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)

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

Environmental Conditions (ECs)

Varying ECs

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

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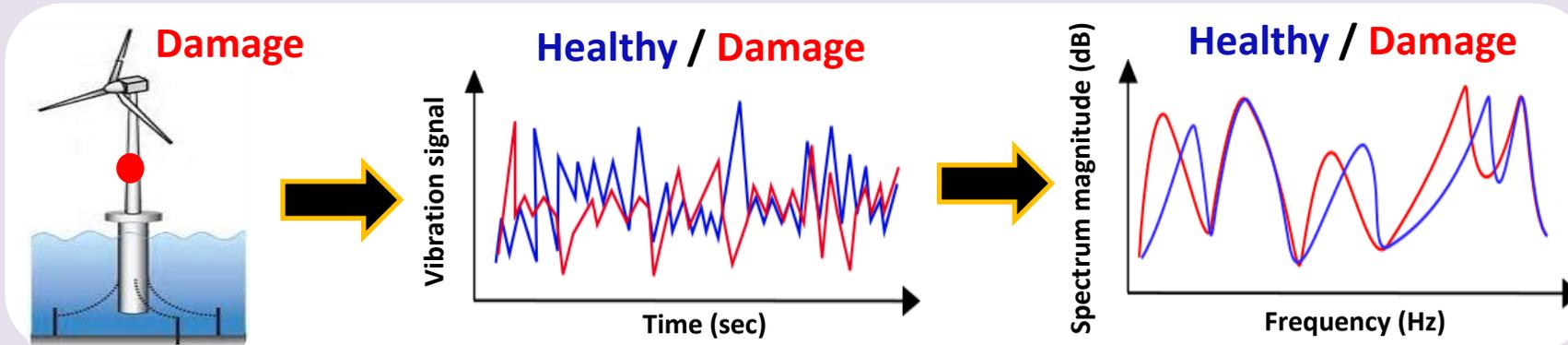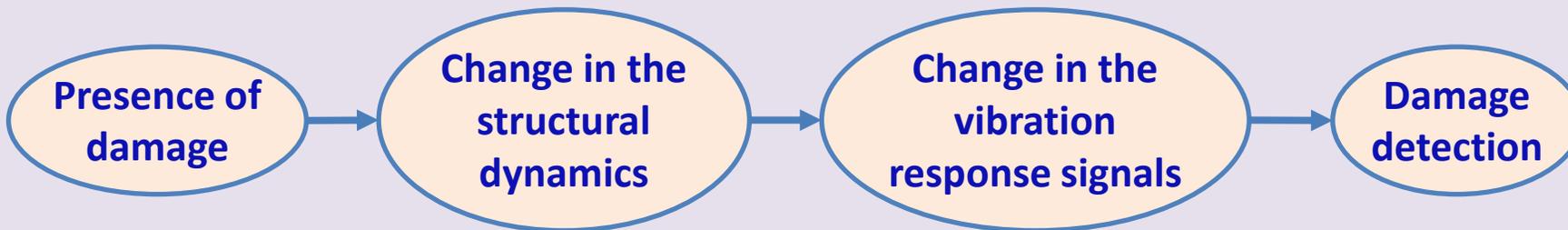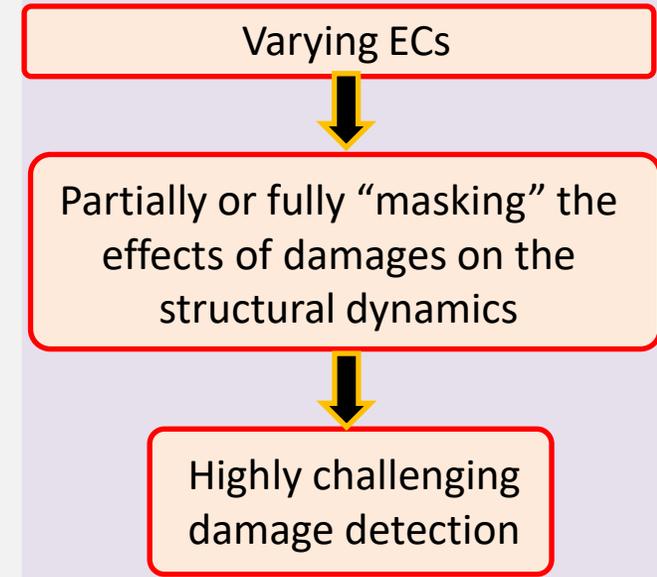
Vibration-based damage diagnosis in the mooring lines of FOWTs under constant and varying ECs

