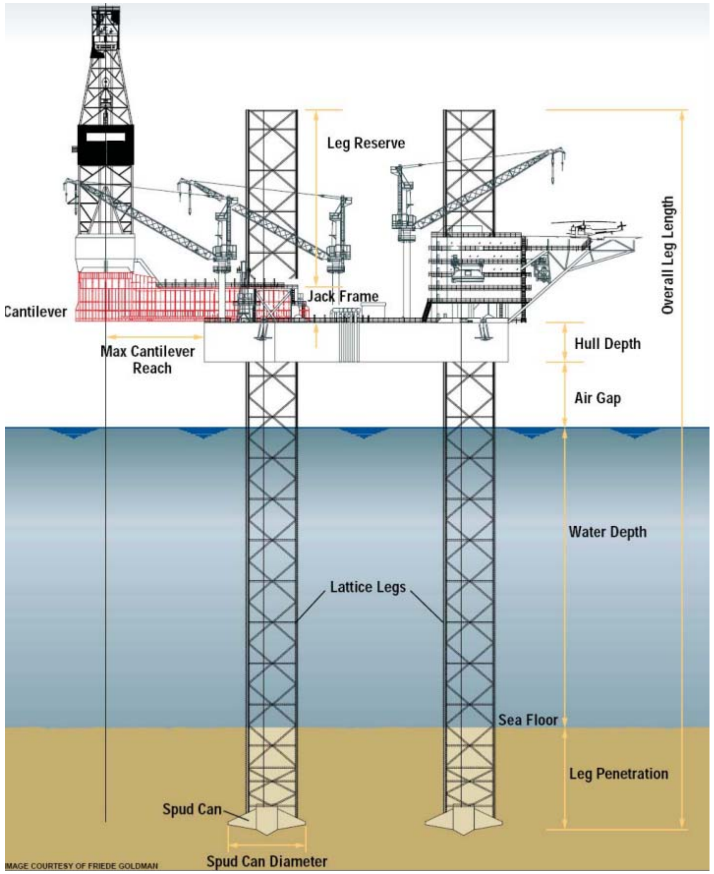
9% are tension leg platforms (TLP);

7% are production spars;

and the remaining 5% are production barges and floating storage and regasification units (FSRUs).

