Identification of wave drift force QTFs for the INO WINDMOOR floating wind turbine based on model test data and comparison with potential flow predictions

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SINTEF Ocean

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WINDMOOR

Objectives

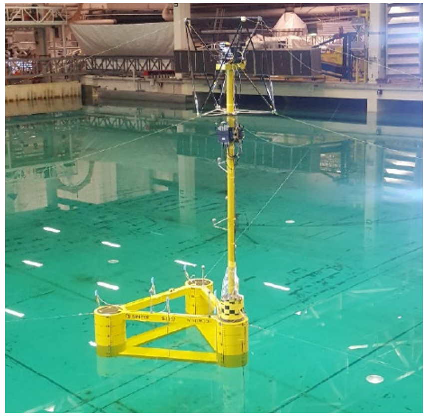
- Identify QTFs of wave drift loads from model test data
- Assess the influence of seastate severity and wave-current effects on the QTFs
- Assess quality of numerical predictions by full 2nd order potential flow calculations

Establish a basis for assessing improved force models to predict wave drift loads

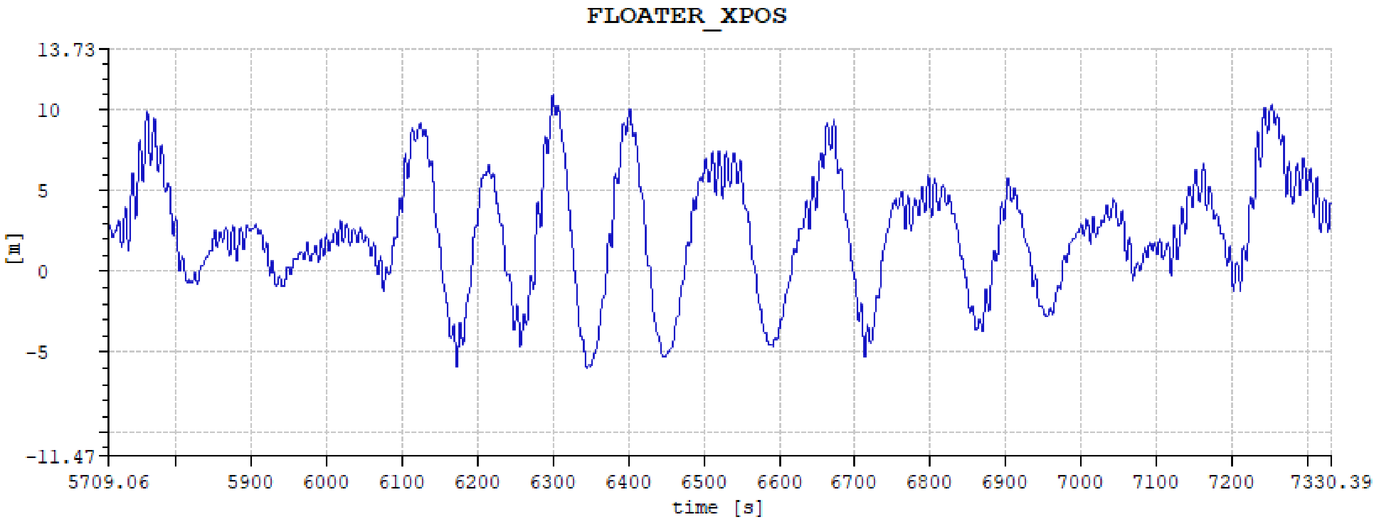
Why

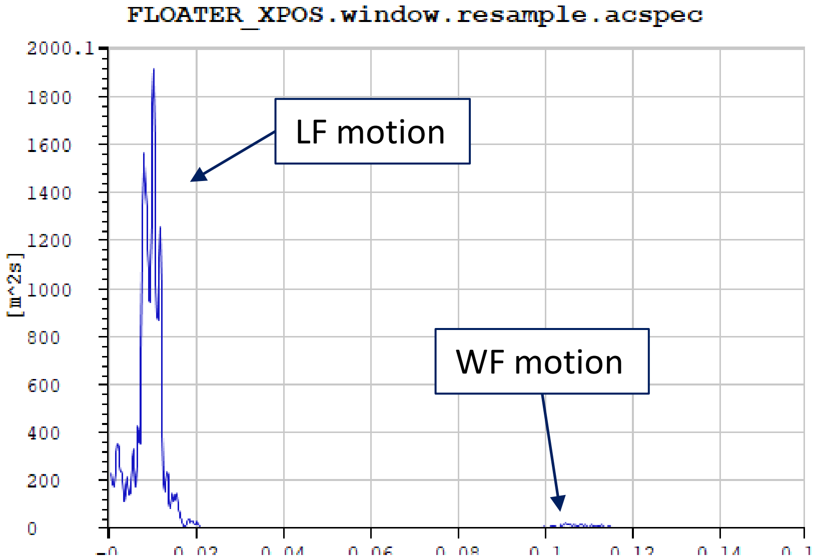
LF motions:

- Large contribution to mooring line loads.
- Large uncertainty in numerical predictions.



INO WindMoor test 4230: Hs = 6.2 m, Tp = 9.0 s, Uc = 0, heading = 0





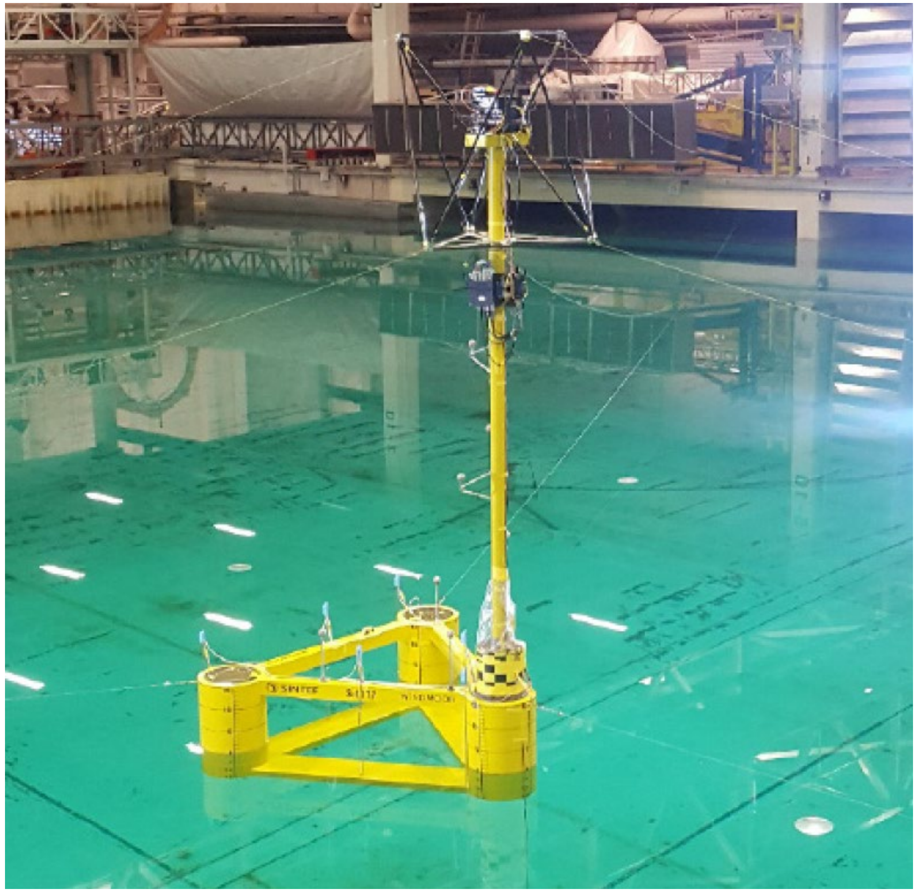
1. Case study

INO WINDMOOR semisubmersible is jointly designed by Inocean and Equinor.

