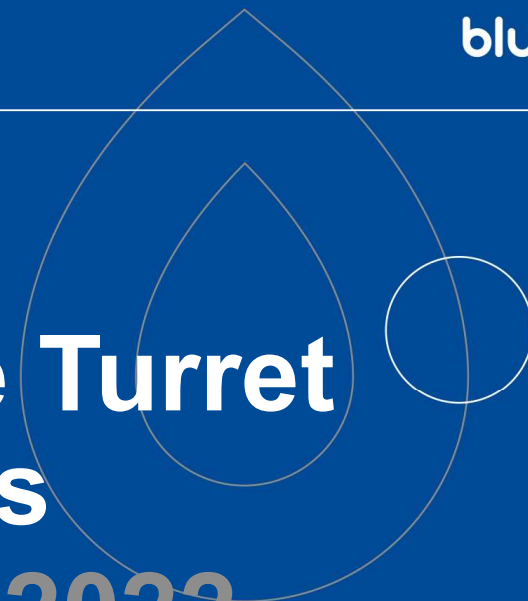
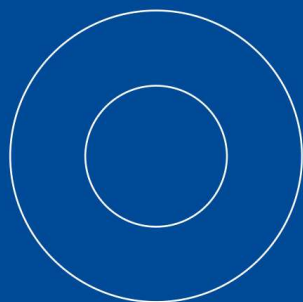


# Experiences Full Scale Turret Mooring Measurements MIUG Rotterdam June 2022

Behnam Bodaghi / Richard Leeuwenburgh



- System Overview
- Turret Load Measurements
- Turret Rotation Measurements
- Turret Position Measurements
- Observations and Lessons Learnt

# System Overview - FPSO

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Bluewater's Aoka Mizu

Location: West of Shetlands

105 kDWT Tanker

L x B x D : 232 x 42 x 22

150m water depth

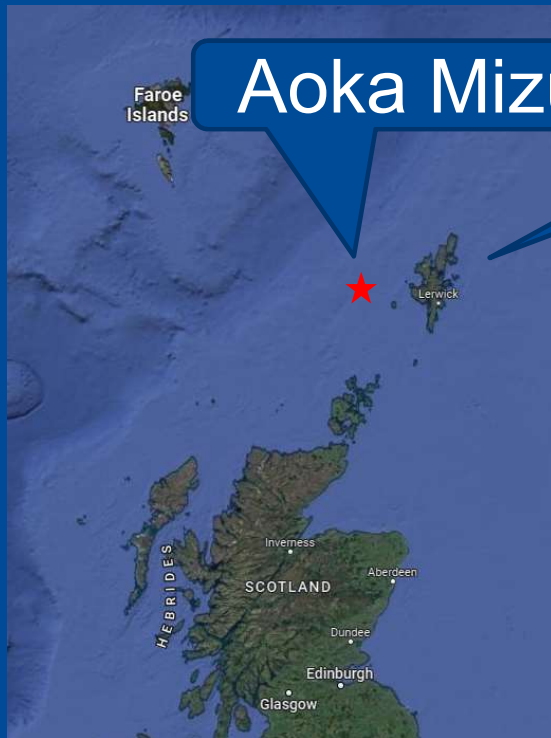
3 x 4 mooring lines (SSW & Chain)

Hs,100yr : 17.2m

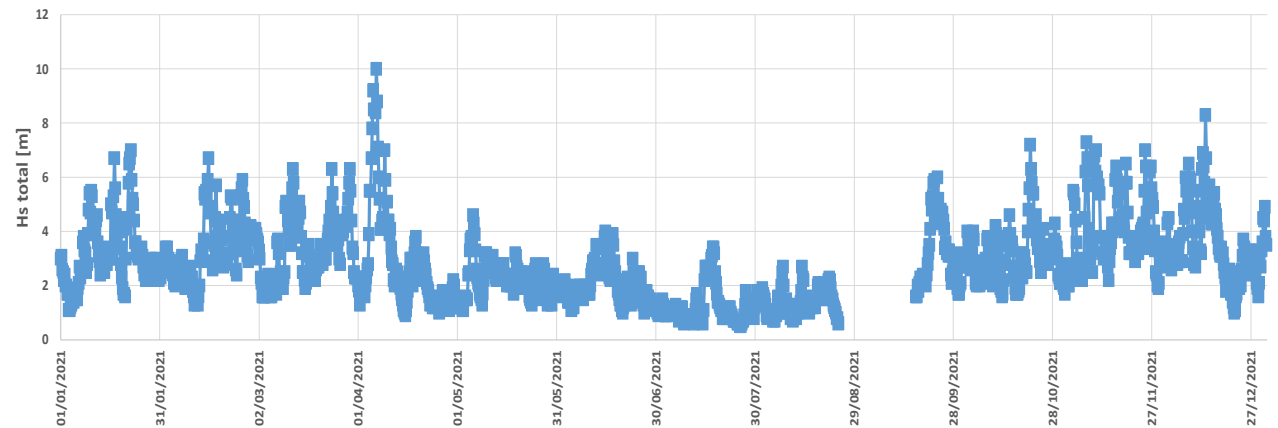
Hs,10000yr : 22.5m

# System Overview - Location

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## Total Significant Wave Height 2021



# Monitoring System Overview - Objectives











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- Operational
  - Improve understanding vessel behaviour
  - Monitor operation within design parameters
  - Condition monitoring (Digital Twin)
- Engineering
  - Verify design assessments
  - Enhance engineering knowledge
- Contribute to Joint Industry Projects
  - Monitas
  - LifeLine





## bluewater

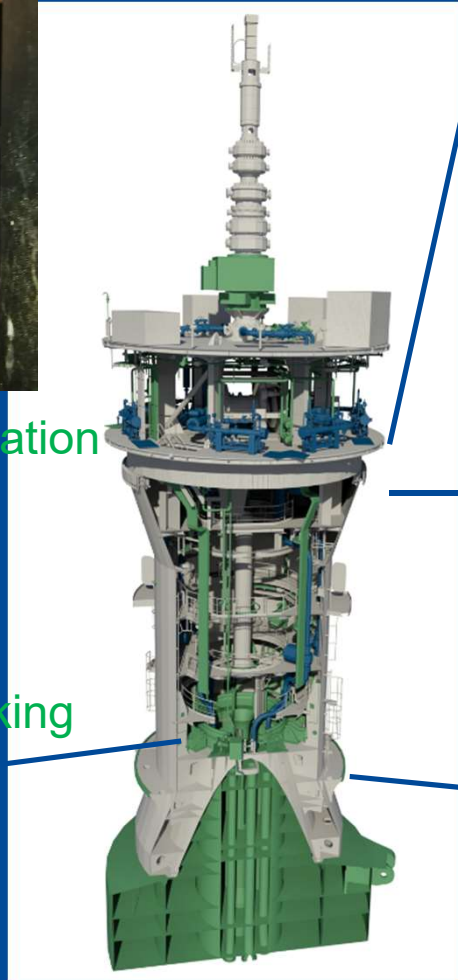
-  = Long base strain gauge (AHMS)  
 = Strain gauge (AHMS)  
 = GPS antennae (TPMS)  
 = Instrument junction box (TPMS)  
 = Strain gauge (green water)  
 = Green water camera
-  = Instrument junction box (AHMS)  
 = Cabinet (AHMS)  
 = WAMOS radar  
 = Cabinet (WAMOS system)