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
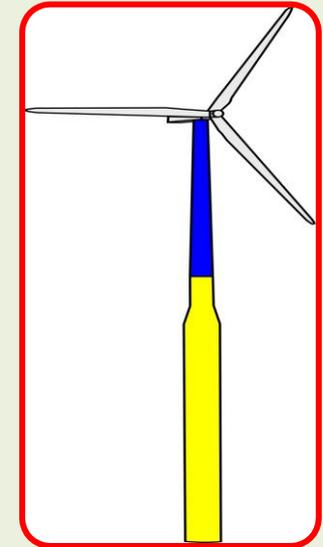
Spar FOWT

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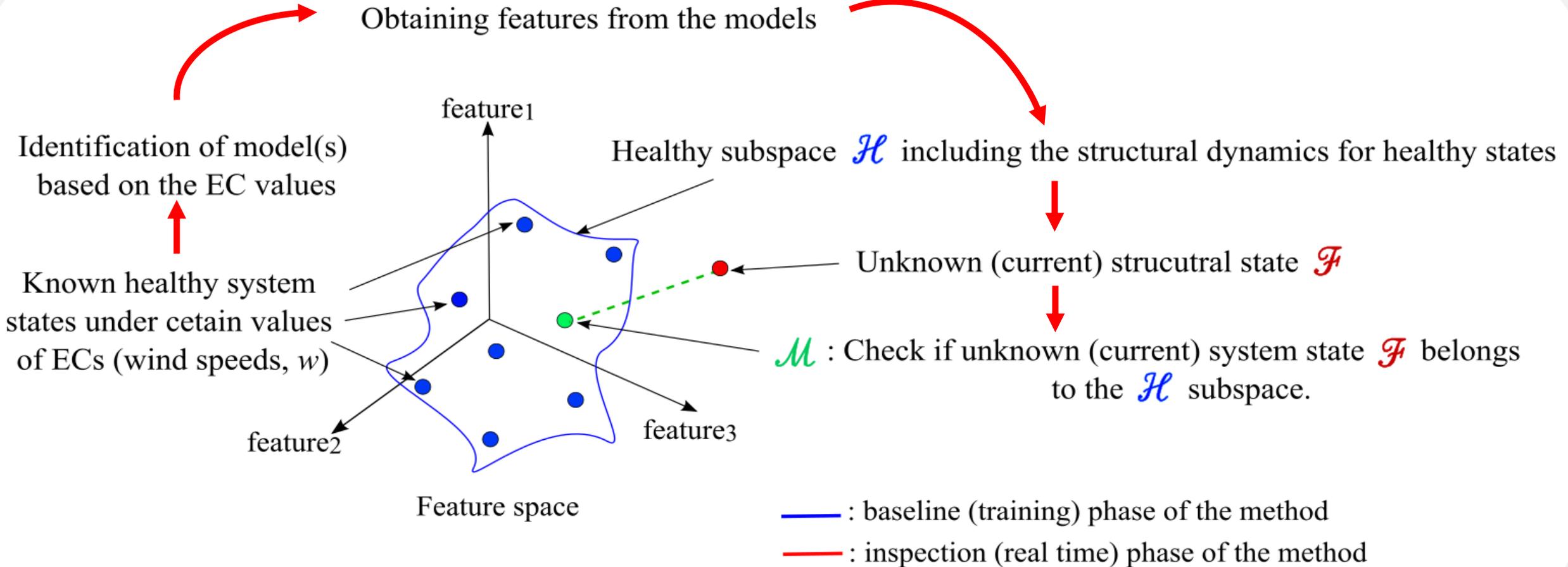
Varying ECs: Wind speed (WS, symbolized by w) and wave height (WH) . **Only WS considered as the main ECs by the methods**.

OC3-HywindSpar FOWT – Delta line

(a)

Wind loadings

Blades

63 m

77.6 m

Tower

10 m

Mean seawater level

Wave / current loadings

70 m

Spar platform

92 m

Fairlead

Delta line (chain / length: 30 m)

9.4 m

Catenary line (chain / length: 935 m)

Delta plate connecting the 2 delta lines & the catenary line

Sea bottom

(b)

