Damage Detection in the Mooring System of Spar Floating Offshore Wind Turbines through Statistical Methods

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Analytics for Asset Integrity Management in Wind farms (AIMWind)

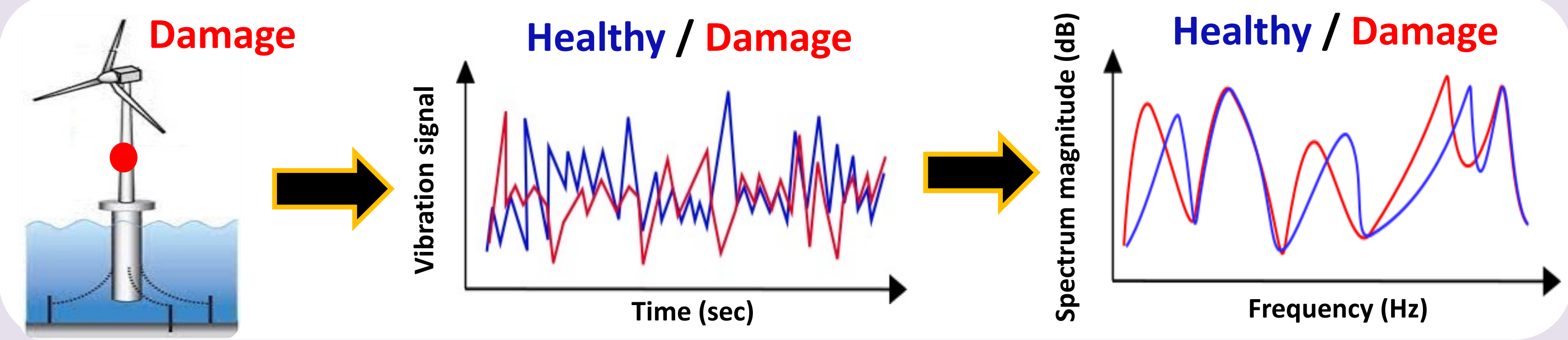
AIMWind

Importance of Damage Detection

Damage in the mooring lines' → increase of tension → loss of stability, high maintenance cost → Floating Offshore Wind Turbine (FOWT) collapse and endangerment of human safety → Early damage detection being important

Fundamental principle of damage detection methods based on vibration signals

Presence of damage → Change in the structural dynamics → Change in the vibration response signals → Damage detection



Environmental Conditions (ECs)

Varying ECs

↓

Partially or fully "masking" the effects of damages on the structural dynamics

↓

Highly challenging damage detection

Vibration-based damage diagnosis in the mooring lines of FOWTs under constant and varying ECs

Characteristics of the methods used for damage diagnosis in the mooring lines of FOWTs

- **Data based models** (developed with acquired signals from the structure)
  - Neural Networks (*Dehkharghani et al. 2021, Gorostidi et al. 2022*)
  - Power Spectral Density (*Jamalkia et al. 2016, Liu et al. 2021*)
- **Explicit modelling methods** (models fully describing the effects of varying ECs on the structural dynamics)
- **Requirement of a large number of data records under different ECs in the baseline (training) phase** (*Gorostidi et al. 2022*)
- **Treatment of damage detection as a classification problem** (an unknown state classified as a healthy or a damage state)

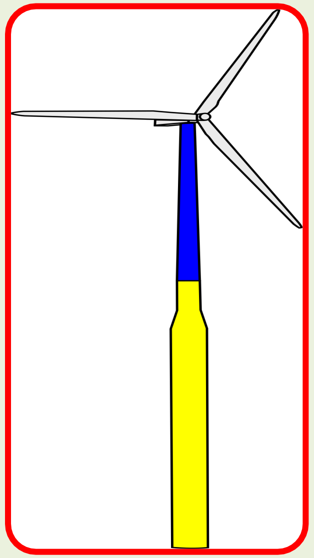
Problems with the aforementioned methods

- **Not clear handling of the different ECs in the baseline phase** (*Liu et al. 2021*)
- **The examination of only damage cases in the inspection (real time) phase** (*Dehkharghani et al. 2021, Liu et al. 2021*)

Goal of the current study

Damage detection in the Delta Mooring System of a Spar Floating Offshore Wind Turbine (FOWT) under varying wind speed and wave height

