Chapter 13

Survival Loads on Tower Structures

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Outline Chapter 13

- Environmental Conditions To Choose
- Ambient Flow Schematizations
- Structure Schematization
- Force Computation
- Force and Moment Integration
- Example

Introduction

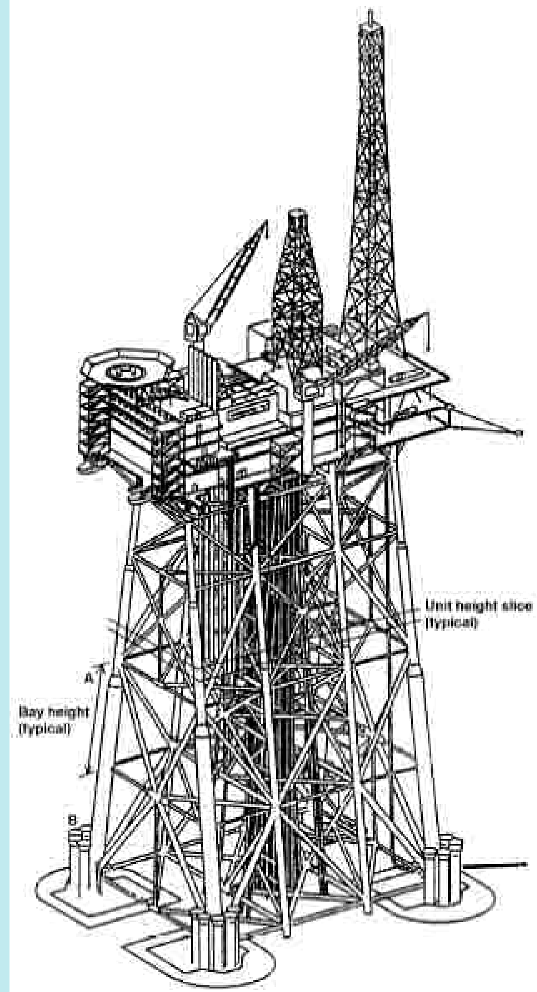
- Objective this chapter :

  Use Simplified means to estimating the largest hydrodynamic forces on an offshore structure.

- Often utilized product design phases :
  - conceptual design
  - *preliminary design*
  - detailed design

- Preliminary design :
  - no need for pinpoint accuracy
  - conservative estimate is preferable *(see next)*

Typical Large Offshore Tower Structure

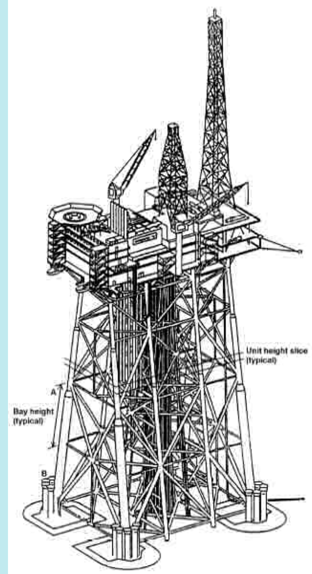


- Preference for conservative design :

  - if (heavy) conservative design survives economical analysis, then detailed design will also.
  - topsides tend to be heavier during design process due to regulations and changes design in requirements.
  - initial overestimation can turn to be handy in later design phase.

- The calculated *(limit)* Loads yields :

  - Largest overall bending moments at mudline level
    -> Axial and Horizontal (->shear) leg forces
  - For wind turbines -> also Torsional load
  - Maximum bracing loads due to wave and current



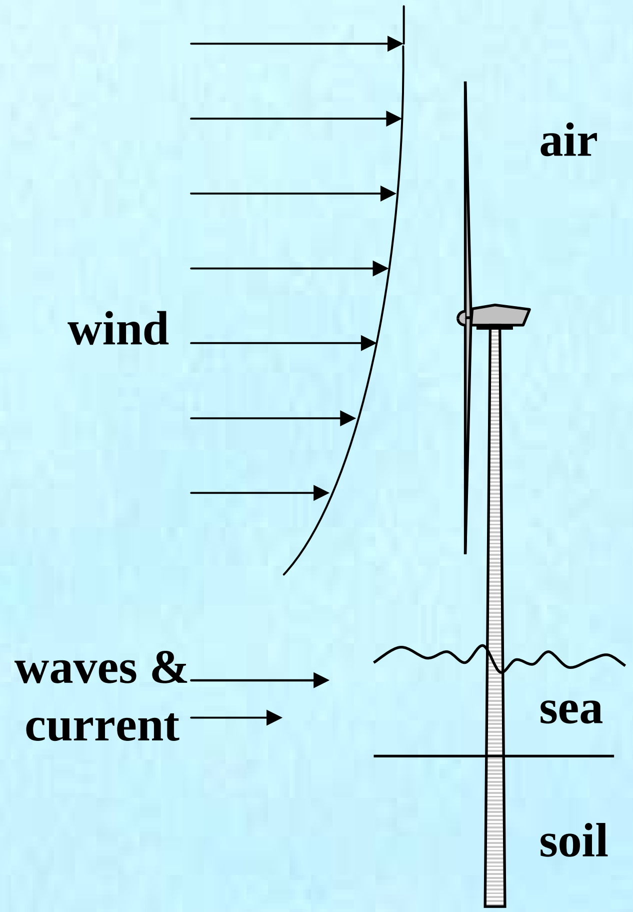
Steps on load *(hydrodynamic)* analysis of an offshore structure :

1- Environmental Conditions
(wind, waves, current, soil, …….. *else ??*)

2- Ambient flow schematization
(raw data to force model)

3- Structural schematization
(anatomy, main elements)

4- Determination of load forces
(ultimate loads, fatigue loads, ..etc.)