Damage locations corresponding to the 3 % & 16 % of the delta line's length

Delta line

Catenary line

Sensor placed on the delta plate

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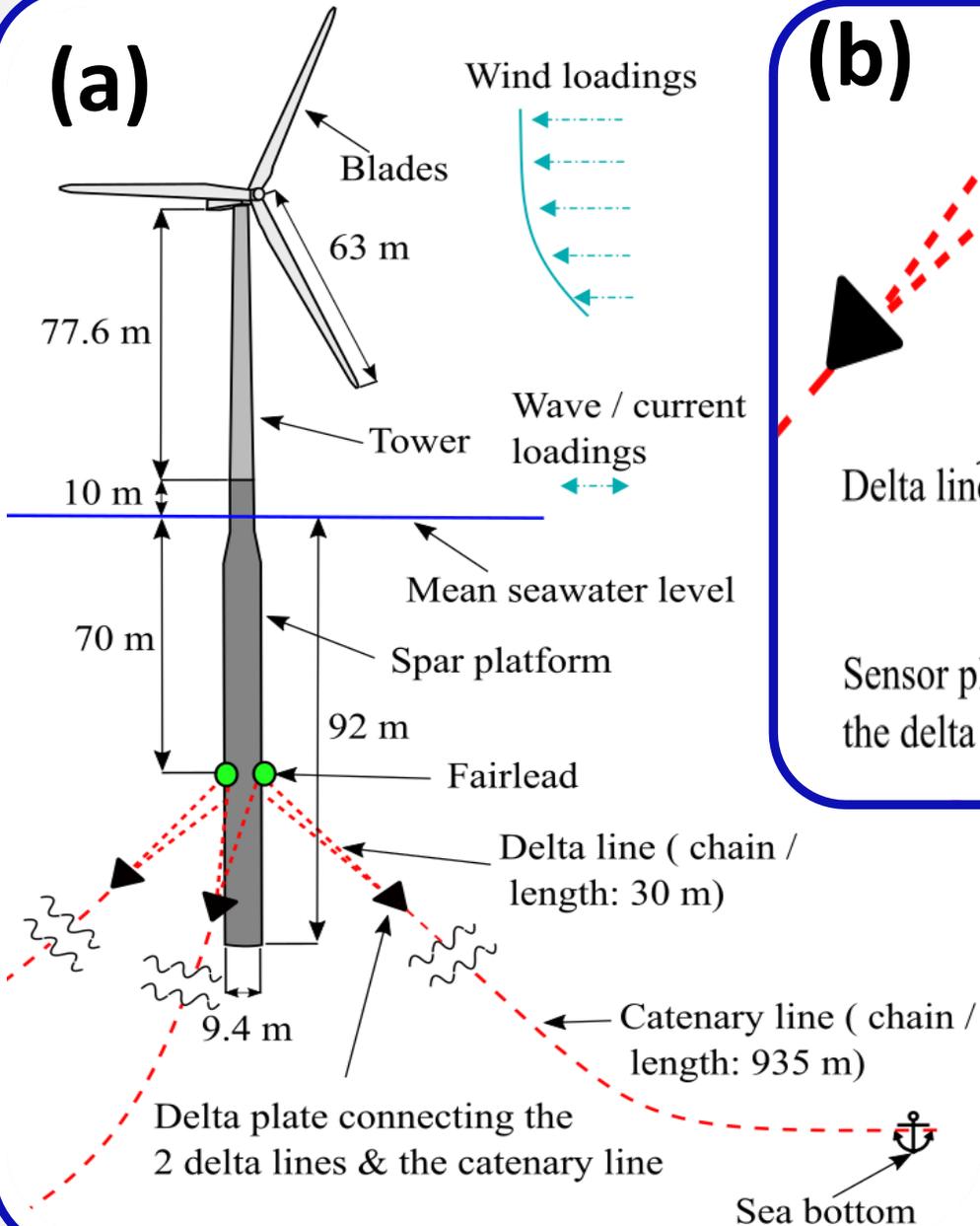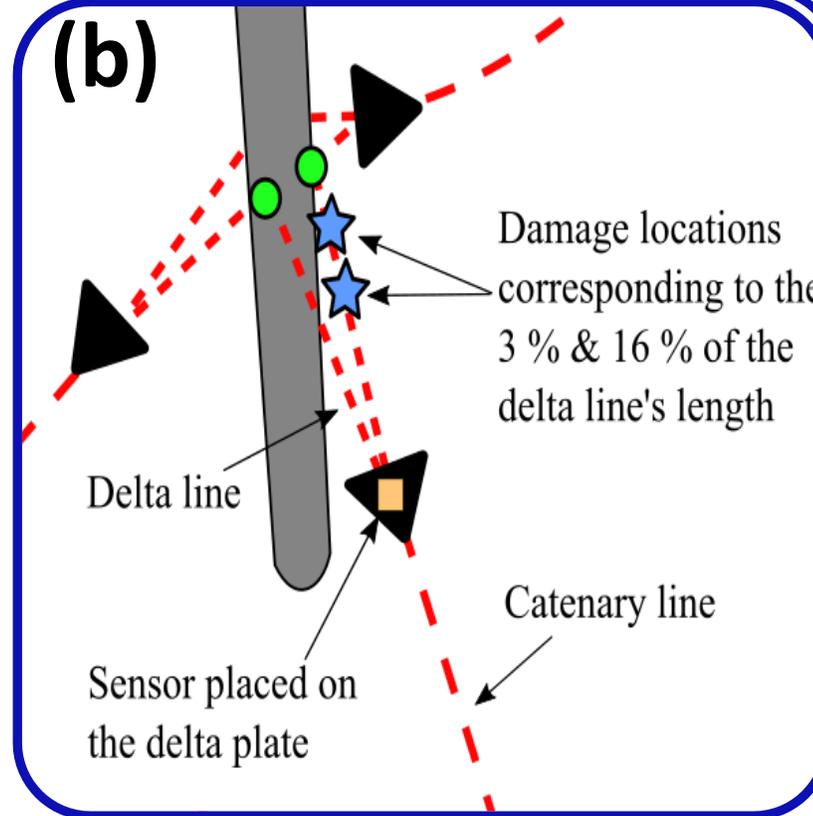
Effects of seven different wind speeds on the healthy FOWT's dynamics though a comparison of Power Spectral Densities (PSDs)

