Pros and Cons of Electrical and Optical Strain Gauges in Offshore Wind Turbine Applications

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HOTTINGER BRÜEL & KJÆR

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“If it goes in the sea, talk to me”

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Topics

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Where we measure
Foundation costs
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Electrical v Optical SG, a quick history
Electrical SG for jackets - why
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Sensor survival, parts 1 and 2
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Optical versus electrical SG, quick tech comparison
Optical versus electrical SG, quick cost comparison
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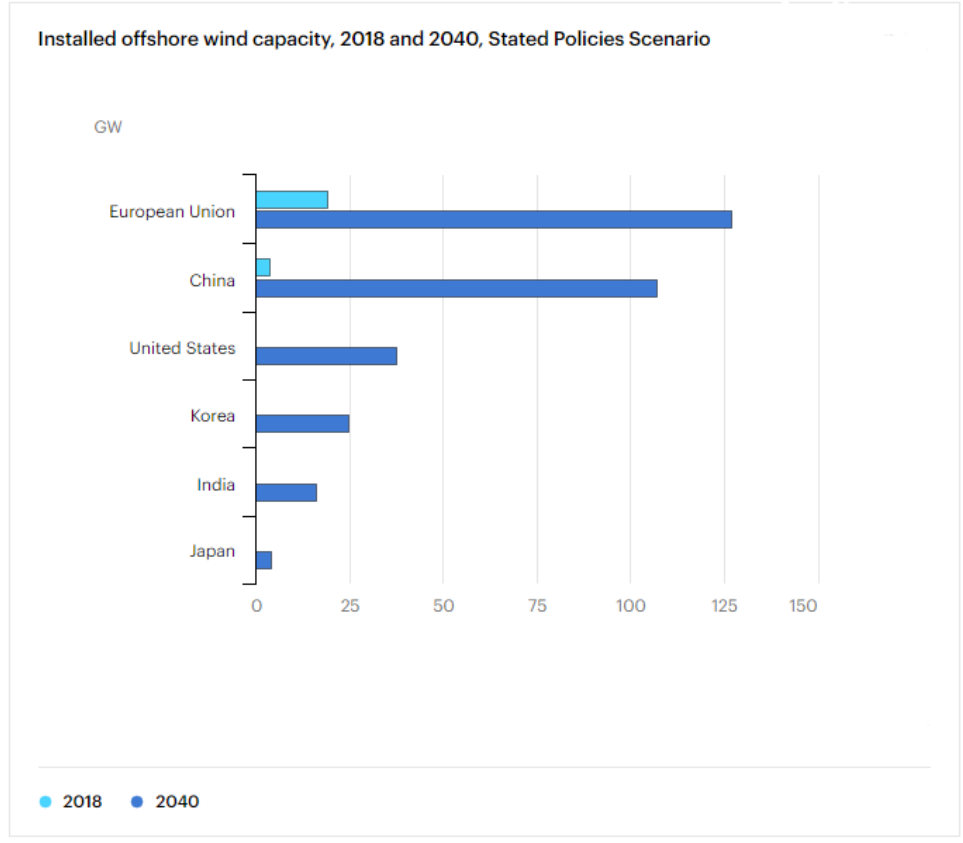
General installation issues in foundations