The examined part of the mooring line is chain

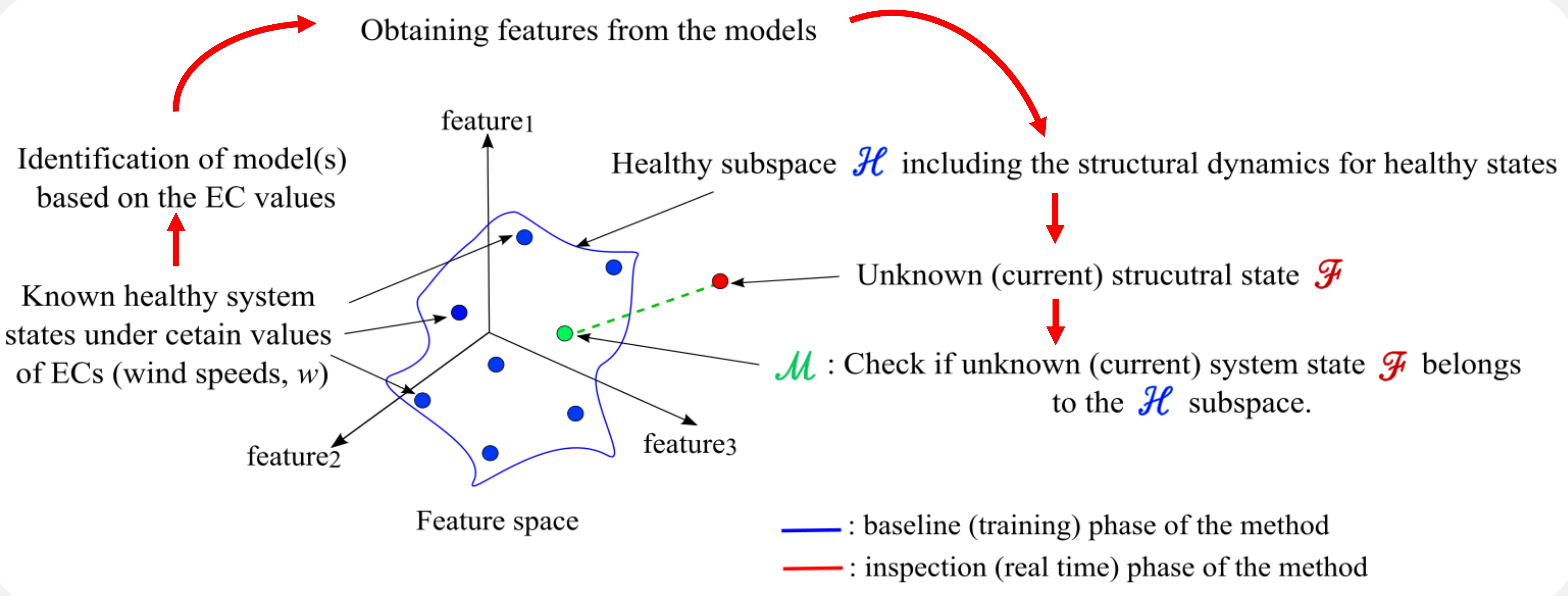


Spar FOWT

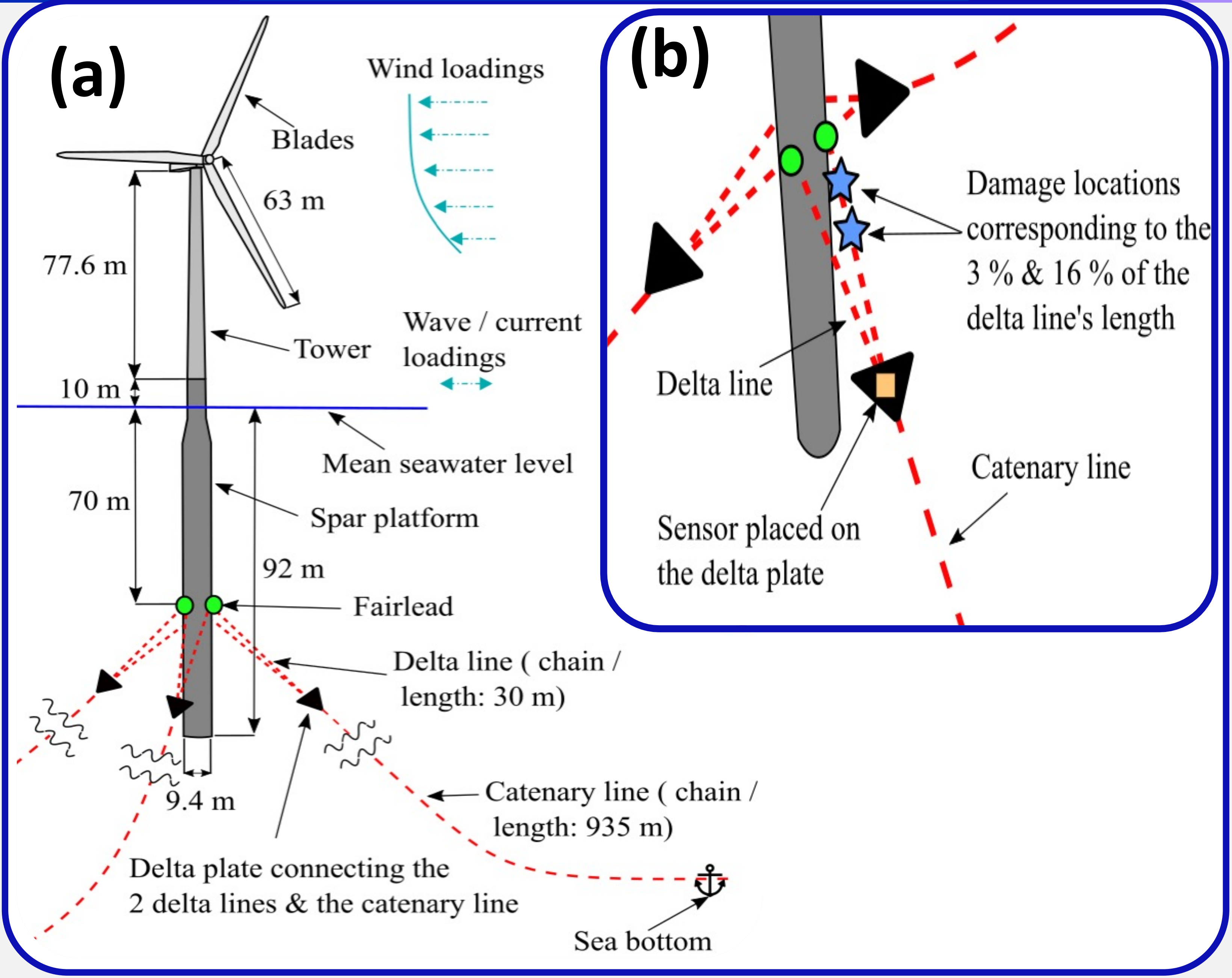
Employed statistical methods for damage detection

- Multiple Model – Power Spectral Density (MM-PSD) method equipped with multiple Power Spectral Density (PSD) models
- Multiple Model – AutoRegressive (MM-AR) method equipped with multiple AutoRegressive (AR) models
- Functional Model Based Method (FMBM) equipped with a single Functional Model (FM)