Parameter	Unit	Value
Column diameter	[m]	15.0
Column height	[m]	31.0
Pontoon width	[m]	10.0
Pontoon height	[m]	4.0
Centre-centre distance	[m]	61.0
Draft	[m]	15.5
Displacement	[t]	14124
Long. centre of gravity (LCG)*	[m]	0.0
Trans. centre of gravity (TCG)*	[m]	0.0
Vert. centre of gravity (VCG)**	[m]	19.4
Long. metacentric height (pitch)	[m]	9.52
Transv. metacentric height (roll)	[m]	9.53
Roll radius of gyr. (Rxx)	[m]	43.6
Pitch radius of gyr. (Ryy)	[m]	44.0
Yaw radius of gyr. (Rzz)	[m]	29.9

* wrt the floater geometric center

** wrt the baseline



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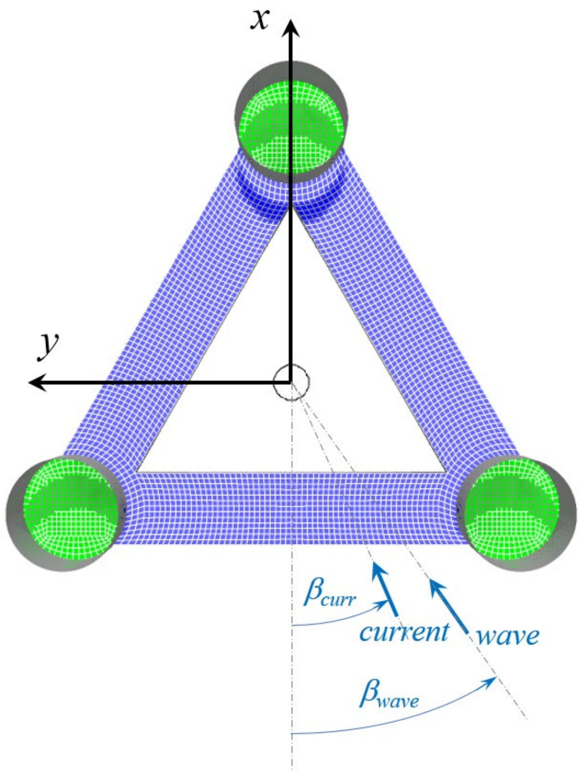
2. Model tests

- Model tests in the Ocean Basin of SINTEF (February 2020)
- Model scale of 1:40
- Water depth of 150 m
- Horizontal mooring system
- Waves and current only
- JONSWAP seastates (long crested)
- 3 hours effective duration of the tests

Test no.	Heading (deg.)	Uc (m/s)	Hs (m)	Tp (s)	Gamma
4010	0	0	4.0	4.5-20	-
4210, 4222, 4223, 4224, 4225	0	0	3.7	7.0	4.90
4230, 4240, 4241, 4242, 4243, 4244	0	0	6.2	9.0	4.90
4270	0	0	3.7	12.0	1.00
4290, 4292	0	0	6.2	12.0	1.23
4662, 4670, 4673, 4674, 4675, 4676, 4677	0	0	11.0	12.0	4.90
4480	90	0	6.2	9.0	4.90
4490	90	0	6.2	12.0	1.20
4510, 4520, 4521, 4523, 4524, 4525	0	0	2.0	7.0	1.06
4560	0	0	15.0	14.0	4.90
4250, 4260, 4261, 4262, 4263	0	1.2	6.2	9.0	4.90
4340, 4350, 4351, 4352, 4353, 4354	0	1.2	11.0	12.0	4.90
4530	0	1.2	2.0	7.0	1.06



3. Method for identification of empirical QTFs

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The floater motion may be represented by:

$$x(t) = x^{(0)} + x^{(1)}(t) + x^{(2)}(t) + E_x(t) \qquad (1)$$

The slow drift oscillations which are assumed to be represented by a 1 DOF oscillator:

$$\ddot{x}^{(2)}(t) + 2\xi\omega_n\dot{x}^{(2)}(t) + \omega_n^2 x^{(2)}(t) = \frac{1}{m} g^{(2)}(t) \qquad (2)$$

The wave exciting forces are represented by an expansion similar to (1):

$$g(t) = g^{(0)} + g^{(1)}(t) + g^{(2)}(t) + E_g(t) \qquad (3)$$

The quadratic component of the exciting force can be represented in terms of the Fourier transform of the wave elevation, $Z(f_n)$, and the complex wave force QTF, $H^{(2)}(f_m, f_n)$:

$$g^{(2)}(t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left[Z^*(f_m)Z(f_n)H^{(2)}(f_m, f_n)e^{i2\pi(f_m-f_n)t}\right]df_m df_n \qquad (4)$$

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3. Method for identification of empirical QTFs

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The Fourier transform of $g^{(2)}(t)$ gives:

$$G^{(2)}(f) = \int_{-\infty}^{\infty} \left[g^{(2)}(t) e^{-i2\pi f t} \right] dt \,, \quad f = (f_m - f_n) \qquad (5)$$

The cross bi-spectrum of $g^{(2)}(t)$ with respect to $\zeta(t)$ is given by:

$$S_{\zeta\zeta g}(f_m, f_n) = < Z^*(f_m) Z(f_n) G^{(2)}(f_m - f_n) > \qquad (6)$$

Manipulation of equations (4), (5) and (6) leads to an expression for estimation of the QTF:

$$H^{(2)}(f_m, f_n) = S_{\zeta\zeta g}(f_m, f_n) / S_{\zeta\zeta}(f_m) S_{\zeta\zeta}(f_n) \qquad (7)$$

where $S_{\zeta\zeta}(f)$ is the wave spectrum.

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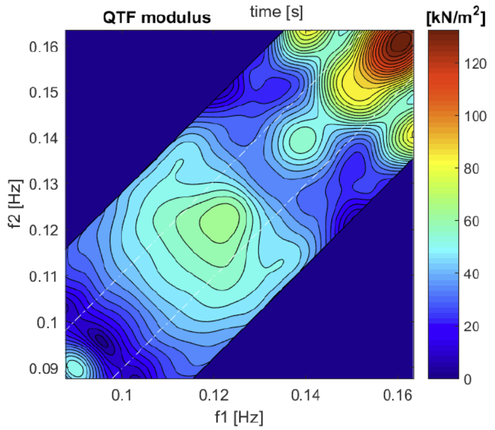
3. Method for identification of empirical QTFs

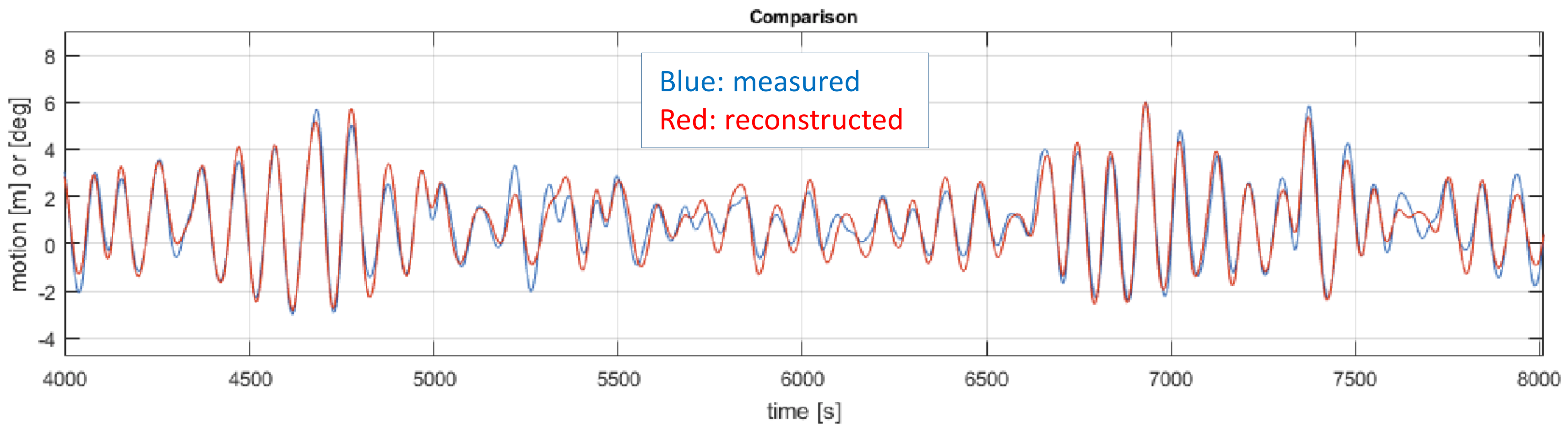
Two steps:

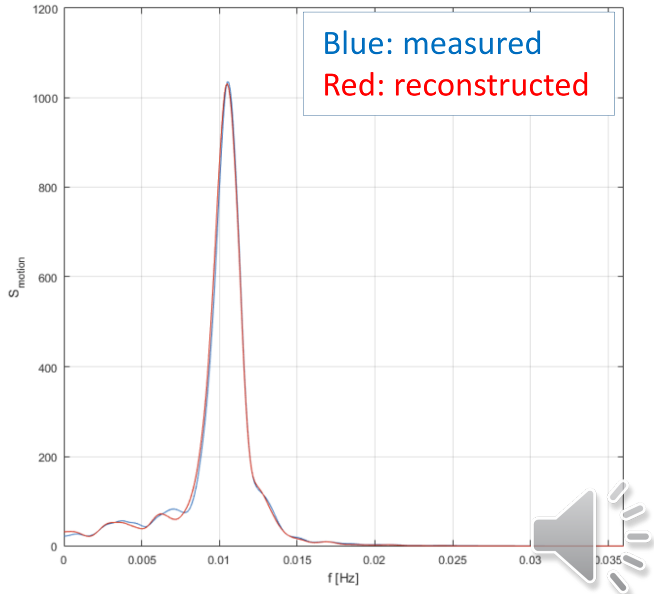
(1) Identify 2nd order wave exciting force time history from measured LF motion signals;

(2) Use the undisturbed incident wave elevation and the estimated 2nd order force, together with cross bi-spectral analysis, to identify the difference frequency wave exciting QTF matrix.



