Projects with Remote Installation ("Tube Post") of Energy Cables in Ducts

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Introduction

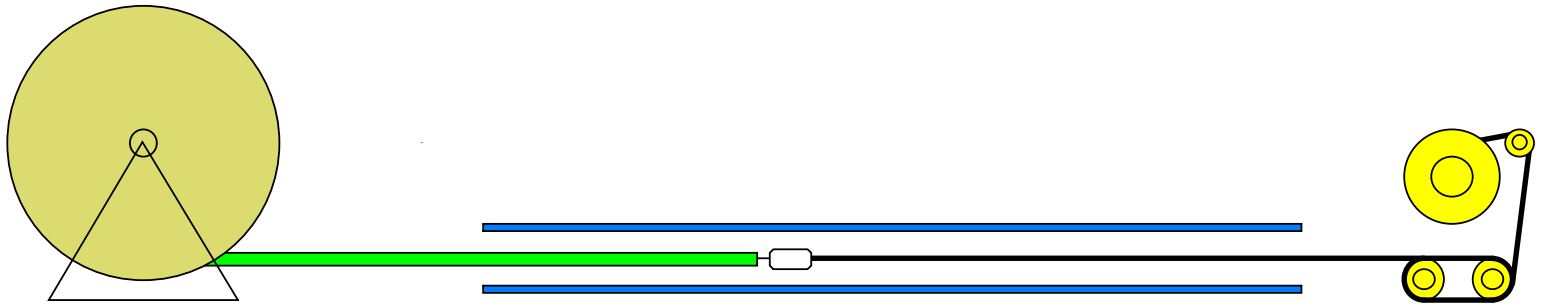
- Cable Installation
  - Aerial
  - Underground
    - Direct Buried
    - In Ducts
- Installation in Ducts using Water under Pressure
  - One step installation, all material and labour one side of duct
  - Long installation lengths, friendly to cable and duct
  - Most appealing: FreeFloating, like “Tube Post”
    - Tested in France and 2 projects in Denmark, one offshore
    - From any convenient launch location to any desired destination
    - Almost no limit of length over which cable can be transported

Benefits Cable in Duct (Pipe)

- General
  - Cable removed or replace without digging
  - Protection of pipe even better than armouring
  - Option of FreeFloating
- Land
  - No need to keep trench open long length and time
- Offshore
  - Standard land cables, save on costs, readily available
  - AC losses minimized
  - Low (zero) risk cable damage during installation
  - Position duct monitored by Intelligent Pigging

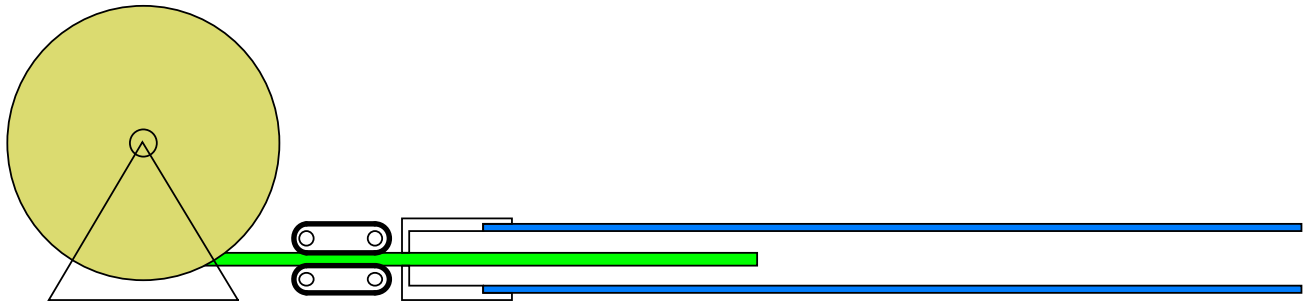
Installation Cable in Duct (Pipe)

- Pulling (winch)



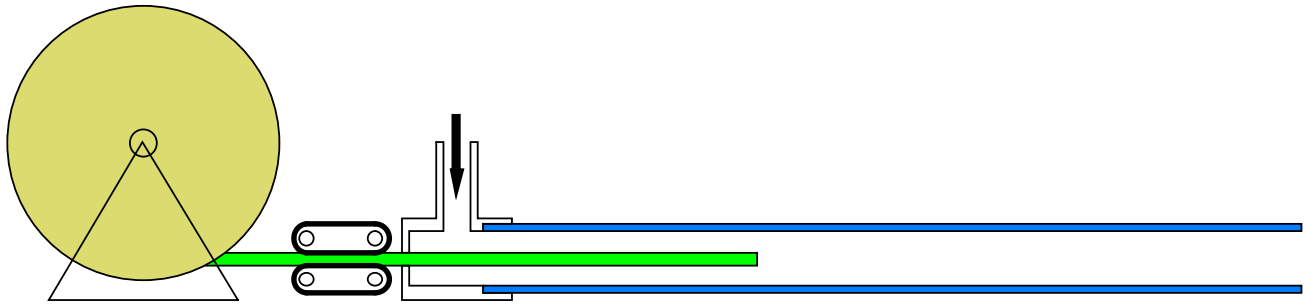
Installation Cable in Duct (Pipe)

- Pulling (winch)
- Pushing



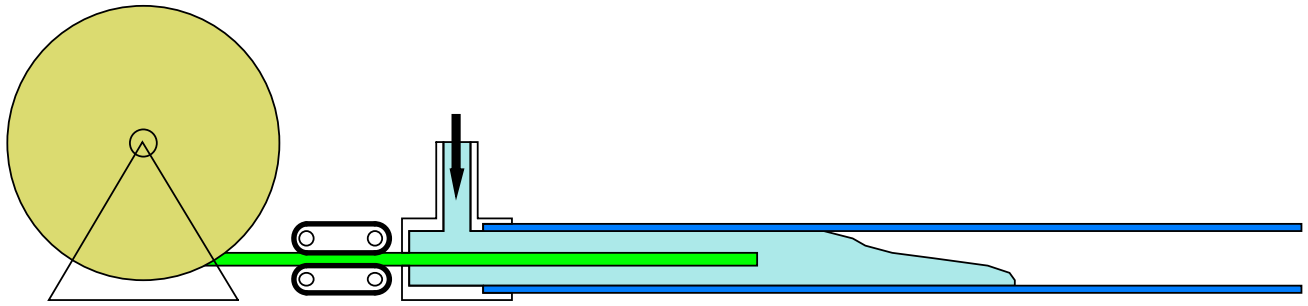
Installation Cable in Duct (Pipe)

- Pulling (winch)
- Pushing
- Blowing



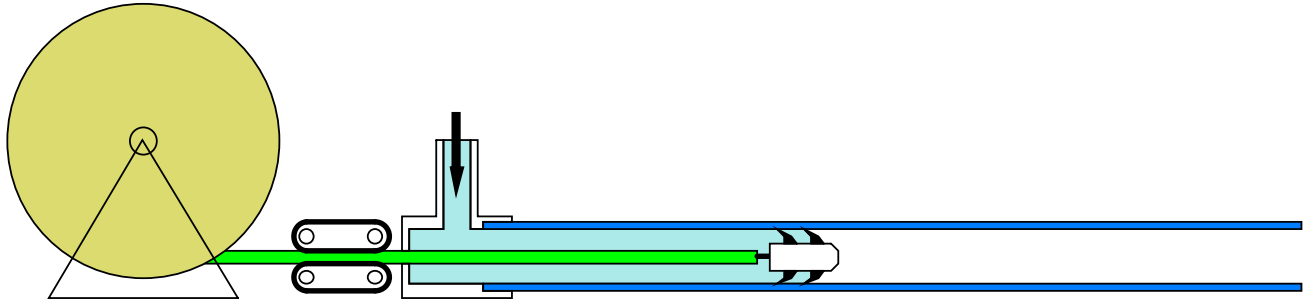
Installation Cable in Duct (Pipe)