Environmental Conditions To Choose

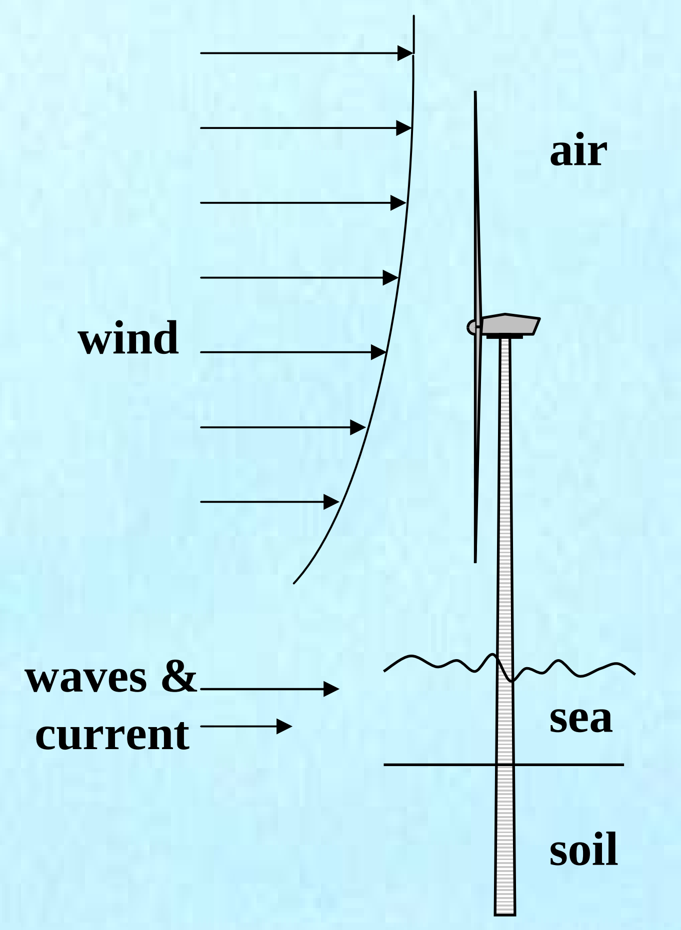
- In preliminary design phase utilize Ultimate (extreme) Loads according to Regulations from e.g. DNV, API, IEC, ... etc.

- Databases for environmental data, e.g. ARGOSS.

    - Wind Speed :
    - Current Speed :
    - Wave Height and Period :

- *Soil data of location of interest :*

    - *Not always needed for prelim design.*
    - *Accurate data can only obtained by performing CPT.*