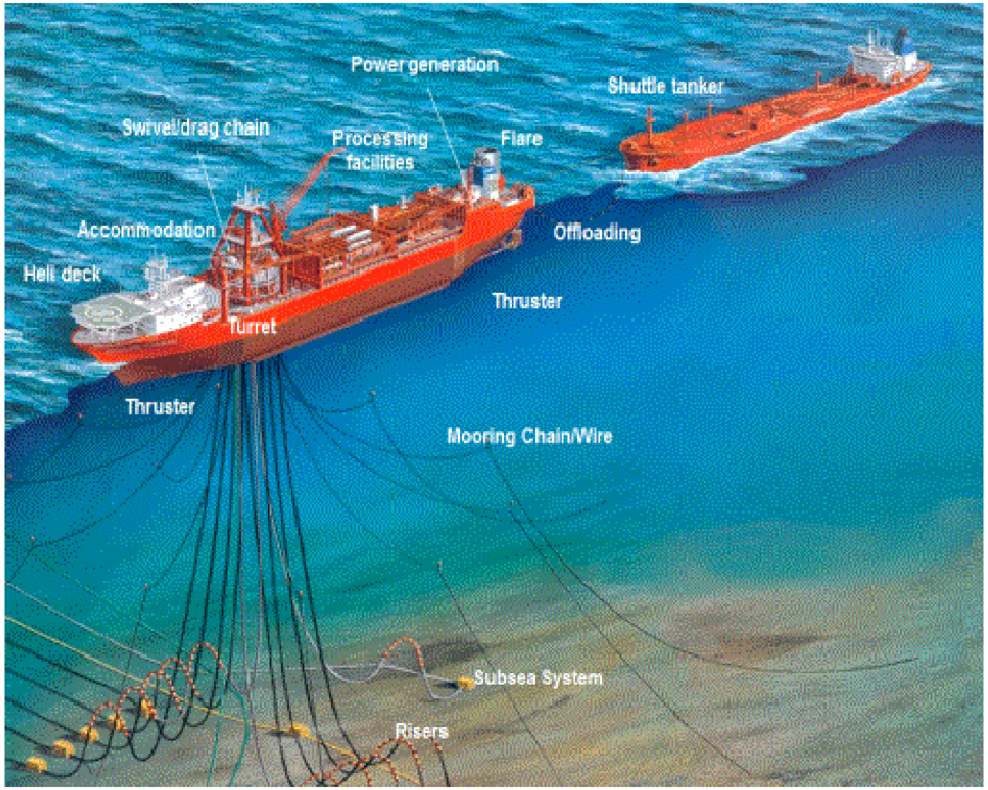
AkerSolutions


Plataforma Troll A


Leg Reserve
Overall Leg Length
Jack Frame
Cantilever
Max Cantilever Reach
Hull Depth
Air Gap
Water Depth
Lattice Legs
Sea Floor
Leg Penetration
Spud Can
Spud Can Diameter
IMAGE COURTESY OF FRIEDE GOLDMAN

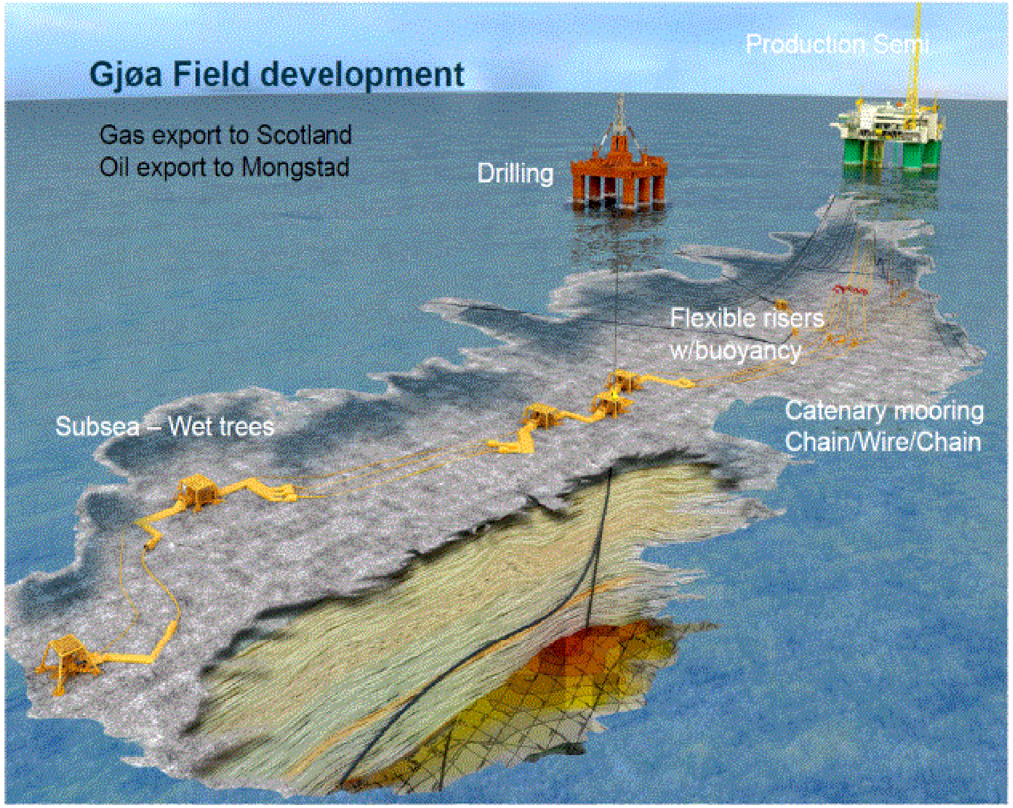
FPSO (Floating Production Storage and Offloading)

- Ship shaped or circular
- **Large storage capacity**
- Large topside capacity
- Good separation between hazardous and non-hazardous areas
- Fair motions
- Flexible risers and turret
- Integration and commissioning inshore



Semi-Submersible (Semi)