Concept of the MM-PSD method (equipped with multiple PSDs), the MM-AR method (equipped with multiple AR models) and the FMBM (equipped with a single FM)



Varying ECs: Wind speed (WS, symbolized by w) and wave height (WH) . **Only WS considered as the main ECs by the methods**.



OC3-HywindSpar FOWT – Delta line

The Structure and Damage

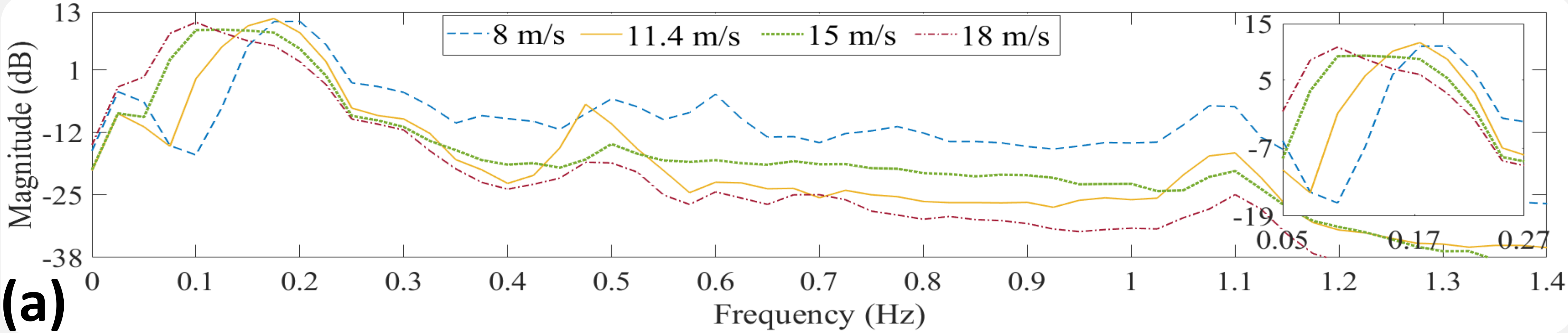
- Delta line (chain) of FOWT's mooring line
- Single damage: Stiffness reduction (%) at of a specific magnitude and at a specific location (2 magnitudes & 2 locations)
- Measurements: heave acceleration (▭)