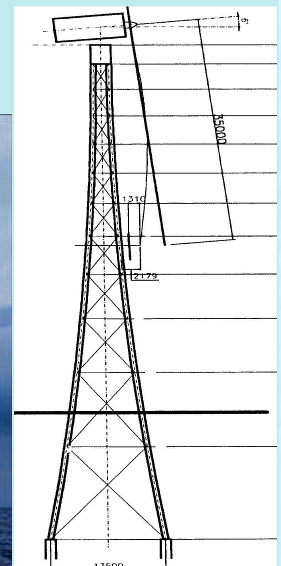


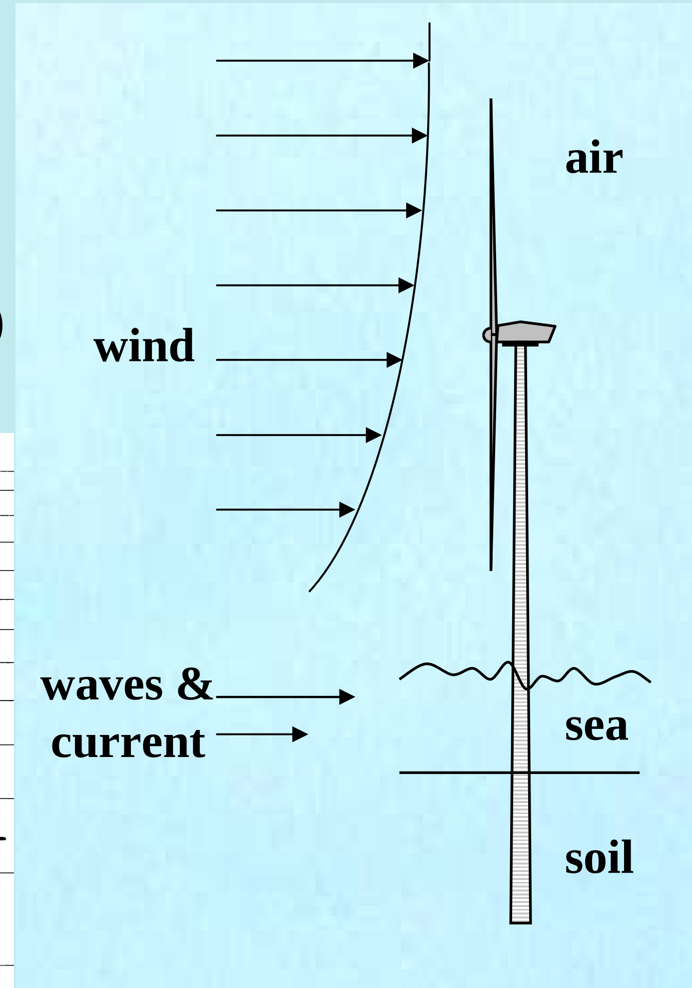
Winds Speed

- Aerodynamic loads generally plays a minor role on Oil & Gas offshore structure. Hydrodynamic loads are dominant.

- Also for Wind Turbines in deeper waters (>20 m.)

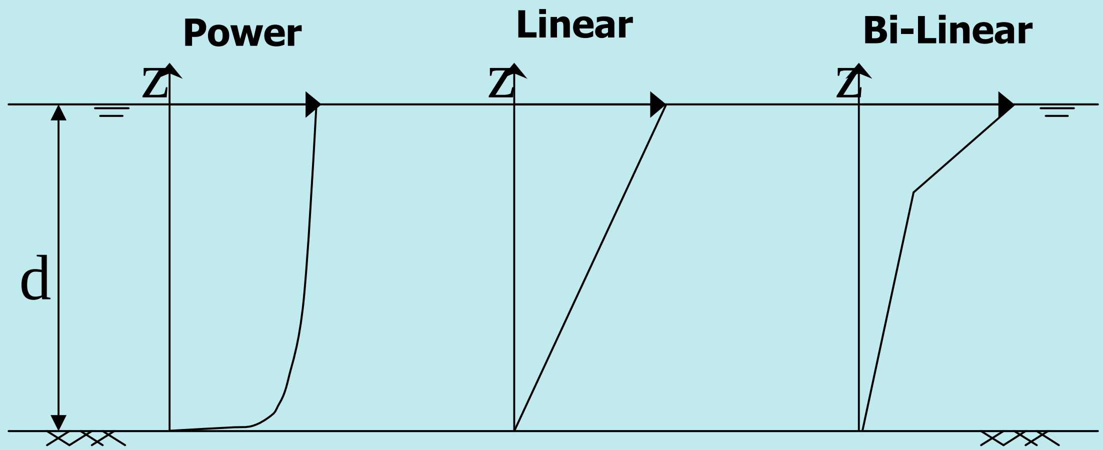
- Significant load for wind turbines in shallow waters.

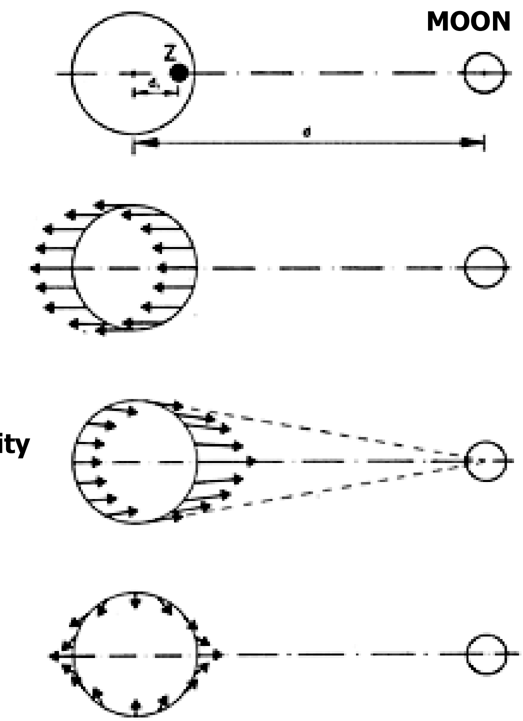




Current Speed

- Cause of current (dominant mechanism)
- Velocity profiles of current





- Tidal effects causes sea level differences *(HAT & LAT)*
- Current (load) significant for survival loads calculations

Wave Height and Period

Choose the wave height and period -> Resulting in Maximum wave force

- Assumptions *(ch. 5)*
  - H_{max} occurs once in every 1000 storm wave
  - the 1000 storm waves will be passed in 3 hours

- Implement in Rayleigh distribution yields :

$$\exp\left\{-2\left(\frac{H_{max}}{H_{1/3}}\right)^2\right\} = \frac{1}{1000} \quad \text{or:} \quad \boxed{H_{max} = 1.86 \cdot H_{1/3}}$$

Significant Wave Height

Concerning the wave period :

- Choosing a **short** wave period , with a certain height, will give **maximum velocities and accelerations** at the water surface ....

- ..... but short waves will 'die out' faster at deeper locations.

- Very short period, combined with very high wave
  -> results in Breaking Wave !