- Flexible concept with large (unlimited) capacity, topside weight and area
- Column stabilized
- **No water depth limit**
- Good motions
- Feasible with Steel Catenary Risers (SCRs) in deep water
- No (limited) storage
- Integration and commissioning inshore



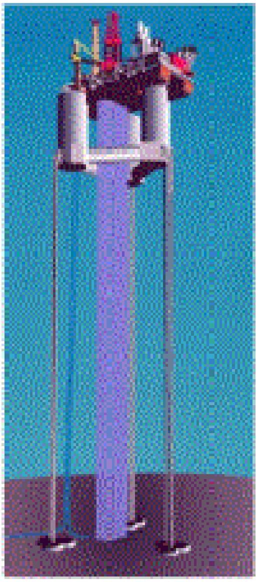
Ultra-Deepwater
Semi-submersible

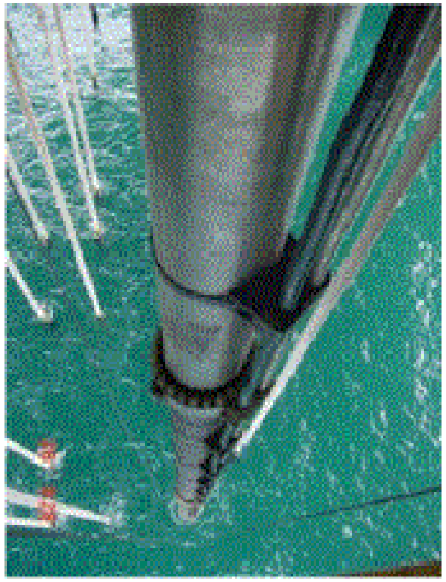
Main Platform Elements - Gjøa

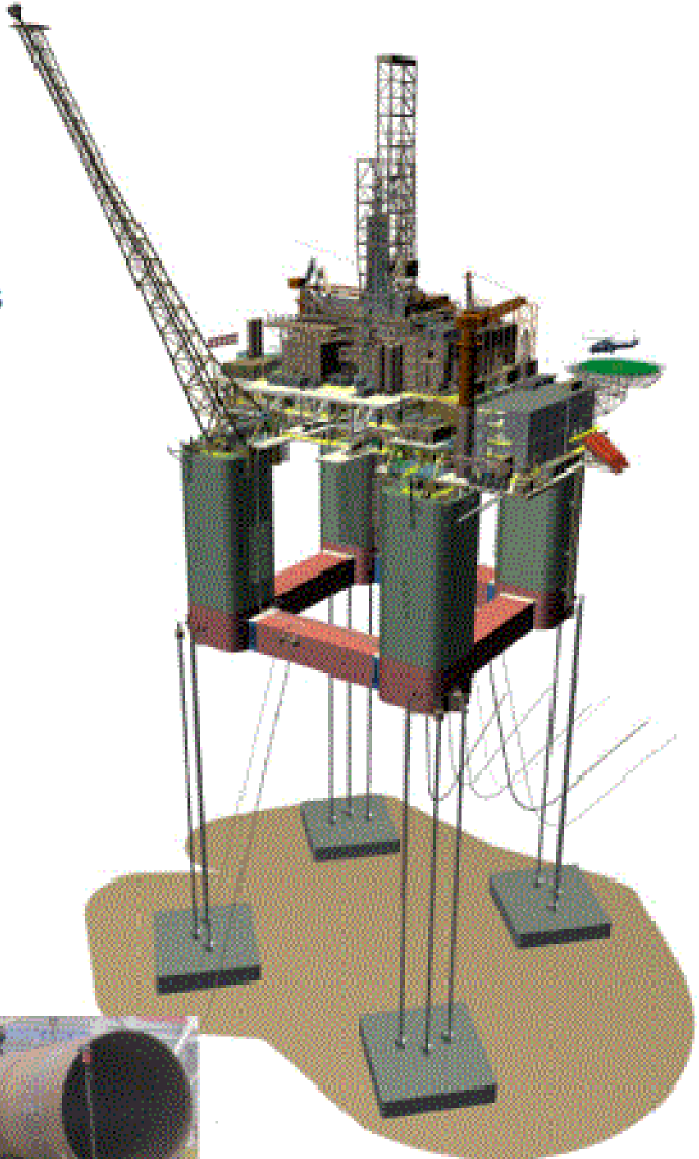
AkerSolutions

TLP (Tension Leg Platform)