Overview of the offshore wind market



Source; IEA.org and 4COffshore

Where we measure

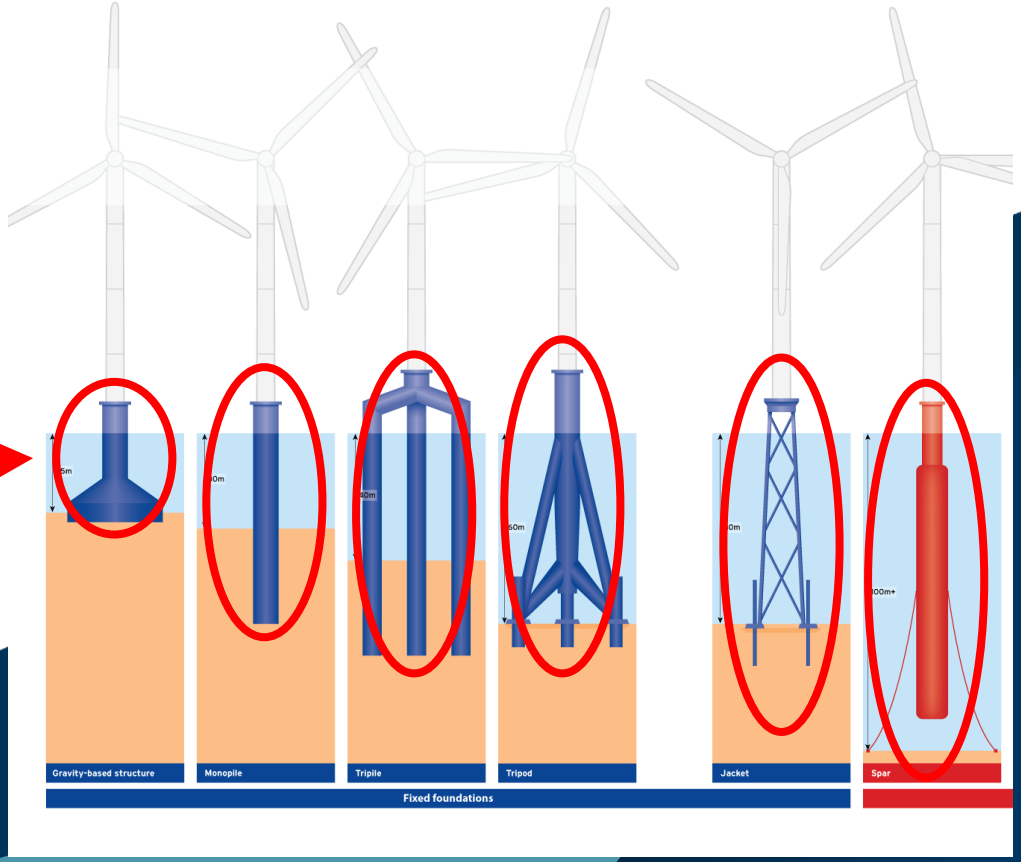
Blades - ice load monitoring, strain monitoring