- Pulling (winch)
- Pushing
- Blowing
- Floating



Installation Cable in Duct (Pipe)

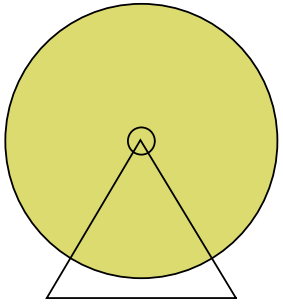
- Pulling (winch)
- Pushing
- Blowing
- Floating
- WaterPushPulling

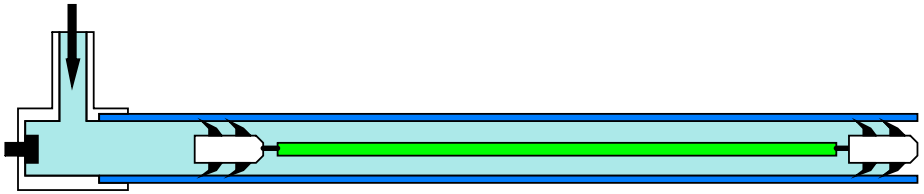


Installation Cable in Duct (Pipe)

- Pulling (winch)
- Pushing
- Blowing
- Floating
- WaterPushPulling
- FreeFloating

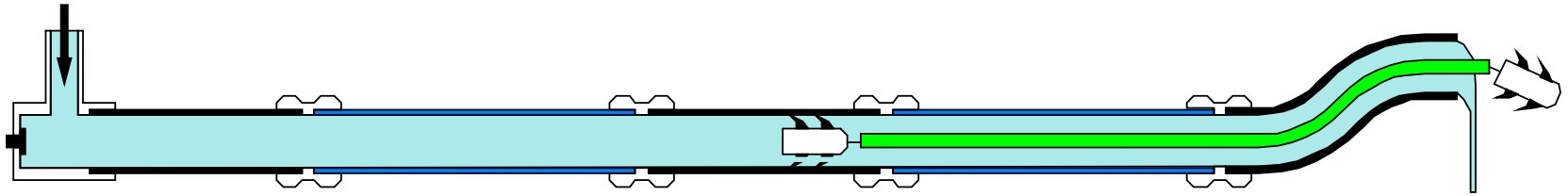
} The new techniques





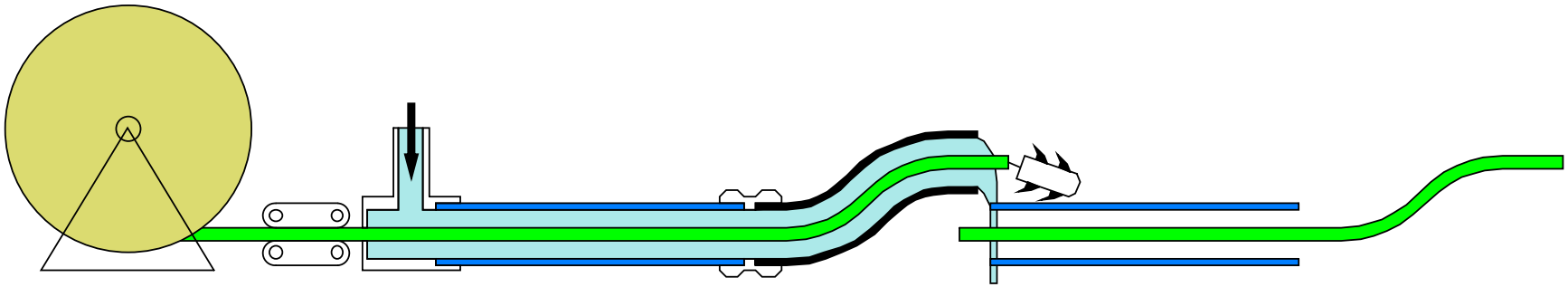
Installation Cable in Duct (Pipe) FreeFloating explained

- Install cable 1 with WaterPushPulling
- Place rear pig and close duct (with extension)
- Flow further (only water, loose from machine) (extension at front for cable overlength)



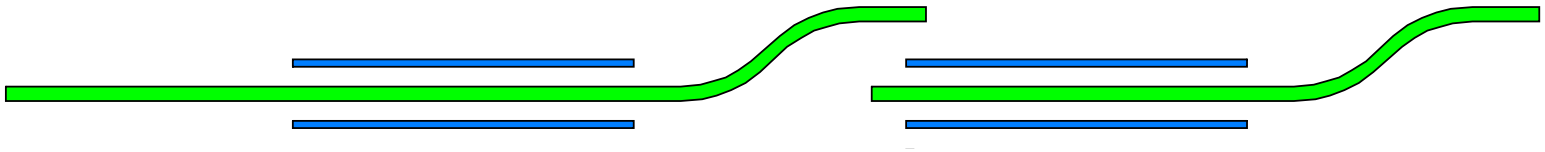
Installation Cable in Duct (Pipe) FreeFloating explained

- Remove duct connection and extension and pigs
- Place new duct extension halfway
- Install cable 2 with WaterPushPulling



Installation Cable in Duct (Pipe) FreeFloating explained

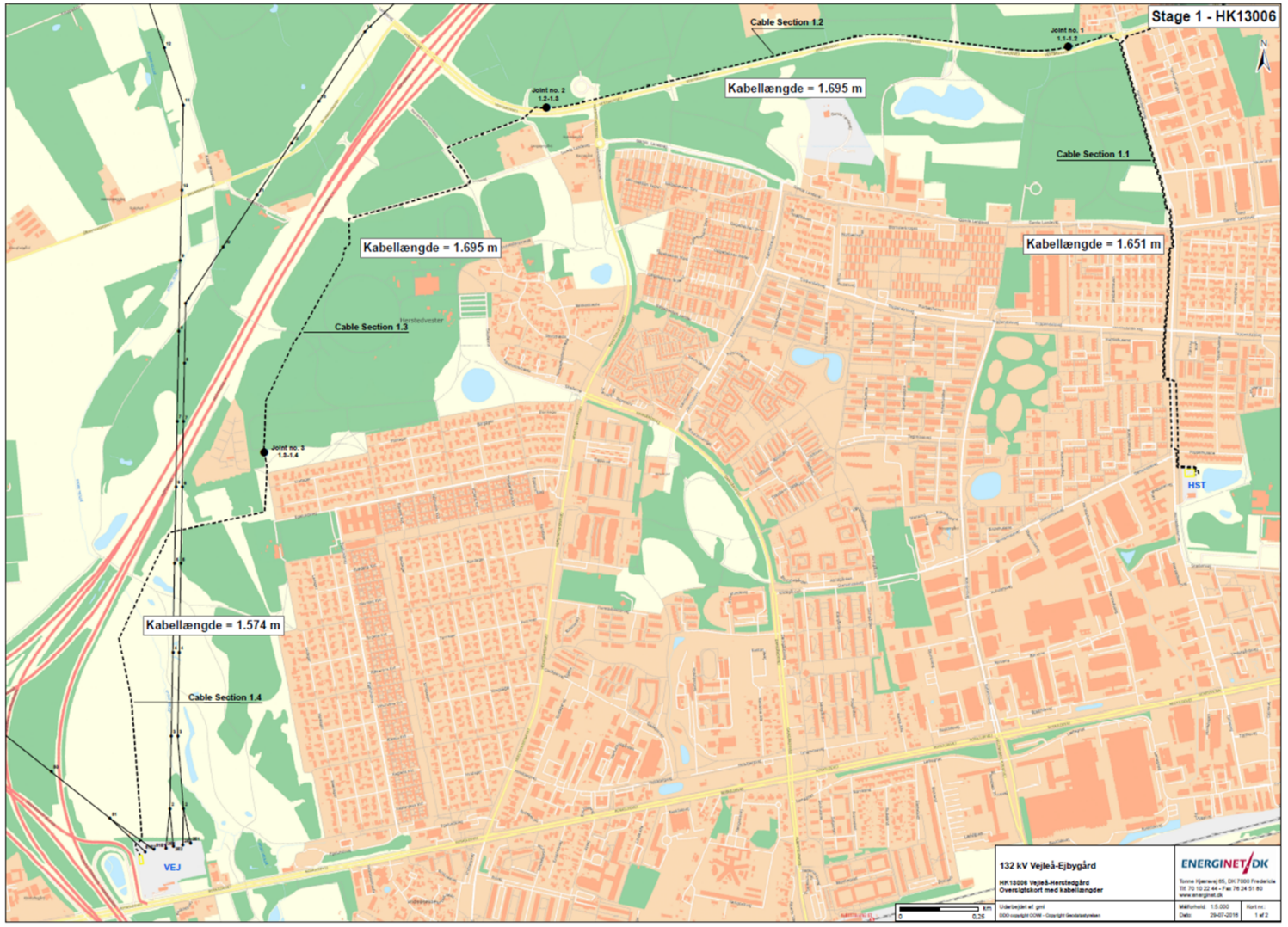
- Remove all extensions, pigs and equipment
- All cables installed
- Can also be done for more than 2 sections
- Difficult to reach locations avoided!