- For deep water and quick estimate :

$$\lambda = 1.56 \cdot T^2 \quad \text{and} \quad \frac{H}{\lambda} < \frac{1}{7}$$

Wave length [m]

Wave Period [s]

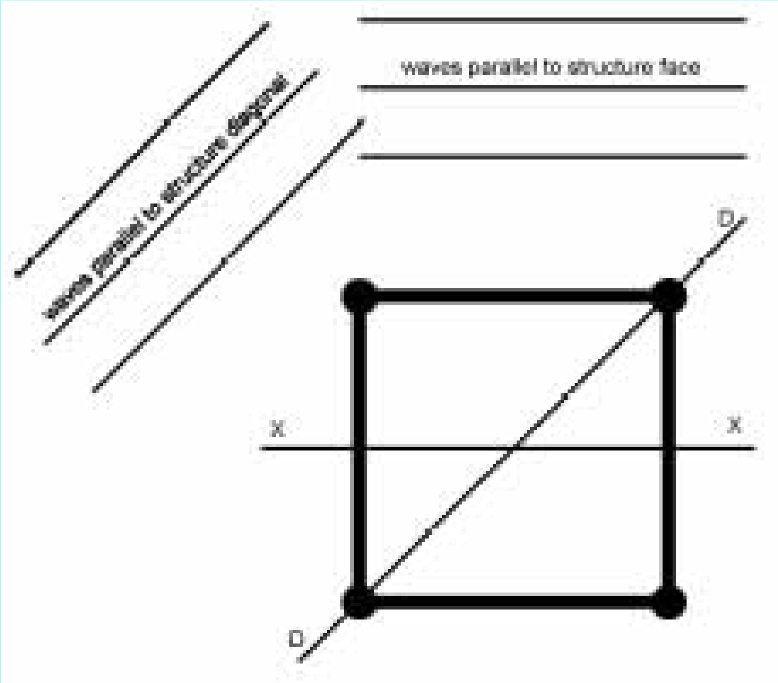
Wave Height [m]

Wind, Current and Wave Directions

- Correlation in direction of Wind, Wave and Current are seldom
- Conservative choice -> simply assume that the directions are co-linear !!
- Orientation of non-circular structure :

  - wave crest **parallel to diagonal** :
    -> Larger pile forces.

  - wave **parallel to structure face** :
    -> Larger forces in the bracings
    bearing the shear forces.



Wind, Current and Wave Occurrence

- Conservative choice applied in the reader
  -> Maxima of these phenomena do occur **simultaneously**

- This will lead to a over-dimensioned result

- Consult regulations directives for proper preliminary design (DNV, IEC, API).

Implications of the choices

- A large wave length (λ) :

    Relative large to the structure's horizontal dimension
    -> Upstream and Downstream members have small phase difference

- Neglecting phase difference -> No reduction of horizontal member forces
  -> Simplify the calculations
  -> Conservative result

- Relative high wave -> KC number high as well
  -> Tends to Drag domination at sea surface and deep waters
  -> In case of current, Drag domination more pronounce !

Implications of the choices, *... continued*

- Lower (deeper) part of the structure :
  Due to decrease of velocity with depth -> KC value decreases as well
  -> Inertia force increases in importance !

- Total resulting Force on the structure is maximum when the wave crest is passing, due to the maximum horizontal water velocity.

- Prediction of wave kinematics over the entire height *(seabed-crest)* is necessary for the calculation.

Ambient Flow Schematizations

From RAW data to INPUT data for load calculations

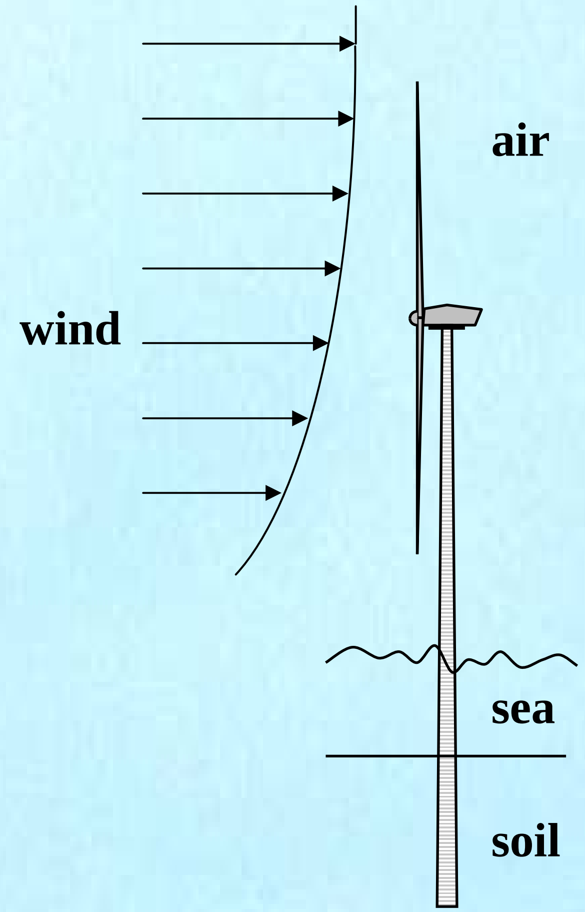
Wind

- Data often related to standard elevation of 10 m.
- Other elevations:

$$\frac{V_{tw}(z)}{V_{tw}(10)} = \left(\frac{z}{10}\right)^{0.11} \quad \text{(at sea)}$$

z	=	desired elevation (m)
$V_{tw}(z)$	=	true wind speed at elevation z (m/s)
$V_{tw}(10)$	=	true wind speed at 10 meters elevation (m/s)

- Gives large overturning moment at structure's base. Not to be neglected in all cases !!
  (types offshore structure).