Generator - torque monitoring on shaft

Tower - tension in bolted joints, strain in tower

TP - strain monitoring

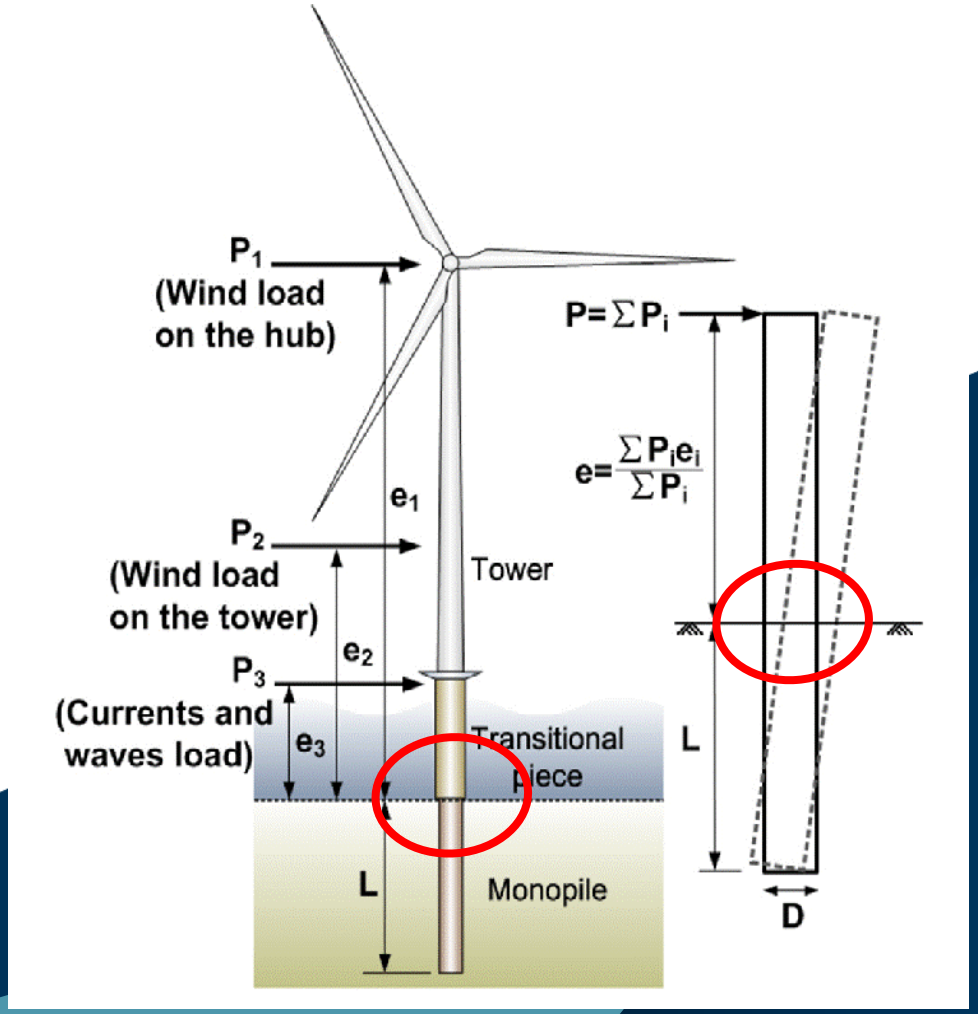
Foundations - strain monitoring



Also; Acc, Incl, wave radar, + …

Where we measure

Calculations based on accelerometer data in the nacelle are often insufficient to ascertain the performance of the foundation - the area of greatest moment is in the seabed/pile interface. Waves, scour and other variables make accurate assumptions difficult.



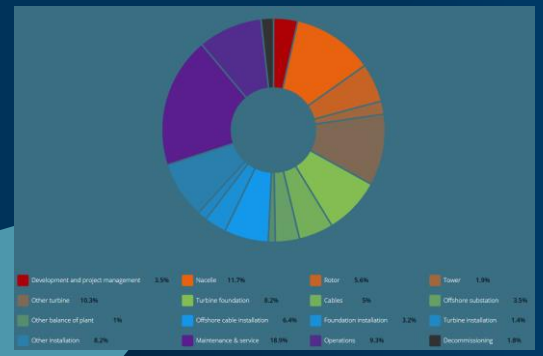
Source; https://www.researchgate.net/figure/Schematic-diagram-of-a-wind-farm-with-a-monopile-foundation_fig1_318594408

Foundation costs

As the seabed is never the same across a site, or different sites, nor is it a constant, and as experience with older design develops, new designs of foundation can help reduce project cost. New designs need measurement data for design validation.

"Foundation costs represent around 20 to 25% of total project capex. Steel monopiles offer the lowest capex and represent 82% of installed capacity in Europe."

"c.12% of the cost of an offshore windfarm is in the cost of the supply and installation of the foundation."



Sources:
https://guidetoanoffshorewindfarm.com/wind-farm-costs
https://analysis.newenergyupdate.com/wind-energy-update/offshore-wind-foundation-shift-hinges-serial-build-gains

Why accurate measurements matter - part 1

Source; YouTube Atlantas Marine Inspection

It’s hard to see stress cracks underwater - and impossible to see them under the seabed!

Why accurate measurements matter - part 2

Source; Wrecksite.Eu / Burbo Bank

The seabed is unpredictable!