Simulation details

- Varying environmental conditions: wave height and wind speed
- Sampling frequency : fs = 10 Hz
- Operational bandwidth : [0 – 1.4] Hz
- Signal length : N = 20000 samples
- Number of simulations: 14 (healthy state under various wind speeds)

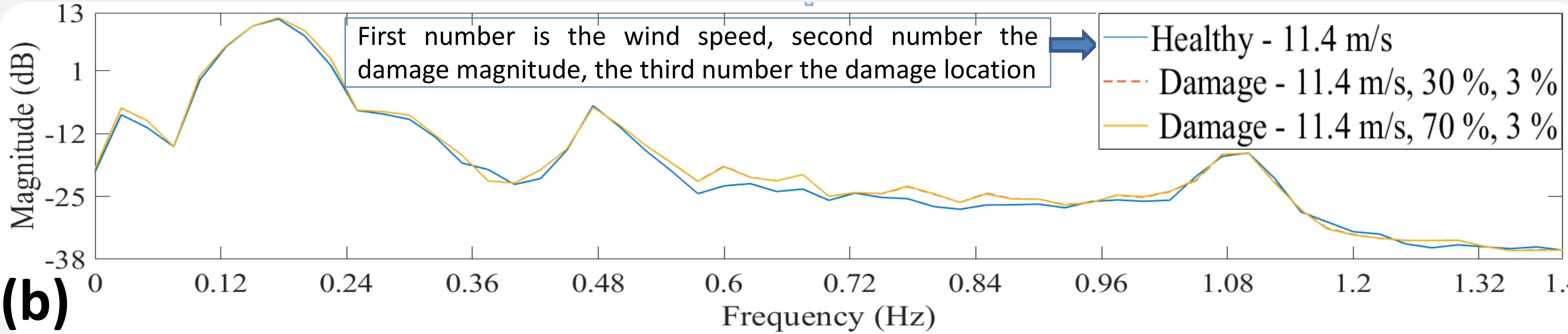
  : 9 (various damage states under various wind speeds)

Effects of seven different wind speeds on the healthy FOWT's dynamics though a comparison of Power Spectral Densities (PSDs)



(a)

Comparison of the effects of damages of different magnitude at same location and the effects of the healthy state (PSDs)



(b)

Results / Baseline (training) phase of the methods

- M=7 simulations from the healthy state, one per wind speed 8, 10.3, 11.4, 13.8, 15, 17.3, 18 m/s (one acceleration signal per simul.)
- Signal length per simulation.: N=20000 samples

PSD identification (used in the MM-PSD method)

- Estimated models : 7 Welch-based PSDs, one PSD per wind speed
- Frequency range: [1 – 1.4] Hz
- Frequency resolution: 0.025 Hz
- Dimension of feature (PSD magnitude) vector : $[57 \times 1] \rightarrow [50 \times 1]$

AR identification (used in the MM-AR method)

- Estimated models : 7 AR(260) models, one AR model per wind speed
- Dimension of feature (AR parameter) vector : $[260 \times 1] \rightarrow [255 \times 1]$

FP-AR identification (used in the FMBM)

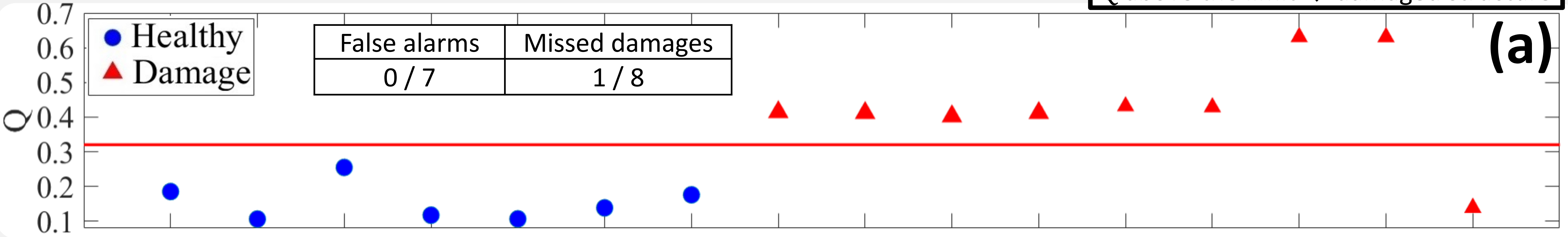
- Estimated models : 1 FP-AR(140) model
- Selected basis functions: 6 Shifted Legendre polynomials of variable