# Monitoring System overview – Turret

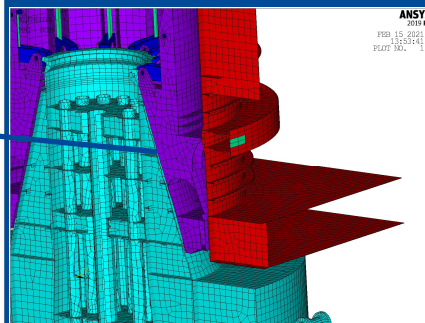
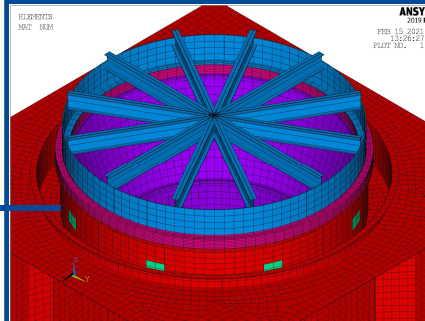
bluewater



2x 2 Turret rotation sensors



12x Buoy Locking Sensors



6x Load cells on the Main Bearing bolts



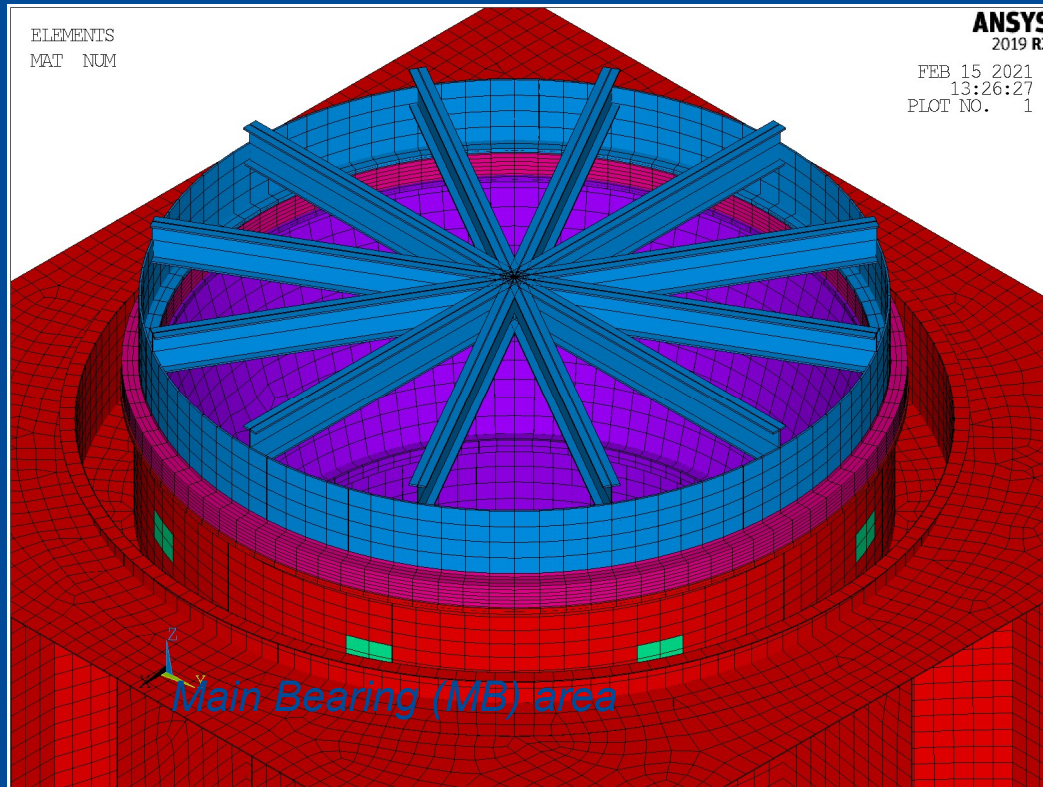
8x Rosettes on the Turret Support Structure



6x Strain gauges on the Lower Bearing

# Vertical Load Main Bearing - Measurements

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Vertical strain sensor output  
*mili-amps*

↓  
x gain

*$\mu\epsilon$  - microstrain*

↓  
x Elasticity modulus  
 *$\sigma$  - stress*

↓  
X Cross Sectional Area  
*force per sensor area*

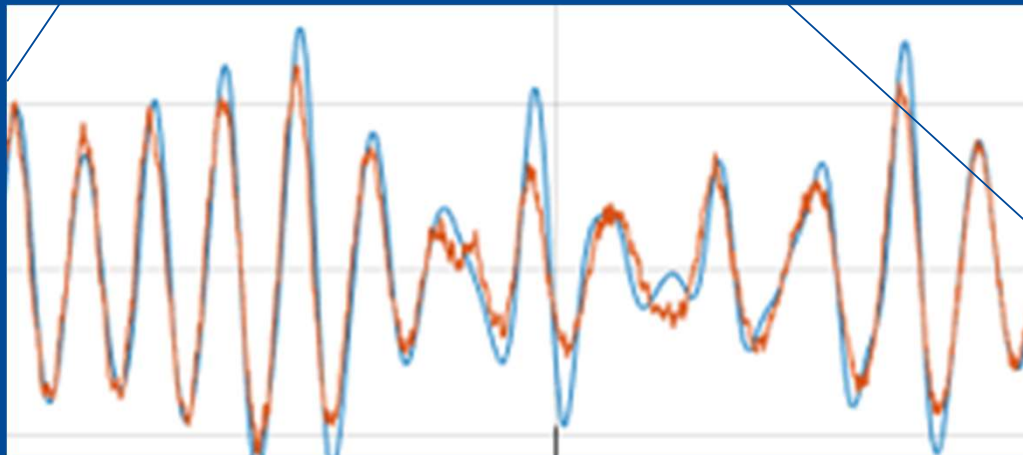
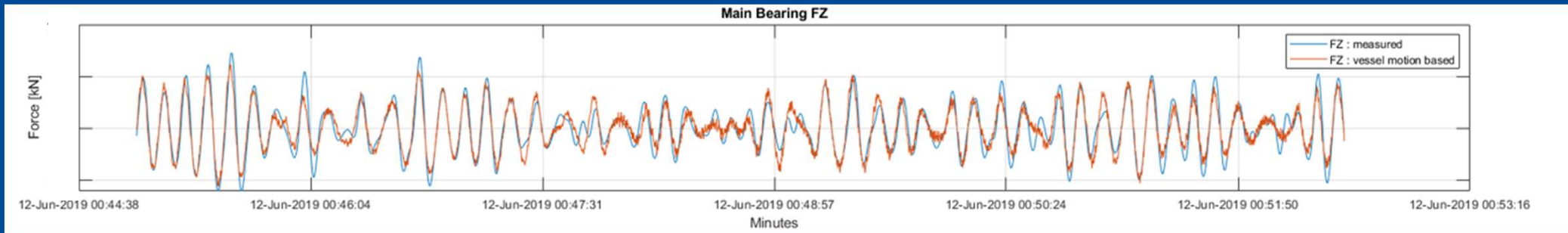
↓  
 $\Sigma$  - 8 sensors  
*Total vertical force*