- Station keeping and stability by tethers
- **Excellent motions**
  - **Top Tensioned Risers (TTRs) and dry trees**
- Large capacity, limited by tethers
- No storage
- Integration and commissioning inshore







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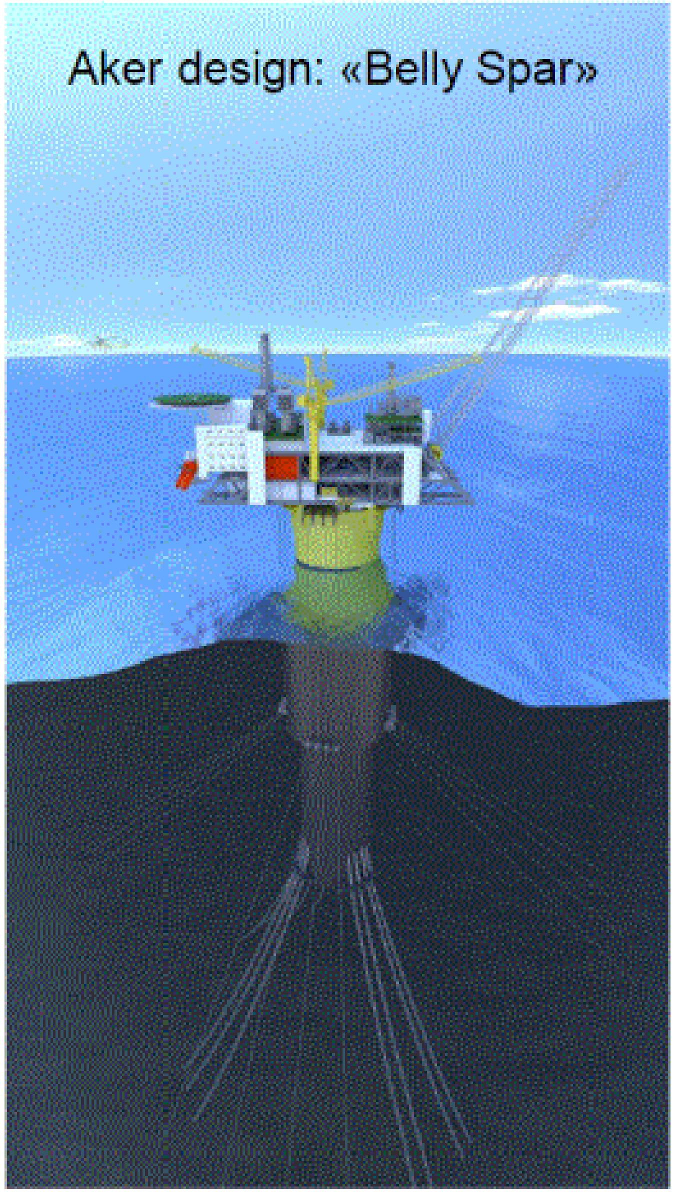
Spar Platforms

- Weight stable (by counter weight)
- Limited capacity, limited footprint
- **Excellent motions**
  - **Top Tensioned Risers possible**
- Storage (limited)
- Integration and commissioning offshore or inshore in deep fjord (> 200 m WD)



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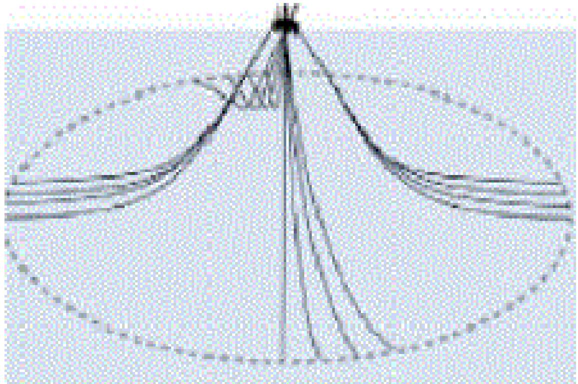
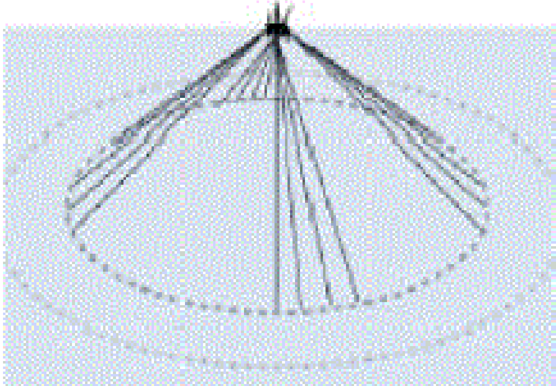
Mooring Systems