Case by case identification/validation: comparison between measured LF motions and reconstructed from the empirical QTF





4. Numerical model

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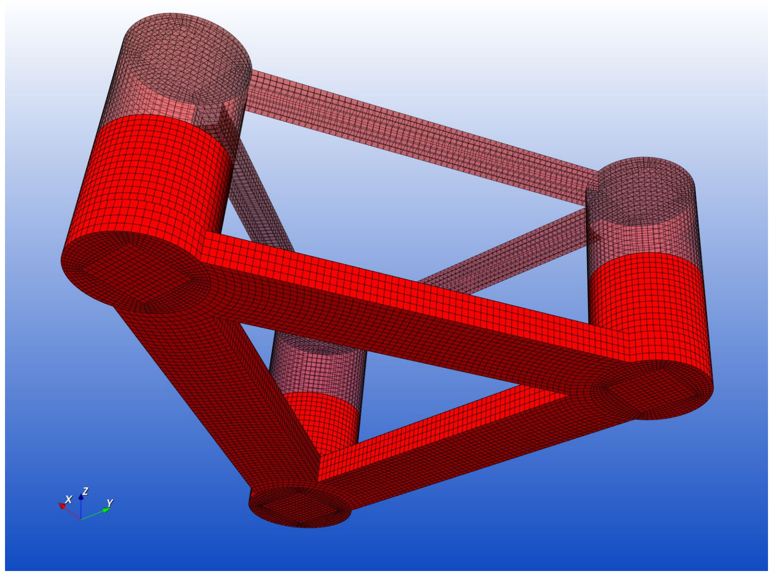
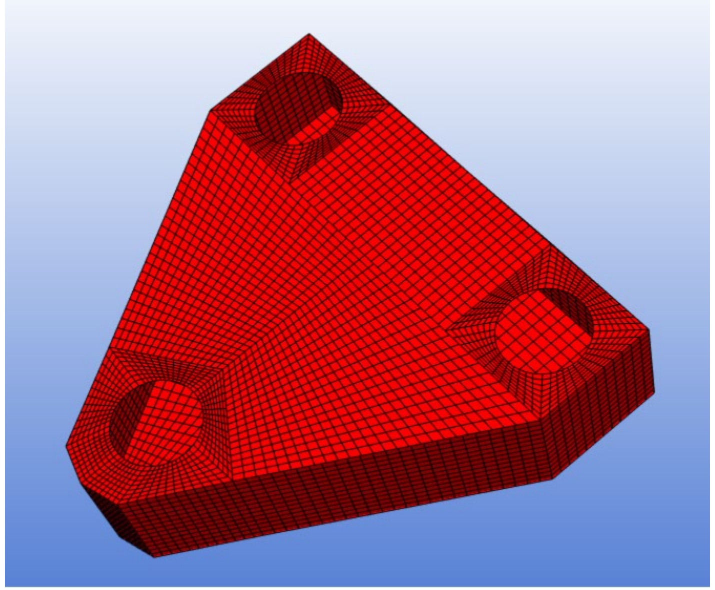
- Calculations performed with Hydrostar v8.1.
- Total of 17176 low order panels.
- Realistic additional damping coefficients used to calculate first order results.
- Wave drift load QTFs given by solution of the 2nd order boundary value problem (middle field method).

Hull mesh (11212 panels)



Control surface mesh (5964 panels)



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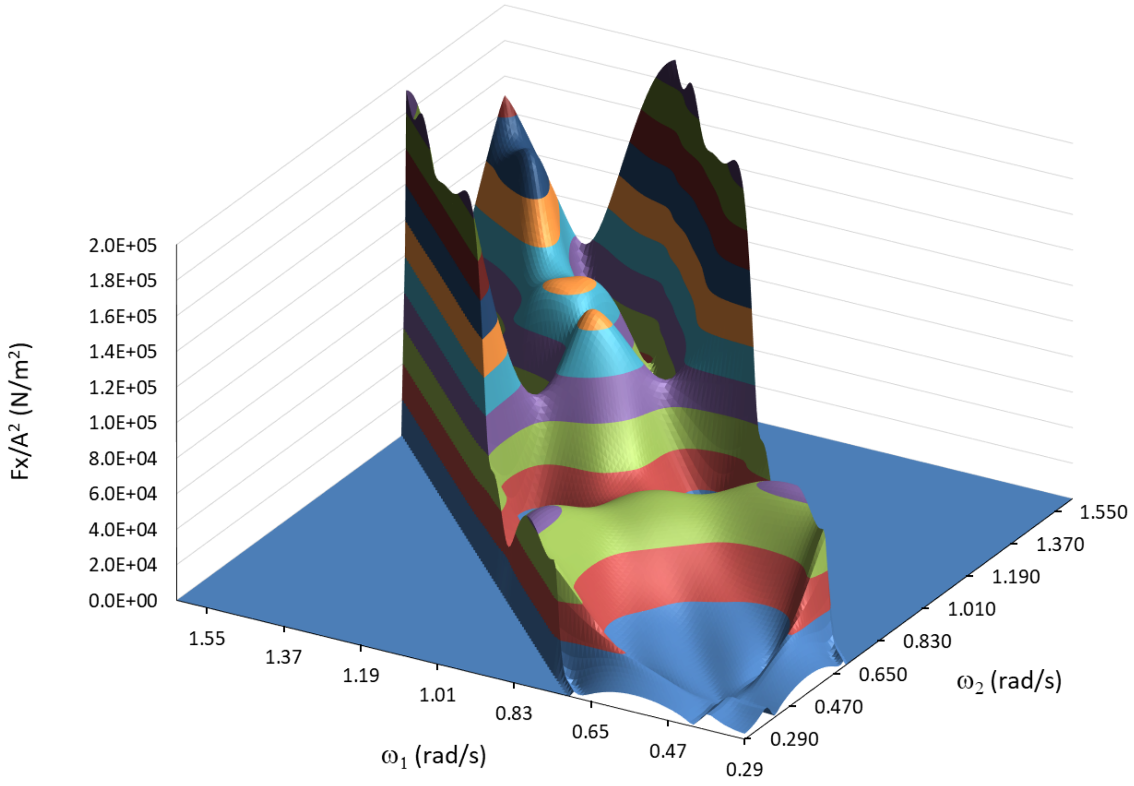
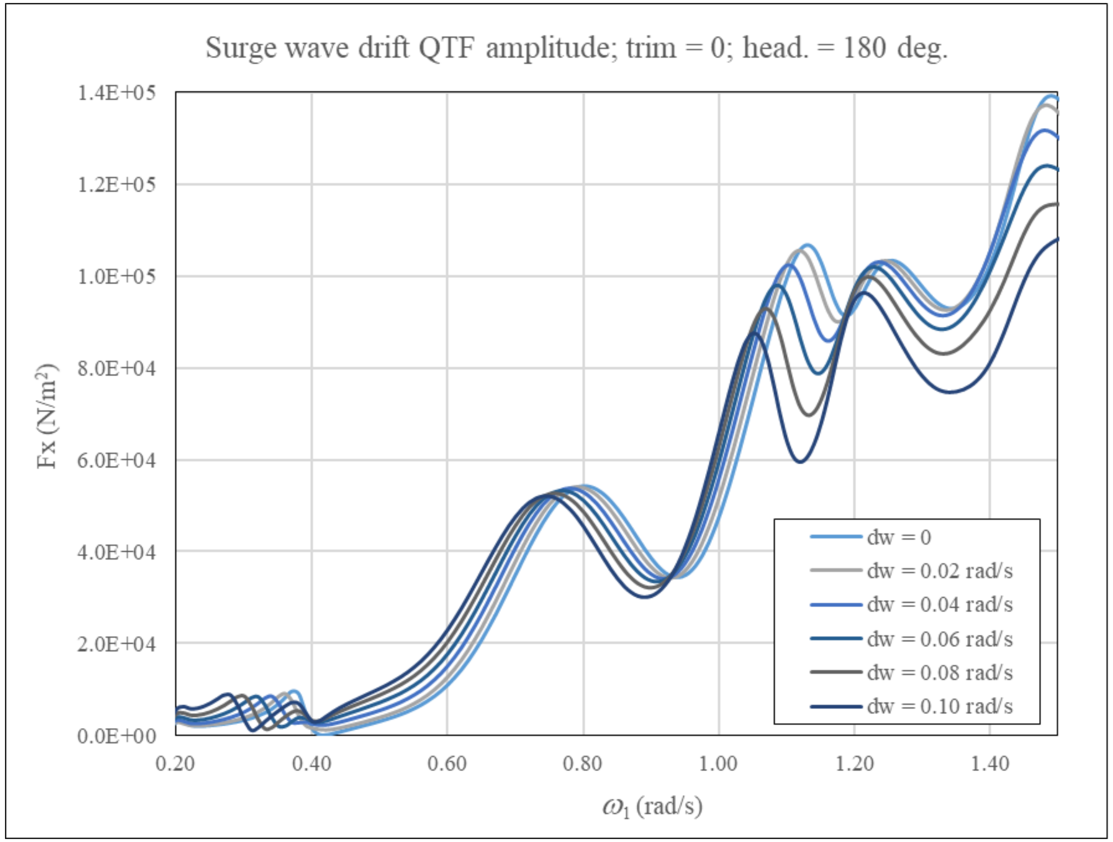
4. Numerical model