Waves

- Linear wave theory convenient, but only predicts the velocities below the MSL ....
- .... while the water velocity in the wave crest is maximum.

  -> Wheeler Stretching is most popular to predict this
  (see CH. 5)

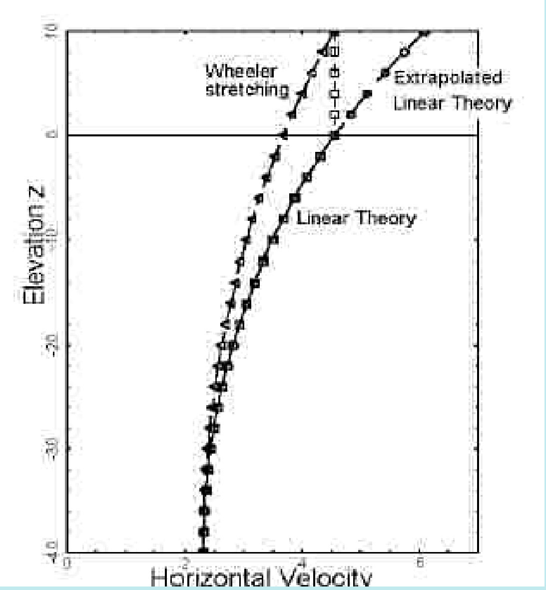
- Extreme wave crest :

  - common rule of thumb

$$\zeta_{max} = +\frac{2}{3}\,H \qquad \text{and} \qquad \zeta_{min} = -\frac{1}{3}\,H$$

Max. wave amplitude

Min. wave amplitude



- Remarks on use of wave formulae *(ch. 5)* :
  - If maxim. velocity is needed -> neglect time function
  - Wave length is large to structures horiz. dimension
    -> no phase difference : 'kx' is zero.
  - Extreme wave crest as previous
  - Full equations must be utilized, in stead of shallow/deep approxims., to evaluate horizontal velocity. Beware of (deep water) simplifications which could lead to less conservative results as the water depth decreases.

Current

- The direction is assumed to be parallel to wave propagation

-> Current velocity , V(z), can be added to the velocity component amplitude, $u_a(z)$, of the wave :

$$U_a(z) = V(z) + u_a(z)$$

Reflections / Remarks

Description of environmental loadings *(Hydrodynamic)* have been simplified considerably :

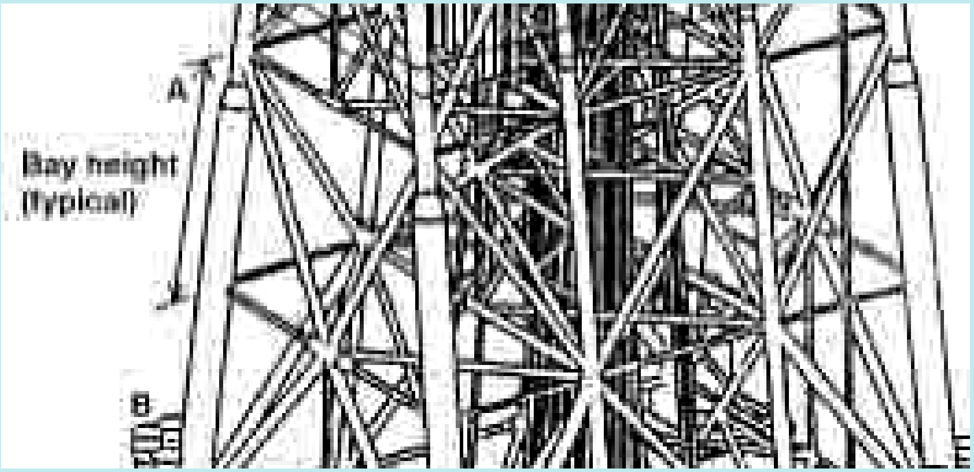
- only conditions under the wave crest are considered
- only hydrodynamic drag is considered
- no spatial phase differences

Necessary additions :