- Purpose of mooring is to keep platform on location

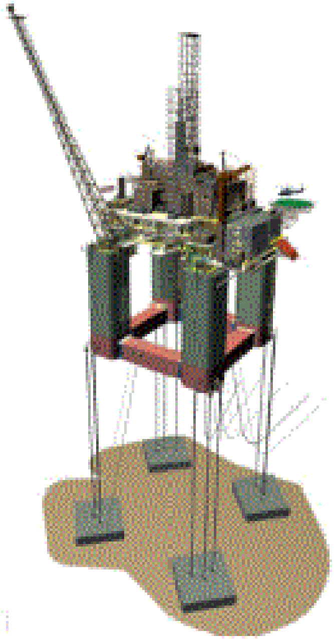
Catenary mooring (traditional)



Taut mooring



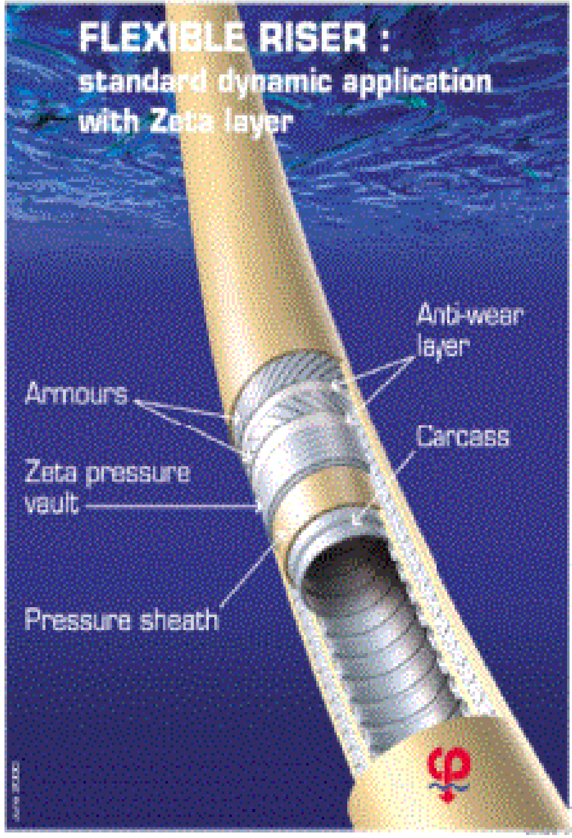
Tethers (steel pipe)



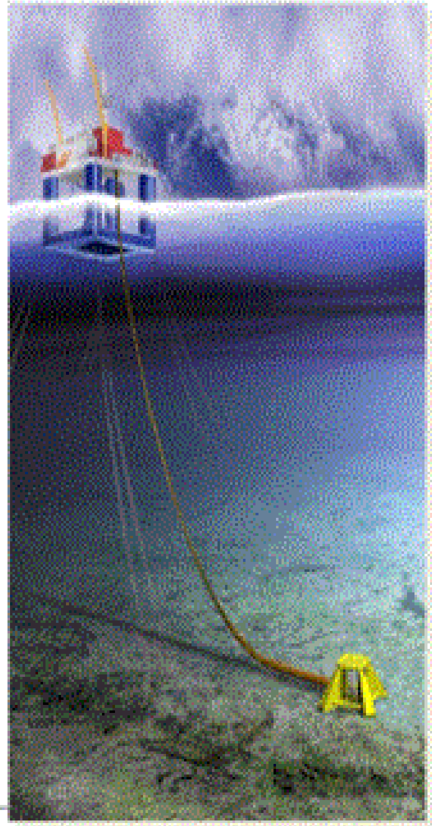
Risers

- The tube that connect the platform to the well head. Purpose is to transport hydrocarbons from the well to the platform or to export hydrocarbons from the platform to pipeline/shuttle tanker