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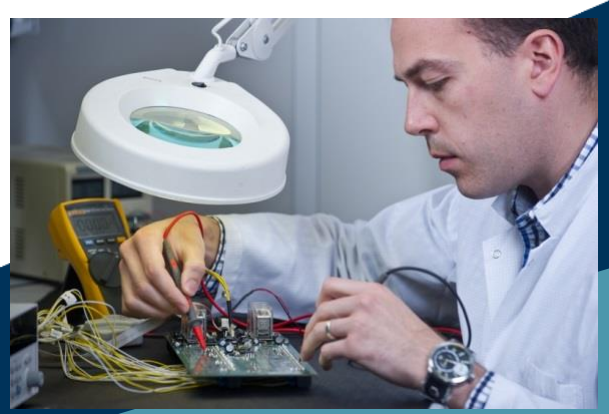
Electrical v optical SG - quick history

- **Electrical**
- Invented in 1938
- HBM founded in 1950 in Bavaria
- First HBM electrical SG amplifier made in 1950
- Owned by Spectris PLC, listed on LSE.

- **Optical**
- Invented in 1969 by Nippon sheet glass
- Fibre Bragg Gratings (FBG) commercialised by 3M in 1995
- HBM Fibersensing founded in 1994, bought by HBM in 2014



Electrical SG for jackets - why

- Complex assembly routine for legs, braces and ‘latticework’ in the yard - lots of soldering to connect sensor positions.
- Repeated ‘splicing’ of optical arrays can cause a poor signal, less so with electrical.
- DAQ package flexibility for other sensors/inputs (wave radar, LIDAR, anemometer signals and other data)

Optical SG for monopiles - why

- Long cable runs with multiple sensors in series, ‘in line’.
- Less weight/mass helps reduce sensor failure due to impact damage during piling.
- Possibility to add accelerometer, displacement and other FBG based sensors in same array.
- Very long distances between sensor and DAQ possible.

Sensor survival - two key points

1 - Protection against seawater

2 - Protection against piling damage

‘Limpet’ type covering, multiple layers. Soft in the inside so as not to induce an offset to the measurement due to stiffness, hard on the outside to protect against impact damage. Learned from mother nature.