Inspection (real time) phase of the methods

- 7 simulations from the healthy state, one per wind speed 10, 11.7, 12, 14.8, 16, 17.3, 18 m/s
- 8 simulations from damage state (magnitudes: 30 & 70 % stiffness reduction, locations: 3 & 16 % of the delta line's length)

Damage detection based on the MM-PSD method

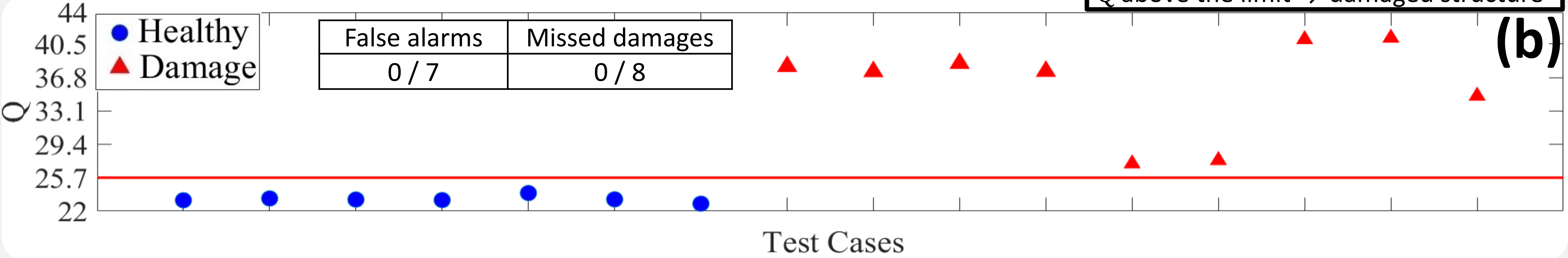
Q above the limit → damaged structure



False alarms	Missed damages
0 / 7	1 / 8

Damage detection based on the MM-AR method

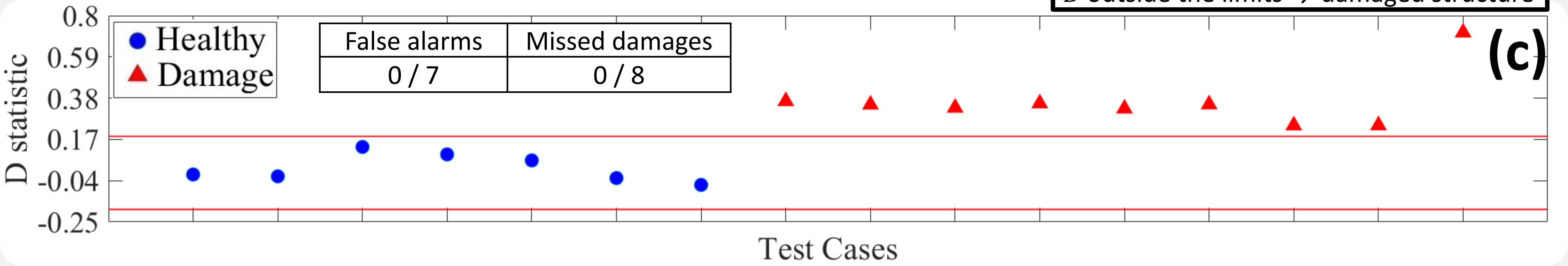
Q above the limit → damaged structure



False alarms	Missed damages
0 / 7	0 / 8

Damage detection based on the FMBM

D outside the limits → damaged structure



False alarms	Missed damages
0 / 7	0 / 8

Conclusions

- **Mooring line damages having small effects on the structural dynamics and thus making damage detection very difficult**
- **More precise description of a spar FOWT dynamics though the parametric models AR and FM**
- **Successful damage detection in the mooring system of a spar FOWT through the statistical methods MM-AR and FMBM**

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