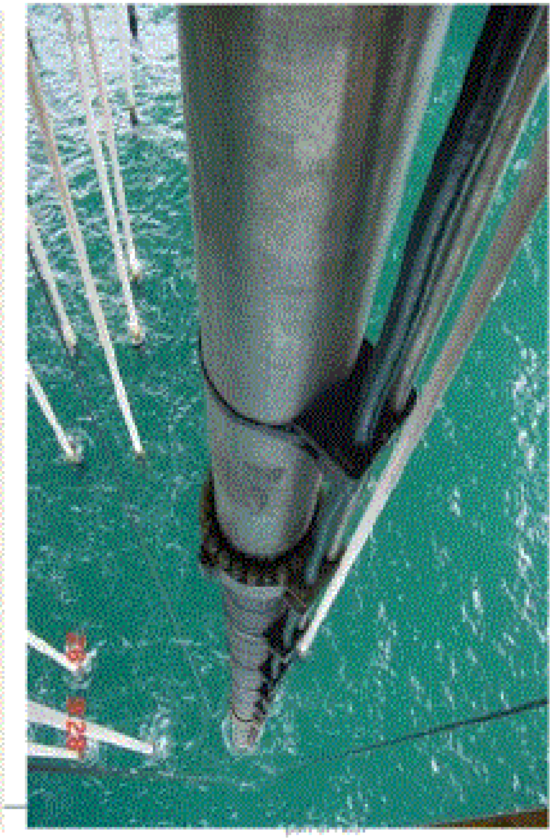
Flexible Risers



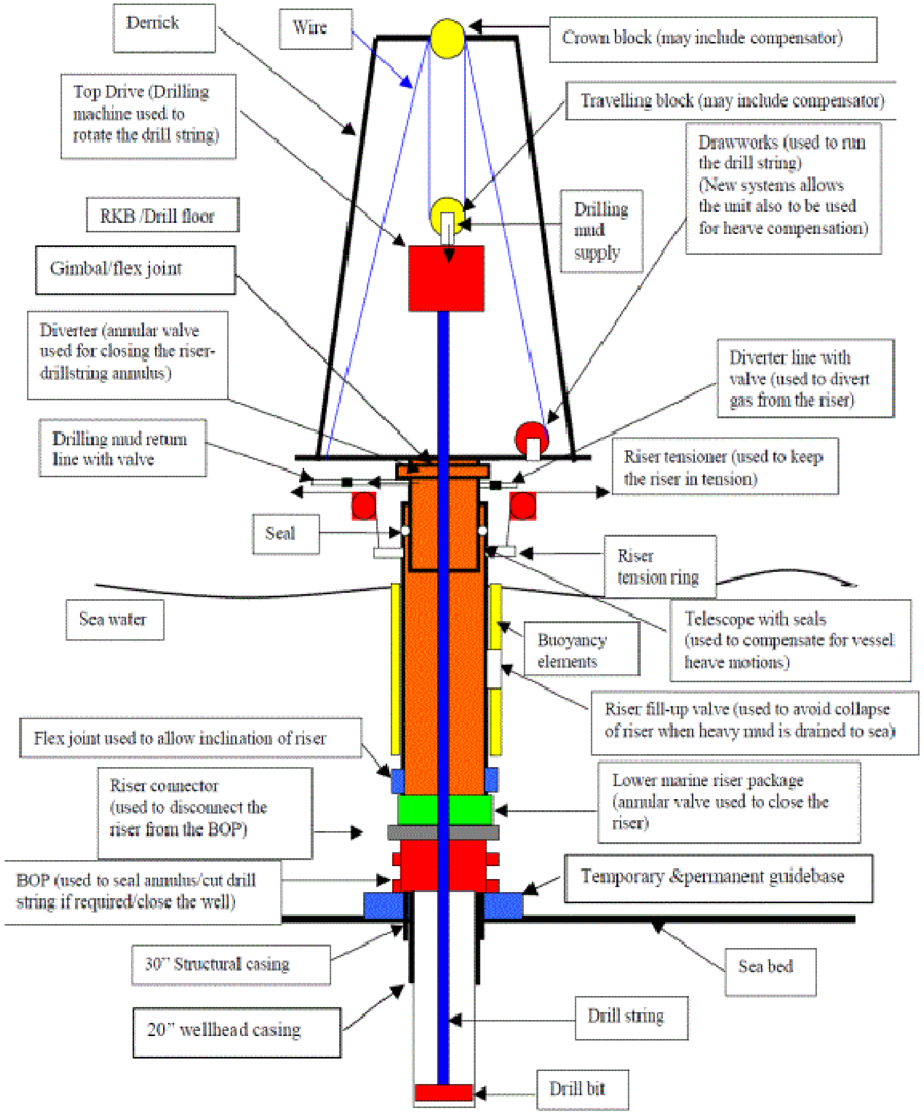
Steel Catenary Risers (SCR)