Sensor survival - two key points

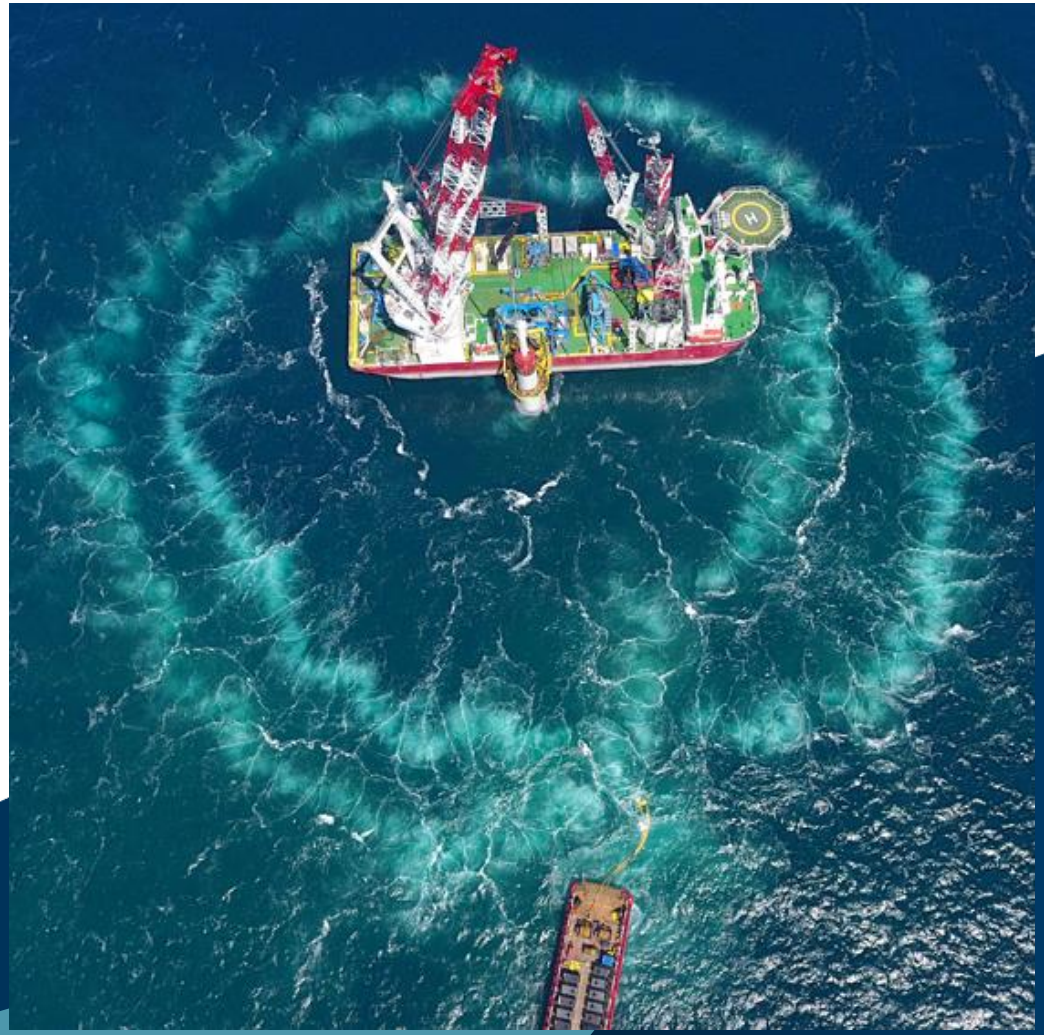
1 - Protection against seawater

2 - Protection against piling damage

Sensor system mass

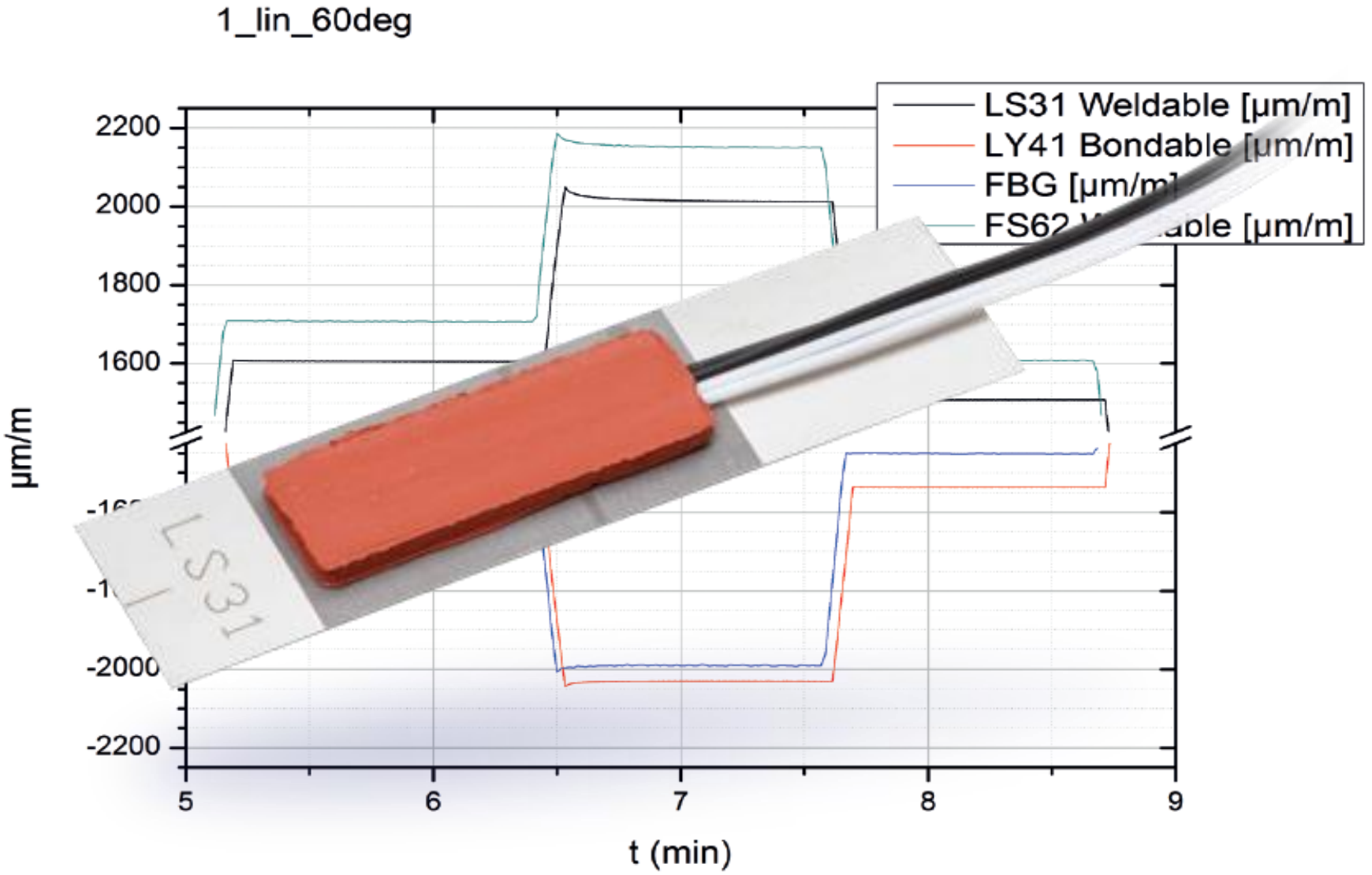
Electrical SG - 250Kg of cabling.
Optical SG - 8Kg of cabling.