First FreeFloating Trial

- It really works!

Copenhagen Project



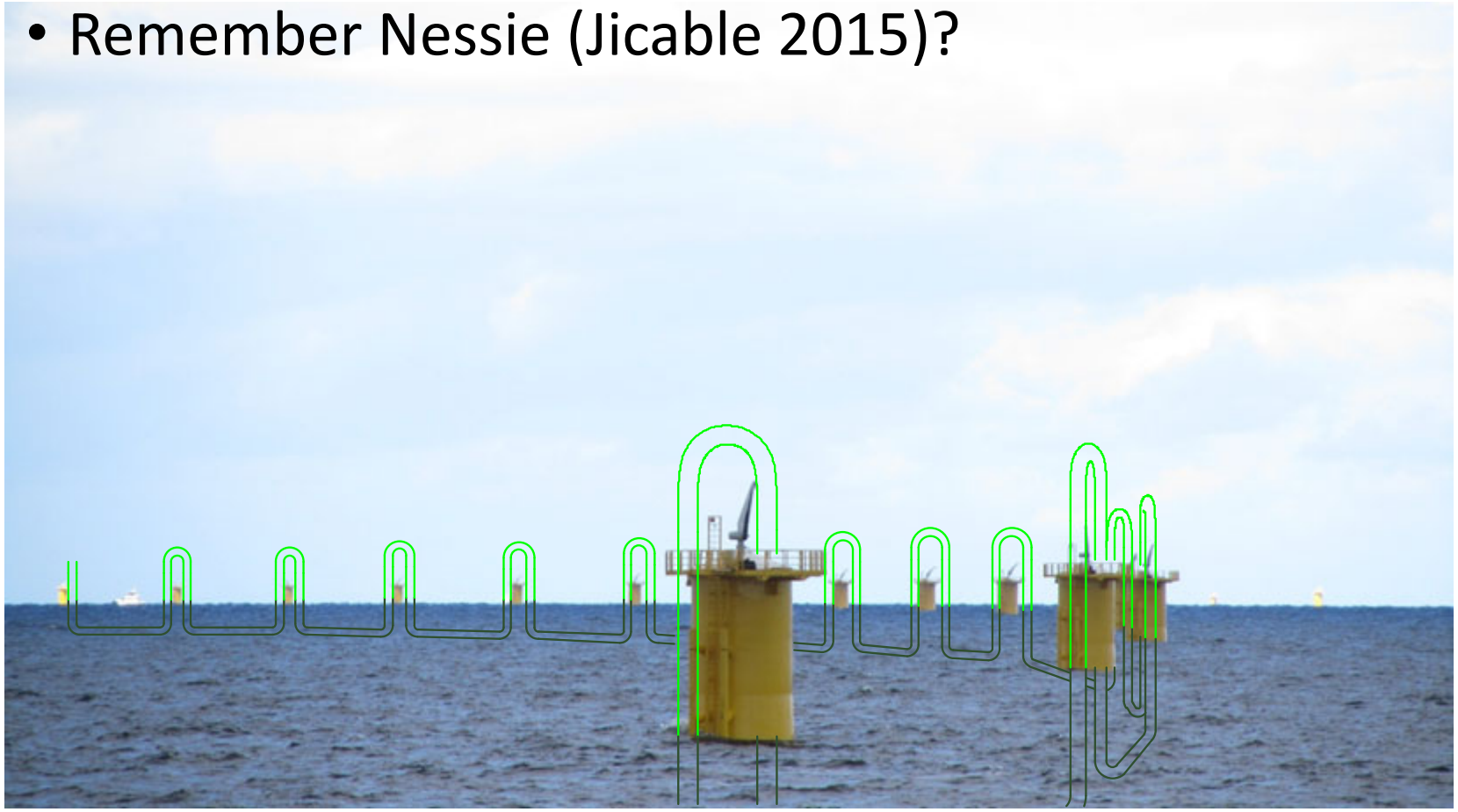
Copenhagen Project

- 2 sections, 1695 m and 1574 m
  - 3 parallel ducts 160/140 mm
  - 3 cables 132 kV, 92 mm, 8.7 kg/m, 36 kN max force
  - 1574 m cables FreeFloated via 1695 m section
- Installing 1st cable, FreeFloating to next section, installing 2nd cable behind 1st, done in 1 day!