Top Tensioned Risers (TTR)



Riser tensioner



(a) Wire-line. (b) N-line.

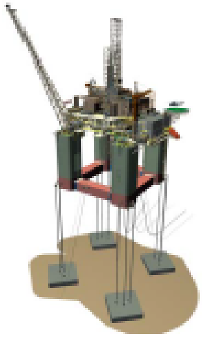
The different riser tensioner systems (National Oilwell Varco, 2007*b*).

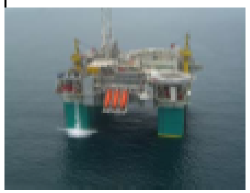
Figure 5.3: Production riser tensioner system at the TLP Jolliet (National Oilwell Varco, 2007*b*).

Principal Selection Criteria

Storage or pipeline?

- FPSO
  - Mild weather: No turret
    - West Africa
    - SE Asia
    - Conversions
  - Severe weather: Turret
    - Aasgard A
    - Norne
    - Skarv
- Drilling capabilities or independent drilling
  - Dry trees or Wet trees
    - TLP / Spar
      - Snorre A
      - Diana
      - Shenzi
      - Tahiti
    - Semi w. drill
      - Njord
      - Snorre B
      - Thunder Horse
  - Semi / mini TLP / Spar
    - Blind Faith
    - Gjøa
    - Typhoon
    - Red Hawk