Surge LF wave load QTF amplitude, numerical





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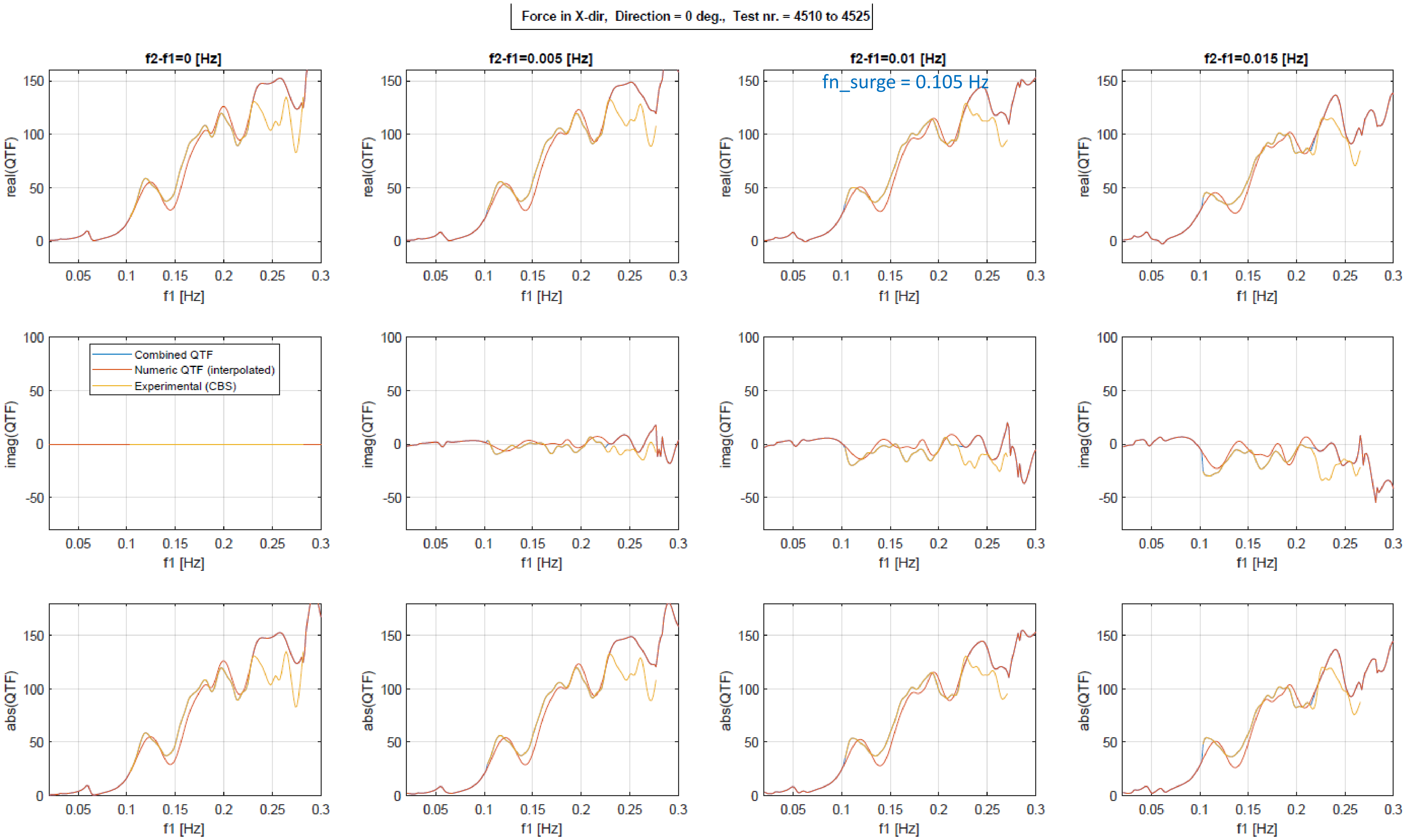
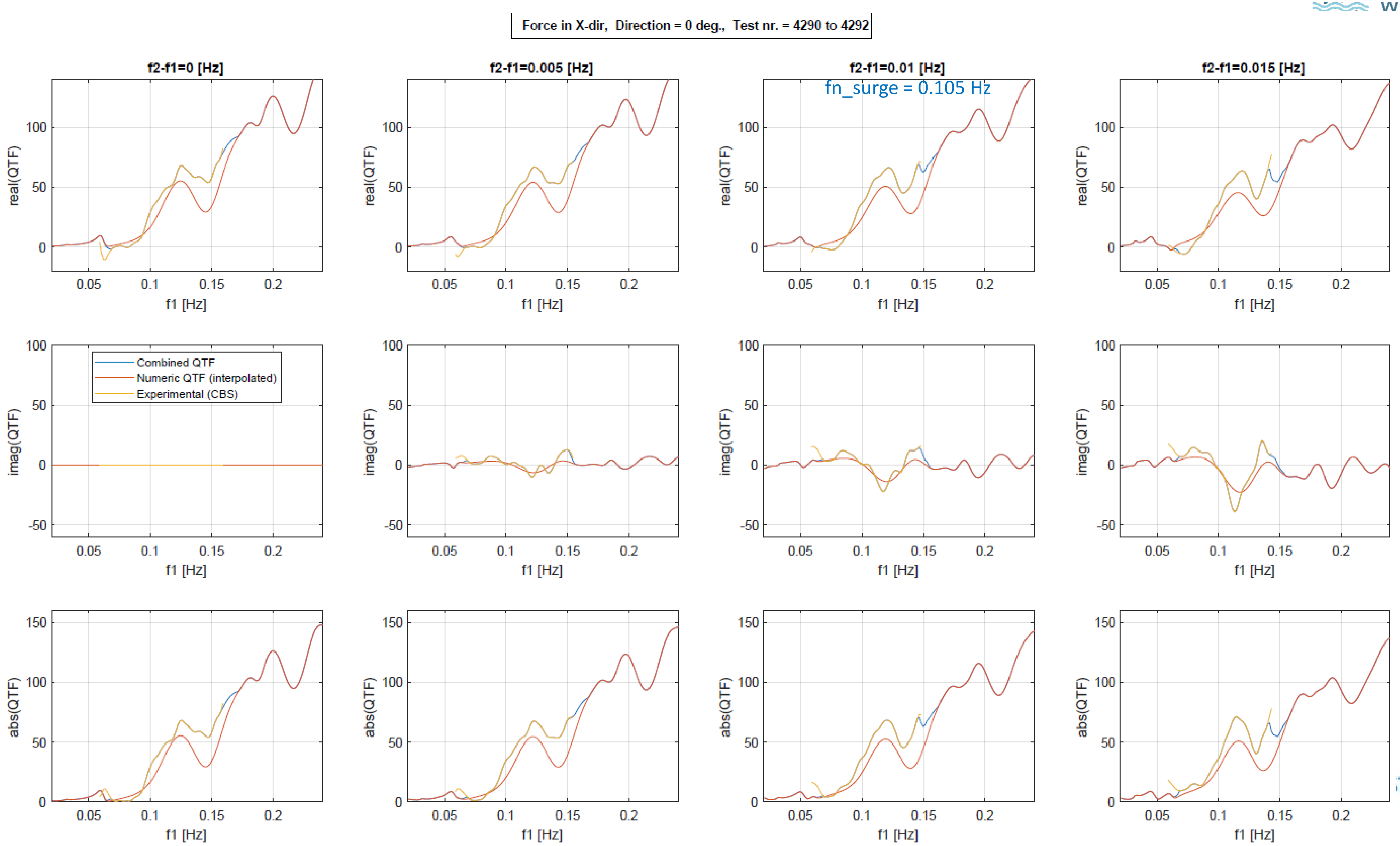
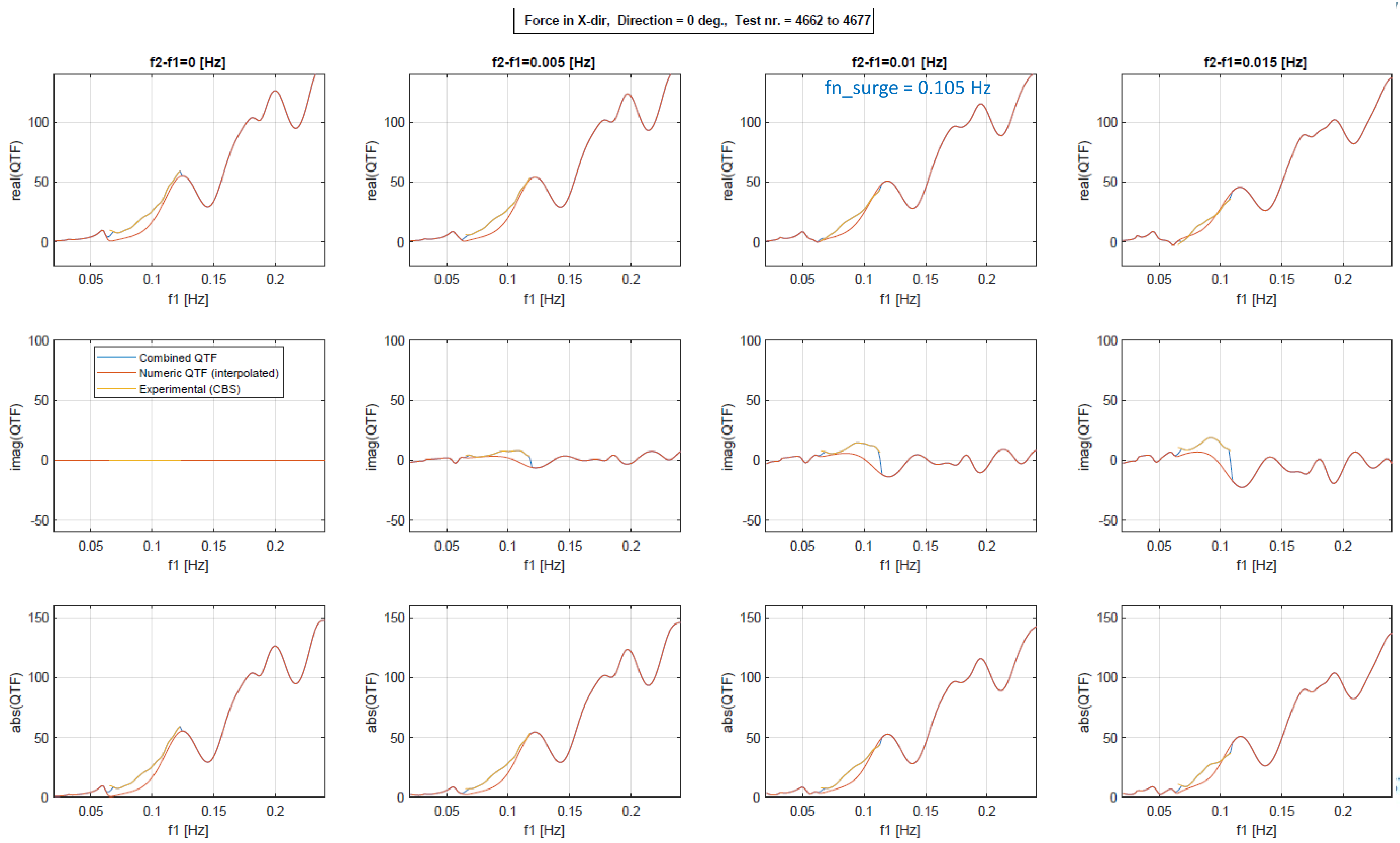
5. Results: surge QTF in small seastates (Hs = 2.0 m, Tp = 7 s, Uc = 0, Heading = 0 deg)