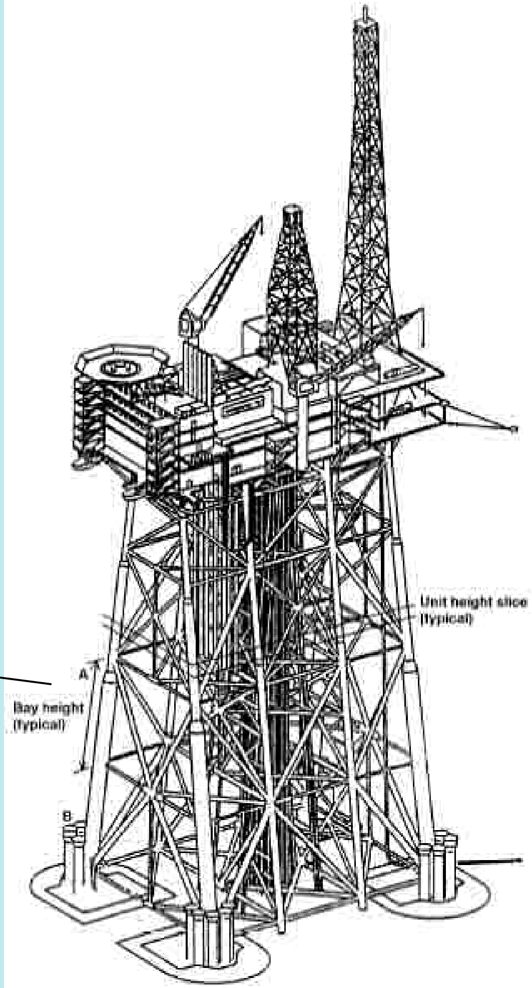
- extend hydrodynamics up to wave crest
- determine valid solution for all water depths

Structure Schematization

Actual truss-like marine structure is rather complex
-> needs to be simplified for 'preliminary' (drag) calculation purposes.



Horizontal Slice



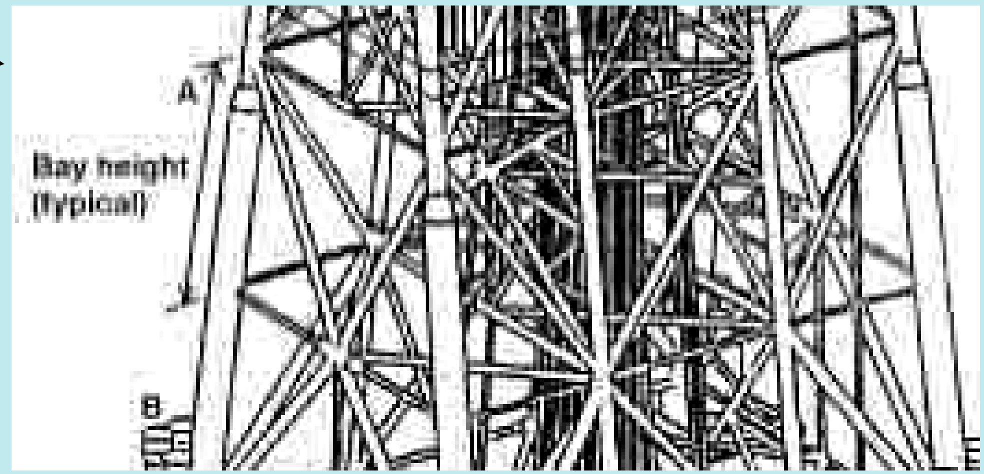
Drag term from Morison :

$$F_{drag_a} = \frac{1}{2}\rho \, C_D \, D \cdot U_a^2$$

F_{drag_a}	=	drag force amplitude per unit length of vertical cylinder (N/m)
C_D	=	drag coefficient, to be discussed later (-)
D	=	cylinder diameter (m)
U_a	=	horizontal velocity amplitude at the chosen elevation (m/s)

Consider a horizontal slice :

Constant term in that slice :



$$\frac{1}{2}\rho \, C_D \, U_a^2$$

members ! neglect the junctions

Still considering horizontal slice .....

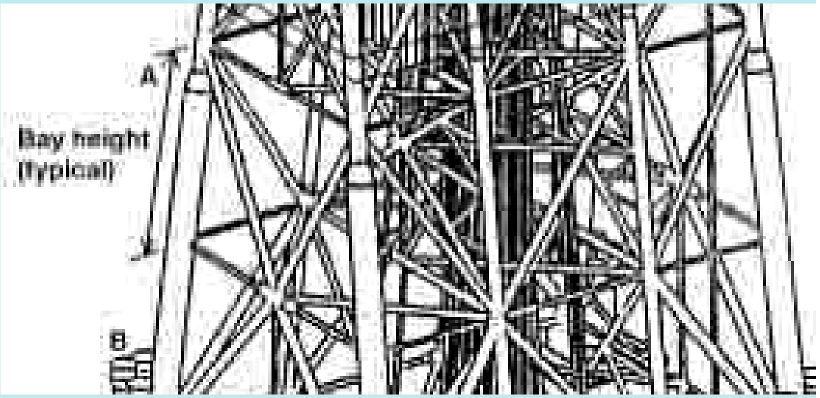
Remaining **:** **D**e **= Area / Unit Length**

equivalent diameter
(summation of members)

of a side view picture,
in the direction of the propagating wave

Contributions to **D**e **:**

- Leg cords, nearly vertical -> actual D.
- ....*next slide*....