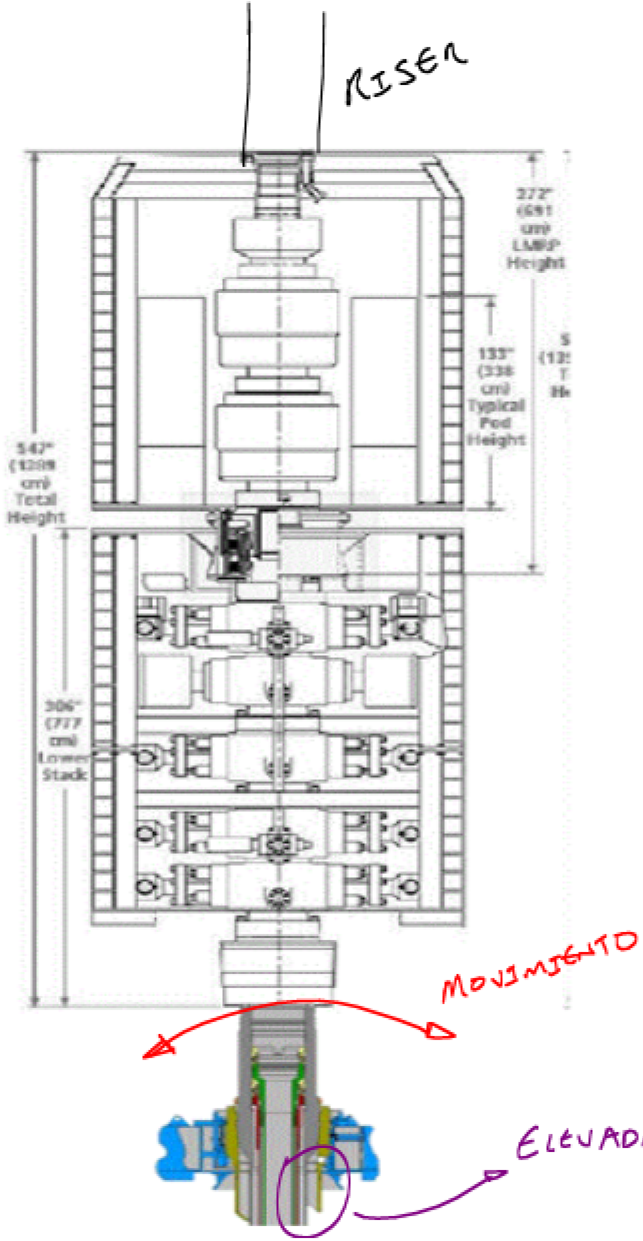


AkerSolutions

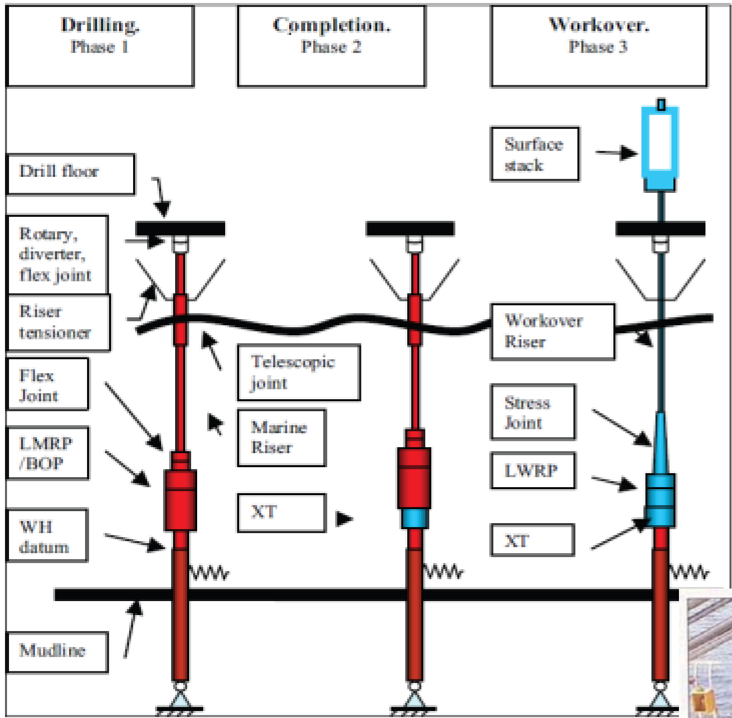
WH Fatigue

Background

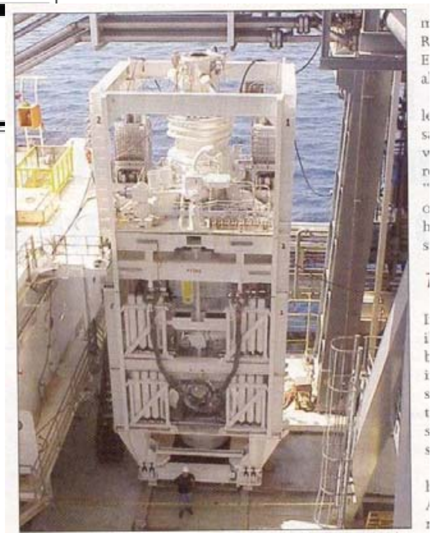
- Increased re-entry on existing wells on the Norwegian continental shelf.
- Complex well designs and operations including multilateral- and smart wells increases drilling time. Increased amount on intervention and work-over operations on sub sea wells.
- Life time extension of wells. Specified total drilling time for new complex wells can be up to 300 days
- Increased size of drilling rigs and weight of BOP's, on new rigs up to 400 ton



ELEVADAS CARGAS : • AXIAL
• FLEXION } → FATIGA



Weight : 250 T in ai


Hydril will supply two BOP control stacks and a multiplex pressure control system similar to this for the Ocean Endeavor (Fig. 3; image from Hydril Co.