Copenhagen Project

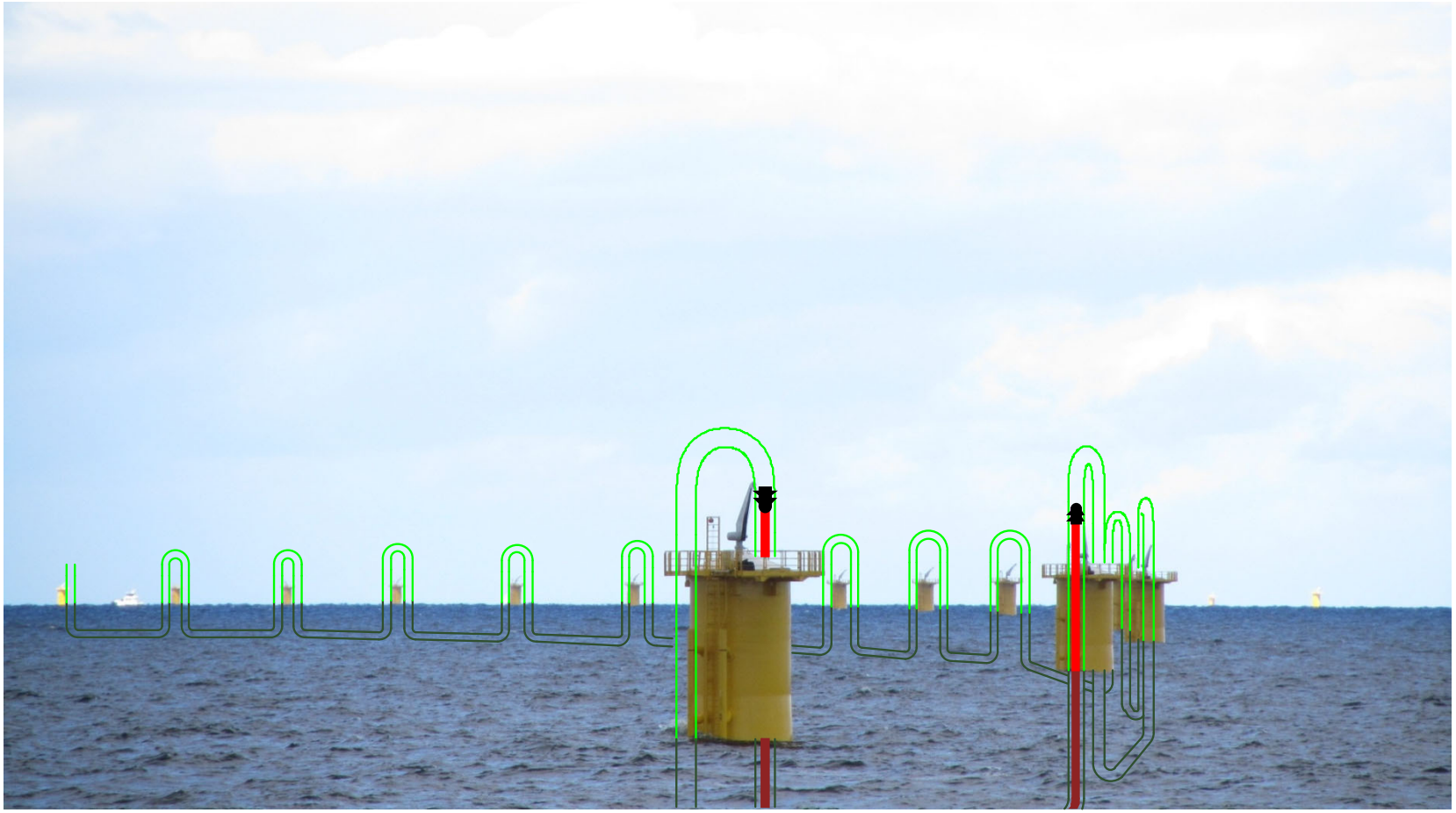
Offshore Wind Farm Project

- Remember Nessie (Jicable 2015)?