# Vertical Load Main Bearing - Validation

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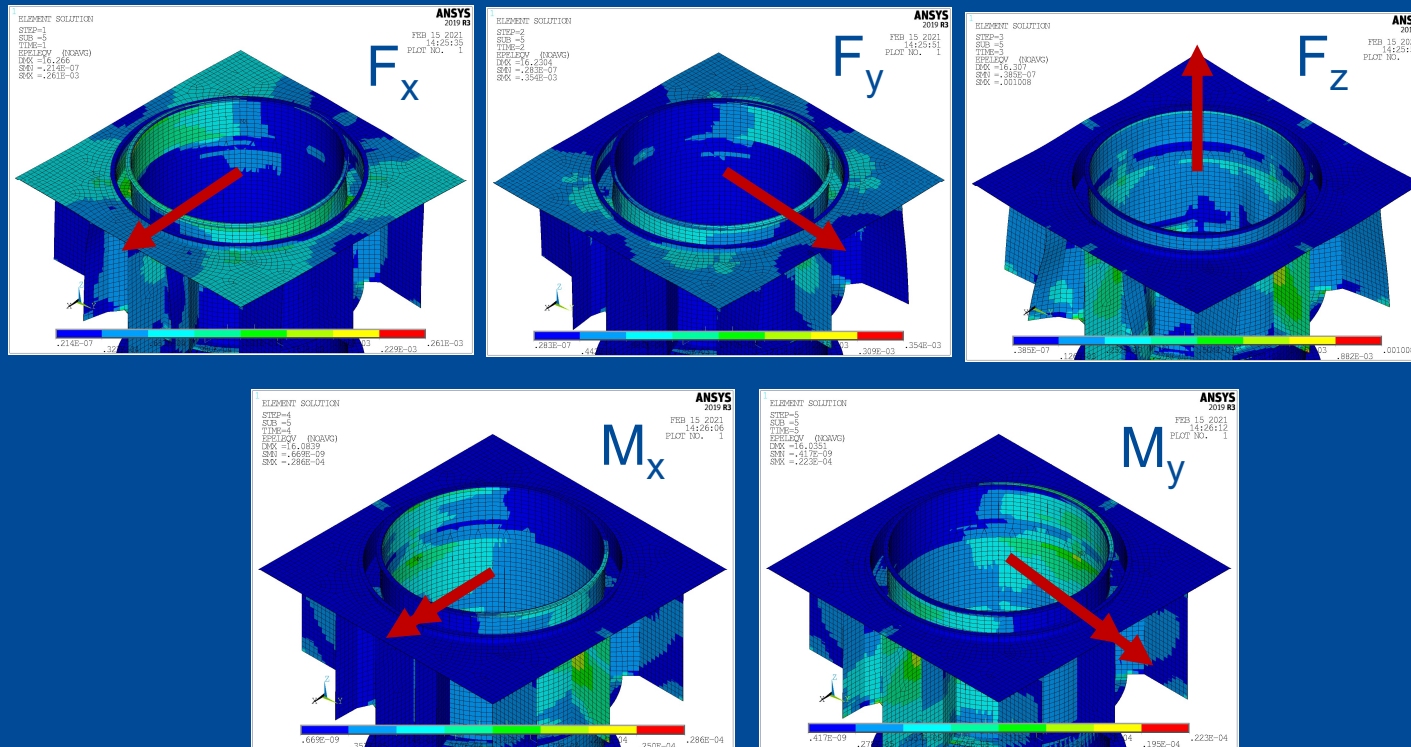
Vertical load compared vs inertia loads (TMS weight x measured acceleration)



- Contributors to vertical load:
  - Mooring and Riser loads
  - Hydrodynamic loads
  - Calibration inaccuracies