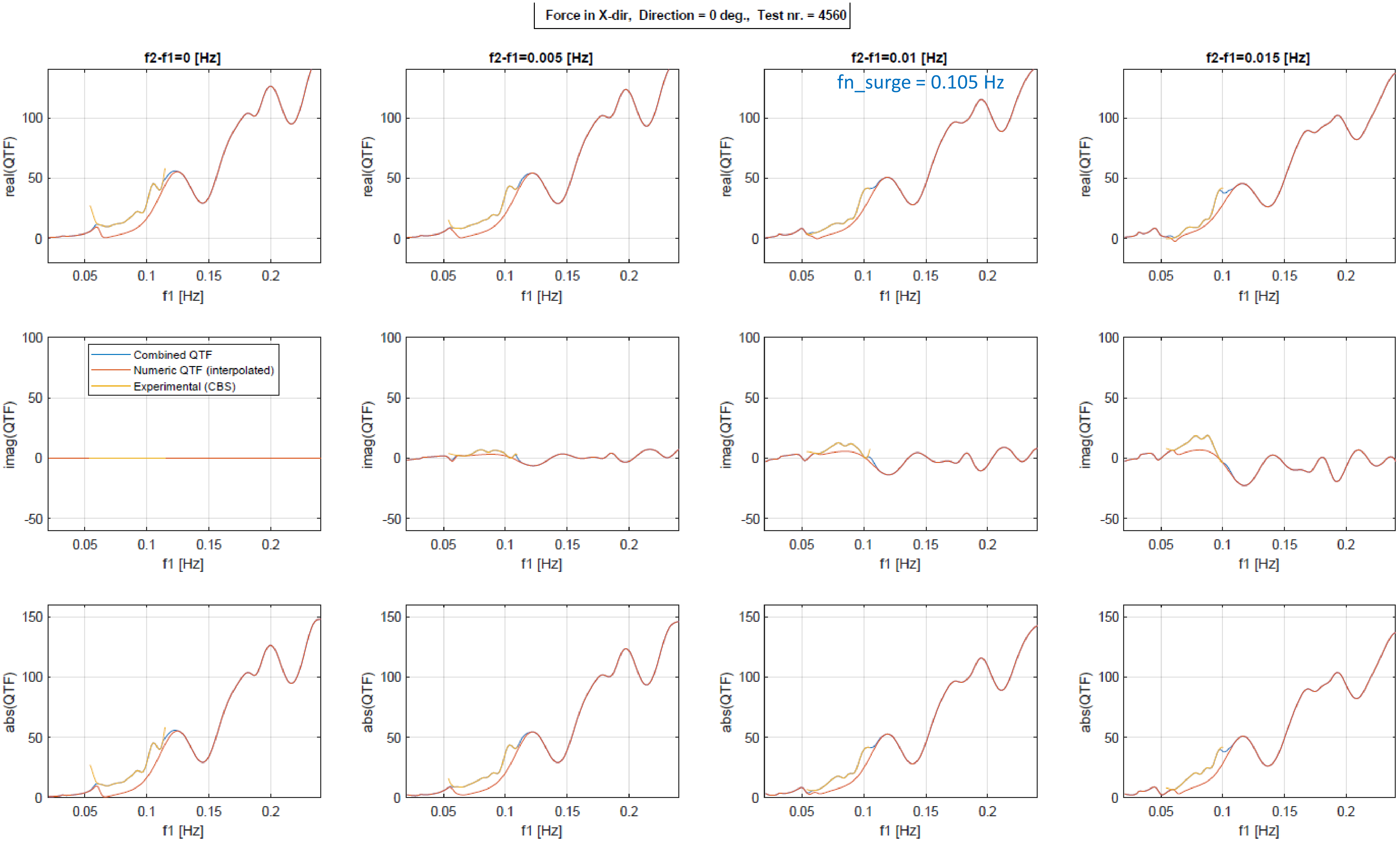
5. Results: surge QTF in moderate/high small seastates (Hs = 6.2 m, Tp = 12 s, Uc = 0, Heading = 0 deg)