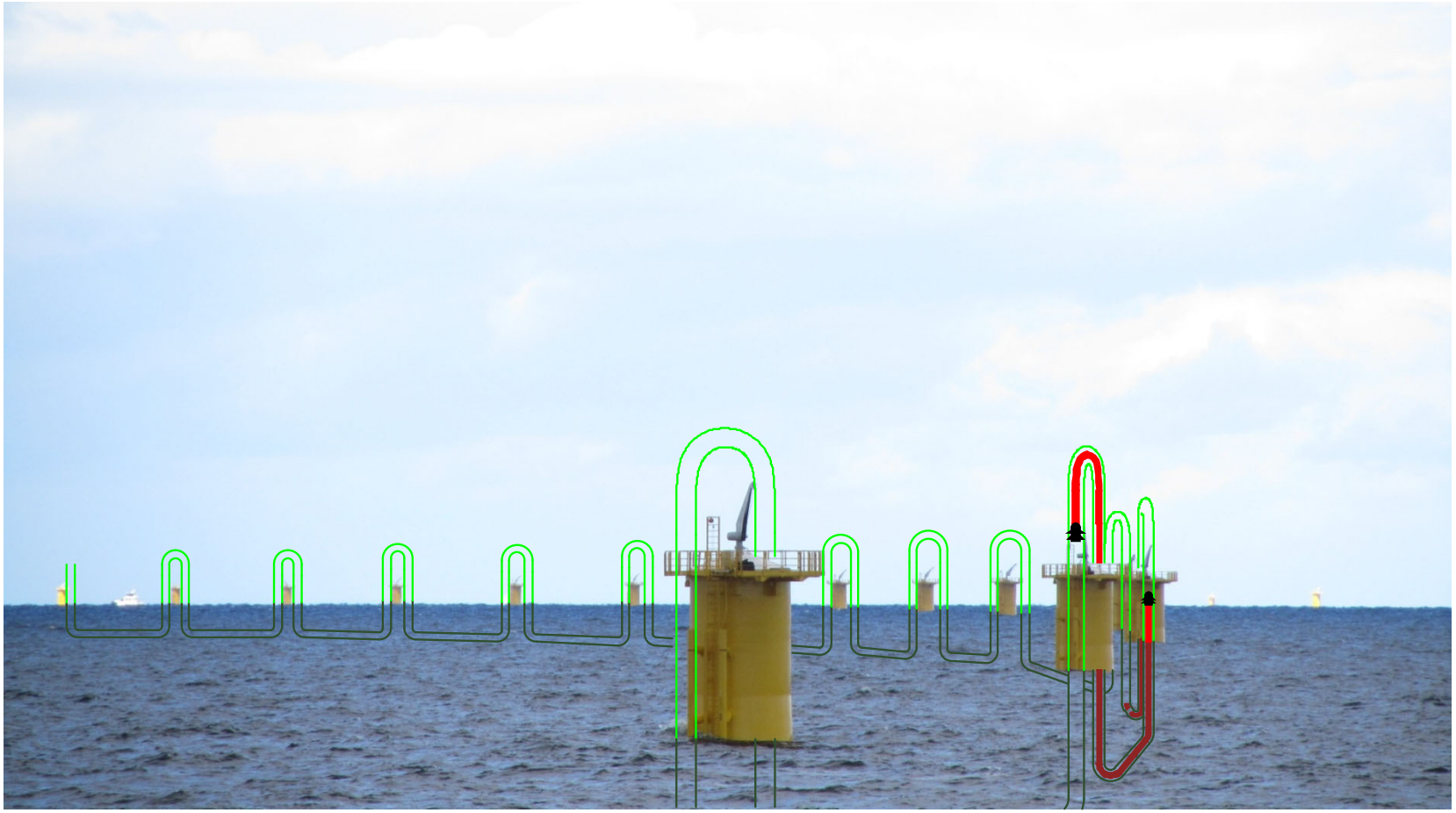


Offshore Wind Farm Project

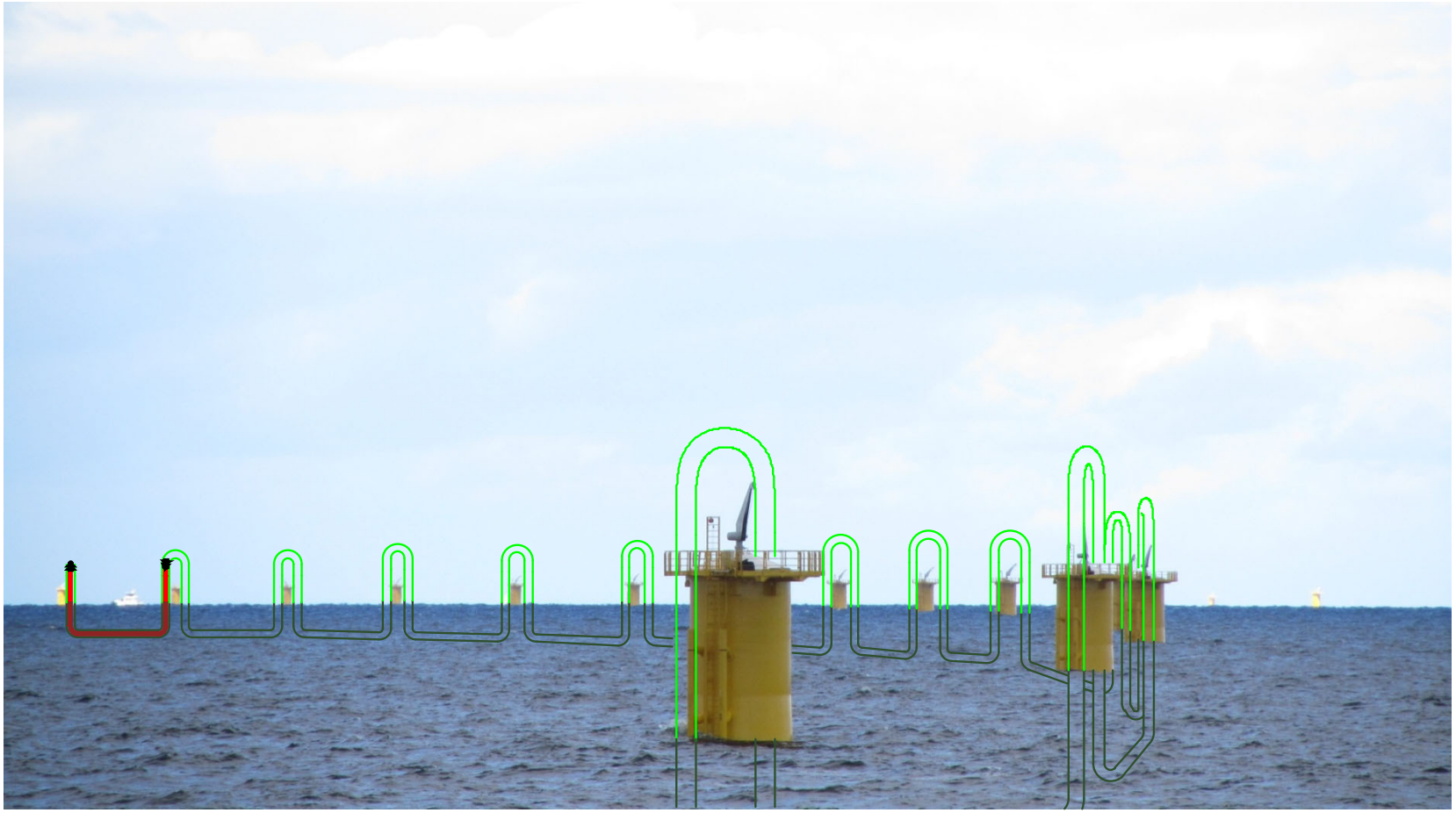
Offshore Wind Farm Project



Offshore Wind Farm Project

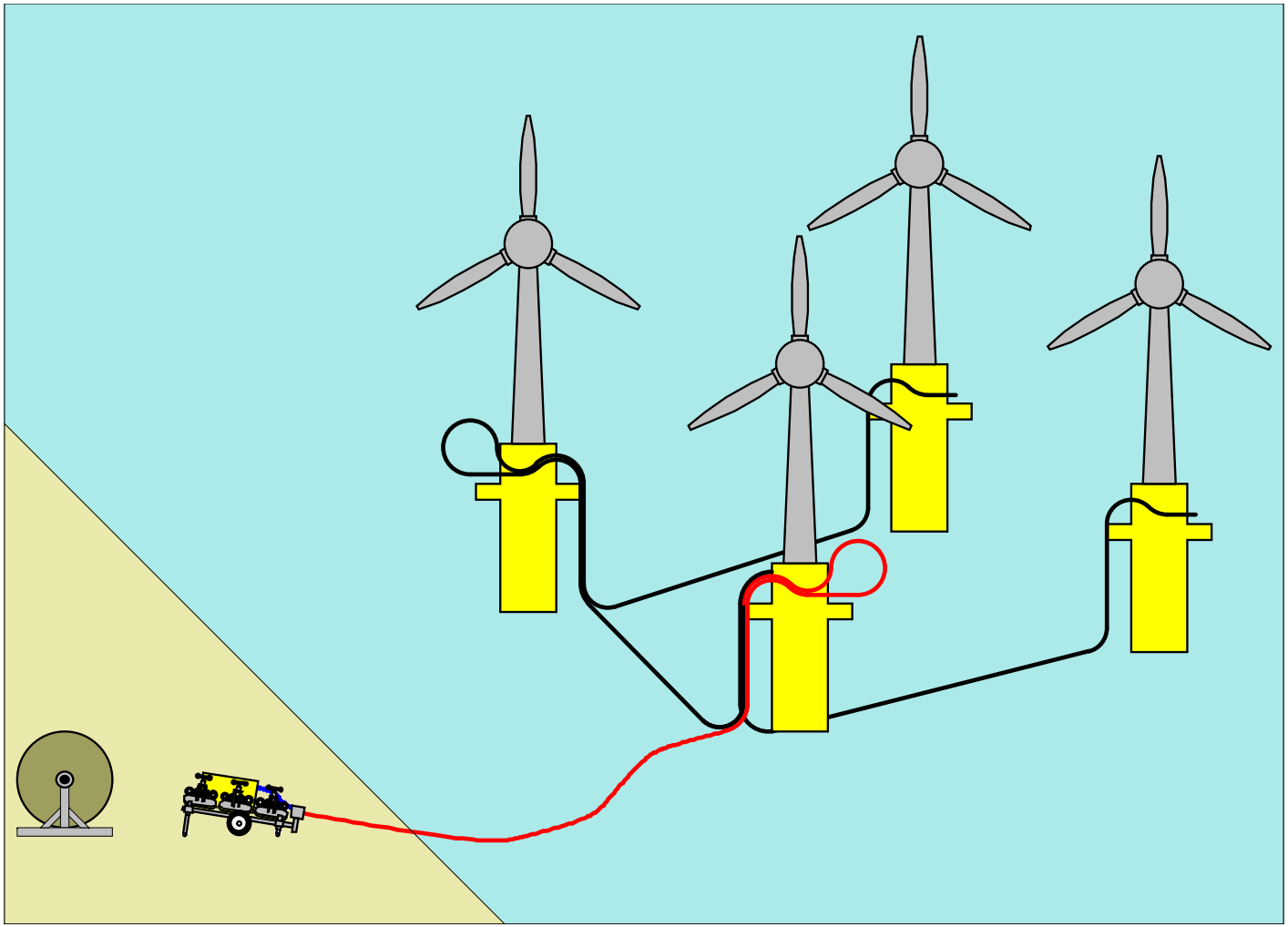


Offshore Wind Farm Project



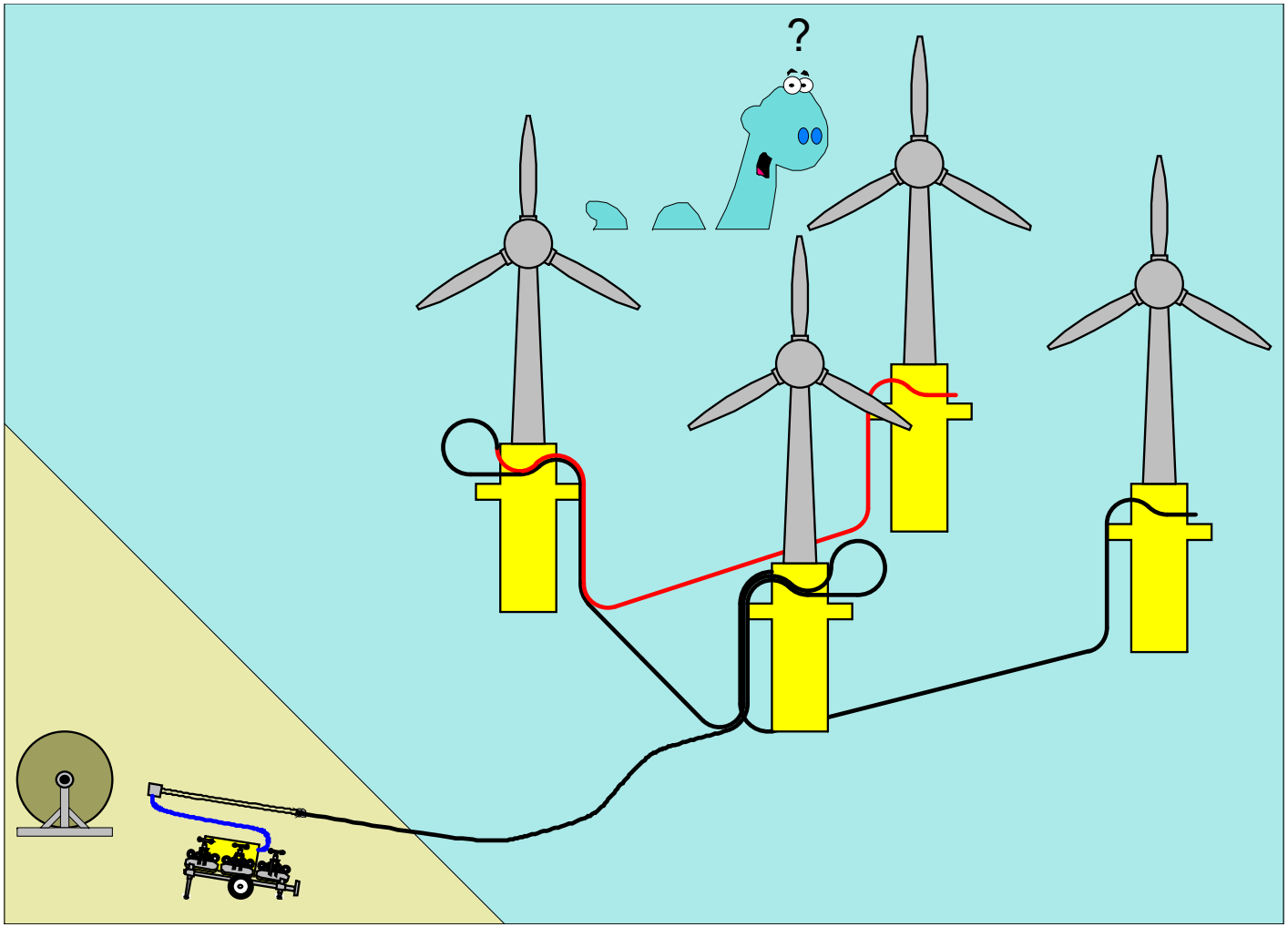
Offshore Wind Farm Project

- Nessie not only legend!
- Done in Denmark



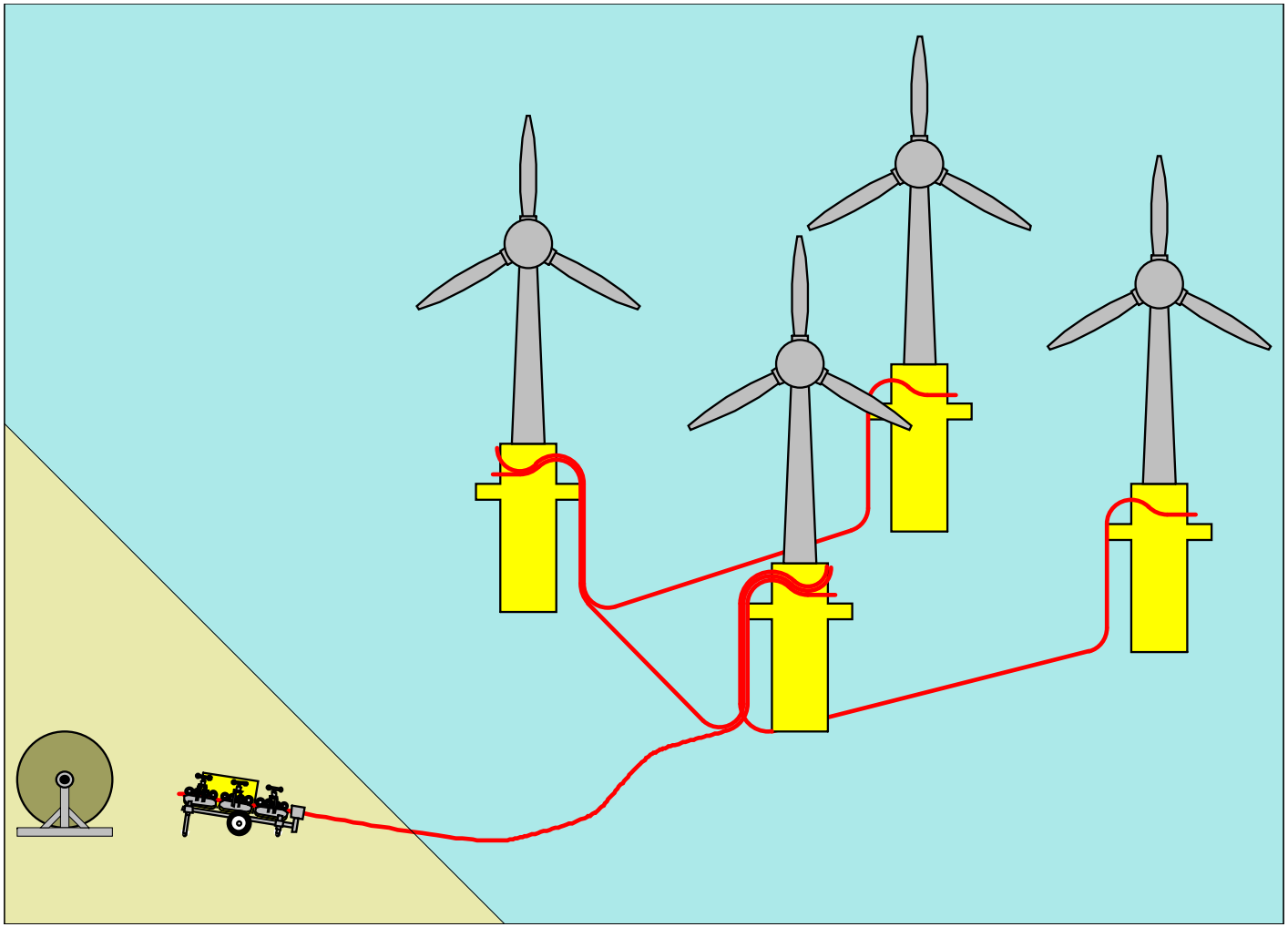
Offshore Wind Farm Project

- FreeFloat to end, 2 loops



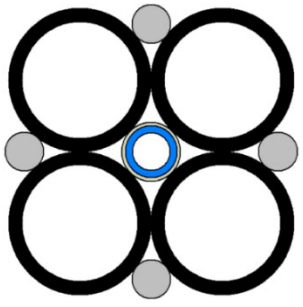
Offshore Wind Farm Project

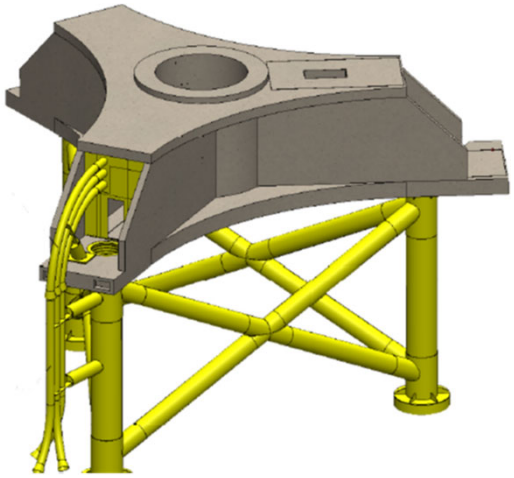
- Ready

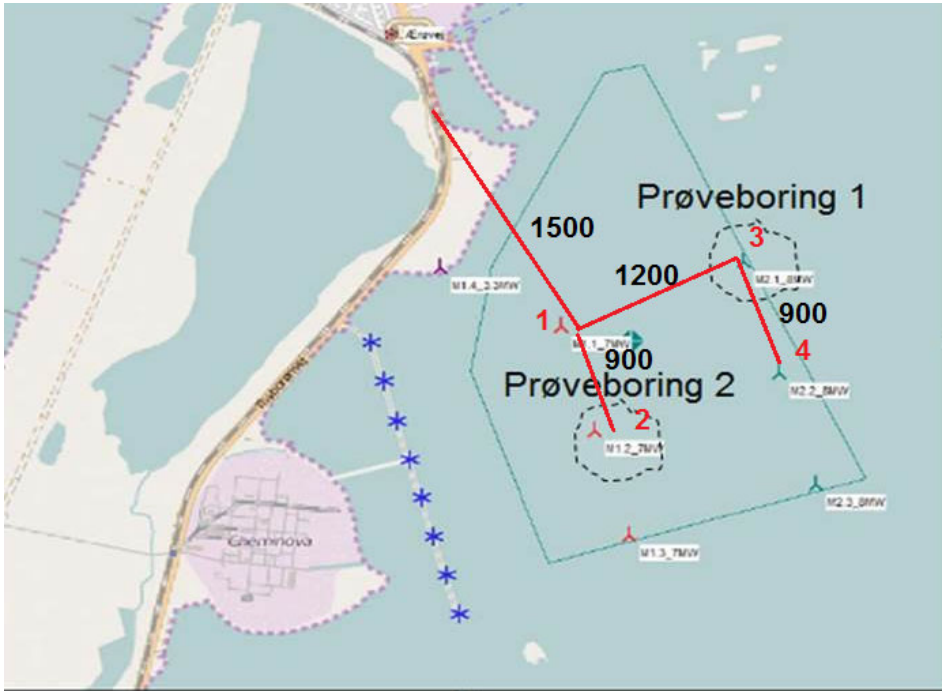


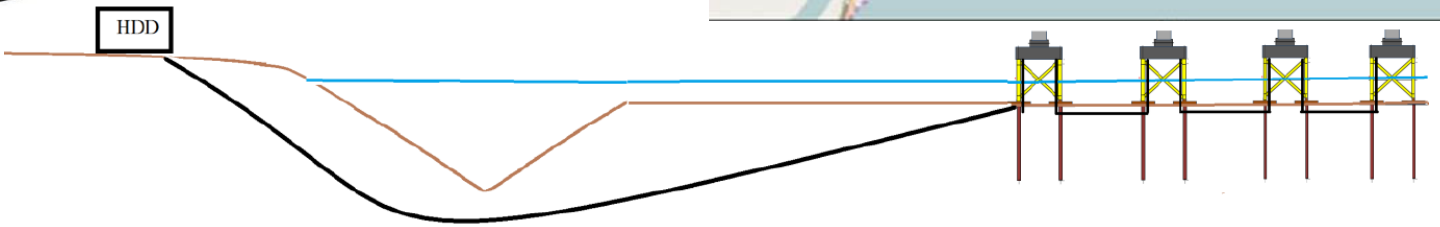
Offshore Wind Farm Project

- Nissum Bredning (Denmark)









Offshore Wind Farm Project

- 4 “near shore” wind turbines, each 7 MW
- Same cables for export and inter array
- 3 cables 72 kV, 630 mm^2 Al, 68.1 mm, 4.6 kg/m, maximum force 18.9 kN
- Bundle of 4 HDPE pipes 110/90 mm with steel ballast
- All 12 cables installed FROM LAND!
  - Except 2 from vessel (was not needed, just to prove!)
  - 3 techniques used for installation:
    - WaterPushPulling
    - Floating
    - FreeFloating