# Turret Loads – 5 DOF

bluewater



Sensor output  
8 rosettes x 3 signals  
*milli-amps*

x gain  
 $\mu\epsilon$  - *microstrain*

Least Square Estimator

=> Best fit for  $F_x$ ,  $F_y$ ,  $F_z$ ,  
 $M_x$ ,  $M_y$  combination

Define unit loads MB

$F_x$ ,  $F_y$ ,  $F_z$  : 1 kN

$M_x$ ,  $M_y$  : 1 kNm

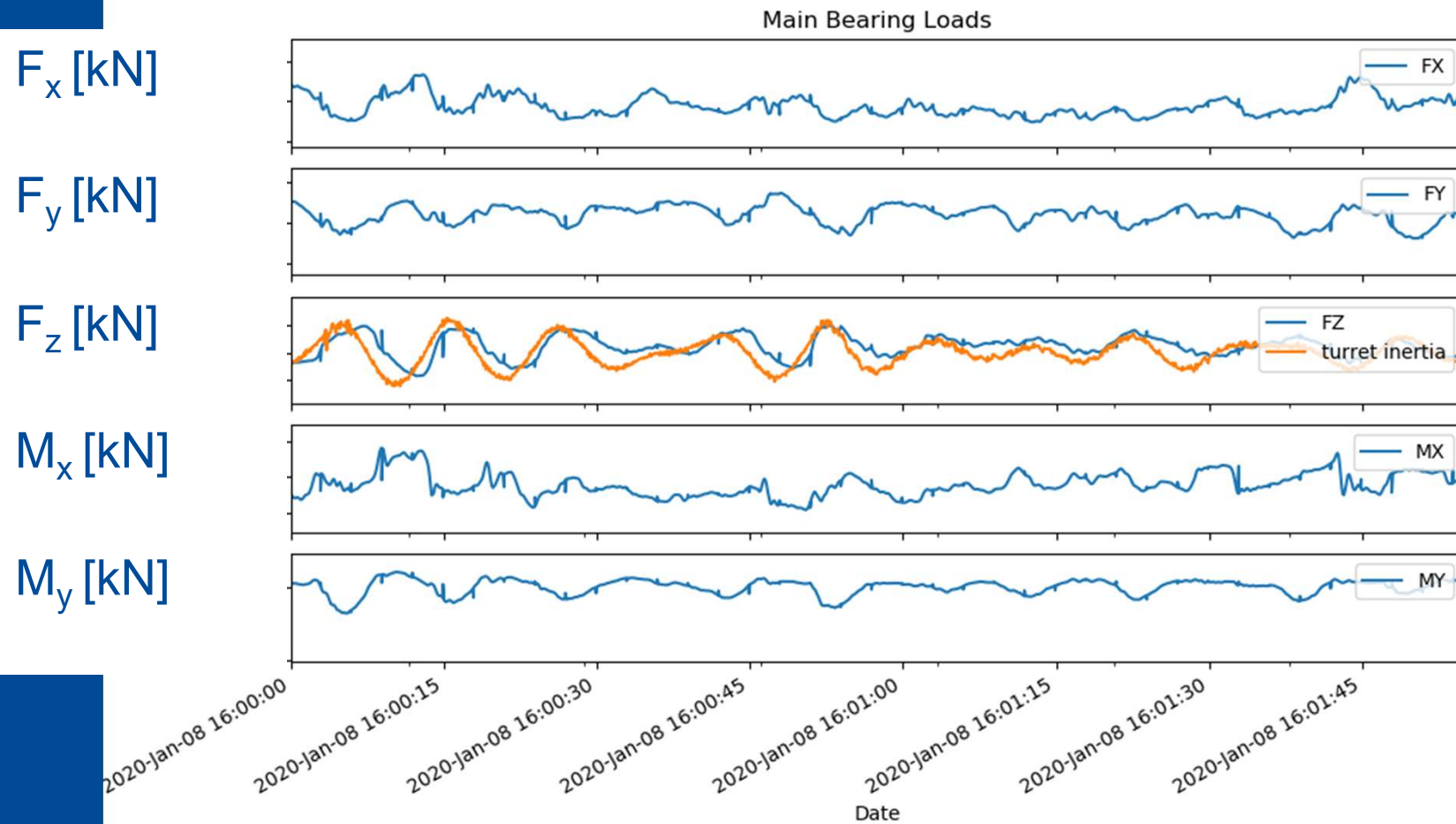
Calculate strain

response for unit loads

$\epsilon_x$ ,  $\epsilon_y$ ,  $\epsilon_{xy}$

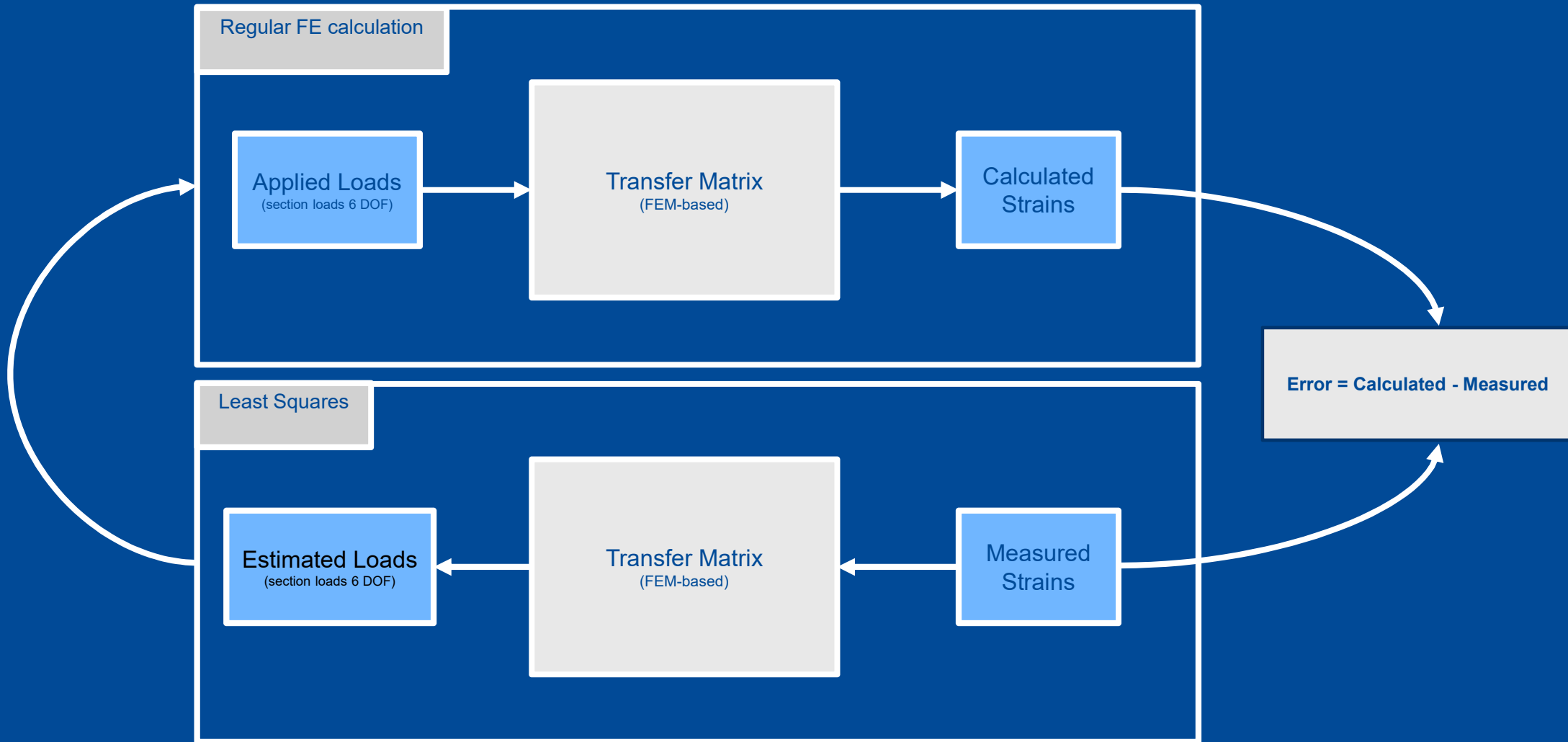
# Main Bearing Loads - Calculated

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# Main Bearing Loads - Validation

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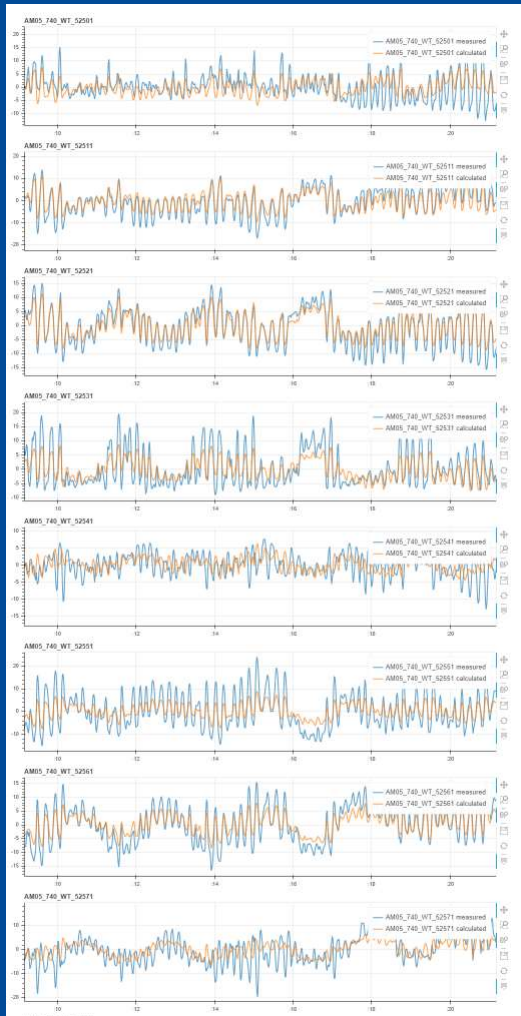