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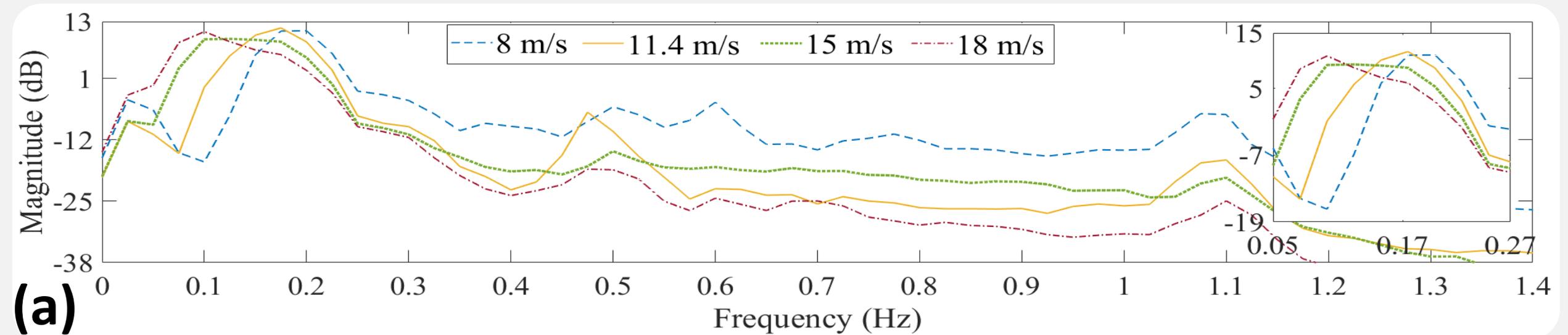
Comparison of the effects of damages of different magnitude at same location and the effects of the healthy state (PSDs)

First number is the wind speed, second number the damage magnitude, the third number the damage location

(b)
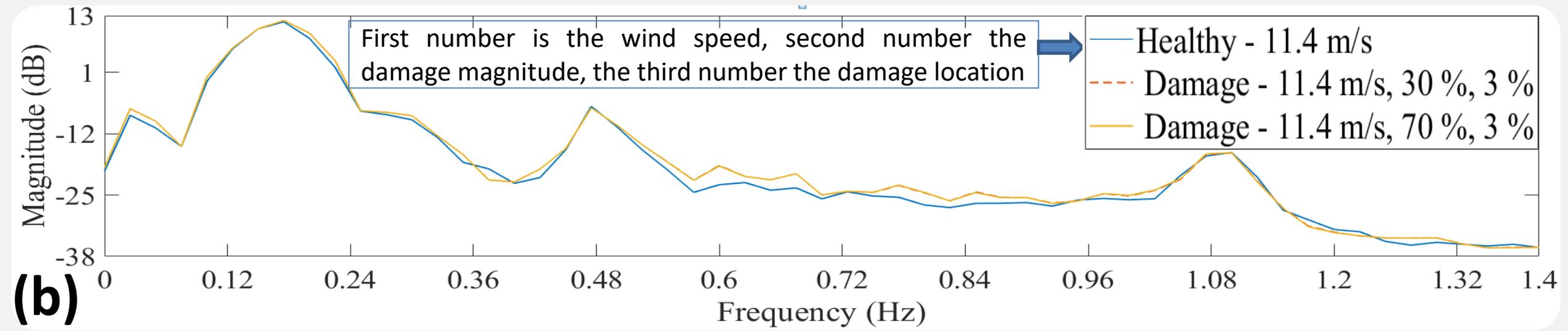
Results / Baseline (training) phase of the methods