(MP with 10 levels of 4 sensors, 80m pile, 40m to DAQ, armoured FBG cable v stranded copper SG cable, estimated)



Pic; https://www.hydrotechnik-luebeck.de/en/

Bonded v welded SG - performance comparison



Optical v electrical SG - quick tech comparison

- **Optical**
- + Fewer cables
- + More stable over time/distance
- + Inexpensive for big systems
- + Good performance in seawater
- + Mix of sensor types in series
- + Better performance for high frequency and high strains
- - DAQ can be more costly
- - Fewer reference installations

- **Electrical**
- + Inexpensive sensors
- + Easy to change/repair
- + More reference installations
- - Long term stability
- - Lots of cables
- - Big systems can be costly
- - Protection critical in seawater

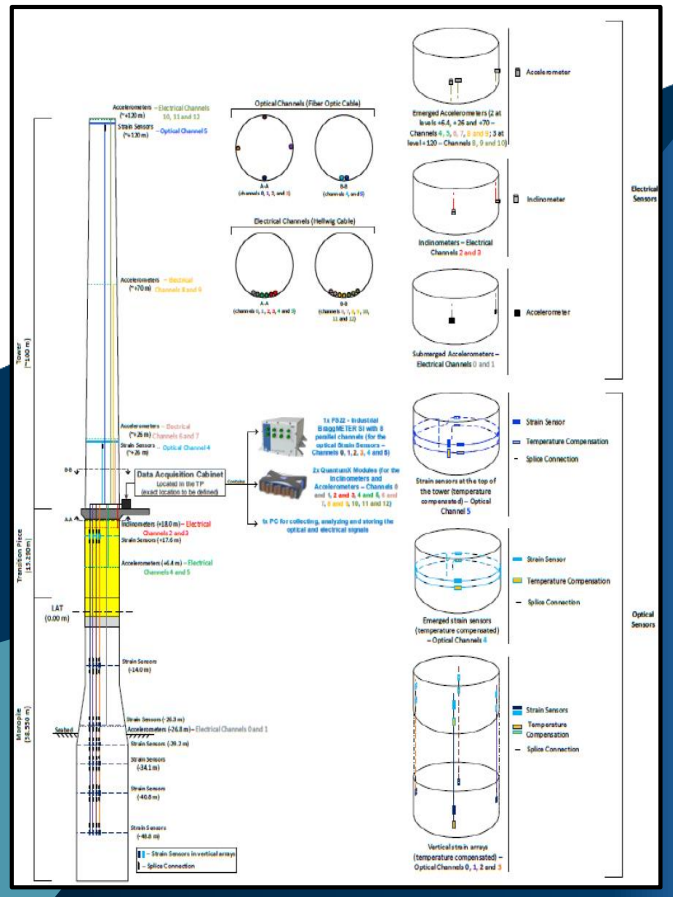
Optical v electrical SG - quick cost comparison