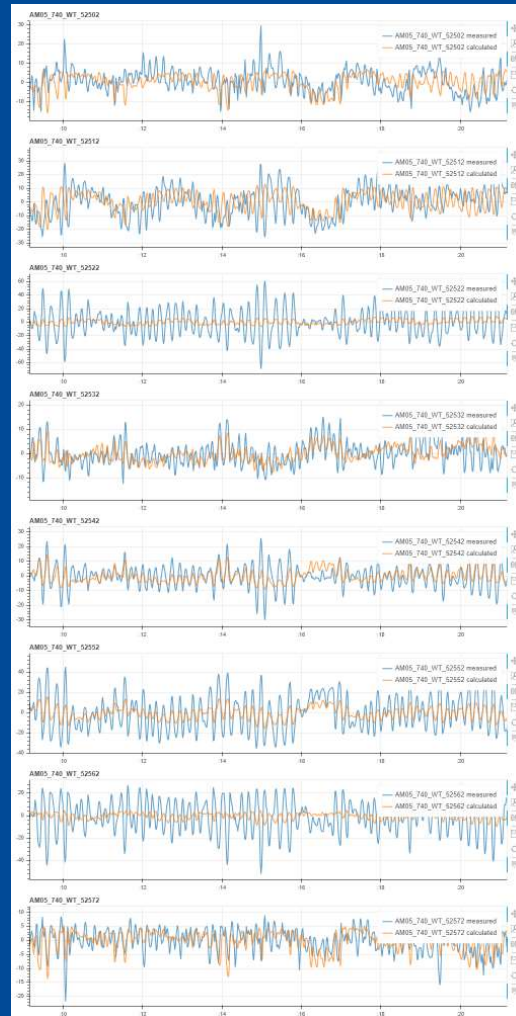
# Main Bearing Loads - Validation

bluewater

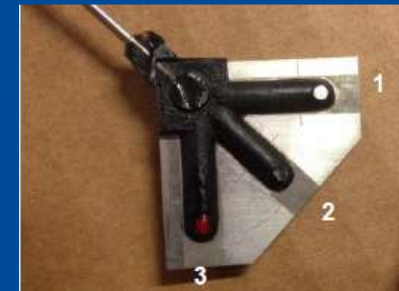
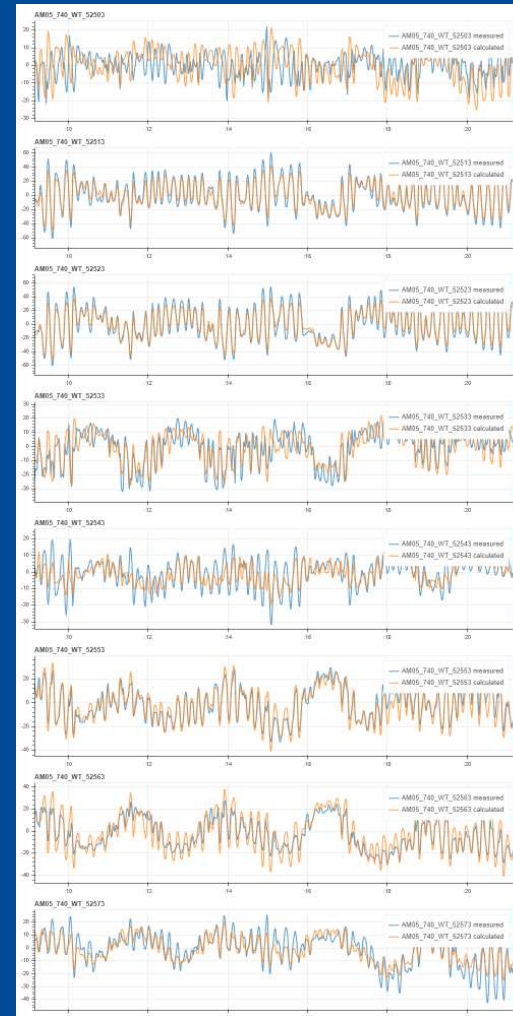
## Rosette 1-8, dir. 1



## Rosette 1-8, dir. 2



## Rosette 1-8, dir. 3



From best to worst match:

- Direction 3
- Direction 1
- Direction 2



**Conclusion:**

- FZ, MX, MY are quite well-estimated.
- FX, FY, MZ still need more work!

# Turret Rotation Measurement System

bluewater

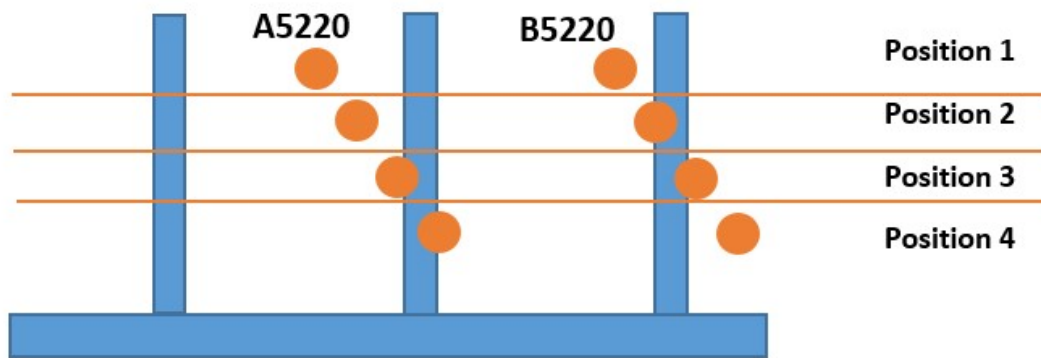


- 2 sets of 2 acoustic sensors
- Collar with 512 teeth

# Turret Rotation Measurement System

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Sensor positions relative to teeth



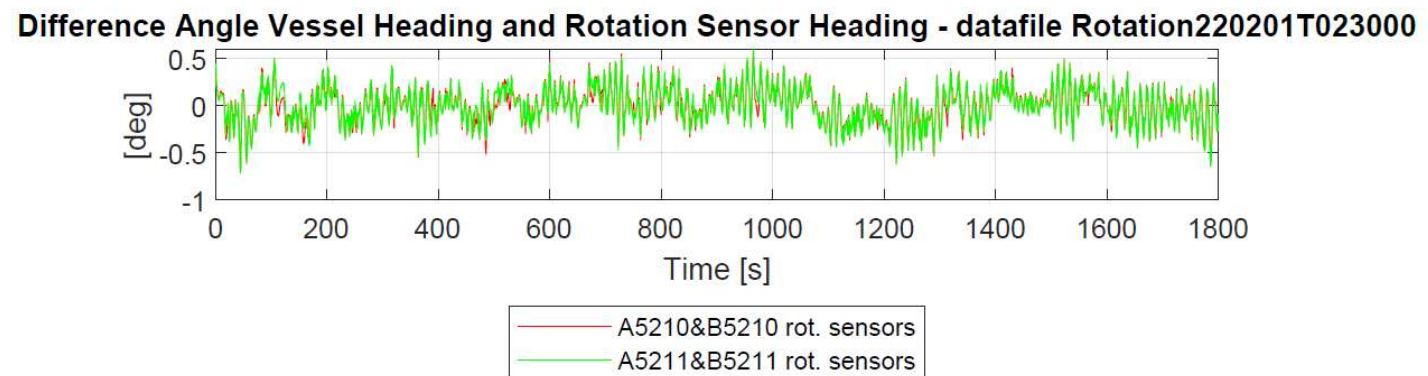
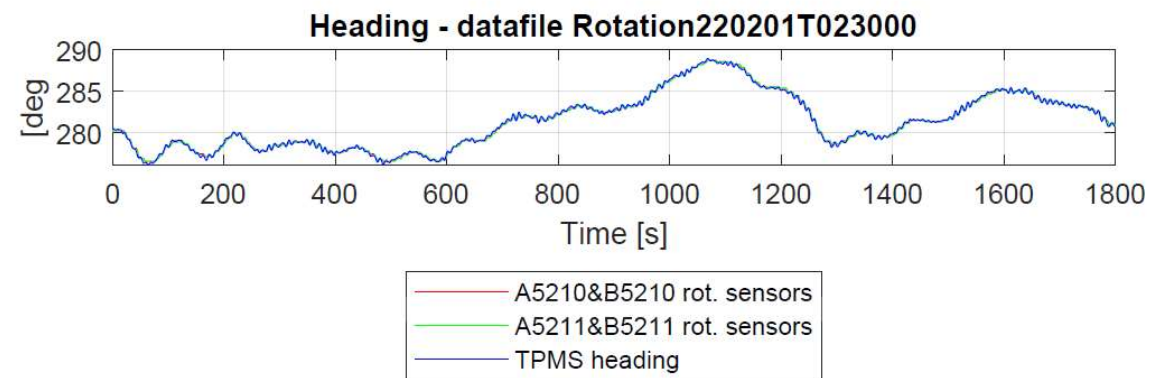
Position	Output A5220	Output B5220
1	0	0
2	0	1
3	1	1
4	1	0