5. Results: surge QTF in moderate/high small seastates (Hs = 11.0 m, Tp = 12.0 s, Uc = 0, Heading = 0 deg)



5. Results: surge QTF in moderate/high small seastates (Hs = 15.0 m, Tp = 14 s, Uc = 0, Heading = 0 deg)



5. Results: surge QTF in moderate/high small seastates

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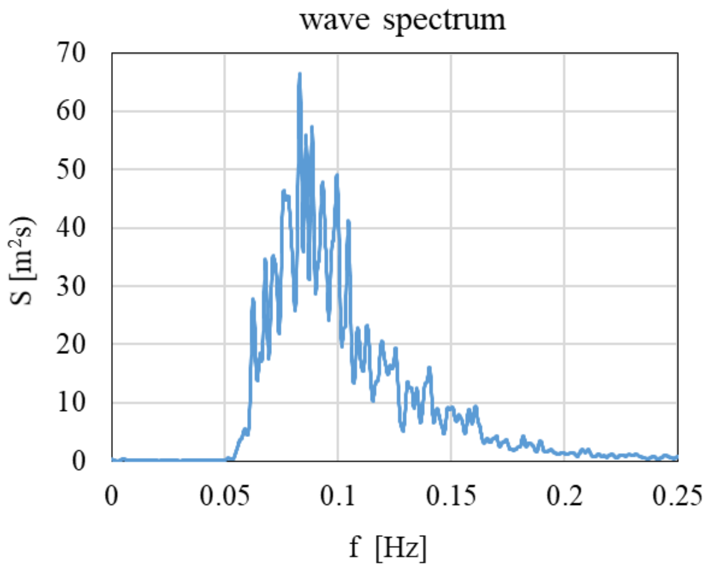
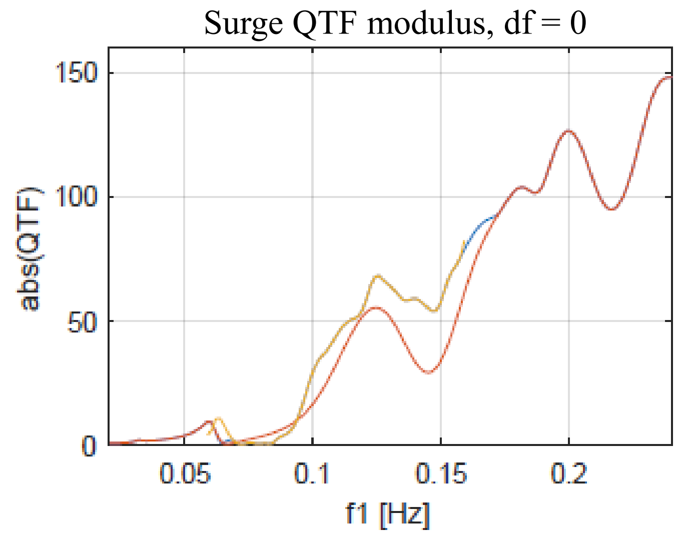
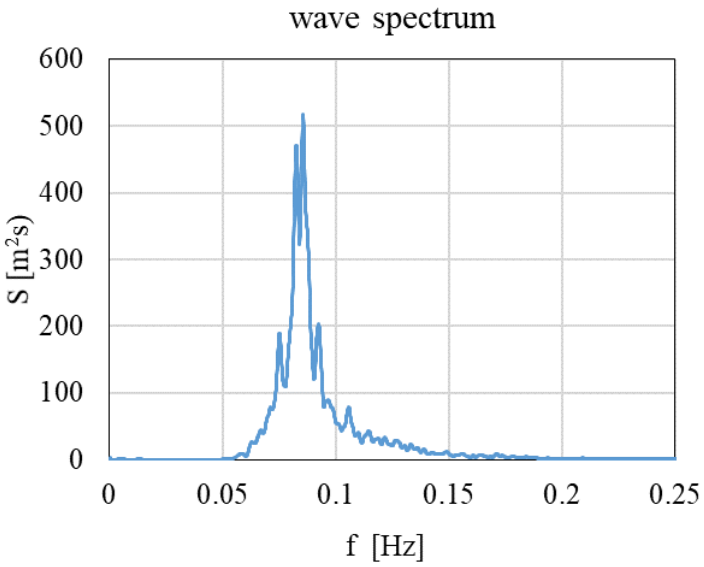
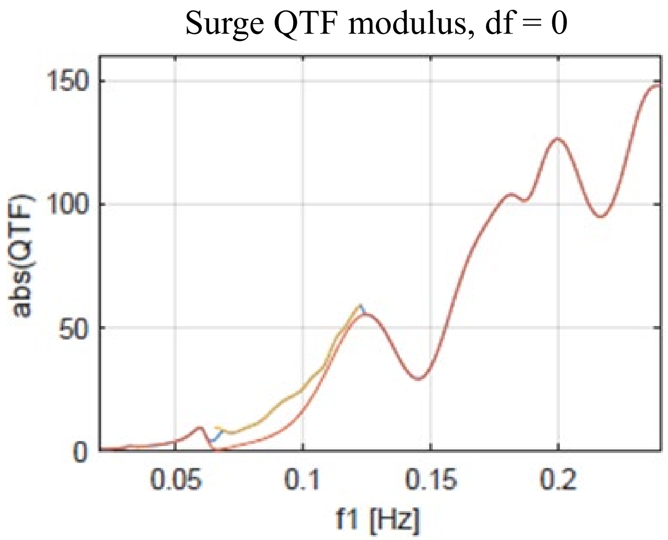
Hs = 6.2 m, Tp = 12 s, γ = 1.23