  - Installation also with bad weather (Beaufort wind force 8!)
  - Installed with up to 28 m/min (FreeFloating)

Offshore Wind Farm Project

Offshore Wind Farm Project

Limits of FreeFloating

- Elevation differences (every 10 m = 1 bar)
- Many sections might give too many bars
  - Downhill: too much pressure on duct
    - Solved by using pig with pressure safety valve
  - Uphill: Not enough pressure to install
    - Solved by using booster pumps at intermediate locations
- No problem for offshore
  - Launch and end point elevation do not differ a lot
  - Pressure can get high at deep dips, but is same for inside and outside duct

Limits of FreeFloating

- What is the maximum (safe) cable speed?
  - Water hammer (water speed $v \geq$ cable speed v_c)?
  - Joukowsky formula for pressure p of water hammer:

$$p = \rho c v$$

  - ρ = cable density (1000 kg/m^3)
  - c = speed of sound in water (1500 m/s)
  - Correction duct expansion: 23% for HDPE duct SDR 11
  - 60 m/min would give 15 bar (without correction), with correction even much less. By far not limiting speed of water flow

Limits of FreeFloating

- What is the maximum (safe) cable speed?
  - Sudden stop cable: lots of inertia! What is force F_c?
  - Calculation analogously water hammer (not entire cable stops at same time, cable compresses and buckles, amount of stopped cable travels backwards like wave):

$$F_c = \sqrt{\frac{m_c}{\frac{1}{k_c} + \frac{c_b \left(D_d - D_c\right)^2}{4\pi^2 B}}} \cdot v_c$$

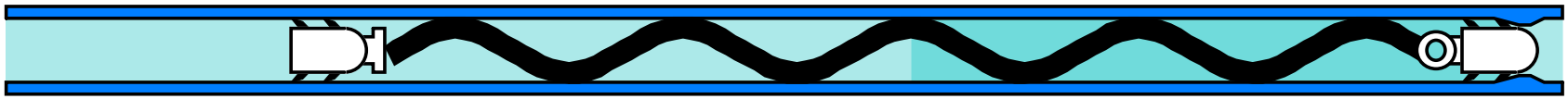
  - m_c = cable mass / unit length, B = cable stiffness, k_c = cable spring constant, D_c = cable diameter, D_d = duct diameter, c_b = constant (2.23 for sine buckling)

Limits of FreeFloating

- What is the maximum (safe) cable speed?
  - Example: Nissum Bredning cable and duct with cable speed 60 m/min $\longrightarrow$ F_c = 12.9 kN
    - Backwards wave travels with speed 2800 m/min! (compare with speed of sound in water of 1500 m/min)
  - Max force on cable = 18.9 kN, so still okay
  - Sidewall pressure and bending radius of cable under buckling far away from critical values
  - Cable can also be suddenly blocked at inlet, no buckling to "absorb" wave (formula with $c_b = 0$) $\longrightarrow$ F_c = 16.6 kN
    - Forward wave now travels with even 3600 m/min!