- 360 deg / 512 teeth / 4 positions : 0.176 deg measurement steps
- If either sensor A5220 or B5220 change of output (1/0) then a rotation change of 0.176 deg is obtained.
- Rotation added or subtracted depends on from which position the sensors go to.
- Compare with vessel heading trace to determine slip stick angle
- No absolute position → suitable for relative motions only

# Turret Rotation - Measurements

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Example Traces (1 Feb 2022 Hs ~2.8 m)

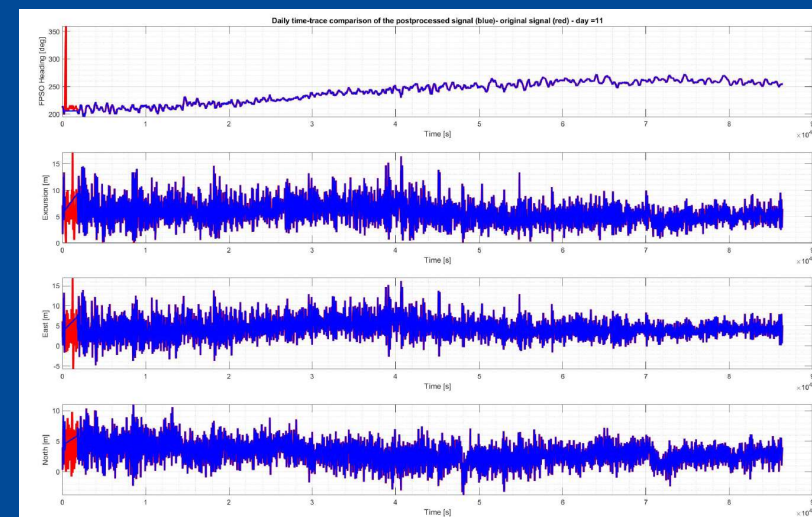




# Turret Position Measurement System

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- The 6 DOF turret position and motions is extracted from:
  - *TPMS*: Provides FPSO positioning data based on DGPS system (0.1s data interval)
  - *SMC*: Provides the FPSO motion and acceleration (0.1s data interval)
  - *LC*: Provides the FPSO loading condition data (10min data interval)
- The signal need to be post processed to removed the extremely high frequency noises, re-estimation of the missed/unrealistic data (such as measured data during system re-starting or etc.)

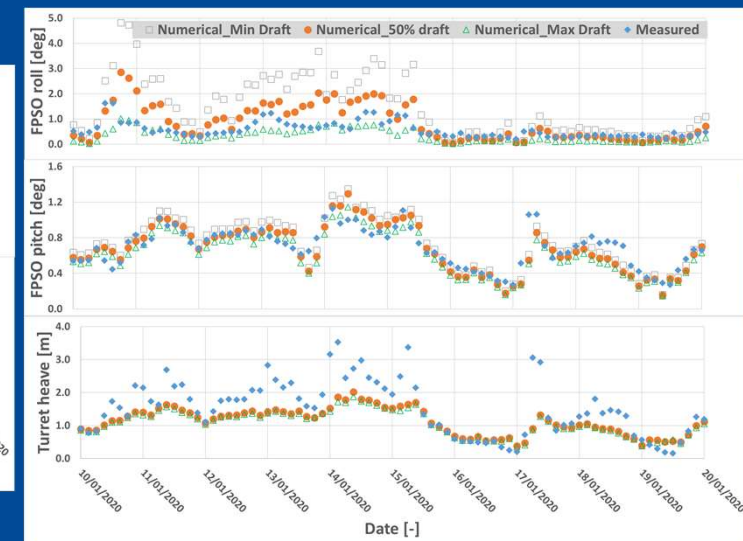
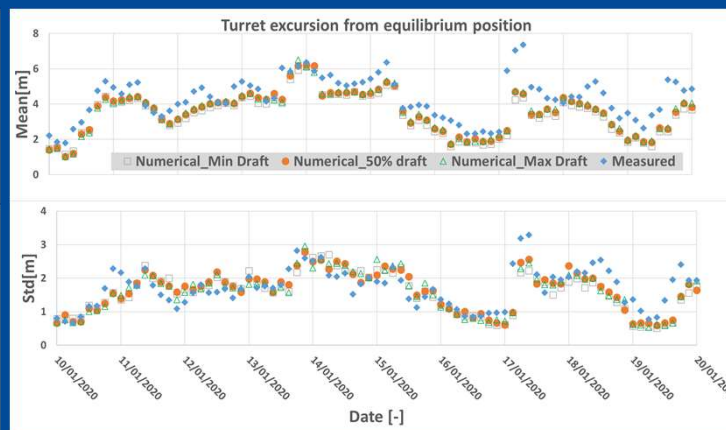
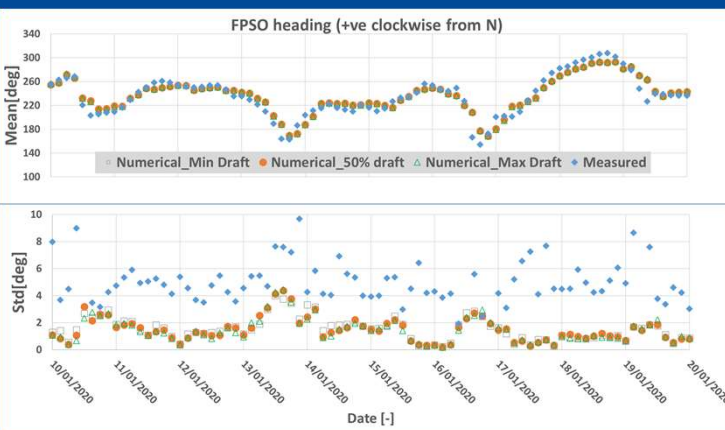


# Turret Position - Verification

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The measured turret position data are compared with the numerical dynamic analysis results for the actual environmental conditions experienced