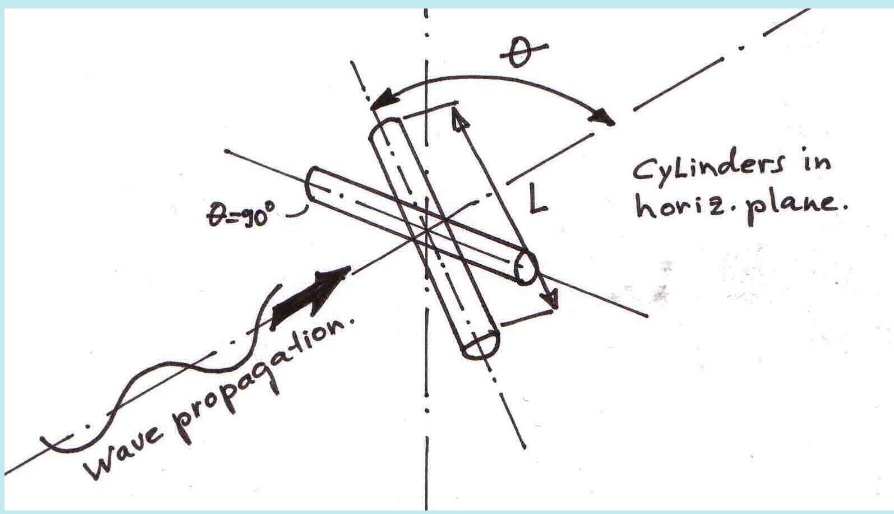
Still considering horizontal slice .....

Contributions to **D**e, ...*continued* **:**

- Horizontal braces at angle θ -> **D**e = L. Sin (θ) , over limited Height D !

Brace length

Brace azimuth to relative to water motion

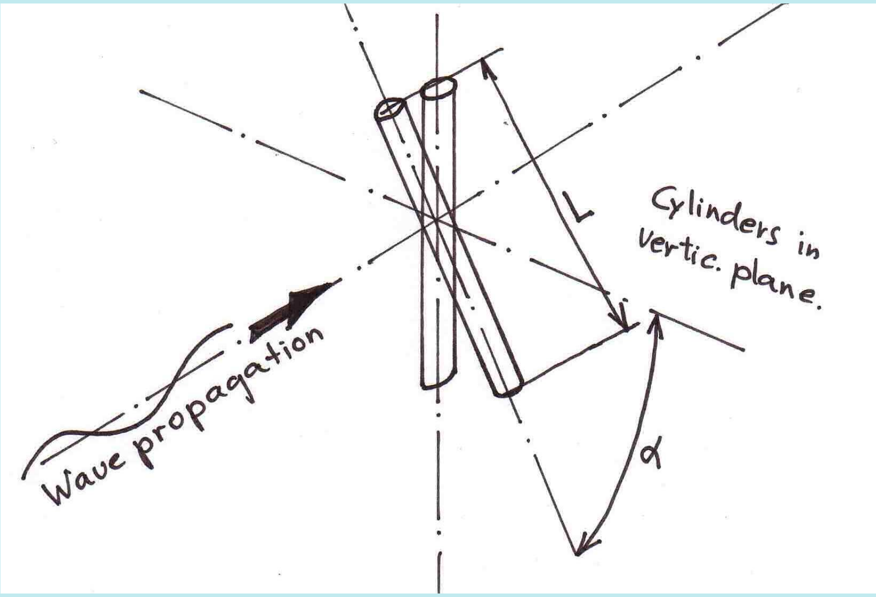


Contributions to **D**e ...., *continued* **:**

- Sloping braces in the plane of the picture :

$$D_e = \frac{D \cdot L}{H_B} = \frac{D}{\sin\alpha} = D \ \csc\alpha$$

H_B = height of the bracing bay (m);
α = slope of brace relative to the horizontal (rad)



Contributions to **D**e ...., *continued* ***:***

- Sloping members with other spatial orientations :

  (wave approach in diagonal direction)

Result of derivation :

$$\ell = \frac{1}{2}\left(\frac{L}{H_B} - 1\right) = \frac{1}{2}\left(\csc\alpha - 1\right)$$

$$D_e = D \cdot \{1 + \ell \cdot [1 - \cos(2\theta)]\}$$

Neglect the extra DRAG of Joints. Compensate this with exaggerated member lengths between the nodes.

Total Equivalent Diameter at a certain elevation , $D_e(Z)$:

$$D_e(Z) = \text{summation of all } D_e\text{'s at elevation } z.$$

- This procedure reduces the **'Forest' of trusses** to **single equivalent diameter** for **each segment** at a certain elevation.
- The equiv. diameter of the vertical cylinder **varies over its height**.
- This procedure only fits for Drag estimation. *Be careful of using this for dynamic calculations.*

Force Computations

So far performed :

- schematization of the environment (Loads)
- schematization of the structure

Next : compute the hydrodynamic forces and associated overturning moment at the mud line.

How to determine the appropriate Drag Coefficient, C_D ?

NOT by using D_e and u_a, and then calculating KC to determine a CD value utilizing a graph. The D_e is not representative in this case.

Depending on the (truss) tower configuration, at a certain elevation the most **representative diameter** has to be 'chosen' in an *engineering intuitive* manner.