Limits of FreeFloating

- Cable and pig (!) hit obstacle
- “Buckle wave” and water hammer wave start
- Waves travel backwards until rear cable end
  - During wave travelling max force and pressure (at wave part)
  - Buckle force and pressure (pig) force do not add
  - Buckle wave travels faster than pressure wave



Limits of FreeFloating

- What is the maximum speed at which we can pump the water (cable) through? Given by Blasius:

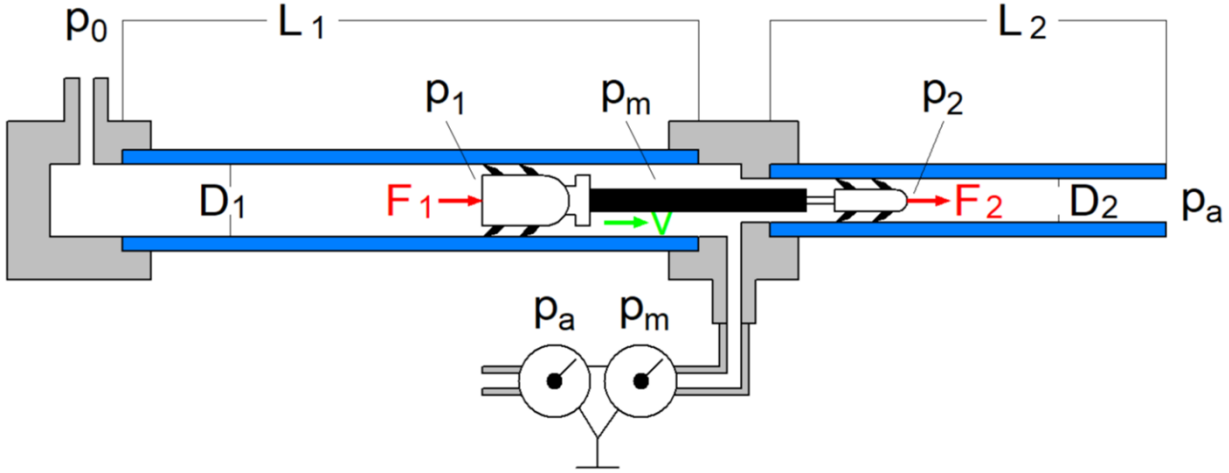
$$v = 2.9 \frac{D_d^{5/7}}{\mu^{1/7} \rho^{3/7}} \left(\frac{p}{L} \right)^{4/7}$$

  - μ = dynamic viscosity of water (10^{-3} Pas)
  - L = length duct
- Example: 160/130 mm duct, 40 km long
  - Speed *v of* 40 m/min (one cable takes net 16.7 hours) →
  - Pressure *p* of 12.4 bar needed, just to pump the water through
  - Remaining pressure can be used to FreeFloat the cable
  - Larger ducts: higher speed and/or longer length possible

Limits of FreeFloating

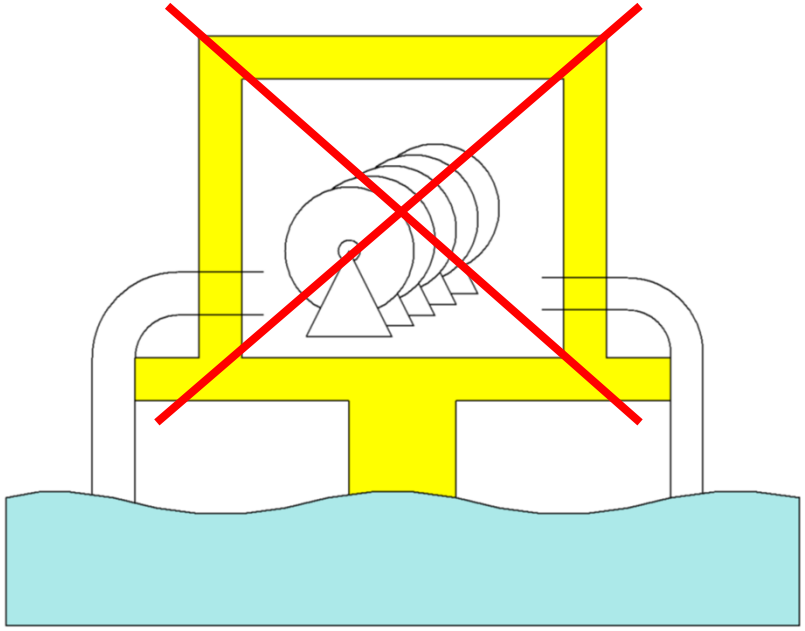
- Long lengths → different duct diameter might exist (outer edges wind farm with smaller cables / ducts)
- Cable passes duct change → pig must be changed
- How to handle different flows?
- How to optimize pressure?

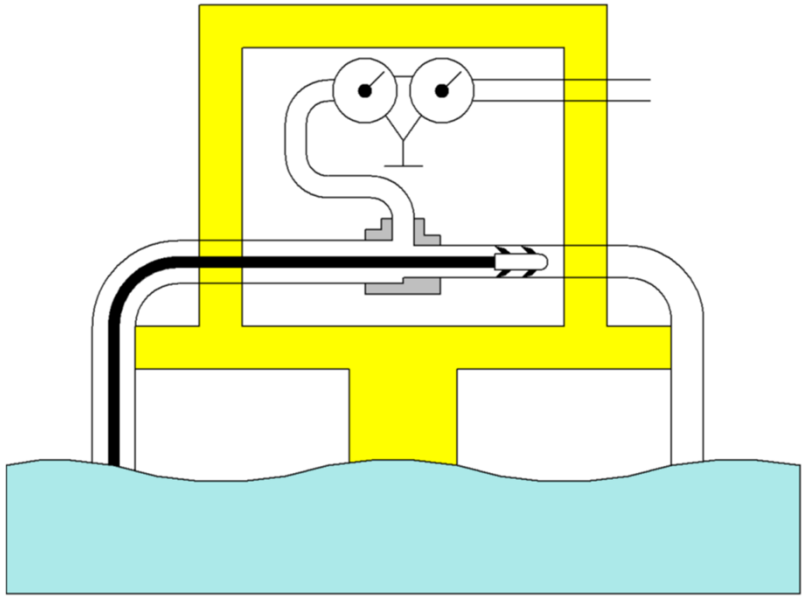
$$p_m = \frac{D_1^2 p_1 + D_2^2 p_2}{D_1^2 + D_2^2}$$



Limits of FreeFloating

- We can install (bring) cables over long length and through ducts with differing diameters
- No need to store heavy cable drums on platforms!





Conclusions

- FreeFloating cable installation technique proved to work in trial and 2 projects, one land, one offshore
- Works from any suitable launch location to any desired destination, avoiding difficult to reach places
- Copenhagen project: from suburb to city center possible
- Offshore wind farm: from land to offshore turbines (also at bad weather, like Beaufort windforce 8)
- FreeFloating can be done safely at high speed and over long lengths
  - e.g. 40 km with 40 m/min in 160/130 mm ducts
  - larger ducts → longer lengths and/or higher speeds

Thanks for Your Attention!