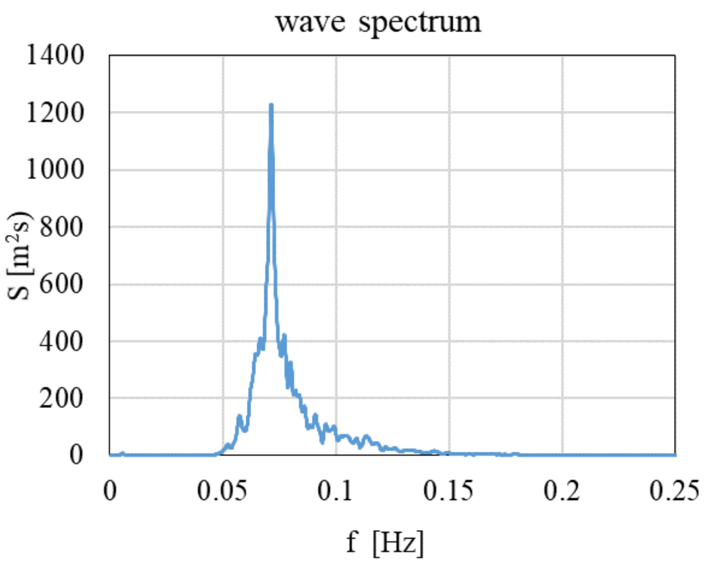


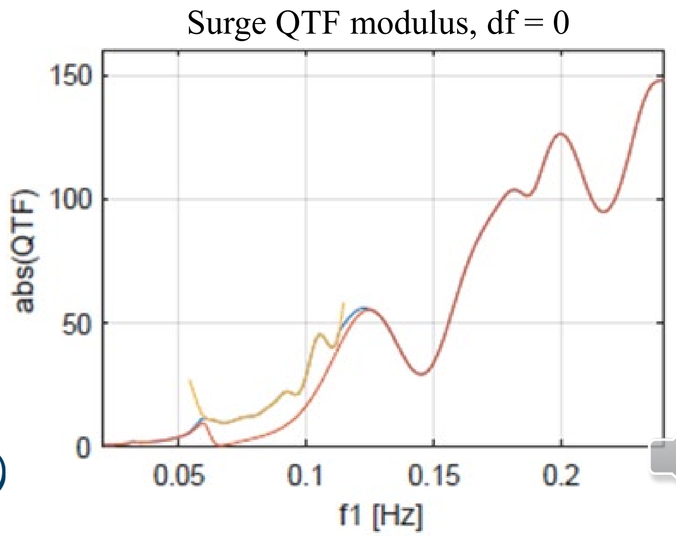
Hs = 11 m, Tp = 12 s, γ = 4.9





Hs = 15 m, Tp = 14 s, γ = 4.9

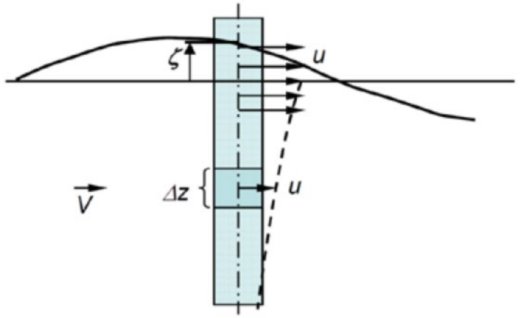


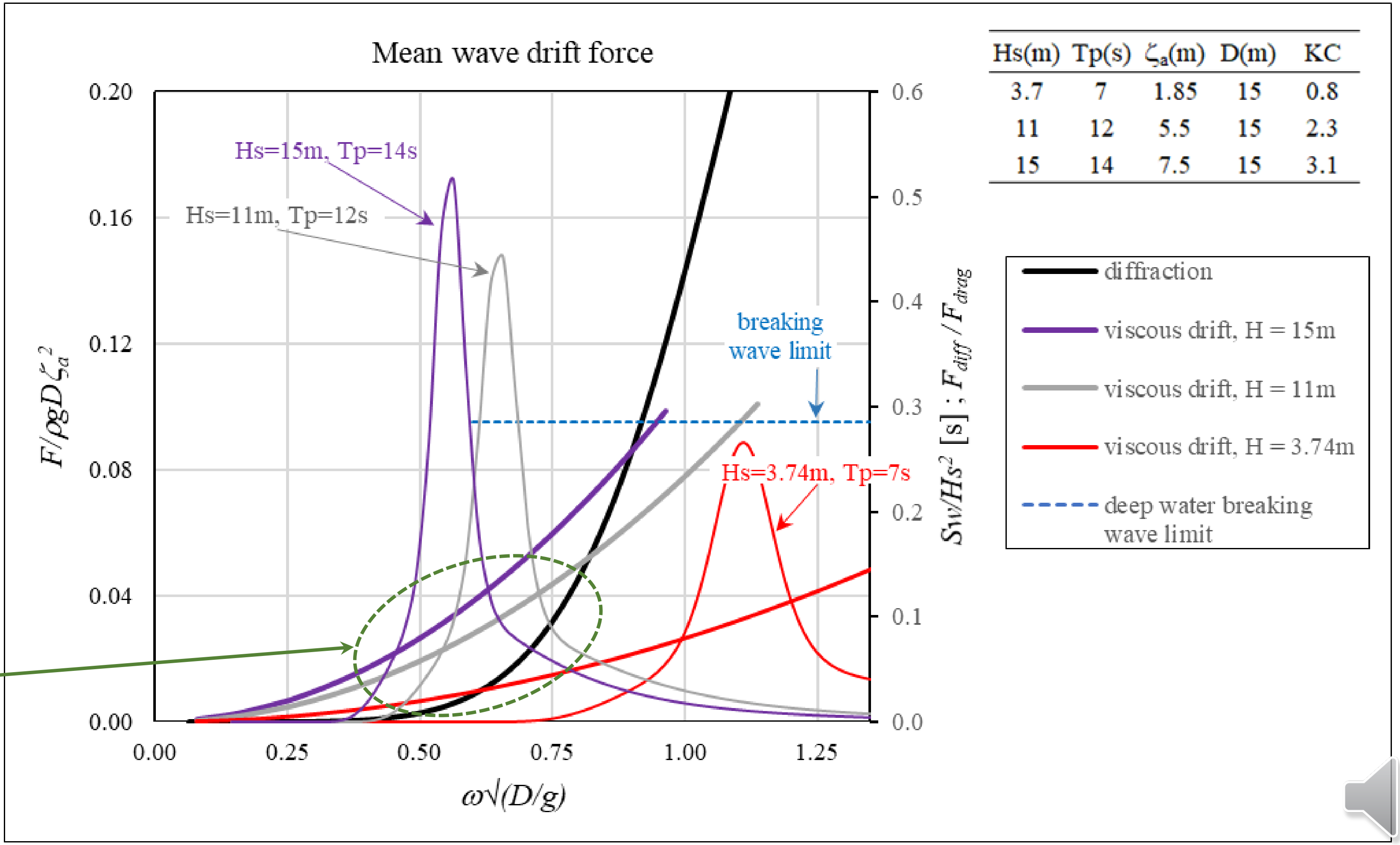


5. Results: discussion of empirical vs numerical QTFs

Mean drag force over one wave cycle
according to Morison's term with Cd = 1.0:

$$F_{drag} = (2/3\pi)\rho D C_D \zeta_a^3 \omega^2$$





Hs(m)	Tp(s)	ζ_a(m)	D(m)	KC
3.7	7	1.85	15	0.8
11	12	5.5	15	2.3
15	14	7.5	15	3.1

Large viscous drift contribution at low frequencies

5. Results: discussion of empirical vs numerical QTFs

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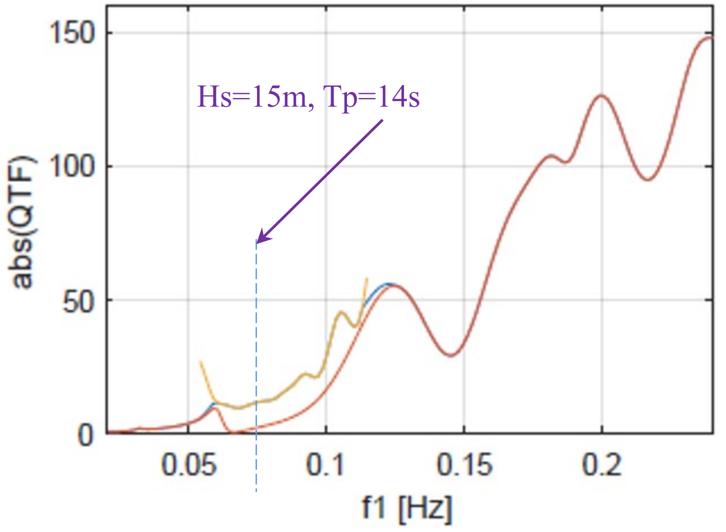