	Resistive strain gauge, compared to optical	Optical strain gauge, compared to resistive	Note
DAQ hardware cost	-10%	+10%	
Strain gauge cost	-75%	+75%	Optical strain gauges include cable as part of array. Resistive gauges require extra cable, hence the large cost difference.
DAQ Installation cost	Same	Same	
Strain gauge installation cost by qualified Engineer	+15%	-15%	
Cabling	3km	Included in strain gauge cost as part of array	
Total difference in cost for an installed system		c.-10%	

COST COMPARISON (48 CHANNEL STRAIN-GAUGE SYSTEM)

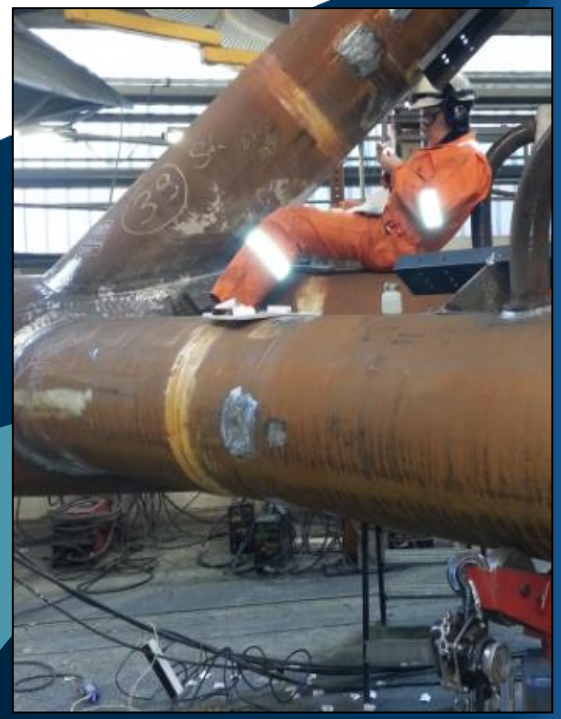
General selection issues in foundations

- *System complexity / multiple sensor types. Eg; strain, temperature, corrosion, accelerometer, inclinometer, wave radar, etc…*
- *Which ones have a proven track record offshore?*
- *Which ones can be combined to reduce cabling?*
- *Which ones can be easily replaced, if needed?*
- *Which sensors are low mass in the case of piling?*
- *How can cable routes be simplified and protected?*
- *Signal stability/distance between position and DAQ?*
- *Redundancy… sensors in series or parallel?*



General installation issues in foundations

- *Time permitted for installation in yard. Each sensor could (depending on choice) take 0.5 to 3.5 hours to install.*
- *Application of protective material over sensor positions.*
- *Installation of protective covers/trays over sensor positions.*
- *DAQ to be installed in the yard, or offshore?*
- *How to handle cable ends for later connection?*
- *Quality of workmanship with sensor installation.*
- *What % of the sensors can we expect to survive piling?*
- *Can I measure during piling?*
- *What long-term performance can I expect?*



- ***Questions?***