Subsequently (after **CD** is determined) :
-> Calculate the maximum DRAG FORCE per unit elevation :

... caused by WAVE and CURRENT ......

$$F_{drag_a}(z) = \frac{1}{2}\rho \; C_D \; D_e(z) \cdot U_a^2(z)$$

... caused by WIND ......

$$F_{wind_a}(z) = \frac{1}{2}\rho_{air} \; C_d \; A_w(z) \cdot V_{tw}^{2}(z)$$

per unit elevation ! (dim. [m]**)**

Force and Moment Integration

At this point :

- Drag Forces caused by wind, waves and current are known at every chosen elevation
- Resulting horizontal force and overturning moment on the schematized structure can be determined

Horizontal Force Integration

- Resulting F_{horiz} : integration of $F_{D max}$ and $F_{Wind max}$ over a segment height.
- Linear interpolations between segments
- If abrupt change of D_e or A_w -> evaluate just below and above the transition
- Add successive transitions to enable approximation of curve by linear interpolation
- Finer integration steps, meaning shorter tower slices, in case of:
  - Conditions change rapidly, e.g. near water surface.
  - Structure change abruptly.

Overturning Moment Integration

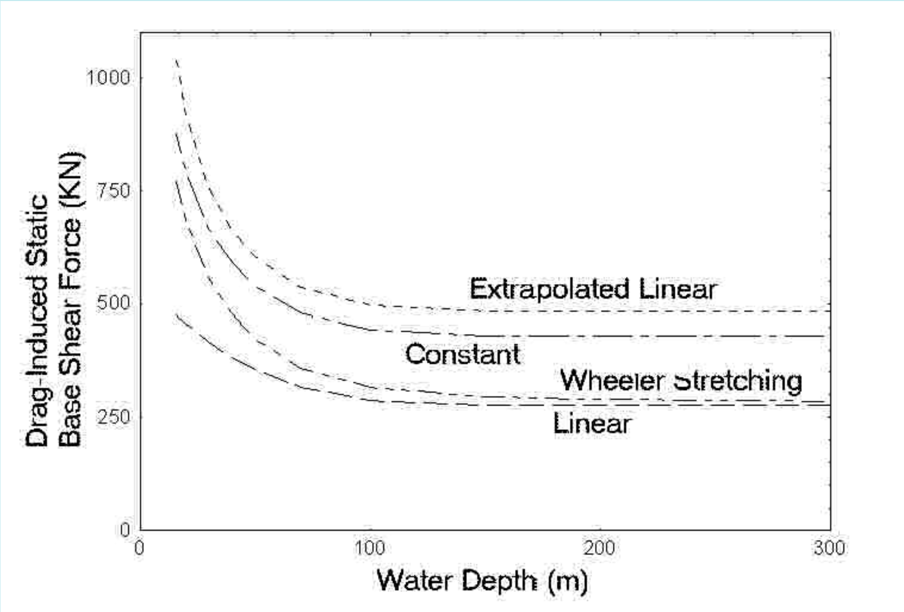
- Overall structural overturning moment about a horizontal centerline/axis at the mudline :

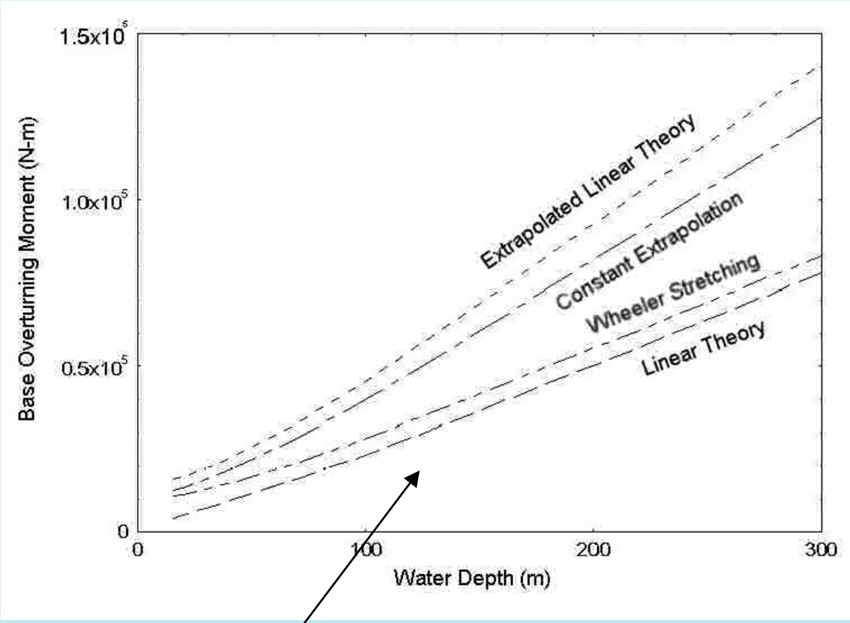
$$\Sigma \text{ Moment} = \Sigma \text{ (Force x Distance)}_{\textbf{segment}}$$

Distance segment-mudline

- Neglect small vertical velocity component near crest.

Example





F drag increase as water depth decreases !
-> shallow water wave
-> increase horiz. veloc.
-> Quadratic *(velocity)* term

compensates more than less tower height.

Extrapolated Linear is expected to give more **conservative** result than **Wheeler Str**.