- 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
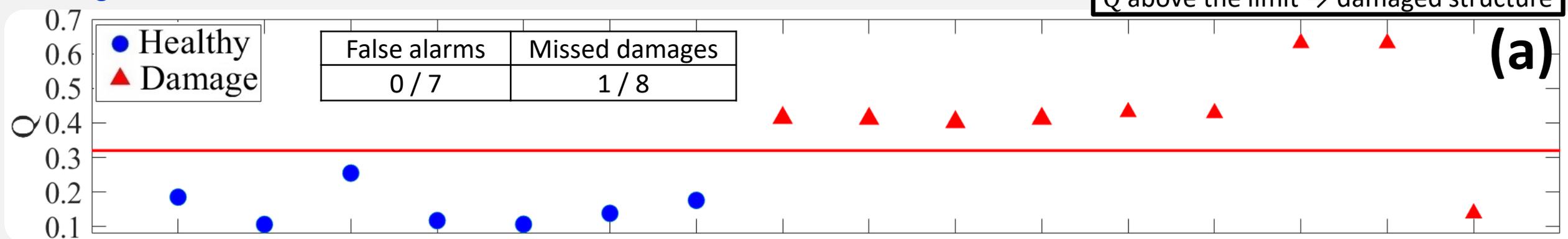
Damage detection based on the MM-AR method

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

(c)
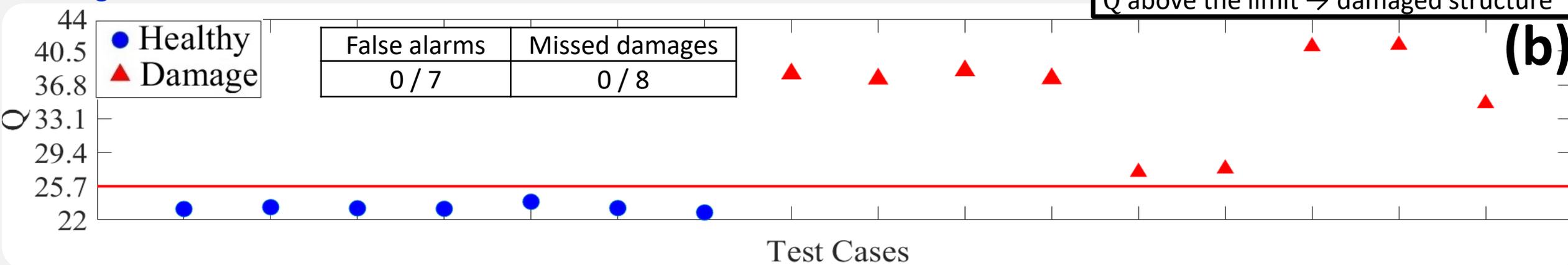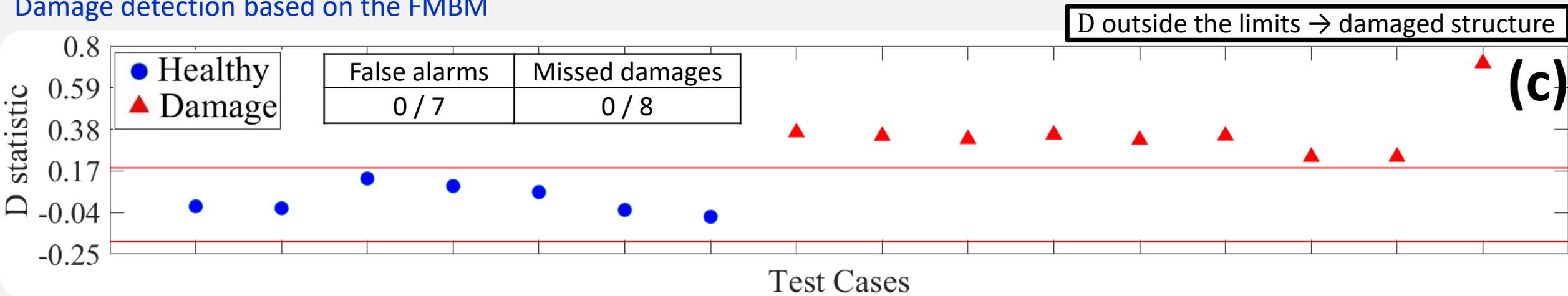
Conclusions

➢ **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**