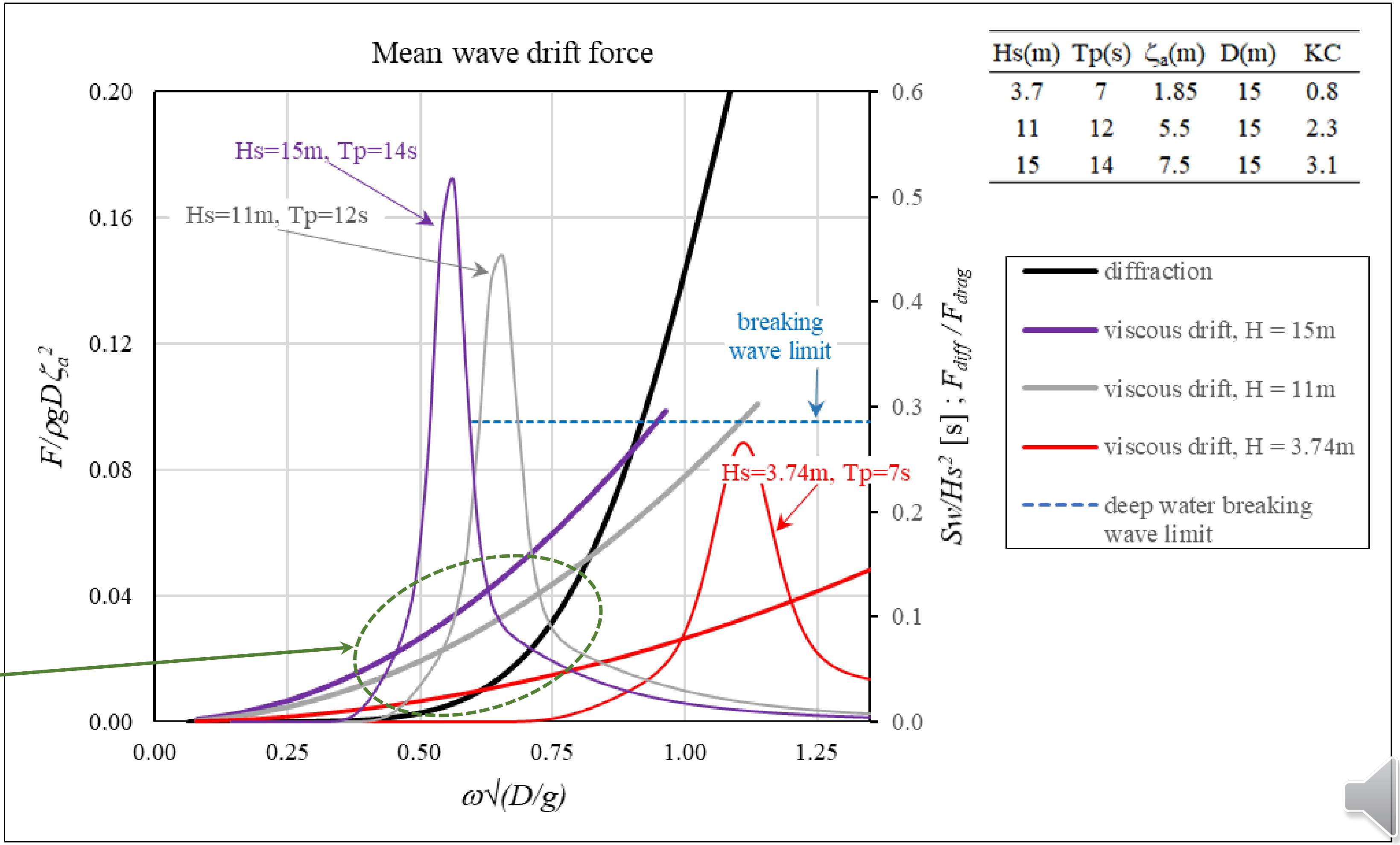

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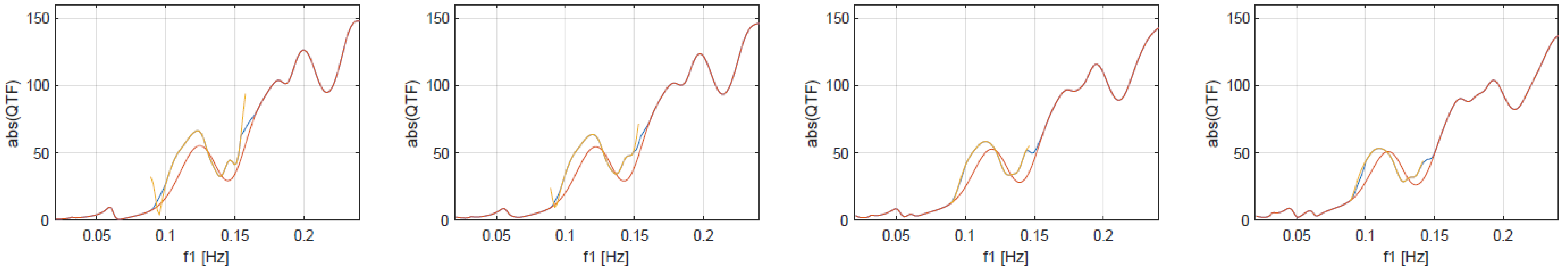
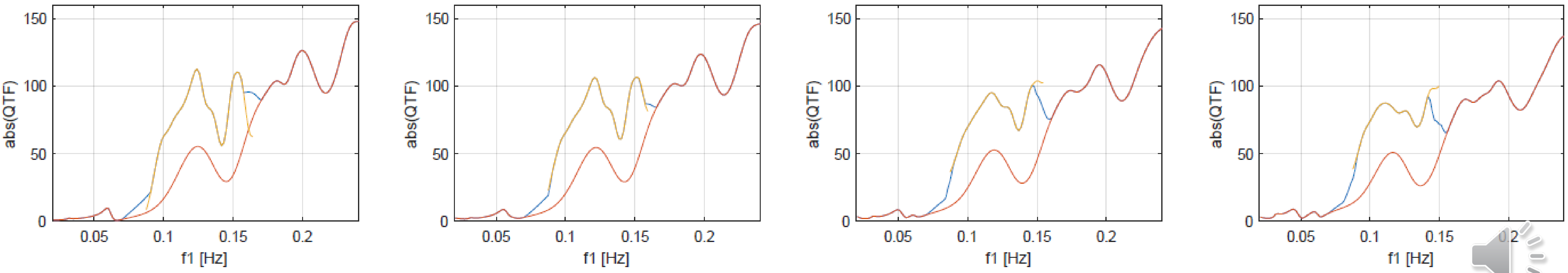
Large viscous drift contribution at low frequencies

5. Results - effect of current (Hs = 6.2 m, Tp = 9 s, Uc = 0 and 1.2 m/s, Heading = 0 deg)

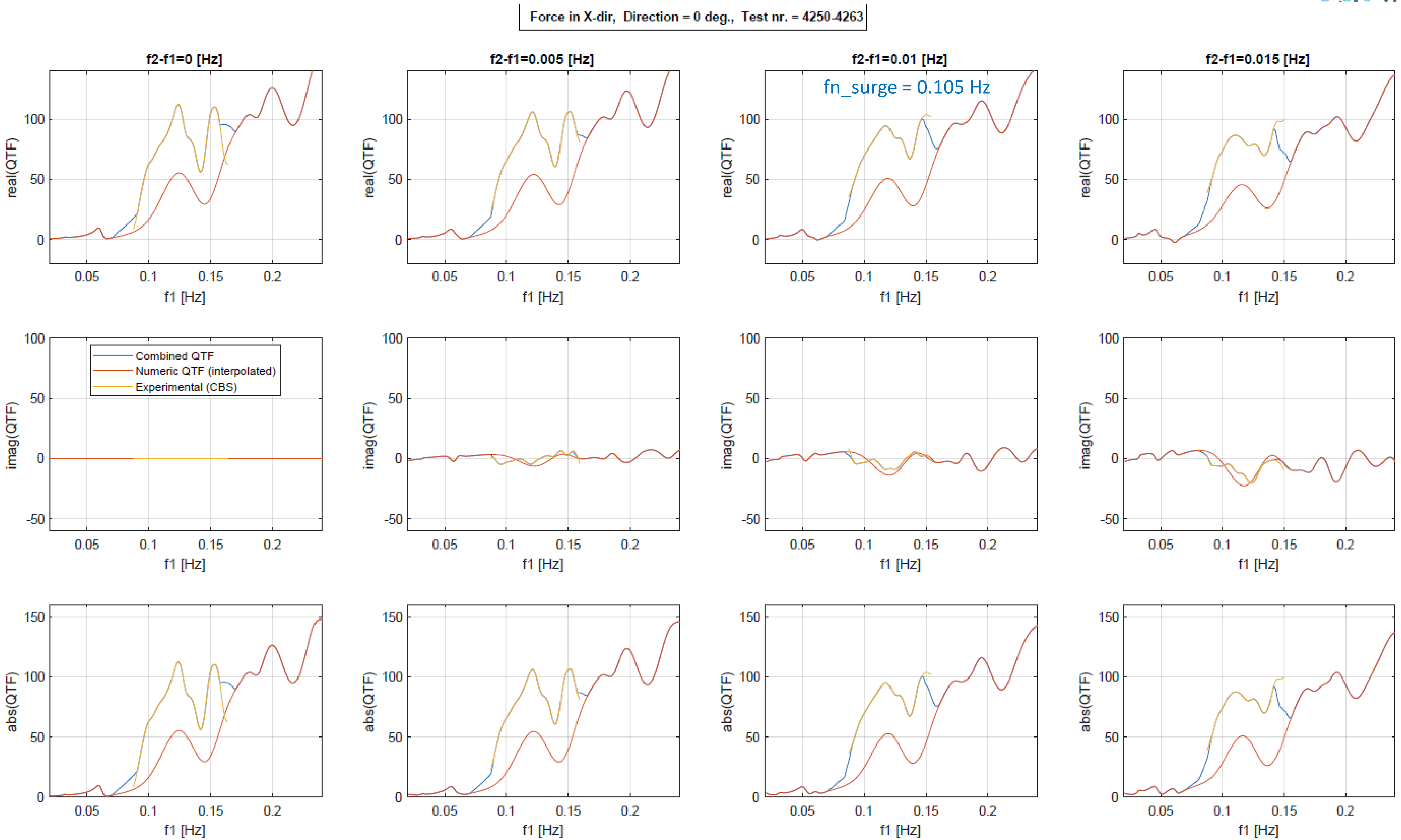
Force in X-dir, Direction = 0 deg., Test nr. = 4230 to 4244 **Uc = 0**



Force in X-dir, Direction = 0 deg., Test nr. = 4250-4263 **Uc = 1.2 m/s**



5. Results: effect of current (Hs = 6.2 m, Tp = 9 s, Uc = 1.2 m/s, Heading = 0 deg)



6. Conclusions

Surge/Sway

- 2nd order potential flow calculations predict well the QTFs of low frequency wave loading in small seastates without current.
- 2nd order predictons underestimate the QTFs in moderate and high seastates, especially at the LF range (below around 0.1 Hz). Viscous drift is believed to be the root cause.
- Current effects result in a large increase of the QTF, which is observed for all diagonals.

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