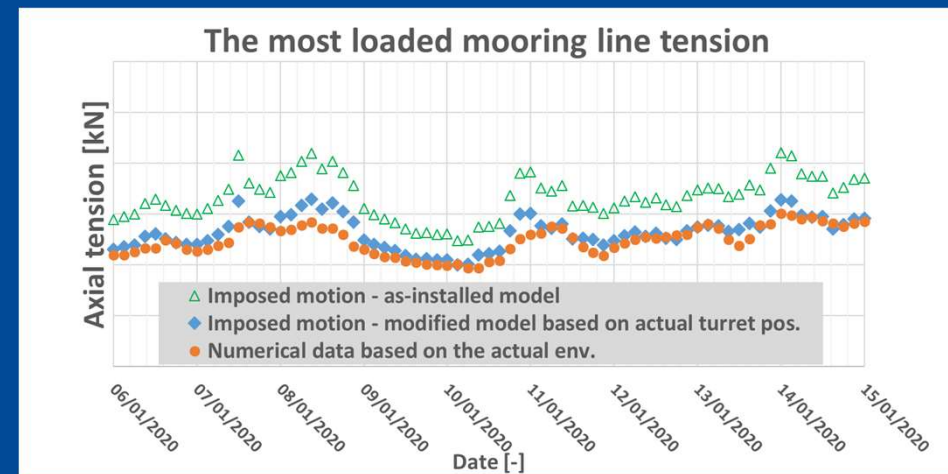
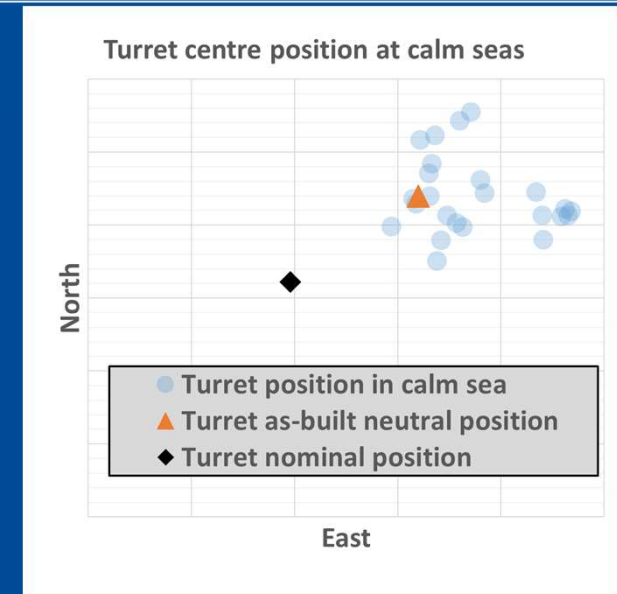
- *The trend is preserved for all turret position data between the numerical and the measured data*
- *Very good agreement of the **mean** and **standard deviation** of the turret motions*
- *The numerical analysis for the intermediate loading condition provides the best match with the measured data*



# Turret Position - Verification

bluewater

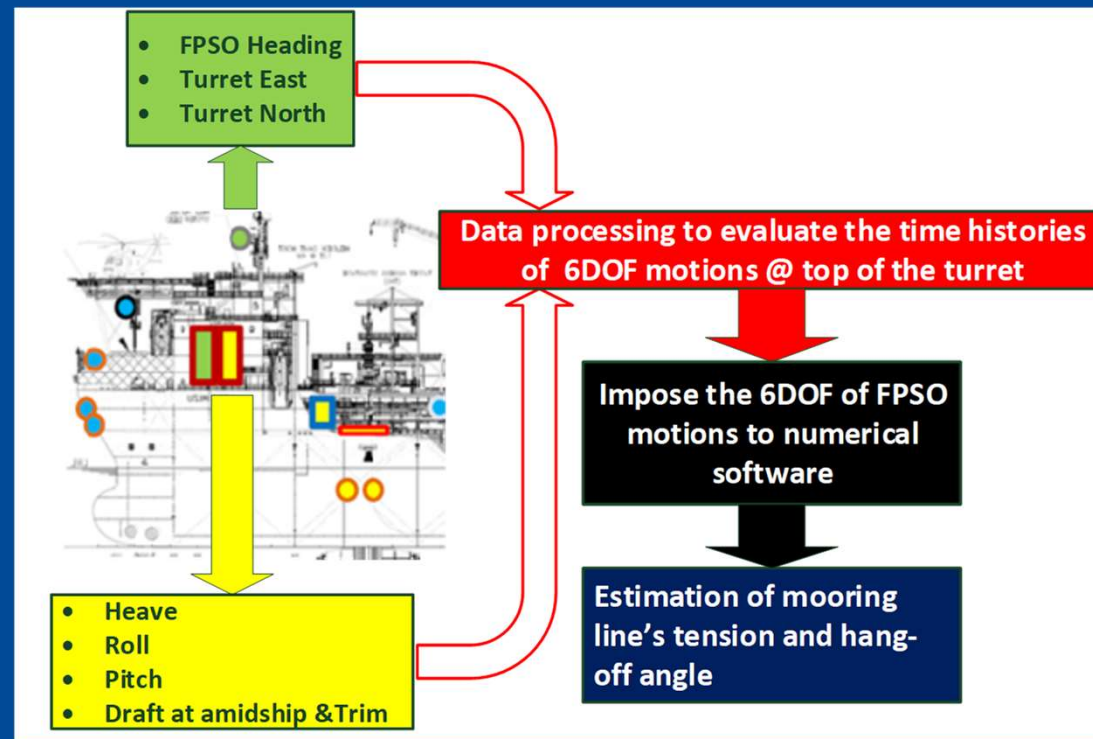
- The turret positions are measured based on the nominal position set in the AMON.
- Post processing of the AMON data in the calm seas, indicated that the turret as-built neutral position is different, mainly due to the installation uncertainties, MG, geodetic data.
- The numerical model shall be modified to set the equilibrium position to estimate a realistic mooring system loads.



# Mooring Line Tension Evaluation

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The mooring and riser/umbilical loads can be evaluated using turret position data

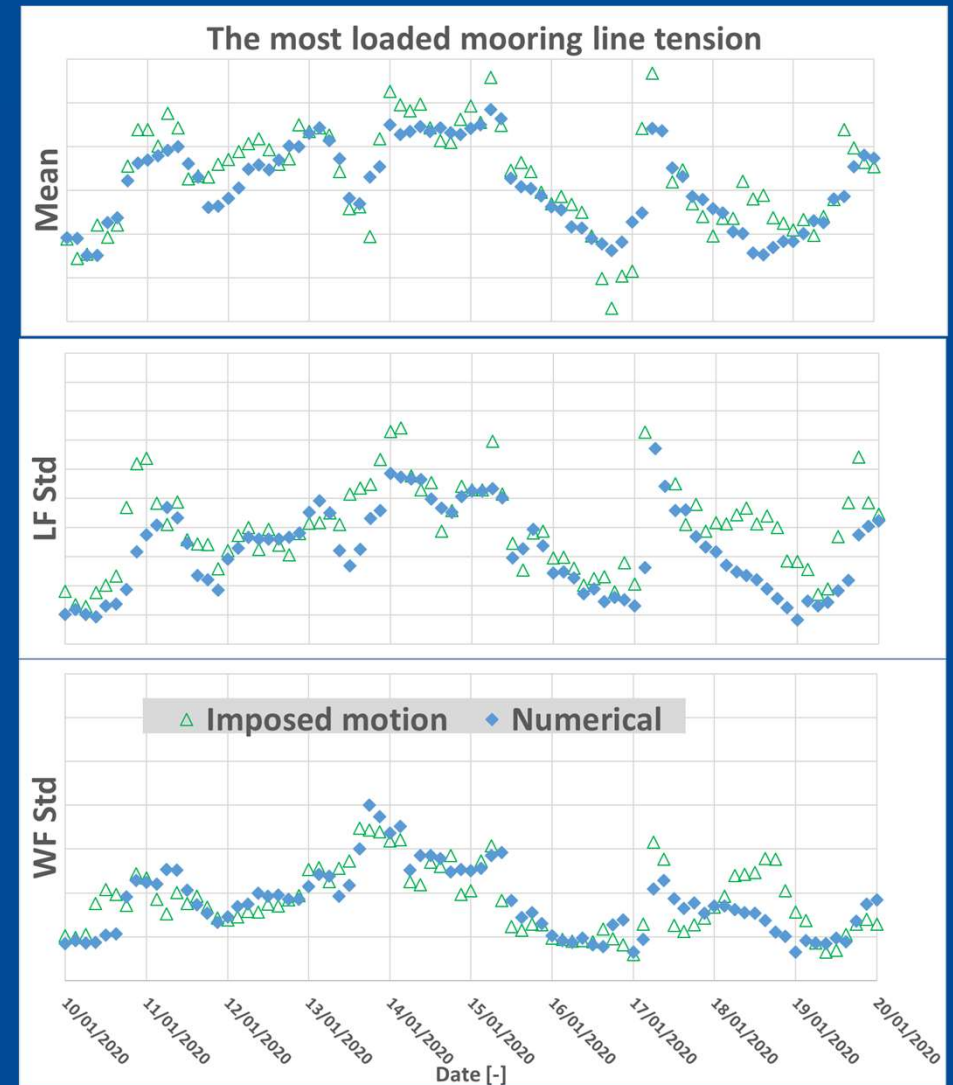




# Mooring Line Tension Evaluation

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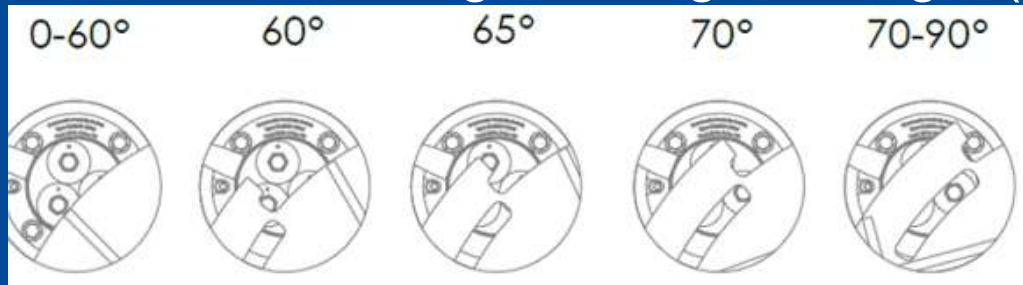
- The mooring line tension calculated by imposing the measured turret motions is compared with the numerical dynamic analysis results for actual environmental data
  - *The trend of the mooring line tension is preserved*
  - *Very good agreement of the mean and LF std loads evaluation*
  - *Good agreement on WF std of the mooring line tension (Sensitive for errors and unknowns such as MG and etc.)*



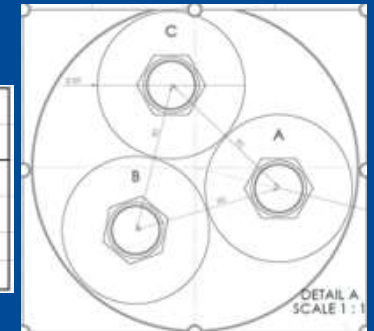
# Mooring Line Inclinator system

bluewater

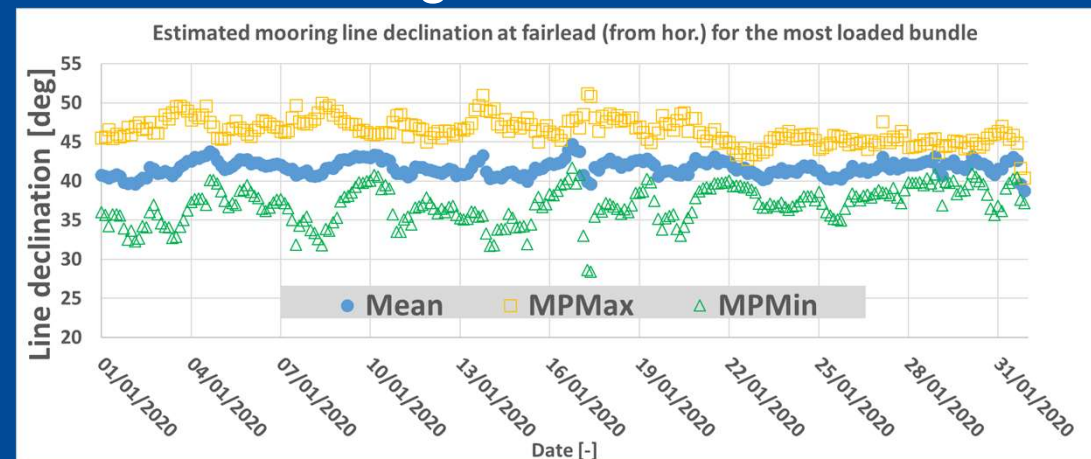
- A mooring line inclinometer system is installed on uni-joints measuring mooring line angle (sector) from the horizontal



Uni-joint Angle [deg]		Proximity switch			Warning
Min	Max	A	B	C	
0	60	1	0	0	Nominal
60	65	1	1	0	Pre-Warning
65	70	1	1	1	Pre-Alarm
70	90	0	1	1	Alarm



- Within the specified period, there is no alarm which is in-line with the estimated declination angles based on the measured turret position data



- Turret rotations are simple 'direct measurements'
  - Valuable to monitor stick-slip of bearings
  - Simple post-processing
  - Valuable for digital twin / condition monitoring
- Turret vertical bearing loads are derived by simple post-processing, therefore good quality data  
(same applies for bearing bolts and locking mechanism)
  - Valuable for digital twin / condition monitoring

- Turret loads require a detailed FE model to post-process, which makes it complicated
  - Combination of strains is caused by a combination of loads
  - Translation/extrapolation remains challenging due to complexity of system (added mass, inertia, as-built, non-linearities, unknowns)
  - Challenging to apply as research and validation tool, which is the ambition



- Turret motions are direct measurements and very suitable for LifeLine for example.
- Line tensions are derived via an analytical model, so 'indirect measurements'
- Do-able, but sensitive for errors and unknowns
  - As-built information (manufacturing and installation)
  - Marine growth
  - Water depth
  - Seabed (slope, trenches)

# Thank You

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